FreeRider: Backscatter Communication Using Commodity Radios

Pengyu Zhang[1], ***Colleen Josephson[1]***, Dinesh Bharadia[2], Sachin Katti[1]
Stanford University[1], UCSD[2]

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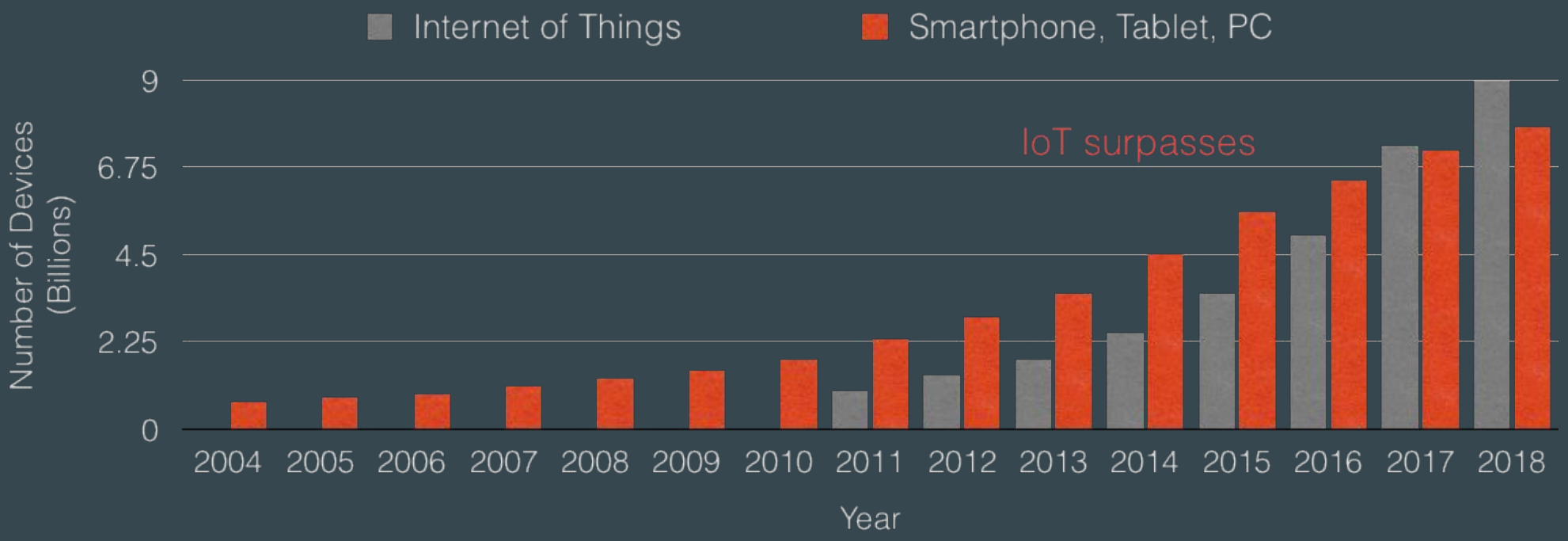
IoT Explosion



Data source: http://www.businessinsider.com/internet-of-things-billions-of-connected-devices-2014-1
https://www.gartner.com/newsroom/id/3598917

IoT has different needs than traditional devices

- Long battery a priority
- Must be small and durable
- Data needs usually modest

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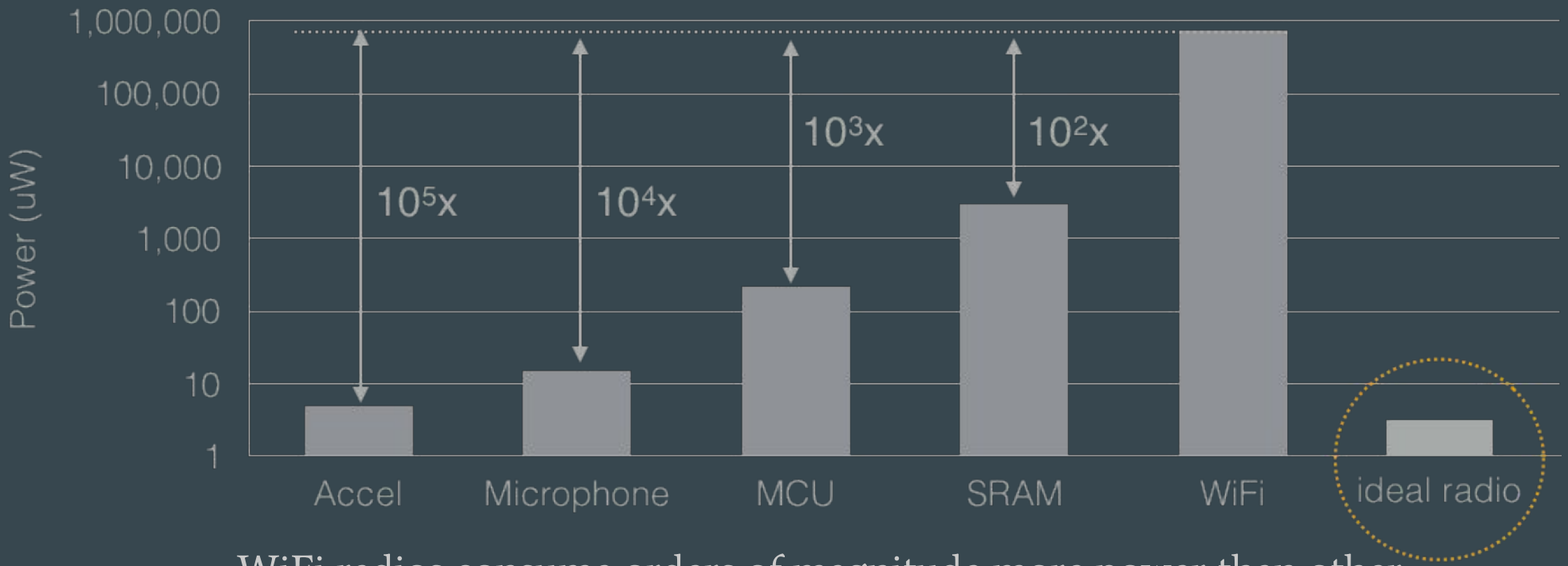
Power consumption in embedded systems

