Method for WSN node current measurement and energy budget calculation

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***Abstract*—In the designing of Wireless Sensors Networks, one of the key aspects is the energy consumption of each individual node that composes it. Instead of which kind of energy source would be used in the network deployment, the characterization of the power consumption in each mode of operation should be made for determine the autonomy of each individual node, allowing the appliance of a diversity of techniques and strategies for increasing the entire network reliability. This paper explains the description of a method that allows the measuring of the sensor node current consumption, for the later calculation of the power consumption and energy budget that the node requires for its normal operation.**

Keywords—WSN; sensor node; current measurement; power budget; energy consumption.

I. INTRODUCTION

A WSN (wireless sensor network) is a collection of low-powered, physically tiny devices, called sensor nodes, which are capable of sensing the physical environment, collecting and processing sensed data[1]. There are a lot of applications in which those networks have been deployed, like in smart cities [2], [3], early warning systems[4], [5], industry processes monitoring [6], among others. The basic element in those networks is the sensor node, which have the task to monitor the variables of interest and to communicate the data acquired to a “sink” node [7], which have the task to communicate all the information to remote servers for their respective analysis and report generating.

One important feature of those networks is their autonomy, referring to the ability of the nodes to operate with their own power source for a long period of time. In the designing process of the node, therefore, the power consumption is a key aspect, looking for a long autonomy without the needing of big primary or secondary battery unit to power the node[8], [9].

It could be found some proposed and implemented strategies to achieve larger autonomy in deployed WSN, such as energy consumption models[10], [11], design oriented strategies [12], [13], or combining secondary batteries with energy harvesting techniques [14], [15]. No matter which strategy is used, a first approach of the power consumption of the node should be made for the right dimensioning of the node software-hardware architecture, given that the reliability of the network is directly dependant of the autonomy of the nodes. To accomplish this, a simple power budget could be made in order to forecast the WSN behaviour related to the availability of the nodes.

Adding the power of each individual element composing the electronic components is a typical method for estimating the energy required for the normal operation of the node. But the different modes of operation in the node leads to the practical issue of measure how much power the node drains in each one of those modes and how much time it takes, for which could be used some current measurement techniques. This is important due the dynamic behaviour of the current drained from the battery in a WSN node and this could affect the practical autonomy once is deployed the network.

For the method described, an analog current to voltage conversion is carried out with the purpose of measure the peak current and period of time for each working mode of a testing WSN node. Is achieved a power budget with the data obtained with the experimental setup described.

II. NODE ARQUITECTURE

A typical wireless sensor network is composed of a set of distributed and scalable sensor nodes, characterized by having low power consuming and low cost, making these particular networks attractive for different applications where must be monitored a physical phenomenon in a wide area. Due to its versatility, WSN can be used in unattended applications such as agriculture, environment or industrial process control.

Traditional sensors networks architecture could be distinguished as a centralized repository, where the sensors nodes are passive units that send data to the central server. Applications subsequently execute over this server, operating over the data stored there[16].

A sensor node typically comprises four parts: one or more sensors, a microcontroller, a wireless transceiver, and a power source. [17]. Fig. 1 shows a simplified components scheme of a sensor node.

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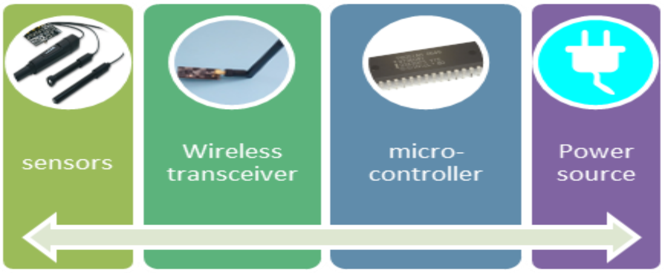


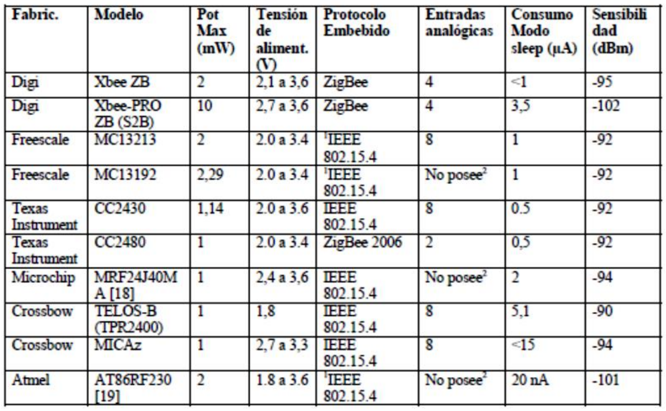
Fig.1. Sensor node structure [18].

