Backscatter and Ambient Communication

18-452/750 Wireless Networking, Spring 2018

Jingxian Wang & Akshay Gadre

18 April 2018

1

Overview

- Motivation
- What is Backscatter?
- Ambient vs. RFID-style backscatter
- Challenges
- Applications
  - Compatibility with commodity devices
  - Long-range Backscatter
  - Sensing Capability

2

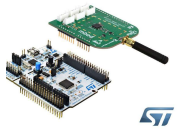
Motivation

- Generation of signals is power-hungry
- Ambient signals exists in the environment


TV


Cellular

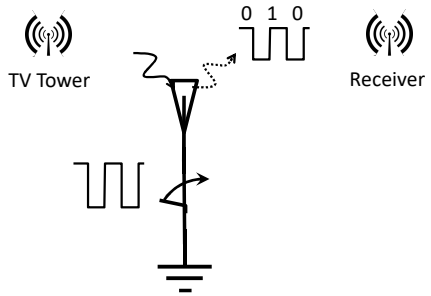

Wi-Fi


LPWAN

Can we harvest power from the existing signals in the air to communicate and sense environment without a battery?

3

Backscatter Communication



'0' bit – Absorb Ambient Signals
'1' bit – Reflect Ambient Signals

Courtesy: **Ambient Backscatter** [ACM SIGCOMM 2013]

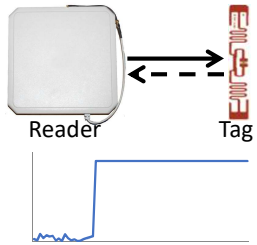
4

Ambient vs. RFID-styled Backscatter

Ambient Backscatter	RFID-styled
○ Uncontrolled signal source	○ Initial interrogator
○ Distributed Communication	○ Centralized Communication
○ Customizable hardware for multiple applications	○ Commodity chip
○ Application-specific protocol	○ EPC GEN 2 RFID Protocol

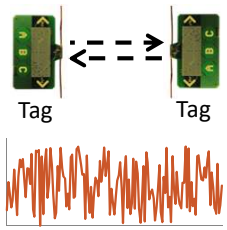
5

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

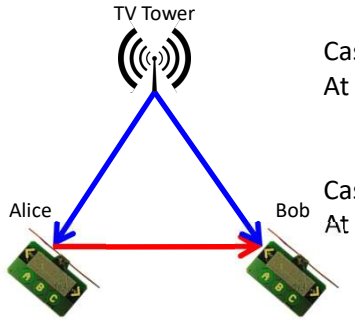
6

Ambient Backscatter Challenges

- Extracting backscattered signals from ambient signals we do not control
- Decoding on a battery-free device
- Designing distributed MAC for battery-free devices

7

How to Extract The Backscattered Signals?



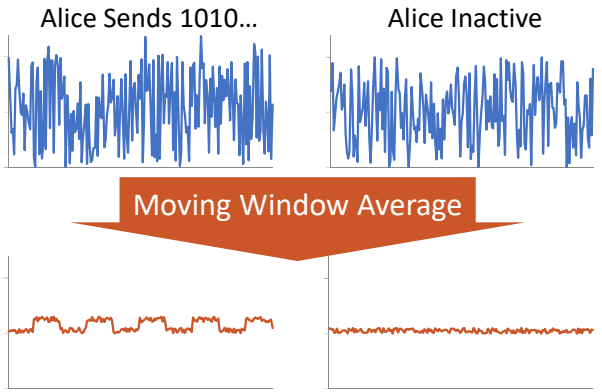
Case 1: Alice absorbs
At Bob: TV signal

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

Reflections of Alice change the average amplitude

8

Solution: Detect Changes in Average Amplitude



9

If we had digital samples, averaging would be easy

Need power-hungry analog-to-digital converters

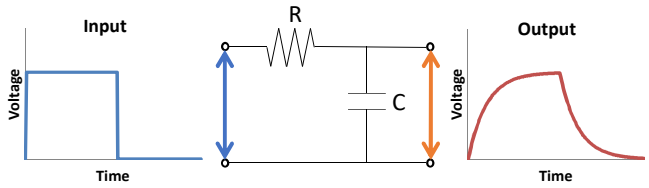
10

Ambient Backscatter Challenges

- Extracting backscattered signals from ambient signals we do not control
- Decoding on a battery-free device
- Designing distributed MAC for battery-free devices

