SANDbed: A WSAN Testbed for Network Management and Energy Monitoring

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***Abstract*—In this paper we present our work-in-progress testbed SANDbed for wireless sensor actuator networks. In contrast to many existing testbed approaches for WSANs we concentrate our research on highly quantized and resolutive distributed energy monitoring in WSANs as well as on flexible management protocols for this kind of testbeds. Therefore the management software is being designed to support any sensor node platform and also any testbed topology.**

I. Introduction

The research cooperation *ZeuS* [1] is a project investigating the basic principles of reliable communication in wireless sensor actuator networks (WSAN). We believe that it is impossible to provide *full* reliability (in terms of authenticity, robustness, latency, etc.). Instead, a *trade-off* must be made, which balances energy consumption against different reliability measurements. If only little energy is available, reliability should be degraded in favour of network lifetime, which leads to the concept of *probabilistic* reliability. As an example, a query-result being authentic with 70% probability may me better than no authenticity at all [2].

In the ZeuS context, the Institute of Telematics is currently developing a testbed to evaluate energy-aware protocols in ways as yet impossible with existing solutions. Our testbed, called *SANDbed* (**S**ensor **A**ctuator **N**etwork **D**evelopment test**bed**), is not only an appliance, but an integral part of the project. It allows us to evaluate protocols and schemes on real hardware, getting real energy measurements to confirm the often untrustworthy simulative evaluations. Nevertheless, the conceptual design allows the testbed to be of use in many other WSAN scenarios beyond ZeuS.

Therefore, the contribution of this paper is twofold. First, we would like to present SANDbed to the community, to establish relations to research beyond the ZeuS cooperation. Second, we would like to point out the challenges implicated by the various requirements we impose. This is of use for other projects that may need evaluation in a WSAN testbed, too.

In the following Sections, we sketch SANDbed, its main features, challenges and current status. For this, we first outline the primary design goals, introducing core features. Then, we draw the architecture of the testbed itself, but also of software components used for management and monitoring. We conclude by specifying the project's current status and future work.

II. Goals

We identified three major goals for SANDbed development. The Testbed should provide side effect free monitoring of motes without any effects caused by the testbed environment itself. This is to obtain results as precise as possible from the examined sensor network. The second goal for SANDbed is to support multiple experimenters with deployment and management of their experiments and results. For experiment evaluation, we want to be able to get significant and detailed information about the used amount of energy on individual motes measured at distributed locations. In the following we describe each goal and resulting design decisions in more detail.

A. Side effect free monitoring

Monitoring of operating wireless sensor networks can be done on the sensor nodes or by dedicated additional hardware. The first approach is quite easy to realize on a single mote by adding software monitoring modules to the application to be analyzed. Especially in complex field research environments, additional hardware cannot be attached due to inaccessible motes, expenditures or integration problems like wiring dedicated monitoring hardware in the field. However a software approach also suffers from side effects with the running application on the monitored mote. Many sensor network specific operating systems' inability to run multiple threads simultaneously leads to imprecise monitoring results and additional energy consumption for monitoring overhead.

To avoid these drawbacks, our approach uses *dedicated monitoring boards* for energy measurement attached to each sensor mote in SANDbed.

B. Deployment and experiment management

As a useful tool for analysis and evaluation of WSAN protocols and algorithms a vital requirement for a testbed is the management of *user-defined experiment* sets. Each experiment set contains binary image files for sensor motes, configurations for scheduled measurements, mote locations of individual applications and tasks. Additionally, an experiment set can contain mote input for experiment runtime. Using experiment sets allows to repeat an experiment easily with slightly modified initial values and random seeds as well as multiuser support by the testbed. We use a database to store experiment sets and results like application data, distributed energy measurement values and serial mote output for debugging purposes.

