SFB 637 Autonomous Logistics

Becker, M.; Yuan, S.; Jedermann, R.; Timm-Giel, A.; Lang, W.; Görg, C.: Challenges of Applying Wireless Sensor Networks in Logistics. In: CEWIT 2009. Wireless and IT driving Healthcare, Energy and Infrastructure Transformation, 2009

Challenges of Applying Wireless Sensor Networks in Logistics

Markus Becker[1], Shaoping Yuan[2], Reiner Jedermann[2], Andreas Timm-Giel[1], Walter Lang[2], Carmelita Görg[1]

[1]TZI ikom, University Bremen, Germany

[2]IMSAS, University Bremen, Germany

Abstract Quality of food is mainly governed by the condition it is transported in. Wireless Sensor Networks have the potential to better control those transport conditions. When moving the Wireless Sensor Networks from a lab environment to the transport processes in harbors and shipping facilities, several challenges have to be met. A system architecture and the challenges faced in a transfer project with industry partners, i.e. radio propagation, autonomy, illustration of data and housing are presented in this article.

Introduction

Food transports are characterized by a high degree of dynamism especially inflicted by the type of good or food in transport. The quality of food is determined to a high degree by the conditions it is transported under. Wireless Sensor Networks, which actively monitor the transport conditions and actively report the measurements (unlike passive RFID), allow the chance to react to changes in the transport conditions early and appropriate. In the transfer project T4 of the Collaborative Research Center 637, Wireless Sensor Networks are applied in areas from fruit transports to food distribution.

System Architecture

In order to make use of Wireless Sensor Networks and the possibilities they are offering, a system architecture has been devised, which enables the gathered data to be transmitted into the Internet. The system architecture is depicted in Fig. 1. In subfigure (a) the system for land transport and in subfigure (b) the system for sea transport is shown. These systems are slightly different due to interfaces to already present telematic unit or to satellite communication systems. The architecture consists of RFIDs and Readers for identification of the goods, Wireless Sensors for supervision of the goods, a Communication Gateway giving the possibility to autonomous selection of communication networks for the data transport. The data is transmitted to a server, which stores it in a database, and creates several dynamic web pages, RSS feeds and graphics. When a telematic unit is present, the data from this unit, will be delivered to the web server using a Web Service.

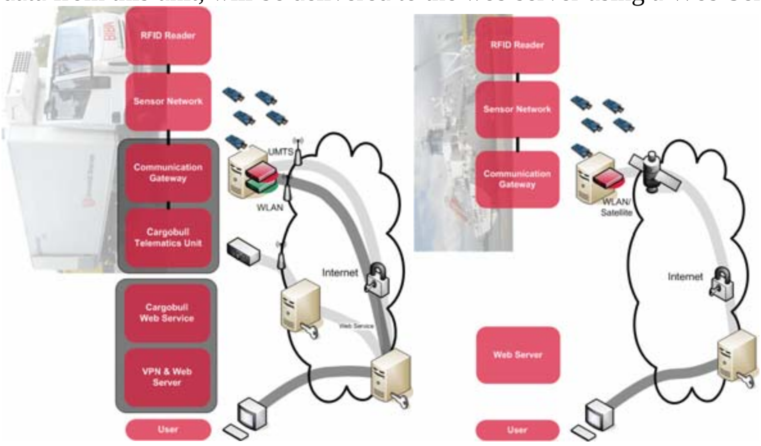

Fig. 1. System Architecture: (a) Land Transport (b) Sea Transport

Challenges

Although Wireless Sensor Networks have been a research field for several years now [1-4], still multiple challenges have to be tackled to apply Wireless Sensor Networks in food transport logistics. During experimental validation with industrial partners, several test setups have been validated and the following four main challenges have been identified: Radio Propagation, Autonomy, Illustration, and Housing. More details on the challenges are explained in the individual paragraphs:

Radio Propagation

Radio waves are attenuated while being transmitted from the sender to the receiver. The attenuation depends on the media between the receiver and the transmitter. Food in many cases consists to big parts of water, which has worse propagation attenuation than air. Especially, in a densely packed environment such as a cargo container as depicted in Fig. 2 the spannable distance is reduced to less than one meter. Similar propagation issues are persistent to RFIDs as well [5, 6] .

