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WSN Nodes: Design Considerations and Energy Management

V.Boitier^{1,2}, P.Tajan¹, and J.M.Dilhac^{1,3}

¹ CNRS, LAAS, 7 Ave du colonel Roche, F-31400 Toulouse, France

² Univ de Toulouse, UPS, LAAS, ³ Univ de Toulouse, INSA, LAAS

E-mail: vboitier@laas.fr, dilhac@laas.fr

Abstract. This paper details some practical considerations about the implementation of low power WSN, with a focus on energy consumption.

1. Introduction

Wireless Sensors Networks (WSN) are necessarily autonomous in energy, particularity that involves the knowledge and control of the energy consumption.

Some aspects related to energy are largely developed in scientific literature, such as reconfigurable interconnections between nodes or on line modifications within the node to adapt functionalities depending on the available energy [1, 2]. Another point is related to Harvesting or Scavenging Systems devoted to power battery-free WSN nodes [3, 4, 5]. However, few papers [6] are dedicated to minimizing the consumption of the measurement sub-part, and on the other hand the complete energetic budget is too rarely described. In this paper, we choose to develop these points based on a practical implementation of an outdoor WSN.

The first part of this paper details the structure of the deployed WSN. The second part explains the End Device structure and its operations. The last part presents some energy considerations (unexpected start-up, wake-up time, energy leakage, autonomy ...). Those aspects are critical for a good design. In this article, they are experimentally illustrated.

2. WSN solution

Each node of the network is based on Jennic 5148 module which has been specifically developed for low power WSN. We have chosen this module because the user has not to interfere with the network layer. The user very simply will have to use a template in order to implement the protocol of its embedded system. We chose a tree topology (fig. 1). The network is made of a supervisor, routers and end devices. The **coordinator** is always ON, aggregating data from sensors and sending them to a computer through a USB line. **Routers** are also always ON, relaying data between end devices and supervisor. Maximum distance between supervisor and end devices ranges between 45 meters (open space) and 10 meters (indoor). The **end devices** perform sensing and transmission of readings.

3. End Device Node (ED)

3.1. Structure of the ED

To offer modularity, each node is made of three parts (fig.2 and fig.3): one part is composed of the Jennic 5148 module (microcontroller and radio), one stack is devoted to energy (supercapacitors storage in [7], secondary battery in this paper with or without a harvesting stage -BQ25504-) and the last part is focused on the measurement circuit and depends of the required specifications.



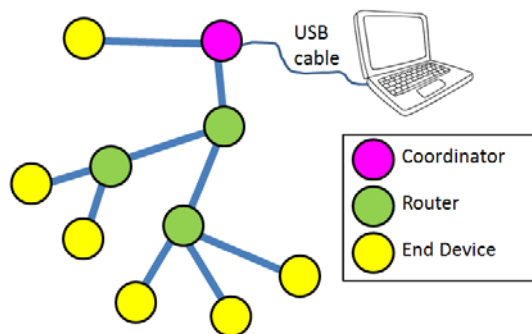


Figure 1. Topology tree.

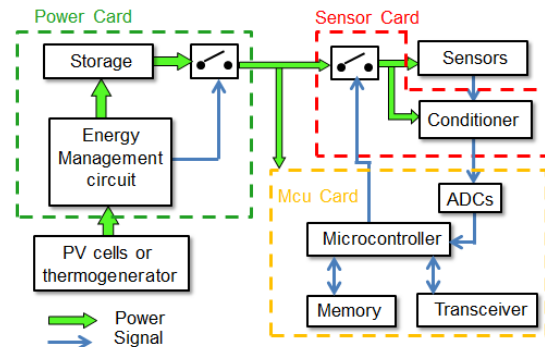


Figure 2. Generic structure of an ED node.

The **Mcu Card** is composed of a JN5148 module which is powered through a LDO Regulator TPS78227 ($V_{out}=2.7V$), which efficiency is greatly better than the TPS73633 previously used. The **Power Card** includes a secondary Li-Ion Coin Cell Battery - LIR2450 3.6V 120mAh and may incorporate a BQ25504 CI which harvests and manages energy from PV cells or from a thermogenerator (STPV1040 circuit has also been tested as a photovoltaic harvester circuit). A load switch (TPS2101) offers the ability to disconnect the battery and the load in order to protect the battery against deep discharge.

