Miniature and Low-Power Wireless Sensor Node Platform: State of the Art and Current Trends

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Abstract—***Wireless sensor node is an autonomous and compact device that has capability to monitor a variety of real-world phenomena. It is designed composed of sensing device, embedded processor, communication module, and power equipment. Wireless sensor node is part of wireless sensor network where hundred or thousand sensor node can be deployed. Over the past decade Wireless Sensor Networks (WSNs) have emerged as one of the computing platforms of note within the electronics community. In prediction, there will be more than 127 million wireless sensor nodes deployed worldwide by 2014. We have surveyed 100 currently available wireless sensor network node platforms have been developed and produced not only by the research institutions, the universities but also some companies in last ten years. In this paper, we present a review of 27 different wireless sensor node platforms. We review these devices under a number of different parameters, and we highlight the key advantages of each node platform according to dimension and power consumption. We also discuss the characteristics and trend of development and deployment a wireless sensor node technology.***

Keywords— Sensor, WSNs, Wireless Sensor Node, Small Size, Low-Power.

I. INTRODUCTION

Wireless sensor networks consist of small devices, called sensor nodes, that are battery powered and are equipped with integrated self-contained sensor devices or instruments with sensing, a data-processing unit, a small storage memory unit, and communication unit (M.A.M. Vieira et al, 2003). Typically, these sensors are randomly deployed in the field. They form an unattended wireless network, collect data from the field, partially aggregate them, and send them to a sink that is responsible for data fusion. The ever-increasing capabilities of these tiny sensor nodes enable the realization of wireless sensor networks (WSN) based on the collaborative effort of a large number of nodes. With these convergences of the technology, wireless sensor networks have emerged as an exciting new computing platform.

Since the first generation of wireless sensor node was developed in the Smartdust project [26] in 1998, mote technology has developed apace of its larger electronic counterparts. The first generation of wireless sensor node products is targeted primarily at the Universities and Research Laboratories for use in experiments and the development of test-beds. However, more and more of companies also are releasing products aimed at the building automation and industrial automation markets. On the World, predicts (On-World WSN Report, 2005) that there will be 127 million wireless sensor node deployed worldwide by 2010.

New academic and commercial sensor node platforms are introduced every year, with more advanced designs currently under development. Like the early days of desktop microprocessor design, there are no metrics currently available to effectively compare sensor node platforms and aid in the choice of the "best" platform for a given deployment. Similarly, sensor network hardware designers do not have a representative set of applications to facilitate circuit and architectural decisions.

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The vision for this technology is to be able to have "anywhere, anytime" monitoring of indoor (home, office, and industrial) and outdoor environments. Sensor networks hold the promise of revolutionizing sensing in a wide range of application domains because of their reliability, accuracy, flexibility, cost-effectiveness, and ease of deployment. Wireless sensor networks are increasingly being deployed in many important applications requiring the interaction between users and the physical world. They allow the physical environment to be measured at high resolutions, and greatly increase the quantity and quality of real-world data and information for applications. Important applications of wireless sensor networks include environmental and habitat monitoring, healthcare monitoring of patients, weather monitoring and forecasting, military and homeland security surveillance, tracking of goods and manufacturing processes, safety monitoring of physical structures and construction sites, smart homes and offices, and many other uses that we do not yet imagine.

In this paper, we present a review of 27 (twenty seven) current wireless sensor node platforms, under a number of different parameters. These parameters range from physical characteristics such as size, and battery life to electrical specifications for the processor, sensor interface, and radio transceiver employed in the respective mote architectures. In detail review, we focus on the investigation and observation of power consumption, and physical dimension of wireless sensor node platform that considered in this review. Our aim is to provide a better understanding of the current state and trend in miniature scale and low power wireless sensor node platform.

Some of works have been done to-date on reviewing and surveying wireless sensor networks node. Luis Ruiz-Garcia et al. review the technical and scientific state of the art of wireless sensor technologies and standards for wireless communications in the Agri-Food sector. They focuses on WSN (Wireless Sensor Networks) and RFID (Radio Frequency Identification), presenting the different systems available, recent developments and examples of applications. Jan Beutel presents a methodology for the classification and interpretation of sensor network platforms. They also develop a set of metrics that can be used to compare and analyse the characteristics of different platforms. A survey the state of the art in programming approaches for WSNs are addressed by Luca Mottola. At the beginning, they present a taxonomy of WSN application, to identify the fundamental requirements programming platforms. Then, they introduce a taxonomy of WSN programming approaches that captures the fundamental differences among existing solutions, and constitutes the core contribution of their research. Moreover, they also map existing approaches back to the application requirements, therefore providing not only a complete view of the state of the art, but also useful insights for selecting the programming abstraction most appropriate to the application at hand. Michael Healy et al. 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. Itziar Marín et al. review of power aware design for sensor nodes. They also present a survey on every sensor node's part that is susceptible of power-aware designing. Vidyasagar Potdar et al. analyses commercially (and research prototypes) available wireless sensor nodes based on these parameters and outlines research directions in this area. They have also presented the WSN mode evaluation based on its key technical specifications. Ian F. Akyildiz et al. survey the applications, developed communication protocols, and real deployment scenarios proposed thus far for WSN is revisited. The objective of the survey revisit is to provide a contemporary look at the current state-of-the-art in WSN and discuss the still-open research issues in this field. They also present a survey of existing products, developed protocols, and research on algorithms proposed thus far for WSN. Carlos F. García-Hernández et al. survey Wireless Sensor Networks (WSN) and their technologies, standards and Applications. Jennifer Yick et al. present a top-down approach to survey different protocols and algorithms proposed in recent years. They have surveyed issues on three different categories: internal platform and underlying operating system, communication protocol stack, and network services, provisioning, and deployment issues. They have summarized and compared different proposed designs, algorithms, protocols, and services. Moreover, they have highlighted possible improvements and research in each area. Marcos Augusto M. Vieira et al. present tutorial of the current state-of-the-art for sensor node, investigating and analyzing some of the architectural challenges posed by these devices, including a survey of sensor node platforms and energy management techniques. They discuss the characteristics and requirements for a sensor node mainly processing, communications, power and sensing components. They also resent a comprehensive comparative study of sensor nodes platforms, energy management techniques, off the-shelf microcontrollers, battery types and radio devices. Limin Wang study the issues and existing protocols in three areas: coverage, routing, and robustness. He presents two types of coverage problems: to determine the minimum number of sensor nodes that need to perform active sensing in order to monitor a certain area; and to decide the quality of service that can be provided by a given sensor network. Jie Chen et al. survey five recent research approaches on coverage of wireless sensor networks and present in some detail the algorithms, assumptions, and results. A comprehensive comparison among these approaches is given from the perspective of design objectives, assumptions, algorithm attributes, and related results. Open research problems on coverage are also discussed. Doug Reitz surveys 15 sensor network security papers chosen from the USC reading list. The many security threats and much smaller set of solutions is presented with an attempt to categorize the security concerns, approaches, and network types into a meaningful presentation without overwhelming the reader as the variety of security threats and sensor network vulnerabilities can be overwhelming potentially causing one to easily to give up hope an throw in the towel on the whole matter. He also attempts to provide a good survey of security issues to consider when designing or considering a WSN application. As emphasized in several of the papers surveyed, if security is taken into account in the design phase, a situation requiring network redesign for security concerns can be avoided. Mark Hempstead et al. provides a survey of ultra low-power processors specifically designed for WSN applications that have begun to emerge from research labs, which require detailed understanding of tradeoffs between application space, architecture, and circuit techniques to implement these low-power systems. They also explore the different application classes and describe system architectures that can take advantage of the event-driven and regular nature of WSN applications. Sanath Alahakoon et al. survey the area of sensor network applications in structures. Five major application areas of sensor networks in civil structures were identified, namely; structural health monitoring, structural damage detection, active control of structures, parameter identification and modeling of structures and building automation. They also identify different usages of sensor networks in structures and further elaborate on different types of sensing together with the techniques associated with processing the parameters sensed by the sensor networks to achieve the desired implementation goals. J. Suh et al. presents a framework for hardware devices and software technology for sensor networks. The focus is giving a snapshot of the first-generation hardware and software for sensor networks, the requirements of the nodes by their capabilities, and an outlook on future implementations. Mokhtar et al. report on currents and new trends in sensor networks. They also presented some of the challenges in designing wireless sensor networks, as well as the state-of the-art and future direction in wireless sensor networks. Ian F. Akyildiz et al. present the state of the art in algorithms, protocols, and hardware for wireless multimedia sensor networks. They also discussed the state of the art of research on Wireless Multimedia Sensor Networks (WMSNs), and outlined the main research challenges. They classified currently off-the-shelf hardware as well as available research prototypes for WMSNs. Furthermore, they discussed existing solutions and open research issues at the application, transport, network, link, and physical layers of the communication stack, along with possible cross-layer synergies and optimizations. Benoit Latre et al. have survey the concept of Wireless Body Area

