Poster: Towards Backscatter-enabled Networked Utensils

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ABSTRACT

Backscatter communication enables wireless transmissions at orders of magnitude lower power consumption when compared to conventional radio transceivers. This introduces novel opportunities for battery-free and ubiquitous sensing. We take advantage of backscatter communication to enable networked utensils. We imagine a scenario where such utensils can provide essential information about the state of the food or the beverage; for instance, the temperature or the quality of food contained in the utensils. We propose *flex* sensors, to achieve this capability, by augmenting utensils with flexible and inexpensive battery-free sensors that can communicate wirelessly. We demonstrate our efforts by designing a smart cup that tracks the temperature of beverage.

KEYWORDS

Temperature Sensing; Battery-free sensing; Backscatter

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1 INTRODUCTION

Recent years have seen a significant interest to develop battery-free IoT devices to allow for a widespread deployment in a sustainable manner. These devices would operate on minuscule energy harvested from surrounding sources such as light, radio-frequency (RF), and heat. Further, they would require little to no maintenance effort, which is commonly associated with battery-powered devices.

A key technology to enable the design of such sensors is RF backscatter, which, by reflecting incident wireless signals, provides transmissions at orders of magnitude lower power consumption when compared to conventional radios [2, 6, 7]. For instance, leveraging backscatter transmissions has led to novel battery-free devices such as cellphones [4], HD-cameras [3], and visible light sensing [5]. Moreover, RFID stickers have been used to monitor the quality and safety of food content by observing variations in backscattered signals [1]. In this poster, we build on the vision of Ha et al. [1], and we imagine everyday utensils having the capabilities to sense, interact and communicate with users. However, unlike their design which requires complex processing and expensive RFID readers for reception, we focus on using commodity transceivers for reception.

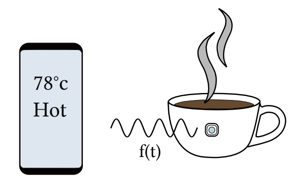

Figure 1: *What is the temperature of my coffee?* A flex sensor is attached to a coffee cup. It senses heat from the cup and communicates temperature readings to a smartphone using the spreadscatter mechanism.

We imagine a scenario like in Figure 1, where a cup notifies the user of the current temperature of a beverage, or if the beverage becomes too cold. To enable this scenario, we conceive the design of *flex* sensors. Flex sensors are self-powered sensors that are flexible, and in a sticker form factor, which allows them to be attached to objects to monitor properties of interest. However, this requires us to address the challenge of unrealiable FS-backscatter transmissions [7]. We address this by building on MIMO systems to design a novel communication mechanism, which we call *spreadscatter*.

In this paper, we present our effort; a flex sensor attached to a cup, which monitors the temperature of the beverage, and communicates its readings using spreadscatter to a user, as shown in Figure 1.

2 DESIGN

Overview. Our system works as follows: first, an edge device generates an unmodulated carrier signal to allow for backscatter transmissions. Next, the flex sensor harvests energy from temperature changes or ambient light to charge an on-board capacitor for self-powered operation. When powered, it monitors the temperature of the beverage by sensing heat radiated through the body of the cup. Finally, the flex sensor digitizes its readings using an ultra-low power ADC, then transmits the bits by encoding ones and zeros as the presence or absence of a frequency shifted carrier signal [7]. The edge devices, by performing energy detection (RSSI sampling), decodes and recovers bits from the transmissions to retrieve the current temperature of the beverage.

Sensing temperature. Flex sensors can be placed on the surface of a utensil, for instance a cup with hot liquid content, and monitor temperature changes from heat that is radiated through the body of the cup. However, this introduces a challenge, as measurements of temperature readings should not be influenced by ambient heat. Therefore, the sensor output has to be calibrated according to the temperature of the utensil. Hence, we perform an experiment to measure the analog output of the sensor at different temperature levels of a beverage, and compare this to the reference temperature measured using an IR thermometer. To sense temperature, we use

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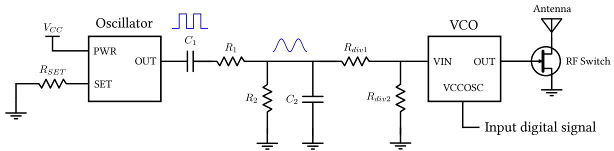


