# On the Integration of Wireless Sensor Networks and Smartphones in the Logistics Domain

Sebastian Zöller, Andreas Reinhardt, Heiko Guckes, Dieter Schuller, Ralf Steinmetz

Multimedia Communications Lab, Technische Universität Darmstadt

Rundeturmstr. 10, 64283 Darmstadt, Germany

Email: {sebastian.zoeller, andreas.reinhardt, heiko.guckes, dieter.schuller, ralf.steinmetz}@KOM.tu-darmstadt.de

*Abstract*—A promising application domain for wireless sensor networks is their use for real-time monitoring in logistics transport processes. Through a constant monitoring of environmental parameters which influence the condition of transported goods, they allow for early transmission of alert messages in case of critical situations. The stakeholders however only benefit from alert messages if they are transmitted in a timely manner, so that they can initiate countermeasures and adapt their logistics processes accordingly. For the required connection between a wireless sensor network and the decision makers' systems, the application of smartphones as bridging devices has been identified as particularly promising. In this paper, we analyze possibilities to interconnect wireless sensor networks with smartphones to enable a long-range transmission of alert messages to decision makers during transport processes. Based on our requirement analyses, we suggest a particular promising connection concept and provide a proof-of-concept implementation of this concept.

## I. INTRODUCTION

Wireless sensor network (*WSN*) technology provides a promising means to realize real-time monitoring of transport processes in the logistics domain. Wireless sensor nodes (*motes*) can sense diverse parameters (e.g., shock, tilt, temperature, or humidity) related to the condition of transported goods and thus determine whether critical thresholds have been reached during a transport. In this case, alert messages can be wirelessly propagated through the WSN and forwarded to a logistics provider's backend system by an appropriate gateway node. Thus, based on the local detection of events during a transport, warnings can be conveyed to responsible decision makers, which can initiate countermeasures in time and adapt their processes accordingly.

In this paper, we focus on the question how such alert messages can be efficiently transferred from WSNs to the responsible decision makers' systems. We particularly address WSN deployments in a container during road transportation with trucks and investigate possibilities to realize the gateway functionality between the WSN and end user systems in such an application scenario. In [1], we have already analyzed different possibilities in this context and identified the application of smartphones as particularly promising. Thus, in this paper we investigate possibilities to integrate motes and smartphones in a logistics context to realize a smartphone-based gateway between WSN and end users' systems. The contributions of this paper are the following: We shortly revisit the application potential of WSN technology in the context of logistics transport processes and present corresponding requirements to be taken into account (*Sec. II*). We present different possibilities to interconnect motes with smartphones and based on different requirement analyses, we present our concept (*Sec. III*). We discuss and analyze a prototypical proof-of-concept implementation (*Sec. IV*), and conclude our paper by presenting conclusions and future work (*Sec. V*).

## II. WSNS IN LOGISTICS TRANSPORT PROCESSES

Motes are able to monitor various environmental parameters that may influence the condition of transported goods in real time, e.g., temperature in the context of temperature-sensitive transports, gas concentrations during the transport of animals, or shake and tilt values when transporting shock-sensitive goods. Thanks to their storage and processing capabilities, they can locally evaluate the sampled data and wirelessly transmit corresponding status and alert messages. This enables them to provide a real-time monitoring of transport processes in logistics, which can for example support Supply Chain Event Management (*SCEM*), as we have pointed out in [1].

A major driving application for real-time monitoring of goods is in the fields of cold chain transport processes and food logistics (e.g., [2], [3]), and approaches to realize an intelligent container, which incorporates such a monitoring infrastructure [4]. In the work at hand, we focus on transport processes in the context of road transportation with trucks and thus on WSN deployments in a container on a truck or a truck's load area. For the general application of WSN technology in such an application context, we have identified four requirement categories to be considered (cf. [1]):

- *Technological requirements* comprise properties and constraints of the applied technology, e.g., energy constraints of WSNs.
- *Economical and organizational requirements* include economical constraints and integration needs in existing infrastructure, e.g., cost-benefit ratio of WSN deployments.
- *Regulatory requirements* comprise constraints by law and standardization bodies, e.g., usable frequency bands for transmission.
- *Logistics market specific requirements* comprise properties and constraints of the application domain, e.g., the prevailing massive cost pressure.