Networks, and reviewed the current research on Wireless Body Area Networks. In particular, they present an overview of the research on the propagation in and on the human body, MAC-protocols, routing protocols, Quality of Service and security. They focus on some applications with special interest in patient monitoring. Then the communication in a WBAN and its positioning between the different technologies is discussed. They also overview the current research on the physical layer, existing MAC and network protocols. Further, cross layer and quality of service is discussed. To conclude, a list of research projects is given and open research issues are discussed. Ian F. Akyildiz et al. present a survey of protocols and algorithms proposed thus far for sensor networks. Their aim is to provide a better understanding of the current research issues in this emerging field. They also attempt an investigation into pertaining design constraints and outline the use of certain tools to meet the design objectives. Zhijun Li et al. outline security and privacy issues in sensor networks, address the state of the art in sensor network security, and discuss some future directions for research. ZHAN An-dong et al. surveyed the state of the art in real-time routing protocols for WSNs. They classify recent real-time routing protocols and discuss open research issues, current RT routing protocols are covered and discussed by the temporal sequence and they also highlight the advantages and performance issues of each routing technique and conclude with a comparative summary of the surveyed approaches. They briefly summarize the system architectures and design issues for sensor networks and their implications on RT routing. I. Khemapech et al. provides a survey of wireless sensor networks technology. Several research works including sensor network applications, components, reliable transport protocols, and congestion control schemes are summarized and compared in different sections. Their paper aims to provide a survey in terms of applications and components, reliable transport protocol and congestion control research in wireless sensor networks. Eiko Yoneki et al. report recent trends in wireless sensor network research including an overview of the various categories of WSN, a survey of WSN technologies and a discussion of existing research prototypes and industry applications. They focus on middleware technology, and describe details of some existing research prototypes, then address challenges and future perspectives on the middleware. Their study highlights that middleware needs to provide a common interface for various functional components of WSN: detection and data collection, signal processing, data aggregation, and notification. By integrating sensing, signal processing, and communication functions, a WSN provides a natural platform for hierarchical information processing.

The rest of this paper is organized as follows: - the introduction of wireless sensor node is discussed in Section 2. Next, the state of the art wireless sensor node is presented in Section 3. In this section, we overview some of consider wireless sensor node platform, and review of sensor node platform dimension and power consumption. Section 4 gives a discussing of trend in wireless sensor node platform, and Conclusions are left to Section 5.unavoidable.

II. Wireless Sensor Node

Wireless sensor network is one of the most essential technologies for implementation of ubiquitous computing. A sensor network is composed of ten of thousands of small devices that called sensor nodes, which are densely deployed either inside the phenomenon or very close to it.

A sensor node is often abbreviated as a node. A sensor is a device which senses the information and passes the same on to a mote. Sensors are used to measure the changes to physical environment like pressure, humidity, sound, vibration and changes to the health of person like blood pressure, stress and heartbeat. A mote consists of processor, memory, battery, A/D converter for connecting to a sensor and a radio transmitter for forming an ad hoc network. A mote and sensor together form a sensor node. The structure of the sensor node is as shown in Figure 1. There can be different sensors for different purposes mounted on a mote.

A wireless sensor node is composed of four basic components, a sensing unit, a processing unit, a communication unit, and a power unit. They may also have additional application-dependent components such as a location finding system, power generator, and mobilizer. Sensors are devices that produce a measurable response to a change in a physical condition. Sensing units are usually composed of two subunits: sensors and analog-to-digital converters (ADCs). The analog signals produced by the sensors based on the observed phenomenon are converted to digital signals by the ADC, and then fed into the processing unit. The processing unit, which is generally associated with a small storage unit, manages the procedures that make the sensor node collaborate with the other nodes to carry out the assigned sensing tasks. A communication unit connects the node to the network. The wireless communication channel enables a medium to transfer signals from sensors to exterior world (provided by a gateway), and also an internal mechanism of communication to establish and maintain of WSN. One of the most important components of a sensor node is the power unit. The power unit has the purpose to supply the energy to the node. Power units may be supported by power harvesting units such as solar cells, thermoelectric, vibration. There are also other subunits that are application-dependent. Wireless sensor nodes are usually deployed over a desired area, they wake-up, self-test and establish dynamic communications among them, composing a network.

III. State of The Art Wireless Sensor Node

We surveyed 100 existing wireless sensor node platforms, which developed in past ten years. Most of wireless sensor node platform developed and deployed by number of the university laboratories and some research institutions. The aim of development wireless sensor node is targeted primarily for use in experiments and the development of test-beds. Even though several wireless sensor nodes released by number of companies aimed at the building automation and industrial automation markets. To deal with the aim of this article, we consider 27 prototype of wireless sensor nodes, which consume power approximately under 25mA (processor active, radio Rx/Tx), and they implement on the small size electronic board to be reviewed. We investigate and review core processing, radio communication, power supply, sensing component, and dimension.

A. Wireless sensor node platform evolution

Main Recent technological advances have enabled the development of miniature, self-contained, battery-powered computing units known as “motes” within the wireless sensor networking arena. The term “mote” was used by researchers in the Berkeley NEST (now WEBS) and CENS projects to refer to these sensor nodes. Several test-beds for wireless sensor networks already exist. This section surveys the current state-of-the-art for wireless sensor node platforms. Figure 6- Figure 9 shows the considered summary of the sensor node platforms, their components, operating system, respective research group, and date of the development. The following motes being considered in this paper:

