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Research Report

The ZRL Wireless Sensor Networking Testbed

Editor:

Hong Linh Truong (hlt@zurich.ibm.com)

Contributors:

Daniel Bauer (dnb@zurich.ibm.com)
Simeon Furrer (sfu@zurich.ibm.com)
Sean Rooney (sro@zurich.ibm.com)
Wolfgang Schott (sct@zurich.ibm.com)
Hong Linh Truong (hlt@zurich.ibm.com)
Beat Weiss (wei@zurich.ibm.com)

IBM Zurich Research Laboratory, 8803 Rüschlikon, Switzerland

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Hong Linh Truong (Editor)
IBM Zurich Research Laboratory
CH-8803 Rüschlikon, Switzerland
Email: hlt@zurich.ibm.com

Contributors:

- Daniel Bauer (dnb@zurich.ibm.com)
- Simeon Furrer (sfu@zurich.ibm.com)
- Sean Rooney (sro@zurich.ibm.com)
- Wolfgang Schott (sct@zurich.ibm.com)
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- Beat Weiss (wei@zurich.ibm.com)

Abstract

This paper describes the ZRL wireless sensor networking testbed built within the framework of the Zurich "Sensor Networks" and "Edge Server Software" projects. Besides its function as a demo platform for customer engagements, the testbed is used to address a wealth of exciting research challenges. We are carrying out performance evaluation with short-range wireless technologies that are highly relevant for sensor networking, such as IEEE 802.15.4 / ZigBee, Bluetooth, and IEEE 802.11. We explore the merits of wireless mesh networking to extend the range and enhance reliability. Also we are developing new light-weight messaging protocols which allow to bring messaging oriented middleware down to very low-end sensors or actuators enabling a true end-to-end solution. In addition, we address the growing need for location-sensing functionality in wireless and sensor networks.

ZRL Sensor Networks project: http://www.zurich.ibm.com/sys/communication/sensors.html
ZRL Edge Server Software project: http://www.zurich.ibm.com/sys/communication/edge.html

Introduction

In a few years, PCs, PDAs, and cell phones will be outnumbered by sensors and actuators. As illustrated in Figure 1 new forms of machine-to-machine communication will emerge and enable a plethora of new services and applications: for industrial automation, asset management, environmental monitoring, in the medical and transportation business, and in a variety of safety and security scenarios. Sensor and actuators have the potential to add a whole new dimension to networking and computing. Their importance - not just in terms of number of devices and volume of processing transactions but also in terms of impacting our every day life - might well eventually surpass that of human-centric devices (PCs, mobile phones, etc.). Indeed, end-to-end computing and machine-to-machine communication offer tremendous opportunities for IBM business, and a wealth of exciting research challenges as well.

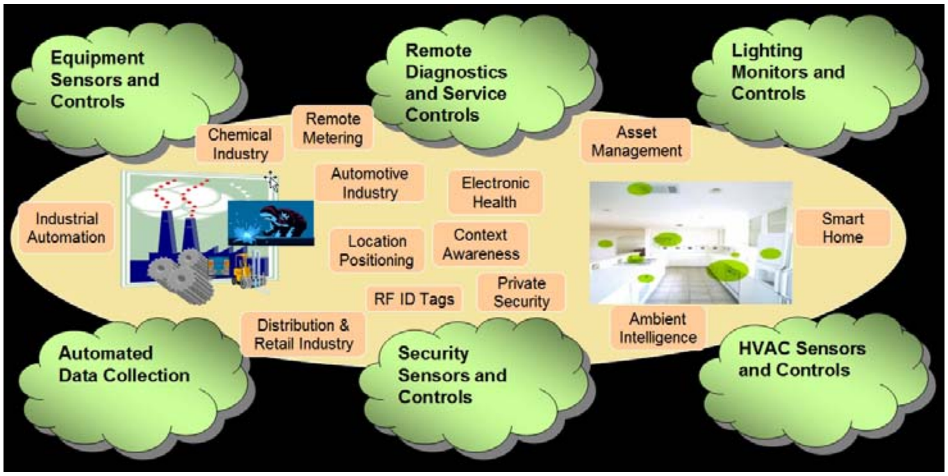

Figure 1: Sensor Applications

IBM's goal in this area is to provide complete end-to-end solutions ranging from sensors and actuators to business applications, such as integrating sensor networks with enterprise computer networks and the Internet. For many applications, such as asset control or condition-based maintenance, a very large number of sensors may create an avalanche of data streaming through the network to the application servers. Data aggregation, abstraction, and filtering at the edge of the network will therefore become a necessity. Also, sensor networks may be deployed in remote locations, which require remote system management for control and configuration as well as support for software updates.