Fig. 2. (a) Placement of Wireless Sensor Network node in the food box (b) Packed pallet (c) Loaded cargo container

In Fig. 3 the Link Quality Indicator for links between Wireless Sensor Nodes (red circles) in a cargo container is depicted. There are few excellent or good links available, some bad links present, and many nodes are not connected at all. The links that are excellent or good, are links that are mostly in an air channel at the top of the cargo container. In order to have a good spatial resolution of the transport conditions, several sensor nodes need to be deployed anyway. These sensor nodes might therefore be used to forward data packets from other nodes in a multihop fashion tackling the challenge of high attenuation in the goods.

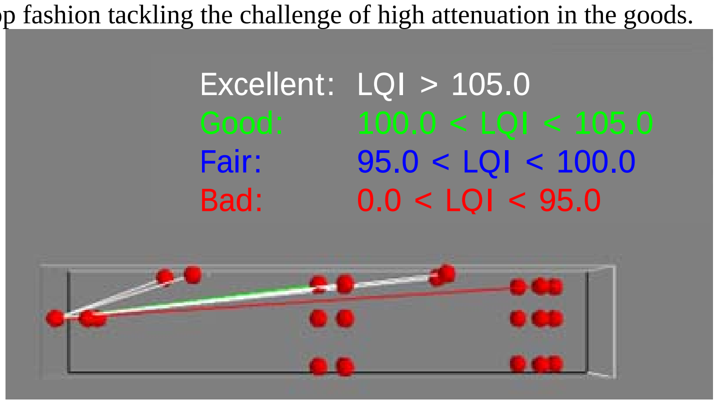

Fig. 3. Radio Link Quality Indicator (LQI) in a fully loaded cargo container

The Received Signal Strength Indicator (RSSI) of links of different media is shown in Fig. 4 and 5 versus the distance between the nodes that constitute the link. In Fig. 4 just links with air as a medium are considered, while in Fig. 5. only links with food are considered. In both diagrams is a minimum squared error linear fitting included. This fitting starts for air medium at ~3dBi, while it starts at ~-30 dBi for food as a medium. The slope for air is approximately -2.5dBi/m. The slope for the second case is based on only a few measurements, thus giving little confidence in it. However, the high attenuation has the effect that, the nodes in the goods are less well connected.

SFB 637 Autonomous Logistics

Becker, M.; Yuan, S.; Jedermann, R.; Timm-Giel, A.; Lang, W.; Görg, C.: Challenges of Applying Wireless Sensor Networks in Logistics. In: CEWIT 2009. Wireless and IT driving Healthcare, Energy and Infrastructure Transformation, 2009

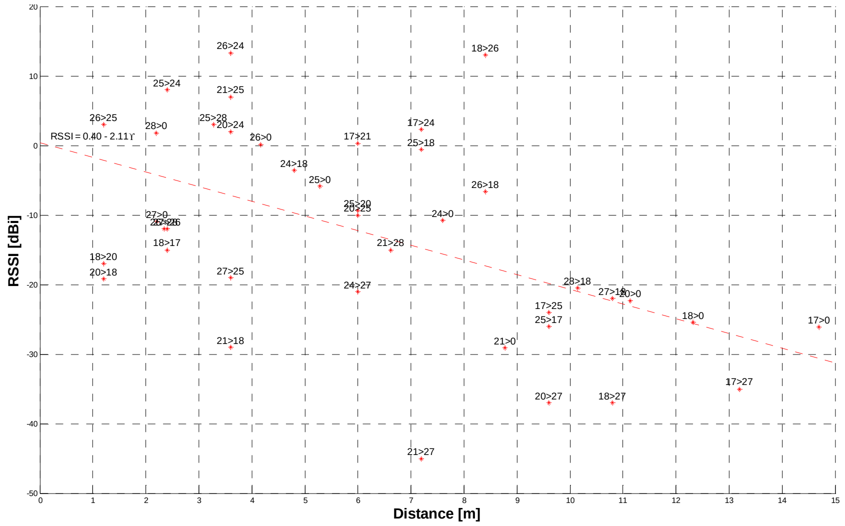

Fig. 4. Received Signal Strength in a cargo container (only radio links **without** cargo in between)

