An Overview of Hardware Platforms Used In Wireless Sensor Nodes

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***Abstract*— In spite of the large amount of papers covering topics related to wireless sensor networks, a comprehensive overview of hardware platforms used to implement the network nodes is missing. There are several papers presenting particular approaches to implement wireless sensor nodes, there are also a few papers giving a brief presentation of hardware platform evolution in the last decade. This paper gives a survey of available hardware platforms, overviews their sensing, computing and communicating capabilities and focuses on the devices used to implement these platforms.**

I. Introduction

Wireless sensor networks are an emerging technology for low-cost, unattended monitoring of a wide range of environments. Use of this technology appears to be limited only by our imagination and ingenuity [3]. According to Chiang [10], a wireless sensor network is made up of three components (see figure 1):

- Sensors Nodes,
- Task Manager Node (User)
- Interconnect Backbone

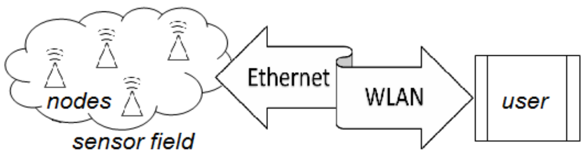

Figure 1. Wireless sensor network

Each sensor node is an embedded system with sensing, processing and communicating capabilities. At least one sensor in the sensor field should be able to communicate with the interconnect backbone.

The interconnect backbone usually includes Internet segments and provides the path for the user to read and control the sensors.

The task manager node is a computer running the user's program, usually data storage, analysis and display applications.

In this paper the focus will be on the sensor nodes, exclusively.

A. Sensor node classes

In a wireless sensor network the nodes are not necessarily identical. In fact some network topologies ask for two or even three type of node to be present in order for the network to work. In [12] Levis presents various network topologies while Baronti in [3] presents three topologies supported by the ZigBee standard: star, tree and mesh. While in mesh networks all the nodes can be identical, in the tree topology three types of nodes are mandatory (see figure 2). These are: end devices, routers and coordinators.

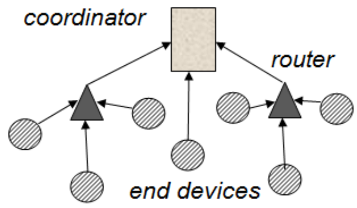

Figure 2. Tree topology

An end device contains just enough functionality to talk to the parent node. They sense the real world and transmit the acquired data. These end devices are kept asleep a significant amount of time, thus their energy consumption is reduced.

Routers may have end device functionality to, but first of all retransmit data from other devices to the coordinator node. Due to this retranslating activity they are active most of the time so they need more energy than an end device.

The coordinator is the most capable device in the network. Stores network information, processes data and bridges to other networks.

Hill in [9] as well as Römer and Matter in [11] classifies sensor according to other criteria.

Hill classifies sensor nodes according to their sensing role and bandwidth in:

- gateway nodes
- high bandwidth nodes
- generic nodes
- special purpose nodes

Gateway nodes have no sensing task, run complex data management applications and connect the WSN to the internet. They are in fact coordinator devices.

High bandwidth nodes are router devices for cameras, microphones or other high data rate sensing devices.

Generic nodes are the most common type of node. They perform low data rate sensing and also routing task if needed.

Special purpose nodes are designed for a specific application. They are usually systems on a chip (SoC) with embedded sensors. They play an end device role in most application.

Römer and Matter in [11] classifies the sensor nodes based on their physical size and proposes the following classes: brick, matchbox, grain, and dust.

Coordinator devices or gateway nodes are usually brick sized. Most high bandwidth nodes and generic sensor nodes are matchbox sized. Special purpose nodes and simple end devices tend to be grain or dust sized.

B. Sensor node architecture

As stated before, a node is an embedded system with sensing, processing and communication capabilities. That implies that a generic sensor node should have three main parts: a sensor or a sensor interface, a microcontroller or microprocessor and a transceiver (see figure 3).

