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Wireless Sensor Networks: A Survey

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Abstract: *Wireless Sensor Networks (WSN), an element of pervasive computing, are presently being used on a large scale to monitor real-time environmental status. However these sensors operate under extreme energy constraints and are designed by keeping an application in mind. Designing a new wireless sensor node is extremely challenging task and involves assessing a number of different parameters required by the target application, which includes range, antenna type, target technology, components, memory, storage, power, life time, security, computational capability, communication technology, power, size, programming interface and applications. This paper analyses commercially (and research prototypes) available wireless sensor nodes based on these parameters and outlines research directions in this area.*

Keywords: Wireless Sensor Network (WSN), FPGA, sensor node, Active Node, CCU.

1. Introduction

In the last few years wireless sensor networks (WSNs) have drawn the attention of the research community, driven by a wealth of theoretical and practical challenges [1]. This progressive research in WSNs explored various new applications enabled by larger scale networks of sensor nodes capable of sensing information from the environment, process the sensed data and transmits it to the remote location [2-4]. WSNs are mostly used in, low bandwidth and delay tolerant, applications ranging from civil and military to environmental and healthcare monitoring.

WSNs as shown in Fig.1 generally consist of one or more sinks (or base stations) and perhaps tens or thousands of sensor nodes scattered in a physical space. With integration of information sensing, computation, and wireless communication, the sensor nodes can sense physical information, process crude information, and report them to the sink. The sink in turn queries the sensor nodes for information. WSNs have several distinctive features like:

a) *Unique network topology*
b) *Diverse applications*
c) *Unique traffic characteristics, and*
d) *Severe resource constraints*

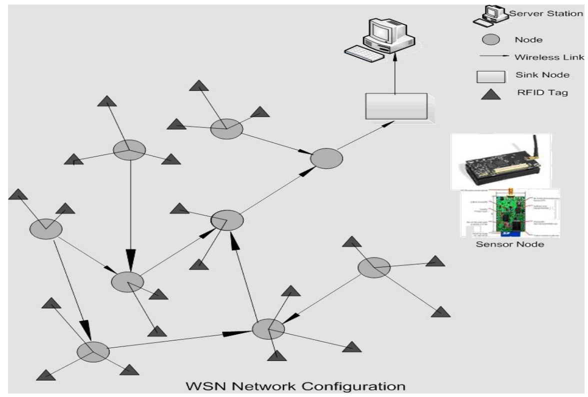

Fig. 1 WSN Network

WSN node is comprised of low-power sensing devices, embedded processor, communication channel and power module. The embedded processor is generally used for collecting and processing the signal data taken from the sensors. Sensor element produces a measurable response to a change in the physical condition like temperature, humidity, particulate matter (e.g. CO_2) etc.

The wireless communication channel provides a medium to transfer the information extracted from the sensor node to the exterior world which may be a computer network and inter-node communication [5]. However, WSN using IEEE 802.15.4 Wireless Personal Area Network protocol (WPAN) or Bluetooth is complicated and costly [10, 18]. Using RFID to implement wireless communication is relatively simple and cheap [6]. Zigbee protocol can also be used for communication; alternatively the RS232 standard for wireless transmission of data can be adopted because the data rate of RFID and that of RS232 is same in terms of bits per second (bps).

The rest of the paper is organized as follow. Section 2 defines the system requirements. Section 3 compares different WSN motes that can be used in variety of WSN configuration targeting different applications. Section 4, evaluates these nodes based upon size, range, technology they have used, storage capacity, communication technology, power, security etc. And finally Section 5 concluded this paper and suggested future work.

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2. System Requirements

Here we discuss some of the characteristic requirements of a system comprising wireless sensor nodes. The system should be:

1. Fault tolerant: the system should be robust against node failure (running out of energy, physical destruction, H/W, S/W issues etc). Some beep mechanism should be incorporated to indicate that the node is not functioning properly.

2. Scalable: The system should support large number of sensor nodes to cater for different applications.

3. Long life: The node's life-time entirely defines the network's life-time and it should be high enough. The sensor node should be power efficient against the limited power resource that it have since it is difficult to replace or recharge thousands of nodes. The node's communication, computing, sensing and actuating operations should be energy efficient too.

