Poster Abstract: MagoNode++: A Wake-Up-Radio-Enabled Wireless Sensor Mote for Energy-Neutral Applications

Mario Paoli*, Dora Spenza, Chiara Petrioli*
University of Rome "La Sapienza" and *WSense s.r.l.
Email: {paoli, spenza, petrioli}@di.uniroma1.it

Michele Magno, Luca Benini
ETH Zurich and University of Bologna
Email: {magnom, lbenini}@iis.ee.ethz.ch

***Abstract*—The combination of low-power design, energy harvesting and ultra-low-power wake-up radios is paving the way for perpetual operation of Wireless Sensor Networks (WSNs). In this work we present the MagoNode++, a novel WSN platform supporting energy harvesting and radio-triggered wake ups for energy-neutral applications. The MagoNode++ features an energy-harvesting subsystem composed by a light or thermoelectric harvester, a battery manager and a power manager module. It further integrates a state-of-the-art RF Wake-Up Receiver (WUR) that enables low-latency asynchronous communication, virtually eliminating idle listening at the main transceiver. Experimental results show that the MagoNode++ consumes only 2.8μA with the WUR in idle listening and the rest of the platform in sleep state, making it suitable for energy-constrained WSN scenarios and for energy-neutral applications.**

I. Introduction

Energy harvesting, which allows to power embedded devices from environmental energy, is presently one of the most promising technologies towards the goal of very long-lasting sensing systems [1]. If the harvested energy is efficiently utilized, nodes of a Wireless Sensor Network (WSN) powered by renewable energy can achieve long-term uninterrupted operation. To reach this goal, the system's energy consumption should be dynamically adapted to the availability of the energy source, so as to achieve Energy Neutral Operation (ENO) [2]. Informally, a node operates in ENO mode if the energy it consumes over a given time period is no greater than the energy harvested during the same time period. Depending on the considered scenario, achieving ENO may be challenging. For example, indoor energy sources such as ambient light in illuminated rooms can provide power only in the order of tens of μW per cm^2. To support energy-neutral operation in such scenarios, the energy consumption of WSN nodes must be reduced as much as possible. The use of a Wake-Up Receiver (WUR) drastically increases the energy efficiency of wireless communication by virtually eliminating idle listening, which is one of the main sources of energy waste in WSNs. Motes equipped with a WUR use a dedicated ultra-low power hardware component to monitor the channel, remaining in a power-saving sleep state until other nodes in the network demand their activation.

In this work we present the MagoNode++, a novel WSN platform for energy neutral applications that combines a wake-up radio, light or thermoelectric harvesters and a battery and power management module for self-sustainable operation and long-lasting sensing systems. To the best of our knowledge, the MagoNode++ is the first WSN platform integrating light/thermoelectric harvesting, power management and radio-triggering capabilities with a power consumption of less than 3μA with the WUR in idle listening.

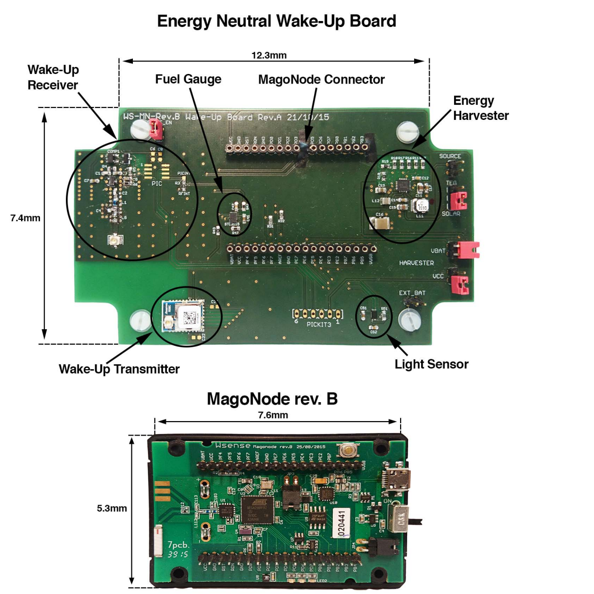

Fig. 1. A MagoNode++ prototype with energy-harvesting and radio-triggering capabilities.

II. MagoNode++ Architecture

The MagoNode++ is built upon the MagoNode [3], a 802.15.4 compliant WSN mote operating in the ISM 2.4 GHz band. The MagoNode rev. B features the ATmega256RFR2 microcontroller and transceiver bundle and the Texas Instruments CC2530 radio front-end, which provides superior radio performance with low-power consumption. Figure 1 shows the prototype of the MagoNode++, composed by a MagoNode and by the expansion board we have developed to exploit energy-harvesting and wake-up radio capabilities.