1) Dot:-the first generation of wireless sensor node developed from research carried out at UC Berkeley in 2000 (J. Polastre et al, 2005).
2) Mica2Dot:-the third generation mote family from UC Berkeley and CrossBow Technology as a research platform for low-power wireless sensor networks. It developed in 2002 ((J. Polastre et al, 2005).
3) U3:-U-Cube, a wireless sensor node that is capable of communicating with other nodes to carry sensing data and queries issued by users. It developed from research carried out at Electrical Engineering Department, the University of Tokyo, Hongo Bunkyoku, Japan in 2003 (Y. Kawahara et al, 2003, S. Saruwatari et al, 2004).
4) Spec:-a single and tiny-chip mote node represents the coming generation of wireless sensor nodes that will be manufactured for pennies and deployed in the millions. It developed by Jason Lester Hill at Berkeley Wireless Research Center, University of California Berkeley in 2003 (J. L. Hill, 2003).
5) Tyndall Mote:-a highly modular, miniaturized wireless sensor platform that addresses the issues of flexibility, power-efficiency and size which are desirable and necessary characteristics for a wireless sensor network platform. The first generation has a 25mm×25mm form factor, and developed at Tyndall National Institute, Cork, Ireland by the Wireless Sensor Networks Team since 2003. The latest design from Tyndall National Institute is The Tyndall 10mm Mote (J. Barton et al, 2006, S. Harte et al, 2007, S. J. Bellis et al, 2005, B. O’Flynn et al, 2005).
6) Mantis Nymph:-the MANTIS (MultimodAl NeTworks of In-situ Sensors) hardware nymph's design was inspired by the Berkeley MICA and MICA2 Mote architecture. It developed from research carried out at Department of Computer Science, University of Colorado at Boulder in 2003 (H. Abrach et al, 2003).
7) AquisGrain:-a versatile IEEE 802.15.4-based ZigBee-ready wireless sensor node platform for continuous patient monitoring. It was developed by Philips Research Aachen, Germany in 2004. The platform has been named AquisGrain, in a reference to the words ‘Grain’, which indicates the small size of the sensor nodes, and ‘Aquisgranum’, the Latin name of the German city of Aachen, where the platform was developed. The current version of AquisGrain sensor nodes has a board size of 35×36 mm2 (P. van der Stok, 2007).
8) BSN:-Body Sensor Network is a miniaturised wearable or implantable wireless sensors provides continuous monitoring of patients under their natural physiological states so that transient but life threatening abnormalities can be detected and predicted. It developed from research carried out at Department of Computing, Imperial College London in 2004 (B. Lo et al, 2005).
9) Particle:-it is platform for rapid prototyping of Ubiquitous and Pervasive Computing environments, for Ad-Hoc (Sensor) Networks, Wearable Computers, Home Automation and Ambient Intelligence Environments. The platform consists of ready-to-run hardware components, software applications and libraries for the hardware and a set of development tools for rapid prototyping. Particle developed at Telecooperation Office (TecO) University of Karlsruhe, Germany in 2004 (Particle Team: “PARTiCLE WEB SITE”. http://particle.teco.edu/)
10) DSYS25sensor:-The DSYS25 sensor platform is a 25mm x 25mm module suitable to be deployed in applications ranging from traffic management to agriculture. DSYS25sensor platform developed in 2004 as part of the D-Systems project at University College Cork D-Systems is a joint project of the National Microelectronic Research Center (NMRC) and the Computer Science Department at University College Cork, Ireland (A. Barroso, et al, 2004).
11) Sensor Cube:-The node based on a stackable hardware design supported by a Tiny OS based operating environment. It is currently 14x14x18mm^3 with integrated coplanar antenna. Each functional block has been implemented as a 14x14 mm^2 printed circuit board. The modules can extract their energy from the environment (e.g. with solar cells), and detect various environmental parameters. It developed from research carried out at IMEC, Integrated Systems Department, Leuven, Belgium in 2004 (K. Raja, 2007).
12) WiMoCA:-Wireless Motion Capture with Accelerometers is a wireless sensor node for a Motion Capture system with Accelerometers (WiMoCA). WiMoCA nodes have been exploited to build a Wireless Body Area Sensor Network (WBASN) that allows to implement a wireless/wearable distributed gesture recognition system where nodes are mounted on many parts of the human body. It developed from research carried out at DEIS - University of Bologna, Italy in 2004 (Elisabetta Farella et al, 2005).

13) TUTWSN:-Tampere University of Technology Wireless Sensor Network is a low energy WSN developed at Tampere University of Technology in 2004. TUTWSN design goal has been minimized radio duty cycle, while maintaining the data transfer requirements of applications (M. Kohvakka et al, 2005).
14) Imote2:-The Intel Mote 2 is an advanced sensor network node platform designed for demanding wireless sensor network applications requiring high CPU/DSP and wireless link performance and reliability. It is originally developed by Intel Research in 2005 (R. M. Kling, 2005).
15) WiMoCA:-Wireless Motion Capture with Accelerometers is a wireless sensor node for a Motion Capture system with Accelerometers (WiMoCA). WiMoCA nodes have been exploited to build a Wireless Body Area Sensor Network (WBASN) that allows to implement a wireless/wearable distributed gesture recognition system where nodes are mounted on many parts of the human body. It developed from research carried out at DEIS - University of Bologna, Italy in 2004 (Elisabetta Farella et al, 2005).
16) uPart:-μParts are very small sensor nodes (10x10mm), with wireless communication, enabling the setup of high density networks at low cost and with a long life time. It developed at Telecooperation Office (TecO) University of Karlsruhe, Germany in 2005 (M. Bigl et al, 2006).
17) XYZ:-This platform designed for experimentation, educational projects and preliminary deployment in industrial environments. It developed from research carried out at Embedded Networks and Applications Lab, Yale University in 2005 (D. Lymberopoulos et al, 2005).
18) TNOde:-the TNOde platform is quite similar to the popular Mica2 platform, but with the Mica2Dot form factor. Developed by TNO (the Dutch Organization for Applied Scientific Research) in 2005 (O. W. Visser, 2005).
19) e-Grain:-eGrain is a distributed sensor node that is implemented in a layer approach, where each functional block is relized in an individual miniature module. The node is developed in 2005 as a part of the eGrain project – Autarkic Distributed Microsystems coordinated by Fraunhofer-IZM Berlin Germany. eGrains concept are tiny, autonomous, functional units, and distinctive, not only through their ability to communicate with each other, but also because they are freely programmable and to a certain degree modular (M. Jürgen Wolf, 2005)
20) ProSpeckz:-it is a very small and simple platform, which is equipped by a Programmable System-on-Chip (PSoC) from Cypress Microsystems. It developed from research carried out at School of Informatics, University of Edinburgh, Scotland in 2005 (D. K. Arvind, 2004).
21) ProSpeckz:-it is a very small and simple platform, which is equipped by a Programmable System-on-Chip (PSoC) from Cypress Microsystems. It developed from research carried out at School of Informatics, University of Edinburgh, Scotland in 2005 (D. K. Arvind, 2004).
22) Eco:-it is an ultra-compact wireless sensor node, which developed at University of California, Irvine, CA, USA in 2006. Eco measures only 12 x 12 x 4.5 mm^3 in volume and weights under 1.6 grams (C.Park, et al, 2005, 2006).
23) ZN1:-it is an ultra-small, low-power sensor-net module, which developed at the Central Research Laboratory, Hitachi Tokyo, Higashi-Koigakubo, Kokubunji-shi Tokyo, Japan in 2006. The sensor nodes has a board size of 15 × 15-mm2 (S. Yamashita et al, 2006)
24) SHIMMER:-SHIMMER (Sensing Health with Intelligence, Modularity, Mobility, and Experimental Reusability) was designed by Benjamin Kuris at the Intel Digital Health Advanced Technology Group, Cambridge MA in 2006. It is a wireless sensor platform designed to support wearable applications. Currently available from RealTime Ltd (B. Kurtis et al, 2005).
25) IRIS:-the latest wireless sensor network module from Crossbow Technologies. Includes several improvements over the Mica2/MicaZ family of products. Improvements include increased transmission range, as well as Crossbow's MoteWorks support.
26) MoteWorks is Crossbow's implementation of the open source TinyOS operating system, and is also available for their Mica2 / MicaZ motes. It is developed in 2007. (Crossbow Technologies Inc, IRIS datasheet).
27) Epic Mote:-Epic is a new open mote platform for application-driven design. Sensornet platforms, like most embedded systems, are tightly coupled to their applications. A key goal of the Epic project is to develop a composable hardware architecture for sensornet modules that specifically supports prototyping, measurement, and reuse. It developed from research carried out at Computer Science Division University of California, Berkeley in 2008 (P. Dutta et al, 2008).
28) SIP:-System-in-Package is a compact wireless sensor node for biomedical signal acquisition. The realized node has a compact size of a 2.5x2.5x0.3 cm3 without a battery and antenna. It developed from research carried out at Institute of Nanoelectronics, Hamburg University of Technology in 2008 (Nashwa Abo Elneel et al, 2009).
29) Irene Mote:-Irene is a platform built around the Epic Core with a number of features which make it ideal for user-centric studies. It developed from research carried out at Computer Science Division University of California, Berkeley in 2009.