4. Programmable: the reprogramming of sensor nodes in the field might be necessary to improve flexibility.

5. Secure: the node should support the following

a. Access Control: to prevent unauthorized attempts to access the node.

b. Message Integrity: to detect and prevent unauthorized changes to the message.

c. Confidentiality: to assure that sensor node should encrypt messages so only those nodes would listen who have the secret key.

d. Replay Protection: to assure that sensor node should provide protection against adversary reusing an authentic packet for gaining confidence/network access, man in the middle attack can be prevented by time stamped data packets.

6. Affordable: the system should use low cost devices since the network comprises of thousand of sensor nodes, tags and apparatus. Installation and maintenance of system elements should also be significantly low to make its deployment realistic.

3. Related Work

Sensor networks are becoming more popular in applications related to environment monitoring to structural health monitoring [15,7] and today a number of research teams are developing efficient nodes for such smart networks capable of processing data at node end before transmitting to base station, having compact size, reduced power consumption, low cost and most important minimum human intervention. In this section we outline some of this related work.

One of the prime examples of such sensor network is a project named "**Smart-Dust**" carried out by University of California at Berkeley, USA [8]. The main objective of the project was to develop a compact size node that includes sensor, capability to compute the sensor data onboard, low cost, minimal power consumption and having bidirectional wireless communication capability.

Another interesting research testbed was the **Spec platform** [11], which integrated the functionality of Mica onto a single 5 mm^2 chip. Spec was built with a micro-radio, an analog-to-digital converter, and a temperature sensor on a single chip, which lead to a 30-fold reduction in total power consumption. This single-chip integration also opened the path to low cost sensor nodes. The integrated RAM and cache memory architecture greatly simplified the design of the mote family. However, the tiny footprint also requires a specialized operating system, which was developed by UC Berkeley, called TinyOS. TinyOS features component based architecture and event driven model that are suitable for programming with small embedded devices, such as motes. The combination of Motes and TinyOS is gradually becoming a popular experimental platform for many research efforts in the field of WSNs.

The **Medusa MK-2** [12] sensor node was developed by the Center for Embedded Networked Sensing (CENS) at UCLA in 2002 to target both high and low-end processing applications. It integrates two microcontrollers, the first one; ATmega128 was dedicated to less computationally demanding tasks, including radio base band processing and sensor sampling. The second one, AT91FR4081, was a more powerful microcontroller (40 MHz, 1 MB flash, 136 KB RAM) that was designed to handle more sophisticated, but less frequent signal processing tasks (e.g., the Kalman filter). The combination of these two microcontrollers provided more flexibility in WSN development and deployment, especially for applications that require both high computation capabilities and long lifetime.

In 2002 the Berkeley Wireless Research Center (BWRC) developed System on Chip (SoC) based sensor node, named **PicoNode II** [16]. It was built using two ASIC chips that implemented the entire node functionality. In the following year, the same team developed a first radio transmitter (that used power less than 400 μW), **PicoBeacon** was purely powered by solar and vibrational energy sources.

Another ASIC based approach was taken by the μAMPS group from MIT. Following their first testbed, **μAMPS-I** [13], the team then tried to build a highly integrated sensor node comprised of a digital and an analog/RF ASIC, µAMPS-II. The interesting feature of **µAMPS-II** was the node's capability to operate in several modes. It can operate either as low-end stand-alone guarding node, a fully functional node for middle-end sensor networks or as a companion component in a more powerful high-end sensor system. Thus, it favored a network with heterogeneous sensor nodes for a more efficient utilization of resources.

The **Free2move** wireless sensor node [14] is based on a transceiver operating in the 2.4 GHz ISM band. The node was initially thought of as an active RFID tag for monitoring temperature in goods. However, it has been shown that it is also possible to use it as a wireless sensor network node. The node is equipped with an extremely low power microcontroller (Microchip PIC16F87), for executing communication protocols and sensor functionality. The memory and processing resources are very limited to keep the price and energy consumption as low as possible. The node is also equipped with a temperature sensor.

Overall we can see that most of the research is focused on developing smart sensing nodes for WSN. Hence we studied the most important nodes in the current literature to see which application can be practical. The next section evaluates these nodes.