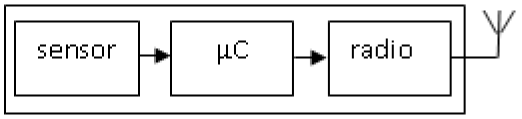

Figure 3. Generic sensor node

Sensors are always embedded in special purpose nodes. The type of sensor depends on the physical parameter subjected to observation. Temperature, light, humidity, pressure, acceleration, magnetic field, sound and vibration are often measured with these types of nodes.

Generic nodes have embedded sensor but usually also have a sensor interface which enables the connection of other analog or digital low data rate sensors.

High bandwidth nodes have a high speed interface to connect to high data rate sensing devices like video cameras.

Gateway nodes usually do not have sensors or sensor interface, their main tasks being data processing, storage and internet connection.

All nodes have more or less processing capabilities. Special purpose and generic nodes have low power 8 or 16 bit microcontrollers for basic data processing and system coordination.

High bandwidth nodes have usually powerful 32 bit microcontrollers and sometimes DSP's or FPGA's for enhanced processing capabilities.

Gateway nodes are more like brick sized computers then embedded systems. They have microprocessors as central processing unit and large amount of memory to store data.

As for communication, special purpose sensor nodes may use radio, laser, infrared or ultrasound.

Generic sensor nodes, high bandwidth and gateway nodes use radio communication, exclusively. Usually, unlicensed frequency bands are used, such as International Scientific and Medical (ISM) frequency bands.

II. Related work

There are a few papers dedicated to sensor node hardware but many papers concerning other aspects of WSN contain detailed hardware description for some specific platforms.

Basaran et all. in [6] reviews five sensor node platforms: ESB/2, Tmote Sky, BTnode, µNode and EYES. The report covers sensor hardware platforms, operating systems, service software distributions, simulation and emulation environments and test beds.

Lewis in [12] gives a comprehensive list of sensors used in sensing nodes and a list of commercially available platforms (in 2004). Yick et all in [8] enumerates five manufacturers of commercial sensor nodes and gives a brief descriptions of their product: Mica, Tmote, SmartMesh, MeshScape and Sensicast families of nodes.

Hempstead in [4] surveys nine hardware systems, while Yu et all. in [1] gives a comprehensive review of hardware platform evolution. Starting with early military systems (SOSUS, AWAKS, ADSID) the author enumerates the research platforms developed at the main American universities: WINS and Medusa from UCLA, Motes and PicoNode from UC Berkeley, µAmps from MIT.

Hill in [9] lists 10 hardware platforms, by classes: one special purpose node (Spec), four generic sensor nodes (Rene, Mica2, Telos, MicaZ), two high bandwidth nodes (BTnode and Imote) and three gateway nodes (Stargate, Cerfcube, PC104 nodes).

A more or less up to date list of prototype and commercial sensor nodes available today is located at http://en.wikipedia.org/wiki/List_of_wireless_sensor_nodes. The list includes sensor node name, microcontroller and transceiver used, the size of program and data memory, the high level programming language and real times operating system if supported. A number of 46 sensing nodes and five gateway nodes are listed.

Tatiana Bokareva's page at http://www.cse.unsw.edu.au/~sensar/hardware/hardware_survey.html lists a number of 32 nodes regardless to their class. Another comprehensive 36 nodes list is available at http://ubimon.doc.ic.ac.uk/ bsn/index.php?m=206&page=0.

III. Hardware platforms

In this paper a number of 67 hardware platforms are considered (see table 1). From these, some are special purpose nodes implemented as systems on a chip, others are high bandwidth nodes, a few are gateway nodes but their majority is made up of generic sensor nodes. In this section we will investigate what is the hardware these platforms use for processing and communication.

Figure 4 gives a short overview about the devices used for processing and control purposes on the hardware platforms under survey.

