Poster Abstract: Wake-up Flooding: An Asynchronous Network Flooding Primitive

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ABSTRACT

We present a new technique for overcoming the fundamental trade-off between energy-efficiency and end-to-end packet latency pervading all event-triggered wireless sensing applications. Instead of applying popular synchronous or pseudo-asynchronous protocols, we leverage state-of-the-art wake-up receivers to facilitate purely asynchronous rendezvous. We then extend the per-hop asynchrony into a multi-hop flooding primitive, termed *Wake-up Flooding*. We describe the underpinnings of the flooding primitive and present preliminary results of wake-up flooding implemented on a custom dual-radio wireless sensing platform deployed in an indoor testbed.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*wireless communication*

Keywords

Wake-up receiver, wake-up radio, flooding, asynchronous rendezvous, wireless sensor networks.

1. INTRODUCTION

Motivation. A decade of sensor network research has produced staple solutions for sensing applications predominantly based on periodic activity patterns, such as data collection and control applications. Typically, such wireless sensing applications consist of a multi-hop network of motes executing a synchronous (*e.g.*, LWB [3]) or a pseudo-asynchronous (*e.g.*, A-MAC [2]) low-power wireless MAC protocol. These two popular classes of protocols aggressively duty-cycle the mote's high-power data radio so to achieve low energy consumption. Low end-to-end packet latency is achieved by carefully tuning the radio duty-cycle to the periodic activity pattern of the observed physical process.

However, the important domain of *event-triggered* sensing applications perform poorly when deployed using synchronous or pseudo-asynchronous protocols. The fundamental characteristic of event-triggered sensing applications, such as tactile prosthetics [1] and safety-critical monitoring [5], is that they exhibit non-deterministic event arrivals. Therefore, since the time until the next event is not known in advance, the radio duty-cycle cannot be optimally tuned to the periodicity of the event arrival process. This leads to a fundamental trade-off between energy consumption and end-to-end packet latency. Either the duty-cycle is increased to achieve a low reporting latency at the cost of higher energy consumption, or the duty-cycle is decreased to achieve low energy consumption but at the cost of higher reporting latency.

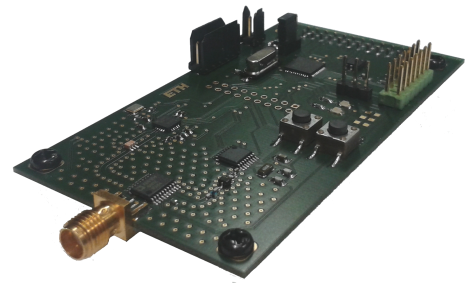

Figure 1: Custom dual-radio wireless sensing prototype used to evaluate *Wake-up Flooding*.

We break this fundamental trade-off by tackling the problem in the *power* domain, instead of the *time* domain. Having the radio always on, *i.e.*, idle listening, is unavoidable when event arrival times are unknown and low end-to-end packet latency is required. Therefore, rather than attempting to minimize the amount of time the radio is active, we instead seek to reduce the power dissipation of the radio in receive mode. We achieve this by applying a purely asynchronous rendezvous scheme [6] that leverages state-of-the-art radio frequency-based wake-up receivers.

Wake-up Receivers. Recent advancements in ultra-low power RF receiver circuitry have made it possible to construct low-complexity On-Off Keying (OOK) demodulators, *i.e.*, an OOK-based wake-up receiver. These receiver circuits are capable of detecting the presence of a specific RF signal, termed carrier burst, while dissipating several orders of magnitude less than traditional data radios. Recent wake-up receiver designs have been proposed [4], which feature practical reception ranges (*i.e.*, up to 30 meters range), support both wake-up and data demodulation, while only dissipating on the order of μW or less.

IPSN '15, Apr 14-16, 2015, Seattle, WA, USA
ACM 978-1-4503-3475-4/15/04.
http://dx.doi.org/10.1145/2737095.2737159.

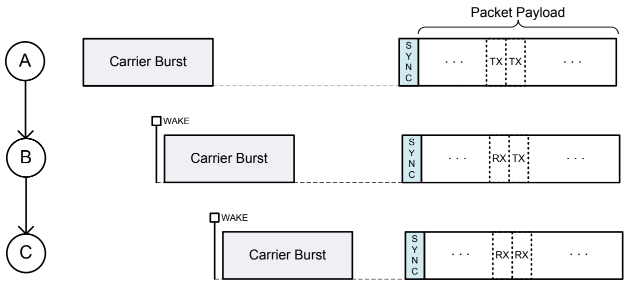

Figure 2: Example wake-up flooding sequence.