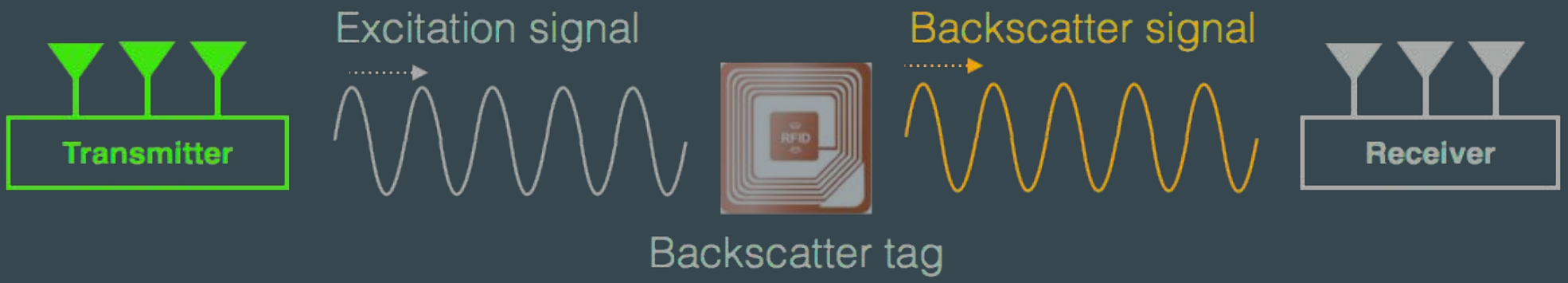


WiFi radios consume orders of magnitude more power than other system components!

Low Power Options

- Duty cycling (Bluetooth)
- Super-Narrowband communications (NB-IoT cellular)
- Passive communication (backscatter)
  - Lowest power
  - RFID

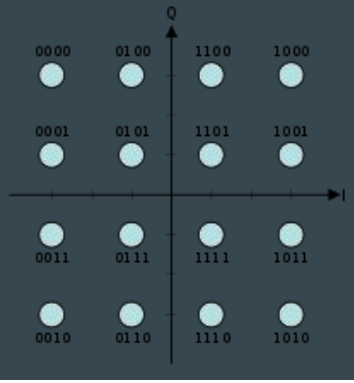
Backscatter primer



Productive vs. Non Productive Excitation

- Non-productive excitation: fixed sinusoidal
  - RFID, Passive WiFi, Interscatter

- Productive excitation: excitation signal contains real data
  - Transits both data and a backscatter communication medium
  - HitchHike, Ambient Backscatter and ***FreeRider***



FreeRider — use existing WiFi, ZigBee and Bluetooth radios to enable productive backscatter communication

