Available online at www.sciencedirect.com
ScienceDirect
Procedia Chemistry 1 (2009) 1195–1198
Procedia Chemistry
www.elsevier.com/locate/procedia
Proceedings of the Eurosensors XXIII conference

Energy Model for the Design of Ultra-Low Power Nodes for Wireless Sensor Networks

Guillaume Terrasson[a,]*, Renaud Briand[a], Skandar Basrour[b], Valérie Dupé[a] and Olivier Arrijuria[a]

[a]ESTIA Recherche, ESTIA, Technopôle Izarbel, 64210 Bidart, France
[b]TIMA, CNRS, Grenoble INP, UJF Grenoble, 38031 Grenoble, France

Abstract

This article describes the modeling of a microsensor node for wireless sensor network applications. Considering the heterogeneous aspect of a sensor node, the developed model allows comparing different node configurations in order to make the best choice of components according to the specifications of the application. Therefore, our model allows identifying the need to design specific element or to use Components Of the Shelf.

Keywords. Power constraint, microsensor node, energy model.

1. Introduction

Recent advancements in electronics and the capability to integrate sensors caused an increasing interest in the development of Wireless Sensor Networks (WSN). Therefore, WSN which could be deployed in wide and inaccessible environment allows the development of new applications in diverse areas such as environment monitoring, event detection and system automation[1,2].

As shown in the literature[2], the autonomy of WSN microsensor nodes constitutes the most important challenge of this new technology. Consequently, energy efficient protocols[3,4] to increase the overall network lifetime are developed and ultra-low power transceivers[5,6] dedicated to WSN applications are designed. Then, works in this area require an energy model to evaluate their impact onto the autonomy.

The goal of our work is to propose a complete energy model for a microsensor node that could be used to compare different node configurations and to find the best sensor node configuration in order to achieve the autonomy of the target application.

This article is organized as follow. First, we present the developed energy sensor node model. Then, the use of our model is illustrated through an example. First simulation results are presented and used to compare the sensor node autonomy achieved by different configurations. And finally, conclusions and perspectives are proposed.

* Corresponding author. Tel.: +33-5-59-43-85-09; fax: +33-5-59-43-84-05.
E-mail address: g.terrasson@estia.fr.

doi:10.1016/j.proche.2009.07.298

2. Energy model for microsensor

As demonstrated in the literature[7], it is necessary to maintain sensor node switched-off as long as possible in order to increase the node autonomy. A node is composed of sensors, analog to digital converters (ADC), processing unit, memory, RF transceiver and battery. The total energy dissipated by the sensor node could be expressed as the sum of the energy dissipated by each element:

$$E_{node} = E_{sensor} + E_{ADC} + E_{\mu C} + E_{trans} + E_{rec} \quad (1)$$

The energy dissipated by an element depends on its state: active or idle. First, the energy dissipated by the sensor is expressed as follow:

$$E_{sensor} = P_{on\_sensor}\,(t_{stabilization} + t_{measure}) + P_{off\_sensor}\left(T_{cycle} - (t_{stabilization} + t_{measure})\right) \quad (2)$$

where $t_{stabilization}$ corresponds to the stabilization time of the sensor and $t_{measure}$ to the duration of the sensing phase which depends on the number of measure to realize and on the ADC conversion time[8]. T_{cycle} defines the periodicity of the microsensor node activity. Moreover, during the sensing phase, ADC converts sensor measures from analogical to digital data. The energy consumed by the ADC in on state is defined as:

$$E_{on\_ADC} = P_{on\_ADC}\left(t_{wake-up\_ADC} + t_{measure}\right) \quad (3)$$

After the sensing phase, the microcontroller could proceed to data processing, formatting and coding in accordance with the application and communication protocols. The energy dissipated during the data processing phase is expressed as:

$$E_{data\ processing} = \frac{N_{soft}}{S_{\mu C}} P_{on\_\mu C} \quad (4)$$

where N_{soft} indicates the number of instruction per cycle according to the embedded software and $S_{\mu C}$ is the microcontroller speed.

