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SENSOR NODE AND ENERGY HARVESTING: A STUDY

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***Abstract*— WSNs have a wide range of potential applications, to science, industry, security, transportation, civil infrastructure, and provide a bridge between the real physical and virtual worlds. That's why conception of WSN nodes must accept most of challenges. To develop a wireless sensor node, a market research of different modules (existing microcontrollers, energy recovery chip, transceivers and sensors) is required. This task has a role in identifying the elements to be included in the new wireless sensor node on top of emerging new requirement. This paper presents existing motes and its hardware characteristics. As powering of these nodes is a bottleneck in wide deployment, we survey state-of-the-art technologies of energy harvesting.**

Keywords—WSN; Sensor node; Energy harvesting; Energy consumption .

I. INTRODUCTION :

A WSN is a network composed of a number of inexpensive miniature devices capable of computation, communication, sensing, actuation and power components named wireless sensor nodes. Those nodes communicate through wireless channels for information sharing and cooperative processing.

The principle of operation of the sensor nodes is the same but the technology used is different and depend on type of the application. Some applications were indicated in [1,2].

Such as the usual hardware components of a sensor node, we can mention radio transceiver, internal and external memories, an embedded processor, a power source and one or more sensors. In most application, the requirements put into the design are high integration, minimal cost, stable performance chip and minimal power consumption, that's why to design a WSN node, means to launch the following challenges: responsiveness, robustness, self-configuration, adaptation and essentially energy efficiency.

Talking about energy efficiency, a sensor node which exploited environmental energy to power its components and to function without human intervention was developed in [3].

Another sensor node design was described in [4] and showed an efficient structure in terms of power consumption and others performances.

In addition to hardware components of a WSN node, energy was consumed in transmitting and receiving data information. For this reason, the choice of the wireless communication module is very important, in [5] the module nRF2401 was used to meet two functional requirements: large amount of data communication and low-power operation.

The use of sensor nodes is not limited to a specified domain, another application with another hardware design of sensor nodes was discussed in [6] which come into view that in control and data acquisition (CODAC) in current and upcoming long discharges nuclear fusion experiments, an event and pulse node (EPN) is used to allow with its architecture the integration of the data acquisition task in the real time and an effective and low latency communication path.

In [7], a study to explain the designs and challenges of the third generation of the sensor nodes was interested in nodes power consumption.

Urban transport system can also exploit capabilities of WSN to ensure low cost, low power consumption, dynamic routing. This idea was more developed in [8] that proposed the use of ZigBee wireless sensor networks such an intelligent transportation system (ITS) solution.

As a cheapest and most power efficient, a sensor node was developed in [9] which described a convenient architecture of this node used in wearable computing research.

Another example of environment monitoring system is showed in [10]. In this application, low power consumption hardware was chosen after hardware comparison of WSN nodes.

II. SENSOR NODES :

Such is mentioned in fig.1 generally a sensor node is composed of four main units [11]:

- Processor unit: regroups the microprocessor and memory unit (storage). This part is responsible for data collection, processing and receiving with other modules;
- Sensor unit: it is a compound module which includes sensors and A/D converter. The type of sensors depends on its application because it should adapt to the requirements of environment;
- Communication unit: controlling communication between sensor nodes, exchange of control information, sending and receiving data collection are the main functions realized by wireless communication module ;

- Power unit: the quality of communication can be directly affected by power supply unit that's why it's not only the base of energy.

Some nodes can include Location Finding System such: GPS (developed by US Defense Department); GLONASS (managed by the Space Forces of the Russian Federation); IRNSS (Indian positioning system by satellites); Beidou (Chinese navigation and positioning system by satellites) and Galileo (European positioning system by satellite project).

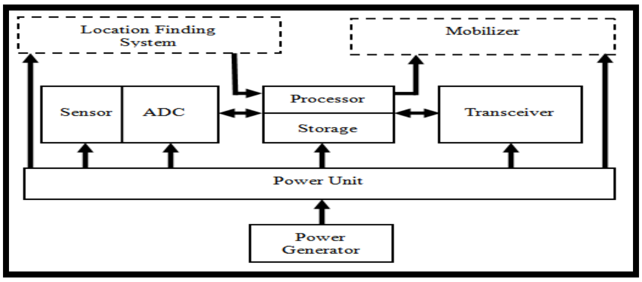

Figure 1: General structure of WSN node

There are many commercial motes such as Mica2, Micaz, TelosB, TmoteSky, SHIMMER, IRIS, SunSpot, etc as shown in fig. 2. The main characteristics of those platforms are summarized in table 1, table 2 and table 3[12-20].