As can be seen in Figure 6 to Figure 9, the wireless sensor node platforms are typically designed around commercial off-the-shelf processors. The most of processors used in those platforms is range from 8-bit processor architecture which has low power, and low clock speed around 31 kHz, to 32-bit processor architecture which has high performance with clock speed greater than 500 MHz. The popular processors widely used in the considered wireless sensor are Atmel ATMega 128L, and the TI MSP430. The Atmel ATmega 128L processor is a low power 8-bit RISC (Reduced Instruction Set Computer) microcontroller. It include in the Mica2Dot motes, Tyndall Mote, MantisNymph, AquisGrain, DSYS25, TNOde, e-Grain, and IRIS. The TI MSP430 processor is an ultra low power 16-bit RISC (Reduced Instruction Set Computer) processor. The MSP430 has been widely adopted in platforms such as BSN, Sensor Cube, TinyNode, Shimmer, Epic Mote and Irene Mote. The other low power microcontrollers are the ATMega163, the PIC18F452, the ATmega8, the rfPIC16F675, the Xemics XE88LC02, the nRF24E1(8051), and the Atmega644P which is used in platform such as Dot, U3, WiMoCA, uPart, TUTWSN, Eco, and SIP respectively. While the low power consumption in standby mode microcontroller, the H8S/2218, is used in ZN1 platform, and high performance microcontroller the OKI ML67Q 500X, and the Intel PXA271 is used in XYZ node and Imote2 platforms respectively.

The memory unit of the sensor node usually consists of both program memory, containing the program code, and data memory which stores sensed information and any data needed for computations. Both of memory is exist in the processor. Since limited Random Access Memory (RAM) is provided by processor, most wireless sensor node platforms are designed with an external flash memory or Electrically Erasable Programmable Read-Only Memory (EEPROM). Due to the non-volatile nature of the EEPROM, it is used in most embedded systems for storing configuration information because it does not require power to retain the stored data. It is also used as an immediate storage for sensor readings. Some sensor nodes have an external memory, examples of which include Dot, Mica2Dot, U3, MantisNymph, AquisGrain, Particel, Sensor Cube, XYZ, Eco, ZN1, Shimmer, TUTWSN, IRIS, Epic Mote, and Irene Mote.

Since the ADC built in the microprocessor chip, some sensor nodes also have sensor built in. For instance, the Atmel Atmega128L MCU has an eight-channel 10-bit ADC that can sample at a rate up to 15.4ksps (kilo-samples per second), whereas the TI MSP430 microcontroller has a 12-bit ADC which provides a high precision reading. In addition, some platforms are equipped with Digital-to-Analogue Converter (DAC) for controlling sensors or actuators. Some sensor node contain integrated sensor, examples of which include Dot, U3, Tyndall Mote, BSN, Particle, Sensor Cube, WiMoCA, IMote2, uPart, XYZ, Eco, TinyNode, ZN1, Shimmer, TUTWSN, IRIS, and Irene Mote.

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. Since the introduction of the IEEE 802.15.4 standard for WSNs, most of the new sensor network platforms are using the Chipcon CC2420 wireless transceiver. Although the power consumption of the CC2420 is higher than the CC1000, the CC2420 can deliver 250 kbps, which is 6.5 times higher than its predecessor. As such, most of the recent wireless sensor node platforms developed are based on the CC2420, such as AquisGrain, IMote2, XYZ, ProSpeckz, ZN1, Shimmer, Irene Mote, and Epic Mote. The Chipcon CC1000 chipset provides a more reliable FSK modulation, selectable modulating frequency, and low power architecture is used in platform such as Mica2Dot, TNOdes, and e-Grain. Other platforms, such as Tyndall Mote, DSYS25sensor, Sensor Cube, and TUTWSN are based on Nordic nRF2401 radio transceivers in order to achieve output power and frequency channels are easily programmable, current consumption is very low, and a built-in Power Down mode makes power saving easily realizable.

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. Due to limited resources in WSN hardware, conventional embedded OS, such as Embedded Microsoft XP or Embedded Linux, are not suitable for WSN platforms. Thus far, the most widely adopted OS by wireless sensor node is the event-based TinyOS. They include Dot, Mica2Dot, Spec, Tyndall, BSN node, DSYS25sensor, Sensor Cube, IMote2, TNOde, e-Grain, Eco, TinyNode, Shimmer, Epic Mote, Irene Mote, and SIP. Another application-driven OS are Pavenet, Mantis, Smart-its, SOS, and Mote Works.

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. Due to the relatively high power requirement for radio transmission, batteries still remain the main source of power for current WSN platforms. Among different battery technologies, Li-ion battery is the most popular choice for WSN hardware because of its high power density. Batteries can be divide into primary (non-rechargeable), and secondary (rechargeable). Primary batteries are often the preferred choice, due to their higher power densities.

B. Review of sensor node platform dimension and power consumption

For many WSNs, node size and power consumption are often considered more important than the actual processing capacity because in most applications the amount of processing involved is relatively light.

1) Node platform dimension

One physical parameter which may dictate sensor node choice for a given application is physical mote size. Figure 2 provides an overall review of the physical dimensions of all the wireless sensor node platforms used in this review.

As can be shown in Figure 2, the smallest wireless sensor node platform in this review is the Spec platform. The Spec, a single-chip mote, measures approximately 2x2.5mm (5mm2) CMOS chip that includes processing, storage, wireless communications and hardware accelerators, has an AVR-like RISC core, 3K of memory, an 8-bit, on-chip ADC, an FSK radio transmitter. Spec represents the future of embedded wireless networking.

uPart is a ultra-small computing and wireless communication embedded computing system with 4 integrated sensors, one LED actuator and power supply. The µPart wireless sensor system especially designed for settings requiring a high population of sensors. Overall outline uPart 10x10x10mm3 (including battery).

The other wireless sensor node platforms provide a modular of hardware architecture. Its modular nature lends itself to the development of a variety of layers for use in different application scenarios. These layers can be combined in an innovative plug and play fashion depending on the particular application requirements. They include the e-Grain, the Tyndall Mote, the Sensor Cube. They measure 10x10x10mm3, 10x10x10mm3, and 14x14x18mm3 respectively.

Eco is an ultra-compact wireless sensor node, which measures only 10x13x8 mm³ (include battery) in volume and weights under 1.6 grams. The compact form factor and low power consumption also make Eco nodes highly suitable for many other applications, including medicine, environmental monitoring, new computer-human interface, and ambient intelligence.

ZN1 is an ultra-small, low-power sensor-net module. ZN1 contain a MCU, ZigBee RF in an ultra-small 15×15x4mm3 module with an ultra-low standby current less than 1 µA.

The DSYS25 sensor platform is a 25x25mm2 module suitable to be deployed in applications ranging from traffic management to agriculture. Additional functionality, such as sensing, is added by stacking layers to the basic unit. A stackable connector system makes the electrical and mechanical interconnections between layers.

2) Node platform dimension

Power consumption module in the sensor nodes includes sensor modules, processor modules, wireless communication modules. With the advances of integrate circuit technology, processor and sensor modules have a very low power consumption. The majority of power consumptions occur in wireless communication module. The communication module in the sending state takes the largest energy consumption, while the energy consumption, which is slightly lower than the sending state, is nearly equal in the idle state and the receiving states. The minimum energy consumption occurs in the sleep time. Therefore, in accordance with the characteristics of power consumption of wireless sensor node above, we consider power consumption of the processor and the communication module as parameters to review with the purposes of the low-power consumption of the wireless sensor nodes platform listed previously.

In this survey, we review power consumption of wireless sensor node platform according to three category modes: processor active, radio active transmit (mode-1), processor active, radio active receive (mode-2), and mode processor sleep, radio sleep (mode-3).

