The ScatterWeb MSB-A2 Platform for Wireless Sensor Networks

Michael Baar, Heiko Will, Bastian Blywis, Thomas Hillebrandt,
Achim Liers, Georg Wittenburg, Jochen Schiller

Freie Universität Berlin
Department of Mathematics and Computer Science
Institute for Computer Science, Telematics and Computer Systems group
Takustraße 9, 14195 Berlin, Germany

{baar|hwill|blywis|hillebra|liers|wittenbu|schiller}@inf.fu-berlin.de

Technical Report TR-B-08-15

September 2008

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Department of Mathematics and Computer Science at Freie Universität Berlin
Takustraße 9, 14195 Berlin, Germany

Abstract— **Wireless sensor networks (WSN) are in a transition from research to real world applications. Robust and efficient hardware platforms are needed. These have to offer sufficient processing power and memory while retaining energy efficiency. In this technical report we present the newest ScatterWeb hardware platform that fits the needs of research and prototyping applications of the near future.**

Index Terms — **wireless sensor networks (WSN), embedded systems, ScatterWeb platform**

1 INTRODUCTION

RESEARCH of wireless sensor networks is often focused on algorithms and simulations. While these aspects abstract from the properties, deficiencies, and specifications of real hardware such issues have to be considered for real-world applications. Industrial adoption of WSNs requires robust and efficient hardware platforms. Energy efficiency is a factor that is always the prime concern of these networks as the devices have limited power resources. We therefore introduce the MSB-A2 sensor node as the newest member of our ScatterWeb research family. Although the data specification of our hardware lets assume a shorter lifetime, the MSB-A2 could be as efficient as the former platform.

Our software is optimized to utilize hardware timers for delays of less than 1 µs and takes advantage of hardware support for sending radio packets in short bursts with high data rates, such that the whole system, including the transceiver, can remain in a low power mode most of the time. We are exchanging short energy draining periods with faster task completion and therefore longer sensor node life time in the end. The successor of the MSB-430 still pursues a modular concept. The MSB-A2 can be extended by various sensors or actors making the platform applicable for many scenarios. The combination of these properties prepares the current ScatterWeb generation for real world applications.

The remainder of the paper is organized as follows. In Section 2, the hardware of the MSB-A2 is introduced. Subsequently, in Section 3 we discuss the operation system software. Three of our current research projects, which utilize the new powerful MSB-A2 nodes are presented in Section 4. The paper ends with a conclusion in Section 5.

2 HARDWARE COMPONENTS

The main design goal of the new platform was to develop a minimal and modular sensor network platform. A minimal design was chosen to have a generic node that is affordable in larger quantities needed for a testbed setup. The board only consists of a microcontroller and a radio transceiver plus interfaces needed for debugging and programming. To achieve maximum modularity nearly all interfaces and I/O pins which have not been connected onboard peripherals or sockets are accessible through a socket rail. Due to these principles the board is programmable out of the box and can be connected to custom hardware with minimum effort.

As microcontroller we chose the LPC2387 from NXP [4], which has an ARM7TDMI-S core and represents the smallest member of the ARM core family. Like all ARM microcontrollers it has a 32 bit wide data- and address bus, but unlike the bigger ARM9 cores it has no memory management unit (MMU) and runs software directly from the internal flash. With 512 KiB ROM and 98 KiB RAM it provides roughly ten times the memory of the formerly used MSB-430 [1]. But with an operating speed of up to 72 MHz it is still less powerful than the microprocessors used in current handheld devices (e.g. HTC XDA ~250 MHz, iPhone 2 ~600 MHz ARM11). A fine-grained power control scheme and flexible clock setup make it a reasonable choice for energy scarce sensor nodes. Other reasons to choose this controller are its large number of I/O options which allow flexible connection of many sensors and actors. Besides the usual general purpose I/O lines, RS232, SPI and I^{2}C, Ethernet, USB (slave), CAN-bus and a SD-card interface are natively supported. Further hardware features provided by the microcontroller unit (MCU) are the real-time clock and a vectored interrupt controller.