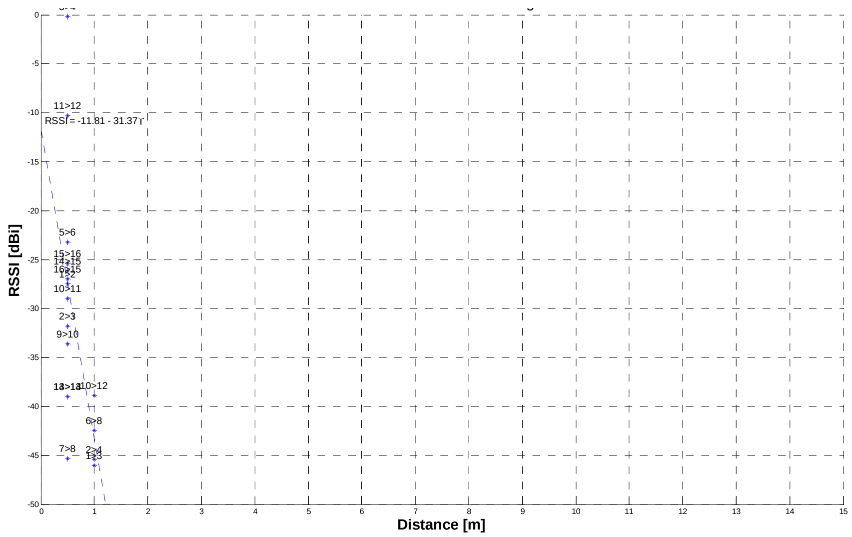

Fig. 5. Received Signal Strength in a cargo container (only radio links **with** cargo in between)

Experimental results of a multihop protocol are shown in Fig. 6 and 7. Fig. 6 depicts the neighborhood relations in a multihop network in a cargo container, showing the top nodes being heavily meshed (mostly air links as in Fig. 4), while the nodes buried in deeper tiers (cargo links as in Fig. 5) are less well connected, but still reachable by other nodes. Fig. 7 shows the paths packets are actually travelling through the multihop network and the respective received signal strengths.

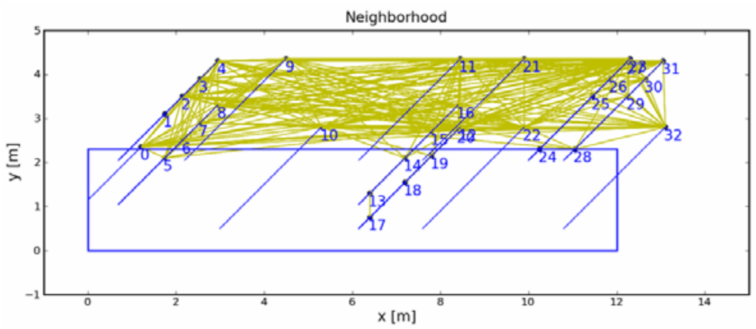

Fig. 6. Neighborhood Relations of Wireless Sensor Nodes in a fully loaded cargo container

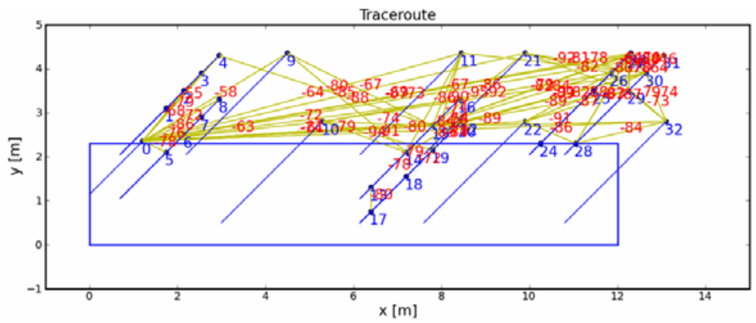

Fig. 7. Radio Packet Travel Paths through a Multihop Wireless Sensor Network

Autonomy

Another important acceptance factor for Wireless Sensor Networks in logistics is autonomous operation and ease of deployment. The operation of Wireless Sensor Networks should not impact the usual processes of the actors in logistics and put additional burden on them. So, Wireless Sensor Networks and their attachment to the Internet needs to autonomously configuring.