In the IBM Zurich Research Laboratory, we are leveraging our expertise in wireless networking, advanced middleware concepts, and embedded platform design to create innovative concepts, efficient architectures and reference designs for end-to-end enterprise solutions. We have built a sensor networking testbed to verify IBM's end-to-end concept and evaluate its performance and scalability. Equally important, the testbed serves as a reference design and demo platform for various customer engagements. Furthermore, the wireless networking components of the testbed serves as a platform for testing and evaluating various mesh networking protocol implementations, such as EmberNet [1], ZigBee [2], tinyDB [3], etc. A photograph of the testbed is shown in Figure 2.

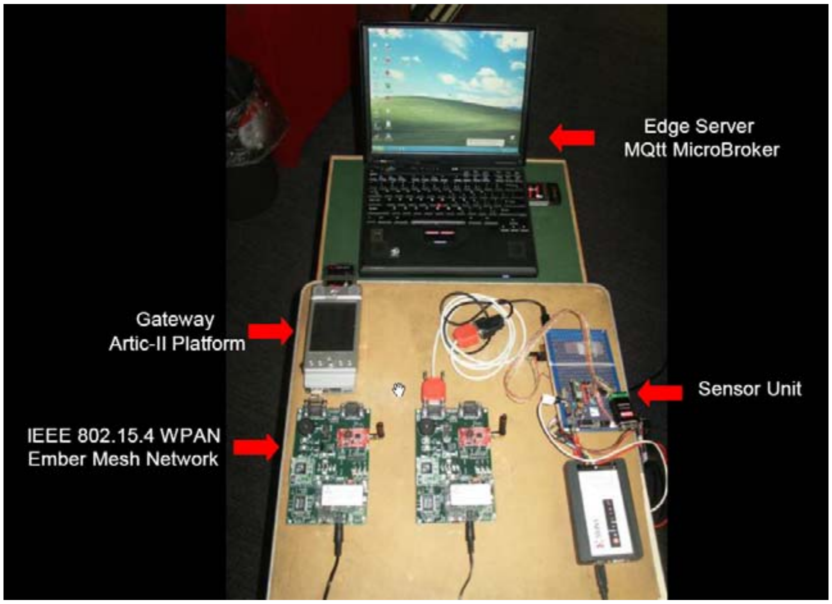

Figure 2: The ZRL Wireless Sensor Networking Testbed

The ZRL Wireless Sensor Networking Testbed

As mentioned before the main goal of the testbed is to prototype an end-to-end enterprise solution which brings the data generated by low-end wireless sensors to IBM WebSphere Application Server. For this purpose, the testbed consists of the following components (see Figure 3):

- A sensor unit equipped with several types of sensors;
- A wireless network;
- A gateway connecting the wireless sensor world with the IBM enterprise computing environment;
- IBM middleware (MQtt, Message Broker, etc.) supporting the distribution of sensor data to the sensor applications; and
- Sensor applications.

Sensor Unit (SU)

The SU consists of two boards, a sensor board and a controller board. To get an understanding of how sensors work and generate data, several types of sensors have been assembled on the sensor board: accelerometers, gyroscopes, compass, and thermometer. The accelerometers and gyroscopes measure the acceleration and rate of turn in a Cartesian co-ordinate system that is body-fixed to the sensor board, while the compass measures the orientation of the sensor board in an earth- fixed co-ordinate system. The sensor board also contains an A/D-converter for converting analog sensor data into digital form, a RS232 serial port interface, and a power supply circuit. The operation of the sensor board is controlled by a Xilinx FPGA. The main functions of the FPGA are:

- collect data generated by the sensors;
- assemble data into a data frame; and

- send the resulting data frames to the RS232 interface.
  (The data frames sent to the RS232 interface are subsequently collected by a radio module for further forwarding to the sensor gateway.)