Figure 2: *Spreadscatter.* We spread the backscattered signal using a VCO to improve the reliability

an ultra-low power sensor (LM94021), whose analog output voltages correspond to temperature values. This experiment allows us to extract temperatures within a range, which for this particular beverage is between 25 °C to 100 °C. Next, we use a linear fit to approximate the voltage-to-temperature conversion function. Thus, we get the following equation:

$$T = -72v + 191 \,, \qquad (\star)$$

where T denotes temperature (°C), and v the voltage value. From this equation, we can proceed to extract the temperature at a given voltage level of the sensor. As an example, a sensor output of v =2.3 V corresponds to a temperature of around 25 °C. In the next section, we describe how we transmit the sensor readings.

Communication without processing. To achieve the lowest power, we avoid computational element [3, 4] and encode the sensor readings directly on backscatter transmissions. To achieve this capability, we build on FS-backscatter [5, 7], and transmit digitsed bits from the temperature sensor on frequency shifted carrier signal. Our mechanism works as follows: We digitize the analog output from the temperature sensor (LM94021) using an ultra-low power ADC (ADS7042). Next, the bits are used to control an osccillator (LTC6906) to enable or disable carrier shifting operation. In other words, when the input digital signal shows a '1', we shift the ambient carrier by the output frequency of the oscillator, and vice-versa. Finally, the edge device, performs RSSI sampling to reconstruct the temperature values.

One problem with the above scheme is that frequency shifted and amplitude modulated signals are prone to reliability issues. LoRea [6], and FS-backscatter [7], building on concept of MIMO, demonstrate that receiver diversity can improve the reliability. However, these systems require multiple devices to generate the carrier signal, which may not be feasible. Thus, we design *spreadscatter*, by building on insight that if we change the frequency of backscatter transmissions at a much higher rate than the rate at which we sample at the edge device, the received signal appear at multiple frequencies simultaneously, as shown in Figure 4(a). We achieve this by generating a spreading signal, and feed it to a voltage controlled oscillator (VCO), which controls the spreading frequency of backscattered signal. The mechanism is enabled or disabled through digitized bits obtained from the temperature sensor and the ADC. We show the schematic of our design in Figure 2.

Power consumption. We estimate the power consumption to be 161 µW, which is sufficient to be operated using harvested energy.

3 PRELIMINARY RESULTS

We investigate the ability spreadscatter to improve reliability of communication. We position a few receivers (CC1310) several meters away from the flex sensor. At the receiver, we perform RSSI sampling on distinct frequencies. Figure 4(b) shows high signal-to-noise ratio (SNR) where the spreaded signal is present. Next, we evaluate the ability to monitor temperature through heat radiated from the cup. We first attach the flex sensor to an empty cup. Next, we pour hot coffee in the cup, and keep track of the analog output of the sensor. Finally, we use Equation (⋆) to convert these values to temperatures. Figure 3 shows the temperature of the coffee over the course of its cooling process. We can to track the temperature of the beverage using our system, which demonstrates its feasibility.

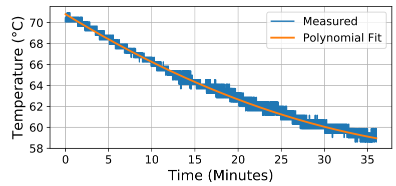
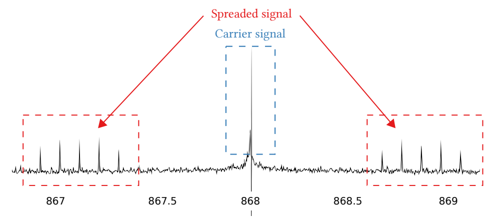
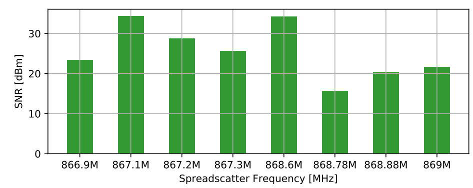


Figure 3: *Coffee monitoring.* We can monitor temperature of coffee through heat radiated from the cup.



(a) Spectrum



(b) Multiple receivers (RSSI)

Figure 4: We spread the backscattered signal to wider bandwidth, which enables us to improve the reliability through receiver diversity.

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