As can be see in Figure 3, the five sensor node platforms consume lowest current *(<16mA*) in mode processor active, and radio active transmit are the *SensorCube* (0.4mA(I_{Proc}), 10.5mA(I_{Rad}), *10.9mA*(I_{Total})), the *Eco* (3mA(I_{Proc}), 10.5mA(I_{Rad}), *13.5mA*(I_{Total})), the U_3 (<1.6mA(I_{Proc}), 12mA(I_{Rad}), *13.6mA*(I_{Total})), the *uPart* (0.3mA(I_{Proc}), 14mA(I_{Rad}), *14.3mA*(I_{Total})), and the *WiMoCA* (3.6mA(I_{Proc}), 12mA(I_{Rad}), *15.6mA*(I_{Total})). The other sensor node platforms consume current in range 16mA to 92.4mA. The *XYZ* platform consumes highest current (75mA(I_{Proc}), 17.4mA(I_{Rad}), *92.4mA*(I_{Total})) in mode processor active, and radio active transmit among the sensor nodes that are review in this paper.

While in mode processor active, and radio active received as can be see in Figure 4, the five sensor node platforms consume lowest current are the *uPart* (0.3mA(I_{Proc}), 4mA(I_{Rad}), *4.3mA*(I_{Total})), the U_3 (<1.6mA(I_{Proc}), 4.8mA(I_{Rad}), *6.4mA*(I_{Total})), the *WiMoCA* (3.6mA(I_{Proc}), 3.8mA(I_{Rad}), *7.4mA*(I_{Total})), the Dot (5mA(I_{Proc}), 4.8mA(I_{Rad}), *9.8mA*(I_{Total})), and the *Particle* (10mA(I_{Proc}), 3.8mA(I_{Rad}), *13.8mA*(I_{Total})13.8mA). The sensor node consume highest current in this mode is the *XYZ* (75mA(I_{Proc}), 19.7mA(I_{Rad}), *94.7mA*(I_{Total})). The other sensor node platforms consume current in range 14mA to 94.7mA.

In mode processor sleep and radio sleep as can be seen in Figure 5, the SIP consumes lowest current among the other sensor nodes to review. The *SIP* consumes only *0.12uA* (0.1uA(I_{Proc}), 20nA(I_{Rad})), and follow by the *WiMoCA* consumes *1.2uA* (0.5uA(I_{Proc}), 0.7uA(I_{Rad})), the *ZN1* consumes *2uA* (1uA(I_{Proc}), 1uA(I_{Rad})), the *SensorCube* consumes *2.4uA*(2uA(I_{Proc}), 0.4uA(I_{Rad})), the *uPart* consumes *2.4uA*(1.8uA(I_{Proc}), 0.6uA(I_{Rad})). The other sensor node platforms consume current in range 3uA to 391uA. The *IMote2* consume highest current among the other sensor nodes that are review in this paper.

Some of sensor nodes beside consume low current as can be seen in Figure 3 to Figure 5, they also have a lower operating voltage. It include in the node platform such as the *uPart* has an operating voltage of the Li coin battery 3 Volt, the U_3 has an operating voltage of 3-AAA rechargeable battery 3 Volt, the *WiMoCA* has an operating voltage of 3-NiMH rechargeable 3.3 Volt, the *Dot* has an operating voltage of battery Li Coin 2.7 volt, the *SensorCube* has an operating voltage of 2-AA-NiMH battery 2.4 Volt, and the *Eco* has an operating voltage of battery Li Coin 3 Volt.

IV. Future Trend in Wireless Sensor Node

The trend in recent generations of wireless sensor nodes is focus on small node size and very low energy consumption while inactive, as for most WSN applications the processor is in sleep mode for greater than ninety nine percent of the time. Energy plays a very important role in sensor node lifetime. Sensor nodes have a limit amount of energy resource that determines their lifetime. Finite node lifetime implies finite lifetime of the applications or, additional cost and complexity to regularly change batteries. Since wireless sensor networks have hundreds or thousands of sensor nodes, and they also are autonomous networks in wide distribution, these devices should be low cost. In order to achieve a cost-effective solution nodes are generally thought to be of small physical dimensions. Size is one of the significant limitations in designing wireless sensor nodes. The sensor node should have a small form factor. It is advantageous for the nodes to be small so that they can be embedded into a wider variety of applications such as body area networks, or as smart tags on retail items, monitoring environmental conditions, tracking goods, and creating intelligent, interactive locations.

In rapid progresses in very large scale integration (VLSI), Micro electromechanical system (MEMS) technology, and developing chip scale package (CSP), the development of wireless sensor node where sensor interface, actuator, processor, storage, communication module, and antenna integrate in a tiny single-chip in order to be a reality. For instance, the Spec platform that claims as the future of embedded wireless networking. It takes the advantages of those technology to deploy a chip node measures approximately 2x2.5mm (5mm2) CMOS chip that includes processing, storage, wireless communications and hardware accelerators. More ever, the solutions of the maximal miniaturization (in millimeter size) of sensor node are based on fabrication of multiple device layers, or stacking of wafers, modularity approach, and 3D packaging technology can be realized in its simplest form with the advance of MEMs technology. e-Grain project takes the advantages of these technology to develop wireless sensor nodes. Starting from modules of 2.6cm (about one inch) edge length in conventional SMD technology, the first step in miniaturization has shrunken the wireless sensor system to 2 cm per side. At this size, the modules were realized with bare dies by flip chip mounting. Later on, prototypes of 1 cm3 were developed, based on a folded flexible substrate. Finally, flip chips on both substrate sides allowed folded modules of only 6mm edge length, which are currently tested.

With the reduction in size, there are greater resource constraints on battery lifetime. The node will be powered by a small battery with limited capacity. Therefore, to have a long lifetime, the system should use as little power as possible. This should be considered in the choice of each component. With the advances of integrate circuit technology, processor, communication device, and sensor modules have a very low power consumption. An alternative technique that has been applied to address the problem of finite node lifetime is the use of energy harvesting. Energy harvesting refers to harnessing energy from the environment or other energy sources (body heat, foot strike, finger strokes) and converting it to electrical energy. The harnessed electrical energy powers the sensor nodes. If the harvested energy source is large and periodically/continuously available, a sensor node can be powered perpetually. Further, based on the periodicity and magnitude of harvestable energy, system parameters of a node can be tuned to increase node and network performance. Since, a node is energy-limited only till the next harvesting opportunity (recharge cycle), it can optimize its energy usage to maximize performance during that interval. Several solution techniques beside hardware approach also have been proposed to maximize the lifetime of battery-powered sensor nodes. Some of these include energy-aware MAC protocols, power aware storage, routing and data dissemination protocols, duty-cycling strategies, adaptive sensing rate, tiered system architectures and redundant placement of nodes to ensure coverage guarantees. While all the above techniques optimize and adapt energy usage to maximize the lifetime of a sensor node, the lifetime remains bounded and finite.

V. Conclusions

Wireless sensor node is an emerging technology in the sensing method, and a promising future technology and currently used in wide range application of distributed system. A great variety of sensor nodes already exist, proving this is a recent and very interesting research topic. More and more of the research institutions and the companies are introduced new wireless sensor node every year, with more advanced designs that targeted both research and commercial.

The node size and power consumption are often considered in currently design of wireless sensor node. In this paper, the state of the art and future direction design in wireless sensor node in order to archive small size and low power consumption was discussed. As an emerging technology, a lot of works need to be done and it will continue in order to achieve maturity and acceptable technology in sensing technology.

VI. Acknowledgement

We would like to acknowledge our reviewer who helped us to improve this manuscript.