The challenge of autonomy has for example been tackled in the Communication Gateway depicted in Fig. 1. The improved architecture of the Communication Service Module in the Communication Gateway can be seen in Fig. 8. It is based on the Linux tool Network Manager, which autonomously monitors and selects communication networks. Network Manager can deal with fixed Ethernet LAN links, Wireless LAN, UMTS/GPRS and CDMA devices. However, the selection of the device to use is based on static priorities. With developments that led to the architecture depicted in Fig. 8. Network Manager's priorities are dynamically and autonomously updated based on the user applications executed on the gateway, e.g. programs evaluating the data sensed by the Wireless Sensor Network. Depending on the importance and amount of the data extracted at the evaluation process, the best suitable communication network is chosen by the Communication Service Module.

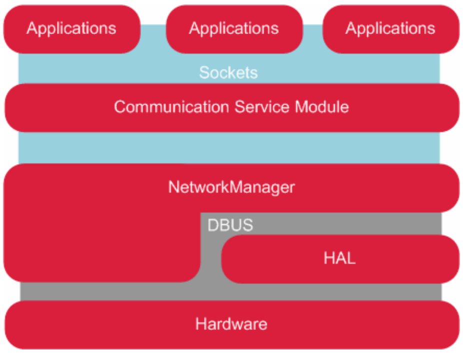

Fig. 8. Architecture of the enhanced Communication Service Module

User interface for data illustration

When implementing Wireless Sensor Networks in logistics, a way to analyze the data gained from transport processes is necessary. A convenient way of presenting and analyzing the data has been found based on a Web Framework named Django Project [7]. This Web Framework enables HTML views on data stored in a database and automatically delivers administration web pages and RSS feeds of the data. A screenshot of one of the created pages is shown in Fig. 9, summarizing conveniently the data from the telematic unit and from the Wireless Sensor Network installed with it.

Fig. 9. Web Interface incorporating data from telematic unit and from the Wireless Sensor Network

Using the JavaScript libraries OpenLayers [8] and Dojo [9], the presentation of data (geographical position of the goods in Fig. 10 and a temperature graph in Fig. 11) is conveniently generated from data in the database.