As different interdependencies between these requirement categories exist, it is important that they are not considered isolated from each other.

## III. Interconnecting Motes and Smartphones

For the realization of intelligent transportation systems, it is essential to transmit alert messages from the WSN to the decision makers' systems with low delays. Only when event notifications are transmitted in a timely manner, the application potential of WSN technology in logistics transport processes, and particularly early warnings of responsible decision makers, can be fully exploited. To realize the required connection between sensors and stakeholders, we have identified the usage of smartphones as gateways for data transmission between a WSN deployed in a container on a truck or a truck's load area as particularly promising in [1]. This leads to an application scenario as depicted in Fig. 1. For this scenario, we investigate possibilities to interconnect motes and smartphones to realize the connection between WSN deployment and the backend systems of decision makers. We therefore analyze technological platforms that could be used in this context and how they can be connected.

### A. Choosing a Wireless Sensor Platform and a Smartphone

For the selection of an adequate wireless sensor platform and a smartphone, we have deduced specific requirements based on the requirement categories presented in Sec. II. A total number of ten requirements have been determined for the selection of a wireless sensor platform:

1) *Adequate power consumption* Motes are supposed to operate for a long time without attendance. Because of their restricted energy budget resulting from battery-powered operation, a low power consumption is essential.
2) *Sufficient radio communication range* To provide communication between the individual motes within a WSN, their transmission range must be sufficient to reach at least one neighboring mote, even when transported goods negatively impact their transmission range.
3) *Compliance to law and standards* To be able to operate a WSN deployed in a container on a truck or in a truck's load area during an international transport process, adherence to national rules has to be guaranteed.
4) *Ease of software development* To allow for efficient software development with reduced development times, well-established solutions are preferable in this context, e.g., already available, reusable, and well-tested code.
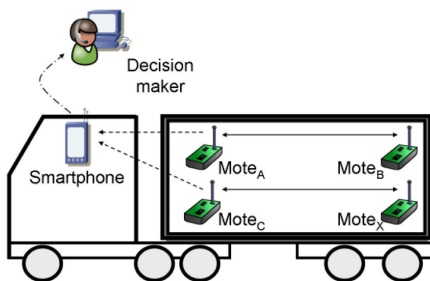


Fig. 1. The investigated application scenario

5) *Adequate interoperability and extendability* To be able to adapt a WSN to changes in the application scenario, like the need to measure more or other environmental parameters or to extend the deployed WSN with new mote platforms, sufficient interoperability and extensibility options have to be provided.
6) *Sufficient scaleability and flexibility in topology* Because motes are prone to failures, e.g., due to battery depletion or physical damage, sufficient scaleability and flexibility is required to cope with such failures.
7) *Adequate price* As the logistics domain faces a huge cost pressure, expenses need to be as low as possible to provide a sufficient return on investment for a WSN deployment in this context.
8) *Sufficient data security level* The data transmitted through the WSN is usually sensitive data from different companies, which necessitates a sufficient level of data security to guarantee that company secrets are protected.
9) *Small size and weight* To save valuable space in the container and avoid a negative impact on the truck's fuel consumption, the motes deployed should be as small and lightweight as possible.
10) *Adequate wake-up time* The wake-up time of a mote also influences its power consumption, as longer sleep cycles can be achieved with shorter wake-up times, which reduces the overall energy consumption of a mote.

For the selection of a WSN platform based on the above mentioned requirements, we conducted a market analysis and compared 22 current mote platforms. Based on this comparison, we came to the decision that the TelosB platform [5] best fits our needs. As current smartphones usually provide sufficient processing and storage capabilities for our needs, we have not taken these into account for selecting a suitable smartphone platform, but identified a different set of four requirements, particular important in our application scenario:

1) *High current and predicted market share* For a solution with current and future relevance, the smartphone platform used must exhibit a high current and predicted market share to provide a sufficient market penetration.
2) *Sufficient support of different communication standards* To be able to interconnect a smartphone and a mote sufficient support of different communication standards is required, e.g., the standard Bluetooth profiles to enable communication with other standard Bluetooth devices.
3) *Hardware expandability* To support even connection concepts to motes which require additional hardware, the opportunity to attach additional hardware to the smartphone should be provided.
4) *Geolocation support* To enrich the information transferred by the smartphone and basically enable location-based services, the smartphone should provide a possibility to determine its current geographic location.