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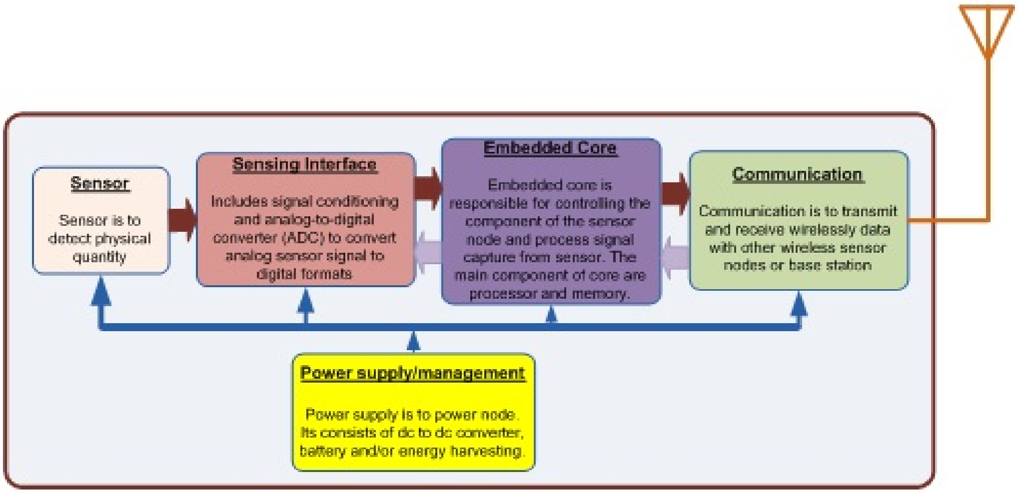

Figure 1. The architecture of wireless sensor node

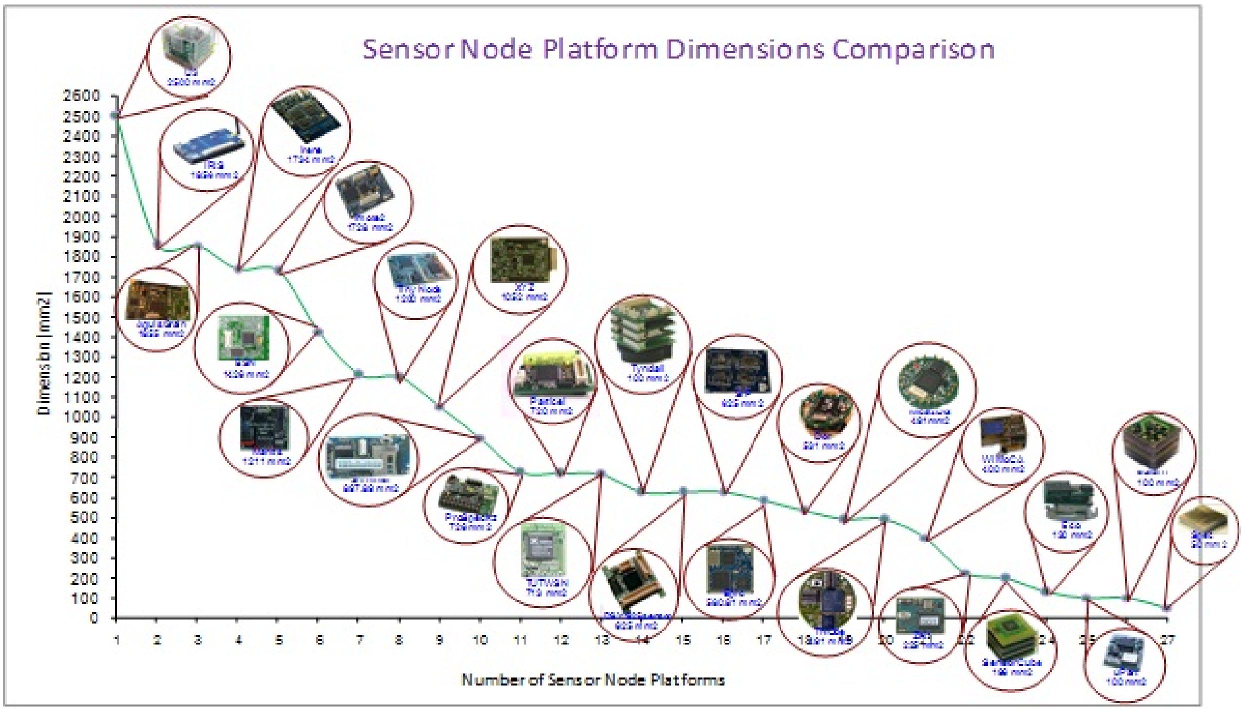

Figure 2. Wireless sensor node dimensions

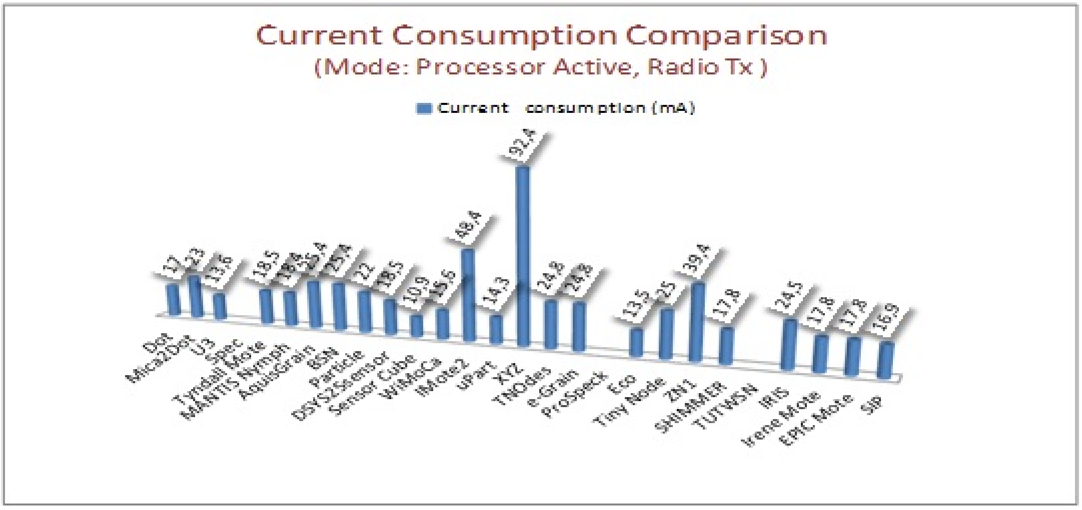

Figure 3. Current consumption Comparison (Mode: Processor Active, Radio Tx)

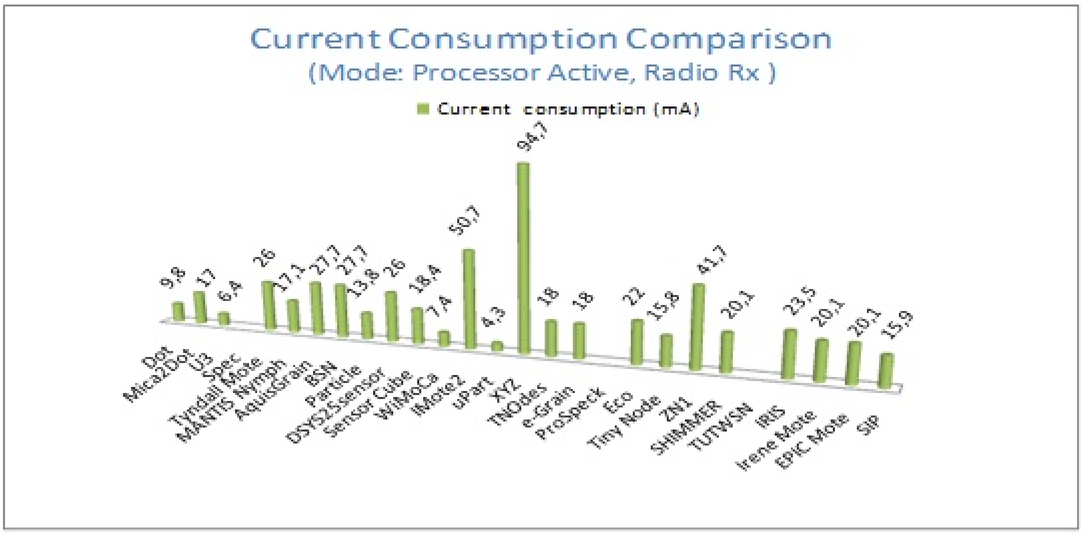

Figure 4. Current Consumption Comparison (Mode: Processor Active, Radio Rx)

