Survey on Wireless Sensor Network Devices

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Abstract - **Wireless sensor networks are networks of compact microsensors with wireless communication capability. These small devices are relatively cheap with the potential to be disseminated in large quantities. Emerging applications of data gathering range from the environmental to the military. As autonomous devices they can provide pervasive distributed and collaborative network of computer nodes. Architectural challenges are posed for designers such as computational power, energy consumption, energy sources, communication channels and sensing capabilities. Embedded Systems provide the computational platform for hardware and software components to interact with the environment and other nodes. This survey presents the current state-of-the-art for wireless sensor nodes, investigating and analyzing these challenges. We discuss the characteristics and requirements for a sensor node mainly processing, communications, power and sensing components. In this survey we present a comprehensive comparative study of sensor nodes platforms, energy management techniques, off-the-shelf microcontrollers, battery types and radio devices.**

I.INTRODUCTION

Wireless sensor network (WSN) is a recent research topic. This network is composed of hundreds or thousand of autonomous and compact devices called sensor nodes. The availability of integrated low-power sensing devices, embedded processors, communication kits, and power equipment is enabling the design of sensor nodes.

Wireless Sensor Network has the potential for many applications: e.g. for military purpose, it can be use for monitoring, tracking and surveillance of borders; in industry for factory instrumentation; in a large metropolis to monitor traffic density and road conditions; in engineering to monitor buildings structures; in environment to monitor forest, oceans, precision agriculture, etc. Others applications include managing complex physical systems like airplane wings and complex ecosystems.

We 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. WSN can be seen as a special case of Embedded System and benefit from the large body of knowledge already present. To our knowledge, there is no comparative study of components off-the-shelf such as microcontrollers, battery types, and radio devices, which is very important for system design, and here a study is presented.

A sensor node is compost of a power unit, processing unit, sensing unit, and communication unit. The processing unit is responsible to collect and process signals captured from sensors and transmit them to the network. Sensors are devices that produce a measurable response to a change in a physical condition like temperature and pressure. The wireless communication channel provides a medium to transfer signals from sensors to exterior world or a computer network, and also a mechanism of communication to establish and maintenance of WSN, which is usually ad-hoc.

Power consumption is and will be the primary metric to design a sensor node. While there is the Moore's Law that predicts doubling the complexity of microelectronic chips every 18 months, and Gilder's Law, which theorizes a similar exponential growth in communication bandwidth, there is no equivalent forecast for battery technology.

II.CHARACTERISTICS AND REQUIREMENTS

In this section we discuss some characteristics and requirements of a sensor node.

- Energy-efficiency

Sensor node must be energy efficient. Sensor nodes have a limit amount of energy resource that determines their lifetime. Since it is unfeasible to recharge thousands of nodes, each node should be as energy efficient as possible. Hence, energy is the major resource, being the primary metric for analysis.

- Low-cost

Sensor node should be cheap. Since this network will have hundreds or thousands of sensor nodes, these devices should be low cost.

- Distributed sensing

Using a wireless sensor network, many more data can be collected compared to just one sensor. Even deploying a sensor with great line of sight, it could have obstructions. Thus, distributed sensing provides robustness to environmental obstacles.

- Wireless

The sensor node needs to be wireless. In many applications, the environment being monitored does not have installed infrastructure for communications. Thus, the nodes should use wireless communication channels. A node being wireless also enable to install a network by deploying nodes and can be used in many others studies for example liquid flow of materials.

- Multi-hop

A sensor node may not reach the base station. The solution is to communicate through multi-hop. Another advantage is that radio signal power is proportional to r4, where r is the distance of communication. Thus, depending on radio parameters as shown in [1], it can be more energy economic to transmit many short-distance messages than one-long distance message.

- Distributed processing

Each sensor node should be able to process local data, using filtering and data fusion algorithms to collect data from environment and aggregate this data, transforming it to information.

