Poster Abstract: A Heterogeneous System Architecture for Event-triggered Wireless Sensing

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***Abstract*—We present a heterogeneous system architecture for event-triggered wireless sensing capable of supporting high spatial resolution. The key differentiator between the proposed architecture and alternative state-of-the-art approaches is the ability to simultaneously maximize operational lifetime and minimize end-to-end latency of detected events. Our novel architecture takes advantage of heterogeneity with respect to the operation of the wireless communication protocol and the construction of the sensing platform. We present a two-hop proof of concept implementation, exhibiting end-to-end latencies on the order of tenths of a second, while dissipating on the order of tens of microwatts during periods of inactivity.**

***Index Terms*—Event-triggered, wireless sensor networks, on-demand network flooding, acoustic emission sensing.**

I. Introduction

Motivation. In this work, we investigate how to design a wireless sensor network for efficient event-triggered sensing. In particular, we focus on event-triggered sensing applications that require high spatial resolution, where, once an event is detected from the underlying physical process under observation, multi-modal wireless sensors within the vicinity of the event are also activated. The spatially-distributed measurement data extracted after the event-trigger provides valuable information about the detected event.

In order to exemplify our proposal, we consider a specific real-world application, the monitoring of acoustic emissions from alpine rock walls [1]. The primary goal of this application is to detect rock damage and fracture propagation by listening for acoustic emissions caused by the expansion of freezing water within the rock wall. These acoustic emissions may be detected using piezoelectric sensors affixed to the surface of the rock wall. Once an acoustic event is detected, *i.e.*, the acoustic signal exceeds a predefined threshold, high-speed signal processing coupled with additional sensor measurements, *e.g.*, from a digital camera, enable characterization of the event. Furthermore, the rapid activation and data acquisition of all neighboring wireless sensors assist in advanced characterization, *e.g.*, event localization. Given the harsh deployment conditions and the severe implications of rockfall, the design of such a network must seek to maximize the operational lifetime, and minimize end-to-end latency, wherever possible.

Challenges. There are four key challenges associated with the design of an efficient event-triggered wireless sensor network. Firstly, the sensor interface must be designed to detect an acoustic event of interest and facilitate its analysis in the digital domain without expending significant energy resources during periods of inactivity. Secondly, in order to provide high spatial resolution, all nodes within the wireless network must be rapidly notified of a detected event. Due to the non-deterministic arrival of events, state-of-the-art radio duty-cycled protocols only exhibit this property with an undesirable increase in energy consumption, resulting in a severe reduction of operational lifetime. Thirdly, once network-wide measurements have completed, all nodes must quickly deliver their data to the sink for post-processing. Since prevalent radio duty-cycled wireless protocols typically only support fixed bandwidth data dissemination, the rapid data rate adaption required to deliver the multi-modal sensor data poses a significant challenge. Finally, the simultaneous execution of sensor data acquisition and the communication protocol stack leads to resource interference on a single-processor platform, giving rise to a degradation of performance in either data acquisition, protocol operation, or a combination thereof.

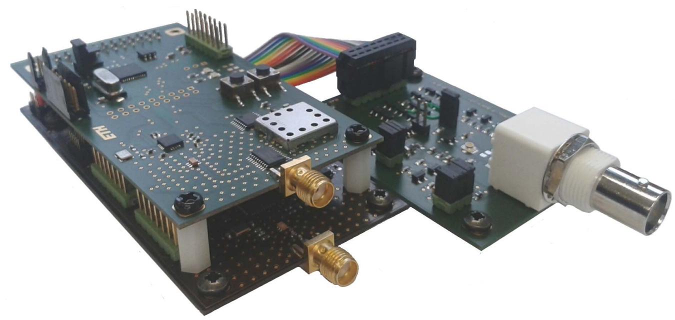

Figure 1. Prototype implementation of a wireless acoustic emission sensing platform, consisting of (right) an analog acoustic sensor interface, (left-top) a Zippy module, and (left-bottom) a custom dual-processor platform for acoustic signal acquisition, characterization and wireless communication.

Our Solution. We tackle these challenges under the premise that the selection of a single communication protocol executing on a single processor, *i.e.*, a classical mote platform, is unable to overcome the complex challenges associated with spatially-diverse event-triggered wireless sensing. Instead, we propose a system architecture where the communication protocol and sensing platform are constructed from heterogeneous components. All system components are carefully chosen to address the aforementioned challenges, while also benefiting from functional diversity (*i.e.*, the weakness of one component is overcome by the strength of another component). We next detail the proposed architecture and present preliminary results based on a prototype implementation, as depicted in Fig. 1.