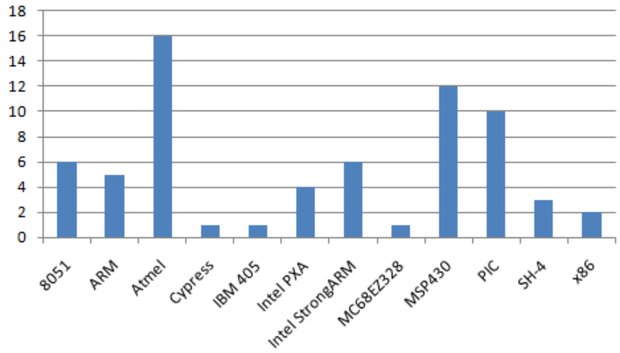

Figure 4. Processors used in sensor networks

TABLE I.
LIST OF HARDWARE PLATFORMS

Ant	iBadge	PIC18F452 based	SunSpot
BSN	iMote	PicoNode	Telos
Btnode	iMote 1.0	ProSpeckz	TinyNode 58 4
CerfCube 1110	iMote2	Rene	Tmote
Cerfcube 255	IpaQ	RFRAIN	Tmote Sky
Cerfcube 405EP	Medusa-MK-II	RISE	U3
CIT	MeshliumXtreme	RSC WINS	uAMPS
cPart	Meshnetics - ZigBit	sGate	uPart
DM182015-	MICA2	Shimmer	waspmote
Dot	MICA2DOT	Smart-it Particle	weC
DSYS25	MICAz	Smart-it uPart0	wee bee
Ember	MITes	SNoW5	WINS 3.0
eyes	NetGate 300	spart	WINS-Hidra
eyesIFXv2	Nymph	Spec	WINS-NG
eZ430-RF2500T	Parasitic	SpotON	XBridge
Flecks	Particle 2/29	SquidBee	XYZ
G-nodes	PC104 nodes	stargate	

One can get a more relevant picture on the processors used if gateway nodes are separated from sensing nodes. Then it would be obvious that sensing nodes usually use low power microcontrollers while gateway nodes uses more powerful microprocessors. Figure 5 presents a graph comparing the numbers of different types of microprocessors used in sensing nodes. Figure 6 gives a similar comparison for processors used in gateway nodes.

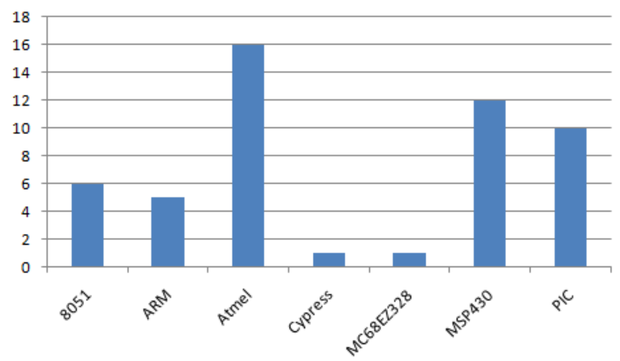

Figure 5. Microcontrollers used in sensing nodes

The 8051 is used almost exclusively in SoC implementations. These are in fact transceiver chips with an 8051 core included. Such chips are nRF24E1 from Nordic, used in MITes, CC1010 from Chipcon, used in RFRAIN or Texas Instruments (after they acquired Chipcon) CC2430, CC2431 used in WeeBee platforms. The newest SoC for sensing application from TI is CC2530. This chip combines a fully integrated, high-performance RF transceiver with an 8051 MCU, 8 KB of RAM, 32/64/128/256 KB of Flash memory, and other powerful supporting features and peripherals.

RISC architecture, 32 bit ARM processors are used for highs bandwidth sensing nodes like Intel's iMote series, UCLA's Medusa-MK-II localizer nodes or Sun Microsystem's SunSPOT (the only sensor platform that uses JAVA running directly on the microprocessor, without any OS). Table 2 shows some parameters of the ARM processors used in these nodes.