III.SENSOR NODE FUNCTIONAL COMPONENTS

Figure 1 presents the system architecture of a generic sensor node. It is composed of four major blocks: power supply, communication, processing unit and sensors. The power supply block consists of a battery and the dc-dc converter and has the purpose to power the node. The communication block consists of a wireless communication channel. Most of the platforms use short-range radio. Others solutions includes laser and infrared. The processing unit is composed of memory to store data and applications programs, a microcontroller and an Analog-to-Digital Converter to receive signal from the sensing block. This last block links the sensor node to the physical world and has a group of sensors and actuators that depends on the application of the wireless sensor network.

Figure 1 also illustrates some challenges for wireless sensor network. A power management layer is necessary to control the main resource of a sensor node, its energy level. The power management layer could use the knowledge of battery's voltage slope to adapt dynamically the system performance [12]. Another advantage is that other energy source can be added and the power management can make the best use of the energy resource. New network protocols are necessary, including link, network, transport, and application layers to solve problems like routing, addressing, clustering, synchronization and they have to be energy-efficient. A micro-kernel for sensor node is necessary. Many operating system exist for small device (like handheld and PDAs), but not as small as a sensor node. Algorithms for filtering and data fusion are also necessary. Many other challenges exist, including localization of sensor node and security issues.

The sensing unit is composed of a group of sensor, which are devices that produce an electrical response to a change in a physical condition. Many type of sensor exists, as for example magnetometer, accelerometer, light, temperature, pressure, humidity. The type of sensors being used in a sensor node will depend on the application, so this paper is not going to deeper exploration on this topic.

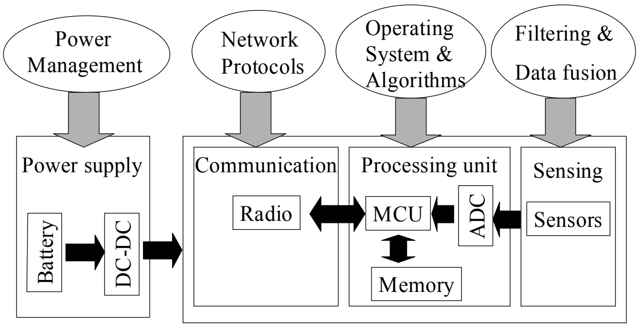

Fig. 1 Sensor node system architecture and challenges.

IV.PROCESSING UNIT

Since the sensor node is expected to communicate, to process and to gather sensor data, sensor nodes must have processing units. The central processing unit of a sensor node determines to a large degree both the energy consumption as well as the computational capabilities of a sensor node. Many different types of CPUs can be integrated into a sensor node and they are discussed in this paper. There are a large number of commercially available microcontrollers, microprocessors and field-programmable gate arrays (FPGAs), which allows a big flexibility for CPU implementations.

A.FPGA

Nowadays, FPGA presents two major disadvantages. Although there is at the market low-power FPGAs as for example CoolRunner-II CPLDs [10] which consumes as low as 14µA standby current, their consumption is not as low as a sensor nodes should be. For example, CoolRunner-II operating at 1.8V and 20MHz needs a current supply of 17.22 mA. Another disadvantage is that today is not possible to turn off separate blocks of a FPGAs. In addition to consuming more power, the FPGAs were not compatible with traditional programming methodologies (i.e. no C compiler). It does not mean that FPGAs are not a good solution for the near future. Maybe with the development of ultra-low power FPGAs, FPGAs will be a good solution for sensor node monitoring a planet, since they have the advantage of being reprogrammables and reconfigurables, eliminating the deployment cost as in spatial applications.

B.Microcontrollers

Nowadays, microcontroller includes not only memory and processor, but non-volatile memory and interfaces such as ADCs, UART, SPI, counters and timers. In this way, it can iterate with sensors and communication devices such as short-range radio to compose a sensor node. There are many types of microcontrollers, ranging from 4 to 32 bits, varying the number of timers, bits of ADC, power consumption, etc. TABLE 1 shows a comparison of actual microcontrollers.

