Implementation and Verification of a Low-Power UHF / LF Wireless Sensor Network as Part of the Intelligent Container

Nils Heidmann a,*, Steffen Janßen b, Walter Lang b, Steffen Paul a

a Institute of Electrodynamics and Microelectronics (ITEM.me), University of Bremen, Germany
b Institute for Microsensors, -actuators and –systems (IMSAS), University of Bremen, Germany

Abstract

In this paper a new Low-Power UHF / LF Sensor System for the use in a container environment is presented. The aim is the dynamic and precise monitoring of physical parameters to minimize the loss of perishable food during transportation. Next to common UHF based Wireless Sensor Nodes [1] an LF interface is added that is able to wake up dedicated Sensor Nodes and request particular sensor values. A basestation is used to handle the communication and monitor the acquired sensor data. The whole system is adapted to the specific needs of transportation and is integrated in a 40 feet refrigerated container and long term measurements are taken to verify the proposed concept.

Keywords: Wireless Sensor Networks; Intelligent Container; UHF; RFID; Low-Power

1. Introduction

The monitoring of environmental parameters, like temperature and humidity, is very important to reduce the percentage of spoiled goods. For this reason the advent of Wireless Sensor Nodes within a transportation container has turned out to be a viable approach. However, these systems have to be scalable and the sampling rate must be adapted to the specific needs of transportation [2]. Also, the power consumption of the single wireless sensor nodes is of great relevance because it is not possible to change any batteries during transportation [3]. Since the transportation of perishable goods can take several weeks and the sensors should not fail the requirements for low-power systems are very high. In this paper an UHF / LF concept for data acquisition and transmission is proposed and tested. The

* Corresponding author. Tel.: +49-421-218-62529; fax: +49-421-218-4434.
E-mail address: heidmann@me.uni-bremen.de.
principle of acquiring sensor data is to request values from a dedicated node ID over LF and send these data via UHF transmission to a basestation. This concept enables low stand-by power consumptions but allows a dynamical adaption of the sampling rate and quantity of the sensor network.

2. Wireless Sensor Node

The task of the wireless sensor nodes is to acquire sensor data within the container. Therefore the nodes are stored at several positions among the transportation goods. Each wireless sensor node consists of a LF-Interface [3], an UHF transceiver, a microprocessor for data processing and a temperature and humidity sensor (Fig. 1). The two communication modules are connected over SPI to the microcontroller and can exchange protocol data or can be used for wake-up commands. The use of wake-up signals is very relevant for the proposed system because except for the LF interface all components can operate in a very low-power mode during transportation. As long as the LF frontend is not triggered by a dedicated sensor ID, the energy consumption of a wireless sensor node is below 100 μW. The wireless sensor node can be activated by one of two LF-antennas that are assembled on the ceiling of the container. After activating the microcontroller through the LF wake-up, the sensor node starts data acquisition and preprocessing. Finally the sensor data are transmitting via UHF to the basestation.

Due to the concept of dynamically requesting dedicated sensor values the system can be easily adapted to the specific needs of transportation. If there is no significant change in temperature or humidity monitored by the different sensor nodes, the sampling rate can be decreased by the basestation by just transmitting less LF commands. It is also possible to downsize the number of requested sensor nodes to lower the overall energy consumption of the system. The main advantage is that no reprogramming of the nodes is necessary because the nodes are always accessible by the LF interface.

Each sensor is packaged into a case of about 90mm x 55mm x 30mm (length x width x height). Due to the high relative humidity within the container during transportation the electronic part has to be protected against the ingress of water. Hence, only the sensor is passed through the package and is protected by a plastic cover (Fig. 2).
3. Integration of the System

The proposed system has been assembled in a 40 feet refrigerated container that is used for the transportation of bananas (Fig. 3). Next to the wireless sensor nodes the system consists of one single basestation that is assembled in the middle of the container ceiling. The basestation consists of an integrated UHF module and connectors for two LF antennas (Fig. 4). The power supply of the basestation is delivered by the refrigeration unit and is set to 24 V in this application. For the LF communication two ferrite antennas are mounted in equal distances on the ceiling. The size of the antennas is specially designed to cover half of the interior of the container. All devices are especially protected by small metal cases to prevent damage during loading and unloading the container.

The basestation is connected over serial communication to a central communication unit. This unit consists of a processing unit that is able to analyze the sensor values and to control the amount of sensor readings. The quantity of the requested nodes is just like the sampling rate controlled by the algorithms running on the processing unit.

The sensor values can be plotted in real time on external software that is also able to control some of the basic parameters of the system. Furthermore, the acquired sensor values are all saved on internal memory and can be manually analyzed and interpreted after the end of the transportation.

4. Measurement Results

For verification the system has been tested with two sensor nodes measuring the temperature and humidity at two different positions within the container. The measurement took more than five days and the sampling frequency was set to one minute for each sensor. This results in more than seven thousands temperature and humidity measurements for each sensor. Even though a frequency of one minute is very high to monitor the parametric changes within the container, it offers a good possibility for visualization and demonstrates the low-power consumption of the system.

The resolution of the sensor is set to 12 bit for temperature and 10 bit for humidity, which is sufficient to measure reliably the change in parameters during the sampling cycles. While testing, the set point of the refrigerated container was changed frequently to verify the measurements of the two nodes. The sensor data are plotted in Figure 5a for temperature and Figure 5b for humidity.
Conclusion and Future Work

The experimental results show that the dynamic measurement of environmental parameters can be reached with the proposed system. Due to the combination of UHF and LF transmission the energy consumption can be reduced down to 100 $\mu$W without losing any degree in flexibility. The wireless sensor nodes can be dynamically waked-up by a base station and sensor values can be requested that are transmitted over UHF. The whole system was integrated in a 40 feet refrigerated container and real temperature and humidity measurements were performed.

Future work will concentrate on up scaling of the system to show the performance while using much more wireless sensor nodes. Furthermore, the algorithms running on the base station will be optimized to get an optimal trade off between overall power consumption and resolution of the system.

Acknowledgements

This research project ('The Intelligent Container') is supported by the Federal Ministry of Education and Research, Germany, under reference number 01IA10001.

References

[1] TmotSky Brochure, Datasheet and Quick Start Guide from http://www.sentilla.com/moteiv-transition.html.
[2] R. Jedermann, C. Behrens, D. Westphal, and W. Lang, Applying autonomous sensor systems in logistics - combining sensor networks, eFIDs and software agents, Sensors and Actuators A: Physical, vol. 132, no. 1, pp. 370 – 375, 2006, the 19th European Conference on Solid-State Transducers.
[3] C. Behrens, O. Bischoff, S. Paul, R. Laur, An Effective Method for State-of-Charge Estimation in Wireless Sensor Networks, Proc. 5th ACM Conference on Embedded Networked Sensor Systems (SenSys) 2007, pp. 427-428, Sydney
[4] D. Müller and K. Finkenzeller, RFID handbook: fundamentals and applications in contactless smart cards, radio frequency identification and near-field communication, 3rd ed. Chichester: Wiley, 2010