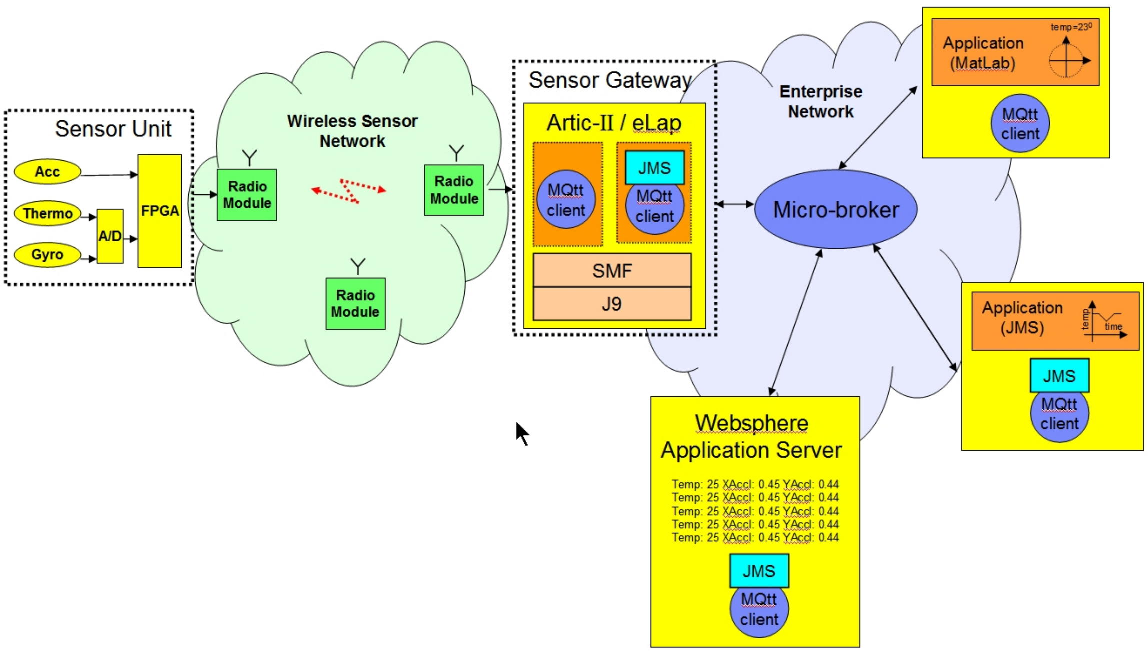

Figure 3: Structure of the ZRL Wireless Sensor Networking Testbed

Wireless Sensor Network (WSN)

The sensor unit uses a Wireless Sensor Network (WSN) to transfer the data frames to the gateway. For this purpose it is attached to a radio module via a RS232 interface. The radio module reads data from the RS232 interface, puts it as payload into a radio message, and sends the message over the radio interface; in the opposite direction, it extracts the payload of the radio messages it received and writes it to the RS232 interface. Such a radio module is also used to attach the gateway to the wireless network, thus allowing the gateway to receive the data frames generated and sent by the sensor unit.

Additional radio modules are also present in the WSN which - together with the “sensor” and “gateway” radio modules – form a so-called “mesh” WSN where each module – or node - operates not only as a data source or sink but also as a data forwarder for other nodes that do not have direct connectivity with their communication peers. The WSN is self-organized, i.e. the nodes automatically establish and maintain connectivity among them. While today's mesh networking protocols were not initially designed for wireless sensor networks, work is underway to achieve scalability to a large number of nodes, and to take into consideration the limitations imposed by low cost, low processing, and low power characteristics of wireless sensor nodes.

We make use of the wireless sensor network part of the ZRL testbed to test and evaluate the performance and scalability of various mesh networking protocols, notably EmberNet [1], ZigBee [2], and tinyDB [3].

The following wireless modules are successfully been employed in the testbed:

- Ember development kit with 802.15.4 radio and Zigbee networking stack [1]; and
- Crossbow "MICAz" Motes with 802.15.4 radio [4].

Sensor Gateway

The sensor gateway is implemented with an Arctic-2/eLap, whose software environment is shown in Figure 4. It contains a PowerPC 405LP with the "MontaVista embedded Linux CEE 3.0" as operating system and the "IBM Websphere Micro Environment" [5] as software environment. Included in the Micro Environment is a J9 Java virtual machine.

The sensor gateway is the bridge between the wireless sensor world and the enterprise computing environment. On the wireless sensor side it is attached to the RS232 interface of a radio module; on the enterprise side it is connected to the enterprise network via an integrated Ethernet port or a IEEE 802.11 WLAN PCMCIA card. It hosts a java "gateway" application which extracts sensor data frames from the information received over the RS232 interface and publishes them to a micro-broker using a MQtt client. See Section "IBM Middleware" for more information on the MQtt protocol and the micro-broker.