EM6603 [13], which is 4-bit, is ultra-low-power but its computational power is also very limit. It is used for RFID applications. Although Atmel AVR microcontrollers are commonly used, there are better choices for sensor node. PIC from Microchip is used to educational purpose, but it is not applicable where energy is crucial. 8051 is available from anyone anywhere, but has low performance, being used only for historical reason. The advantages of DragonBall MC9328MX1 are that it is 16-bit and has a Bluetooth Accelerator radio interface. It also has a Time Processing Unit (TPU), a co-processor unit that seems to be able to perform various real-time control tasks (like sampling a pin). The shortcomings are performance (only 2.7 MIPS), no integrated memory or flash, relatively large footprint (TQFP 144, TQFP 100), not ultra-low-power.

Microcontroller MSP430F149 is a good option for sensor nodes since it is 16-bit 8 MIPS, providing more computational power, and also ultra-low power. It is equipped with a full set of analog and digital processors. It has embedded debugging and in-system flash programming through a standard JTAG interface, and is supported by a wide range of development tools including gcc [19] and IAR Embedded Workbench.

The ARM family has floating-point computational capabilities, being a possibility for devices demanding more computational power, such as a gateway or a robust sensor node, which can be the head of hierarchical wireless sensor network cluster. One common example is the processor module Intel StrongArm SA1100 embedded controller. The SA1100 is a general-purpose, 32-bit RISC microprocessor based on the ARM architecture that is rated the most efficient processor (in MIPS/Watt). The processor offers a 16KB instruction cache, an 8KB data cache, serial I/O and JTAG interface all combined in a single chip. Program and data storage are provided by 1MB SRAM and 4MB of bootable flash memory. Connection with the sensor modules is easily achieved using the 4-wire SPI interface. The processor has three states: normal, idle and sleep that can be controlled to reduce power consumption.

C.Low Power X Energy-Efficient

As pointed by Srivastava [14], it is important to differentiate low power from energy-efficient. Low power is a quality of a device that consumes low energy per clock and energy-efficient is a device that consumes low energy per instruction. For example, ATMega128L @ 4MHz consumes 16.5 mW and ARM Thumb @ 40 MHz consumes 75 mW. But, ATMega128L @ 4MHz efficiency is 242 MIPS/W, spending 4nJ/Instruction and ARM Thumb @ 40 MHz efficiency is 480 MIPS/W, spending only 2.1 nJ/Instruction.

Other examples taken from [14] are:

- 0.2 nJ/Instruction for Cygnal C8051F300 @ 32 KHz, 3.3V;
- 0.35 nJ/Instruction for IBM 405LP @ 152 MHz, 1.0V;
- 0.5 nJ/Instruction for Cygnal C8051F300 @ 25MHz, 3.3V;
- 0.8 nJ/Instruction for TMS320VC5510 @ 200 MHz, 1.5V;
- 1.1 nJ/Instruction for Xscale PXA250 @ 400 MHz, 1.3V;
- 1.3 nJ/Instruction for IBM 405LP @ 380 MHz, 1.8V;
- 1.9 nJ/Instruction for Xscale PXA250 @ 130 MHz, .85V.

Thus, the choice of MCU depends on application scenario. The ideal choice of microcontroller is the one that matches its performance level with application's need.

V.POWER

The power supply block consists of a battery and a dc-dc converter and has the purpose to power the node, since the sensor node needs energy to monitor the environment.

It might be possible to extend lifetime of a sensor node by extracting energy from the environment, as for example light, vibration, RF. Amirtharajah et al. [4] have demonstrated a MEMS system that extracts electric energy from vibrations. Nowadays, CMOS transistors and solar cells arrays can be co-fabricated. The Icarus process [3] combines solar cells, high voltage CMOS, and SOI (Silicon-on-insulator)-MEMS structures on the same die. With the addition of isolation trenches, devices and MEMS structures can be electrically isolated, and solar cells can be stacked to yield high voltages.

TABLE 2 [5] shows a comparison of energy sources. These sources are based on a combination of published studies, theory, and experiments.

A.Battery

Batteries supply power to the sensor node. It is important to choose the battery type since it can affect the design of sensor node. Battery Protection Circuit to avoid overcharge and/or over discharge problem, power voltage regulator and others components may be added to the sensor nodes.

There are many types of batteries being used in a variety of applications. Batteries can be divide into primary (non-rechargeable), and secondary (rechargeable). They also can be classified according to electrochemical material used for electrode such as NiCd, NiZn, AgZn, NiMh, and Lithium-Ion.

