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A Comparative Study on Hardware Platforms for Wireless Sensor Networks

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Abstract— **Recently, Wireless Sensor Networks (WSNs) attract a great deal of research attention, and are envisioned to support a variety of applications, including building monitoring, environment control, wild-life habitat monitoring, forest fire detection, industry automation, military, security, and health-care. Over the years, we have seen a variety of hardware platforms for WSNs to facilitate developing WSN applications. In this paper, we provide a comprehensive review of existing hardware platforms for WSNs. We first present the hardware architecture of a wireless sensor node. We then survey the major hardware platforms for WSNs and present a comparison of these hardware platforms. Finally we present some recommendations from the perspectives of hardware platform developers and hardware platform users. The authors hope that making information about existing hardware platforms will assist researchers working in this area to appreciate the diversity of platforms available to them and to help them select the most appropriate platform for their purposes.**

Keywords— **Wireless sensor networks; wireless sensor node; hardware platforms for wireless sensor networks.**

I. INTRODUCTION

A WSN is generally composed of a centralized station (sink) and tens, hundreds, or perhaps thousands of tiny sensor nodes. With the integration of information sensing, computation, and wireless communication, these devices can sense the physical phenomenon, (pre-)process the raw information, and share the processed information with their neighboring nodes.

Within the last decade, hardware design for WSNs is one of the most researched areas in scientific community and several hardware platforms for WSNs have been proposed and implemented. Hardware design is still a critical issue as computationally efficient low power processors, low power transceivers, capable storage area, long life, small size and low cost come in contradiction with each other.

In this paper, we present the hardware platforms for WSNs. This paper is organized as follows. Section II presents the hardware architecture of a wireless sensor node. Section III surveys some available hardware platforms for WSNs and presents a comparison of these hardware platforms. Section IV presents some recommendations from the perspectives of hardware platform developers and hardware platform users. Finally, we conclude this paper in Section V.

II. HARDWARE ARCHITECTURE OF A WIRELESS SENSOR NODE

The hardware architecture of a wireless sensor node consists of four main components, as shown in Fig. 1.

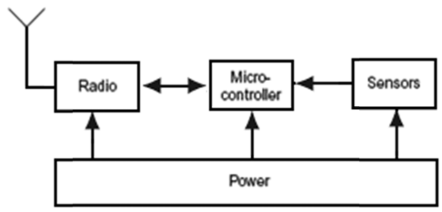

Fig. 1 Hardware architecture of a wireless sensor node

A. Communication Device

This gives the wireless sensor node its communication capabilities. It is typically a radio transceiver with an antenna. Of the hardware components of a wireless sensor node, the radio is usually the most power-consuming component. Compared to the power consumption of the microcontroller or the sensors, the radio transceiver often uses ten times as much power. This is due to the processing required for modulating and demodulating the radio signal.

B. Microcontroller

This gives the wireless sensor node its behavior. It runs the software of the wireless sensor node. A microcontroller is a microprocessor with built-in memory, timers, and hardware for connecting external devices such as sensors, actuators, and radio transceivers. Due to cost and power constraints, the microcontrollers used in wireless sensor nodes are much smaller than the microprocessors used in general purpose PCs. Typically, a wireless sensor node microcontroller has a few kilobytes of on-chip memory and is run at a clock speed of a few megahertz.

C. Set of Sensors

These give the wireless sensor node a way to interact with the physical world. Sensors are used to sense the environment. The sensors and actuators attached to a wireless sensor node range from very simple to very complex such as temperature sensor, humid sensor, light sensor, ultrasonic range device.

D. Power Source

A wireless sensor node is driven by electronics, and electronics need power. Therefore, every wireless sensor node needs a power source. Batteries are the most common power source for today's wireless sensor nodes. Lithium cell batteries are currently the most common. With low-power hardware and proper energy-management software, a wireless sensor node can have a lifetime of years on standard lithium cell batteries.

III. Available Hardware Platforms for Wireless Sensor Networks

While the particular sensor types vary significantly depending on the application, a limited number of wireless modules have been developed to aid research in WSNs. Table I and Table II summarizes the major characteristics of popular platforms that were designed over the past few years. The timeline for these platforms is also shown in Fig. 6. As can be observed, the capabilities of these platforms vary significantly. However, in general, the existing platforms can be classified into two based on both their capabilities and the usage. Next, we overview these existing platforms as low-end and high-end platforms.

