Demo: Enabling Asynchronous Awakenings in Wireless Sensor Networks Towards Removing Duty-Cycle Barriers

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ABSTRACT

Typical wireless sensor network applications follow duty-cycle mechanisms, yielding important energy savings by reducing the power consumption of idle listening. However, this approach still dictates predefined cycles of active operation, which in some application scenarios is meaningless. Extended lifetime can be achieved by asynchronously awakening sensor network's nodes only when truly required. In this work we present NITOS wake-up receiver that can be employed by typical sensor nodes to provide asynchronous wake-ups and substantially reduce their energy expenditure. Our wake-up circuit operates in the 868 MHz band and is activated by LoRa frames using *OOK* modulation. The developed system supports selective awakenings with the aid of a low-power micro-controller dedicated to sample the acquired signal and identify the wake-up address.

KEYWORDS

Wake-Up Radios, Wireless Sensor Networks, Low-Power Consumption

1 INTRODUCTION

The unprecedented growth of Wireless Sensor Networks (WSNs) has revolutionized the way we interact with the physical context, improving our everyday life in several aspects. Several WSN applications require increased life-duration, while battery replacement is an impractical or sometimes an infeasible task. A typical principle that deals with the excessive energy consumption is duty-cycling. Duty-cycling [4], [3] suggests that sensor nodes enter into a low-power mode (sleep state), where they turn off all the electronics except of a clock circuit dedicated to providing a wake-up interrupt, in order to save as much energy as possible during their inactive periods. Although substantially reducing the energy expenditure, this technique implies several limitations and drawbacks. For example, idle-listening [10] is reduced considerably, but still remains present, since duty-cycle defines fixed intervals of active operation.

The research leading to these results has received funding from the European Union's H2020 Programme under grant agreement no. 687983 (MAZI Project).

WiNTECH'17, October 20, 2017, Snowbird, UT, USA

ACM ISBN 978-1-4503-5147-8/17/10.

https://doi.org/10.1145/3131473.3133330

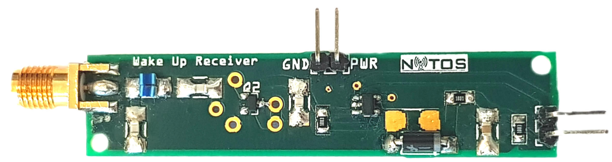


Figure 1: NITOS Wake-Up Radio Testing Prototype

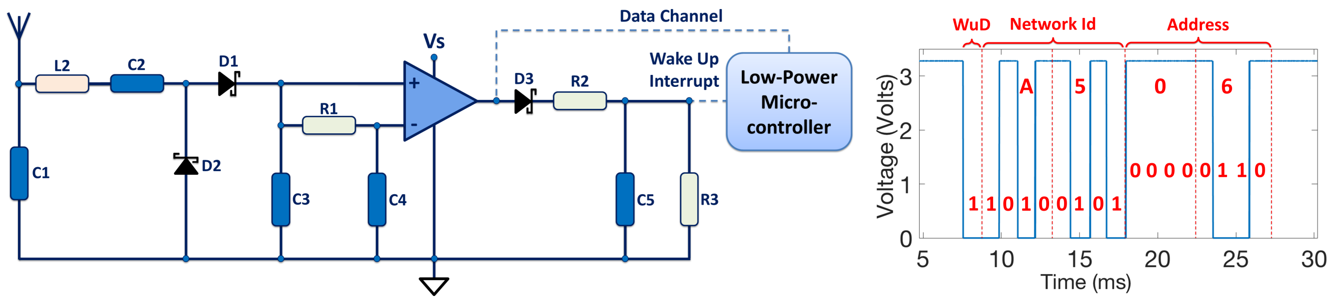
However, a wide range of sensing application scenarios are event-based and do not require fixed wake-ups that only account for energy wastage. Moreover, this approach fails to serve time-critical applications that require immediate response towards sensing an abrupt event.

All the above, motivate the development of wake-up radios to allow asynchronous awakenings, towards eliminating duty-cycle constrains. Several works have proposed novel schemes exploiting wake-up radios [8], [7] that use external nodes to propagate wake-up frames to targeted nodes. Inspired by [9], we adopted a similar scheme and developed an ancillary radio module dedicated to providing an interrupt signal to the host sensor node, in order to activate it only when required. Our prototype uses *OOK* modulation and operates in the band of 868 MHz, engaging LoRa transceivers to achieve long-range distances. In the next section we present the development of the wake-up radio module along with the implementation details.