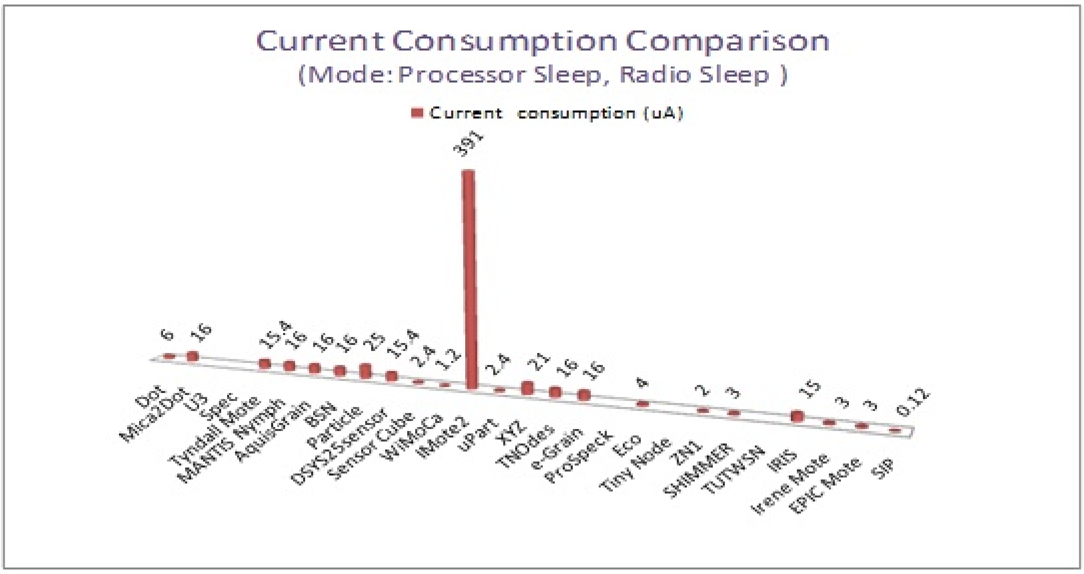

Figure 5. Current consumption Comparison (Mode: Processor Sleep, Radio Sleep)

SENSOR NODE	Dot	Mica2Dot	U3	Spec	Tyndall Mote	MANTIS Nymph
DEVELOPER	UC Berkeley	UC Berkeley /Crossbow	Aoyama-Morikawa Lab	UC Berkeley	Irelands National ICT Research Institute	U Corolado
DATE	2000	2002	2003	2003	2003	2003
EMBEDDED COMPUTING SPECIFICATIONS						
Type	ATMega163	ATMega128L	PIC18F452	AVR RISC Core	ATMega128L	ATMega128L
Architecture	8 bit RISC	8 bit RISC	8 bit	RISC	8 bit RISC	8 bit RISC
Clock	8 MHz	8 MHz	10 MHz	4 - 8 MHz	8 MHz	8 MHz
Program memory	16 Kbyte	128 Kbyte	32 Kbyte	< 0.1 Mbyte	128 Kbyte	128 Kbyte
Data memory	1 Kbyte	4 Kbyte	1 Kbyte	3 Kbyte	4 Kbyte	4 Kbyte
External memory	32 Kbyte	512 Kbyte	256 Byte	N/A		512 Kbyte
DATA ACQUISITION SPECIFICATIONS						
ADC Channel	8	8	8	N/A	8	8
ADC Resolusion	10 bit	10 bit	10 bit	8 bit	10 bit	10 bit
ADC Sampling rate	15 Ksps	15 Ksps			15 Ksps	15 Ksps
DAC Channel						
DAC Resolution						
WIRELESS COMMUNICATION SPECIFICATIONS						
Type	RFM TR1000	Chipcon CC1000	CDC-TR-02B	FSK Transmitter	Nordic nRF2401	Chipcon CC1010
Frekuensi	916.5 MHz	900 MHz	315 MHz	902.4 MHz	2400 MHz	300 – 1000 MHz
RF output Power		-20 - 10 dBm				-20 - 10 dBm
Data rate	115.2 Kbps	38.4 Kbps	115.2 Kbps	19200 Kbps	1000 Kbps	76.8 Kbps
Outdoor range		304.8 meter	30 meter			
Indoor range		152.4 meter		12.2 meter	15 meter	
PROGRAMMING & SENSOR INTERFACE SPECIFICATIONS						
Expansion	None	18-pin	26-pin			20-pin
Communication	IEEE 1284, RS232	IEEE 1284, RS232	I2C, SPI,USART	SPI, UART, RS232		I2C, JTAG
Integrated sensor	Yes	No	Yes (motion, photo, temperature)	No	Yes (temperature, humidity, light, 2-axis accelerometer)	
OPERATING SYSTEM & TOOLS						
OS	TinyOs	TinyOs	Pavenet	TinyOs	TinyOS	Mantis
Programming language	C Language	C Language	C language	C Language	C Language	C language
Programming tools			U3 SDK			
Compiler			CCS C Compiler			
POWER UNIT SPECIFICATIONS						
Power source	Battery LI Coin (CR2032)	Battery Coin Cell (3V)	Rechargeable battery (3-AAA)			2 AA battery
Minimum operating voltage	2.7 Volt	2.7 Volt	3.0 Volt			
Lifetime					3 years	

Figure 6. State of the art wireless sensor node platform

SENSOR NODE	BSN	Particle	DSYS25sensor	Sensor Cube	WiMoCA	iMote2
DEVELOPER	Imperial College in London	Teco, University of Karlsruhe	NMRC & University College Cork, Ireland	IMEC, Leuven, Belgium	DEIS - University of Bologna, Italy	Intel and UC Los Angeles
DATE	2004	2004	2004	2004	2004	2005
EMBEDDED COMPUTING SPECIFICATIONS						
Type	TIMSP430F149	PIC18F6720	ATMega128L	TIMSP430	ATmega8	Intel PXA271
Architecture	16bit RISC		8bit RISC	16bit RISC	8 bit RISC	Intel processor
Clock	8 MHz	20 MHz	8 MHz	8 MHz	4 MHz	104 - 520 MHz
Program memory	60 KByte	128 Kbyte	128 Kbyte	48 KByte	8 Kbyte	32 Mbyte
Data memory	2 KByte	4 Kbyte	4 Kbyte	10 Kbyte	1 Kbyte	32 Mbyte
External memory	512 Kbyte	512 Kbyte		16Mbyte		
DATA ACQUISITION SPECIFICATIONS						
ADC Channel	8	12	8	8	8	
ADC Resolusion	12bit	10 bit	10 bit	12bit	10 bit	
ADC Sampling rate	485 Ksps		15 Ksps	485 Ksps		
DAC Channel				2		
DAC Resolution				12bit		
WIRELESS COMMUNICATION SPECIFICATIONS						
Type	Nordic nRF2420	RFM TR1001	Nordic nRF2401	Nordic nRF2401	RFM TR1001	Chipcon CC2420
Frekuensi	2400 MHz	868.35 MHz	2400 MHz	2400 MHz	868.35 MHz	2400 MHz
RF output Power						-10 - 0 dBm
Data rate	250 Kbps	115.2 Kbps	1000 Kbps	1000 Kbps	115.2 Kbps	250 Kbps
Outdoor range	50 meter		10 meter (Low power mode)			125 meter
Indoor range		30 meter	15 meter	15 meter	30 meter	50 meter
PROGRAMMING & SENSOR INTERFACE SPECIFICATIONS						
Expansion	20-pins	21 - pin	80+40+20-pin			100-pin
Communication	SPI, I2C, UART	I2C, USB, RS232		SPI, I2C	SPI, I2C	USB,RS 232, I2C, UART SPI, GPIO, JTAG
Integrated sensor	Yes (ECG, accelerometer 2-axis, temperature)	Yes (acceleration, light temperature, microphone)		Yes (temperature, light, humidity)	Yes (acceleration 3-axis)	Yes
OPERATING SYSTEM & TOOLS						
Name	TinyOs		TinyOS	TinyOs		TinyOs
Programming language	C Language	C Language	C Language	C Language	C Language	C Language
Programming tools						Open source
Compiler						
POWER UNIT SPECIFICATIONS						
Power source		Battery AAA (1.2 Volt)	Batery Coin Cell (3 Volt)	NiMH battery 2AA (2.4 Volt)	3-NiMH rechargeable	NiMH Battery 3AA
Minimum operating voltage		3.3 Volt			3.3 Volt	3.2 Volt
Life time						