The sensors are passive units programmed for sensing different variables (temperature, gas, humidity, etc.) and sending them for processing. A microcontroller processes and prepares the packets to be transmitted using some wireless standard (like IEEE 802.15.4) to a central server. Those sensor nodes are mainly battery powered, thus having restricted amounts of energy.[19].

An important parameter for the development of a sensor network is the optimization of the energy consumption of the nodes, usually stored in batteries. It is also important to bear in mind that those are rechargeable batteries (also known as secondary batteries), which leads to an energy behaviour of the node linked to the particularities of the charge-discharge ratio related to the particular chemistry (Ni, Lead-Acid, Li, etc.). The stored energy in the chosen battery must lead a long lasting performance of the node, enabling it to have energy available for all the programmed state functions, given that an absence of a single node could provoke a WSN malfunction.

The nodes of Wireless Sensors Networks usually have a states-based working scheme. The node passes through several states periodically, usually a state to sense, another state to transmit (both can be encompassed in an awakened macro state) and another state known as sleep. The consumption in each state is different, having their maximum energy consumption in the wireless communication modes, and minimum in sleep mode[20], [21].

Table 1. Some platforms available for their use in WSN networks.



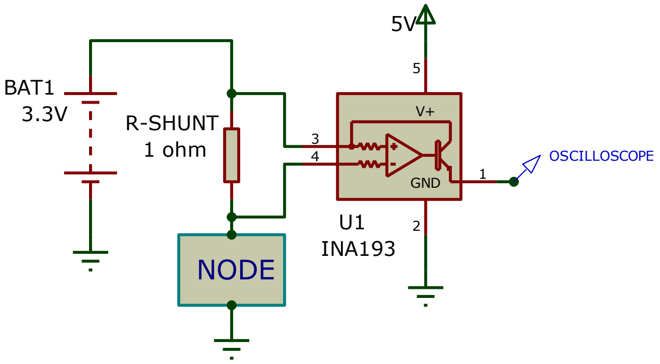
Fabric.	Modelo	Pot Max (mW)	Tensión de aliment. (V)	Protocolo Embebido	Entradas analógicas	Consumo Modo sleep (µA)	Sensibilidad (dBm)
Digi	Xbee ZB	2	2,1 a 3,6	ZigBee	4	<1	-95
Digi	Xbee-PRO ZB (S2B)	10	2,7 a 3,6	ZigBee	4	3,5	-102
Freescale	MC13213	2	2.0 a 3.4	[1]IEEE 802.15.4	8	1	-92
Freescale	MC13192	2,29	2.0 a 3.4	[1]IEEE 802.15.4	No posee[2]	1	-92
Texas Instrument	CC2430	1,14	2.0 a 3.6	IEEE 802.15.4	8	0.5	-92
Texas Instrument	CC2480	1	2.0 a 3.4	ZigBee 2006	2	0,5	-92
Microchip	MRF24J40MA [18]	1	2,4 a 3,6	IEEE 802.15.4	No posee[2]	2	-94
Crossbow	TELOS-B (TPR2400)	1	1,8	IEEE 802.15.4	8	5,1	-90
Crossbow	MICAz	1	2,7 a 3,3	IEEE 802.15.4	8	<15	-94
Atmel	AT86RF230 [19]	2	1.8 a 3.6	[1]IEEE 802.15.4	No posee[2]	20 nA	-101

Table 1[22] shows data on the consumption of some sensor nodes available in the market, taking into account the minimum consumption status of each node.

III. EXPERIMENTAL SETUP

The key aspect of the procedure explained below is the choice of a suitable current consumption measurement method in a node selected for testing, considering that the waveform of each operational states of the node must be visualized in an oscilloscope, which can only measure voltage waves. Therefore, a current to voltage conversion must be carried out. Some techniques for current measurement could be implemented [23], [24], however, the typical peak current consumption of a WSN node is above tens or some hundreds of mA [22], [25], allowing the choice of integrated circuits known as *current gauge* or *current monitor*. Those IC's have an internal circuitry that takes the differential voltage in the terminals of an external shunt resistor (through which flows the current to be measured), making some signal conditioning and amplification for having a linear and low-noise voltage signal at the output terminal. The choice made for the experimental setup is depicted in the fig. 2.

