

On the RFID wake-up impulse for multi-hop sensor networks

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Abstract

Communication protocols for wireless sensor networks reduce the energy consumption by duty cycling the node activity and adopting a periodic sleeping scheduling. This approach often results in idle listening and therefore energy dissipated for listening to a channel free from packet transmitted. Duty cycling trades-off energy consumption due to idle listening and high end-to-end delay. Proposed solutions mitigate this issue for example through extra low-power radio components (wake-up radio) that listen to the radio and wake-up the node if some channel activity is sensed. These extra components also consume some energy to listen to the channel. In contrast, we propose an on-demand wake-up capability, namely RFIDimpulse, which is achieved through using an off-the-shelf battery-less RFID tag attached to each sensor node that is also provided with RFID reader capability. Because modern RFID techniques can trigger all the neighbouring tags at once or pinpoint a particular tag, RFIDimpulse provides both unicast and multicast capability. RFIDimpulse allows event-driven communication and eliminates node idle listening.

1 Introduction

The advent of battery-operated wireless sensor networks technology is currently attracting great interests in a number of fields such as electronic payments, goods and material handling, security, structural monitoring and tracking. Wireless sensor technology consists of battery-operated autonomous wireless modules equipped with sensing capability. In wireless sensor networks, energy consumption is a primary issue as battery replacement is costly and sometime difficult according to application. In general, nodes wake-up periodically to listen for incoming packets from neighbours and re-synchronize their internal clock at regular intervals. In case no packets are destined to them, they switch-off the radio and set a counter for the next channel assessment. The energy dissipated in idle listening of the channel represents a great percentage with respect to the total energy consumption. As a result, idle listening is the main source of energy dissipation in sensor networks. Furthermore, energy saving mechanisms based on node duty cycling cannot turn-off completely the microprocessor that regulates the node's internal clock, which also has a negative effect on the network

operative lifetime.

A viable solution to this problem is to couple RFID technology with wireless sensor networks. RFIDs, as a more efficient alternative to bar codes, allows remote item identifications without line-of-sight (LOS), which makes the technology useful to automate inventory control and electronic payments. Attaching RFID tags sensor nodes provides a mechanism to remotely wake-up the microprocessor and radio of the receiving sensor nodes on demand. This paper proposes a technique named RFIDimpulse, which aims to totally remove the idle listening and put both microprocessor and radio in deep sleep to reduce the energy consumption to a minimum. RFIDimpulse can couple wireless sensor nodes with either the passive RFID, which does not consume any supplementary energy, or the active RFID, which provide a higher transmission range.

In the remainder of this paper, we firstly describe relevant related approaches in the domain, and then we describe the RFIDimpulse technique and present some MAC/routing implications. Finally, we provide some initial measurements obtained through Philips Aquisgrain nodes and conclude the paper.

2 Related work

Common energy-efficient communication protocols used for wireless sensor networks such as [4, 6, 7, 8, 9] are based on duty -cycling the activity of nodes. Some approaches result in idle listening at the receiver such as SMAC [4] or TMAC [5]. In alternative approaches, the idle listening is shifted at the transmitter such as in BMAC [6] or in MERLIN [9] so to save energy for low data rate scenarios. In general, current protocols can only reduce but not eliminate idle listening, which remains the main source of power dissipation in sensor networks. In the pursuit of mechanisms that would greatly reduce the node duty cycle and allow a fast channel assessment, the authors in [14] proposed a support from a special hardware transceiver that can reduce time needed for a radio to perform clear channel assessment. By introducing extra hardware, the mechanism can mitigate further the idle listening but it does not eliminate it. Furthermore, such time slotted communication approaches such as [9, 4, 10] must rely on a tight time synchronization procedure, for example [11], with an increase in transmission overhead. Although these drawbacks can be resolved by allowing remote wake-up capabilities, this field is relatively new and it has not been

fully investigated.

An alternative approach is to use a low-power radio component such as PicoRadio [13] to watch the channel when the node enters the sleep mode. The drawbacks of PicoRadio is that it uses extra node energy to power up a separate low-power radio to monitor the channel activity and to wake-up the main radio transceiver in case channel activity destined to the node is sensed.

An RFID wake-up scheme similar to RFIDimpulse has been previously presented in a poster in [17]. However, the authors only provide a high level description without providing any details about how the methodology can be implemented and the communication implications for access control and routing in a multihop network.

