Becker, M.; Wenning, B.-L.; Görg, C.; Jedermann, R.; Timm-Giel, A.: Logistic applications with Wireless Sensor Networks. In: Proc. of HotEmNets 2010. 2010

Logistic applications with Wireless Sensor Networks

Markus Becker, Bernd-Ludwig Wenning, and Carmelita Görg
Communication Networks, TZI
University Bremen
Germany
Email: {mab|wenn|cg}@comnets.uni-bremen.de

Reiner Jedermann
Institute for Microsensors, -actuators and -systems
University Bremen
Germany
rjedermann@imsas.uni-bremen.de

Andreas Timm-Giel
Institute of Communication Networks
Hamburg University of Technology
Germany
timm-giel@tuhh.de

***Abstract*—Wireless Sensor Networks have been deployed for environmental monitoring, home automation, and advanced metering application fields among others. Only few examples of monitoring cargo transports by Wireless Sensor Networks have been reported on. The authors have deployed mobile Wireless Sensor Networks in a cargo container on a trans-atlantic cargo vessel as well as on a lorry to monitor the transport conditions inside the container. This submission reports on the experiences gained from those particular deployments and the open research issues for mobile Wireless Sensor Networks for logistics.**

I. Introduction

Logistics is a multi-player business which has changed significantly in the last decade. The changes are driven by several factors, e.g. by smaller batch sizes (because of customization and individual orders) or by technological changes (RFID). Information technology becomes an integral part of logistics and helps in lowering costs. The change to a more decentralised control of logistic processes and application of information technology in logistics is the topic of the interdisciplinary research project CRC637 [1].

Within this project researchers are also studying the application of Wireless Sensor Networks (WSN) in logistics, i.e. transport of food. Fig. 1 shows one application scenario, where WSN nodes are attached to goods (mostly food because of their perishable nature). The goods are loaded from a warehouse to a freight vehicle, in which their nodes need to self-organize and form a network of nodes, which can deliver information of the goods' state to the outside world using a gateway (e.g. a telematic unit).

WSN as information source is enabler for a new type of logistics, e.g. dynamic FEFO (first expire, first out). Contrary to the currently employed FEFO strategy which uses static best before dates, dynamic FEFO takes the real best before dates into account using information acquired during storage and transport. As the supervision of goods in transport is mandatory and even standards exist for temperature loggers [2], the usage of WSNs and their dynamic data enable an even more sophisticated logistics.

The improvements by a better food transport logistic are among others the reduction of food scrap, improved food quality and better visibility of risks along the food transport chain. The additionally acquired information can be fed into production planning systems for further data mining.

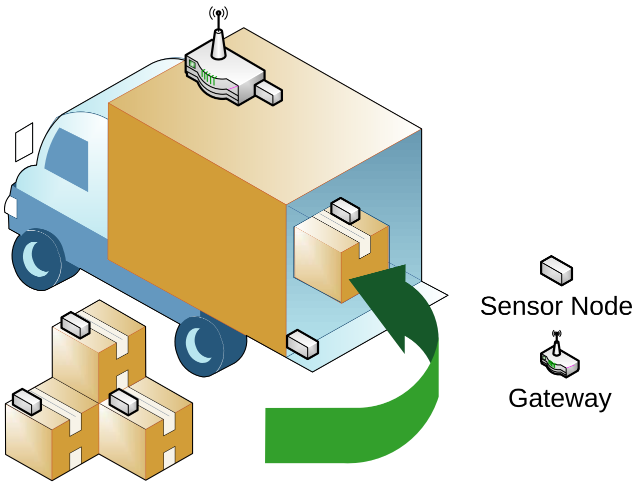


Fig. 1. Wireless Sensor Network for Logistics

Logistics benefits clearly from Wireless Sensor Networks. However, the requirements of logistics for applicable WSNs are challenging. The authors have deployed WSNs in several food transports and are reporting on their experiences and state research challenges with mobile WSNs.

The remainder of the submission is structured as follows: In section II the system architecture and deployments are described. Some of the important experiences of applying Wireless Sensor Networks in logistics are pointed out in section III. Several future items for the research agenda for an all-encompassing application of Wireless Sensor Networks in transport logistics are denoted in section IV. Finally, the article closes with the conclusions in section V.