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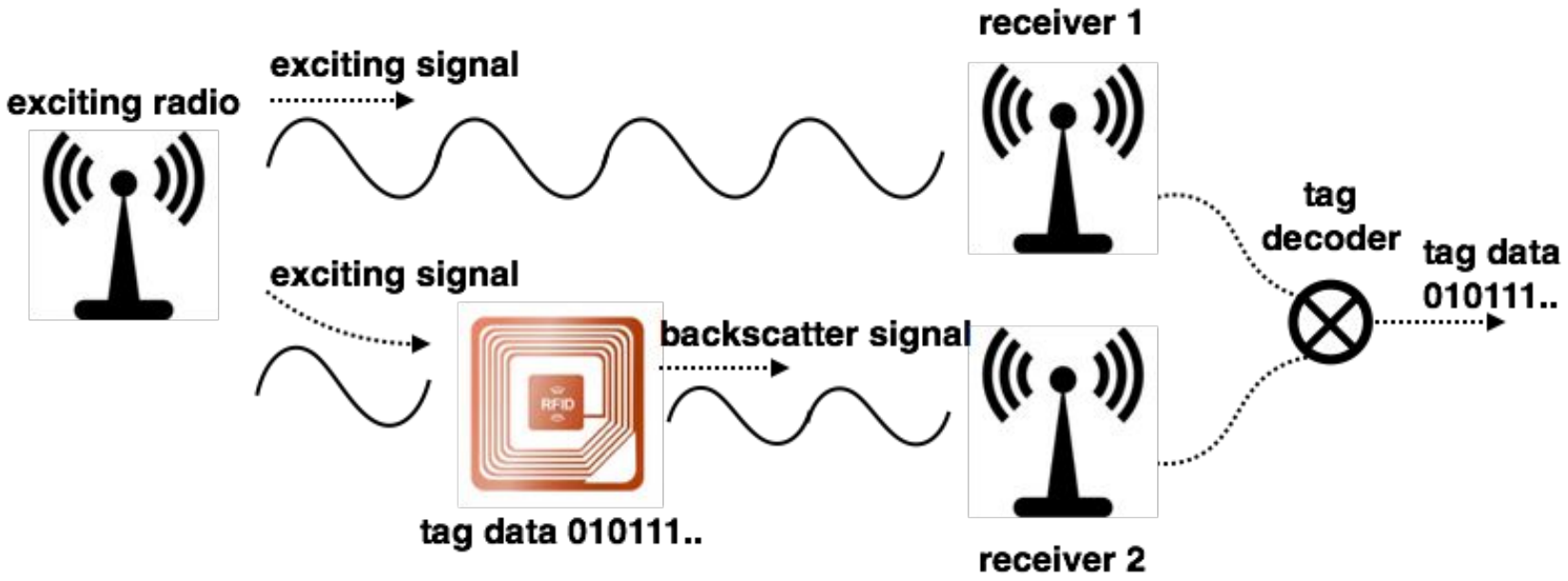
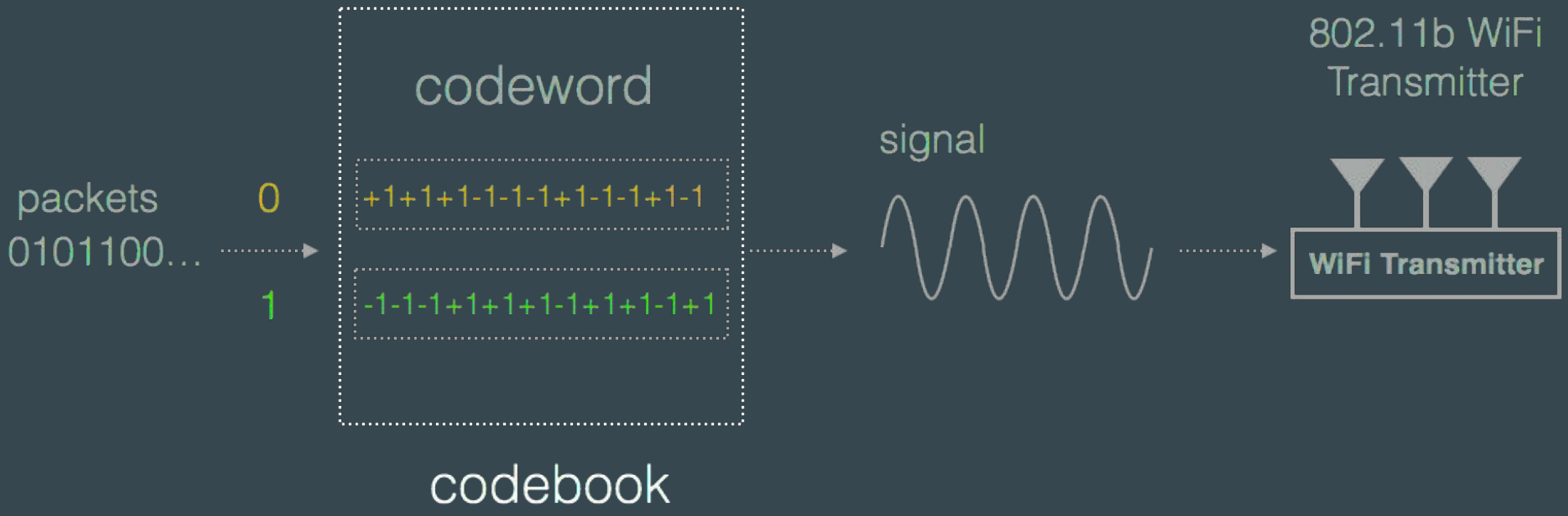
FreeRider System Overview



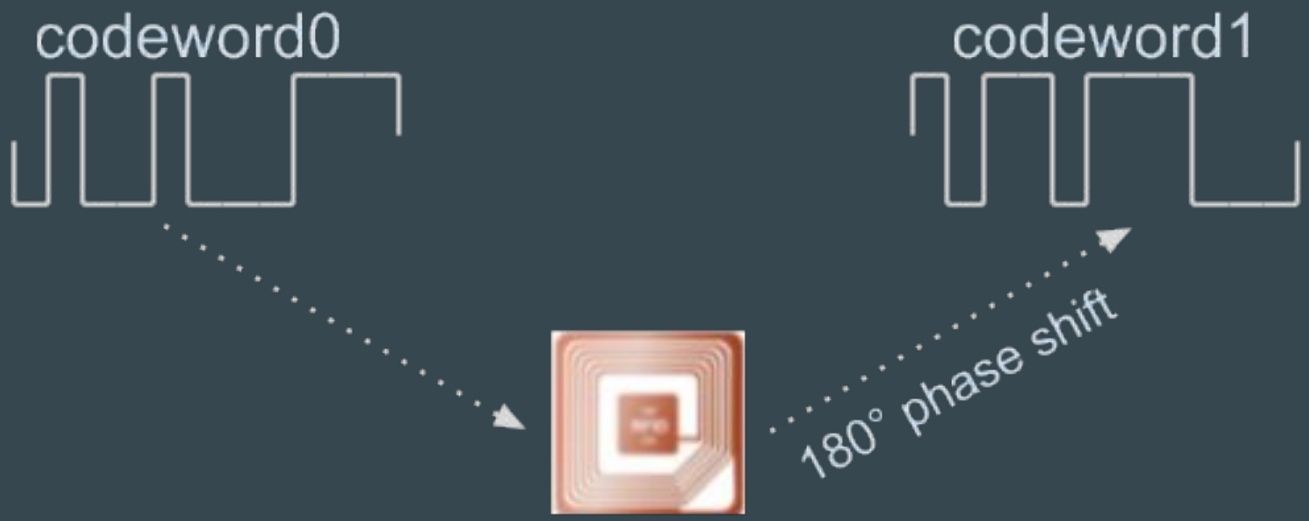
Receivers compare backscatter signal with excitation signal to extract tag data