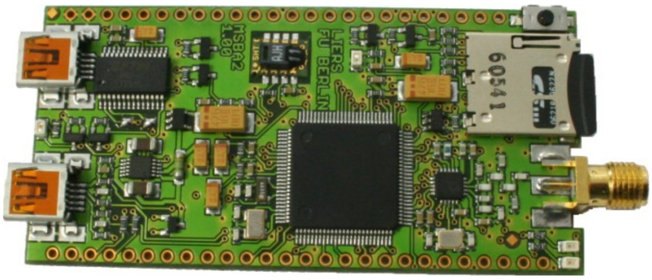

Figure 1. Photograph of the ScatterWeb MSB-A2 board

Figure 1 shows the MSB-A2 board. Peripherals and power source are designed for use in the WISEBED testbed (see 4.2) and as development system. Power is provided through either of the USB ports. As a trade-off for a maximum number of available I/O pins the board's schematic prevents use of the Ethernet interface.

2.1 *I/O Interfaces*

Most MCU I/O ports that are available for custom extensions are externally accessible. Two 10-Bit digital-analog converters (DAC) and a single analog-digital converter (ADC) provide analogue in- and output. Since most of today's sensors already provide digital interfaces, more accurate converts have not been a requirement for our design.

47 digital I/O pins (some with IRQ support) are freely disposable. One serial transmitter (UART) is exposed via a FTDI USB converter to allow flashing and terminal functionality. A natively supported USB slave port is also exposed for future applications. CAN and I²C supporting circuitry and connecters may be added using an extension board.

2.2 *Radio*

The MSB-A2's radio part has been designed for 868 MHz ISM band. The radio chip, a CC1100 from Texas Instruments [5] supports the 315 and 434 MHz bands as well. It implements parts of a media-access-control (MAC) protocol on the receiver side and includes "wake-on-radio" capabilities. Figure 3 shows the transmission of two acknowledged data packets using wake-on-radio. The sender transmits each packet in burst mode until the receiver is woken up and acknowledges the packet.

The CC1100 minimizes the computational load on the microcontroller as all the address filtering is performed in the radio hardware. A software MAC for the sender's side and the Micromesh routing protocol (MMR) [15] have been developed to take advantages of the hardware features. The CC1100 transceiver could use much higher data rates than the formerly used CC1020. The maximum data rate is 500 kbit/s and the typically used data rate in our software is 400 kbit/s. Figure 2 shows a signal spectrum of the radio. Using 400 kbit/s in the 868 MHz ISM band, the power consumption with 10 dBm output power is around 78 mW.

The CC1100 transceiver may be replaced by the revised CC1101.

2.3 *Sensors*

For laboratory and testbed use, the board has been equipped with the Sensirion SHT11 temperature and relative humidity sensor. It provides calibrated digital output with good accuracy at room temperature [6]. Further sensor may be attached using the pin-connectors.

2.4 *Comparison to MSB-430*

A basic application compiled for the 32-bit ARM controller roughly has twice the code size as if compiled for the MSB-430 (using a 16-bit MSP430 MCU). The increased computation power is of advantage, if actually needed (e.g. localisation or pattern analysis), but also requires more energy. However, if all device drivers are optimized for asynchronous operation it should not increase the overall energy consumption of the device since the duty cycle is reduced accordingly.