A. Low-End Platforms

The low-end platforms are characterized by their limited capabilities in terms of processing, memory, and communication. These platforms are usually envisioned to be deployed in large numbers in a WSN to accomplish sensing tasks as well as providing a connectivity infrastructure. The following platforms have been mostly used in developing communication protocols recently.

1) *Mica Family:* The Mica family of nodes consist of Mica, Mica2, MicaZ, and IRIS nodes and are produced by Crossbow [1]. Each node is equipped with 8-bit Atmel AVR microcontrollers with a speed of 4–16MHz and 128 KB of programmable flash. While the microcontrollers are similar, the Mica family of nodes have been equipped with a wide range of transceivers. The Mica node includes a 916 or 433MHz transceiver at 40 kbps, while the Mica2 platform is equipped with a 315/433/868/916MHz transceiver at 40 kbps. On the other hand, the MicaZ and IRIS nodes are equipped with IEEE 802.15.4 compliant transceivers, which operate at 2.4GHz with 250 kbps data rate. Each platform has limited memory in terms of RAM (4–8 KB) and data memory (512 KB). Moreover, each version is equipped with a 51-pin connector that is used to connect additional sensor boards and programming boards to the mote.

Fig. 2 highlights the components of a typical hardware platform, the MicaZ board from Crossbow Technology. It shows the microcontroller, the power source, the radio transceiver, and an extension connector for connecting sensors or actuators. The power source is a battery pack consisting of two AAA cell batteries. The radio transceiver is mounted on the flip side of the board and cannot be seen. The system uses an external antenna attached to the side of the board. The board does not contain any sensors. Instead, sensors or actuators can be attached to the board through the extension connector. This allows the board to be used as a prototyping system for a wide range of different applications.

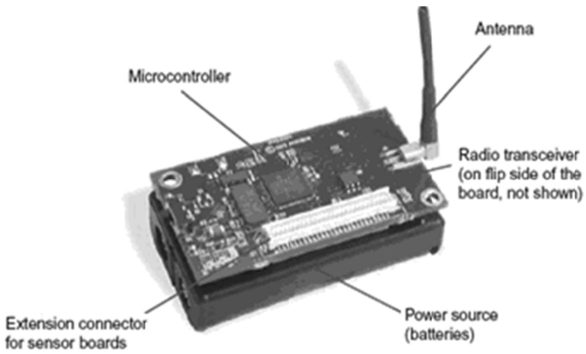

Fig. 2 A MicaZ board

2) *TelosB/Tmote:* An architecture similar to the MicaZ platform has been adopted for the TelosB motes from Crossbow and Tmote Sky motes from Sentilla [2]. A Tmote Sky board is shown in Fig. 3.

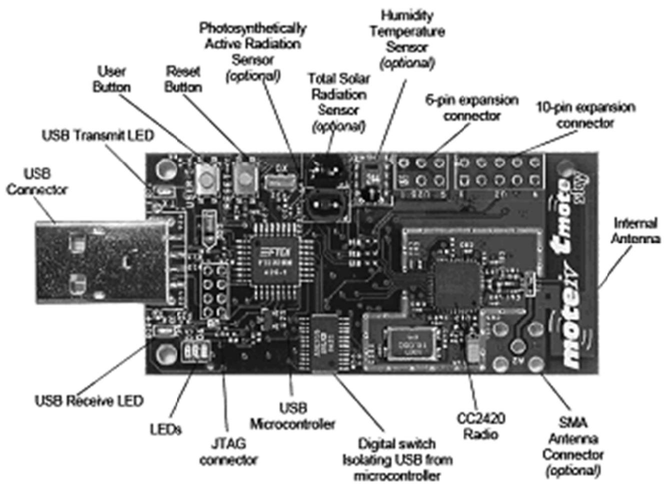

Fig. 3 A Tmote Sky board

While the transceiver is kept intact, TelosB/Tmote motes have larger RAM since an 8MHz TI MSP430 microcontroller with 10 KB RAM is used. Furthermore, TelosB/Tmote platforms are integrated with several sensors including light, IR, humidity, and temperature as well as a USB connector, which eliminates the need for additional sensor or programming boards. Moreover, 6- and 10-pin connectors are included for additional sensors.