II. System Architecture and Deployments

The authors' mentioned deployments can be divided into land and sea deployments. One deployment was with a food distributor to hotels and restaurants in a delivery vehicle. Another deployment was in a storage facility for food ripening. Yet another deployment was in two cargo containers on a vessel from Central America to Europe. The food was monitored especially for temperature and humidity. Sensors for the monitoring of ripening gases, such as Ethylen are in development [3].

The system architecture for the sea transport is depicted in fig. 2, while for the land deployment it is shown in fig. 3.

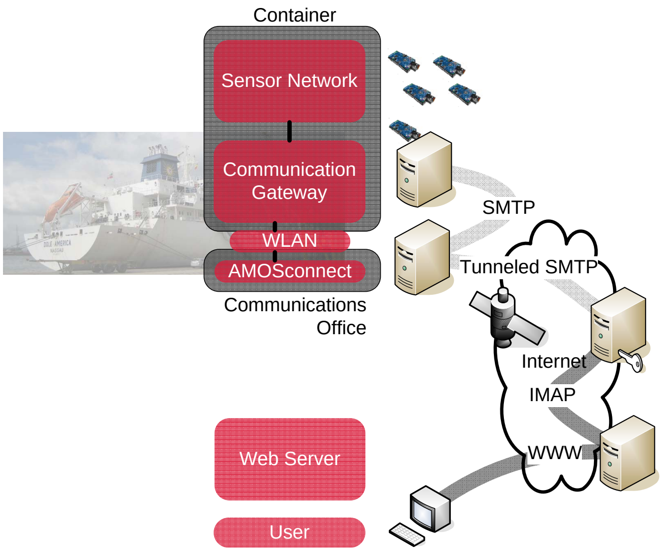


Fig. 2. System Architecture for Sea Transport

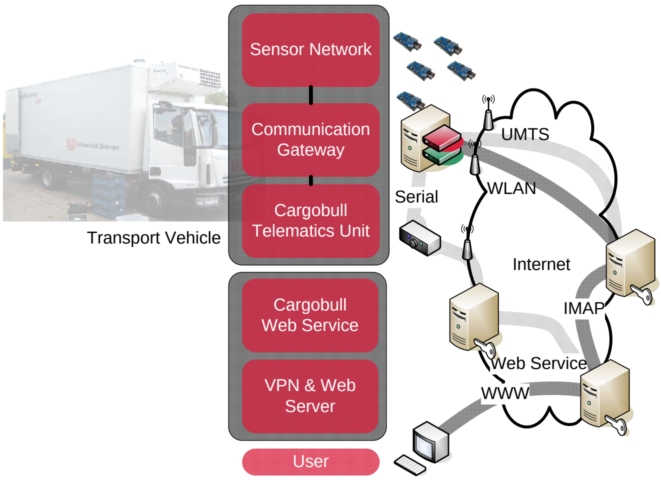


Fig. 3. System Architecture for Land Transport

A. Gateway

The architecture differs mainly in the uplink of the Wireless Sensor Network gateway. For the sea transport the satellite system on the vessel was used by connecting the cargo containers' WSN gateways to the vessel's network via WLAN. The satellite system (Stratos/Xantic AmosConnect [4]) is providing a Simple Mail Transport Protocol (SMTP) server, which was used for delivering the messages to the satellite system. The messages are then sent over the satellite link to an Email Server, from where an Internet Message Access Protocol (IMAP) cron job is fetching them regularly and inserts them into a database provided by a server running the Django Project Web Framework [5].

For the land deployments the uplink was provided in a different way. The gateway (the same hardware as for the sea deployment) is equipped with WLAN and UMTS cards and is able to choose between them according to application profiles (based on security, cost, etc.). Additionally as future logistic WSNs would be tightly integrated with telematics units, a current telematic unit can be used for data transmission as well. The telematic unit is additionally providing further information such as location, ignition state, refrigeration unit state, etc. This data is provided by the telematic unit operator, it is accessible over Push Web Services and is integrated with the WSN data on the Django Web Server.

The user can currently access the information using his web browser and an RSS feed reader. A diagram created by the Django Web Server is shown in figure 4.