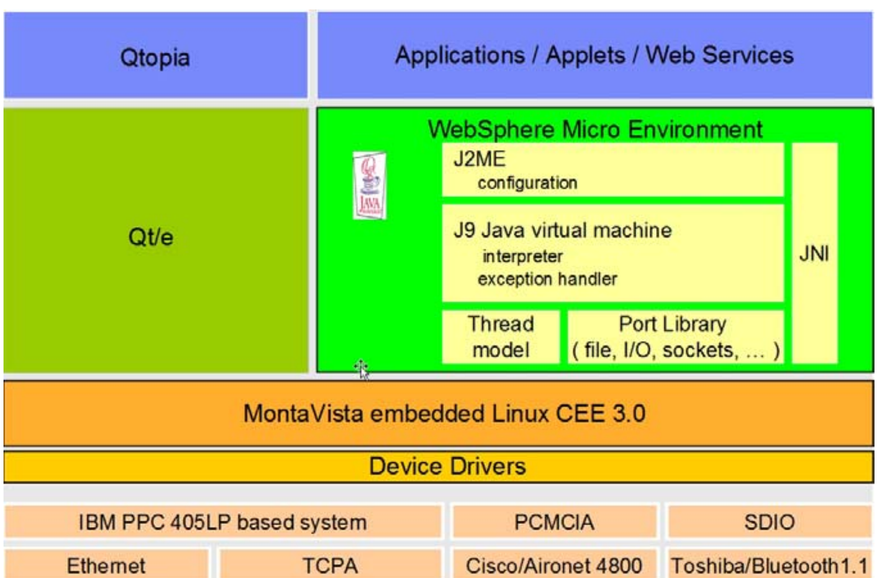

Figure 4: eLap Software Environment

IBM Middleware

In the ZRL sensor networking testbed, the gateway is connected to an IBM WebSphere micro-broker using the Websphere MQ Telemetry Transport (MQtt) [6] protocol to distribute the collected sensor data to multiple applications. Furthermore the testbed uses the IBM Service Management Framework (SMF) [7] to remotely install and manage applications running on the gateway.

The main function of the micro-broker and the MQtt protocol [6] is to connects the "sensor world" with the backend computing environment of the enterprise, thus making the field data collected by the sensors available to all applications in the same way as any other enterprise information. The MQtt protocol is based on a publish/subscribe messaging model for distributing information to interested applications. Publishers send (publish) messages to the broker on a specific "topic" (similar to the subject of an e-mail). Subscribers register (subscribe) their interest in certain topics with the broker. The broker manages the connections to the publishers and subscribers and distributes the messages it receives from the publishers to the subscribers according to their subscribed topics.

The broker can also perform certain message processing tasks. For example it can transform raw sensor data into an XML-formatted message, which is more useful for many enterprise applications. The communication between publishers and subscribers is anonymous — they do not need to be known about each other. This decoupling makes the system future-proof, since the binding between information producers and information consumers is performed via ‘topics’, and new applications with new combinations of topics can be added and deployed at any time.

The MQtt protocol is an open and lightweight publish/subscribe protocol designed specifically for remote telemetry applications and optimized for communications over low-bandwidth, high-cost networks.

The ZRL testbed uses the IBM SMF [7] to remotely install and manage applications running on the sensor gateway. SMF is IBM’s implementation of the Open Services Gateway initiative (OSGi) architecture specified by the OSGi Alliance [8]. The OSGi architecture is based on Java to ensure its independence from operating systems and processor architecture. It allows applications to share a single Java Virtual Machine (JVM), and can install, start, stop, update and uninstall applications on the fly without affecting the operation of other applications.

Sensor Applications

As described above, the gateway publishes the sensor data it receives from the sensor unit to the micro-broker, thus making the sensor data accessible to any application running in the network. As soon as an application subscribes to the sensor data, it gets the data from the micro-broker.

In our testbed, the sensor data are graphically visualized with a Matlab program which uses the MQtt protocol to communicate with the micro-broker and get access to the data. A screenshot of this program is illustrated in Figure 5. The diagram on the left indicates the orientation of the sensor board in the earth-fixed reference co-ordinate system. The right diagram indicates the acceleration vector of the sensor board measured in the x-y plane of the co-ordinate system that is body-fixed to the board. The value of this vector equals the gravity acceleration g if the measured value lies on the circle. In addition, the temperature and the angular rate of the board measured with respect to the z-axis of the sensor board co-ordinate system are given in numerical representation.