The **Sensor Card** adapts the sensor outputs to the voltage range required by the ADCs of the Mcu. A load switch controlled by the Mcu will stop sending power to the board in order to minimize the consumption as the Mcu enters in sleep mode. Several cards with different conditioning stages have been designed accordingly with sensors. Only analogic sensors are presented in this paper.

3.2. Working principle

Medium Access Control: to initiate connection (fig.4), a large power level is necessary. Once connection established, to maintain it, a beacon is used (10ms emission with a period up to 6s). The average power required is then of 13mA under 3.6V.

Steady state (fig. 5): after a sleep time phase (depending upon module type, $I_{sleep} \approx 4$ to $10\mu A$ @ 3.6V), with periodic beacon activity, the wake-up is triggered during 100ms every 24s; the microcontroller activates sensing and sends data to the coordinator. Then after turning off the sensing devices, it goes back into the sleep mode. This sequence is active till network is active and node is powered.

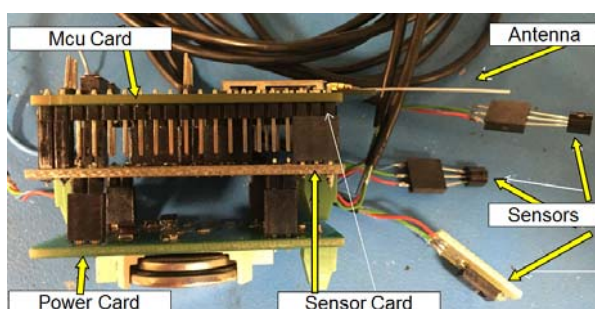


Figure 3. Assembled End Device.

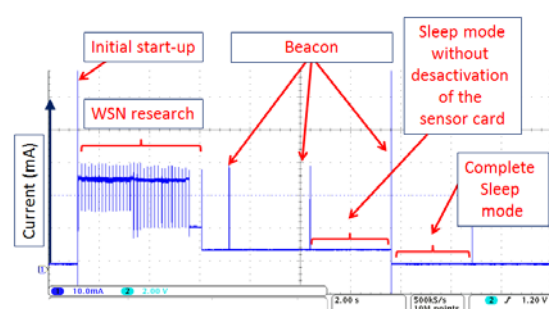


Figure 4. Current furnished to ED during start-up.

4. Energy issues

4.1. Setting of End Devices (ED)

A reduced sampling frequency (for instance one measurement or message each 15 min) is required to minimize energy consumption, but is not enough in the deployment / initialization phase of the network, particularly if the end device is positioned close to the maximum connecting range.

Consequently, we incorporated an initial phase, 5 min in duration, during which each 6s a counting data is transmitted. This allows the operator to properly adjust position of end device together with aerial orientation, therefore helping for a proper start-up of network. Of course, this implies an added, small but unavoidable, energy budget.

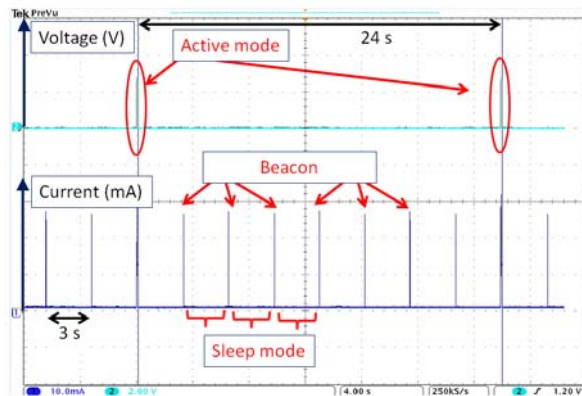


Figure 5. (up) Sensor card supply voltage, (down) Battery current.

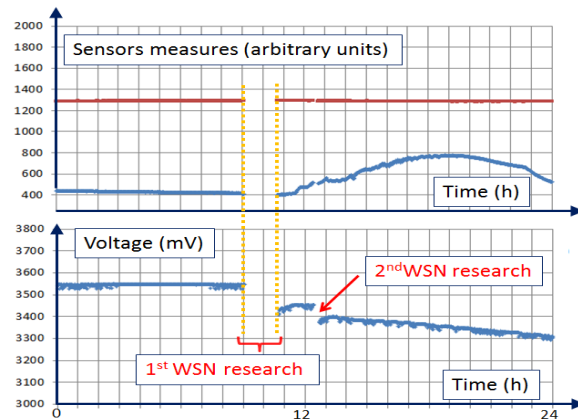


Figure 6. (up) Measurements performed by ED, (down) Battery voltage.

