Wireless Sensor Node Hardware: A Review

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Abstract— **Wireless Sensor Networks (WSN) are becoming increasingly popular, due to the benefits they bring to many applications as well as the increasing availability and maturity of the underlying technology. The fundamental building blocks of these networks are the sensor nodes themselves, the sensors attached to these nodes, and the software running on the nodes. A basic sensor node platform consists of a CPU, a radio and a power supply. For the last 10 years a number of research institutions and companies have been designing and producing nodes with these three components as a minimum. We review how these sensor nodes have evolved over this time and we also categorize the features of various platforms so as to enable an application developer to quickly determine which node is appropriate for their particular network or which features are desirable for inclusion on a custom built sensor platform.**

I. INTRODUCTION

Technological advancements in recent years have enabled the development of tiny, cheap, disposable and self contained battery powered computers, known as sensor nodes or “motes”, which can accept input from an attached sensor, process this input and transmit the results wirelessly to some interested device(s). When a number of these nodes work together, conceivably up to hundreds of thousands, a Wireless Sensor Network (WSN) is formed.

These wireless sensor networks have the potential to allow a level of integration between computers and the physical world that, to date, has been impossible. The uses for such networks is almost limitless and include such diverse applications as a counter sniper system for urban warfare [1], tracking the path of a forest fire [2], determining the structural stability of a building after an earthquake [3], or a wide range of personal health uses [4, 5], etc.

Advances in wireless communication have been a major factor in allowing the development of large networks of sensors. However, as stated in the IEEE 802.15.4 standard specification [6], the wireless connectivity of the sensors is not so much a feature of the sensors but rather an application enabler (unlike the majority of wireless applications currently available). This is the case because wired sensor networks on the required scale would be very costly to build and maintain and also very costly to install, making them impractical.

The resources of conventional computing systems, such as personal computers, mobile phones, etc, increase almost exponentially as technology improves. This is not expected to happen with sensor nodes. Instead advancing technology is more likely to be used to decrease the cost of the nodes. The vision is for these motes to be truly disposable, with an eventual price point of one to two dollars each and a lifetime of at least a year, but of course this is totally application dependent. At this reckoning most commercial sensor nodes will need to drop in price by fifty to one hundred times or more before wireless sensor networks become ubiquitous. This might seem a massive requirement but two factors need to be remembered. Firstly, current commercial products are aimed at being prototyping or development platforms, with costly components and features that are likely to be unnecessary for most deployments. Also, as technology improves, causing prices to drop, WSN deployments are likely to become more widespread, thus allowing economies of scale to come into play at the manufacturing level, driving cost down further.

Table 1 shows the evolution of sensor nodes from the early WeC and Rene motes produced by UC Berkeley to the current state of the art Sun Spot, SHIMMER and IRIS motes by Sun Microsystems, Intel and Crossbow respectively. Currently the most popular nodes, in research institutions at least, are the Mica2, MicaZ and Telosb/Tmote Sky, primarily as they have been commercially available for the longest period of time.

As can be seen from this table, the capabilities of the sensor nodes vary widely, especially in terms of the power of the microcontroller, memory capacity and radio being used. However, despite these variances, all sensor nodes can be said to be composed of four basic sub-systems; a computing sub-system, a communication sub-system, a power sub-system and a sensing sub-system.

II. COMPUTING SUB-SYSTEM

The computing sub-system is responsible for controlling the components of the sensor node and performs any required computations. It consists of two sub-units, the processor and the storage unit.

An important aspect of processors in sensor nodes is different operational modes, usually Active, Idle and Sleep

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TABLE I. SELECTION OF SENSOR NODES FROM 1998 TO 2007

