Demo Abstract: Sender-Triggered Selective Wake-Up Receiver for Low-Power Sensor Networks

Johannes Blobel and Falko Dressler

Distributed Embedded Systems, Dept. of Computer Science, Paderborn University , Germany

{blobel,dressler}@ccs-labs.org

Abstract—**Wake-up receivers can be used in wireless sensor networks to solve the problem of node synchronization in an energy efficient manner. Conceptually, the idea is to use a dedicated wake-up signal before the actual transmission over a main radio transceiver. Several ideas have been discussed in the literature on how to make such an architecture as energy efficient as possible. State of the art are multi-stage wake-up receivers that first detect a code, i.e., an ID, before powering up the main receiver and the microcontroller. We recently introduced an extension to this scheme that adds a flexible addressing functionality. With this so called Selective Wake-Up Receiver (SWuRx), the sender can decide whether it wants to wake up all nodes in communication range (broadcast), a subset of nodes (multicast), or just a single node (unicast). In this demo, we present for the first time a prototype of our developed SWuRx. The wake-up signal contains an address and a mask and is send with a Software Defined Radio (SDR). The LEDs on our prototype show the nodes address as well as the received data. If a node is woken up by the wake-up signal, this is shown to the user by turning on a light. This way the user can directly observe the effect of different wake-up signals.**

I. INTRODUCTION

Energy efficiency and enhanced network lifetime are important objectives in the design of communication protocols for wireless sensor networks [1]. Idle listening and overhearing are two main sources of energy consumption without providing actual functionality to the system. Therefore MAC protocols for wireless sensor networks have been developed that use duty cycling to reduce the time a node's transceiver must be switched on [2]. While this greatly helps reducing the power consumption, it also adds additional overhead and latency to the system and, most importantly, requires accurate synchronization of all the nodes.

The alternative to duty cycling is to use a wake-up receiver [3]. These receivers only consume some nW to µW and can, therefore, be active all the time. The general idea is to first send a wake-up signal that is received by the wake-up receiver, which, in turn, powers up the full radio transceiver and the microcontroller. Meanwhile, multi-stage wake-up systems have been described in the literature that are more selective by identifying a node specific wake-up sequence in order to reduce false wake-ups. Existing wake-up receivers have some addressing capabilities by simple pattern matching [3]. But these receivers can only support one wake-up scheme at the same time (unicast, multicast, or broadcast). To change from one scheme to another all nodes would have to be reconfigured.
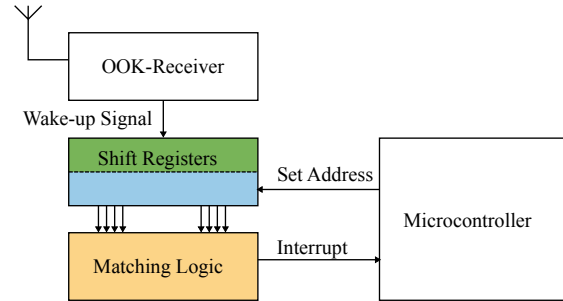

Figure 1. Basic Architecture of our SWuRx platform. The shift registers store the received data (green) and the predefined address of the node (blue). The logic gates (orange) check if the received data causes a wake-up for this node.

We developed a new technique for such wake-up receivers in which we send an address *combined* with a mask in the wake-up signal [4]. This allows the *sender* of the signal to determine the wake-up scheme without reconfiguring the nodes. Due to the increased flexibility in node selection we call this a Selective Wake-Up Receiver. To show the feasibility of our scheme and to conduct real-world measurements, we have built a prototype using standard logic gates and shift registers. The required overhead for the matching logic is relatively small and could easily be integrated in an IC.

II. SELECTIVE WAKE-UP RECEIVER

Commercially available wake-up receivers like the AS3933 from AMS can decode an On-Off-Keying (OOK) modulated signal and check whether this signal contains a certain predefined pattern. The pattern can be configured by the nodes microcontroller via an SPI interface and can be changed during runtime. We exploit this capability for building our new SWuRx approach.