11

Use RC Circuits to Average

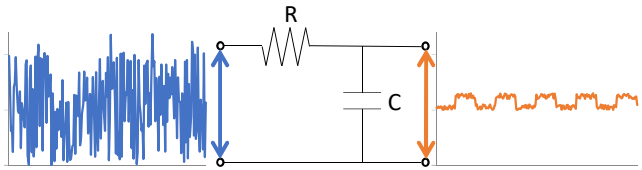


- Capacitor slowly charges/discharges when voltage is applied/removed

Provides a cheap, analog, exponential moving average

12

Use RC Circuits to Average

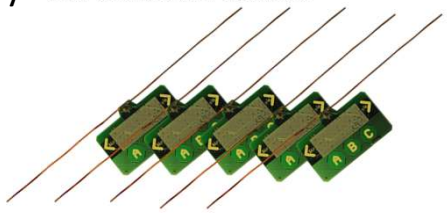


- Capacitor slowly charges/discharges when voltage is applied/removed

By picking the right RC values,
we can selectively filter out the high TV frequencies

13

Once they can decode bits…



Link Layer
Physical Layer

Distributed MAC?

14

Ambient Backscatter Challenges

- Extracting backscattered signals from ambient signals we do not control
- Decoding on a battery-free device
- Designing distributed MAC for battery-free devices

15

Use CSMA to Avoid Collision

- CSMA uses carrier sense, i.e. energy detection
- Battery-free devices do not have energy levels
  - Requires power-hungry ADCs

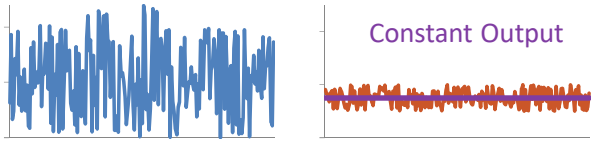
Challenge: Energy detection
without access to the energy levels

16

Solution: Leverage Hardware Properties for Energy Detection

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

In the absence of backscattering, we see a constant output



17

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

18

Application:
Inter-technology Backscatter

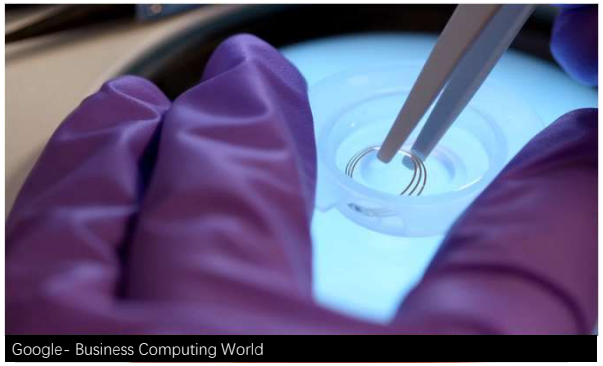
19

Brain implants for reanimation of limbs

20

Courtesy: Inter-Technology Backscatter [ACM SIGCOMM 2016]

Contact lenses that measure blood sugar

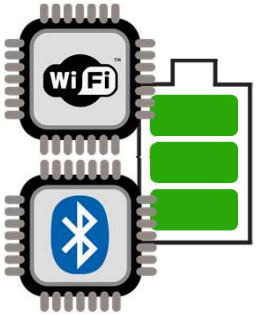


21

Can implanted devices talk to smartphones?