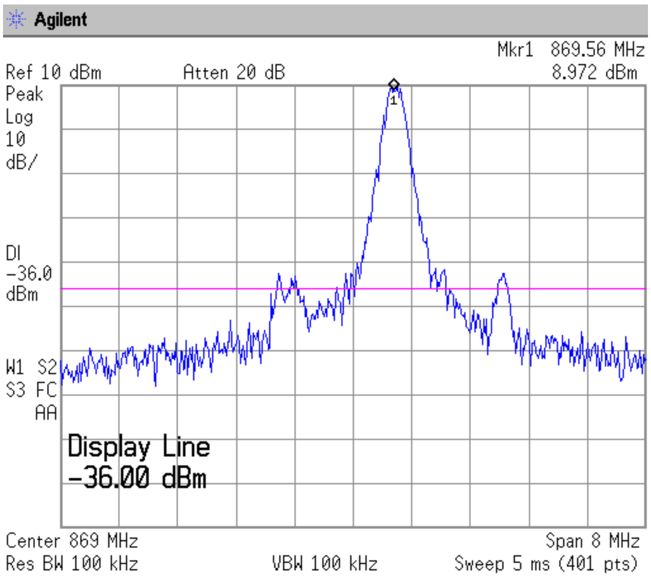

Figure 2. Spectrum plot of a MSB-430 sending with 100 kbit/s

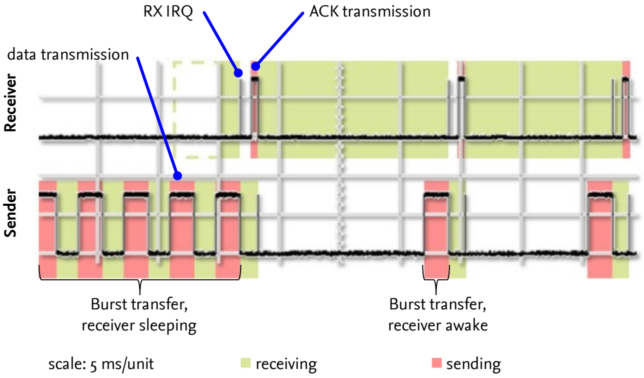

Figure 3. MSB-A2 MAC packet transmission process using CC1100 wake-on-radio functionality

The LPC2387 has a very fine grained power management which offers four operation modes with different power consumptions. Every peripheral unit on the chip can be turned off completely for further energy saving. The clock system provides three clock generators for the CPU, USB and peripherals which can be configured independently from each other to optimize the overall power consumption of the clock system.

3 SOFTWARE SUPPORT

Detailed knowledge on the sensor node hardware has been proven as a clear advantage for efficient software development in the past. As maintaining a completely independent operating system is time consuming, we decided to merge several solutions to a powerful software platform. As core we chose the Contiki 2.2 operating system from SICS [3] which already supports our legacy platforms ESB and MSB-430 [2]. We designed an object-oriented hardware abstraction layer (HAL) for Contiki that makes device drivers independent of the specific hardware platform, provides hassle-free usage for applications and integrates concurrency and energy management [8]. We developed the Micromesh routing protocol as a simple and efficient reactive routing protocol, designed specifically for use in multi-hop wireless ad-hoc networks. Our routing protocol makes use of reliable concepts from known routing protocols like AODV [10] and DSR [11] while combining their benefits to achieve the goals of minimum memory and energy consumption. Furthermore it is easier to implement than AODV and DSR and has no restrictions regarding the network topology. MMR makes use of the MSB-A2's MAC layer to detect link breakages and thus responds to changes in the network topology.

We are currently implementing efficient and optimized driver implementations on top of the HAL as a robust base for complex hardware setups. A multi-tasking microkernel is planned.

4 APPLICATIONS

4.1 *FeuerWhere – Tracking Fire Fighters*

In our joint-project "FeuerWhere" [9] we use an extended version of the MSB-A2 to interconnect fire fighters in an ad-hoc network. An additional nanoLoc radio [7] will provide ranging information to allow mobile indoor localisation. In addition, MSB-A2 devices will route vital parameters from body-area networks carried by the fire fighters as well as location data out of the building. Reliable communication has to be provided in the harsh real-life environment of fire incidents and will be tested by the Berlin fire brigade. With additional sensors, GPS and TETRA (terrestrial trunked radio) connectivity, we will make use of the full capabilities of the device.

4.2 *WISEBED*

The European Union sponsored WISEBED project has the goal to provide a multi-level infrastructure of inter-connected testbeds. Therefore, a large-scale wireless sensor network for research purposes located in various countries is to be set up. An interdisciplinary approach integrating the aspects of hardware, software, algorithms, and data is pursued. Forming a well-organized network from small-scale heterogeneous devices will be the major challenge of the project. The scattered testbed will allow research in a new perspective. In this context the MSB-A2 wireless sensor node will be part of our contribution to the project. We will exploit the wireless mesh network (WMN) located at *Freie Universität Berlin* [12] by deploying sensor nodes inside the enclosing of our mesh routers. Both networks will benefit from the emerging hybrid testbed as we discussed in [12].