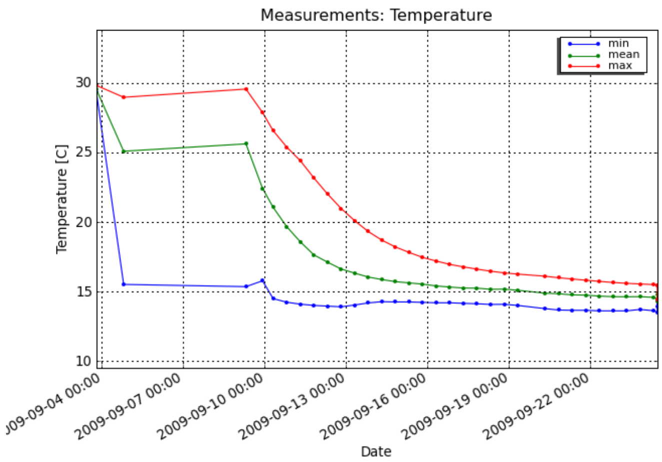


Fig. 4. Measurement data graphically rendered by the Web Server

B. Wireless Sensor Network

The WSN consists of 20 TelosB sensor nodes and was running a modified version of EPFL's SensorScope networking protocol [6]. The application was extended to store measurements to flash memory as well. A watchdog component has also been integrated to make sure the nodes are awake and in a working state. The watchdog is resetted in the Medium Access Control sublayer send function. The nodes were enclosed in IP65 water resistant housings with pressure compensation units because of the expected pressure and relative air humidity changes.

III. Experiences

During the logistical deployments several experiences were made. This section describes the experiences that were deemed important for logistical applications.

A. Signal attenuation

The major challenge discovered, when we deployed WSN nodes in the cargo container densely packed with fruits, was the signal attenuation. The attenuation was even higher than with previous preparational tests, which were executed with fruits which have been transported for two weeks. During that time the fruits lost water content and the surrounding air was of higher relative humidity compared to the conditions at the start of the transport, due to the cooling unit. Fig. 5 shows the moisture on the fruits, which was also prevalent on the housing of the sensor node at unloading.

Fig. 5. Humid environment of the WSN node

The higher attenuation by the high relative humidity in the air and moisture on the housing resulted in a lower connectivity between the nodes and left 2 nodes without connectivity to any neighbour node, although the distance to the closest neighbouring nodes was only 50 cm. Fig. 6 shows the reported link quality (as calculated by SensorScope) between the nodes. Node 0 was the basestation node, the nodes 17-20 were on top of the fruits, all other nodes were in different layers of 4 palettes. Even between the nodes of one palette the link quality can be poor, across different palettes there are rarely connections. The top nodes are properly connected to each other and to the basestation.

			Palette 1				Palette 2				Palette 3				Palette 4				Top Nodes			
	Node ID	BS 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	BS 0																					
Palette 1	1	97		90	41		16				58			91	94	33			90	84	100	
	2	99	90			47						100	93		94				90	84		
	3		25	25		74	73				75	49		59	10	27			33	25	38	
	4		14	41	73		70	79	81		75			36	20	12			12	16		
Palette 2	5		16		72	71		79	66	100	73			93	75	21				30		
	6					70	66		72													
	7					71	60	78		94												
	8								75													
Palette 3	9			24	78	78	80		18			63		15	91	20						
	10		100		52	83	40				51		75	41	66	100			100			
	11										85	46		79	100							
	12		75		20	49	29				37	42	63						16		50	
Palette 4	13	98	90	89	27	34	21				84	16	15	40		77			87	52	40	46
	14		100		66	33	28				40	100			75					100		
	15			66																		
	16																					
Top Nodes	17	99	90	90	16	83	16				44	61	50	20	94	14				84		66
	18	97	90	83	100	100					66			66	100	66			90		91	
	19		100	9	34		33				44			41	41	100				78		91
	20			33	20		22				33			100	28	100			23		84	

Fig. 6. Mean reported link quality

The hop count of the received packets as shown in tab. I resembles the low connectivity in the WSN of the container, although the dimensions of the network are rather small with a size of 40' x 8' x 8'6" (approx. 12m x 2.4m x 2.6m) of the container. Approximately two thirds of all received packets were sent over more than 1 hop, while more than 25 % of all messages that arrived at the basestation were transmitted over 4 or more hops, despite the limited dimensions of the WSN.

TABLE I
HOP COUNT OCCURENCE OF THE CONTAINER WSN

# hops	1	2	3	4	5+
occurunce	7771	3647	5715	4004	2394

B. *Decentralised storage of data*

When designing the system architecture, one main focus was on a reliable storage of the acquired data. It was therefore decided to store the acquired data in a decentralised fashion as shown in fig. 7. One level of storage was implemented on the individual sensor nodes by writing regularly to the flash memory of the nodes. Another level of storage was performed on the communication gateway, where all data received over the attached node and the serial forwarder, is written to an embedded database file (i.e. SQLite [7]). Additionally, summaries of different compressions are taken from this database and sent to a server in the Internet, which stores it in its database provided by the Web framework.