Codewords



WiFi, Zigbee and Bluetooth use a finite set of codewords to represent 0s and 1s

Codeword translation



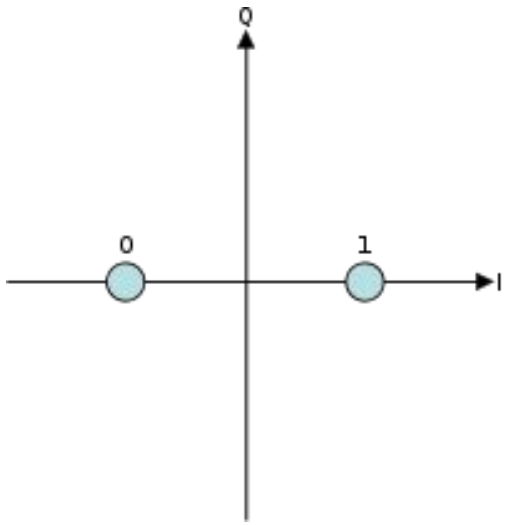
One valid codeword translated to another.
This allows commodity radios to receive backscatter

How to encode information? A binary example

Original excitation codeword	Backscattered codeword	Decoded tag data
C_1	C_1	0
C_1	C_2	1
C_2	C_1	1
C_2	C_2	0

Case study: 802.11g/n codeword translation

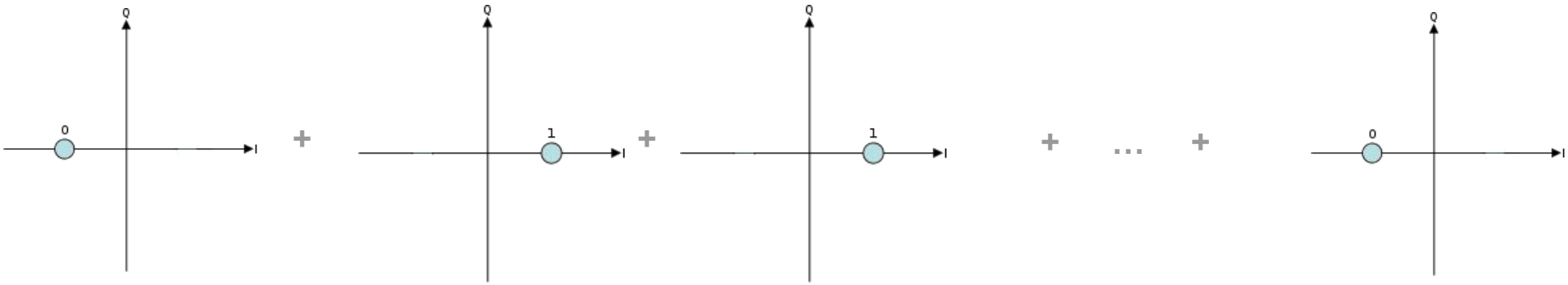
- OFDM has 52 subcarriers
- 6Mbps rate uses BPSK subcarrier modulation



BPSK subcarrier

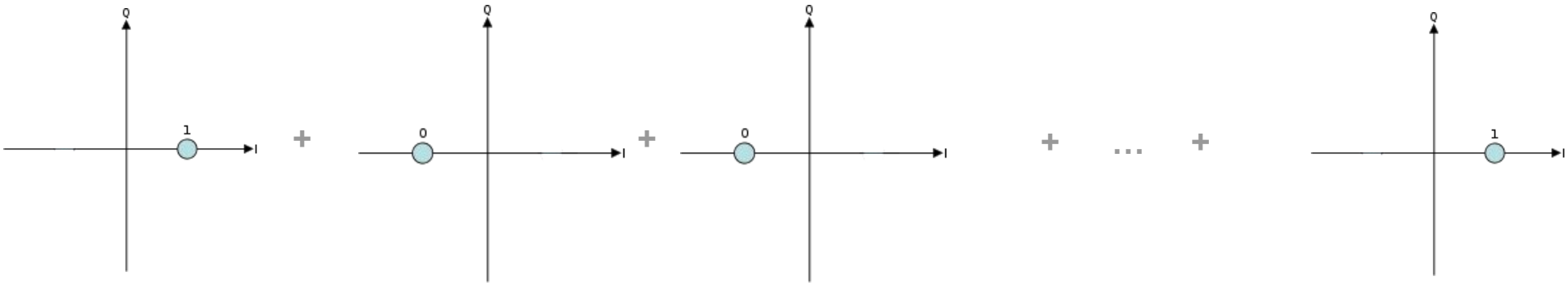
OFDM binary codeword translation

Original codeword:



