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Demo: Passive Sensor Tags

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ABSTRACT

The sensing capabilities of an Internet-of-Things (IoT) network are usually fixed at deployment. Adding new sensing modalities is a cumbersome process because it requires altering the deployed hardware. We introduce *passive sensor tags* that allow to easily and seamlessly add new sensors to existing IoT deployments without requiring hardware modifications or additional energy sources. Passive sensor tags employ backscatter communication to generate transmissions that can be decoded by the radio transceivers present in today's IoT devices. Furthermore, unlike recent works, our approach does not require dedicated infrastructure to generate the unmodulated carrier used for backscatter communication.

The demo showcases our prototype of a passive sensor tag collecting sensor data and delivering it to unmodified commodity IoT devices using passive 802.15.4 transmissions.

CCS Concepts

•Networks → Network architectures; Wireless access networks;

Keywords

Backscatter communication, Internet of Things, Wireless

1. INTRODUCTION

The Internet of Things blurs the distinction between the physical world and the digital world by instrumenting the physical world with digitally controlled sensors and actuators. Today, deployments of IoT networks are usually tied to a specific application. The deployed hardware needs to be modified to add new sensing modalities. This leads to a rigid, inflexible design.

Our vision (Figure 1) is to develop *passive sensor tags* that simplify the process of augmenting the sensing capabilities of commodity IoT devices. In our vision, an IoT device can be given new sensing modalities by simply placing nearby a passive tag carrying the new sensor. The IoT device can then

Figure 1: **Passive sensor tags add new sensing capabilities to commodity IoT devices.** To query a tag, a device requests its neighbors to generate a constant carrier (1), which reaches the tag (2). The tag modulates the carrier with a valid 802.15.4 packet to the requesting device (3).

query a nearby passive sensor tag using its existing radio transceiver—it would not be necessary to install a new radio chip or to physically connect a sensor to a commodity device. Furthermore, passive sensor tags are battery-free to avoid an explosion of maintenance cost as more tags are installed. Instead of having batteries, the tags would rely on power wirelessly provided by nearby commodity devices or harvest power from the environment.

Passive sensor tags would allow to easily separate the concerns of sensing capabilities and energy availability. To add new sensing capabilities, an operator simply installs more passive sensor tags; to increase the energy available in the network, he equips the IoT devices with larger batteries or connects them to the mains grid.

Our work builds on recent results that enable backscatter communication with commodity wireless protocols, such as Bluetooth Low Energy [6] or WiFi [8] unlike the existing work, our approach does not require dedicated infrastructure to provide the unmodulated carrier. Instead, we leverage the radio test mode present in many commodity IoT devices to generate unmodulated carriers [1, 2, 4]. Our work also differs from earlier work in that we target the 802.15.4 protocol that is widely used in IoT networks.

2. PASSIVE 802.15.4 TRANSMISSIONS

Next we present a review of 802.15.4, followed by a description on how its modulation can be realized by backscatter devices and how we propose to generate the carrier.

802.15.4 recap. IEEE 802.15.4 [5] specifies a physical layer in the 2.4 GHz ISM band with 16 channels spaced at 5 MHz intervals. Data is modulated using Offset Quadrature Phase-Shift Keying (OQPSK) and transmitted at 250 kbps.

802.15.4 uses spread spectrum to increase robustness. Each

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Figure 2: **Passive sensor tag prototype (left) with commodity IoT devices (right).**

4-bit payload symbol is mapped to a 32-bit pseudo-random chip sequence, which is then modulated using OQPSK. Since each OQPSK symbol takes on one of four phases, it encodes two chips [7]. A straightforward way of generating an OQPSK-modulated signal is to change the phase of the carrier to the corresponding phase of each symbol.

Backscatter transmissions. Backscatter communication modulates a carrier “in the air” by either reflecting or absorbing it. This allows to realize ultra low-power transmitters by separating the energy-intensive carrier generation from the transmission process.

A backscatter transmitter operates by switching its antenna between two states, short circuit and open, causing the antenna to reflect or absorb any signal reaching it. This effectively multiplies the signal reaching the antenna by the signal driving the switch. Consider a constant carrier of frequency f_c reaching the antenna while the switch is driven at a frequency Δf , the resulting signal is

$$2 \sin(f_c t) \sin(\Delta f t) = \cos[(f_c + \Delta f)t] - \cos[(f_c - \Delta f)t].$$

This means that the incoming carrier is shifted to new frequencies $f_c + \Delta f$ and $f_c - \Delta f$. Since the phase information from both signals is preserved, an incoming carrier can be modulated with sensor data. Specifically, a passive tag can transmit 802.15.4 packets by changing the phase of the signal that drives the switch while maintaining a constant frequency Δf . Modulating in this manner allows the 802.15.4 receiver to avoid interference from the unmodulated carrier.

Generating a carrier with commodity IoT devices. We leverage the test mode present in many commodity 802.15.4 transceivers to generate a carrier. This feature is intended for regulatory licensing but it suits our needs as the source of a constant carrier.

3. PASSIVE SENSOR TAG PROTOTYPE

Our prototype is based on the DE0-nano development board (Figure 2, left) [3] which features an Altera Cyclone IV FPGA. We implement in the FPGA all the logic to generate an 802.15.4 baseband signal for a given sensor payload. The sensor tag modulates the baseband signal on a carrier with an intermediate frequency $\Delta f = 10$ MHz. The resulting signal controls a GPIO pin that drives a simple backscatter transmitter consisting of a transistor switch (BFT25A) connected across the antenna terminals. When the pin is high, the switch is closed and incident radio waves are reflected, when the pin is low, incident radio waves are absorbed.

To query a sensor tag (Figure 1), an IoT device requests its neighbors to generate a carrier on a channel 10 MHz away from the current channel (i.e., two 802.15.4 channels

away). A 10 MHz spacing guarantees negligible interference of the carrier on the reception channel while keeping the intermediate frequency reasonably low. Neighbors that receive the request change to the indicated channel and generate a carrier for a fixed duration. Meanwhile, the requesting device stays on the original channel and receives the transmission from the passive sensor tag.

4. DEMO

We will demonstrate our prototype of a sensor tag that transmits 802.15.4 packets containing sensor data to unmodified IoT devices with no need for dedicated infrastructure. Our prototype leverages a carrier generated by the IoT devices themselves. We show that the sensor tag’s transmissions can be received by TMote Sky motes, widely used in research, and RedBee EconoTag nodes, another IoT platform with an 802.15.4 transceiver.

The demo will work as follows: The passive tag will periodically collect measurements from its sensor. Meanwhile, the receiving IoT device will request its neighbors to generate a carrier. The passive tag can then utilize this carrier to relay the value of its sensor to the nearby commodity device. The most recent sensor data received is displayed in a prominent way. The cycle is repeated continuously.

5. ONGOING RESEARCH

Our system, has no downlink communication to the passive tags. For now, querying for sensor data is done implicitly: the tag transmits its readings continuously but those transmissions are only effective in the presence of the unmodulated carrier. The request for unmodulated carrier acts as a query. Note that the process can be made more efficient once two-way communication is added to the tag.

Other open issues relate to medium access control and spectrum efficiency. We plan to study the impact of the carrier on other commodity devices and networks such as WiFi and Bluetooth, as well as on other passive sensor tags. As our passive sensor tags currently lack the ability to sense the wireless channel, developing a suitable medium access mechanism is challenging.

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