SNoW⁵: A versatile ultra low power modular node for wireless ad hoc sensor networking

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Abstract This technical report presents the architecture of the ultra low power sensor node *SNoW⁵* for ad hoc wireless sensor networking (WSN). *SNoW⁵* was developed at the University of Wuerzburg and aims on WSN research, educational and commercial applications. An overview over the basic concept, its hardware design and a tabular comparison to other existing nodes will be given. We conclude this technical report with a survey of our research so far and a short look on future works.

1 Introduction

Powerful information technology is already an inherent part of everybody's daily life. Unfortunately, most systems are rather large in size and depend on static and inflexible infrastructures. Therefore, current research focuses on small-sized and mobile devices which will be deployable into almost any object to directly support humans as well as machines. Carefully designed networks of flexible autonomous devices will lead to increased convenience, performance, security, etc. However, one must always take into concern, that minimalistic computers have low performance due to very restrictive requirements like ultra low power consumption. Thus, the demand for wireless networks of small autonomous devices increased heavily within the last few years. These wireless sensor networks (WSN) use the combined power of many small devices to solve even complex problems under exceptional circumstances for which a single device was too weak. Nevertheless, the successful coordination and interaction of these sensor nodes is a hard problem, comprising research areas like communication, self-organization, fault-tolerance, distributed algorithms and low-power design in both hardware and software.

Several sensor nodes are already available for research and commercial applications but after careful examination of these nodes we decided to develop a new one from scratch to meet our requirements more exactly. The most detailed knowledge of all software and hardware concepts combined with the large amount of features allows us to precisely observe theoretical considerations under hard real-life conditions. Thus, this technical report describes which hardware components were selected to make *SNoW⁵* as versatile as possible (see Figure 1).

2 *SNoW⁵* specifications, features and extensions

This section describes the hardware components used for *SNoW⁵* in detail and illuminates why each one was chosen (see Figure 2). As already mentioned, some other sensor boards already exist. Table 1 shows a detailed summary over the specifications and features of *SNoW*^{5} and compares it to a few other nodes available. As you can see, the named sensor nodes are somewhat similar in some points. In some other points the differences are rather large.

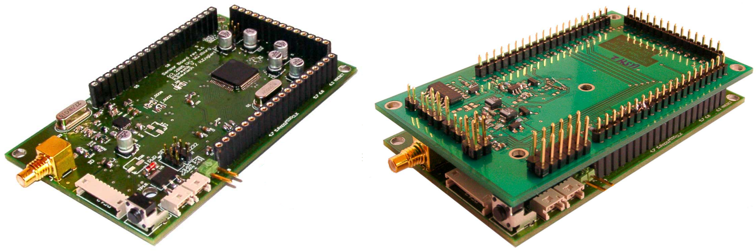

Figure 1. The *SNoW*^{5} main board (left) and with one stacked daughter board (right)

As *energy efficiency* is an important aspect, power consumption was minimized to make *SNoW*^{5} work for a long time even with limited power supply like a simple battery. The usage of renewable power supplies via solar panels and Piezo elements is planned for the near future. Therefore not only ultra low power components but also extended support for energy saving modes was required in both hardware and software. Special power saving concepts were implemented within our operating system and the communication protocols for example.

A *powerful core MCU* was another important issue. After careful comparison of quite a number of architectures, we selected TI's $16\ \mathrm{bit}$ ultra low power MCU family MSP430x16xx [1]. The device we prefer is the MSP430F1611 with $48\ \mathrm{kB}$ of flash memory, $10\ \mathrm{kB}$ of RAM and five operation modes with different power consumptions from $0.2\ \mu\mathrm{A}$ up to $9\ \mu\mathrm{A}$ at $8\ \mathrm{MHz}$ (software adjustable). In addition, various on chip peripherals are provided by the MSP430 and can be used on board or through the node's pin headers: $8 \times 12\ \mathrm{bit}$ ADC, $2 \times 12\ \mathrm{bit}$ DAC, $2 \times 16\ \mathrm{bit}$ timer with capture/compare, brownout detector, hardware multiplier, $6 \times 8\ \mathrm{bit}$ general purpose digital I/O ports and integrated bus protocols for serial communication like SPI, I^2C and RS232. These features allow comfortable usage of external analog and digital components like sensors and actors.

Another goal was *modularity* and *customizability*. As the support for a large variety of additional digital and analog devices is very important for our research, we decided to pursue a stackable design where sensors and actors can be easily attached to each node. Therefore we made all relevant digital and analog signals of the onboard devices available on pin headers. In this way it is not only possible to plug several expansion boards on a node at the same time to expand its capabilities as required by the specific application, this concept also allows us to avoid placing any sensors directly on the main board as this would restrict the versatility of *SNoW*^{5} due to preassigned I/O signals that could be used wiser within some other applications. This concept even permits buses for connecting devices on different expansion boards. We preserve the option to mount sensors on the case of the node where they are in direct contact with the environment.

