Poster: A Battery-free Backscatter Communication System for Non-persistent Carriers

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Abstract

We propose a strategy to increase data yield in battery-free backscatter communication systems. Backscatter communication technology relies on ambient radio frequency (RF) signals for low-power wireless transmission. However, the instability of ambient RF signals in diverse environments leads to low data yield and the risk of information loss. Additionally, the reliance of battery-free devices on erratic energy harvesting results in frequent and unanticipated energy failures, causing transmission interruptions. To address these issues, our approach incorporates an RF detector for signal strength detection and integrates non-volatile memory to checkpoint unsent packets during energy failures. The experimental results show that the proposed strategy achieves a high data yield even in scenarios with realistic energy and low carrier availability.

1 Introduction

Backscatter communication has emerged as a promising solution for wireless transmission of battery-free devices, due to its low power consumption. By leveraging ambient RF signals, this technology enables data transmission through selective reflection or absorption, achieving a power consumption in the order of microwatts [5]. We tackle two problems: non-persistent carriers and when energy from the environment is not consistently available.

Non-persistent Carriers. Ambient RF signals from TV and cellular communications are widely available in urban areas, but might not be of consistent strength in diverse environments (indoors, outdoors, day, and night). In situations where the signal strength is weak, backscatter transmission becomes infeasible. Unfortunately, many backscatter communication systems lack the functionality to detect the carrier signal. Consequently, a backscatter device does not know if a sufficiently strong ambient signal is available for successful communication, and transmitted data might be lost.

Energy Failures. Additionally, battery-free devices rely on ambient harvesting as their power source. Similar to the ambient signal, ambient energy is erratic, leading to frequent and unpredictable energy failures. In scenarios where the carrier signal is available but an energy failure occurs, the backscatter transmission might be interrupted, and the unsent packets stored in the main memory (volatile memory) will be lost.

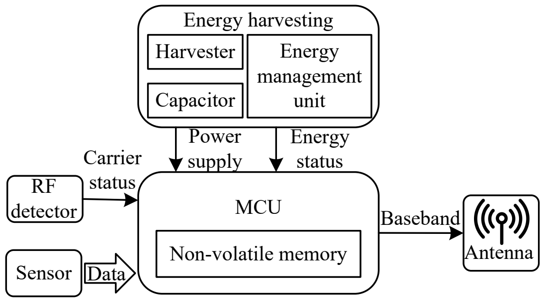


Figure 1: Overview of system architecture.

In summary, the uncertainty in ambient signals and ambient energy leads to data loss, and thereby low data yield.

Our solution. To address these problems, we propose a novel strategy, which aims to increase the data yield of battery-free backscatter communication systems operating in diverse carrier and energy environments. We achieve this by incorporating an RF detector into our system, enabling the detection of the available carrier strength for backscatter transmission. Additionally, we leverage concepts from intermittent computing [1] to store unsent packets to non-volatile memory (NVM) before energy failures.

2 Design

Fig. 1 provides a block diagram of our battery-free backscatter system. The system consists of three main components: a microcontroller (MCU), an energy harvesting system, and an RF detector. The MCU, based on the Cortex M0+ architecture, executes the proposed strategy in this work and is implemented using a Raspberry Pi Pico with attached flash memory. The energy harvesting system powers the entire system and reports the energy status to the MCU through the comparator in the energy management unit. When the voltage of the capacitor (V_c) falls below the threshold voltage (V_t), the energy management unit signals the MCU to indicate the energy stored in the capacitor is depleting. The threshold voltage is calculated based on the requirement for the checkpoint procedure in the worst-case scenario, where all packets stored in volatile memory need to be successfully checkpointed. The RF detector is responsible for detecting the ambient signals and indicating whether the current carrier signal is available or not [4].

The state machine diagram, depicted in Figure 2, illustrates the control flow of the proposed strategy. Upon powering the

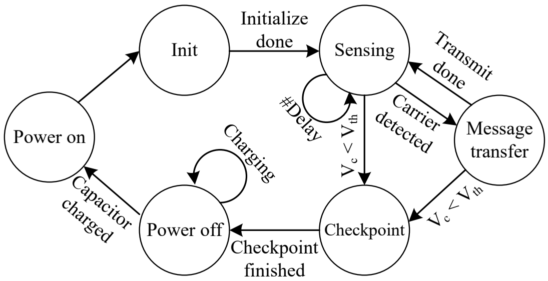
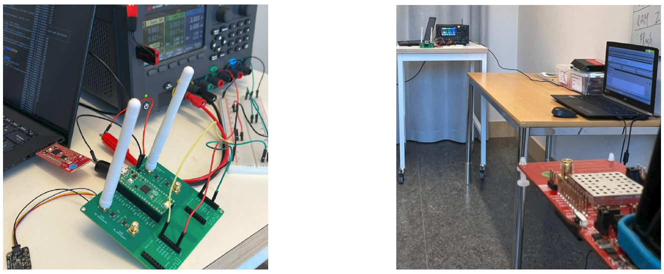