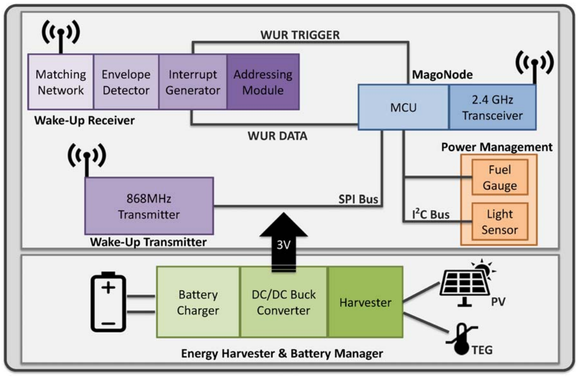

Fig. 2. Architecture of the MagoNode++.

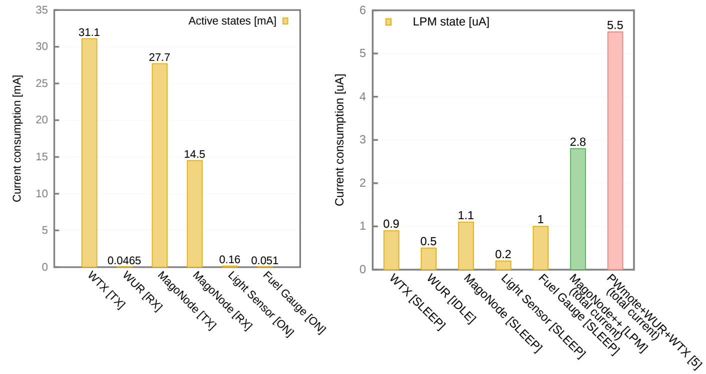

Fig. 3. Current consumption of the components of the MagoNode++ in active and sleep states.

The architecture of the MagoNode++ is depicted in Fig. 2.

Energy Harvester and Battery Manager Module The core of the energy harvesting subsystem is an energy-harvesting integrated circuit designed for low-power application, the BQ25570 by Texas Instruments. The BQ25570 efficiently converts and stores energy generated from various sources, including photovoltaic panels and thermoelectric generators, using a dynamic MPPT algorithm. The harvested energy is accumulated in a storage device, such as supercapacitors or Li-Ion, Li-Polymer, NiCd or NiMH batteries. The BQ25570 is equipped with a nano-power buck converter to supply the load with a regulated voltage.

Power Management Module To support energy-neutral operation, a WSN platform should provide fine-grained estimations of energy harvesting and consumption. To calculate the energy budget in a reliable and low-power way, we equipped the MagoNode++ with a fuel gauge (the ST STC3115) that estimates the battery state of charge (SOC) based on its voltage and on the current flowing from and to the battery. For fine-grained estimations of the harvested energy, a high-accuracy low-power light sensor (the Rohm BH1750FVI) allows to correlate data about the energy gathered from the solar panel with luminance variations. As for energy consumption, the amount of energy needed to perform a given task can be estimated by either using the fuel gauge or by referring to a look-up table reporting the power consumption of common operations (computed offline and stored in the mote's memory at programming time).

Wake-up Receiver and Wake-up Transmitter Use of a wake-up radio increases the energy efficiency of wireless communication by eliminating idle listening on the main radio transceiver. The wake-up module of the MagoNode++ is composed by a ultra-low-power wake-up receiver (WUR) and by a wake-up transmitter (WTX) to send awakening requests. The wake-up system uses on-off keying modulation and it is optimized to work at 868MHz. The WUR module features high sensitivity (up to -55dBm), short wake-up latency, nano-ampere current consumption (560nA at 3V) and selective addressing capability [4].

III. Experimental Results

We experimentally determine the current consumption of the MagoNode++ in different operational states by performing measurements using a digital multimeter. Results for a supply of 3V are reported in Figure 3. The first histogram depicts the current consumption of the system in typical active states: data transmission and reception using the main transceiver, wake-up message transmission and reception, light sensor sampling and SOC estimation. The second histogram shows the current consumption of the MagoNode++ in its lowest power consumption state, denoted as Low Power Mode (LPM), and details the current drained by each individual module in this state. Results show that the MagoNode++ consumes only 2.8μA in LPM with its WUR module in listening mode, outperforming existing prototypes such as [5] (PWmote V1 MSP430+CC2420, WUR and WTX CC1100) with a reduction of almost 50% in energy consumption.

Overall, the low power consumption, energy-harvesting and radio-triggering capabilities of the MagoNode++ make it suitable to challenging application scenarios that requires high energy efficiency and self-sustainable operations.

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