Our Goal

Interactive devices that compute and communicate \textit{without} batteries
What We Are AFer

How to power computation, sensing, and communication?
Leverage Existing Wireless Signals

Available at almost any time and place, rain or shine
Recent Work Harvests 10s of $\mu$W [‘09]

- Enough for computation and sensing

- Orders of magnitude less power than needed for radio communication [‘13]
Challenge: Communication Between Battery--Free Devices

• Generating radio signals is expensive

• Could duty cycle
  – Limits interactive applications

Can we communicate without either device generating radio signals?
**Ambient Backscatter**

Use existing signals instead of generating our own

TV Tower

Works with only ~5% of the harvested power!

Bob  Alice

‘0’ bit – Absorb TV Signals
‘1’ bit – Reflect TV signals
Challenges
• Reader sends constant wave

• Receive chain: 100s of mW

• Reader centrally coordinates
RFID

• Reader sends **constant** wave
• Receive chain: **100s of mW**
• Reader **centrally** coordinates

Ambient Backscatter

• Uses **uncontrollable** signals
• Receive chain: **0.5 μW**
• Need **distributed** MAC
Challenges

• Extracting backscattered signals from ambient signals we don’t control

• Decoding on a battery--free device

• Designing distributed MAC for battery--free devices
Challenges

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How Do We Extract The Backscattered Signals?

Case 1: Alice absorbs
At Bob: TV signal

Case 2: Alice reflects
At Bob: TV signal + Weak Reflection

Alice’s reflections change the average amplitude
Solution: Detect Changes in Average Amplitude

- Alice Sends 1010...
- Alice Inactive

Moving Window Average
If we had digital samples, averaging would be easy

Need **power-hungry** analog-to-digital converters
Challenges

• Extracting backscattered signals from ambient signals we don’t control

• Decoding on a battery--free device

• Designing distributed MAC for battery--free devices
Use RC Circuits to Average

- Capacitor slowly charges/discharges when voltage is applied/removed

Provides a cheap, analog, exponential moving average
Use RC Circuits to Average

- Capacitor slowly charges/discharges when voltage is applied/removed

By picking the right RC values, we can selectively filter out the high TV frequencies.
Now that we can decode bits...

- Link Layer
- Physical Layer
- Distributed MAC?
Challenges

• Extracting backscattered signals from ambient signals we don’t control

• Decoding on a battery--free device

• Designing distributed MAC for battery--free devices
We Use CSMA

• CSMA uses carrier sense, i.e. energy detection

• Battery-free devices do not have energy levels
  – Requires power-hungry ADCs

Challenge: Energy detection without access to the energy levels
Solution: Leverage Hardware Properties for Energy Detection

1. RC circuit filters out the TV signals
   ➔ Removes high-amplitude variations

2. In the absence of backscattering, we see a constant output
Solution: Leverage Hardware Properties for Energy Detection

- No backscatter => See all 0s or all 1s
- Backscatter => See many transitions
- Use bit transitions as proxy for energy detection
Evaluation
Prototype Using Off-the-Shelf Components

- Battery--free
- Harvests and backscatters TV signals at 539 MHz
- Microcontroller performs computation
Tested Locations

• Seattle area with a 1MW TV tower at 539 MHz

• Indoor and outdoor environments

• Distances up to 10.5 km from the TV tower
  – TV power ranged between –24dBm and –8dBm
What Bit Rates Can We Achieve?

• Three bit rates: 10kbps, 1kbps, 100bps

• BER versus distance between two devices
What Bit Rates Can We Achieve?

These results show the feasibility of Ambient Backscatter
Applications
Identifying Misplaced Items
In Grocery stores or Warehouses (e.g., Amazon)

• With ambient backscatter, devices can figure out they are misplaced on their own

• We built a preliminary system with cereal boxes
Identifying Misplaced Items
In Grocery stores or Warehouses (e.g., Amazon)

Works even if not all tags are in range of a reader
Conclusion

• We develop
  – The first primitive that enables communication without either device generating RF signals
  – A battery-free hardware prototype that computes and communicates using only TV signals

• We transform existing signals into both a power source and a communication medium
  – Opens up new research opportunities

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Video demo