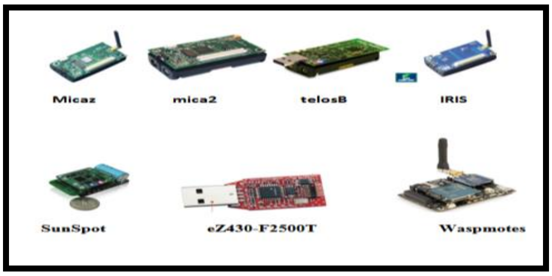

Figure 2: Commercial motes

Table 1: Manufacturing Specifications

Motes	Year	Manufacturer	Radiochip	Battery
MICAZ/ MICA2	2004/2005	Crossbow	Chipcon CC2420/ CC1000 /CC2410	2XAA
TelosB	2005	Crossbow	CC2420	2XAA
SunSpot	2005	Sun	Chipcon CC2420	750mAh Li-Ion
SHIMMER	2006	Intel	Chipcon CC2420	250mAh Li-Ion
IRIS	2007	Crossbow	ATRF230	2XAA
eZ430-F2500T	2007	Texas Instruments	Chipcon CC2500	2XAAA
Waspmotes	2013	Libelium	XBee 802.15.4	1150mAh Li-Ion

Crossbow 3 is one of the only companies which have produced several generations of platforms sensors: MICA platforms in the first generation, MICA2 / MICAZ / IRIS platforms in the second generation and IMOTE2 the platform in the third generation.
It can be seen from Table 1 that the chip CC2420 radio is frequently used in the platforms of the different motes thanks to having a low cost and being highly integrated radio transceiver for wireless communication in the 2.4GHz band. The use of this chip is the most adequate for low power and low voltage wireless applications because it is compatible with ZigBee/IEEE-802.15.4.

Table 2: Characteristics of the memory capacities

Motes	Controller	Freq (MHz)	Bus size (Bits)	FLASH (Bytes)	RAM (Bytes)	EEPROM (Bytes)
MICAZ/ MICA2	AT Atmega 128L	16	8	128K	4K	512K
TelosB	TI MSP 430F1611	8	16	48K	10K	1M
SunSpot	AT ATmega 91RM9200	180	32	4M	512K	No support
SHIMMER	TI MSP 430F1611	8	16	48K	10K	No support
IRIS	AT Atmega 128L	16	8	640K	8K	4K
eZ430-F2500T	TI MSP 430F2274	16	16	32K	1K	No support
Waspmote	AT Atmega 128L	16	16	128K	8K	4K

MICAZ motes uses the same radio chip that TelosB but a different microcontroller which reduces the program memory.

ATMEGA128L is less efficient than MSP430 at the level of consumption, the resolution of the A / D converter and the response time. Data acquisition is accomplished on eight channels and each channel includes a 12-bit AD converter circuit.

The MSP 430 and TelosB mote are frequently chosen but this does not mean that TelosB hasn't drawbacks such as absence of RF amplifier and low operating frequency.

Some energy characteristics which are operating voltage, current and power consumption of each mode are summarized in table3.

Motes using the CC2420 are the most efficient since this radio chip can operate on eight different transmission power levels. Taking into account the 4 modes, we can notice that TelosB is the best.

After this comparison, we can understand the frequent use of TelosB motes. That's thanks to four main points:

- Energy consumption;
- Bandwidth;
- Memory size;
- Calculation capacities.

Table 3: Operating voltage, Current and Power Consumption of motes

Motes	Operating voltage(V)	Active mode		Sleep		Receiving		Transmitting		Power Consumption Sleep/idle/power Down
		Current (mA)	Power Consumption (mW)	Current (µA)	Power Consumption (µW)	Current (mA)	Power Consumption (mW)	Current (mA)	Power Consumption (mW)	
MICAZ/ MICA2	2.7 to 3.3	8	33	15	30	18.8	56.4	17.4(0dBm)	52.2	1.28mW
TelosB	1.8 to 3.6	1.8	3	5.1	2	19.7	56.4	17.4(0dBm)	52.2	1.28mW
SunSpot	5(±10%)	25	92.5	500	1850	18.8	56.4	17.4(0dBm)	52.2	1.28mW
SHIMMER	1.8 to 3.6	1.8	5.94	5.1	16.83	18.8	56.4	17.4(0dBm)	52.2	1.28mW
IRIS	2.7 to 3.3	8	21.6	8	21.6	16	48	17(3dBm)	51	60nW
eZ430-F2500T	1.6 to 3.6	0.270	0.594	0.7/0.1 (stand by/off)	1.54/0.22 (stand by/off)	21.2	38.16	16.6(0dBm)	29.88	4.5mW
Waspmotes	2.7 to 3.3	8	21.6	8	21.6	50	148.5	45(0dBm)	165	33µW