OFDM binary codeword translation

180 degree translation:



subcarrier 1 subcarrier 2 subcarrier 3 subcarrier 52

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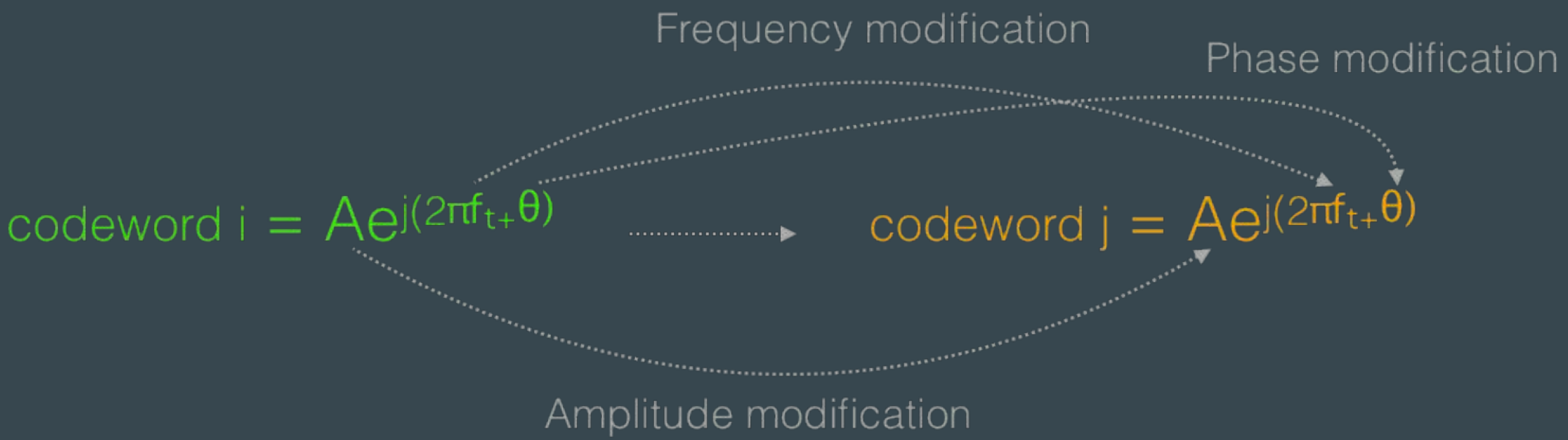
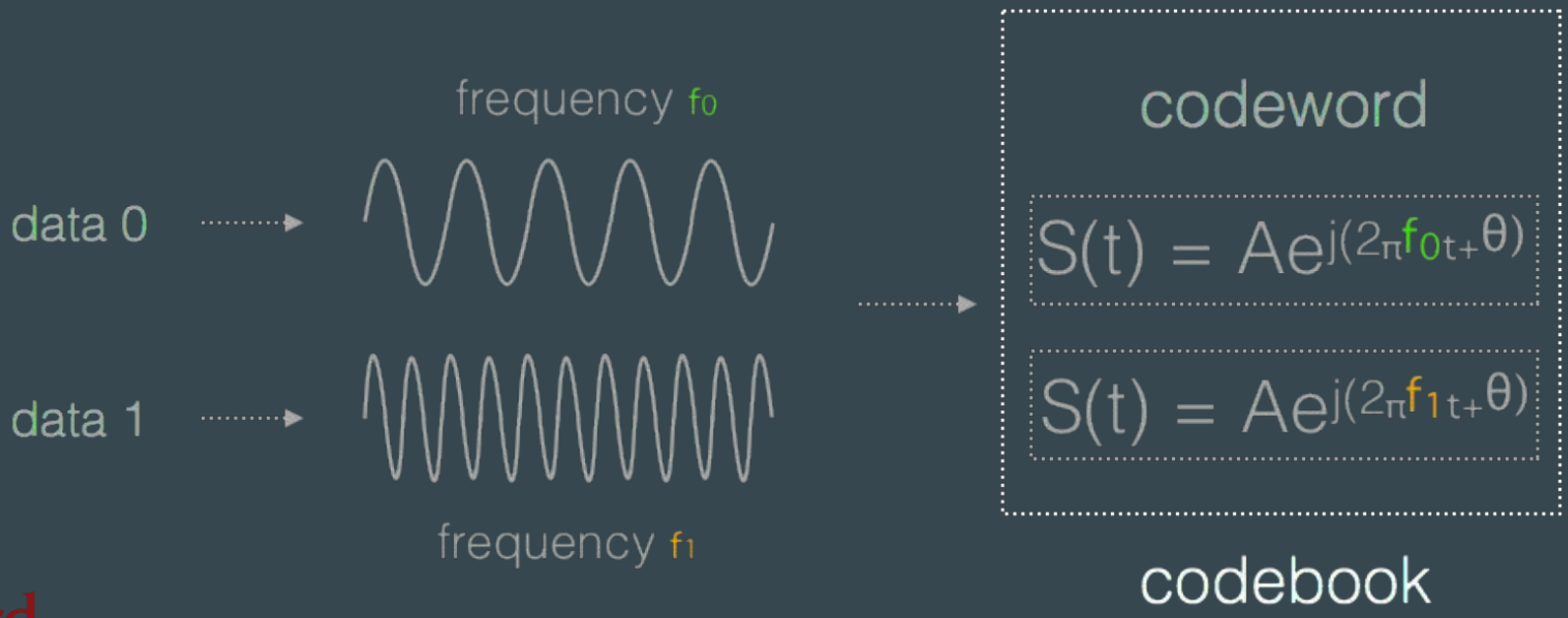
3-dimensional codeword translation