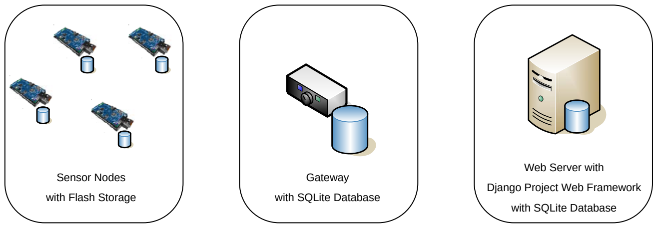


Fig. 7. Distributed storage of data

During sea transport after about 2 days, while more containers were added in a different harbour (this involves containers being dropped onto each other from about 40 cm heights to operate the twistlocks of the containers), the BIOS battery of one of the gateways was shortly disconnected due to the vibrations and the BIOS lost its settings. Due to the lost settings, the gateway's following reboot failed. Because of the decentralised storage of data on all involved components, much of the data was recovered after unloading and reading out the flash of the WSN nodes.

This redundant data storage has proven to be helpful for debugging, analysis of connectivity, online functionality visibility, visualisation, and postprocessing of the data and increases the robustness of information collection by the system.

IV. FUTURE DIRECTIONS

For a full support of the general application area Logistics, more challenges have to be solved.

A. *Integration with telematic units*

Telematic units are already present in many currently built freight vehicles. Those telematic units usually have hard-wired sensors attached. Those sensors could be replaced with WSN nodes, reducing the need for wiring the vehicle (which is one of the main cost factors of equipping a vehicle with a telematic unit). Additionally, WSN nodes that belong to freight owners could be integrated. Research should work on preprocessing the data on the telematic unit, taking into account the ownership of the goods and the nodes. The additional supervision service might get billed to the sender of the good. Methods to configure the supervision, for billing and notification of the owner should be researched.

B. Service Discovery for WSNs

One of the challenges of general-purpose WSNs in logistics includes self-configuration of sensor nodes especially in the case of mobility (typically present in logistics). When a node enters a new WSN, e.g. as in fig. 1, it needs to configure the channel, acquire connectivity within the network and to the gateway. Additionally the node has to figure out, where to send its data to (a database at the gateway, in the network behind the gateway, in the Internet).

WSN for logistics are very likely not tailor-made WSNs, but general-purpose WSNs with tailor-made services. Logistics involves many parties (senders, shippers, receivers). The WSN nodes are thus of different ownerships (e.g. the gateway node belongs to the container owner, the freight supervision node is owned by the sender or the receiver), are possibly of different hardware platforms, have different supervision algorithms (depending on the good to supervise). A WSN in logistics would therefore be made up out of nodes which are greatly varying. Tailor-made WSNs (e.g. based on query-based protocols) would therefore not be applicable, but standardised protocols which allow for dynamic reconfiguration are needed.

In addition to globally standardised physical layer, medium access control, and networking protocols, a mechanism for solving the typical dynamic application layer problems in logistical applications is needed. One such mechanism are service discovery protocols. The protocols are distributing available services in the network. Nodes could then discover services at their current location and could reconfigure themselves to integrate in the prevalent network.

Exemplary services of Wireless Sensor Networks are:

- Measurement and supervision services (e.g. humidity, temperature, gases)
- Identification services
- Gatewaying services
- Database services
- Data processing services
- Time service

The solution needs to enable service discovery between Wireless Sensor Networks and Internet Protocol Networks, so that nodes in a local-area IP network can discover services in the Wireless Sensor Network (shown in figure 8a) and vice versa (shown in figure 8b). In logistical applications special sensors are for example gas detection sensors and door opening sensors, which are required for food environment monitoring and container or warehouse security violation detection. Simple WSN nodes with usual sensors have to deliver the data to an IP network, the location of the delivery is likely to change before, during and after transport, so that the need for discovery of the delivery location as shown in figure 8b is obvious. The shown use cases are just two examples of many use cases in logistics and even more in other application domains (e.g. smart grids). A generic solution for across-network service discovery thus has high applicability for the shown and mentioned uses cases.

The common service discovery solutions for Internet Protocol (IP) based networks are extremely resource demanding, so that they are not feasible in this form for the resource constrained devices in Wireless Sensor Networks. The devices are particularly constrained in terms of memory, computational power, communication bandwidth and energy. Thus new and adapted methods (e.g. by employing the Trickle algorithm [8]) are necessary in this domain.