4. Evaluation

Wireless sensing technology comprising self-reliant, battery-powered nodes is pushing sensing to the extreme. Sensor modules, motes, and ICs all have had a huge impact on the industry as parts of wide-ranging wireless sensor networks. In this section we compare the design of WSN sensor nodes proposed by a number of research groups. The comparison is broadly based on following technical features

1. Design Range
2. Antenna design
3. Target Technology
4. Components
5. Non Volatile Storage
6. Communication technology
7. Power
8. Security measure
9. Size
10. Programming and Sensor Interface
11. Applications

4.1 Target Technology

In this section evaluate the motes based on the following technical features i.e. design range, antenna, components, non-volatile storage, and power.

From Table 1 it is clear that effective range of motes is entirely defined by the antenna design. The average range is in between 100ft (30.48 meters) to 250ft (76.2 meters) however, there are few motes like Mica2 and Iris that would offer 1000ft addressable range capability and this would be good for a larger coverage area but on the other hand larger the coverage area the lesser will be the average life time of the WSN node [9, 17] so trade-off between the node life time and coverage area should be taken into account during the selection of WSN nodes while planning a WSN network.

Next if we look at the microcontroller it includes not only memory and processor but also non-volatile memory and interfaces such as Analog to Digital Converters (ADC's), Serial Peripheral Interface (SPI), Universal Asynchronous Receiver Transmitter (UART), counters etc. Every mote also uses non-volatile storage element for storing useful information and the sizes vary in the range of 32KB to 4MB depending upon the nature of application.

Other than the non-volatile memory most of the motes use Microcontrollers (like AT90LS8535, ATmega163, ATmega103L, ATmega128, TI MSP430 and XM2110CA) as a central processing unit having clock frequency in the range of 4 MHz to 8 MHz. The effectiveness in terms of energy consumption of a microcontroller or microprocessor is governed from the energy it consumes per instruction execution (measured in nJ/instruction).

The AT90LS8535 (WeC, Rene 1999) is an 8-bit microcontroller consumes 15 mW (consumes 3.75 nJ/instruction) power in active mode and 45 µW power in sleep mode and have 1msec wakeup time.

ATmega163 (Rene 2000, Dot 2000) is an 8-bit microcontroller consumes the same power as AT90LS8535 both in active (consumes 1.875 nJ/instruction) and sleep mode but it has 36µsec wakeup time so it is fast to respond changes.

Mica uses ATmega103L microcontroller (4 MHZ) with 128 KB program memory and 4 KB RAM. It consumes 16.5 mW power (4.125 nJ/instruction) during active mode and draws less than 1µA during sleep mode. The major drawback of ATmega103L is that it is not self-programmable so we do need some support of co-processors.

ATmega128 (Mica2, Mica2Dot: most widely used microcontroller because of its Tiny OS support in addition to MSP430 alone) is an 8-bit microcontroller with 128 KB in-system programmable flash. It consumes 8mW (Mica2Dot, consumes 1.08 nJ/instruction) and 33mW (Mica2, consumes 4.459 nJ/instruction) during active mode and 75 µW in sleep mode (Mica2, Mica2Dot) and have 180µsec wakeup time. It has large space for programming memory and RAM as compared to AT90LS8535, ATmega163 and ATmega103L.

The TIMSP430 (TmoteSky, TelosB) is an ultra low power microcontroller ideally suited for WSN application. It consumes 3mW power (TmoteSky, consumes 0.375 nJ/instruction) and 3.24 mW power (TelosB, consumes 0.405 nJ/instruction) in active mode and 6 µW power (TmoteSky) and 15 µW (TelosB) in sleep mode and has 6 µsec wakeup time. Although it consumes less power but it does not have more program memory and RAM as compared to ATmega128.

Imote2 uses Intel's processor (Intel PXA271 having operating frequency of 400 MHz have 32MB program memory and RAM) and SunSpot uses ARM920T (having clock frequency of 180MHz and have 4MB program memory and 512 KB RAM) and supports Zigbee/CC2420. So Imote2 and SunSpot are ideally suitable for applications requiring intensive processing power like the case of visual information processing (monitoring the surroundings e.g. surveillance) or for an application that keeps long history of the recorded information (e.g. CO_2 emission track). Imote2 also support separate interface for the camera as well. These two motes also support high program memory and RAM as compared to the rest of motes and again is true for the above mentioned applications. Once the sensing and processing of information is complete, the next most important factor that determines the quality of a node is its communication technology. We now evaluate these modes based upon the communication technology they implement.