TABLE 3, based on [1] and [6], compares some batteries types. NiMh and Lithium-Ion are the most commercializing batteries.

The battery type will depend on the application. If there is not a harvest energy source, non-rechargeable battery is a good choice since non-rechargeable have higher energy density. Among the rechargeable batteries, Li-based battery would appear to be the best choice. However, there are a number of other considerations and the proper choice of battery technology is not obvious without a detailed examination of the application operational profile. For instance, in a pulse-discharge scenario, a Li battery would perform poorly while a NiCd would perform well due to the large differences in the internal resistance of these battery types. Furthermore, Li-based battery is high cost.

Among the rechargeable battery types, Nickel Metal Hydride (NiMH) is the only environmentally friend product. It energy density is only lower than Li-battery types and it can be recharged at any time without experiencing voltage depression (memory effect). The disadvantage is that it needs overcharge/over discharge protection.

B.Energy Management Techniques

There are two major power saving schemas, dynamic power management (DPM) [8] and dynamic voltage scheduling (DVS).

The basic idea behind DPM is to shutdown the devices when not needed and get them back when needed. Turning off some components gives good energy savings, but in many cases, it is not know beforehand when to turn on or off a particular device. A solution is a stochastic analysis to predict future events. An embedded operating system that is able to support DPM is also needed. For this approach, the microcontroller should have the states: active, sleep and idle. However, it is important to consider that transitioning between these operating modes involves a power and latency overhead.

The main idea behind DVS is to charge the power to match the workload, avoiding idle cycles. DVS reduces the power consumed by a processor by lowering its operating voltage. By varying the voltage along with the frequency, it is possible to obtain a quadratic reduction in power consumption. The problem is the fact that future workloads are non-deterministic. For this approach, the microcontroller should permit to change its voltage supply and clock. The choice has been StrongARM SA-1100 that can vary voltage and frequency from 59MHz/0.79V to 251 MHz/1.65V.

VI.COMMUNICATION

Sensor node must communication among them and some also to a base station using a wireless communication channel. We explore three possibilities, optical, infrared and radio frequency (RF).

A.Optical communication (laser)

The advantages of optical communications are:

- Spend less energy than radio;
- Security since there is no broadcast and if a channel is intercepted it would interrupt the signal;
- No need for antenna.

The disadvantages are:

- Needs line of sight ("LOS"), since the laser beam of the transmitting device must be line up to the optical receiver. It involves not only a temporal step but also a spatial acquisition step;
- Sensible to atmospheric conditions;
- The communication is directional and due to the fact that sensor nodes will be deployed, this is not an attractive solution.

B.Infrared

Infrared communication is usually directional. Since sensor nodes will be deployed, a good solution adopted by PushPin project [18] is to use a diffuser made of sandblasted polycarbonate tubing to create a more omnidirectional communication range within a plane. But, the node still needs to be aligning within the plane. PushPin project adopted IrDA transceiver 83F8851. Its disadvantage is short-range of 1m. The advantage of infrared is no need for antenna.

C.Radio-frequency (RF)

RF communication is based on electromagnetic waves. One of the most important challenges in RF communications devices is antenna size. To optimize transmission and reception, an antenna should be at least $\lambda/4$, where λ is the wavelength of the carrier frequency. Assuming a sensor node radio with a quarter of wavelength to be 1 mm, the RF carrier frequency would have to be 75 GHz, which is slightly out of the range of modern low power RF electronics. It is also necessary to reduce energy consumption with modulation, filtering, demodulation, etc. RF communication advantages are its ease of use, integrality, and well established in the commercial marketplace, which make it an ideal testing platform for sensor node.

Several aspects affect the power consumption of a radio, including the type of modulation, scheme used, data rate, transmit power. In general, radios can operate in four distinct modes of operation: transmit, receive, idle, and sleep. Most radios operating in idle mode results in high power consumption, almost equal to receive mode, thus, it is important to shutdown the radio.