HitchHike only changes the phase. FreeRider can change phase, amplitude and frequency

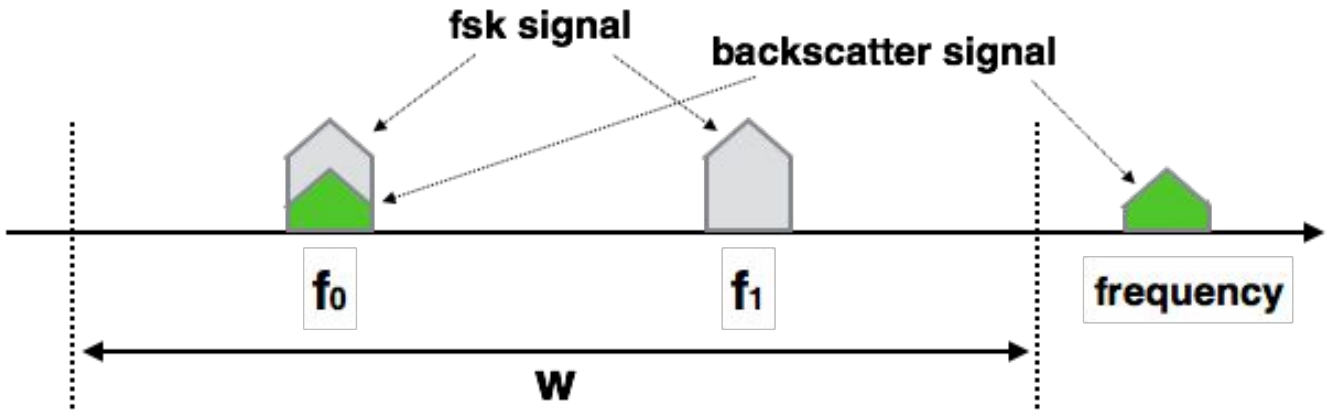
Case study II: Bluetooth codeword translation

GFSK modulation

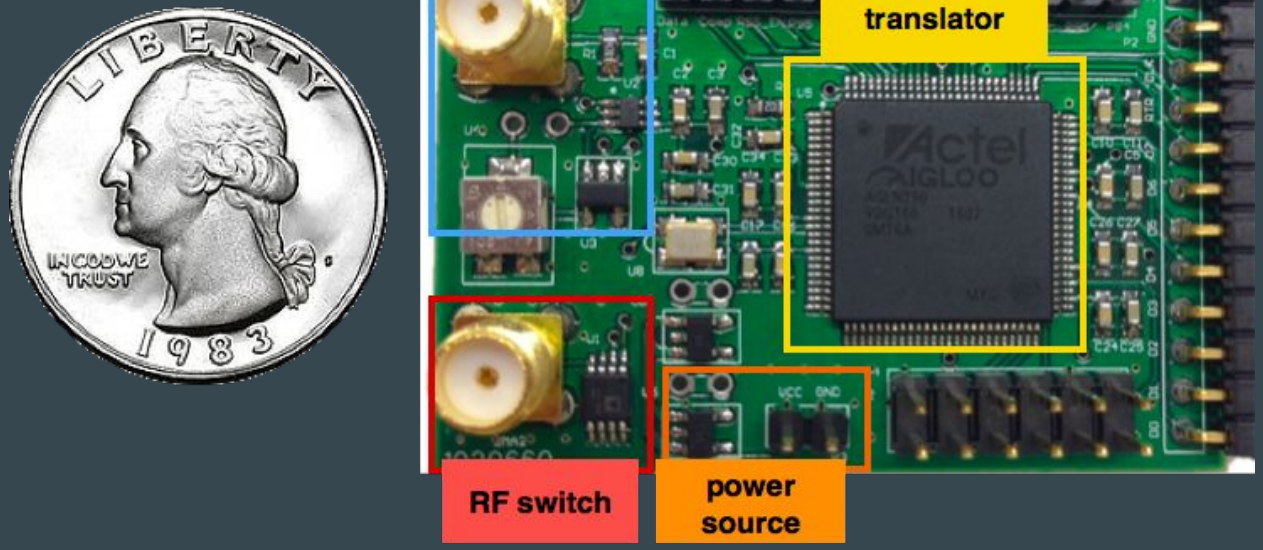


GFSK codeword translation

Let $\Delta f = |f_0 - f_1|$. Shift the incoming codeword by Δf to encode data1. Signals outside the channel are treated interference, solving the double sideband problem.