4.2 Communication Technology

While designing a WSN the designer must pay key attention to the life time of the entire network because one of the main objective of WSN is to have minimum human intervention. Other than processing the communication part is considered to be the second largest energy consuming element of the node. The RF transceiver consumes most of the energy during the active state. Network lifetime can be increased by having nodes only operate their radios for brief periods of time.

The CC1000 is a very low power CMOS RF Transceiver (Mica2Dot, Mica2) support data rate up to 76.8 Kbps using frequency shift keying (FSK). It has an internal bit synchronizer that simplifies the design of a high speed radio link with the Central Control Unit (CCU). It consumes 29 mW in Rx mode, 42 mW in TX mode and draws 0.2 µA in power in down mode. Its advantage over TR1000 is that it can easily be programmed for operation at other frequencies between 300 MHz to 1000 MHz.

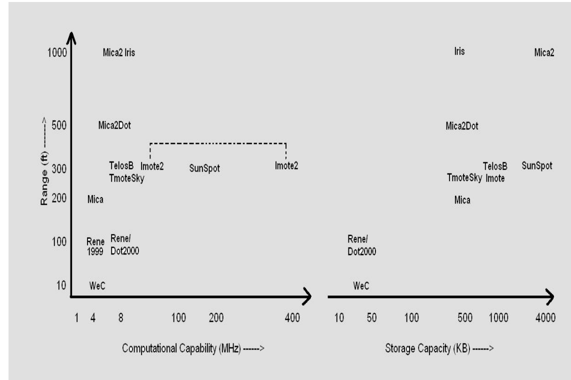

Fig. 3 Classification of WSN motes based on storage capacity & computational capacity

The CC2420 (Tmote Sky, Telos B, Imote2, SunSpot, Iris) is a true single-chip 2.4 GHz IEEE 802.15.4/ Zigbee [19] RF Transceiver with MAC supported transceiver designed for low-power and low voltage wireless applications. It includes a digital direct sequence spread spectrum base band modem providing a spreading gain of 9dB and an effective data rate of 250 Kbps using Offset quadrature phase-shift keying (O-QPSK). It provides extensive hardware support for packet handling, data buffering, burst transmissions, data encryption (Hardware MAC encryption AES-128), data authentication, clear channel assessment, link quality indication and packet timing information. It consumes 19.7 mA in Rx mode of operation and 17.4 mA in TX mode. In-addition to hardware support it also performs all communication related processing on-chip, thus leaving the processor free to do other processing. The high data rate in terms of bps is generally required in high-end application like surveillance, high speed sensor data, vibration measurement etc. The two former RF transceivers (TR1000 and CC1000) have no Zigbee support.

Also RF transceivers are most sensitive to power variations but CC2420 has in built power regulator. Another major development in RF transceiver technology was shown by Chipcon CC2431 [22] which include a microcontroller with a radio that supports ZigBee/IEEE 802.15.4 standard. It also implements a unique on-chip feature called "location engine" to estimate relative location of sensor nodes with 0.5m resolution.

Fig.3 & Fig. 4 classifies computational capability and storage capacity of various motes against the mote's addressable range. From this it would be obvious that all mote's are broadly classified into nine different groups based on the effective addressable range (AR), computational capability (CC) and storage capacity (SC) as shown in Table 2.

Table 2 Comparison of different mote's against their addressable range, computational capability, storage capacity

	AR	CC	SC
WeC	Short	Low	Low
Rene 1999	Med-Short	Low	Low
Rene/Dot 2000	Med-Short	Med	Low
Mica	Med	Low	Med-High
TmoteSky, TelosB, Imote2	Med	Med	Med-High
Imote2	Med	High	Med-High
SunSpot	Med	High	High
Mica2Dot, Iris	Large	Med	Med-High
Mica2	Large	Med	High

This concludes the evaluation of the motes based on its key technical design parameters.