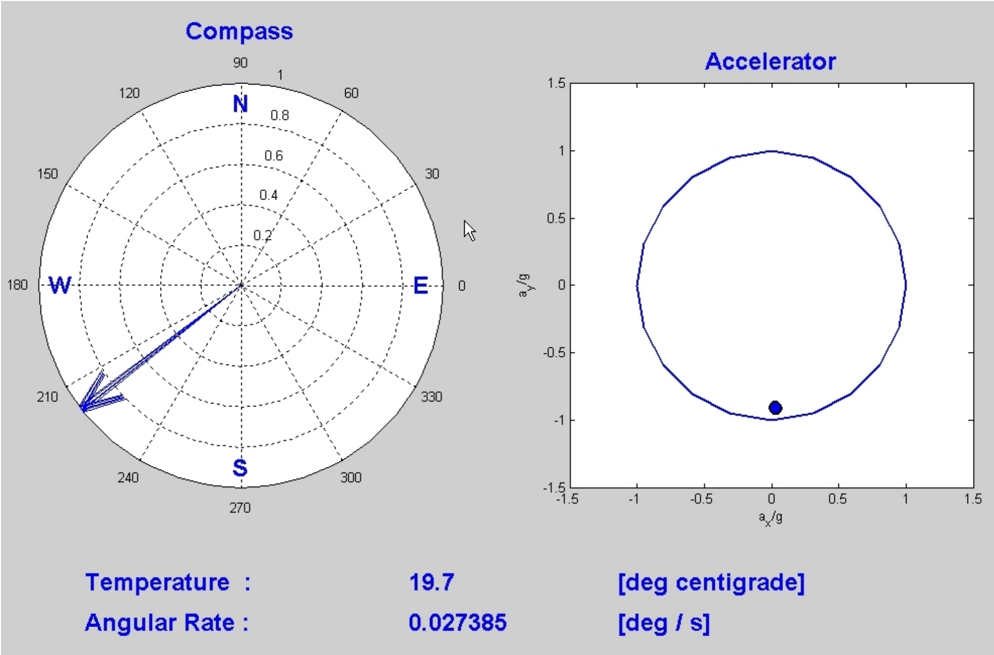

Figure 5: Visualization of Sensor Data

Another J2EE application runs within WebSphere Application Server and makes the sensor data available as web pages. This application consists of a message bean entity that reads the raw sensor data from the micro-broker. A java bean processes the raw sensor data and creates an HTML table out of it. This table is then embedded in HTML pages by a servlet that makes the pages available to HTML clients, i.e. browsers.

Conclusion

We have described the ZRL wireless sensor networking testbed. Besides its function as a demo platform for customer engagements, we are using this testbed to address a wealth of exciting research challenges. We are carrying out performance evaluation with short-range wireless technologies that are highly relevant for sensor networking, such as IEEE 802.15.4 / ZigBee, Bluetooth, and IEEE 802.11. We explore the merits of wireless mesh networking to extend the range and enhance reliability. Also we are developing new light-weight messaging protocols which allow to bring messaging oriented middleware down to very low-end sensors or actuators enabling a true end-to-end solution. In addition, we address the growing need for location-sensing functionality in wireless and sensor networks.

Related Publications

P. Chevillat, P. Coronel, W. Schott, et.al., “WWRF Briefings 2004: Wireless Body Area and Sensor Networks. Wireless World Research Forum”, Dec. 2004.

R. Clauberg, “RFID and Sensor Networks”, RFID workshop, Univ. of St. Gallen. Sept. 2004.

S. Rooney, D. Bauer, and P. Scotton, “Edge Server Software Architecture for Sensor Applications”, IEEE Intern. Symposium on Applications and the Internet, Jan. 2005.

S. Rooney, D. Bauer, and P. Scotton, “Distributed Messaging using Meta Channels and Message Bins”, 9th IFIP/IEEE Intern. Symposium on Integrated Network Management”, May 2005.

B. Radunovic, H.L. Truong, and M. Weisenhorn, “Receiver Architectures For UWB-Based Transmit-Only Sensor Networks”, 2005 IEEE Intl. Conf. on Ultra-Wideband (ICU 2005), Sept. 2005.

P. Coronel, S. Furrer, and W. Schott, “An opportunistic energy-efficient medium-access scheme for wireless sensor networks”, Proc. of IEEE Intl. Conf. on Communications, May 2005.

References

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[2] ZigBee Alliance, http://www.zigbee.org/en/

[3] TinyDB, A Declarative Database for Sensor Networks, http://telegraph.cs.berkeley.edu/tinydb/

[4] Crossbow Technology Inc., http://telegraph.cs.berkeley.edu/tinydb/

[5] IBM WebSphere Everyplace Micro Environment, http://www-306.ibm.com/software/wireless/weme/features.html

[6] IBM WebSphere Telemetry Integration, http://www-306.ibm.com/software/integration/mqfamily/integrator/telemetry/

[7] IBM Service Management Framework, http://www-306.ibm.com/software/wireless/smf/

[8] OSGi Alliance, http://www.osgi.org/