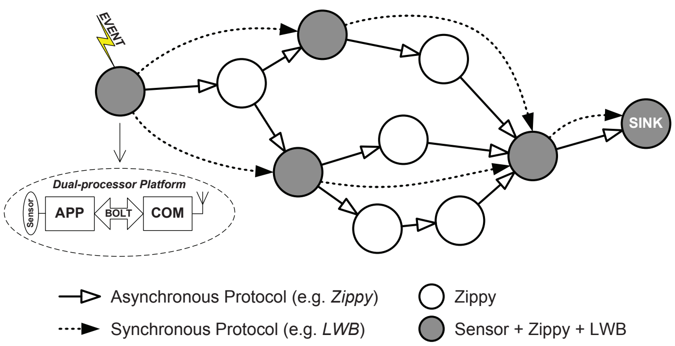

Figure 2. Heterogeneous system architecture that supports event-triggered wireless sensing with high spatial resolution, while simultaneously maximizing operational lifetime and minimizing end-to-end latency.

II. Architecture Overview

The proposed architecture for event-triggered wireless sensing with high spatial resolution is illustrated in Fig. 2. The four fundamental components constituting its design are as follows:

Analog Sensor Interface. The detection and acquisition of an acoustic event is partitioned into two hardware components, namely, *(i)* an ultra-low power always-on event detector circuit, and *(ii)* an on-demand high-power amplifier and signal conditioning circuit. The first component is designed to drive an external interrupt line when an input signal exceeds a programmable threshold. When an event is detected, the second component amplifies and filters the signal prior to high-speed analog-to-digital conversion. The low-power design of the analog sensor interface ensures that only minimal energy resources are consumed during periods of inactivity, while the energy budget for event acquisition and characterization is determined by the required precision.

Network Wake-up. Due to the non-deterministic nature of acoustic events, we employ an asynchronous protocol, *e.g.*, Zippy [2], for the rapid wake-up of a multi-hop network. The Zippy protocol provides on-demand network flooding through the use of ultra-low power wake-up receivers equipped at each node, albeit with reduced per-hop range compared to using high-power transceivers. As depicted in Fig. 2, this practical limitation may be overcome by deploying additional Zippy-enabled nodes to provide sufficient wake-up coverage.

Rapid Bandwidth Adaption. The multi-hop dissemination of event data to the sink is facilitated by the Low-power Wireless Bus (LWB) [3]. The ability for the LWB to allocate new data streams and update its round interval upon request makes the protocol well suited to the requirements of spatially-distributed event-triggered wireless sensing.

Dual-processor Platform. In order to mitigate the resource interference associated with the simultaneous execution of time-critical tasks on a single-processor, we map application, *i.e.*, acoustic event processing, and communication, *i.e.*, the LWB execution, tasks onto dedicated processors. Interconnecting the two processors with Bolt [4] ensures that each processor can share information through an asynchronous message passing scheme, without impacting the timing characteristics of each individual processor. The unique properties of Bolt not only minimize resource interference, but also give the system designer great flexibility in selecting processors that match the specific needs of the target application.

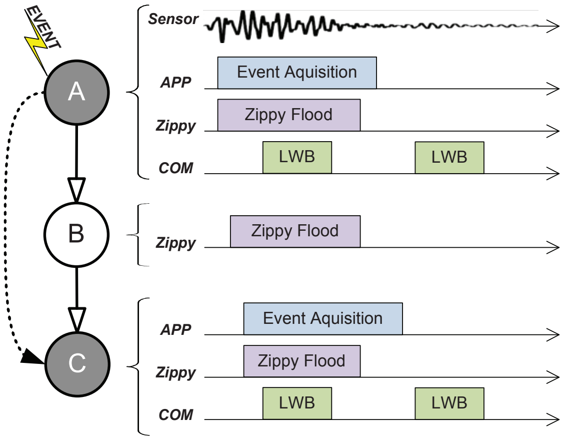

Figure 3. Activity sequence of a two-hop proof of concept implementation. An acoustic event is detected and characterized at node *A*, while a Zippy flood wakes up all remaining nodes. Node *C* schedules a LWB round for the robust data dissemination of all event data.

III. Preliminary Results

Prototype Implementation. We have developed a custom wireless platform for acoustic emission sensing, as illustrated in Fig. 1. The platform consists of a power-optimized analog acoustic emission detection circuit interfaced to a dual-processor platform having support for the Zippy protocol. A 32-bit ARM Cortex-M4 application processor (APP) is dedicated to the resource intensive event acquisition and characterization extraction, while a 16-bit SoC communication processor (COM) is dedicated to the time-critical operation of the LWB.

Experimental Setup. Two prototype platforms and one Zippy platform were arranged in a two-hop wired network using an RF circulator. As depicted in Fig. 3, an acoustic event is injected into node *A* using an arbitrary waveform generator. Once the event is detected, an on-demand Zippy flood propagates to nodes *B* and *C*, awaking them from deep sleep. After the Zippy flood, node *A* delivers the event data to node *C* using a scheduled LWB round.

Results. The end-to-end latency observed on the prototype is on the order of tenths of a second, thus demonstrating fast reactivity to detected events. During periods of inactivity, the analog sensor interface dissipates 10.2μW, the developed sensing platform dissipates 8.1μW, and the Zippy platform dissipates 9.6μW, making it feasible to operate the wireless sensing platform for several years using a coin-cell battery.

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