Figure 1 shows the basic architecture of our system. It consists of a microcontroller, a low-power OOK receiver and the wake-up logic. In the initialization phase, the microcontroller configures the OOK receiver and writes the node's address $A = \{a_0, a_1, a_2, a_3\}$ into the corresponding shift register (blue) of the wake-up receiver. It can then turn to an energy saving sleep mode from which it can later be woken up using a hardware interrupt. The wake-up signal consists of a target address (or pattern $P = \{p_0, p_1, p_2, p_3\}$) and a mask $M = \{m_0, m_1, m_2, m_3\}$. If such a wake-up signal is received and decoded by the OOK receiver, it is stored in the second shift register (green), whose outputs are also connected to the
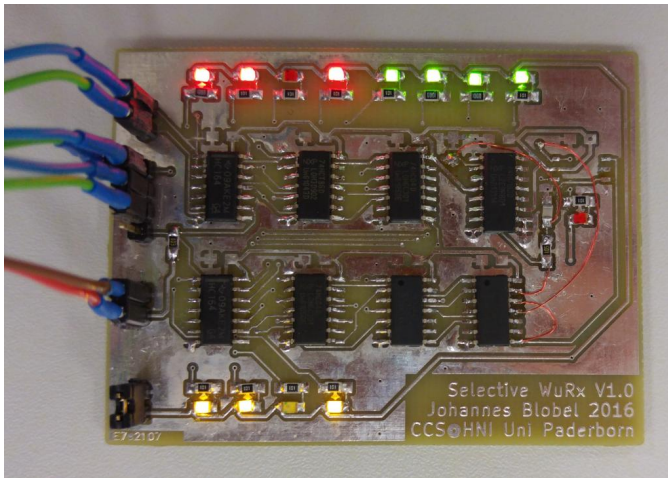
Figure 2. Hardware prototype of the pattern matching logic. The lower LEDs (yellow) show the nodes predefined address. The upper LEDs show the received address (red) and the received mask (green).

matching logic. The pattern matching logic circuit (orange) checks for each bit in parallel, if the node's address matches the received one or if the corresponding mask bit is set to 0. If this check is true for all bits, an interrupt signal is raised that wakes-up the microcontroller. The boolean function determining if an interrupt I is raised is given by:

$$I = \bigwedge_{i=0}^{i \leq 3} \neg(a_i \oplus p_i) \vee \neg m_i \qquad (1)$$

III. DEMONSTRATION SETUP

Our hardware prototype consists of an MSP430 microcontroller on a TI Launchpad, an AS3933 wake-up receiver (which only serves as an OOK receiver here), and a PCB with the aforementioned logic gates (cf. Figure 2). To emphasize the mobile character of the receiver, it is powered by a battery. The internal state of the shift registers can directly be seen via the LEDs on the logic PCB. They show the node's address (yellow), the received address (red), and the received mask (green).

In order to demonstrate the functionality of our SWuRx, we allow the user to send different wake-up signals to multiple wake-up receivers and observe which of them is woken up by this signal. Figure 3 shows a structural overview of our demo setup. On the sending side the demo includes a laptop with an interface where the user can select different wake-up signals to send, a visual representation of the signal (with GNU Radio) and the actual sending device (an SDR, Ettus USRP B210) connected to the laptop. The user can either send predefined messages (unicast, multicast, broadcast) or define a custom address and mask to be send.

On the receiving side, we use prototype wake-up receivers, each configured to have a different address. The address of each receiver can be seen via the LEDs on the PCB. Due to the low data rate of the OOK receiver (200 kbit/s), the shifting in of the received data into the registers can also be observed as a short blinking of the LEDs. To show the wake-up interrupt,
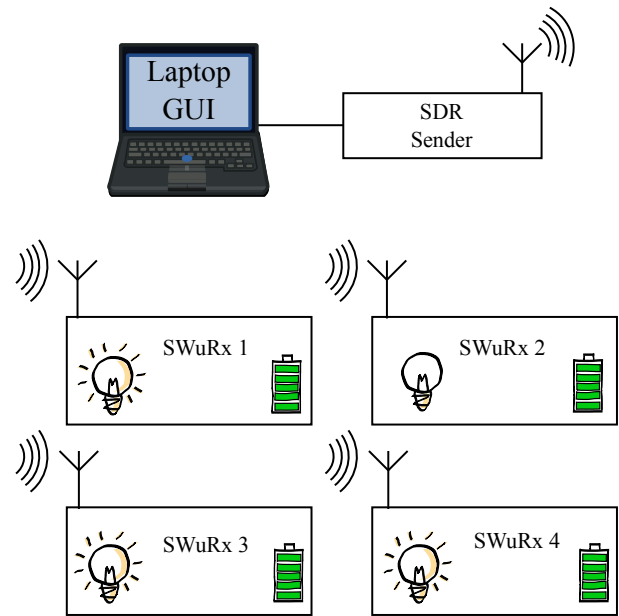

Figure 3. Overview of the demo setup. The laptop can send wake-up messages via a software defined radio. Multiple prototypes of our SWuRx are used to receive the signal and indicate the wake-up address.

each receiver is connected to an additional signaling lamp, that lights up for some seconds, if a wake-up signal is received. This way, the user can send a wake-up signal, see the internal state of the wake-up receiver (via the LEDs on the PCB as shown in Figure 2) and observe which nodes are woken up by the signal. If, for example, a unicast wake-up is send, only one node will wake up, if a broadcast is send, all receivers will wake up accordingly.

IV. CONCLUSIONS

Our proposed architecture allows to use the wake-up receiver technique in a more flexible way. The sender can determine whether to wake-up one specific node (unicast), a group of nodes (multicast), or all nodes in range (broadcast). This technique can make wake-up based mobile nodes even more power efficient, since it can further reduce the time that a node is switched on. The demo we created shows this functionality in an interactive and intuitive way by letting the user send different wake-up messages and observe which nodes are woken up by this signal.

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