Hardware Prototype



SPICE projection of mass-produced power consumption: ~30 uW

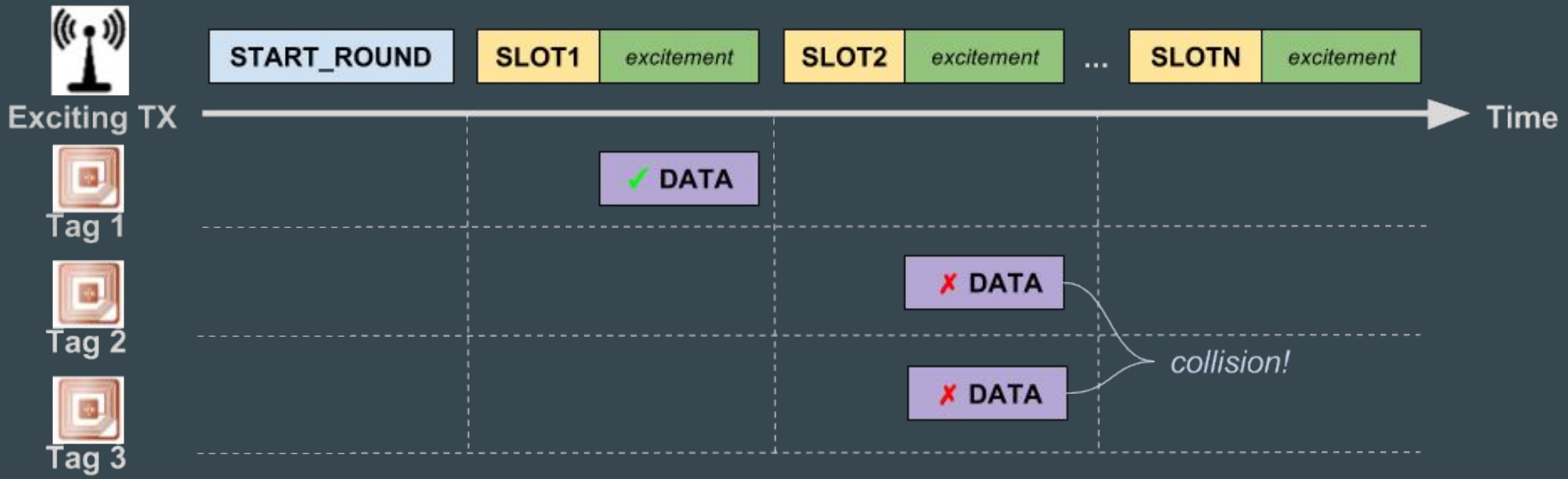
Managing multiple tags: WiFi case study

How to coordinate multiple tags using WiFi when the tag cannot decode WiFi?

Packet-width modulation

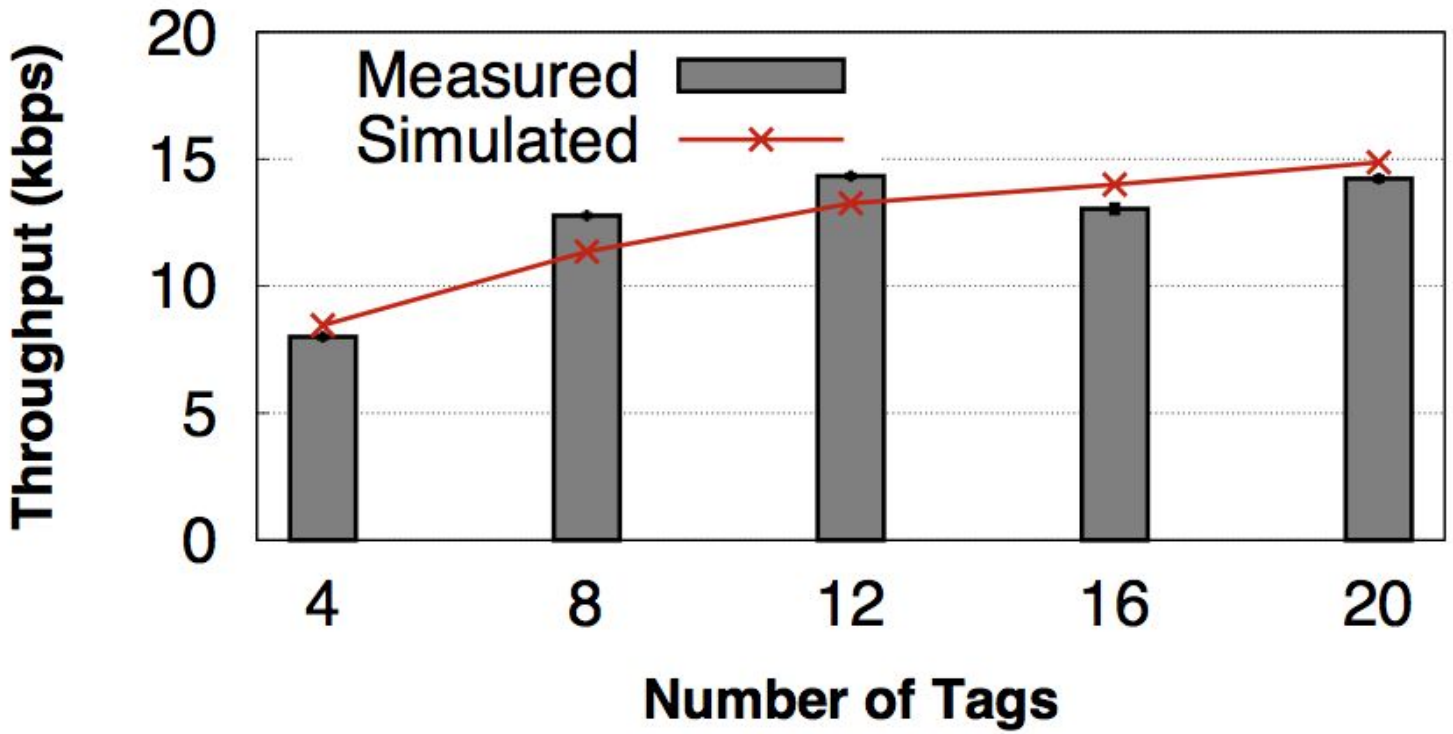
- Packet duration encodes control messages
- Duration measured by envelope detector
- Can use commodity transmitters
- Robust to interference
- Currently binary symbols, ~500bps
- Used to implement a framed slotted-Aloha based random-access scheme