Based on these requirements, we compared currently offered platforms and decided that an Android-based smartphone best fits our needs, specifically we used a Google Nexus One [6].

## B. Connecting a Wireless Sensor Platform to a Smartphone

One design possibility for a connection between the chosen TelosB mote platform and the chosen smartphone platform is to extend the smartphone in a way that enables IEEE 802.15.4 wireless communication as shown in Figure 2. This requires adding additional hardware to the smartphone to provide support for IEEE 802.15.4 and a corresponding software support for the additional hardware. Usually, the latter requires "rooting" the smartphone. A second design option is to extend the TelosB in a way that enables Bluetooth communication as shown in Figure 3. A third option is to use a device with Bluetooth and IEEE 802.15.4 radio as a bridge between the Android phone and the TelosB mote (cf. Fig. 4). The device could be deployed in the driver's cabin and thus powered directly by the truck. Therefore, this type of gateway device would not have any constraints with regard to its power consumption, and it would also allow the usage of different Android smartphones due to its generic Bluetooth communication interface.

To assist in the selection between the presented connection concepts, several application-specific requirements have to be considered. In this context, we have identified the following five essential requirements:

1) *Reusable, flexible, fault-tolerant, and interoperable solution* Since hardware and specifications are prone to constant change, the solution should not be bound to an individual device, but rather support a whole category of devices, like all Android devices, and should be not prone to errors.

2) *Only unobtrusive modifications to the existing software platform (i.e., no rooting of the phone)* Because rooting the smartphone or heavy kernel modifications might open up security risks or restrict interoperabilty or porting of the solution, such modifications should not be required.

3) *Low costs* Due to the huge cost pressure prevailing in the logistics domain, expenses and initial investment costs should be minimized.

4) *No negative influence on the existing hardware* A good solution should not negatively influence the employed smartphone or motes, e.g., reduce their lifetime by significantly increased power consumption.

5) *Low and easy maintenance* The solution should require only sufficiently low maintenance cycles and should be easily replaceable in case of failure.

Based on these requirements, and some additional real-life tests (a set of experiments was conducted on a truck's load area as shown in Fig. 5), we propose a connection concept employing a wireless bridge between mote and smartphone as depicted in Fig. 4.



Fig. 5.   Experimental setup in the conducted field test

## IV. PROOF-OF-CONCEPT IMPLEMENTATION

We have realized the connection concept depicted in Fig. 4 in a proof-of-concept implementation. As wireless bridge between the chosen TelosB and the Google Nexus One smartphone we have decided to use a modified TelosB mote. This results in a prototypical setup as depicted in Fig. 6. In order to provide Bluetooth functionality to the bridging TelosB mote, we used a Bluetooth 2.0 to UART adapter from SURE Electronics[1] [7] and soldered it to the 10 pin extension connector of the TelosB mote. To test the setup and implementation we wrote an Android Activity, which establishes a connection to the mote and displays various status information. On the TelosB, we deployed an application, which sends an increasing counter wrapped in an Active Message over UART



Fig. 2.   Connection using a rooted smartphone with additional hardware



Fig. 3.   Connection using a mote extension via UART and a Bluetooth module



Fig. 4.   Connection using a bridging device between smartphone and mote

---

[1]This adapter has been chosen for price and availability reasons. Aiming at a prototypical proof-of-concept implementation, we considered the security drawbacks inherent to Bluetooth 2.0 as negligible in our context.
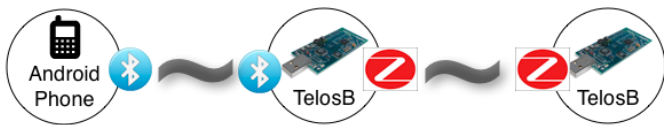
Fig. 6. Prototype concept for mote and smartphone integration with an intermediated bridge