III. OTHER DESIGNED MOTES :

ZHENG et al. [21] chose to use in the processing module the enhanced version of the industry standard microcontroller 8051 core included in the CC 2431 chip . The combination of the industry-standard enhanced 8051 MCU with the loading CC2420 RF transceiver [22] makes the use of CC2431 in the wireless communication module possible through its characteristics cited in [23]. As a sensor module, a digital temperature sensor DS18B20 [24] is exploited. The challenge made by this design was to eliminate the effect of sources of interference, for example, the variation of high frequency signal was eliminated using a filter circuit. Tests done by ZHANG et al. show that desired results have been well achieved: good communication and anti-jamming capabilities.

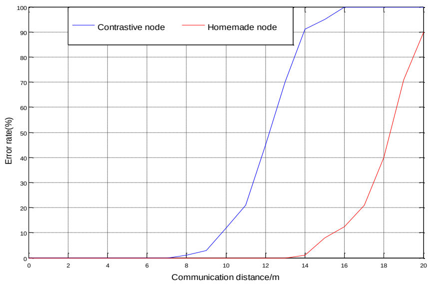

Figure 3: Curve of error rate Contrast with distance

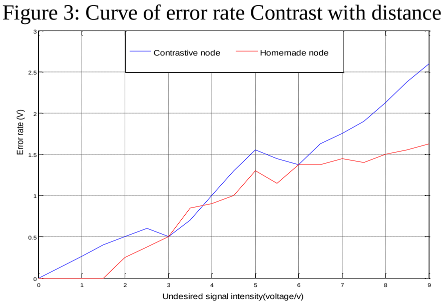

Figure 4: Error rate varying with Noise level

Another field of use of WSNs was developed by Xiong et al. [25]. The objective of the idea was to solve the problems of existing online monitoring systems where wiring is too complicated. In this case sensor nodes used for online monitoring of large electrical equipment is composed of the CC2431, thanks to its powerful functions, four types of sensors(UV sensors, ultrasonic sensor, temperature sensor and humidity sensor) and a chip AT45DB041[26] which represent the Flash ROM memory. Low power consumption is one of the points respected by this design that’s why a chip MAX 2323 is exploited such the serial interface circuit [27].

Zieliński et al. [28] developed another application of WSNs: Active Vibration Control (AVC) [29]. They tried to replace a large centralized system (wire) with small low power nodes. Tow printed circuit boards (PCB) constituted the real prototype. The first contains a low power microcontroller PIC16LF88 and a power supply circuit, the second was composed of serial switching over the inductance (serial SSHI) circuit, a detection circuit and wireless communication using MRF24J40[30]. Thanks to being compatible with the Arduino architecture, the device can be easily used with different microcontrollers.

According to Zieliński et al. this design may improve AVC within the scope of costs and energy consumption. The particularity of those nodes is the use of piezoelectric element such a source of harvesting energy.

A wireless sensor node based on a new hybrid chemical sensor was developed by Cai el al. for monitoring heavy metal [31]. The technique is very adapted for the monitoring and forecasting of pollution of heavy metals.

According to Cai et al. the specific requirement of the wireless sensor node power consumption impose the choice of ultra-low-power microcontroller MSP430FG4619 [32].

A hybrid chemical sensor, that accomplish the transformation of $Zn^{2+}, Pb^{2+}, Cu^{2+}$ and H^{+} concentrations in water environment into electric signal, was included in the transducer unit with another sensing circuit that receives the analog input and gives the digital output. The communication unit used a RF transceiver. Six microelectrode arrays (MEA) and four Light addressable potentiometric sensors (LAPS) were combined on the same silicon chip to constitute the hybrid chemical sensor.

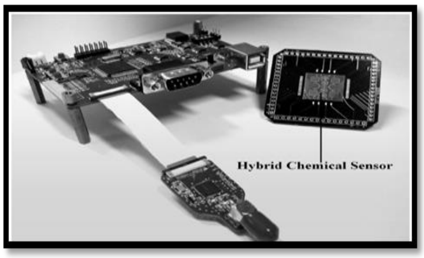

Figure 5: Prototype of the wireless sensor node

In the same theme of low power consumption, Gajjar el al.[12] created an Ultra-low Power Mote (ULPM). The hardware block is mainly composed by TI MSP430F5132 microcontroller as processing element, TI CC2500 as transceiver and HTU21D sensor for relative humidity and temperature measurements from Measurement Specialties.