Platform	CPU	Clock (MHz)	RAM/Flash/ EEPROM	Radio Transceiver	BW (kbps)	Freq. MHz	OS	Year
WeC	Atmel AT90LS8535	4	512/8K/32K	RFM TR1000	10	916.5	TinyOS	1998
Rene 1	Atmel AT90LS8535	4	512/8K/32K	RFM TR1000	10	916.5	TinyOS	1998
AWAIRS 1	Intel StrongARM SA1100	59-206	1M/4M	Conexant RDSSS9M	100	900	MicroC/ OS	1999
µAMPS	Intel StrongARM SA1100	59-206	1M/4M	National LMX3162	1000	2400	µOS	1999
Rene 2	Atmel Atmega 163	8	1K/16K/32K	RFM TR1000	10	916.5	TinyOS	2000
Dot	Atmel Atmega 163	8	1K/16K/32K	RFM TR1000	10	916.5	TinyOS	2000
Mica	Atmel Atmega 128L	4	4K/128K/512K	RFM TR1000	40	916.5	TinyOS	2001
BT Node	Atmel Atmega 128L	8	4K/128K/4K	ZV4002 BT/ CC1000	1000	2400	TinyOS	2001
SpotON	Dragonball EZ	16	2M/2M	RFM TR1000	10	916.5		2001
Smart-its	PIC 18F252	8	3K/48K/64K	Radiometrix	64	433	Smart-its	2001
Mica2	Atmel Atmega 128L	8	4K/128K/512K	Chipcon CC1000	38.4	900	TinyOS	2002
Mica2Dot	Atmel Atmega 128L	4	4K/128K/512K	Chipcon CC1000	38.4	900	TinyOS	2002
iBadge	Atmel Atmega 128L	8	4K/128K	Ericsson ROK101007 BT	1000	2400	Palos	2002
CENS Medusa MK2	Atmel Atmega 128L/ Atmel AT91FR4081	4/40	4K/32K 136K/1M	RFM TR1000	10	916	Palos	2002
iMote	Zeevo ZV4002 (ARM)	12-48	64K/512K	Zeevo BT	720	2400	TinyOS	2003
U3	PIC 18F452	0.031-8	1K/32K/256	CDC-TR-02B	100	315	Pavenet	2003
Spec	8-bit AVR-like RISC	4-8	3K	FSK Transmitter	100		TinyOS	2003
RFRAIN	Chipcon CC1010 (8051)	3-24	2K/32K	Chipcon CC1010	76.8	0.3 - 1000	RFRAIN Libraries	2003
Nymph	Atmel Atmega 128L	4	4K/128K/512K	Chipcon CC1000	38.4	900	Mantis	2003
Telos	TI MSP430F149	8	2K/60K/512K	Chipcon CC2420	250	2400	TinyOS	2004
MicaZ	Atmel Atmega 128L	8	4K/128K	Chipcon CC2420	250	2400	TinyOS	2004
CIT Sensor Node	PIC 16F877	20	368/8K	Nordic nRF903	76.8	868	TinyOS	2004
BSN node	TI MSP430F149	8	2K/60K/512K	Chipcon CC2420	250	2400	TinyOS	2004
MITes	nRF24E1 (8051)	16	4K/512	Nordic nRF24E1	1000	2400		2004
AquisGrain	Atmel Atmega 128L	4	4K/128K/512K	Chipcon CC2420	250	2400		2004
RISE	Chipcon CC1010 EM (8051)	3-24	2K/32K	Chipcon CC1010 EM	76.8	0.3 - 1000	TinyOS	2004
Particle2/29	PIC 18F6720	20	4K/128K/512K	RFM TR1001	125	868.35	Smart-its	2004
Pluto	TI MSP430F149	8	4K/60K/512K	Chipcon CC2420	250	2400	TinyOS	2004
DSYS25	Atmel Atmega 128L	4	4K/128K	Nordic nRF2401	1000	2400	TinyOS	2004
EnOcean TCM120	PIC 18F452	10	1.5K/32K/256	Infineon TDA 5200	120	868	TinyOS	2005
eyesIFXv2	TI MSP430F1611	8	10K/48K	Infineon TDA 5250	64	868	TinyOS	2005
iMote2	Intel PXA 271	13-104	256K/32M	Chipcon CC2420	250	2400	TinyOS	2005
uPart0140 ilmt	rfPIC 16F675	4	64/1K	rfPIC 16F675	19.2	868	Smart-its	2005
TelosB/ Tmote Sky	TI MSP430F1611	8	10K/48K/1M	Chipcon CC2420	250	2400	TinyOS	2005
Ember RF Module	Atmel Atmega 128L	8	4K/128K	Ember 250	250	2400	EmberNet	2005
XYZ sensor node	OKI ML67Q500x (ARM/THUMB)	1.8-57.6	4K/256K/512K	Chipcon CC2420	250	2400	SOS	2005
Ant	TI MSP430F1232	8	256/8K	Nordic nRF24AP1	1000	2400	Ant	2005
ProSpeckz II	Cypress CY8C2764	12	256/16K	Chipcon CC2420	250	2400	Speckle net	2005
Fleck	Atmel Atmega 128L	8	4K/128K/512K	Nordic nRF903	76.8	902-928	TinyOS	2005
Sun Spot	Atmel AT91FR40162S	75	256K/2M	Chipcon CC2420	250	2400	Squawk VM (Java)	2005
ECO	nRF24E1 (8051)	16	4K/512/32K	Nordic nRF24E1	1000	2400		2006
SHIMMER	TI MSP430F1611	4/8	10K/2G	WML-C46A BT/ CC2420	250	2400	TinyOS	2006
IRIS	Atmel ATmega 1281	8	8K/640K/4K	Atmel ATRF230	250	2400	TinyOS	2007