Our Solution. We present *Wake-up Flooding*, an asynchronous flooding primitive that leverages state-of-the-art wake-up receivers, coupled with a novel wake-up packet flooding technique, to achieve synchronized and energy-efficient multi-hop data dissemination.

2. WAKE-UP FLOODING OVERVIEW

The ability to flood a packet using a wake-up receiver is made possible by performing three unique steps, namely, *(i)* carrier burst relaying, *(ii)* synchronization bit transmission, and *(iii)* payload propagation. Each step is briefly described next in the context of the example sequence illustrated in Fig. 2, and assuming all three motes in the network are equipped with a data radio and a wake-up receiver.

Carrier Burst Relaying. All motes within the network, starting with the initiator of the flood (*i.e.*, mote A in the example), must transmit a carrier burst using their high-power data radio. This sequence of bits will be received by the wake-up receiver in the next hop, causing a WAKE event to trigger, *i.e.*, an interrupt on the attached microcontroller. The microcontroller will then awake from deep sleep, and proceed to broadcast a carrier burst in order to wake-up the next hop. Carrier burst relaying ensures that all motes in the topology are awake, but only provides loose time synchronization to its nearest neighbor.

Synchronization Bit. After transmission of the carrier burst, the flood initiator will start to transmit the synchronization, or SYNC, bit. When the nearest neighbor detects the beginning of the SYNC bit using its wake-up receiver, it immediately starts transmission of the SYNC bit using its data radio. As this process repeats through the multi-hop topology, all motes will be tightly time synchronized to their nearest neighbor at the end of the SYNC transmission.

Payload Propagation. The packet payload is then propagated through a k-hop network by encoding the packet payload using a repetition code, whereby each bit is repeated $(k-1)$ times. The replication of each payload bit enables the simultaneous decoding and propagation of each bit by multiplexing between bit reception using the wake-up receiver and bit transmission using the data radio.

3. PRELIMINARY RESULTS

Prototype Implementation. We developed a custom dual-radio wireless sensing platform, as illustrated in Fig. 1, to evaluate the performance of wake-up flooding. The platform consists of an ultra-low power 16-bit MSP430 microcontroller, a CC110L data radio, and a wake-up receiver adapted from Gamm et al. [4].

Experimental Setup. Three prototype sensor nodes were deployed on the FlockLab [7] indoor testbed, as depicted in

Figure 3: Excerpt of the FlockLab deployment map, highlighting the three motes used to evaluate wake-up flooding.

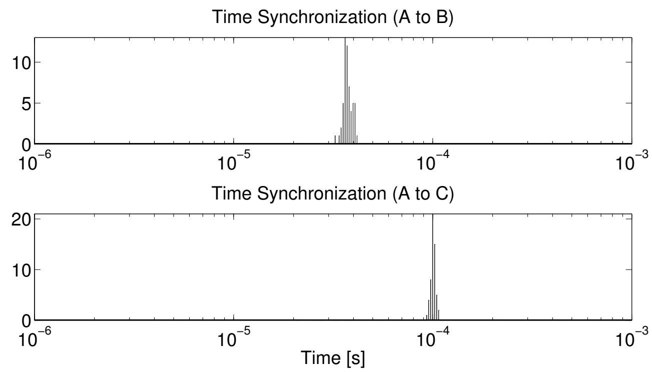

Figure 4: Time synchronization after reception of SYNC bit between motes A-B and A-C.

Fig. 3. A sequence of 50 wake-up floods, each containing a random sequence of 32-bits of payload, were initiated at mote A and successfully received at motes B and C.

Results. A histogram of the measured time delay after the SYNC bit reception between the flood initiator and the first-hop participant B, and between the flood initiator and the second-hop participant C, are presented in Fig. 4. An average of 37.9μs and 101.8μs was measured between the flood initiator and nodes B and C, respectively. The power dissipation of the prototype wireless sensor node during idle listening was measured at 3.2μA at a supply voltage of 3.0V.

The preliminary results demonstrate the ability of wake-up flooding to tightly synchronize an asynchronous multi-hop network in time and data, while consuming less than 10μW in idle listening.

Acknowledgments. This work was evaluated by the SNSF and financed by the Swiss Confederation and Nano-Tera.ch.

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