SANDbed allows to manage all motes by a web-based graphical user interface which provides functionality, e.g. running experiment applications and monitoring the status of individual motes. The intended purpose of the GUI is twofold. On one hand it provides a network management interface for the testbed and the embedded sensor network. Network management becomes necessary especially because we want to support and maintain heterogeneous mote types in a single sensor network and extensions to our management and monitoring hardware. Using a common network management protocol in SANDbed even enables us to integrate SANDbed in an Internet environment. On the other hand the GUI can also be used to setup, deploy and evaluate new protocols and applications. Mote programming can be done via interface from everywhere without physical access to the motes hardware making SANDbed a worthwhile tool for fast development and deployment of new ideas and sensor network prototypes.

C. Distributed energy measurement

The third goal for SANDbed development is to optimize *energy efficiency* of resource constrained wireless sensor actuator networks in order to increase network lifetime. In particular, the distributed nature of wireless sensor networks leads to difficulties in determining the impact of network-wide effects of communication algorithms and architectures. Motes can suffer increased energy demands even if they are not directly involved in a communication process between two nodes. MAC-layer characteristics like observing radio channels for incoming messages or free time slots to send own messages to active nodes are examples of such energy demanding behavior. To pinpoint those effects, we have to measure the used energy not just as sum over the complete run of an experiment, but in very short time intervals of milli- and microseconds.

We are planning to expand SANDbed with the capability of measuring energy consumption on mobile motes for advanced applications like event tracking. Protocol behavior may even depend on different kinds of energy supply or take remaining energy into account. SANDbed is therefore able to simulate various battery models and energy supplies specified by experimenters.

III. Architecture

A. Hardware architecture

The hardware architecture of SANDbed is organized in a tree-like structure shown in Figure 1, enabling high scalability of the testbed.

The root level of the tree comprises the user interface and the database. The database is used for storing all information of SANDbed that requires persistence. SANDbed stores its configuration, user data, experiment configuration and results in this database, where the data is provided to the user interface or the testbed itself. The second tree level is formed by the management nodes connected to the Internet. Each

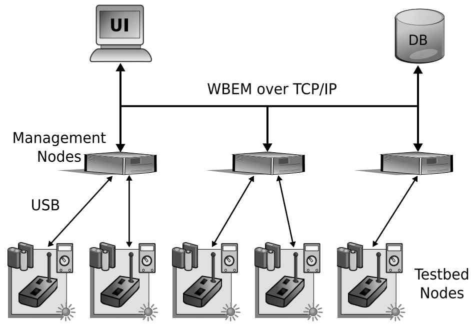

Fig. 1. SANDbed architecture

management node is responsible for monitoring a couple of motes connected over the USB interface. The leaves of the tree are the testbed nodes, consisting of a mote (e.g., MicaZ [3]) and the Sensor Node Management Device (SNMD). Figure 2 shows a possible configuration of a testbed node.

This architecture allows side effect free monitoring in a controlled testbed environment resulting in more precise measurements of energy usage without impact on mote hardware resources. Therefore we designed two orthogonal, non-interfering communication infrastructures in SANDbed. The *horizontal* wireless in-sensornetwork communication is controlled by the researched application while we *vertically* use a TCP/IP and wired USB infrastructure for management and monitoring communication in SANDbed.

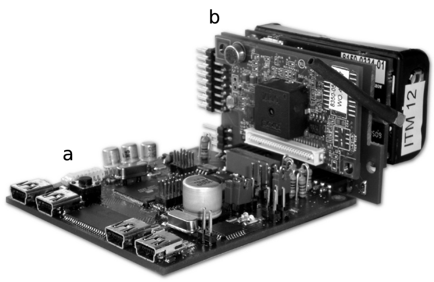

Fig. 2. (a) Sensor Node Management Device (SNMD) with (b) adapted MicaZ and Sensorboard forming one possible configuration for a testbed node

Sensor Node Management Device: SNMD is developed with the intention to analyze the energy consumption behavior of the motes. We achieve this by completely controlling and monitoring the energy supply of the managed sensor nodes. SNMD is able to provide power supply to the motes from an attached battery or by simulating a battery. The battery simulation is done by using USB as power source and controlling the voltage supplied to the sensor notes. SNMD is capable of high resolutive measuring of the voltage and current consumed by the nodes. The measurement results can be provided live (each sample individually) or buffered and sent in chunks over USB.