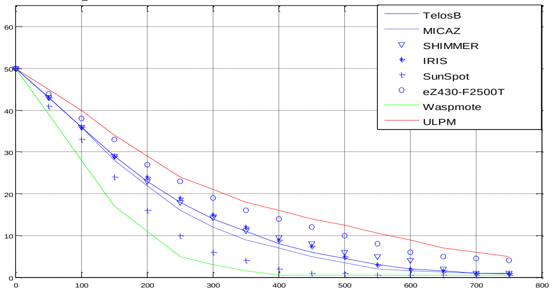

Figure 6: Total residual energy of the network over rounds

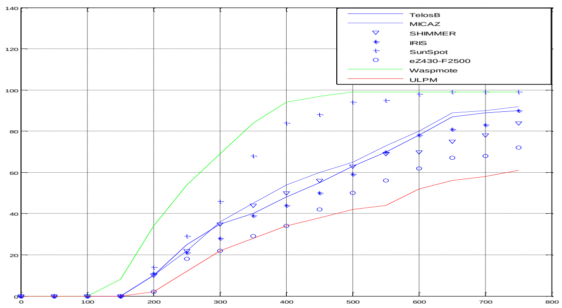

Figure 7: Number of nodes dead over rounds

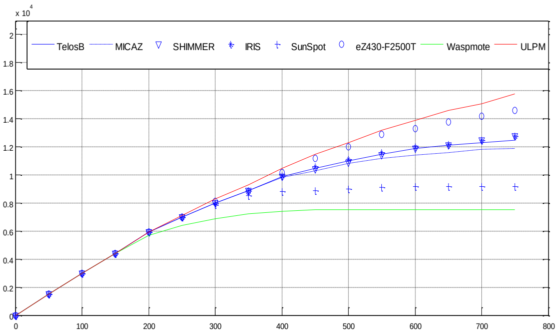

Figure 8: Total amount of data received at the BS over round

Comparing results of using ULPM and seven other motes shows that ULPM shows best performance in terms of network lifetime, data transmitted to BS and energy consumption of the network.

WSNs are frequently used in environmental monitoring application (EMA). According to Manuel et al. [33], in this case, the TelosB motes are used thanks to many caracteristiques such as program memory, consumption, AD converter resolution and timer response. In the same theme, according to Ahmad H et al.[34] WSNs are the best solution of problem of monitoring over extended areas (pollution monitoring, emergency response during catastrophic events or environmental monitoring) in terms of hardware costs and deployment costs. In this application, the Libelium Waspmotes was chosen with some modifications such solar panels performance to exploit sunlight available in arid, desert environments and memory devices to have more advanced computational capabilities.

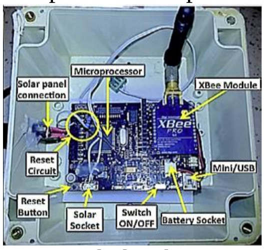

Figure 9: deployed Waspmotes Sensor node

Figure 10: Modified mote

Another node used to monitor environmental parameters is designed by Ruqiang Yan et al. [35]. In this application, Ruqiang et al. put into consideration many performances. That's why they chose the MSP430F149 as a microcontroller having the capability of ultralow power consumption and short waking-up time (less than 6 µs).

The MSP430F149 can work with five low power modes to achieve extended battery. As a source of supply voltage (3.3V) of the sensor node, the AMS1117-3.3 voltage regulator is chosen with low intrinsic consumption current from two 3.7V (2400mAh) lithium batteries. The communication module is based on the chip CC1101.

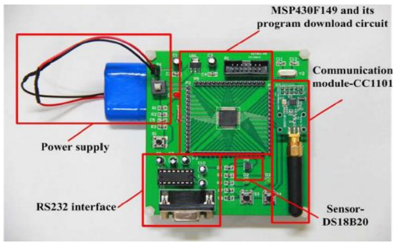

Figure 11: Sensor node developed for Temperature monitoring

A common focus has driven research on WSNs. It is Energy efficiency. Nodes of a WSN are typically equipped with batteries. The depletion of their energy means the death of the node. The replacement or recharge operation has a negative influence on WSN performances. Therefore, it is necessary to extract energy from the surrounding environment.

IV. TYPES OF ENERGY HARVESTING :

Three phases can describe the processes realized by EH circuit: capture, accumulation and storage of unexploited energy for surrounding environmental sources such mentioned in fig.12. The EH circuit should consume smaller power than the energy provided by the ambient sources. This type of circuit is used for applications that needs continuous supply of low power or the applications that need high power for a small duration of time. The energy can be derived from solar, thermal, vibration or RF sources.