3) Eyes and EyesIFX v2: The Eyes platform has been designed as a result of a 3-year European project and is similar to the TelosB/Tmote architectures. A 16-bit microcontroller with 60 KB of program memory and 2 KB data memory is used in EYES [3]. Moreover, the following sensors are embedded with the mote: compass, accelerometer, and temperature, light, and pressure sensors. The EYES platform includes the TR1001 transceiver, which supports transmission rates up to 115.2 kbps. The platform also includes an RS232 serial interface for programming.

EyesIFXv2 [4] is a sensor node developed by Infineon [5] for the Energy-efficient self organizing and collaborative wireless sensor networks project EYES. Infineon has combined EYES baseband hardware with a number of optimized peripheral sets to create a series of chips aimed at specific automotive, industrial and consumer applications. An EyesIFXv2 board is shown in Fig. 4. As other sensor boards (e.g., T-Mote), EyesIFXv2 nodes are equipped with an ultra-low power MSP430F1611 microcontroller by Texas Instruments, combined with a transceiver from Infineon and a USB interface. Some sensors and digital outputs are present on the board.

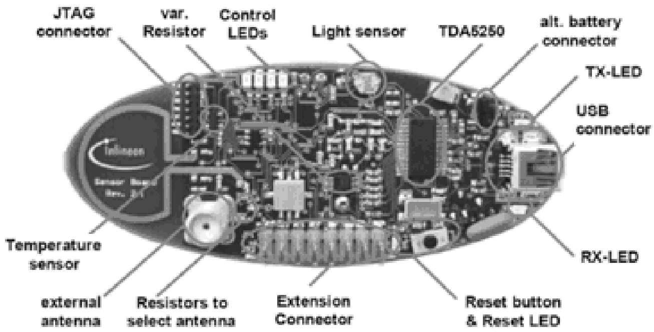

Fig. 4 An EyesIFX v2 board

In addition to these platforms, several low-end platforms have been developed with similar capabilities as listed in Table I and shown in Fig. 6. An important trend to note is the appearance of proprietary platforms from the industry such as V-Link [6], TEHU [7], and the National Instruments motes [8] in recent years.

The low-end platforms are used for sensing tasks in WSNs and they provide a connectivity infrastructure through multi-hop networking. These nodes are generally equipped with low-power microcontrollers and transceivers to decrease the cost and energy consumption. As a result, they are used in large numbers in the deployment of WSNs. It can be observed that wireless sensor platforms generally employ the Industrial, Scientific, and Medical (ISM) bands, which offer license-free communication in most countries. More specifically, most recent platforms include the CC2420 transceiver, which operates in the 2.4GHz band and is compatible with the IEEE 802.15.4 standard. This standardization provides heterogeneous deployments of WSNs, where various platforms are used in a network.

B. High-End Platforms

In addition to sensing, local processing, and multi-hop communication, WSNs require additional functionalities that cannot be efficiently carried out by the low-end platforms. High-level tasks such as network management require higher processing power and memory compared to the capabilities of these platforms. Moreover, the integration of WSNs with existing networking infrastructure requires multiple communication techniques to be integrated through gateway modules. Furthermore, in networks where processing or storage hubs are integrated with sensor nodes, higher capacity nodes are required. To address these requirements, high-end platforms have been developed for WSNs.

1) Stargate: The Stargate board [9] is a high-performance processing platform designed for sensing, signal processing, control, and sensor network management. Stargate is based on Intel's PXA-255 Xscale 400MHz RISC processor, which is the same processor found in many handheld computers including the Compaq IPAQ and the Dell Axim. Stargate has 32MB of flash memory, 64MB of SDRAM, and an onboard connector for Crossbow's Mica family motes as well as PCMCIA Bluetooth or IEEE 802.11 cards. Hence, it can work as a wireless gateway and computational hub for in-network processing algorithms. When connected with a webcam or other capturing device, it can function as a medium-resolution multimedia sensor. Fig.5 illustrates an Stargate board.