Quite a number of expansion boards are already available or under development providing the possibility to attach resistive sensors for example. An ultrasonic transceiver for distance measurement is supported as well as an acoustic amplifier for audio applications. In the near future special communication boards with IR, USB, WLAN, GPRS and extensions for orientation and movement detection can be expected.

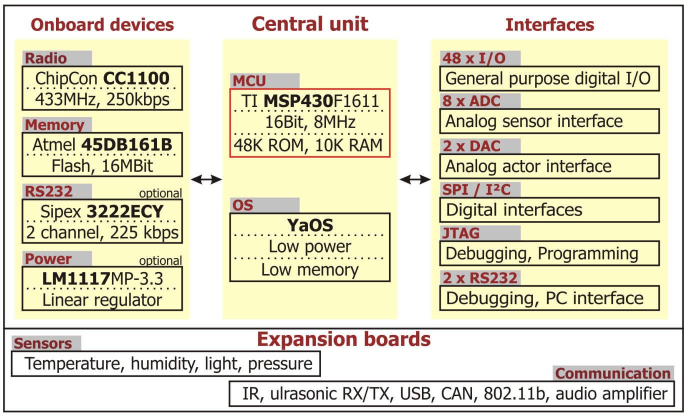

Figure 2. *SNoW*⁵ – a rough overview

A *compact design* was possible by careful selection of small devices. Nevertheless we rated convenient debugging and adaptability more important than small dimensions. For the benefit of easy and rapid prototyping of expansion boards we decided to use a $2.54\ \mathrm{mm}$ grid for the headers. Though this increases the overall size of the nodes we support standard bread boards and allow comfortable debugging via scopes and logic analyzers. For specific applications, the node's dimension can be easily reduced to about 50% of size by omitting debugging headers.

The next focus was on *flexible communication*. As long distance wireless communication is essential within any WSN we decided to use the highly configurable multi channel radio transceiver ChipCon CC1100 [2] with adjustable base frequency (see Table 1). This is of special interest for researching various wireless communication protocols. Some special features of the CC1100 are SPI interface, Wake-on-Radio RX ($\geq 1.8\ \mu\mathrm{A}$), integrated hardware address check and its digital RSSI/LQI output. The latter can be used to adjust TX power for dynamic cell sizes or even to roughly localize a node relative to its neighbour nodes as proposed in [3]. Its data rate ranges from $1.2 - 500\ \mathrm{kbit/s}$ and the two $64\ \mathrm{byte}$ RX/TX buffers allow MCU-independent reception and transmission. For increased versatility in communication and application debugging we added two serial ports which can be individually enabled on demand and extended via USB. The reason for actually providing a RS232 interface was not only the additional debug/communication channel but the possibility to easily attach ready-made devices like GPS modules to *SNoW*⁵ (not yet available as expansion boards). Consequently it is no problem to use a single node as gateway from a PC to the wireless network. A JTAG port allows convenient programming and in-circuit-debugging of the applied MSP430 MCU.

Although cooperation between the nodes of a WSN accounts for its overall performance, we decided to facilitate *complete autonomous and network independent operation*. *SNoW*⁵ is able to compute or collect environmental data over a long period without communicating with other nodes. To store even a large amount of information (logs, measured values, etc.) the non-volatile data flash Atmel AT45DB161B [4] is available on board. This byte addressable 16 Mbit memory also holds the node's basic configuration like its unique ID and communication parameters. The reason for selecting this very device were the two 528 byte data buffers allowing a very smart implementation of an embedded file system [5] that saves valuable RAM within the MSP430 MCU and has some other interesting features.

Finally, the *small but powerful operating system YaOS* was designed to handle all attached devices and to provide a simple to use interface for the application running.