To our knowledge, the most relevant contribution on remote wake-up mechanisms is the remote radio-triggered sensors in [12]. The work in [12] proposes different circuits that can be remotely triggered by the transmitter. The proposed circuits wake-up the node if a packet at a particular frequency is received. In this approach, a node can wake up the entire neighborhood simultaneously. Alternatively, it employs multiple transceivers to transmit radio signals at different frequencies simultaneously so that a transmitting node can select a receiver. This is not always available in off-the-shelf sensors. Furthermore, the approach presents a limited operating distance of about 7m. In contrast, our approach uses ISO standard RFID protocols such as ISO18xxx, that use one channel to enable all neighbouring nodes to receive the impulse and wake up simultaneously or the RFID reader can select which neighbouring node to trigger. The combination of RFID technology and wireless sensors are already available off-the-shelf, for example in [15], which provides RFID reader transmitting range of 10m for passive RFID tags and 50-70m for active RFID tags.

3 RFIDimpulse-based node wake-up

3.1 Overview

In this section we firstly provide an overview of RFID technology and then we focus on how such a technology can be applied to improve the communication of wireless sensor networks. Finally, we discuss MAC and routing implications in a multihop environment.

3.2 Basics on RFID technology

The two main modules constituting the RFID technology are the RFID reader and the RFID tag, also called transponder. In general, due to far-field emissions, a transponder is able to capture EM waves propagating from a dipole antenna attached to the RFID reader. Although the antenna at the transponder absorbs most of the energy radiated at a particular frequency, an impedance mismatch will result in some energy reflection. The RFID reader is provided with a sensitive radio receiver that can detect the energy reflected to identify the presence of the tag. This technique is known as back scattering. According to the complexity and the ISO standard adopted the reader can pinpoint a particular tag or receive from all the neighbouring tags. The latter case has implications for the MAC layer, as RFID can provide a form collision avoidance for standard wireless communication among the sensors.

3.3 RFIDimpulse-based node wake-up

This section firstly describes some preliminary energy consumption results to motivate our design choices for RFIDimpulse. Secondly, we describe the relevant hardware connection for our approach. Third, we focus on the microcontroller power modes and describe why normal duty cycling techniques cannot utilize deep energy saving schemes. We finally describe the RFIDimpulse technique and how it can achieve a minimal energy dissipation for sensor networks.

In our preliminary results in table 1, obtained by measuring the energy consumption of the Philips Aquisgrain platform equipped with a cc2420 radio [3] and ATmega128 microprocessor [2], we can see that the microprocessor is the most energy-consuming device after the radio. Therefore, an appropriate power save methodology should address the consumption of both microcontroller and radio. The CPU/microcontroller (MMCU) is the controlling component of a sensor node as it is responsible for accessing the channel, interacting with other nodes, switching on and off the radio and processing data. All these tasks are regulated by a small oscillator connected to the MMCU that provides time awareness by transmitting regular tick interrupts. This allows the node to duty cycle the activity of the radio to reduce power consumption. MMCUs for WSNs are also capable of going into sleep mode. A low frequency clock, namely watchdog counter, is set-up to wake-up the MMCU after a certain timer fires. As a result, the MMCU wakes up periodically and, in turn switches on the radio to listen for incoming packets. The oscillator cannot be switched off completely otherwise the node will lose the time knowledge for MMCU and the radio that cannot wake up regularly to receive incoming packets from neighbours. If the watchdog is not set, a node whose radio is asleep, the only way to activate the MMCU is through an external interrupt that is sent to one of its pins.

Providing the nodes with an RFID tag and RFID reader capability can provide a means for generating such interrupts to the MMCU. As shown in figure 1, the MMCU is connected to an RFID reader and we also connect the the passive/active RFID tag to the pin of the MMCU that is programmed to accept external interrupts. In case a node transmitter wants to send a packet to a neighbouring node (receiver), it uses the RFID reader to trigger the neighbouring RFID tag. The EM waves captured at the receiver are sufficient to generate a small wake-up interrupt to the local MMCU that in turn wakes up the radio and listens for incoming packets. In our measurements on the Aquisgrain, we identified that a voltage of 0.5/0.6 V on a certain pin is identified as an interrupt. This voltage level is comparable to the voltage reported in [12]. The wake-up process takes a certain amount of time (about 2.4msec for CC2420 and 128 μ sec for the Atmega128 MMCU) that should be accounted for by the transmitter before sending the packet through the normal WSN communication protocol adopted. The technique allows event-driven communication between nodes in a wireless sensor network by reducing MMCU activity and radio idle listening to zero. Although RFIDimpulse uses RFID tags to generate the interrupts, the same results can be ob-