After that, transmit data depends on the goal of the application. In fact, in some cases, it is possible to aggregate several measurements before sending data. In other applications, data is sent only when an event is detected. Moreover, in several cases, a receiver is needed to relay data from another node, to treat an acknowledgement or a station base request. The energy consumption of the transmitter and receiver in on state is defined as:

$$E_{on\_trans} = \left(t_{wake-up\_trans} + \frac{N_{bits\_trans}}{D_{inst}}\right) P_{on\_trans} \text{ and } E_{on\_rec} = \left(t_{delay} + \frac{N_{bits\_rec}}{D_{inst}}\right) P_{on\_rec} \quad (5)$$

where N_{bits_trans} and N_{bits_rec} are respectively the number of bits to transmit or to receive. D_{inst} is the instantaneous data rate. t_{delay} corresponds to the delay between the end of the transmission and the reception of the first data bit.

Finally, concerning the microcontroller, its on-state energy consumption is expressed as follow:

$$E_{on\_\mu C} = P_{on\_\mu C}\left(t_{wake-up\_\mu C} + t_{on\_sensor} + \frac{N_{soft}}{S_{\mu C}} + t_{on\_trans} + t_{on\_rec}\right) \quad (6)$$

As demonstrated by (6), the on state time of the microcontroller depends on the other element. In fact, the role of the microcontroller is to manage the different operating modes of the node: measure, process, transmit and receive.

3. Simulation results

3.1. Car park application

An example of WSN dedicated to car park is considered to illustrate the use of our model. Table 1(a) presents the main specifications of this application. The purpose of this application developed by ESTIA Recherche is to detect free parking by implementing magnetic microsensors under asphalt to guide future users. The main characteristics of the COTS used for the development of a first microsensor node prototype are presented in Table 1(b). The ADC is included into the microcontroller.

Table 1. (a) Specifications related to our application and (b) Component characteristics used in our sensor node.

Parameters	Value
Bits to transmit (N_{bits_trans})	200 bits
Bits to receive (N_{bits_rec})	50 bits
Measure periodicity (T_{cycle})	30s
Autonomy	> 8 years

(a)

Node element		I_{on} (mA)	I_{off} (mA)	t_{on} (ms)	$t_{wake-up}$ (ms)
Magnetic sensor		10	1	2	3
Microcontroller PIC		5	1	17	1
TR1000	Transmitter	12	0.5	6.7	0.02
	Receiver	4.8		1.7	0.01
CC1100	Transmitter	17	0.4	6.7	1
	Receiver	15		1.7	0.02

(b)

3.2. Impact of the RF transceivers choice

Considering the specifications of the Table 1(a), our model is firstly used to compare the two different RF transceivers presented in Table 2(a). From results like the graphic presented in Fig. 1(a) and obtained with Matlab, we can evaluate the autonomy of the two configurations using different data rate. As shown in Table 2(a), it has been demonstrated that the CC1100 becomes more interesting than the TR1000 if the data rate is superior at 60kb/s. Moreover, with these two configurations, the autonomy of the microsensor node is inferior to the goal of 8 years.

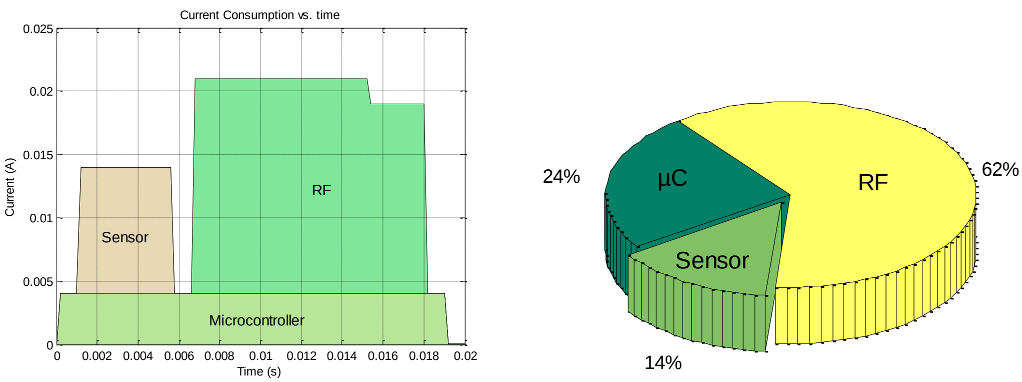

Fig. 1. (a) Power-consumption vs. time with CC1100 @ 30kb/s and (b) part of the microsensor elements into the average power-consumption for the car park management application using CC1100.