modes as a minimum. This is important so as to preserve power as much as possible without impeding the operation of the processor when it is required.

As can be seen from table 1, the processors used in sensor nodes to date range from ultra-low power 8 bit micro-controllers which can be clocked at speeds as low as 31 kHz, to powerful 32 bit ARM processors that can be clocked at greater than 200 MHz. The price that needs to be paid for using faster and more powerful processors is increased power consumption and purchasing cost. The trend in new generations of sensor nodes is to use low power processors that focus on very low energy consumption while inactive, as for most WSN applications the processor is in sleep mode for greater than ninety nine per cent of the time.

The storage unit of the node usually consists of both flash memory, containing the program code for the node, and RAM, which stores sensed information and any data needed for computations. Some motes also have non-volatile storage for off-line data capture for later retrieval. For example the Shimmer mote has a built in micro SD card interface allowing up to two gigabytes of data storage. However writing to the SD card incurs a high cost power wise, on par with sending the same amount of data over a low power radio, so this option is generally only suitable for applications which allow large capacity power supplies. There can be anything up to an order of magnitude, or more, difference between the storage capabilities of different sensor nodes, the choice being made on the basis of the required and desirable storage capacity versus extra cost.

III. COMMUNICATION SUB-SYSTEM

The communication sub-system is required to enable the sensor nodes to communicate with each other and with a base station. Generally the communication sub-system is a short range radio but the use of infrared communication, ultrasound and inductive fields has also been explored.

While cheap and can be implemented with low power consumption, the major drawback with infrared communication is the need for an unobstructed line-of-sight between the communicating devices. Ultrasound is usually ruled out due to the fact that the network coordinator requires high energy and the form factor of the equipment is also a major problem (i.e. miniaturization). Despite being used extensively for Radio Frequency Identification (RFID) applications inductive field communication is also not suitable due to the high energy requirements of the network coordinator and also because of its very low range.

Radio frequency (RF) communication is ideal for sensor nodes because it is not limited by line of sight and current technology allows implementation of low-power radio transceivers with data-rates and ranges scalable according to application. The RF spectrum is a scarce resource and is regulated by most governments. There are, however, unlicensed bands, known as the industrial, scientific and medical (ISM) bands, inside which it is free to operate once the device conforms to the rules that control the band. An important point to note is that the ISM bands were originally chosen to allow electromagnetic interference (EMI) emissions of products to bleed into without causing problems for other devices. As this is still the case any device, even ones that use no RF communication, are a potential source of interference. Also most humans resonate at 900-1000 MHz and as the ISM bands are multiples of our fundamental frequency, crowds of people can have a major impact on the effectiveness of the communications [7]. However wireless sensor networks still tend to operate inside these bands in order to keep costs down. Other problems that should be considered is that the unlicensed bands change from country to country and there are lots of other devices that also operate in these bands, e.g, wireless local area networks, wireless keyboards, home automation systems, wireless surveillance cameras, etc., providing additional interference.