4.3 *AVS Extreme - Fence Monitoring*

The aim of the Fence Monitoring project is to provide perimeter security by attaching MSB-A2 sensor nodes equipped with accelerometers to a fence. The nodes run a distributed event detection system [12] to cooperatively recognize previously trained patterns in the acceleration data, e.g. caused by a person climbing over the fence, and alert the base station whenever an event is classified as a potential security breach. The lifetime of a typical deployment is expected to range between three months and two years. Hence, we focus on the trade-off between event detection accuracy and energy conservation using the low power modes of the MSB-A2.

5 CONCLUSION

We presented the new ScatterWeb MSB-A2 hardware platform for wireless sensor networks which we believe will enable access to a broad range of computation-intense real-life applications, while still being reasonably energy efficient.

Microcontroller		NXP LPC2387
		32-bit ARM7 TDMI-S core
Memory	RAM	98 KiB
	Flash-ROM	512 KiB
Processor frequency		up to 72 MHz
Supply voltage		5 V USB (2.7 - 3.6 V)
Power consumption		<1 µA - 150 mA
Transceiver		Chipcon CC1100
Radio frequency	in ISM band	863 - 870 MHz
Transmission power		-52.0 - 8.6 dBm
	range	> 600 m (400 kbit/s)
Radio data rate	raw max.	500 kbit/s
	typical*	400 kbit/s
Input/Output	analog	2 x 12-Bit DAC
		2 x 12-Bit ADC
	digital	18 I/O pins

Tab. 1 Key features of the modular sensor board MSB-A2

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Telematics
Computer Systems

Freie Universität Berlin

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The latest ScatterWeb research platform

Platform Concept

- Versatile, extendable module
- Sophisticated hard- and software integration
- Enabling demanding real-world applications

Core Features

- 32-bit ARM7TDMI-S based microcontroller (512 KiB Flash-ROM, 98 KiB RAM, up to 72 MHz)
- 868 MHz ISM-band TI Chipcon CC1100 radio with wake-on-radio support
- Serial (USB) programming

Energy

- Good scalability of power consumption for computational power and peripherals
- Low overall power consumption < 1 µA ... 150 mA

Extensive Connectivity Options

- microSD-Card storage
- Primary USB for programming
- Secondary native USB port
- Native Ethernet and CAN bus support

High-Potential Challenging Applications

- Low-energy sensor networks
- Autonomous indoor localisation
- Resource demanding networked applications

Robust Software Platform

- Based on Contiki 2.2 core (SICS)
- Object-oriented Hardware Abstraction Layer
- Micromesh routing protocol
- ScatterWeb middleware services

FeuerWhere – Tracking Fire Fighters

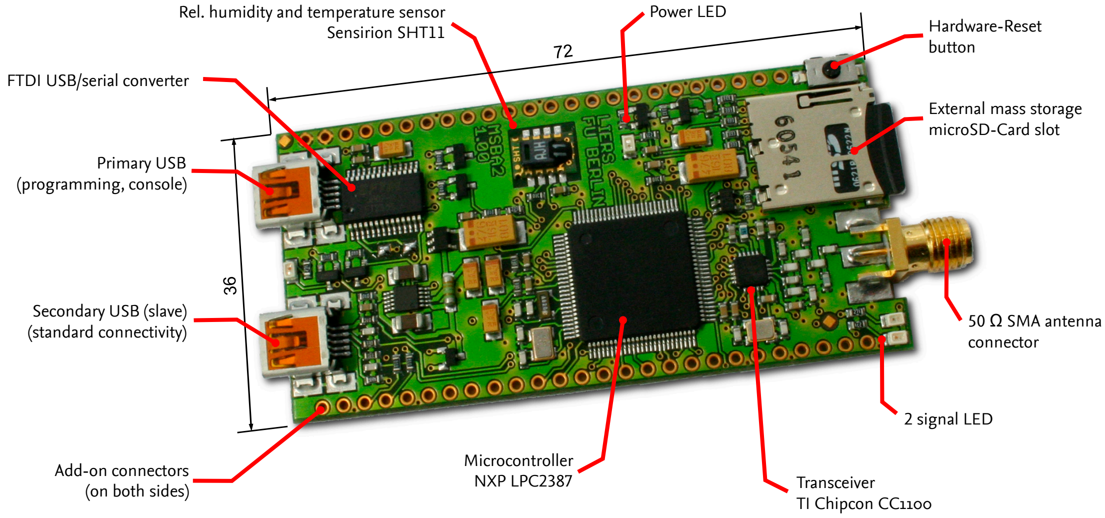
- Extended MSB-A2 board with sensors, additional nanoLoc radio, GPS, TETRA and BAN connectivity
- Indoor localisation and routing
- Prototype usage in harsh, real-life environments
- Schedule 01/2008 – 06/2010
- Berliner Feuerwehr, Nanotron, IHP, MSA AUER