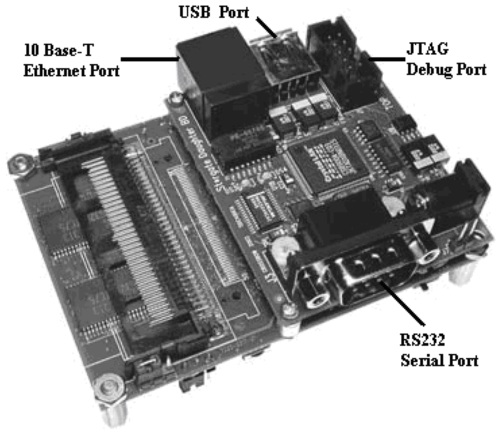

Fig. 5 An Stargate board

Stargate NetBridge [10] was developed as a successor to Stargate and is based on the Intel IXP420 XScale processor running at 266MHz. It features one wired Ethernet and two USB 2.0 ports and is equipped with 8MB of program flash, 32MB of RAM, and a 2GB USB 2.0 system disk, where the Linux operating system is run. Using the USB ports, a sensor node can be connected for gateway functionalities.

2) Imote and Imote2: Intel has developed two prototypal generations of wireless sensors, known as Imote and Imote2 for high-performance sensing and gateway applications. Imote [11] is built around an integrated wireless microcontroller consisting of an 8-bit 12MHz ARM7 processor, a Bluetooth radio, 64 KB RAM, and 512 KB flash memory, as well as several I/O options. The software architecture is based on an ARM port of TinyOS.