4.2. Sleep mode.

A proper setting of the sleep mode is mandatory. Experimentally, we noticed that an inadequate programming of microcontroller leads to an extra consumption in the sleep mode (400 μ A instead of 5 μ A). Care must be taken to actually switch off important functions such as UART, Flash Memory, ADC, together with setting unused inputs and outputs to high impedance mode.

4.3. Re-establishing radio link.

If the connectivity is lost, the end devices concerned enter a high consuming phase ($\langle i_{ED} \rangle = 4$ mA) while trying to re-establish the connection with routers. In fig.6, router has been inadvertently switched off for 100 minutes, and after being turned on again, network connectivity is re-established but the voltage level at battery terminals of the ED dropped from 3.55V to 3.45V.

4.4. Active mode duration.

When the microcontroller is turned on, data sampling through the ADC must be delayed until sensors output transient phase is terminated (1ms in our case). In active mode, the end device consumption is of the order of about 20mA for Jennic module, and between 40 and 100mA for Sensor Card. Therefore the active mode duration will be adjusted to a minimum.

4.5. Using an Energy Harvester.

The energy harvester must be properly designed because, if not, the energy captured would be insufficient to power the devices. This is illustrated by fig.7: the voltage between the battery terminals at end of day is there less than at the beginning, showing that the energy balance is negative and that the energy reserve is decreasing. On the other hand, when the photovoltaic cell connected to BQ 25504 is not illuminated, the integrated circuit consumes a rather large amount of energy ($I_{BQ} = 14\mu$ A), to be compared to $I_{JENNIC} = 4\mu$ A when the Jennic module is in sleep mode. In a similar situation, with STPV1040 device, the consumed current is even higher: 100 μ A.

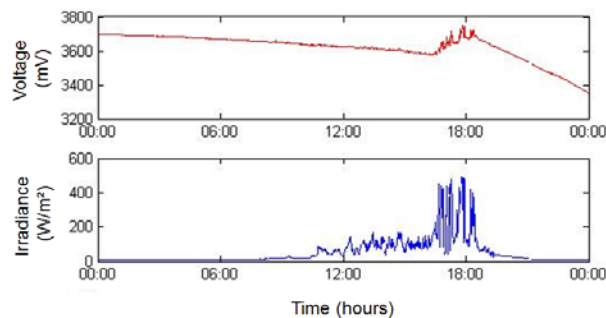


Figure 7. (up) Coin cell voltage, (down) solar irradiance.

mode :	init	beacon (7 beacons then 1 measure)	measure and communication	sleep	total
time	4 s	12 ms each 3.3s	110ms each 26.2s		
current	25mA	12 mA	13.6 mA	4.4 μ A	
voltage max	4V	4V	4V	4V	
energy	0,4J	4mJ for one beacon and 28 mJ /26.2s	5,8mJ /26,2s	0.46 mJ / 26.2 s	10.3mJ /26,2s

Tab.1. Detailed consumption of a node (according to fig 5).

4.6. Autonomy vs temperature

If during a lab test, the autonomy (@T $\approx 23^{\circ}\text{C}$) more or less fitted with calculations (within a 5% error margin), when performing similar tests outdoor in Summer (Tab.1) with a cell coin LIR 2450 submitted to daily temperature variations (15°C to 47°C), the lifetime was then much lower than expected (≈ 20 days instead of 45 days).

4.7. Router consumption.

In the above context, the router consumption is constant and quite large, 45 mA, and implies either to have a very large energy storage and harvesting system, or alternatively to have the router plugged to the mains.

5. Conclusion

We have presented the practical implementation of a low power wireless network, stressing the issues associated with the reduction of energy consumption and network initial setting. With respect to this last point, the connecting range of nodes is limited and environment sensitive. Initial deployment is therefore facilitated by a preliminary phase (even if energy demanding) in favor of telecommunication setting and optimization. With respect to the environment, high temperatures and humidity jeopardize energy autonomy. Harvesting ambient energy may balance these effects, but the harvester consumption when no ambient energy is accessible must be taken into account.

At the software level, active phases must be limited to the minimum required, and at the hardware level sensors must be chosen as energy efficient and exhibiting short transients when switching from sleep to active modes. Provided that these general guidelines are considered, the concept of autonomous wireless sensor network makes sense.

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