Figure 2: Software state machine.

system, the system starts in the initial state where all state variables are initialized. After initialization, the system enters the *Sensing* state, where it periodically requests information from the sensor and stores the data in the main memory of the MCU. Once the carrier is detected, the system moves to the *Message Transfer* state and starts the transmission task for the packets stored in the main memory and attached NVM buffer of the MCU. If the carrier signal persists for a duration longer than the transmission time and the energy remaining in the capacitor is still sufficient, the state machine returns to the *Sensing* state to continue sensing data and await the next available carrier. In the *Sensing* or *Message transfer* state, if the voltage of the capacitor (V_c) falls below the threshold voltage (V_t), indicating the capacitor's energy depletion, the state machine transitions to the *Checkpoint* state. The purpose of this state is checkpointing the sensor data stored in the main memory to the attached NVM buffer. Once the checkpoint procedure is completed, the system moves to the *Power off* state and resumes after the capacitor is fully charged.



(a) Backscatter tag, carrier generator, and digital power supply.

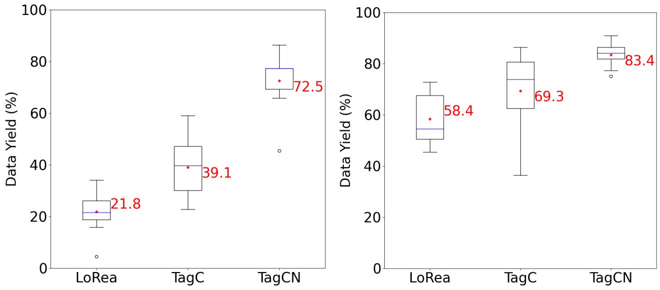
(b) Backscatter receiver.

Figure 3: Experimental setup.

3 Experiments

We devise our experiment based on the LoRea backscatter platform [3, 5]. To evaluate the effectiveness of our proposed strategy, we develop a system named TagCN and compare it with two different configurations of LoRea: a baseline and an advanced configuration. The baseline configuration is the original LoRea system, which lacks the ability to detect the ambient RF signal and checkpoint the unsent packets to flash. The advanced configuration, named TagC, is the system equipped with an RF detector and using our strategy but does not include the functionality to checkpoint the unsent packets to flash. The experimental setup, shown in Fig. 3, consists of a backscatter tag, carrier generator, digital power supply (Fig. 3a), and a backscatter receiver (Fig. 3b).

Experiment setting. To compare the performance of our strategy against the other configurations, it is important to maintain consistent ambient energy conditions for different configurations. To simulate the energy behavior, we use the actual energy trace data collected from a solar panel deployed on campus outdoor stairs [2] and use a digital power supply for energy simulation. The capacitor volume for the energy harvesting system is 40 mF. To model the varying active time and frequency of the available ambient carrier signal, we generate the carrier signal using the Poisson distribution with two different arrival rates, denoted as λ. This approach allows us to simulate different patterns of carrier availability in terms of active time and frequency.



(a) $\lambda = 0.25$

(b) $\lambda = 0.75$

Figure 4: Data yield under campus stairs energy trace.

Experiment results. In Fig. 4, we present the data yield for three different configurations based on a 2-hour campus stairs energy trace. For each configuration, we conduct 10 experiments and present the results using box plots, with the numbers in the figures highlighting the average data yield.

In Fig. 4a, the arrival rate of Poisson distribution is 0.25, i.e., a low frequency and active time of the carrier signal. The average data yield of LoRea, TagC, and TagCN are 21.8%, 39.1%, and 72.5%, respectively. The results show that the TagCN achieves the highest data yield among all configurations.

In Fig. 4b, the arrival rate of Poisson distribution is 0.75, indicating a high frequency and long active time of the carrier signal. As a result, LoRea achieves an average data yield of 58.4%, while TagC achieves 69.3%, both showing improved performance. In addition, our system, TagCN, outperforms them all with the highest average data yield of 83.4%. In summary, the experimental results show that the proposed strategy achieves the highest data yield, irrespective of the diverse carrier signal environments employed.

4 Conclusion

In this work, we propose a novel strategy to improve the data yield for battery-free backscatter systems. To evaluate the effectiveness of our approach, we perform experiments using an actual backscatter tag. On average, our results demonstrate a significant 37.9% improvement in the data yield compared to previous works.

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