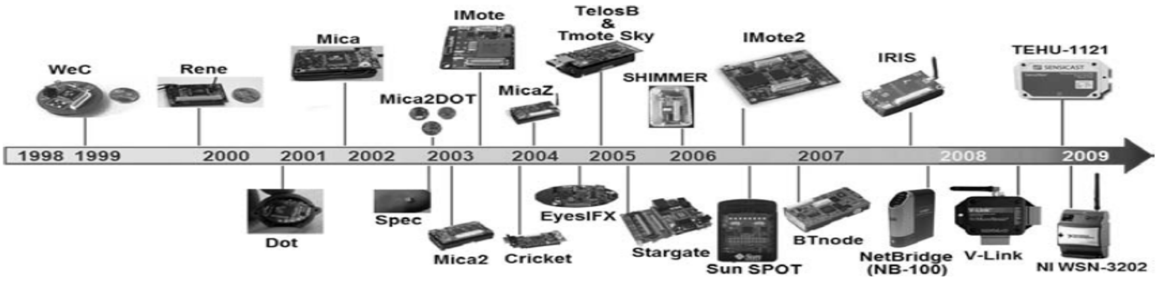

Fig. 6 Timeline for the hardware platforms for WSNs

TABLE I
COMPARISON OF LOW-END PLATFORMS

Platform	Microcontroller/Processor	Radio Transceiver	Centre Frequency	Operating System
Mica2 [13]	ATMega 128L, 8bit,128KB program memory, 4KB SRAM	Chipcon CC1000	315/433/868/916 MHz	TinyOS, SOS, Mantis
Mica2 Dot [13]	ATMega 128L, 8bit, 128KB program memory, 4KB SRAM	Chipcon CC1000	315/433/868/916 MHz	TinyOS, SOS, Mantis
MicaZ [13]	ATMega 128L, 8bit , 128KB program memory, 4KB SRAM	Chipcon CC2420	2.4 GHz	TinyOS, SOS, Mantis, Nano-PK, RETOS, LiteOS
IRIS [13]	ATmega 1281, 8bit, 128KB program memory, 8KB SRAM	Atmel AT86RF230	2.4 GHz	TinyOS, LiteOS
Cricket [14]	ATmega 128L, 8bit , 128KB program memory, 4KB SRAM	Chipcon CC1000	433MHz	TinyOS
Eyes [3]	MSP430F149, 16bit, 60KB program memory, 2KB SRAM	RFM TR1001	868 MHz	TinyOS, PEEROS
EyesIFX v1 [15]	MSP430F149, 16bit, 60KB program memory, 2KB SRAM	Infineon TDA5250	868 MHz	TinyOS
EyesIFX v2 [4]	MSP430F1611, 16bit, 48KB program memory, 10KB RAM	Infineon TDA5250	868 MHz	TinyOS
BTnode [16]	ATmega 128L, 8bit , 128KB program memory, 4KB SRAM	Chipcon CC1000 and Bluetooth radio	433 – 915MHz and 2.4GHz	TinyOS
Telos B [17]	TI MSP430F1611, 16bit, 48KB program memory, 10KB RAM	Chipcon CC2420	2.4 GHz	Contiki, TinyOS, SOS, RETOS
Tmote Sky[18]	TI MSP430F1611, 16bit, 48KB prog ram memory, 10KB RAM	Chipcon CC2420	2.4 GHz	Contiki, TinyOS, SOS, RETOS
Sun SPOT [19]	AT91SAM9G20 processor, 32bit, 64KB ROM, 2x16KB SRAM	Chipcon CC2420	2.4 GHz	N/A
Shimmer [20]	TI MSP430 F1611, 16bit, 48KB program memory, 10KB RAM	Chipcon CC2420 and Bluetooth radio	2.4 GHz	TinyOS
V-Link [6]	Not specified	IEEE 802.15.4 compliant RF transceiver	2.4 GHz	Not specified
TEHU-1121 [7]	Not specified	IEEE 802.15.4 compliant RF transceiver	2.4 GHz	Not specified
NI WSN-3202 [8]	Not specified	IEEE 802.15.4 compliant RF transceiver	2.4 GHz	Not specified

TABLE II
COMPARISON OF HIGH-END PLATFORMS

Platform	Processor	Memory	Mote/Board Connectors	Operating System
Stargate [9]	Intel PXA255 Processor, 400MHz	64MB SDRAM, 32MB Flash	PCMCIA and compact flash connector, 51-pin expansion Connector for Mica2 Motes; Ethernet, RS232 Serial, JTAG, USB Connector via 51-pin Daughter Card Interface	Embedded Linux
Netbridge NB-100 [10]	Intel IXP420 Xscale Processor, 266MHz	32MB RAM, 8MB Flash, 2GB USB Flash Disk	Mica2, MicaZ, IRIS, Telos Connector Ethernet, USB connector	Debian Linux
Imote [11]	ARM7 processor, 12MHz	64KB SRAM, 512KB Flash	I2C, UART, USB, JTAG connector	TinyOS
Imote2 [12]	Marvell PXA271 Xscale Processor, 13 – 416MHz	256KB SRAM, 32MB SDRAM, 32MB Flash Memory	Integrated 802.15.4 radio, support for external radio through SDIO, and UART; USB client and host, 2xSPI, 3xUART, Camera, I2C, I2S, GPIO, AC97 connector	TinyOS, Linux, SOS

The second generation of Intel motes, Imote2 [12], is built around a new low-power 32-bit PXA271 XScale processor at 13–416 MHz, which enables DSP operations for storage or compression, and an IEEE 802.15.4 ChipCon CC2420 radio. It has large on-board RAM and flash memories (32MB), additional support for alternate radios, and a variety of high-speed I/O to connect digital sensors or cameras. Its size is also very limited, 36 mm × 48 mm × 9 mm, and it can run TinyOS, SOS and Linux operating system.

IV. Recommendations

This section presents some recommendations from the perspectives of hardware platform developers and hardware platform users.

A. Developers' Perspective

Several issues need to be improved in terms of hardware platforms for WSNs. Perhaps the most important issues in order to increase popular use and production are size and cost. In order to disseminate this kind of technology, cost is an important factor, given that one WSN can use hundreds of sensors, making every little increase in price have an exponential effect on the total price.

The boom in the use of wireless sensor networks has caused different chip manufacturers to develop new circuits adequately integrated for these types of applications. This fact is quite relevant and will make it possible in the near future for the development of wireless applications to increase considerably. The future development of this technology will integrate more functions and reduce the size. In this regard, the contribution from silicon manufacturers will be very important for reducing price and size.

New encapsulation formats and mono-chip solutions can help to reduce size with better production quality. Custom solutions or FPGA solutions can also help pave the way. With these two factors, more general uses will be available to meet customer needs.