5. Conclusion

WSN is a promising future technology and presently used in range of application that requires minimum human intervention. In this paper we have surveyed the WSN technology. We have also presented the WSN mode evaluation based on its key technical specifications. Although researchers have already designed a number of network configurations like heterogeneous and single-hop which uses WSN technology but in such configurations most of the processing is carried out at the server end. It would be good if in-network processing capability will be incorporated at node's end. By this way the node pre-processes the data and sends wirelessly the compact form of the extracted information to the sink.

References:

[1] I.F. Akyildiz, T. Melodia, and K.R. Chowdhury, "A Survey on wireless multimedia sensor networks," Computer Networks (Elsevier) J., vol. 51, pp. 921-960, 2007.

[2] J. Feng, F. Koushanfar, M. Potkonjak,"System-Architectures for Sensor Networks Issues, Alternatives, and Directions", IEEE International Conf on Computer Design (ICCD), Germany, 2002. pp. 226- 231

[3] D. Culler, D. Estrin, M. Srivastava, "Overview of Sensor Networks", IEEE Computer, USA, vol 37, pp. 41-49, August 2004.

[4] K. Raja, I. Daskalopoulos, H. Diall, S. Hailes, T. Torfs, C. Van Hoof and G.Roussos, "Sensor Cubes: A Modular, Ultra-Compact, Power-Aware Platform for Sensor Networks", Int Conf on Inf Proc in Sensor Networks (IPSN SPOTS), USA, pp. 2065-2075, vol 48, No6, April 2007.

[5] L. Tomas J. Marusak, "Bi-directional Wireless Detection System" USA, Jun. 19, 2008, p. 18.

[6] K. S. Hitoshi Kitayoshi, "Long Range Passive RFID-Tag for Sensor Networks," in *Vehicular Technology Conference, 2005. VTC-2005-Fall.* 2005 IEEE 62nd, Dallas, USA, 25-28 Sept., 2005, pp. 2696-2700.

[7] A. M. Bratkovski, "Monitoring an environment using RFID assembly." vol. WO/2006/094085, W. I. P. Organization, Ed. USA: HEWLETT-PACKARD Development Company, L. P., 2006, p. 13

[8] Smart Dust, Autonomous sensing and communication in a cubic millimeter http://robotics.eecs.berkeley.edu/~pister/SmartDust/ Aug. 18, 2008

[9] B.J. Y. Young-I Kim, Jae-Ju Song, Jin-Ho Shin, and Jung-I Lee "Implementing a Prototype System for Power Facility Management using RFID/WSN," in Proceeding of world academy of science, engineering and technology, Venice, Italy, Nov. 2006, pp. 1-6

[10] IEEE 802.15 WPANTM Task Group http://ieee802.org/15/index.html Aug. 15, 2008.

[11] WSN Lab:http://www.jlhlabs.com/ Aug. 20,08.

[12] UCLA WSN Projects: http://nesl.ee.ucla.edu/projects/ahlos/mk2 Aug.20, 2008.

[13] MIT WSN Research Group: http://mtlweb.mit.edu/researchgroups/icsystems/ gallery.html, Aug. 20, 2008

[14] U. W. Bilstrup, P.A, "An architecture comparison between a wireless sensor network and an active RFID system," in *Local Computer Networks, 2004. 29th Annual IEEE International Conference on*, Halmstad University, CERES, Nov. 2004, pp. 583- 584.

[15] Y.-I. Y. Kim, Bong-Jae. Song, Jae-Ju. , "Implementing a Prototype System for Power. Facility Management using RFID/WSN," pp. 70-75, in *IADIS International Conference WWW/Internet SPAIN, 2006*

[16] N. Cho, S.J. Song, S. Kim, S. Kim and H. J. Yoo, "A 5.1 microwatt UHF RFID Tag chip integrated with sensors for wireless environment monitoring" *Proc of the ESSCIRC* Grenoble, France (2005).

[17] C. W. Fu, Bang. Lim, Hock Beng. , "An Enhanced Sensor Scheduling Protocol for Wireless Sensor Networks," in *Distributed Comp Sys Workshops, 2008. ICDCS '08. 28th Int Conf on*, Beijing, China 17-20 June 2008, pp. 303-308.