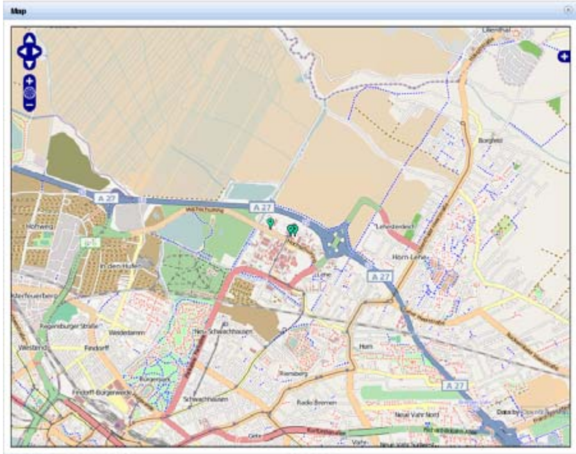

Fig. 10. Display of the position using free and open map data

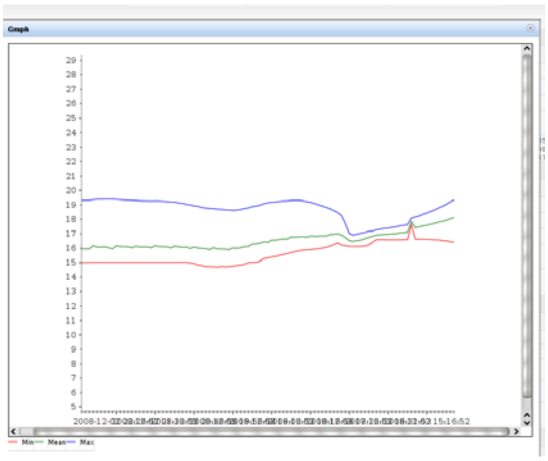

Fig. 11. Graphical Representation of data from the Wireless Sensor Network

Housing

For the application of Wireless Sensor Network the housing of the individual nodes has to meet several requirements. The housing e.g. needs to be water tight, so that the electronics encased are safeguarded against it. The housing has to withstand cleaning with steam jet. Additionally care has to be taken that the housing is food safe, as it might come into contact with the transported food. Additionally, the housing should not be made out of metal, as the this would inhibit or constrict radio propagation between the nodes, further limiting the range of the devices already restricted as shown in first challenge. Fig. 12 to 14 show different generations of housings for the sensor nodes. The first generation housing was a simple card box housing, while the second generation is a stock screwable plastic box. For the third generation a rapid prototyping 3D printed housing will be custom manufactured. This will fit custom rechargeable batteries and the sensor node and is faster to assemble than the 2nd generation screwable housing.

Fig. 12. 1st generation card box housing

Fig. 13. 2nd generation screwable plastic box

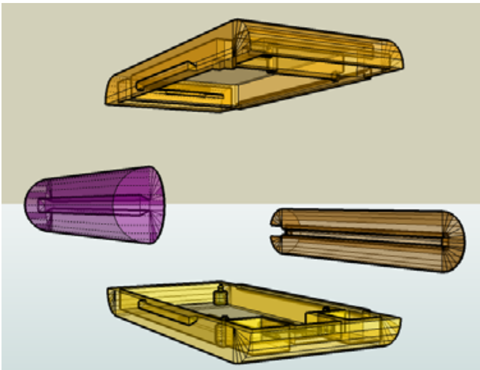

Fig. 14. 3rd generation rapid prototyping plastic housing

Conclusion

Four challenges that appear when bringing Wireless Sensor Network from the lab and demonstrations to logistical processes were presented, namely: Radio Propagation, Autonomy, Illustration and Housing. Extensive implementations and measurement campaigns have been conducted in the process of tackling the challenges. In conclusion it can be said that though several challenges in applying Wireless Sensor Networks in logistics exist, most of the challenges are solvable with today's technologies.

Acknowledgments This research was supported by the German Research Foundation (DFG) as part of the Collaborative Research Centre 637 "Autonomous Cooperating Logistic Processes".

References

[1] K. Römer and F. Mattern: The Design Space of Wireless Sensor Networks, IEEE Wireless Communications, Vol. 11 No. 6, pp. 54-61, December 2004.
[2] M. Ringwald and K. Römer: Deployment of Sensor Networks: Problems and Passive Inspection, IEEE WISES 2007, Madrid, Spain, June 2007.
[3] G. Werner-Allen, P. Swieskowski, and M. Welsh: MoteLab: A Wireless Sensor Network Testbed. In Proceedings of the Fourth International Conference on Information Processing in Sensor Networks (IPSN'05), Special Track on Platform Tools and Design Methods for Network Embedded Sensors (SPOTS), April 2005.
[4] I.F. Akyildiz and W. Su and Y. Sankarasubramaniam and E. Cayirci: Wireless Sensor Networks: A Survey. IEEE Computer, vol. 38, no. 4, pages 393-422, Mar. 2002.
[5] D. Dobkin and St. Weigand: Environmental Effects on RFID Tag Antennas. In: Microwave Symposium Digest, 2005 IEEE MTT-S International. DOI: 10.1109/MWSYM.2005.1516541. 2005.
[6] Jedermann, R.; Stein, K.; Becker, M.; Lang, W.: UHF-RFID in the Food Chain - From Identification to Smart Labels. In: Coldchain Manangement. 3rd International Workshop, Bonn, 2008.
[7] A. Holovaty and J. Kaplan-Moss: The Definitive Guide to Django: Web Development Done Right. ISBN: 978-1590597255. Apress. 2007.
[8] Website: http://docs.openlayers.org/ Last accessed: 13th January 2009
[9] Website: http://dojotoolkit.org/ Last accessed: 13th Januaray 2009