

# Poster Abstract: Wake-up receivers for energy efficient and low latency communication

Fayçal Ait Aoudia\*, Michele Magno<sup>†</sup>, Matthieu Gautier\*, Olivier Berder\*, Luca Benini<sup>†</sup>

\*IRISA, University of Rennes 1

Email: {faycal.ait-aoudia, matthieu.gautier, olivier.berder}@irisa.fr

<sup>†</sup>ETH Zürich

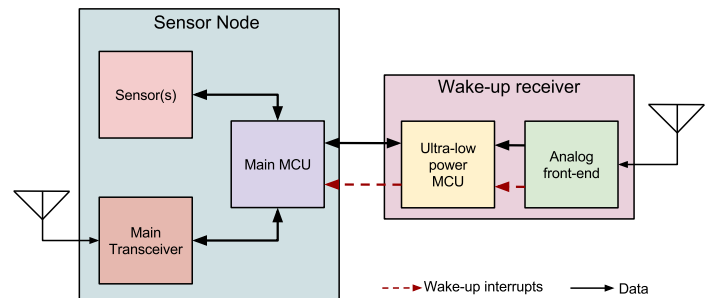
Email: {magnom, lbenini}@iis.ee.ethz.ch

**Abstract**—Long lifetime is the most pursued goal in Wireless Sensor Networks (WSNs). As communication is typically the most energy consuming task, a lot of effort has been devoted to design energy efficient communication protocols using duty-cycling in the last decades. However, in the recent years, a new kind of Ultra Low Power (ULP) receivers, called Wake-up Receivers (WuRx), is emerging. These devices allow the continuous monitoring of the wireless channel while having a power consumption orders of magnitude less than typical WSNs transceivers. WuRx can wake-up the rest of the system (microcontroller (MCU) and main radio) using interrupts only when needed, minimizing the idle listening. In this work, we present an experimental and an analytical study which ultimately serve as guidelines for the design of communication protocols leveraging WuRx.

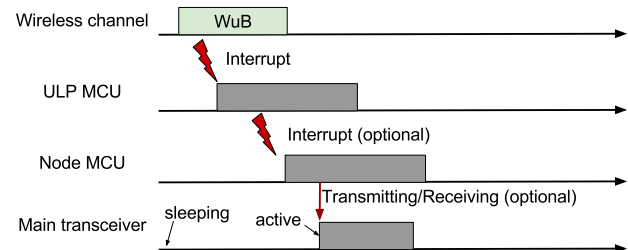
## I. INTRODUCTION

WSNs are enabling many cyber-physical applications such as environmental monitoring, structural health monitoring, etc. In order to maximize the lifetime of WSNs, a recent promising approach is to use WuRx [1], [2]. In this approach, each node is equipped with a WuRx that is always listening to the medium allowing the other components to be in low power state. Moreover, WuRx are able to wake-up the whole system by sending interrupts when they receive a wireless message. For instance, a node can wake-up a neighboring node by sending a specific message, called Wake-up Beacon (WuB), which is received by its neighbors through their WuRx. This approach permits pure-asynchronous communication, therefore minimizing idle listening which is one of the main sources of energy waste in WSNs. Moreover, novel WuRx embed computational capabilities allowing them to process the data embedded in the WuB. This computational capabilities allow parts of the communication protocols to be executed directly on the WuRx, avoiding unnecessary waking-up of the main MCU.

To fully exploit this emerging technology, novel communication protocols must be carefully designed and optimized. In this work, we evaluate experimentally and analytically the benefits of using WuRx in low throughput WSNs. To achieve this goal, a transmitter initiated MAC with acknowledgment that leverages WuRx was implemented on a real hardware. Moreover, the state-of-the-art PW-MAC [3] protocol that focuses on energy efficiency and is based on the traditional duty-cycling approach has been implemented as well to permit a comparison with a traditional approach. Power consumption measurements have been carried out, and combined with an analytical model used to evaluate the benefits of using emerging WuRx.



(a) Hardware architecture of a node equipped with a WuRx.



(b) The different stages of a WuB reception.

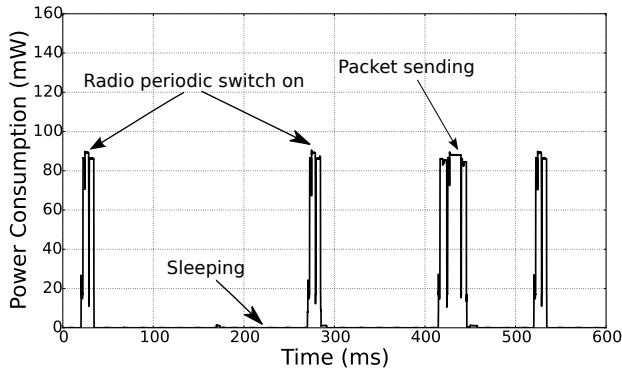
Fig. 1: Using the WuRx with a sensor node.