WISEBED Distributed Testbed

- Integrated into a wireless mesh network
- Up to 70 nodes spanning several buildings
- Advanced network management interface
- Interconnected to an European testbed project
- Network for research and teaching purposes
- Schedule 07/2008 – 06/2011

AVS Extrem – Fence Monitoring

- Detection of security breaches at the perimeter of fenced areas
- In-network distributed event detection based on movement patterns
- Deployment-specific training of new event types
- Schedule Q1/09 - Q4/11 (TBC)



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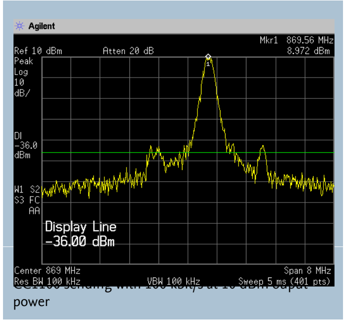
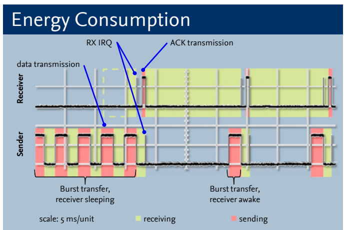
Radio Amplitude Spectrum

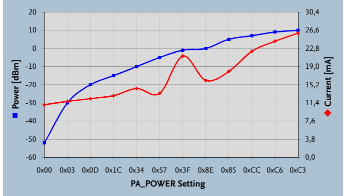


CC1100 sending with 100 kBit/s at 10 dBm output power

Energy Consumption

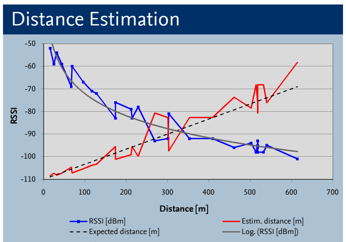


MSB-A2 MAC packet transmission process using CC1100 wake-on-radio functionality



Current consumption of CC1100 chip and radio output power in dependency of amplifier setting

Distance Estimation



Correlation of CC1100 received signal strength, estimated and actual distance between two nodes

Technical Data

Microcontroller		NXP LPC2387 32-bit ARM7TDMI-S
vectored interrupt controller		32 x Vectored IRQ 1 x Fast IRQ
memory	RAM ROM	98 KiB 512 KiB
clock frequency		up to 72 MHz
Power consumption		< 1 µA ... 150 mA
supply voltage		5 V USB (2.7 - 3.6 V)
Radio Transceiver		TI Chipcon CC1100
frequency	in ISM band	863 - 870 MHz
output power	attenuation max. range	-52.0 ... +8.6 dBm > 600 m (400 kbit/s)
data rate	raw max. typical	500 kbit/s 400 kbit/s
Input/Output (available for add-ons)	analog digital	1 x 10-Bit DAC 5 x 10-Bit ADC 47 I/O pins
sensors	rel. humidity temperature	±3.5 %RH ±0.5 °C at 25 °C

Department of Mathematics and Computer Science, Institute for Computer Science, 09 / 2008