ECE 463: Digital Communications Lab.

Lecture 12: IoT II: Backscatter
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Previous Lecture:

✓ IoT Intro.
✓ Spread Spectrum
✓ Chirp Spread Spectrum
✓ Low Power Wide Area Networks

This Lecture:

☐ Backscatter Communication
☐ RFIDs
☐ NFC
IoT: Backscatter Communication

- Low power: No Battery
- Low cost: 10 cents
- Low range: 10 – 15 meters
- Low Data rates: 10Kbps – 640 Kbps
RFID: Radio Frequency Identification

Active RFID
- Has battery
- Longer range
- Shorter life span
- Transmits its own signal using OOK

Battery Assisted RFID
- Has battery
- Battery used from computation & sensing but not communication
- Backscatters a reader’s signal using OOK

Passive RFID
- No battery
- Short range
- Long life span
- Backscatters a reader’s signal using OOK
RFID: Radio Frequency IDentification

Passive RFID

HF (Same as NFC)  UHF

125 kHz / 134 kHz  13.56 MHz  860 ~ 960 MHz
RFID: Radio Frequency IDentification

HF (Same as NFC)
- Range: < 1cm
- Data Rate: bps to few kbps
- Technology: Backscatter over Inductive Coupling

UHF
- Range: Few meters
- Data Rate: 100s kbps
- Technology: Backscatter over RF

125 kHz / 134 kHz
13.56 MHz
Backscatter Communication

• A flashlight emits a beam of light

• The light is reflected by the mirror

• The intensity of the reflected beam can be associated with a logical “0” or “1”
Backscatter Communication
Backscatter Communication

Reader shines an RF signal on nearby RFID tags. Tags reflect the reader’s signal using ON-OFF keying.
Backscatter Communication

Switch “Off”

Antenna Switch

Switch Controller

Energy Harvester

Switch “On”

Energy Harvester

Switch Controller
RFID: Energy Harvester

\[ V_{\text{in}} \]

Diagram:
- Positive input (+)
- Ground (Gnd)
- Capacitors (C_1, C_2)
- Diodes (D_1, D_2)
RFID: Energy Harvester

\[ V_{in} \]

\[ C_1 \quad D_2 \quad D_1 \quad C_2 \]

\[ Gnd \quad Gnd \]

\[ V_{in} \quad \text{wavy line} \quad Gnd \]

\[ -V_S \]
RFID: Energy Harvester
RFID: Energy Harvester
RFID: Energy Harvester
Multi-Stage Energy Harvesters can be used to amplify the voltage. (N stages $\rightarrow$ NVs)
Backscatter Communication

- Reader Transmits Continuous Sine Wave

\[ x(t) = \cos(2\pi f_c t) \]

- Tag either reflect or doesn’t reflect the signal

\[ s(t) = \begin{cases} 
\alpha \cos(2\pi f_c t) & \text{bit} = 1 \\
0 & \text{bit} = 0 
\end{cases} \]

- \( \alpha \) is reflection coefficient \( \alpha \ll 1 \)

- Reflection can be 70dB to 90dB weaker than transmitted signal.
Backscatter Communication

• Reader Receives

\[ y(t) = h_s x(t) + h_t s(t) \]

• \( h_s \) is self-interference channel

• \( h_t \) is composite channel (Reader-to-Tag and back Tag-to-Reader)

\[ y(t) = (h_s + b\alpha h_t) \cos(2\pi f_c t) \]
Backscatter Communication

- Reader Receives

\[ y(t) = (h_s + b\alpha h_t) \cos(2\pi f_c t) \]
Backscatter Communication

• Reader Receives

\[ y(t) = (h_s + b\alpha h_t) \cos(2\pi f_c t) \]

• Reflection can be 70dB to 90dB weaker than transmitted signal.

• Reader must cancel self-interference to be able to decode.

• Reader uses a full-duplex radio
  o Can transmit and receiver at the same time!
  o Cancels Self-Interference Signal

\[ y'(t) = b\alpha h_t \cos(2\pi f_c t) \]
Full Duplex Radios

• Radios are typically half duplex: Cannot transmit and receive at the same time

What happens if we transmit and receiver at the same time?
Full Duplex Radios

- Radios are typically half duplex: Cannot transmit and receive at the same time

What happens if we transmit and receive at the same time?

Self-Interference
Full Duplex Radios

- Radios are typically half duplex: Cannot transmit and receive at the same time

(1) Self-Interference saturates the Amplifiers & ADCs
(2) Self-Interference results in negative SINR of RX signal
(1) Self-Interference saturates the Amplifiers & ADCs

(2) Self-Interference results in negative SINR of RX signal

- Radio knows the self-interference signal \( \rightarrow \) Can cancel it out
(1) Self-Interference saturates the Amplifiers & ADCs
(2) Self-Interference results in negative SINR of RX signal

- Radio knows the self-interference signal → Can cancel it out
- For RFID: self-interference is a single sine wave → Easy to filter
- For Classical Radios: self-interference is wideband → Harder to cancel
Backscatter Communication

• Both Reader and Tag Use ON-OFF Keying for modulation

• Bit Encoding, however, can differ.

• Reader-to-Tag Encoding: Pulse Interval Encoding (PIE)
Backscatter Communication

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Backscatter Communication

- Reader-to-Tag Encoding: Pulse Interval Encoding (PIE)

**Why use PIE encoding?**

Signal is on for longer time

Maximize energy harvesting at the tag.
Backscatter Communication

• Tag-to-Reader Encoding:
  • FM0
  • Miller Code (M=2, 4, 8)
Backscatter Communication

• Tag-to-Reader Encoding: FM0
• Inverts the switch at every symbol
• 0 bits has extra switch mid-symbol
Backscatter Communication

• Tag-to-Reader Encoding: Miller
• Inverts the switch between two consecutive 0 bit symbols
• Inverts the switch in the middle of 1 bit symbol
• Multiple by square wave of M times symbol rate for M=2,4,8
Backscatter Communication

- Tag-to-Reader Encoding: Miller
- Inverts the switch between two consecutive 0 bit symbols
- Inverts the switch in the middle of 1 bit symbol
- Multiple by square wave of M times symbol rate for M=2,4,8
Backscatter Communication

• Tag-to-Reader Encoding:
  
  • FM0: High Data Rate: 40 Kbps- 640 Kbps
  
  • Miller Code (M=2, 4, 8)
    
    o Multiple switches per bit.
    o Robust to Multi-Reader, Multi-Tag scenarios.
    o Robust to noise.
    o M=2, Data Rate: 20 Kbps – 320 Kbps
    o M=4, Data Rate: 10 Kbps – 160 Kbps
    o M=8, Data Rate: 5 Kbps – 80 Kbps