Sensor Node	**Mica2 MPR410CB** [6]	**BTnode** [7]	**ESB ScatterWeb** [8]	**EYES** [9]	**Telos** [10]	***SNoW***^{5}
Developer	Crossbow	ETH Zurich	FU Berlin	Univ. of Twente	UC Berkeley	Univ. of Wuerzburg
Date	2002	2004	2005	2003	2004	2005
Microcontroller unit						
IC	ATMega128L	ATMega128L	MSP430F149	MSP430F149	MSP430F1611	MSP430F1611 / F16xx
Speed (MHz)	7.37	7.37	?	5	0.4 - 8	0.4 - 8
Architecture	8 bit RISC	8 bit RISC	16 bit RISC	16 bit RISC	16 bit RISC	16 bit RISC
Flash ROM / RAM (kB)	128 / 4	128 / 4	60 / 2	60 / 2	48 / 10	48 / 10
Power, active(mA) / sleep(μA)	8 / 15	8 / 15	3.2 / 1.6	3.2 / 1.6	4 / 2	4 / 2
Wakeup time (μs)	180	180	6	6	6	6
Onboard memory						
IC	AT45DB041B	62S2048U	MC 24LC64	ST M25P40	ST M25P80	AT45DB161B
Type / Interface	Flash / SPI	SRAM / ?	EEPROM / I^2C	Flash / SPI	Flash / SPI	Flash / SPI
Non-volatile	yes	no	yes	yes	yes	yes
Size (kB)	512	240	64	512	1024	2048
Power, idle (μW)	5	?	0.03	150	150	5
Power, read / write (mW)	10 / 37.5	? / ?	0.15 / 0.3	12 / 45	12 / 45	10 / 37.5
Primary wireless communication						
IC	CC1000	CC1000	TR1001	TR1001	CC2420	CC1100
Interface	SPI	SPI	non-SPI	non-SPI	SPI	SPI
Data rate (kbit/s)	38.4	38.4	19.2	57.6	250	500
Modulation	FSK	FSK	OOK,ASK	OOK,ASK	O-QPSK	2FSK,GFSK,ASK,OOK,MSK,QPSK
Frequency (MHz)	433	433-915	868	868	2400	315, 433, 868, 915
HW addr. check, dig. RSSI/LQI	no	no	no	no	yes	yes
RX / TX @ 0 dBm (mA)	7.4 / 10.4	7.4 / 10.4	3.8 / 12	3.8 / 12	18.8 / 17.4	14.5 / 16.1
Low power RX / sleep (μA)	74 / 0.2	74 / 0.2	1800 / 0.7	1800 / 0.7	– / 1	15 / 0.4
Interfaces / Sensors / Misc						
PC Communication	RS232	Bluetooth / JTAG	RS232 / JTAG	RS232 / JTAG	USB	RS232 / JTAG
Extension pins / DC ports	51 / 1	55 / 1	24 / 1	14 / 1	16 / 1	67 / 1+2 (free for expansion)
Digital I/O / ADC / DAC	? / ? / 0	21 / 2 / 0	8 / 0 / 0	8 / 8 / 0	13 / 6 / 2	41 / 8 / 2
Accessible buses	SPI, I^2C	SPI, I^2C	SPI	–	SPI, I^2C	SPI, I^2C
Overall DC / physical specifications						
Size (mm × mm)	32 × 58	32 × 58	≈ 45 × 54	≈ 32 × 92	32 × 65	50 × 85
Supported operation voltage (V)	2.7 - 3.3	3.3 or 3.8 - 5	3 - 26	3	1.8 - 3.6	1.8 - 20
Regulated supply	no	yes	yes	no	no	yes
Power, active mode (mA)	30	≈ 33	12	?	14	8

Table 1. Node comparison table

3 Applications

SNoW^5 pursues two basic concepts: due to its small, customizable and energy efficient design paired with various communication channels it is ideal for various demanding applications. In addition, modularity and easy debugging enables our node for research and education. So, recommended fields of application are role-based scenarios where differently equipped nodes cover distinct areas of a comprising complex task.

One example is the supervision of territories and buildings for security, informational and controlling aspects. This is even possible in dangerous and misanthropical environments where no communication infrastructure is available and ad hoc networking is mandatory. Another reason for using *SNoW*^{5} is its easy adaptability to the requirements given. This is especially interesting for task forces like firefighters employing a node in a large variety of situations. Here it can be used for measuring gas concentrations, locating persons and finding escape routes.

Its profits for research and education is the easy accessibility via serial interfaces and JTAG from a workstation. This allows development and analysis of embedded software/middleware like distributed and low power algorithms, operating systems and communication protocols. Functionality of sensors and actors can also be explored.

4 Conclusion and future work

In this technical report we have initially defined our demands on nodes of a WSN. According to these requirements we developed the *SNoW*^{5} node, whose architecture and features were outlined. Differences to other nodes were shown as detailed table. Some examples of particularly suitable applications for *SNoW*^{5} in commercial and research areas close this technical report.

The successful establishment of a wireless sensor network using *SNoW*^{5} finally enables us to evaluate theoretical assumptions under hard real-world conditions. Thus we are currently researching on theoretical problems like self-organizing and fault-tolerant systems. Underlying aspects will be network protocols, routing, time synchronization, power saving concepts, localization and embedded systems software design. Future work will also lead to several daughter boards for sensors and actors in addition to those mentioned above. We will also look for hardware improvements and miniaturization of the *SNoW*^{5} main board. Our long-term objective is the specification of hardware and software requirements leading to a mass market SOC design for generic WSN nodes.

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