Competition: Synchronous Transmissions + Channel Sampling = Energy Efficient Event-Triggered Wireless Sensing Systems

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Abstract

Power efficient Wireless Sensor Networks, able to communicate events with high reliability and low end-to-end latency, have proven to be a valuable component of numerous event-triggered systems applications.

To date, the best performance in this direction has been consistently demonstrated by protocols relying on floods of simultaneous transmissions (ex. Glossy and Back-to-Back Robust Flooding). However, while event-triggered systems do not always have events to report, these protocols continue to periodically send floods, resulting in unnecessary spectrum occupation and energy consumption. Moreover, the frequent flooding represents a key obstacle for practical event-triggered applications and standardization.

Our paper proposes replacing the floods with Synchronized Channel Sampling (SCS) rounds. This results in a significant reduction in the spectrum usage and energy consumption, while maintaining the same level of reliability and latency in waking the network up in case of an event. Furthermore, SCS seamlessly supports applications where multiple motes can detect events simultaneously.

1 Introduction

Wireless Sensor Networks (WSNs) have experienced a surge in applicability to numerous novel domains, but event-triggered systems remain a particularly challenging application. These systems need WSNs to convey events that are not periodic, but require a time bounded response, as well as high reliability and energy efficiency levels. Such systems apply to numerous tasks, ranging from automatic fire suppression [8], to artificial skin for human prostheses [7].

To date, the best performing WSNs have been the ones relying on floods based on synchronous transmissions, such as Glossy [2] or Back-to-Back Robust Flooding (B2B) [5]. These flooding-based protocols (hereafter refered as glossy-style protocols) have systematically won the top places at the latest series of the EWSN dependability competition, an independent benchmark of state-of-the-art protocols for event-triggered systems [9], with B2B being the most recent winner (2017).

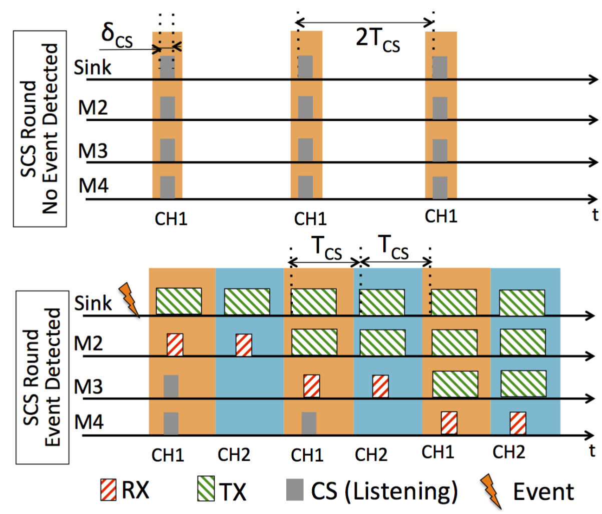

Figure 1. Timing diagram of SCS in a 3-hop network in the absence of events to be notified (top), and waking up the network upon detection of an event (bottom).

This paper addresses the fact that event-triggered systems not always have events to report, but glossy-style protocols continue to send periodic floods, resulting in unnecessary spectrum occupation and energy consumption. The former factor leads to co-existence issues with neighboring networks, which represent a key obstacle for practical event-triggered applications and standardization. Therefore, this study proposes Synchronized Channel Sampling (SCS), a network wake-up mechanism that can replace the floods in protocols that rely on synchronous transmissions (including Crystal [3], Glossy [2], eLWB [10], Chaos [4] and B2B [5]). SCS reduces the transmissions and idle power consumption, while keeping state-of-the-art reliability and latency. Moreover, SCS seamlessly supports applications where multiple motes can detect events and require to wake the network up simultaneously.

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2 Synchronized Channel Sampling

We propose SCS as an energy efficient alternative to the floods that rely in synchronous transmissions. SCS listens during short intervals and only wakes up the network in case an event is detected. Therefore, we manage to minimize the idle listening required for SCS, while ensuring a high event-detection reliability.

The sole requisite is a synchronization error under 500 μs, which is easily achievable by sending a flood from the sink every few tens of seconds [2] and is common in glossy-style protocols (ex. [3]). Figure 1 displays the timing diagram of an SCS round in a 3-hop synchronized WSN performing two basic actions: **checking** the network, in the absence of any events (top) and **waking up** the network upon detection of an event (bottom). The protocol performs the following steps:

Checking. SCS checks the network by using several Channel Samplings (CS). A CS consists of measuring the Received Signal Strength Indication (RSSI) in the channel, in order to determine if there is a transmission to be received. Periodic CS enables the motes to keep the radio inactive during most of the time. It is typically used in asynchronous low-power listening medium access control protocols, as a way of minimizing the energy consumption (ex. B-MAC [6] and WiseMAC [1]).

Fig. 1 (top) displays each mote performing three synchronized CS in channel 1 with period $2 * T_{CS}$, where T_{CS} = 1ms. Each channel sampling has a duration δ_{CS} = 300us (cc2420).

Waking Up. Upon detection of an event, the sink transmits a tone to wake the neighbors up. The synchronization enables the starting of the transmission shortly before the CS in the network, in order to ensure a reliable detection. The motes that wake up will relay the tone in order to propagate the wake-up indication. Since the CS relies on RSSI measurements, the payload of the tone is irrelevant. Moreover, the tones does not require a tight temporal alignment for a correct detection, as opposed to primitives that depend on constructive interference or capture effects (ex. floods in Glossy or B2B).

Fig. 1 (bottom) shows the network relaying a wake-up indication from the sink. In order to minimize false wake-ups due to interference, the detection of the tone during the CS in channel 1 is repeated in other channels. For illustration purposes we use one single verification in channel 2.

The checking and waking up operations are performed three times in this example. This corresponds to the diameter of the network (3 hops), and it is the minimum required to propagate the wake-up signal to all the motes. This means that the power consumption of SCS depends on the diameter of the network, as is the case in glossy-style protocols.

The active time of the radio for an SCS check is smaller than the one for a flood based in synchronous transmissions, for a given network diameter [2]. Thus, it is reasonable to expect that SCS is a more energy efficient primitive than a flood in glossy-style protocols.

The reduction in the number of transmissions enabled by SCS also improves the co-existence with other networks, thus bringing the protocols that rely on synchronous transmissions closer to practical applications.

3 Communicating Event Information

SCS can be the base for a reliable and energy-efficient WSN that enables any mote to detect events (source) and send related data to any other mote (destination).

The network requires a sink that keeps the synchronization by sending floods with a period of several tens of seconds. Moreover, the motes can perform SCS rounds (as seen in Fig. 1) with a period T_w. This mechanism provides a low power consumption while no events are present and a high reliability network wake-up in case one or several motes detect an event simultaneously.

T_w determines the predominant component of the end-to-end event latency, which is the delay between the detection of an event and the wake-up of the network (in average $T_w/2$).

Upon wake-up, the network can transition towards a scheme that provides an exclusive slot to each mote for sending its event-related information (similar to the Event-based Low Power Wireless Bus (eLWB) [10] or Crystal [3]).

The sending within a slot can be done by floods that rely on synchronous transmissions, to ensure a reliable reception by all the motes in the network. B2B's code is publicly available and is used to generate the floods in the competition.

Each flood contains the source ID, destination IDs and the event information (ex. the values registered in the GPIO pins). The flood is expected to be received by the entire network, thus the target motes can be identified with the destination IDs.

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