As shown in Fig. 1(b), our model demonstrates the preponderant part of the transceiver into the average power consumption of the sensor node.

3.3. Impact of the microcontroller speed

Contrary to simple energy model presented in literature[7], our model allows evaluating the autonomy of a sensor node without neglecting the impact of the processing time due to microcontroller speed and implemented software and protocols. In our application, sensor data are first processed by the PIC microcontroller and then transmit by the CC1100 using its own protocol. Considering an operating speed of 20MHz for the microcontroller, the total processing duration is estimated at 2ms. As an illustration, Table 2(b) presents a comparison of node autonomy using two different microcontroller speeds. It demonstrates that the lower speed allows a better autonomy whereas the duty cycle is longer than the High Speed case. It has been demonstrated that the choice of the microcontroller speed is a compromise between the autonomy and the periodicity T_{cycle} of the measure.

Table 2. Results comparison (a) between two RF transceivers and (b) using two microcontroller speeds of the PIC16F using for the prototype.

RF transceivers	Data rate (kb/s)	Average power consumption (µW)	Autonomy (years)
TR1000	30	7	7.8
CC1100	30	10.6	5.1
	60	7.8	6.9

(a)

Microcontroller Speeds	Power consumption (mW)	Average power consumption (µW)	Autonomy (years)
32 kHz	0.055	9.5	7.8
20 MHz	4	10.6	5.1

(b)

3.4. Synthesis

A first prototype is designed in order to validate the concept of our target application. Using the CC1100 transceiver at 30kb/s, the first average power consumption is measured at 11 µW. The error with our model is inferior to 5% and is explained by the instantaneous microcontroller consumption measured near 5mA @ 3V. Therefore, it confirms that the required autonomy could not be achieved using COTS. Using our model, it has been demonstrated the preponderant part of the transceiver into the average power consumption of the sensor node. Therefore, we decided to design a specific transceiver under power consumption constraint. A top-down design approach has been developed to design of ultra-low power Low-Noise Amplifier[9] adapted to our application.

4. Conclusions

The developed model allows studying the impact of the hardware and software choices into the node autonomy. It could be used to evaluate the best configuration of a sensor node according to the application specifications and eventually to underline the need to design a specific element for the target application.

Acknowledgements

This research was financially supported by the CABAB and the Conseil Régional of Aquitaine.

References

1. I. Akyildiz, W. Su, Y. Sankarasubramian and E. Cayircil. "A Survey on Sensor Networks". *IEEE Communications Magazine.* August 2002, pp. 102-114.
2. D. Culler, D. Estrin and M. Srivastava. "Overview of Sensor Networks". *IEEE Computer.* 2004, Vol. 37, 8, pp. 41-49.
3. M. Perillo, W. Heinzelman. "Wireless Sensor Network Protocols". *Fundamental Algorithms and Protocol for Wireless and Mobile Networks.* CRC Hall, 2005.
4. W. Heinzelman, A. Chandrakasan and H. Balakrishnan. "Energy-Efficient Communication Protocol for Wireless Microsensor Networks". *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences.* January 2000, Vol. 2.
5. A-S. Porret, T. Melly, D. Python, C-C. Enz and E-A. Vittoz. "An Ultralow-Power UHF Transceiver Integrated in a Standard Digital CMOS Process: Architecture and Receiver". *IEEE Journal Of Solid-State Circuits.* March 2001, Vol. 36, 3, pp. 452-466.
6. T. Melly, A-S. Porret, C-C. Enz and E-A. Vittoz. "An Ultralow-Power UHF Transceiver Integrated in a Standard Digital CMOS Process: Transmitter". *IEEE Journal Of Solid-State Circuits.* March 2001, Vol. 36, 3, pp. 467-472.
7. A-Y. Wang, C-G. Sodini. "A Simple Energy Model for Wireless Microsensor Transceivers". *IEEE Global Telecommunications Conference (GLOBECOM '04).* 2004, Vol. 5, pp. 3205-3209.
8. Hill, Jason Lester. "System Architecture for Wireless Sensor Networks". *PhD Thesis.* University of California, Berkeley, 2003.
9. G. Terrasson, R. Briand and S. Basrour. "A Design Technique for Power Constrained CMOS Low-Noise Amplifier Dedicated to Wireless Sensor Networks". *Journal of Low-Power Electronics.* American Scientific Publishers, August 2009.