22

Conventional radios consume too much power



Replacing implant batteries requires surgery

23

Problem: Creating RF signals is power expensive

Solution: Recycle RF signals from external devices

24

Interscatter Communication

Recycle Bluetooth signals to create WiFi

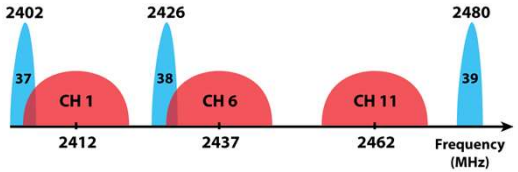
Creates WiFi packets for 28 μW of power

25

Problem: Bluetooth and WiFi are different protocols

Challenge 1: Different modulation

Challenge 2: Different frequencies and bandwidth



Solution

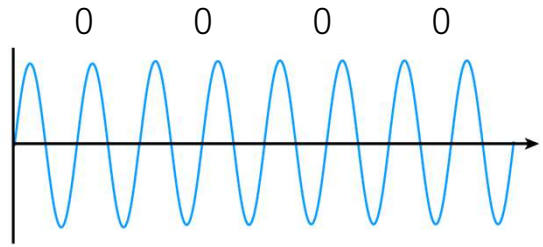
Step 1: Convert the bluetooth signal to a monotone signal

Step 2: Convert the monotone signal to a WiFi packet

27

How do we convert a bluetooth signal to a monotone signal?

- **Bluetooth uses frequency shift keying**

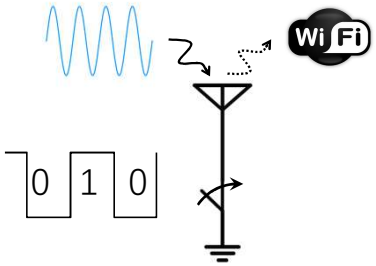


Solution: Create a monotone by sending the same bit repeatedly

28

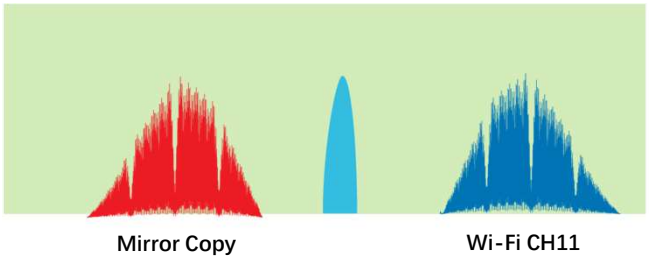
How do we convert a monotone signal to a WiFi Packet?

- Use Passive WiFi (NSDI '16) (out of scope of this presentation)



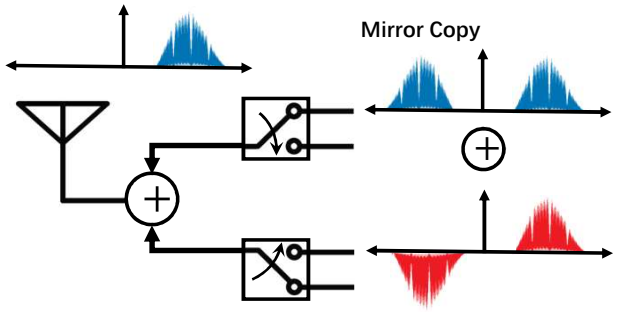
29

Problem: Mirror image outside ISM Band



30

Solution: Cancel mirror copy using two switches



31

Application: LoRa Backscatter

32

Hypothesis: No technology exists today which satisfy these requirements

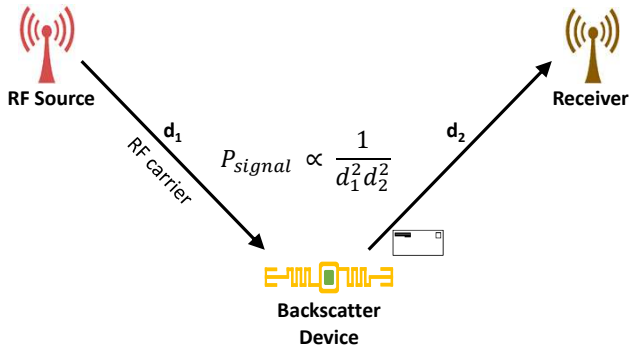
Active Radios	RFID
✗ $2-$4 price point	✓ Costs <10 cents
✗ Consumes 10-1000 mW	✓ uW power budget
✗ Incompatible with printed batteries & require external components	✓ Small flexible sticker form factor & low peak currents
✓ Wide area coverage including through wall propagation	✗ Short range and does not work through walls and obstacles

Can we get the best of both worlds?