Fig.: 2. Experimental setup for node current consumption measurement



In the above circuit, to power the node is used a 3.3 V_{DC} source, and the current that flows out from this source first goes thru a 1Ω resistor before entering the node. This resistor, label R_{SHUNT} in the fig. 2, creates a differential voltage between its terminals, which are connected to the INA193 input pins[26], performing this way a current to voltage conversion corresponding to the equations (1) and (2),

$$V_{OUT} = 20 \text{ x } V_{SENSE} \qquad (1)$$

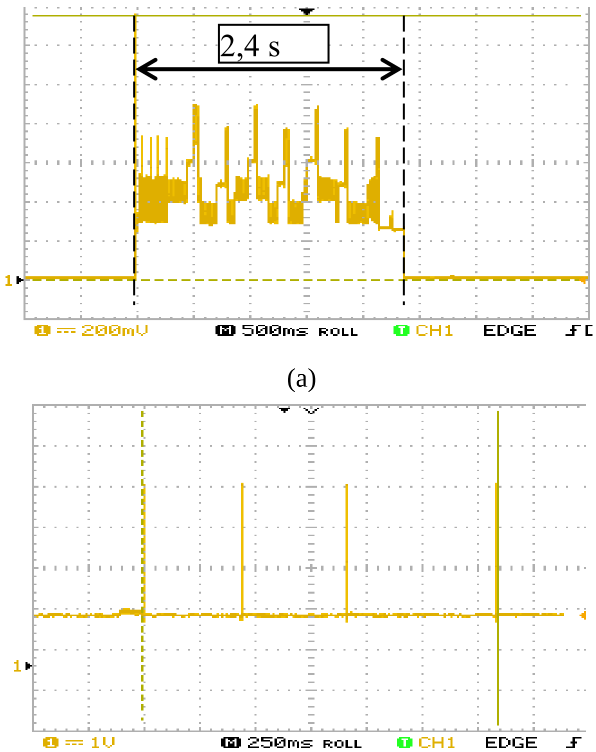
$$V_{SENSE} = I_{R\text{-}SHUNT} \text{ X } R_{SHUNT} \qquad (2)$$

In Fig.2 the 20 V/V gain (20V output per 1V differential input between input pins 3 and 4) allows an easy way to calculate the current thru the R_{SHUNT} of 1Ω just dividing the values measured in the oscilloscope by 20. The INA193 IC is powered with a 5V source with the purpose of having a maximum measurement of 250mA, assuming this value as the higher current consumption of the node. For other current measurement ranges, it could be changed the R_{SHUNT} or the power source of the INA193 IC, having in mind that the maximum current to be measured by the gain of the IC should not be higher than the polarization voltage used in it.

After the development of the circuit depicted in the fig.2, it is necessary to choose the testing frame to be transmitted by a testing node. For this, a worst-case scenario was choice, because of any other situation should have less power consumption than this one, giving the node some operating margin. The wireless testing frame that will be explained in the remaining (worst case mentioned above) was assumed to be the network discovery routine which consists of 3 or 4 communication routines, each one of them composed of a send, receive, and analyze sequences, instead of the single transmission developed in a normal sensing task of the node. Other criteria used for the described measurements, is that the working cycle of each node in the network is composed of a sensing routine each 30 minutes, and between them a sleep mode is programmed in the node.

IV. MEASUREMENTS

After the described setup, the measurements are ready to be made. For that, proper configuration of the oscilloscope must be carried out in order to have a complete view of the waveform, at least for one of the idle and communication operational states of the testing node. The sleep mode current could be measured with an ammeter, and adding it to the power budget, taking into account that the operation time of the node is deterministic as mentioned above.



(a)

(b)

Fig 3. Oscilloscope images of the current consumption in the testing node: (a) Between sleep modes, (b) zoomed view of a starting sequence frames.

In the fig. 3, the waveform of the testing node is depicted. In fig. 3 (b) it could be seen 4 pulses of current for the testing node in the communication routine, each one of them representing a single frame composed of a wireless send and receive frame. The time between those pulses are waiting pauses for acknowledge response, that are part of the idle state in the power budget. For the measurements, each one of those pulses had 4,4 V peak, corresponding to a current of 220mA according with the V/V conversion made by the IC explained before. It could be seen the current for the idle operation mode of the testing node between those pulses, that includes all subsystems involved like microcontrollers, sensors, power control sub-circuits, among others. With the same conversion ratio between voltage and current of the circuit depicted in fig. 2, the current measured for the idle mode is 58 mA.