As can be seen from table 1 a wide variety of radios have been used on sensor nodes. Most current motes use a radio chip which conforms to the IEEE 802.15.4 standard, but some nodes use Bluetooth as an alternative. The argument for using Bluetooth is that it allows easy interoperability with a range of existing devices such as mobile phones and laptop computers without the need for additional hardware. The price that needs to be paid for this interoperability is increased energy consumption. Older generations of nodes tended to use radios that conformed to proprietary standards or to no standards at all.

IV. POWER SUB-SYSTEM

The power sub-system usually consists of a battery which supplies power to the sensor node. For many applications of wireless sensor networks the required lifetime of the sensor nodes may be weeks, months or even years and battery recharging or replacement is unlikely to be feasible, especially in large scale deployments with thousands of widely dispersed nodes, or for nodes placed in hazardous environments. For this reason the developer must ensure every aspect of the network, communication algorithms, localization algorithms, sensing devices, etc., must be as efficient as possible in their energy usage.

A power generator may also be included to recharge the battery onsite. Photovoltaic, motion/vibration and thermoelectric energy conversion are all possible sources of power, depending on the location of the node [9].

For a significant sub-set of WSN applications power supply is not a major limiting factor, a category many current deployments fit into. Wireless sensor networks enable very remote, very large scale deployments but are also useful in more mundane situations. For example for industrial monitoring, while a suitable wired networking infrastructure, or wireless local area network infrastructure, might not be present in a factory, and excessively costly to install, very often a power infrastructure is already present, i.e. the mains power supply. Another example is that for many health applications the sensor nodes are easily accessible, allowing recharging or replacement of batteries at regular intervals. This is a fact that is largely ignored by the research community, primarily as limited energy capacity results in the more difficult and more interesting research problems. However as most commercially viable sensor networks fall into this category, at least for the moment, sub-optimal solutions for the major issues that effect these networks are the only ones currently available, especially along the lines of data aggregation, querying, etc.

V. SENSING SUB-SYSTEM

Sensor transducers translate physical phenomena to electrical signals. Therefore the sensing sub-system of the node is its link to the outside world. The output of the sensors may be digital or analog signals. If the output is analog the node must also include an analog to digital converter (ADC) in order to allow the processor to read the data. Some nodes have sensors built in, such as temperature, humidity and light sensors on the Tmote Sky and a three axis accelerometer on the Shimmer, but many do not, instead providing suitable ports to allow a variety of sensors to be attached to allow for more versatility.

Attaching a sensor with a digital output to a mote is generally a simple exercise, but analog sensors offer some complications. If a node does not have a built in ADC one must be included, and without careful design external ADCs can often send an excessive number of interrupts to the MCU, seriously impacting on the other functions of the node. The two most commonly used processors on sensor nodes to date, the Atmel ATmega 128L and the Texas Instruments MSP430 both contain integrated ADCs. However the resolution and quality of these ADCs are often found to insufficient for many applications, with the ATmega 128L supplying a 10 bit ADC and the MSP430 offering a 12 bit ADC.

VI. OPERATING SYSTEM SUPPORT

Programming wireless sensor nodes is generally a difficult task. This is the case for a number of reasons, including the constrained memory and processing power, the requirement to manage the radio communication and the need to conserve energy as much as possible.

A number of operating systems are now available for wireless sensor nodes to aid in the development process, which, as with traditional operating systems, manage the node's hardware and provide a high level interface to this hardware for the programmer. A major feature of these operating systems is that they provide power management for the nodes, doing everything possible to reduce energy consumption and increase battery life as well as managing the wireless communication between nodes. Code for early WSN deployments was written from scratch on an application by application basis as with most embedded systems, but newer deployments make use of the available operating systems to benefit from the ease of use and reliability they provide.

Table 1 show the most common operating system for each of the motes listed. TinyOS is by far the predominant OS for sensor nodes, with the greatest hardware support and largest user base, but a number of other WSN specific operating systems are available each with their own strengths and weaknesses [10].

VII. CONCLUSIONS

Sensor nodes have evolved considerably in recent years but there is still no one size fits all solution for wireless sensor networks. For the majority of WSNs the choice of sensor node is, and will continue to be, very application dependent.

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