## II. ENERGY EFFICIENT MAC WITH WAKE-UP RADIO

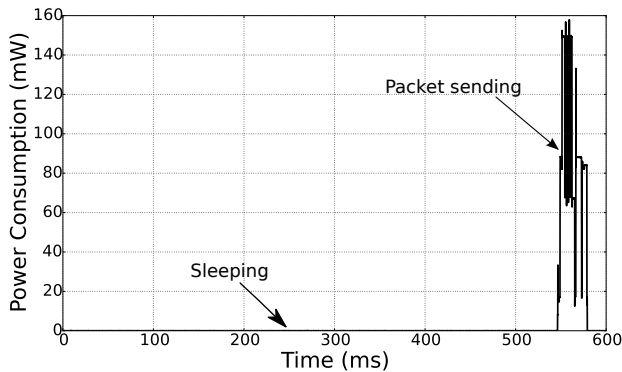
Figure 1a shows the block architecture of a wireless node equipped with a WuRx, which is composed by two main blocks, an analog front-end and an ULP MCU. Only the radio front-end is always awake, while the ULP MCU is awakened by the analog front-end only when a WuB is detected. As shown by Figure 1b, when a WuB arises, the analog front-end wakes-up the internal ULP MCU, which can then process the incoming data bits. If required, the ULP MCU wakes-up the main MCU, which can then use the main transceiver to continue the communication process.

In this work, the WuRx from [4] is employed and evaluated in a whole deployed network. This WuRx receives data with On-Off Keying modulation (OOK) and works in the 868 MHz frequency band with a bitrate of 1 kbps. The sensitivity in these conditions was measured to be  $-55\text{dBm}$ . The embedded ULP MCU is the PIC12LF1552 from Microchip. The power consumption of the whole WuRx was measured to be  $1.83\mu\text{W}$  in continuous listening mode and  $284\mu\text{W}$  when receiving data

with the ULP MCU active processing them.



(a) Periodic wake-ups and packet transmission using PW-MAC. The wake-up interval is set to 250 ms.



(b) Packet transmission using the WuRx.

Fig. 2: Power consumption incurred by PW-MAC and the use of WuRx.

A comparison with a traditional duty-cycling approach allows us to evaluate the WuRx, and PW-MAC has been chosen and implemented as it focuses on power efficiency. Figure 2a shows measurements of the power consumed by a node executing PW-MAC. Using PW-MAC, the node periodically switched on the radio to receive protocol beacons, which incurs idle listening when no packet is received, leading to waste of energy. On the other hand, when the WuRx is used, the node only wakes-up when it needs to receive or send packets as shown by Figure 2b, and the idle listening is therefore eliminated.

Using these in-field measurements, the benefits of WuRx compared to PW-MAC has been analytically evaluated in terms of power consumption and latency for values of the wake-up interval, *i.e.* the time between two periodic wake-ups of the node, ranging from 50 ms to 2 s. Figure 3 shows the results for a node which receives an average of 1 packet per second,

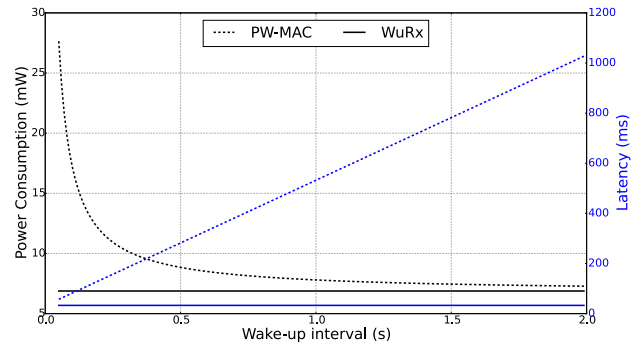


Fig. 3: Power consumption and latency comparison.

locally generates packet at the same rate and forwards all of them. As the WuRx approach does not require periodic wake-ups, the wake-up interval does not impact its performances, but it strongly impacts those of PW-MAC. From these results it can be seen that even with high values of the wake-up interval (2 s), the power consumed by PW-MAC is still higher than with the WuRx, while low values of the wake-up interval (50 ms) leads to low latencies close to the ones obtained with the WuRx, but at the cost of high power consumption. For typical values of the wake-up interval of 250ms and 500ms, the WuRx overcome PW-MAC of respectively 37.1 % and 22.2 % regarding the power consumption, and respectively 79.03 % and 88.3 % regarding the latency.

### III. CONCLUSION

The preliminary results presented in this work show the benefits of wake-up receivers in terms of power consumption and latency. We are currently extending our analytical model and realizing more experimentations in order to study the potential benefits of WuRx regarding various parameters, such as its power consumption, the throughput of the nodes, the size of the WuBs, the duty-cycle of traditional MAC protocols, etc. Ultimately, the results of our study will serve as guidelines for the design of communication protocols leveraging WuRx.

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