Courtesy: LoRa Backscatter [ACM UbiComp 2017]

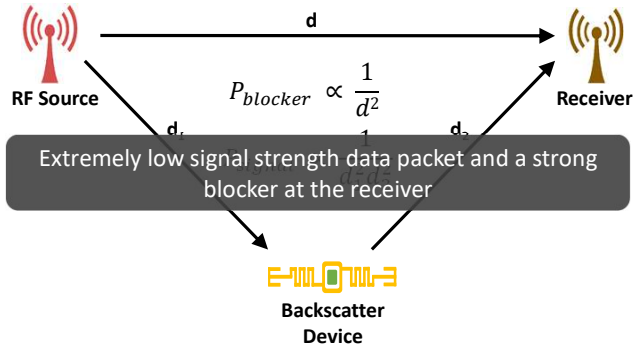
33

Challenge: Signal Propagation in Backscatter Systems



34

Challenge: Signal Propagation in Backscatter Systems



Extremely low signal strength data packet and a strong blocker at the receiver

35

Our Solution: Clean slate design of backscatter system

- Use coding to achieve optimal tradeoff between sensitivity and data rate
- Modulation scheme resilient to single tone interference

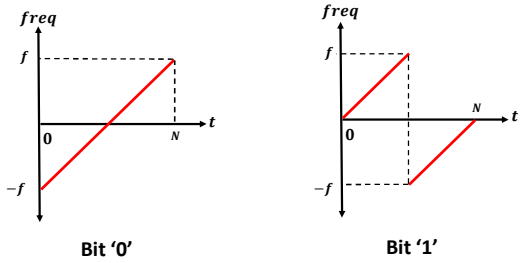
Chirp Spread Spectrum Modulation

- Decode signals down to -148 dBm
- 50 bps to 32.5 kbps data rates
- Blocking immunity of 90 dB

36

Chirp spread spectrum modulation

Linearly vary the frequency of the carrier with time



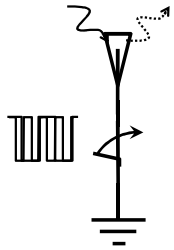
Bit '0' Bit '1'

Data is encoded in cyclic shifts of frequency

37

Synthesize CSS using backscatter

Linearly vary the frequency of the square wave at the backscatter switch



38

Application:
WiSh: Wireless shape sensing using passive RFIDs

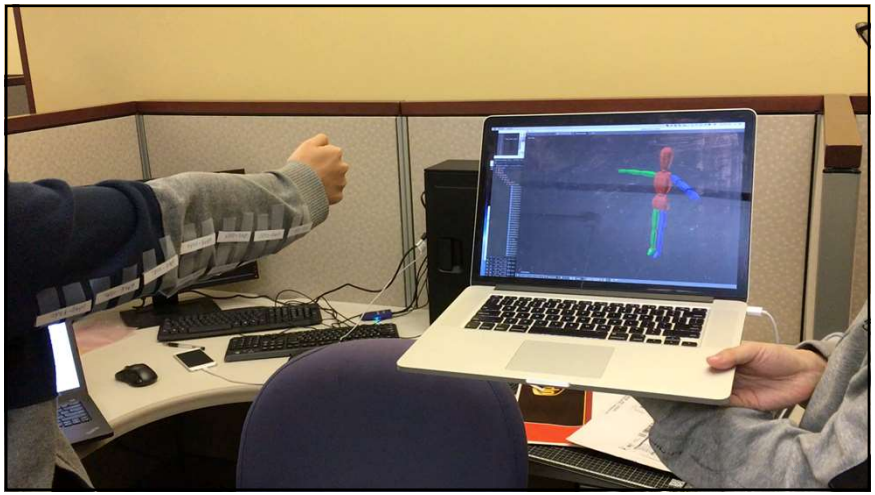
39

Courtesy: WiSh [ACM MOBISYS 2018]

Application:
RF-Wear

Courtesy: RF-Wear[ACM UBICOMP 2018]

41



Thank you!

- Question?

43