Complementary to the above, a single frame measurement must be carried out. It means that each one of the pulses depicted in the fig. 3 (b) should be zoomed out for better measurements of the time required for each frame to be transmitted. It's depicted in the Fig. 4 the measurements of a single frame pulse.

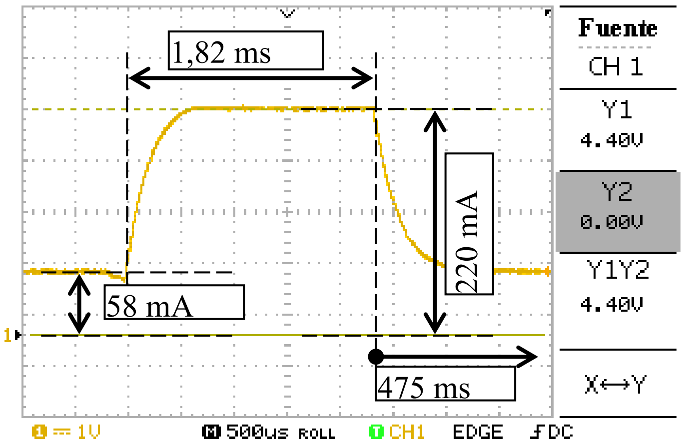


Fig. 4. Oscilloscope image of detailed current values in a single frame pulse of the testing node.

Notice that even when a peak amplitude of the signal is 4,4 V, the real value corresponds to a current of 220 mA given the gain of the INA193. Additionally, when zooming a single frame of the fig. 3(b), the oscilloscope resolution only allows the view of a single square pulse containing all the frame details explained in the above paragraphs. The 475ms in the lower side of the fig. 4 represents the time until the next pulse.

V. THE POWER BUDGET

Once the current amplitude has been measured, the next step is to estimate the period of each operational mode. That is, how much time takes the sleep, idle, and communication times in the node. For the sleep mode, it could be taken the period of time established between sensing – transmission routines. The idle and communication period times have to be measured between consecutive sleep modes directly with the oscilloscope as shown in the fig. 3(b).

Having the time and current amplitude of each operational states measured in the testing node, the power consumption calculations could be made. For this, a simple equation in which the energy is a product of power and time is used.

$$E_{[J]} = P_{[W]} \cdot t_{[s]} \quad (3)$$

The power is calculated then as the current by voltage product, assuming that the voltage in the node have a constant value of 3.3 V_{DC}. Are summarized in the next table the results of the above calculations, using a sleep period of 30 minutes between sensing and communication routines.

Table 2 power budget for the testing node

Working mode	**Current (mA)**	**Power (mW)**	**Time (s)**	**Energy (mJ)**
Sleep	0,055	0,165	1800	297
idle	58	191,4	2,57	492
Communication	220	726	0,00728	5,2
			Total	794,2

Notice that the communication mode time in the table 2 correspond to 4 pulses as measured in fig. 3(b). The sleep current consumption was measured with a digital ammeter, because of the length of time that it takes.

CONCLUSION

The method of using a voltage to current conversion by using a shunt resistor is suitable for estimating the power consumption of a WSN node, allowing more accurate measuring with the data acquired. After all the above process, the power consumption of the node could be used to estimate the autonomy of it, leading to a better design of the power source to be used. Moreover, if some energy harvesting/ scavenging will be involved in the design process of the node, is it possible to have a better approach of the autonomy, using the energy produced for the alternative source selected to supply the energy required by a number of sensing routines.

From the table 2, it could be seen that even though the highest power consumption corresponds to the communication operational mode, the percentage of time for this is negligible when compared with the idle time. It is noteworthy that in the node power consumption profile, the energy required for the communication routines is not an important element in the power budget (only a 0,65% of the total energy, and 1,05% vs. the idle energy), due the short time that it requires in comparison of the idle state as shown in the table 2. Instead of that, a better strategy is to reduce as much as possible the consumption of the electronics that composes the node itself, reducing this way the energy of the idle state. It could be made choosing the lowest current consumption components, implementing analog switches to "turn off" certain sections of the node, using more efficient power IC's, among others. Furthermore, the results of the power budget measurement method described could lead to a better WSN network routing strategy implemented for energy saving purposes.

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