Furthermore, SNMD provides a comprehensive extension interface which can be used for attaching add-ons like displays, SD-cards, etc. Storing the logs and measurement results on SD-cards enables long term buffered measurements and stand-alone operation. In addition, the extension interface can be used to simulate different environmental conditions for the attached mote. This can be achieved by connecting the SNMD output ports to the input of the mote, thus directly feeding it with simulated sensing data.

Due to the power supply being the only really required interface between SNMD and the mote, every sensor node platform with compatible electrical characteristics can be adopted for operation within SANDbed. Primary benefit of this fact is again side free monitoring, because there is no need of adapting existing WSAN-applications. In fact, the mote has no knowledge of being monitored in a testbed at all.

Table I summarizes the most characteristic technical specifications of the SNMD. Currently the SNMD is in preproduction state being tested as prototype.

TABLE I
TECHNICAL SPECIFICATIONS OF SNMD

Measurement sampling rate: unbuffered buffered	 $max\ 20kHz$ $max\ 400kHz$
Sampling resolution	$16\ bit$
Measurement accuracy	$< 2\%$
Sample buffer	$896kB \widehat{=} 448.000\ samples$
Current measurement range	1). $0 - 100mA$ 2). $0 - 200mA$ 3). $0 - 500mA$
Voltage measurement range	$0 - 10V$
Charging Capabilities:	1). NiMH - $maxI = 200mA$ 2). Li-Ion - $maxI = 200mA$
Node power supply type	1). Real battery 2). Simulated battery using USB-Power
Power output: $maxU_{out}$ $maxI_{out}$	 $4,2V$ $1A$
Programmer capabilities	Any Atmel AVR Chip
PC-Connection	Over USB-Hub
User interface	Serial-USB command line
Extension Interface	I^2C SPI 16 bit I/O Subsystem SD-Card

B. Software architecture

For managing and monitoring objectives we favor standards over proprietary solutions. Therefore the management software of SANDbed is designed as a client-server architecture based on the Web-Based Enterprise Management (WBEM) [4]. WBEM is a set of open standards defined by Distributed Management Task Force (DMTF). One of these is the Common Information Model (CIM) [5] which we use for designing the SANDbed information model. The management information is exchanged between clients and servers over the CIM-XML protocol [6] that uses XML over HTTP to exchange CIM information.

The management nodes implement the server side of WBEM. Therefore every client with WBEM abilities is able to manage our testbed. We prefer WBEM over other network management protocols like SNMP [7], because of its object orientation. This empowers us to easily implement device hierarchies and remote method invocations. The latter are indispensable for controlling the experiment runs and mote behavior.

IV. FUTURE WORK

SANDbed is still in development state. While the hardware is almost in production state, the management software is our next stage of development. The preliminary examinations of the SNMD are very impressive, so we are going to start deployment of SANDbed in the near future. The first SANDbed deployment site will be at the Universität Karlsruhe (TH). There, we will gain experience in managing and monitoring sensor networks and especially distributed energy measurement. In future we will extend SANDbed by further sites, so that more interested scientists will be able to participate in enhancement of SANDbed and performing experiments in wireless sensor actuator networks.

V. CONCLUSION

In this paper, we presented our WSAN testbed SANDbed. We pointed out the major goals, namely *side effect free monitoring*, easy *deployment and management* of WSAN experiments, and last but not least *distributed energy measurement*. We sketched the testbed architecture and showed its current status. Several issues, we identified, have not yet really been addressed to in other WSAN research. However, for a satisfying development and realistic evaluation of WSAN protocols, these issues *must* be solved. Here, the SANDbed will be a step into the right direction.

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