C.1.Modulation

Here, we discuss three popular modulation schemes, OOK (On/Off key), ASK (Amplitude Shift Key), and FSK (Frequency Shift Key).

OOK is the special case of ASK modulation where no carrier is present during the transmission of a zero. OOK modulation is a very popular modulation used in control applications. This is part due to its simplicity and low implementation costs, OOK modulation has the advantage of allowing the transmitter to idle during the transmission of a zero, therefore conserving power. The disadvantage of OOK modulation arises in the presence of an undesired signal.

FSK modulation is commonly believed to perform better in the presence of interfering signals. However, it is usually more difficult and expensive to implement.

ASK modulation offers the advantage of being more immune to interfering signals than OOK and is easier to implement at a lower cost that FSK modulation.

Both OOK and ASK receivers require an adaptable threshold or an automatic gain control (AGC) in order to ensure an optimal threshold setting. The FSK modulation does not usually require this because it incorporates a limiter that keeps the signal envelope amplitude constant over the useful dynamic range [27].

C.2. Off-the-shelf radio components

RFM TR1000 is a hybrid radio transceiver [11] that is very well suited for wireless sensor network application: it has low power consumption and has small size. The TR1000 supports RF data transmission rates up to 115.2 kbps, and operates at 3 V. In the 115.2 kbps amplitude-shift keyed, the power consumption during receive is approx. 14.4 mW, during transmit 36 mW, and in sleep mode 15 μW. The transmitter output power is maximal 0.75 mW. This component has been used in most of sensor node platforms.

Chipcon's CC1000 is a very low power CMOS RF transceiver qualified for data rates up to 76.8 Kbit/s. It has an internal bit synchronizer that simplifies the design of a high-speed radio link with the microcontroller. The signal interface can also be configured for a UART serial bus interface taking benefit of the hardware UART in a microcontroller. In power-down mode, the CC1000 current consumption is 0.2 μA. The CC1000 is designed primarily for FSK systems in the ISM/SRD bands at 315, 433, 868 and 915 MHz. Its advantage over TR1000 is that it can easily be programmed for operation at other frequencies between 300 MHz and 1000 MHz.

The radio component depends on the frequency band of the application. If instead of frequency band between 300 and 1000 MHz, ISM (Industry, Scientific and Medical) spectrum is desired, a choice is LMX3162, which was adopted at μAMPS project. LMX3162 is a single Chip Radio Transceiver that is a monolithic, integrated radio transceiver optimized for use in ISM 2.45 GHz wireless systems.

Bluetooth is a standard that provides for the specification of small-form factors, low-cost, short range radio links [28]. The Bluetooth standard provides specifications for the radio link, baseband link, and the link manager protocol. The radio link specifies factors like the RF power, frequency spectrum, and modulation scheme Bluetooth devices are classified into 3 power classes.The first power class is designed for long range (~100m), with maximum output of 20 dBm and 100mW. The second class is for ordinary range devices (~10m), with 4dBm and 2.5 mW. The third power class is for short range devices (~10cm), with 0dBm and 1mW [30].

TABLE 4 compares Bluetooth devices with components already discussed. Bluetooth throughput is high for a sensor node, since it increases the sensor node complexity to receive data at this high speed, not being a good solution. Bluetooth can be a good solution for gateways or sensor nodes that need to transmit at high speed such as a video.

Another option is the solution adopted at WINS project [7], which uses a radio module Conexant Systems RDSSS9M Digital Cordless Telephone (DCT) chipset which implements a 900 MHz spread spectrum RF communications link. The chipset has an embedded 65C02 microcontroller that performs all control and monitoring functions required for direct sequence spread-spectrum communication (12 chirps/bit) as well as data exchange with the processor module. The radio operates on one of 40 channels in the ISM frequency band, selectable by the controller. The RF portion of the radio is capable of operating at multiple transmit power levels between 1 and 100 mW enabling the use of power-optimized communication algorithms.

