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Device and operation mechanism for non-beacon IEEE802.15.4/Zigbee nodes running on harvested energy

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ABSTRACT

The power supply is one of the main constraints when operating Wireless Sensor Networks (WSN). The most obvious energy source for a WSN node is a rechargeable or non-rechargeable battery. Batteries seriously limit WSNs usage and are associated to the increasing cost of large networks. Low cost networks will be achieved when battery consumption becomes substantially reduced or eliminated. Within this scope, powering WSN devices using mains power, is not an advantage since node installation requires complex and time consuming actions. Replacing batteries is therefore an important topic even in environments with mains power availability. In this paper, a battery-less device running an IEEE802.15.4/Zigbee protocol stack on harvested energy is proposed. Its operation mechanism and required software adaptation to sustain this complex protocol are described. The protocol compliant node uses a contact-less scavenger system that is able to power a WSN node from mains power lines thus providing an inexpensive and easily installable device even for non-skilled users.

1. Introduction

The energy source is the main constraint when operating Wireless Sensor Networks (WSN) [1,2]. The most obvious energy source for a WSN node is a primary or secondary battery (i.e. rechargeable or non-rechargeable). However, batteries have a number of drawbacks that seriously limit the usage of WSNs, and are in fact the main limitation to their widespread use. The WSN implementation/operation cost can be significantly reduced if node battery consumption is substantially reduced or eliminated. Eliminating batteries is an advantage in environments such as industrial platforms or large commercial and service buildings. Presently, due to the high competitiveness levels worldwide in large modern industrial plants, the overall reliability and the effective maintenance management are critical aspects. For instance, when using a large number of three-phase squirrel-cage induction motors, the implementation of integrated motor monitoring and diagnosis systems is highly desirable [3]. The same applies to distributed consumption monitoring in large commercial buildings for energy management purposes. In these cases, there is plenty of available energy supply, but installing a node may require wire cutting and/or screw fastening. Moreover, maintenance tasks are frequently executed without stopping machine operation and thus performed under high power load. Connecting a WSN node to a power line in industrial environments therefore requires a skilled technician to execute hazardous operations. Home automation provides a different scenario with similar considerations. Monitoring a large number of electrical charges in

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large office buildings requires the installation of a significantly large number of wireless devices. Again in this case, despite local power availability, the use of devices with no need for maintenance may decrease operation costs. Together with energy source, WSN protocol operation is a fundamental issue. Data must be identified and related to its origin, network traffic must be routed and a network topology must be put into operation. Nodes must follow a protocol to be part of the network and are required to execute bidirectional communications. Moreover nodes must be able to listen before transmitting thus requiring more energy than if they were only sending a small number of bytes. Protocol operations such as registering with the network or joining to a group of nodes within the network are required. Protocol requires energy availability that is strongly correlated to protocol complexity.

In this paper, a battery-less device running an IEEE802.15.4/Zigbee node powered by an electromagnetic harvesting source using a Split-Core Toroidal Coil Current Transformer (SCCT) is proposed. System design options and operational analysis are addressed.

This paper is organized as follows: In Section 2 a review of energy harvesting solutions and related work is presented. Section 3 describes IEEE802.15.4/Zigbee data frame format characteristics that are relevant for the developed device, including also operational timing IEEE802.15.4/Zigbee mechanisms and related energy consumption. The implemented system architecture, hardware characteristics and capacitor based operation of the proposed device are described in Section 4. Original and proposed software adaptation of Texas Instruments Zigbee stack (Z-Stack) are described in Section 5. The proposed changes implement a task scheduler that prevents system catastrophic power down. The task scheduler algorithm is analyzed in Section 6. Conclusions are in Section 7.

2. Energy harvesting devices, technologies and related work

Battery replacement can only be achieved by power energy scavenger systems that, to this date, present severe limitations. Energy harvesting is the process by which energy is collected and stored from the environment. Energy can be captured from a number of sources. Solar power, salinity gradients, thermal energy, kinetic energy, wind energy, nuclear radiation and radio frequency are some possibilities to scavenge energy to power embedded systems [4–9]. Photovoltaic solutions are perhaps the most obvious power source for WSN nodes. Photovoltaic panel powering can be differentiated into two profiles as they are placed outdoor or indoor. Outdoor solar energy harvesting presents a large variation of scavenged power as day light varies from a clouded to a sunny day. Indoor variation are due to different light sources and different illumination profiles [4,10–16]. Mechanical force can generate energy if an inertial mass is used to create movement. Movement can be converted into electric energy using three mechanisms: electrostatic, piezoelectric and electromagnetic [4,17–19]. A vibrating piezoelectric device is used to convert mechanical energy from pressure, vibrations or force into electricity. The piezoelectric harvester consists of a capacitor formed by one or several piezoelectric layers sandwiched between metallic electrodes. The principle of operation of the energy scavenger is based on the mechanical strain exerted on a piezoelectric mass. Electrostatic energy harvesting is done by changing the capacitance of a variable capacitor. This mechanism uses plate vibration of a previously charged capacitor to produce electrical energy. Promoting changes on a magnetic field through mechanical vibration can be characterized as electromagnetic energy harvesting. An electromagnetic induction is therefore achieved by using a permanent magnet, a coil and a mechanical device. Thermal energy harvesters are based on the Seebeck effect, which states that a voltage is created at the junction of two different metals or semiconductors if a temperature difference exists between both plates. The core element of a thermal energy harvester is the thermopile, which is a device formed by a large number of thermocouples placed between a hot and a cold plate and connected thermally in parallel and electrically in series [20–23]. Radio frequency is identified as a possible energy harvesting source for embedded systems. RFID[1] is a common technology in which a small circuit is powered by radio frequency bursts. The exact same principle can be adopted by WSN nodes as a radio frequency burst can be used to power a group of nodes [10,24–27]. A nuclear diode junction battery is presented in [28–31]. This work suggests a 50+ year lifelong energy source with 1.5 V voltage value and currents of nano to microampere. The used 63Ni isotope is a device that directly converts nuclear to electric energy with a very low alpha radiation emission. In general, the output of an energy harvester cannot be used to directly power embedded system circuits [10,32,16]. Conversion circuits must therefore be used to accommodate voltage and power levels. Power management circuits must be able do adapt to harvester conditions and characteristics. The variability in voltage, power density, and duty cycle requires careful design of conversion circuitry to effectively collect harvested energy. The power management unit should be able to handle very low feeding power and should also be self-starting.

The work presented in [33] reviews and compares available options for powering WSN nodes from large electric and magnetic fields which exist near high-voltage electrical installations such as substations. In [34] a microprocessor controlled electromagnetic energy harvesting device from a single high voltage transmission line is presented. This system is able to scavenge energy from line currents between 65 A and 130 A. A magnetic power generator and a voltage multiplier are used. In [35] a communication concept for inverter fed electric motors is presented. Power-line communication is used to send motor operational data. Power supply is obtained by inductive coupling from the remaining motor phases. In [36] a small electromagnetic energy harvesting device is proposed, where several topologies for the magnetic coupler are tested. This energy harvesting device is used to charge a battery that can in turn power a wireless device. These works investi-

[1] RFID: Radio-Frequency Identification.