C. Mobility solutions for IP enabled WSNs for logistics

Within the last years the Internet Protocol (IP) has entered the Wireless Sensor Network field. An IP adaptation layer for IEEE 802.15.4 [9] has been standardized in RFC 4944 [10] by the Internet Engineering Task Force (IETF) 6LoWPAN working group. The standardisation of the protocols is an important factor for the usage of 6LoWPAN in logistics, where long-lived world-wide standards are necessary.

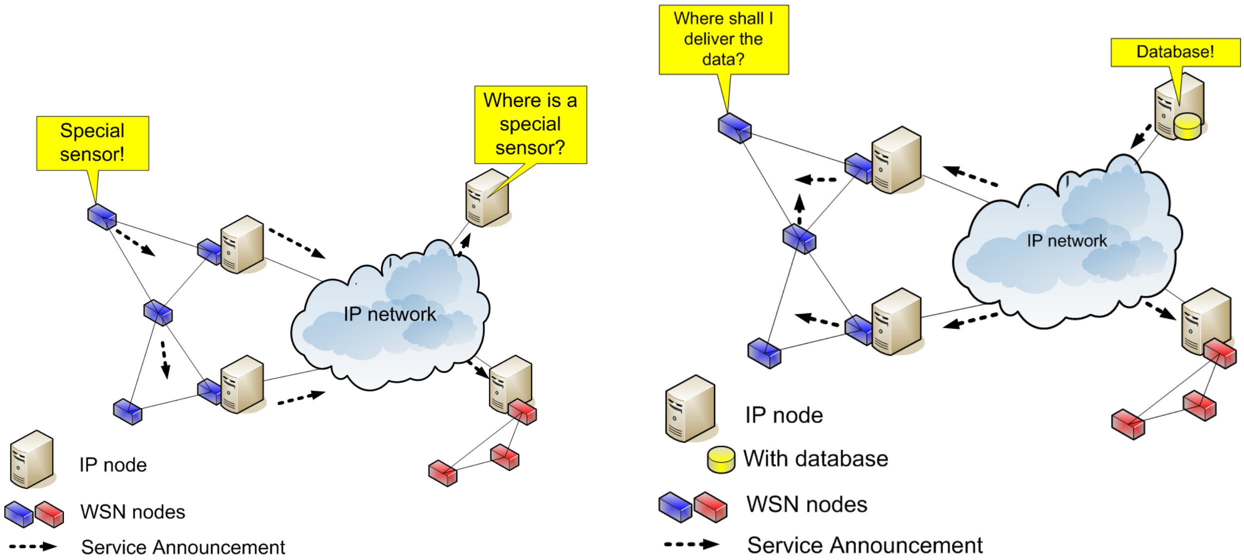
6LoWPAN adds the flexibility that the translation between WSN application format and backend format does not necessarily need to be performed on the WSN gateway computer, but can also be done somewhere in the traditional IP domain. For logistics this gives the required flexibility for the WSN protocols to differ between different nodes and logistics role-players (senders, shippers, receivers) without requiring translation services for each individual node with its specific protocol at the gateway.

The move of sensor networks to IP is thus of great value to the application field logistics. However, several challenges arise with this move for logistics. Without IP enabled WSNs solutions for those challenges would have been required as well, but with IP enabled WSNs they can be solved with already available IP solutions.

As logistics is inherently mobile, the goods and WSN nodes are mobile as well. The nodes are going to be attached to various networks over their transportation duration, e.g. at the sender's warehouse, in the transportation vehicles, in a distribution center and at the receiver's facility. Intra-network mobility is usually handled by the routing protocol of the WSN; Inter-network mobility needs support by the nodes or the gateways though, so that they are connected and reachable from the outside. For this reason research on mobility protocols for IP enabled WSNs should be performed.

For IP mobility support several solutions exist: Mobile IP (MIP) [11], Proxy Mobile IP (PMIP) [12] and Network Mobility (NeMo) [13]. The requirements from logistics, as well as the resource constraints of the WSN are limiting the applicability of the solutions though. Logistical processes exhibit individual nodes' (one node loaded into a vehicle) as well as network of nodes' mobility (a vehicle is assigned a

Becker, M.; Wenning, B.-L.; Görg, C.; Jedermann, R.; Timm-Giel, A.: Logistic applications with Wireless Sensor Networks. In: Proc. of HotEmNets 2010. 2010



(a) Discovering a Sensor (b) Discovering a Database

Fig. 8. Service Discovery in WSNs

new address because of a new dial-in or a change from WLAN to UMTS). Additionally, the nodes might belong to different owners, thus implying different Home Agents. A possibility would be the presence of a service provider, which enables a proxy solution.