C.3. Wake up Radio Challenge

An important challenge for the communication block unit is the design of a wakeup radio, a low-power radio that can receive very simple communication and in particular detect whether a communication with its own node is desired. In this case, it can power up the main radio that will then receive the actual communication. In PCs, external events such as keyboard presses or arrival of network packet result in the rest of the system waking up. However, in sensor nodes, this approach is not valid since it is highly desirable to turn off the radio because it is usually more power-consuming than the other components. Turning off the radio, unfortunately, means that a neighboring node that detected an interesting event cannot wake a node up. This can lead to miss events and packets, increasing latency and wasting of energy. Hence, a radio technological challenge is to have an ultra low-power communication channel to wake up neighboring nodes on demand. Currently, such wakeup radios are still an area of active research in chip design and communications research.

VII.CASE STUDY: SENSOR NODES

This section surveys the current state-of-the-art for sensor node platforms.

TABLE 5 shows some sensor node platform, their components, operating system and respective research group. The majority of components were already analysis in this paper.

At Berkeley, the Smart Dust project [26], which aims at the develop sensor node of milimetric size. Their focus is on miniaturization of sensor node so that it has a dust size. Since this is a long time project, the first step was the development of the Mote's family. The WeC Mote was one of the first types of sensor node developed in this project. Then, they upgrade to Mica Mote and finally to Mica2 Mote. The designer claims that the advantage of this last mote is its radio, which is more robust (CC1000) compare to TR1000. Another advantage is that it does not need a co-processor to reprogram the sensor node. The AT90LS8535 and ATMEGA 103L program did not allow reprogramming only a part of the memory, needing an extra processor to help reprogram the sensor node. Mote's family uses TinyOS [28], a compact and simple event-based operating system.

The PicoRadio project [24] at Berkeley Wireless Research Center is another project at Berkeley. The objective is to develop a low-cost and low-power sensor node. Its focus is at the radio hardware, link and network layer stack.

Medusa Mk-2 [21] and iBadge [22] are sensor nodes from UCLA. These sensor nodes use more than one processor and iBagde also includes a Bluetooth chip. These devices provide a good solution for gateway.

PushPin [18] is a sensor node that is part of a MIT project. Although main objective is for a paintable computer, Pushpin's requirements also meet the wireless sensor network needs. It used a different approach for communication, using infrared. Its operational system Bertha is interesting since it fits in 8051 and its purpose is for distributed system.

EYES [20] project is a European Research group. The first prototype of the EYES low-end sensor node has been designed and a small series has been produced. The processor used in this prototype is MSP-430F149, produced by Texas Instruments. A sensor node is also equipped with an auxiliary serial EEPROM memory of 8 Megabits (used for application and data storage). They are also developing an operating system for wireless sensor network.

µAMPS (micro-Adaptive Multi-Domain Power-Aware Sensors) project [17] and WINS [16] from Rockwell Science Center chose low power StrongARM (SA-1100) microprocessor for computation, using DVS as their main energy management techniques, which was explained before in this paper. µAMPS can program to change dynamically the voltage supply and clock frequency of the SA-1100 from 74 to 206 MHz and 0.85 to 1.44 V, respectively.

VIII. CONCLUSION

WSNs present fascinating challenges for the application of distributed signal processing and distributed control. These systems will challenge us to apply appropriate techniques to construct cheap processing units with sensing nodes considering energy constraints.

We presented a tutorial of the current state-of-the-art for wireless sensor nodes, investigating and analyzing some of the architectural challenges posed by these devices. A great variety of sensor nodes already exist, proving this is a recent and very interesting research topic. A survey of sensor node platforms and energy management techniques was discussed.

For future work, our goal is to design a complete low-cost, energy-efficient sensor node.

TABLE 1
MICROCONTROLLER COMPARISON

Characteristic	AT90LS8535	ATMega 103L	PIC16F8X	MSP430 F149	StrongARM SA-1100
Bits	8	8	8	16	32
Flash	8	128	68	60	
RAM	512B	4KB	1B	2048B	
ADC	10 bit	10 bit		12 bit	
Timers	3	3	1	3	
Operating Voltage	4-6V	2,7-3,6V	2-6V	1.8-3.6V	3-3.6V
Power Active	6.4 mA	5.5mA	2mA @5V, 4 MHz	400 uA @3V	230mW @133MHz
Power Idle Mode	1.9 mA	1,6mA		1,3uA	50mW@133MHz
Power-down Mode	<1uA	<1uA	<1uA	<0.1uA	Typical 25uA