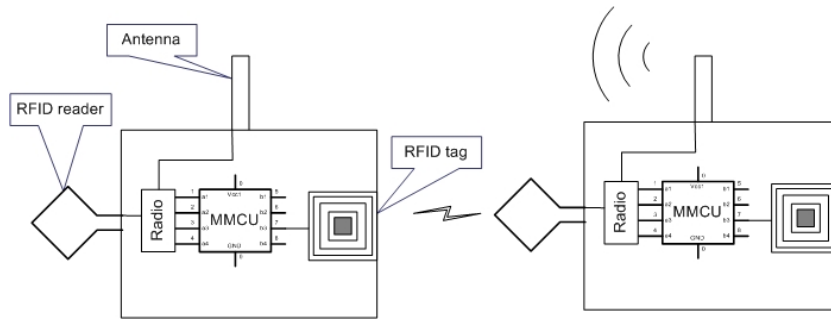


Figure 1. Logic connections of RFID tag, microcontroller and RFID reader on a sensor node

Current (mA)	power ON	stand-by	power-down
ATMega128	12	4.1	0.1
CC2420	24	1	0.25

Table 1. Current measurements at the oscilloscope for the Philips Aquisgrain node

tained through the usage of a standard coil located at the receiver. However, a coil would only be sufficient to wake up all the neighbouring nodes. Additional motivating factors for using RFID over a coil are due to some MAC and routing implications that are discussed in section 3.5.

3.4 MAC implications

The reasons dictating the choice of connecting an RFID tag rather than a simple coil are threefold.

- A simple coil would indistinctly generate a local interrupt if a signal was received. In contrast, an RFID reader can pinpoint a particular tag or receive from all the neighbouring tags according to the ISO standard used, for example the ones of the family ISO 18xxx [16].
- Through the RFID back scattering technique it is possible to identify the ID of nodes in the vicinity, receive acknowledgements, and chose the appropriate recipient before the actual packet transmission.
- Current RFID standard protocols provide back scattering delay mechanisms so that the RFID reader can detect the presence of several nodes at once.

In general, with an appropriate choice of ISO standard 18.xxx the node can wake up a particular recipient to perform unicast communication or wake-up all neighbouring nodes to perform local broadcast. After turning on the node/s, the communication will fully adhere with the medium access control (MAC) characteristics adopted, for example IEEE 802.15.4 [18]. In order to enhance the system, during a unicast transmission or reception, the RFID tag might be disabled to prevent the back scattering technique to respond to another neighbouring node willing to transmit, as is proposed in [17]. It is interesting to note that RFIDimpulse does not need the RFID tag to communicate back to the RFID reader through back scattering. This can extend the range of the RFIDimpulse technique. According to transmission

power/distance law $Pt \sim D^\alpha$, $2 \leq \alpha \leq 4$ in space, an RFID reader with a standard transmission range of D can wake up a remote node at a distance between $4D$ and $16D$, when no back scattering is required.

3.5 Multihop routing

Although the RFIDimpulse technique is independent from the routing protocol used, it can have interesting implications in a multihop environment. Providing a routing table with RFID tag identification number and relative node ID, it is possible to wakeup nodes in series from a source to a destination to prepare them for an upcoming multihop packet transmission. For example a source node can select which neighbour to wake-up according to a certain cost function and pinpoint it with the RFID reader. The procedure can be repeated until the destination is reached. Once the nodes involved are in listening mode, a message passing procedure can enable the packet to rapidly hop from one node to another. Of course, using multi-hop source routing with RFIDimpulse requires a robust addressing scheme through which nodes can determine which neighbors to target for wakeup.

4 Initial results

In our experiments we used the ATMega128 microprocessor that has 6 sleeping modes, depending on which microprocessor modules are turned off. In general, all functions that are not used should be disabled. The lowest possible power consumption is achieved with the power-down mode which saves the content of the registers but freezes the oscillator, disabling all the other chip functions but the interrupt handler. The functions are re-established only following reception of an external interrupt by the apposite pin. By using RFIDimpulse, we can adopt the power down mode that does not require any watchdog low frequency clock, which reduces the current consumption in sleeping mode from $250\mu A$ (with the watchdog active) to $100\mu A$ (power down mode). The power down mode provides maximal energy savings as only the interrupt handler is enabled and all the oscillators are off.

5 Conclusion

This work has presented RFIDimpulse as a viable solution to eliminate the idle listening in wireless sensor networks. The technique is based on the usage of an RFID reader and an RFID tag attached to sensor nodes. This allows sensor

nodes to constantly sleep while idle. Should a sensor node have a packet to transmit, it can remotely wake-up the receiving node. The paper discusses the usage of passive and active RFID tags and some MAC and routing implications related to the technique.

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