Backscatter and Ambient Communication

Yifei Liu
Outline

1. Introduction
2. Ambient Backscatter
3. WiFi Backscatter
4. Passive WiFi Backscatter
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Introduction

- Backscatter: The reflection of signals waves back to direction from which they came.
- Complex computing function unit are increasingly embedded in tiny applications such as wristband, medical devices. But there is no more room for wires and batteries.
- System harvests power in whole band for computation and communication.
- A new communication primitive where devices communicate by backsttering ambient WiFi Signals.
Concept of Backscatter

- Reflect existing signals in a way to transmitted information:
  - Inductive modulation: low frequency
  - Backscatter modulation: high frequency
- Commonly used by RFID:
  - Limited computation in RFID chip.

Image credit: http://www.erplan.it/rfid/
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Ambient Backscatter: Introduction

Similar to RFID but
1. Doesn’t require specific power infrastructure.
2. Works by modulating the reflection of an existing RF signal.
3. No interference with legacy devices.
4. Backscattering is achieved by changing the impedance of an antenna in the presence of an incident signal.
Ambient Backscatter: Challenge

1. The ambient signals are controlled by the sender, TV, WiFi, etc.
   a) Variational signal
   b) Signal encoded
   Solution: slow down the ambient signal. How?
   a) Average the received signal across multiple samples.
Ambient Backscatter: Challenge


![RC Circuit Diagram]

Ambient Backscatter: Challenge

3. Collision if many devices need to share the channel.
   Solution:
   a) Devices can decode each other’s transmissions.
   b) Energy detection by leveraging the property of the analog comparator.

\[ D = 1 - \frac{|\#\text{ones} - \#\text{zeros}|}{\#\text{ones} + \#\text{zeros}} \]

Detection equation
The transmitter, receiver, and the harvester are all connected to a single antenna and use the same RF signals.

The harvester collects energy from the ambient signals and uses it to provide the small amount of power required for communication and to operate the sensors and the digital logic unit.

Backscatter transmitter includes a switch that modulates the impedance of the antenna and causes a change in the amount of energy reflected by the antenna.
Ambient Backscatter: Prototype

- Battery free.
- Harvest energy from TV signals at 539mHz
- 1Kps at 76cm
- MSP430 controller

### Power Consumption of Analog Components

<table>
<thead>
<tr>
<th></th>
<th>Tx</th>
<th>Rx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Backscatter</td>
<td>0.25uW</td>
<td>0.54uW</td>
</tr>
<tr>
<td>Traditional Backscatter</td>
<td>2.32uW</td>
<td>18uW</td>
</tr>
</tbody>
</table>
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WiFi Backscatter: Motivation and Challenges

Motivation:
WiFi connectivity for low power devices.

Challenges:
- WiFi transmission require much more energy than other RF applications.
- WiFi devices can only access WiFi signals.

Ref: “Wi-Fi Backscatter: Internet Connectivity for RF-Powered Devices”, Bryce Kellogg, etc
WiFi Backscatter: Components

- Three Actors:
  - WiFi reader (WiFi device)
  - WiFi helper (AP)
  - WiFi backscatter tags

- Two connection link:
  - Downlink: Reader to Tag
  - Uplink: Tag to Reader
WiFi Backscatter: Uplink

- Modulation: Transmit data by modulating the WiFi channel. Reflected signal depends on the antenna's impedance. Modulates only when queried by reader. Doesn’t change the channel within every WiFi Packet.
- CSI extraction:
  1. Moving average filter to remove temporal variations.
  2. Use correlation with preamble to find out good sub-channels.
  3. Use weighted average to combine sub-channel information.
- CSI decoding:
  Apply simple threshold on the weighted CSI.
- Decoding using RSSI:
  Choose channel with max correction value.
WiFi Backscatter: Downlinks

Challenges:
- Wifi Reader can only transmit Wi-Fi packets.
- Tag cannot decode WiFi transmissions.

Solution
- Encode information with the presence and absence of Wi-Fi packets.
- Circuit in tag can detect energy during a packet transmission
WiFi Backscatter: Implementation

- Uplink: How to work with WiFi network?
  Solution: be agnostic to WiFi traffic.

Use Wi-Fi timestamp to reconstruct bits
WiFi Backscatter: Implementation

- Downlink: How to send data to the tag?
  Solution: Encode data as presence/absence of WiFi packet
WiFi Backscatter: Implementation

- **Downlink**: How the tag is detecting these Wi-Fi Packets.
  Solution: 2. Low power packet detection based on OFDM PAR.

Can detect packets as short as 50 µs
Consumes µWs of power
WiFi Backscatter: Implementation

- How to deal with multi TAGS?
  Solution: 1. WiFi device act as a central coordinator.
             2. None of tags transmit concurrently
WiFi Backscatter: Prototype

2.4G WiFi channel with RSSI and CSI

Intel 5300 Wi-Fi Cards

Wi-Fi Backscatter Prototype

<table>
<thead>
<tr>
<th>MSP430</th>
<th>RF switch</th>
<th>Peak Finer</th>
</tr>
</thead>
<tbody>
<tr>
<td>5uW</td>
<td>0.65uW</td>
<td>9.0uW</td>
</tr>
</tbody>
</table>

Uplink: 2.2 meters, 1kps
Downlink: 3.0 meters, 20kbps
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Passive WiFi Backscatter: Introduction

Key idea:
- Decouple the baseband digital logic from the power-consuming RF components.
- Perform coding and modulation in baseband.
- Create 802.11b transmissions by reflecting or absorbing the tone using digital switch.

Ref: Passive Wi-Fi: Bringing Low Power to Wi-Fi Transmissions. Bryce Kellogg
Passive WiFi Backscatter: Challenges

- Interference between backscattered signal and plug-in device.

Solution:
1. Traditional system uses a full-duplex radio.
2. Set the plugged in device’s frequency outside the desired WiFi channel.
Passive WiFi Backscatter: Challenges

- Create 802.11b transmissions using backscatter.
  Solution:
  1. Shift the out-of-band tone from plugged-in device to desired channel. Sinusoidal signal multiplication.
  2. Use DSSS and CCK encoding on top of DBPSK and DQPSK modulation.
  3. Approximate a digital square as sinusoid and modulate phase.
Challenges

- Sharing the WiFi network.

Solution:
1. Delegate the task of carrier sense to the plugged-in device.
2. Share the ISM band.
3. ACK and re-transmission
Implementation

- FPGA Prototype:
  - Altera Cyclone II
  - Custom backscatter switch
  - 2-11 Mbps WiFi and 250 kbps Zigbee IC

- Implementation
  - Verilog baseband, RF switch, custom PLL
  - TSMC 65nm Lower power Process
  - 28 µW at 2 Mbps

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<thead>
<tr>
<th></th>
<th>1 Mbps</th>
<th>11 Mbps</th>
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</thead>
<tbody>
<tr>
<td>Baseband Frequency Synthesizer</td>
<td>5.6 µW</td>
<td>5.6 µW</td>
</tr>
<tr>
<td>Baseband Processor</td>
<td>5.0 µW</td>
<td>48 µW</td>
</tr>
<tr>
<td>Backscatter Modulator</td>
<td>3.9 µW</td>
<td>5.6 µW</td>
</tr>
<tr>
<td><strong>Total Power</strong></td>
<td>14.5 µW</td>
<td>59.2 µW</td>
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Questions?