Another important point is that the hardware should have the capacity to work with very small voltages and very small power consumption, in order to reduce the size of the batteries and to prolong their life. However, power consumption cannot be reduced only by using lower voltage; a better design of the MAC components, hardware, and software must also be implemented.

Reducing consumption consists of two issues: extending the WSN applications while reducing the price of the final solution. More battery changes are needed if consumption is high, which will have a direct effect on the final price. Reducing consumption by half means reducing the number of battery changes by half, which implies savings in both maintenance and batteries.

B. Users' Perspective

Application requirement is another important consideration in selecting an appropriate hardware platform. Users should understand application needs such as: microcontroller, frequency, bit rate, operating system support. Understanding application needs will help users select the most appropriate platform for their purposes (refer to Table I and Table II).

For large-scale applications, an important consideration is the cost factor, which impacts the choice of hardware platforms. There are many different hardware platforms to develop a WSN application. Users must therefore evaluate developing cost of their application to select the most appropriate hardware platform for their application.

V. Conclusions

In this paper, we presented an in-depth critical survey of a number of existing hardware platforms for WSNs. The contributions of our work are two-fold. First, we provide a comprehensive review of existing hardware platforms for WSNs. Second, we present some recommendations from the perspectives of hardware platform developers and hardware platform users. We hope that making information about these hardware platforms will assist researchers working in this area to appreciate the diversity of hardware platforms available to them and to help them select the most appropriate hardware platform for their purposes.

References

[1] Crossbow technology. [Online]. Available: http://xbow.com

[2] Sentilla. [Online]. Available: http://www.sentilla.com/moteiv-transition.html

[3] L. F. W. van Hoesel, S. O. Dulman, P. J. M. Havinga, and H. J. Kip, "Design of a low-power testbed for wireless sensor networks and verification," Technical report, University of Twente, 2003.

[4] The EyesIFX platform. [Online]. Available: www.tinyos.net/ttx-02-2005/platforms/ttx2005-eyesIFX.ppt

[5] Infineon. [Online]. Available: http://www.infineon.com/cms/en/product/index.html

[6] V-Link. [Online]. Available: http://www.microstrain.com/product_datasheets/2400_v-link_ datasheet.pdf

[7] TEHU – 1121. [Online]. Available: http://www.adaptive-wireless.co.uk/wp-content/uploads /TEHU_1121_ver1_2011-Adaptive.pdf

[8] National Instruments. [Online]. Available: http://www.ni.com/wsn/

[9] Stargate. [Online]. Available: http://bullseye.xbow.com:81/Products/Product_pdf_files/Wireless_p df/Stargate_Datasheet.pdf

[10] Stargate NetBridge. [Online]. Available: http://www.hoskin.qc.ca/uploadpdf/Instrumentation/CrossBow/hoski n_NB100_47e010f295856.pdf

[11] Imote. [Online]. Available: http://webs.cs.berkeley.edu/retreat-1-03/slides/imote-nest-q103-03-dist.pdf

[12] Imote2. [Online]. Available: http://wsn.cse.wustl.edu/images/e/e3/Imote2_Datasheet.pdf

[13] MPR-MIB Users Manual. [Online]. Available: http://www.cs.ucsb.edu/~nchohan/docs/moteManual.pdf

[14] Cricket. [Online]. Available: http://cricket.csail.mit.edu/

[15] EyesIFX v1. [Online]. Available: http://www.snm.ethz.ch/Projects/EyesIFXv1

[16] BTnode. [Online]. Available: http://www.btnode.ethz.ch/Documentation/ BTnodeRev3HardwareReference

[17] TelosB. [Online]. Available: http://www.willow.co.uk/TelosB_Datasheet.pdf

[18] Tmote Sky. [Online]. Available: http://www.bandwavetech.com/download/tmote-sky-datasheet.pdf

[19] Sun SPOT. [Online]. Available: http://www.sunspotworld.com/docs/Yellow/eSPOT8ds.pdf

[20] Shimmer. [Online]. Available: http://www.eecs.harvard.edu/~konrad/ projects/shimmer/SHIMMER-GettingStartedGuide.html