Figure 7. State Of The Art Wireless Sensor Node Platform (Continue)

SENSOR NODE	XYZ	TNOdes	e-Grain	ProSpeckz	Eco	Tiny Node	ZN1
DEVELOPER	Yale University's ENALAB	TNOdes TM	Fraunhofer IZM, Berlin	U Edinburgh	UC Irvine	EPFL in Switzerland	Central Research Laboratory, Hitachi Ltd, Japan.
DATE	2005	2005	2005	2005	2006	2006	2006
EMBEDDED COMPUTING SPECIFICATIONS							
Type	OKI ML67Q 500X	ATMega128L	ATMega128L	Cypress CY8C2764	nRF24E1(8051)	TIMSP430F1611	H8S/2218
Architecture	32 bit ARM7 TDMI core	8 bit RISC	8 bit RISC	8 bit	8 bit 8051 Core	16 bit RISC	16 bit
Clock	1.8 - 57.6 MHz	8 MHz	8 MHz	12 MHz	16 MHz	8 MHz	16 MHz
Programmemory	256 Kbyte	128 Kbyte	128 Kbyte	16 Kbyte	4 KByte	48 KByte	
Data memory	4 Kbyte	4 Kbyte	4 Kbyte	256 Byte	256 Byte	10 Kbyte	12 Kbyte
External memory	512 Kbyte				32 Kbyte	512 Kbyte	128 Kbyte
DATA ACQUISITION SPECIFICATIONS							
ADC Channel	4	8	8		9	8	
ADC Resolusion	10 bit	10 bit	10 bit		6 - 12 bit	12 bit	
ADC Sampling rate		15 Ksps	15 Ksps		100 Ksps	485 Ksps	
DAC Channel						2	
DAC Resolution						12 bit	
WIRELESS COMMUNICATION SPECIFICATIONS							
Type	Chipcon CC2420	Chipcon CC1000	Chipcon CC1000	Chipcon CC2420	Nordic nRF24E1	XE1205	Chipcon CC2420
Frekuensi	2400 MHz	900 MHz	900 MHz	2400 MHz	2400 MHz	869 MHz	2400 MHz
RF output Power	-10 - 0 dBm	-20 - 10 dBm	-20 - 10 dBm	-10 - 0 dBm	-20 - 0 dBm		-10 - 0 dBm
Data rate	250 Kbps	38.4 Kbps	38.4 Kbps	250 Kbps	1000 Kbps	76.8 Kbps	250 Kbps
Outdoor range	125 meter	152.4 meter	152.4 meter	125 meter	10.6 meter	600 meter	125 meter
Indoor range	50 meter			50 meter			50 meter
PROGRAMMING & SENSOR INTERFACE SPECIFICATIONS							
Expansion	30-pin				16-pin	30-pin	30-pin
Communication	I2C, UART, GPIO, JTAG RS232, SPI, SIO				SPI, RS232, Digital I/O GPIO, UART	USART, SPI, I2C, RS232	JTAG, PIO, AD, IRQ
Integrated sensor	Yes(temperature, light, acceleration)				Yes (Acceleration, Light)	Yes (temperature, humidi light)	Yes (temperature, pulse, accelerator, humidity, pyroelectric)
OPERATING SYSTEM & TOOLS							
Name	SOS	TinyOs	TinyOS		TinyOs	TinyOs	
Programming language	C Language	C Language	C Language		C Language	C Language	
Programming tools	ARM7TDMI GNU tool						
Compiler	the ARM-GCC compiler						
POWER UNIT SPECIFICATIONS							
Power source)	Ni-MH rechargeable batteries (3 AA-3.6 Volt)			Lithium Button cell	Battery Li Coin	2 AA Alkaline cell	Li-Ion rechargeable battery
Minimum operating voltage	2.5 Volt	2.5 Volt		3 Volt	3.0 Volt	3.0 Volt	2.7 Volt
Life time					4 hour (50% duty cycle)		15 years

Figure 8. State Of The Art Wireless Sensor Node Platform (Continue)

SENSOR NODE	SHIMMER	TUTWSN	IRIS	Irene Mote	EPICMote	SIP
DEVELOPER	Intel Digital Healt Group	ICDS, Tampere University of Technolog	Crossbow	UCLA Berkeley	UCLA Berkeley	IN, Hamburg University of Technology
DATE	2006	2006	2007	2008	2008	2008
EMBEDDED COMPUTING SPECIFICATIONS						
Type	TI MSP430F1611	Xemics XE88LC02	ATMega128L	TI MSP430F1611	TI MSP430F1611	Atmega644P
Architecture	16 bit RISC	CoolRisc 816 processor	8 bit RISC	16 bit RISC	16 bit RISC	8 bit RIS
Clock	8 MHz	4 MHz	8 MHz	8 MHz	8 MHz	4 MHz
Program memory	48 KByte	22 Kbyte	128 Kbyte	48 KByte	48 KByte	64 Kbyte
Data memory	10 Kbyte	1 Kbyte	4 Kbyte	10 Kbyte	10 Kbyte	4 Kbyte
External memory	2 Gbyte	8 Kbyte	512 Kbyte	16 Mbyte	16 Mbyte	
DATA ACQUISITION SPECIFICATIONS						
ADC Channel	8		8	8	8	8
ADC Resolusion	12 bit	16 bit	10 bit	12 bit	12 bit	10 bit
ADC Sampling rate	485 Ksps		15 Ksps	485 Ksps	485 Ksps	
DAC Channel	2			2	2	
DAC Resolution	12 bit			12 bit	12 bit	12 bit
WIRELESS COMMUNICATION SPECIFICATIONS						
Type	Chipcon CC2420	Nordic nRF2401	Atmel ATRF230	Chipcon CC2420	Chipcon CC2420	AT86RF230
Frekuensi	2400 MHz	2400 MHz	2400 MHz	2400 MHz	2400 MHz	2400 MHz
RF output Power	-10 - 0 dBm			-10 - 0 dBm	-10 - 0 dBm	
Data rate	250 Kbps	1000 Kbps	250 Kbps	250 Kbps	250 Kbps	250 Kbps
Outdoor range	125 meter		> 300 meter	125 meter	125 meter	> 300 meter
Indoor range	50 meter	15 meter	> 50 meter	50 meter	50 meter	> 50 meter
PROGRAMMING & SENSOR INTERFACE SPECIFICATIONS						
Expansion			51-pin			
Communication	SPI, GPIO, USART	UART, SPI, RS232	USB, RS232, I2C, SPI		SPI, I2C, JTAG, UART Digital I/O	I2C, JTAG, USB
Integrated sensor	Yes (accelerator)	Yes (temperatur)	Yes (temperature, light,	Yes (acceleration 3-axis)		
OPERATING SYSTEM & TOOLS						
Name	TinyOs		Mote Works	TinyOs	TinyOs	TinyOs
Programming language	C Language	C Language	C Language	C Language	C Language	C Language
Programming tools						
Compiler						
POWER UNIT SPECIFICATIONS						
Power source		2 battery CR2450 battery (3Volt)	Battery 2AA	Li+ Button Cell (CR2450)		
Minimum operating voltage		2.25 Volt	2.7 Volt	2.7 Volt	2.7 Volt	
Life time		900 days				

Figure 9. State Of The Art Wireless Sensor Node Platform (Continue)