[18] J.-S. H. Lee, Yang-Chih. , "ITRI ZBnode: A ZigBee/IEEE 802.15.4 Platform for Wireless Sensor Networks," in *Systems, Man and Cybernetics, 2006. SMC '06. IEEE Int Conf on*, Taipei, Taiwan, 2006, pp. 1462-1467.

Mote Type	 WeC	 Rene 1999 2000	 Dot 2000	 Mica	 Mica2Dot
Design	Broadcast communication	Broadcast communication	Broadcast communication	RFID based Heterogeneous Network	RFID based Heterogeneous Network
Range	15 ft/4.572 m	100 ft/30.48 m	100ft/30.48 m	200ft/60.96 m	500 ft/152.4 m
Antenna Design	Integrated	Integrated/External	Integrated	Integrated	Integrated
Target Technology Frequency Type Program Memory RAM Active Power Sleep Power Wakeup Time	MicroCntrl 4 MHz AT90LS8535 8 KB 0.5 KB 15 mW 45 µW 1000 µSec	MicroCntrl 4 MHz 8 MHz AT90LS8535 ATmega163 8 KB 16 KB 0.5 KB 1 KB 15 mW 15 mW 45 µW 45 µW 1000 µSec 36 µSec	MicroCntrl 8 MHz ATmega163 16 KB 1 KB 15 mW 45 µW 36 µSec	MicroCntrl 4 MHz ATmega103L 128 KB 4 KB 16.5 mW <1 µA drawn	MicroCntrl 7.4 MHz ATmega128 128 KB 4 KB 8 mW 75 µW 180 µSec
Components	MicroCntrl, Storage Memory, on-board light and temperature sensors	Storage Memory, MicroCntrl, GPIO, sensor interface	Sensor Interface, MicroCntrl, Storage Memory	GPIO, SPI, MicroCntrl, Storage Memory	GPIO, SPI, MicroCntrl, Storage Memory
Non-Volatile Storage Chip Connection Type Size	Yes 24LC256 I^2C 32 KB	Yes 24LC256 I^2C 32 KB	Yes 24LC256 I^2C 32 KB	Yes AT45DB041B SPI 512 KB	Yes AT45DB041B SPI 512
Communication Tech Radio Data Rate Modulation Type Rx Power/ Rx Sensitivity Tx Power @ 0dBm/ Tx Sensitivity	TR 1000 10 Kbps OOK 9 mW 36 mW	TR 1000 10 Kbps OOK 9 mW 36 mW	TR 1000 10 Kbps OOK 9 mW 36 mW	TR 1000 50 Kbps ASK 12 mW 36 mW	CC 1000 38.4 Kbps FSK 29 mW 42 mW
Power Source Min Operating Volt Total Active Power	Coin Cell 2.7 V 24 mW	Battery 2.7 V 24 mW	Battery 2.7 V 24 mW	Battery 2AA 2.7 V 27 mW	Battery 2AA 2.7 V 44 mW
Programming & Sensor Interface Expansion Communication Integrated Sensor	None/ 51-pin IEEE 1284/ RS232 Yes	None/ 51-pin IEEE 1284/ RS232 No	None IEEE 1284/ RS232 Yes	51-pin IEEE 1284/ RS232 No	19-pin IEEE 1284/ RS232 No
Size	0.98x0.98x0.51 (inches) 24.89x24.89x12.95 (mm)			1.24x2.21 (inches) 31.5x56.13 (mm)	Quarter size as compared to Mica2 (25mm) 25 mm
Security	No Unique ID (UID), limited security	No Unique ID (UID), limited security	limited security	Elliptic Curve Cryptography	Elliptic Curve Cryptography
Applications	Designed for Environmental Monitoring having onboard temperature and light sensors.	Large federated networks for high-resolution sensing of environment	Large federated networks for high-resolution sensing of environment	Environmental Monitoring, vibration detection in bridges, monitoring the condition of machinery	"Smart Dust" and RFID technology for "smart" environmental monitoring, home sensor network, battlefield monitoring