Characteristic	Atmel AT91M 42800A	MC68HC 05PV8A	80C51RD+	EM6603	DragonBall MC9328 MX1
Bits	16/32	8	8	4	16
Flash			64kB		
RAM	8KB	192B	1024B	96x4B	128KB
ADC	0	8bit	0	0	13 bit
Timers	6	1	1	1	2
Operating Voltage	2.7-3.6 V	3.3-5.0 V	2.7- 5.5 V	1.2-3.6 V	1.62 to 3.3 V
Power Active		4.4mA	16mA @16MHz	1.8uA @32KHz	90mA @96MHz
Power Idle Mode		1.95mA	4mA @16MHz	0.35 uA	0.16 mW
Power-down Mode		485uA	50uA @16MHz	0.1uA	

TABLE 2
COMPARISON OF ENERGY SOURCES

Energetic source	Power Density
Solar (outdoors)	15mW/cm^2(direct sun)
	0.15mW/cm^2(cloudy day)
Solar (indoors)	0.006mW/cm^2(standard office desk)
	0.57mW/cm^2(< 60W desk lamp)
Vibrations	0,01-0,1mW/cm^3
Acoustic noise	3E-6mW/cm^2 a 75dB
	9,6-4mW/cm^2 a 100dB
Passive human-powered systems	1,8mW(shoe inserts)

Nuclear reaction	80mW/cm^3 1E6mWh/cm^3

TABLE 3
BATTERY TECHNOLOGY COMPARISON

Battery	Rechargeable?	Volumetric density(Wh/l)	Environmental or Health concerns
Alkaline-MnO2	No	347	
Silver Oxide	No	500	
Li/MnO2	No	550	
Zinc Air	No	1150	
Sealed Lead Acid	Yes	90	Yes
NiCd	Yes	80-105	Yes
NiMH	Yes	175	No
Li-ion	Yes	200	Yes
Li-Polymer	Yes	300-415	

TABLE 4
RADIO COMPONENTS

	TR1000	CC1000	LMX3162	Philstar PH2401
Modulation Type	OOK/ASK	FSK		GFSK
Carrier Frequency	916,5 MHz	300 to 1000 MHz	2.45GHz	2,4 GHz
Operating Voltage	3V	2.1 V to 3.6 V	3.0 –5.5 V	1.8 V
Current Transmit mode	12mA	16.5mAat 868MHz, 0dBm	50mA	<20mA
Current Receive Mode	3.8 mA @115.2 kbps 1.8 mA @ 2.4kbps	9.6 mA at 868MHz	27mA	<20mA
Throughput	OOK 30 kbps ASK 115.2 kbps	up to 76.8 kbit/s		1Mbit/s
Receiver Sensitivity	-97dBm @115.2 kbps	-110 dBm at 2.4 kBaud	-93dBm	-84dBm
Transmitter Power	0dBm	-20 to 10 dBm	-7.5dBm	+2dBm

TABLE 5
SENSOR NODE PLATFORMS

	µAMPS	WINS	Pico Node	PushPin	Eyes
Radio	LMX3162	Connexant's RDSSS9M	Proprietary	IrDA transceiver 83F8851	TR1000
Processor	StrongARM SA-1100	StrongARM SA-1100	DW8051	Cygnal C8051F016	MSP430F149
Operating system	RedHat eCos	µC/OS-II		Bertha	
Memory	512KB Flash	4MB Flash			8Mbit

	WeC Mote	Mica Mote	Mica2 Mote	Medusa MK-2	iBadge
Radio	TR1000	TR1000	CC1000	TR1000	TR1000 Bluetooth ROK101007
Processor	AT90LS8535	ATMEGA 103L	ATMEGA128L	ATMEGA128L AT91FR4081ARM THUMB	AtMEGA 103L TMS320 VC5416
Operating system		TinyOS	TinyOS		
Memory	32KB EEPROM	512KB Flash	4 Megabit Flash	1 MB Flash	

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