TABLE II
PROCESSORS USED IN HIGH BANDWIDTH NODES

processor	**clock**	**flash**	**RAM**	**node**
ARM920T	180MHz	4M	512k	SunSPOT
ARM core	12 MHz	512k	64k	iMote
ARM7 TDMI	12-48MHz	512k	64k	iMote1
ARM11	400MHz	32M	32M	iMote2
ARM THUMB	40MHz	1M	136k	Medusa MK-II

Undoubtedly the most popular microcontroller family in generic sensor nodes is Atmel's AVR. As one can see in figure 5, 16 of 67 nodes use one of these controllers. If one takes a closer look, 11 out of 16 are an ATmega 128 L type microcontroller which turns out to be the most popular processor for generic wireless sensors.

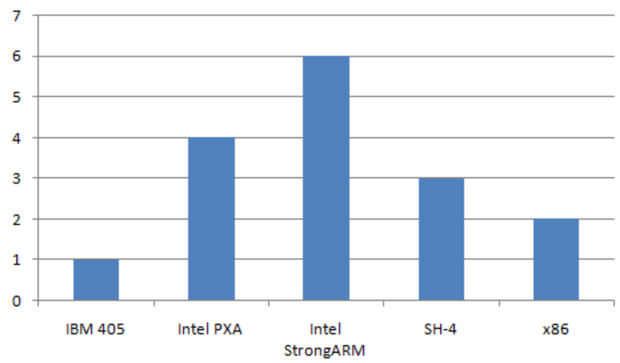

Figure 6. Microprocessors used in gateway nodes

ATmega 128L is a low power, RISC architecture, 8-bit microcontroller. It has 133 instructions, mostly single clock cycle executable. It has up to 16MIPS throughput at 16MHz. Its main hardware resources are: on-chip 2-cycle multiplier, 128Kbytes of in-system self-programmable flash memory, 4Kbytes EEPROM and 4Kbytes internal SRAM. The internal 10-bit resolution SAR ADC has 8 multiplexed channels.

In order to reduce power consumption, six sleep modes are available: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby. Operating voltage may be as low as 2.7V while speed grades are between 0 and 8MHz.

Platforms using these microcontrollers are MICA2, MICA2Dot and MICAz (Crossbow), BTnode (ETH Zurich), Ember (Ember), Flecks (ICT Center Australia), Nymph and WaspMote (Libelium).

Another frequently used microcontroller family is Texas Instrument's MSP430. As one can see in figure 5 12 out of 67 nodes uses this type of microcontroller. These are well known platforms like: eyes (MSP430F149), BSN, SNoW, Telos, Tmote and Tmote Sky, Ant (MSP430F1232), Shimmer (MSP430F1611), TinyNode (MSP430F1611), G-nodes (MSP430F2418).

The MSP430 16-bit microcontroller platform of ultra-low power RISC microprocessors from TI was designed for low power and portable applications. For the F1xx series the speed grade is 8MHz and the hardware resources include up to 60k flash and 10k RAM. Other important resources are a 10 channel 12 bit SAR ADC and a 3 channel DMA system which, enables data acquisition while the CPU is asleep. The F2xx series of microcontrollers exhibits a speed grade of 16MHz and up to 120k flash.

Other very important features are the low supply voltage (1.8V) and ultra low power consumption:

- Active Mode: 330 µA at 1 MHz, 2.2 V
- Standby Mode: 1.1 µA
- Off Mode (RAM Retention): 0.2 µA

PIC microcontrollers appear in 10 of 67 platforms investigated. But these are not members of a specific family (like Atmels ATmega 128L or TI's MSP430F). One can find PIC12F675 on uPart platforms, PIC16F877 on CIT nodes or PIC18F6720 on Particle platforms.

IV. CONCLUSIONS

It is obvious (see figure 5) that almost all types of microcontrollers (von Neumann or Harvard, RISC or CISC architectures) are represented in generic sensor nodes. But it is also clear that two families are most widely used: ATmega 128L and MSP430F.

If for the MSP430 family of microcontrollers the extreme low power consumption, the 16bit multiplicator and the direct memory access (DMA) system represents factual advantages over the competitors, the case of ATmega128L family is not so easy to explain. It may be the user friendliness of the development platform the open source policy of some important developers and the last but not least codes reuse the main factors beside this microcontroller's outstanding success.

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