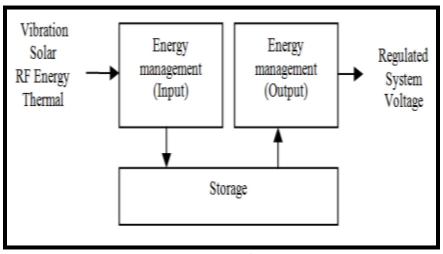

Figure 12: general description of energy harvesting circuit

A. Mechanical vibration:

This type of power scavenging is based on the principle that if an inertial mass is subjected to some movement electrical energy can be generated using three mechanisms:

- Piezoelectric: in this case mechanical (pressure, vibration) energy would be converted into electricity. An example of application is described by Joseph Sankman et al.[36,37]
- Electrostatic: in this type, mechanical energy is exploited to generate electrical energy by using vibration to separate planes of initially charged varactors (variable capacitor). One dedicated voltage sources is required for this type of energy generation to charge the capacitors initially.
- Electromagnetic: being free of the effects of mechanical damping makes electromagnetic induction a useful method of energy harvesting for which Permanent magnets, coils and resonating cantilever beam are utilized. Its large size prevents integration of this type of energy harvester with WSN nodes but it is possible in some cases [38].

B. Solar:

Solar or photovoltaic cell is used in this technique. Its principle is that optical energy mainly from sunlight is converted into electrical energy. A large number of photons is absorbed using photovoltaic materials.

A solar energy harvesting system can be decomposed as shown in fig.13.

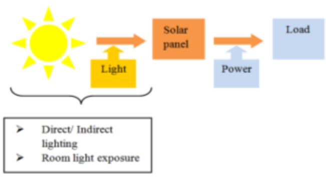

Figure 13: general structure of solar energy harvesting system

The output of solar cell which has conversion efficiency up to 30% depends on the sunlight as well as on the load attached to it. In other words, if the number of photons is enough to activate the electronic optical cool, it is possible to obtain electricity through appropriate structural design. We can cite solar cells and solar panel. Another example of a time slotted solar energy harvesting node which use six different statistical models is described in [39].

Hence it is best suited for applications that have ample exposure to sun (outdoor environment). But it doesn't mean that this type of energy harvesting is not available for indoor application [40]. The use of solar energy harvester is detailed in [41, 42].

C. RF Enery Harvesting:

Two ways are possible:

- Active EH by using a dedicated energy transmitter or passive energy using the ambient sources of energy present in environment such as propagating radio waves or sun light.
- Energy from RF commercial broadcasting stations like TV or radio are used to supply energy to WSN. The main element of Energy harvester circuit in this case is the rectenna (rectifier + antenna)[43]. The antenna is connected to a tuner stage which selects one out of the possible commercial broadcasting channels. The output of antenna is the usable DC power. This DC power is stored in an energy storage device before being delivered to a load.

D. Thermoelectric:

The generation of electricity using a temperature gradient is referred to as thermoelectricity. A temperature difference between two junctions of a conducting material creates a potential difference which is used by thermoelectric generators (TEG).

In general, the TEG is formed by a junction of two dissimilar materials: an n-type (negatively charged) and p-type (positively charged) semiconductors as shown in fig.14 [44]. Thermoelectric devices can generate electric energy when a temperature gradient exists across the device [45].

Connecting many junctions electrically in series and thermally in parallel makes large voltage outputs possible. Typical performance is 100-200μV/K per junction. To capture mW.s of energy from industrial equipment structures and even the human body, TEG can be utilized. They are typically coupled with heat sinks to improve temperature gradient.

As each type of energy harvesting, thermoelectric circuits have advantages like absence of materials that mast be replenished, continuous operation for many years. However, we find also downsides which are low efficiency and high costs.

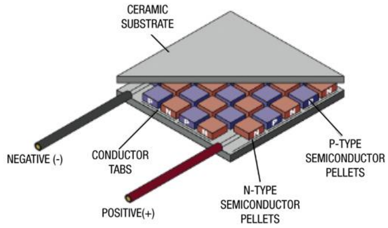

Figure 14: Thermoelectric generator module construction

V. CONCLUSION :

In this paper, we tried to study various examples of using WSNs, challenges of sensor nodes conception and some energy harvesting sources in addition to network support for low-energy design. It was noted that the minimum energy consumption is an important challenge in every design. We have an interest in hardware architecture to know the components that can influence energy efficiency in processing tasks and also in wireless communication. This is achieved either by the low power modes, or by specific communication protocols. We are aiming to develop that point in more details.

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