V. Conclusion

Wireless Sensor Networks are of interest to transport logistics. This application field is governed by cost and quality pressure. WSNs allow for improvement in quality by better supervision and also cost improvements by less losses and improved handling during the transport. The application field has thus the backing of an industry contrary to WSN deployments for wildlife monitoring which have been popular as a research field in the WSN community. The described deployments have shown that WSNs are applicable for food transport monitoring and online data can be gathered even when the cargo is in the middle of the atlantic ocean. The integration into the backend systems, general applicability so that a multitude of containers, vehicles and goods are equipped with sensor nodes, need further research though. Self-configuration and mobility issues have been raised and should be solved for the general applicability of WSNs for logistics.

Acknowledgment

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

References

[1] Collaborative Research Centre 637: Autonomous Cooperating Logistic Processes — A Paradigm Shift and its Limitations. Available at: http://www.sfb637.uni-bremen.de/?&L=2. Retrieved on 17th Feb. 2010.

[2] EN 12830:1999 Temperature recorders for the transport, storage and distribution of chilled, frozen, deep-frozen/quick-frozen food and ice cream - Tests, performance, suitability. 1999.

[3] A. Sklorz, D. Mrugala, and W. Lang: IR-Ethylene Concentration Measurement in Fruit Logistics. Smart Systems Integration 2009, European Conference & Exhibition on Integration Issues of Miniaturized Systems - MEMS, MOEMS, ICs and Electronic Components (SSI '09); Brussels, Belgium, March 10-11 2008, ISBN 978-3-89838-616-6, pages 383-390.

[4] Xantic/Stratos: AmosConnect Installation Guide. Available at: http://www.stratosglobal.com/support/page-support_productDocumentation.cfm?docID=25. Retrieved on 17th Feb. 2010.

[5] J. Forcier, P. Bissex, and W. Chun: Python Web Development with Django. Addison-Wesley Professional. 2008.

[6] G. Barrenetxea, F. Ingelrest, G. Schaefer, M. Vetterli, O. Couach, and M. Parlange: SensorScope: Out-of-the-Box Environmental Monitoring. In Proceedings of the 7th international Conference on information Processing in Sensor Networks (April 22 - 24, 2008). Information Processing In Sensor Networks. IEEE Computer Society, Washington, DC, 332-343. DOI= http://dx.doi.org/10.1109/IPSN.2008.28

[7] SQLite Documentation. Available at: http://www.sqlite.org/docs.html. Retrieved on 17th Feb. 2010.

[8] P. Levis and T. Clausen: The Trickle Algorithm. draft-levis-roll-trickle-00. Informational Internet-Draft. 2010. Available at: http://www.ietf.org/internet-drafts/draft-levis-roll-trickle-00.txt

[9] IEEE Computer Society: IEEE Standard for Information technology – Telecommunication and information exchange between systems - Local and metropolitan area networks - Specific requirements. Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs). New York, NY, USA. Oct 2003.

[10] G. Montenegro, N. Kushalnagar, J. Hui, and D. Culler: Transmission of IPv6 Packets over IEEE 802.15.4 Networks. IETF Request for Comments (RFC) 4944. Standards Track. Internet Engineering Task Force. Sept. 2007. Available at: http://www.ietf.org/rfc/rfc4944.txt

[11] D. Johnson, C. Perkins, and J. Arkko: Mobility Support in IPv6. IETF Request for Comments (RFC) 3775. Standards Track. Internet Engineering Task Force. June 2004. Available at: http://www.ietf.org/rfc/rfc3775.txt

[12] S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, and B. Patil: Proxy Mobile IPv6. IETF Request for Comments (RFC) 5213. Standards Track. Internet Engineering Task Force. August 2008. Available at: http://www.ietf.org/rfc/rfc5213.txt

[13] V. Devarapalli, R. Wakikawa, A. Petrescu and P. Thubert: Network Mobility (NEMO) Basic Support Protocol. IETF Request for Comments (RFC) 3963. Standards Track. Internet Engineering Task Force. January 2005. Available at: http://www.ietf.org/rfc/rfc3963.txt