Mote Type	 Mica2	 Tmote Sky	 Telos B	 Imote2	 Sun Spot	 Iris
Design	RFID based Heterogeneous Network	Mesh Networking	Basic Node Experimental purpose	Heterogeneous Networks	Mesh Networking	Large Scale Sensor Networks (1000 + points)
Range	1000 ft/304.8m	250 ft/76.2m	300 ft/91.44m	300 ft/91.44 m	300 ft/91.44m	1000ft/304.8m
Antenna Design	Integrated	Integrated	Integrated	Integrated, External	Integrated	Integrated
Target Technology Frequency Type Program Memory RAM Active Power Sleep Power Wakeup Time	MicroCntrl 7.4 MHz ATmega128 128 KB 4 KB 33 mW 75 µW 180 µSec	MicroCntrl 8 MHz TIMSP430 60 KB 2 KB 3 mW 6 µW 6 µSec	MicroCntrl 8 MHz TIMSP430 48 KB 10 KB 3.24 mW 15 µW 6 µSec	MicroPro 13-400 MHz IntelPXA271 32 MB 32 MB 1400 µW	MicroPro 180 MHz ARM920T 4 MB 512 KB 25-90 mA draw 32 µA	MicroCntrl 8 MHz XM2110CA 128 KB 8 KB draw 8 mA draw 8 µA
Components	GPIO, SPI, MicroCntrl, Storage Memory	MicroCntrl, Sensor Interface, GPIO, DMA, Storage Memory	MicroCntrl, Sensor Interface, Storage Memory, LCD Display	MicroPro, Integrated Radio 802.15.4, camera interface, Sensor Interface, Storage Memory, JTAG	GPIO PWM capable, Analog I/P, Switches, Sensor interface, Current O/P pins, Storage Memory	MicroCntrl, GPIO, SPI, Sensor Interface, Storage Memory
Non-Volatile Storage Chip Connection Type Size	Yes AT45DB041B SPI 4MB	Yes STM24M01S I C 512 KB	Yes STM25P80 I C 1MB	Yes STM25P80 I C 1MB	Yes SPI 4MB	Yes SPI 512 KB
Communication Tech Radio Data Rate Modulation Type Rx Power/ Rx Sensitivity Tx Power @ 0dBm/ Tx Sensitivity	CC 1000 38.4 Kbps FSK 29 mW 42 mW	CC 2420 250 Kbps O-QPSK 38 mW 35 mW	TI CC 2420 250 Kbps O-QPSK 41.4 mW 35 mW	TI CC 2420/Zigbee 250 Kbps O-QPSK -9dBm -24 – 0 dBm	TI CC2420 250 Kbps O-QPSK -101dBm	TI CC 2420 250 Kbps O-QPSK -101dBm 3 dBm (typ)
Power Source Min Operating Volt Total Active Power	Battery 2AA 2.7 V 89 mW	Battery 2AA 1.8 V 32 mW	Battery 2AA 1.8 V 32 mW	Battery 3AA 2.8 V 86.8 mW	Battery 2AA 3.0 V	Battery 2AA 2.7 V
Programming & Sensor Interface Expansion Communication Integrated Sensor	51-pin IEEE 1284/ RS232 No	10-pin USB Yes	16-pin USB/RS232 Yes	100+-pin USB/RS232/ I C Yes	20-pin USB/RS232/ SPI Yes	51-pin USB/RS232 / I C/SPI Yes
Size	2.25x1.25x.25 (inches) 57.2x31.8x6.35 (mm)	2.58x1.26x.26 (inches) 65.5x32x6.6 (mm)	2.55x1.24x.24 (inches) 64.8x31.5x6.1 (mm)	1.4x1.87x.32 (inches) 35.6x47.5x8.12 (mm)	1.357x1.94 (inches) 34.47x49.26 (mm)	2.25x1.25x.25 (inches) 57.2x31.8x6.35 (mm)
Security	Elliptic Curve Cryptography	Encryption + Authentication	64 bit MAC address for UID, Elliptic Curve Cryptography	Elliptic Curve Cryptography	Public-key cryptography	Security is provided
Applications	Environmental Monitoring, vibration detection in bridges, monitoring the condition of machinery	Monitoring Applications, Rapid application prototyping	Low Power Research development, WSN Experimentation	Digital Image Processing, Industrial monitoring and Analysis, Seismic and Vibration monitoring	Developing new architecture for auto-configuration of the sensor network and its global connectivity to the Internet	Indoor building monitoring and security, Acoustic, Video, Vibration and other high speed sensor data

Table 1: WSN Motes Comparison Chart