2 SYSTEM IMPLEMENTATION

The developed prototype receiver consists of low-cost electronics and a low-power micro-controller. The schematic diagram of the receiver is illustrated in Fig. 2(a), while the actual board in Fig. 1. For the wake-up receiver a matching network, a passive rectifier and a comparator to grenade interrupts were used. Moreover, a low-power micro-controller is responsible for processing the received signal and identifying the acquired address to verify whether it should wake the host node. To awake the network's nodes we utilize LoRa radio transceivers, by modulating the propagated information using *On-Off Keying (OOK)* modulation. Briefly, *OOK* scheme defines that the presence of a carrier for a specific duration represents a binary one, while its absence for the same duration represents a binary zero.

On the receiver side, the matching network consists of a capacitor and an inductor element that together form an LC filter used to reject undesired transmissions. In essence, the filter is designed to tolerate signals in the band of 868 MHz. Then, a passive rectifier in the topology of an envelope detector is formed with the aid of two Schottky diodes, used to discard the high frequency signals



(a) Wake-Up Receiver Circuit

(b) Obtained Wake-Up Signal

Figure 2: Wake-Up Receiver Circuit & Obtained Wake-Up Signal

and to deliver the modulated *OOK* signal. Of course, a low-power comparator is used to aid the extraction of the received signal. The obtained signal is then provided to an auxiliary micro-controller that is responsible for checking for the matching address. More specifically, we employed the MSP430F2013 MCU that is constantly configured in the deep-sleep mode LPM4 (Low-Power Mode 4). When a signal is received by the circuit, an interrupt is generated that awakens the low-power micro-controller, in order to process the signal and determine whether the modulated address refers to it. In case of address matching the low-power MCU awakens the host node. Notably, the utilized MSP430 features ultra-fast wake-up time, which ensures fast alternation to a working state to process the acquired signal.

To awake the network's nodes we use LoRa [2], which is a low-power ultra-long range IoT technology. As described, the wake-up packet is modulated using *OOK* modulation, which in essence means that we transmit a carrier to represent binary one, or we suspend the transmission to represent binary zero. Of course, the signal is modulated at a fixed transmission rate, known to the receiver, so that it can extract the information by the received signal. Notably, the modulated packet contains two chunks of information, the *network id* and the *address* of the targeted node. This way, the wake-up circuit, ensures firstly that the packet belongs to its wake-up network and secondly whether the address refers to it. Of course, sensor nodes, can support more than one wake-up addresses, so that we can awaken a set of nodes at the same time. An instance of the received signal is illustrated in Fig. 2(b), as obtained by the wake-up circuit. The received signal contains the *network id* and the *address*, which is the *0xA5* and *0x06* respectively, but depicted inversely. Naturally, this wake-up packet was intended to awake node *number 6*. It is worth noting that the wake-up signal begins with an artificial delay *(WuD)* to allow the activation of the MSP430, prior to the reception of the modulated information.

Finally, we characterize our implementation in terms of power consumption by using our high-end power consumption monitoring tools developed in [6], [5]. The total consumption when idle is roughly as low as 700 nA, very close to the consumption of [9] that features 650 nA in the same state. Notably, the consumption when processing a received packet is just 1.8 μA, since the MSP430 is switched to the LPM3 and not in its typically active state. This plays significant role in the depletion of the battery, especially in a network with many wake-up packets being transmitted or other active transmissions in this band that activate the MSP430.

3 DEMONSTRATION

To demonstrate the performance of our system we use a set of wake-up receivers attached to a state-of-the-art sensing platform, the eZ430-RF2500 [1]. We propagate wake-up requests by an neighboring node to selectively awake the first node and the second one afterwards. Of course, the developed system features a broadcast address, in order to wake-up all the networks nodes or a set of them, towards serve complicated scenarios such as packet forwarding. During the demonstration, the nodes will be configured to sleep and they will be activated when receiving a wake-up packet. An LED will indicate their activation and a neighboring node operating as receiver will obtain their transmitted packets.

4 CONCLUSIONS

In this work we presented the NITOS wake-up receiver, attached to off-the-shelf sensor devices to provide asynchronous awakenings. Our implementation drains roughly 700 nA when idle and just 1.8 μA when receiving and processing a wake-up request. The main advantage of the proposed scheme is the utilization of LoRa transmitters to allow for long-range distances. Our future plans include experiments in different distance ranges and under varying wake-up transmission rate.

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