to the connected Bluetooth adapter, which afterwards relays it via Bluetooth to the Android smartphone. After activating Bluetooth on the smartphone and binding the Bluetooth Adapter, the Android Activity was started. After the manual connection and pairing with the SURE adapter, the Activity establishes a connection between the Nexus One smartphone and the TelosB bridging mote. From this point, status messages with the increasing counter value are transmitted from the TelosB mote via the Bluetooth adapter to the Google Nexus One smartphone, which is shown in Fig. 7. Additionally, we sent messages from the smartphone to the mote and remotely controlled the TelosB's LEDs. Unfortunately, the TelosB platform uses the same communication port for both the CC2420 radio and its extension port. Thus, we were not able to use both the TelosB radio and the Bluetooth adapter at the same time, but had to make use of resource arbitration in the TinyOS application in order to switch between those two.

## V. CONCLUSIONS AND OUTLOOK

Wireless sensor networks provide a promising means to enable real-time monitoring of logistics transport processes. Nevertheless, the monitored data and corresponding alert messages have to be transmitted to the responsible decision makers quickly. For this purpose, a long-range connection between wireless sensor network and end users' backend systems is needed. To provide such a connection, the usage of smartphones has been proposed as particularly promising.



Fig. 7. Proof-of-concept implementation

Thus, in this paper we have analyzed different possibilities to interconnect wireless sensor nodes and smartphones in the context of transport processes employing road transportation with trucks. On the basis of different requirement analyses, we have proposed one particular connection concept using a dedicated wireless bridge device between wireless sensor network and smartphone and provided a proof-of-concept implementation for this concept.

As we are currently not able to automatically switch between the communication channel with the smartphone and the communication channel with the wireless sensor network on the bridging device in our actual implemented prototype solution, we plan to test our solution on other hardware platforms. In the work at hand, we focused on the integration of wireless sensor networks and smartphones. Thus, to really provide the whole connection between a wireless sensor network and the end users' systems, possibilities to efficiently transmit data from the smartphone to those systems have to be investigated. Furthermore, security aspects were not part of our investigation. Hence, necessary and demanded security levels of the different stakeholders in the envisioned application scenario of road transportation have to be examined and possibilities to realize these have to be researched.

## ACKNOWLEDGMENT

## REFERENCES

[1] S. Zöller, A. Reinhardt, M. Meyer, and R. Steinmetz, "Deployment of Wireless Sensor Networks in Logistics - Potential, Requirements, and a Testbed," in *Proceedings of the 9th GI/ITG KuVS Fachgespräch Drahtlose Sensornetze*, R. Kolla, Ed. Julius-Maximilians-Universität Würzburg, Sep 2010, pp. 67–70.

[2] L. Ruiz-Garcia, P. Barreiro, J. Rodriguez-Bermejo, and J. I. Robla, "Review. Monitoring the intermodal, refrigerated transport of fruit using sensor networks," *Spanish Journal of Agricultural Research*, vol. 5, no. 2, pp. 142–156, 2007.

[3] R. Jedermann and W. Lang, "The Minimum Number of Sensors - Interpolation of Spatial Temperature Profiles in Chilled Transports," in *Proceedings of the 6th European Conference on Wireless Sensor Networks*, 2009, pp. 232–246.

[4] R. Jedermann, J. D. Gehrke, M. Lorenz, O. Herzog, and W. Lang, "Realisierung lokaler Selbststeuerung in Echtzeit: Der Übergang zum intelligenten Container," in *Wissenschaft und Praxis im Dialog*, H.-C. Pfohl and T. Wimmer, Eds. Hamburg: Deutscher Verkehrs-Verlag, 2006, pp. 145–166.

[5] MEMSIC Inc., "TelosB Mote Platform," Online: http://memsic.com/support/documentation/wireless-sensor-networks/category/7-datasheets.html?download=152:telosb (last access: July, 20 2011), 2006.

[6] Google, "Nexus One – Google Phone Gallery," Online: http://www.google.com/phone/detail/nexus-one (last access: July, 20 2011), 2011.

[7] SURE Electronics, "Bluetooth Serial Converter UART Interface 9600bps User's Guide," Online: http://www.sure-electronics.net/download/GP-GC021_Ver1.0_EN.pdf (last access: July, 20 2011), 2008.