MAC scheme


START_ROUND
SLOT1
excitement
SLOT2
excitement
...
SLOTN
excitement
Exciting TX
Time
✓ DATA
Tag 1
✗ DATA
Tag 2
collision!
✗ DATA
Tag 3

Selected results

Multi-tag evaluation: aggregated throughput



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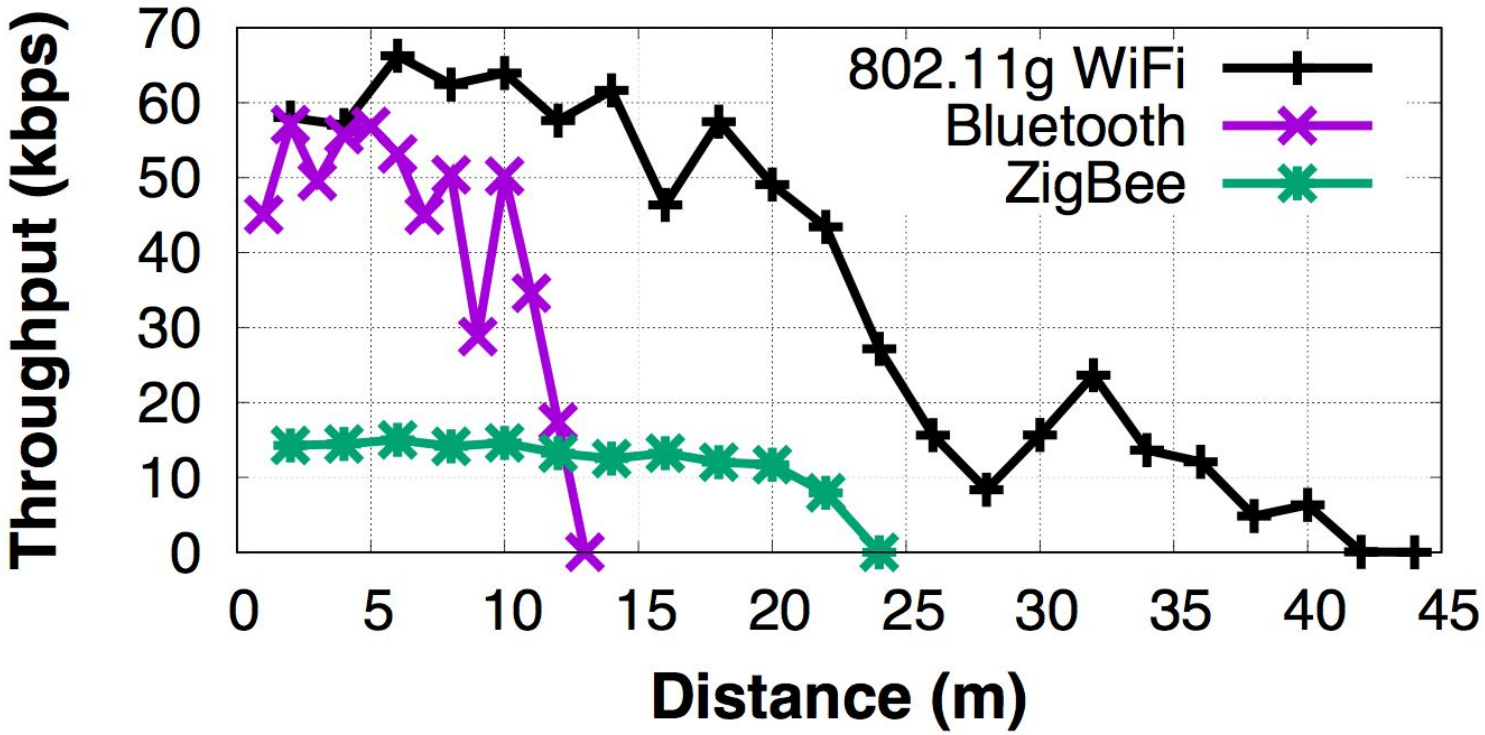
Single-tag evaluation: throughput



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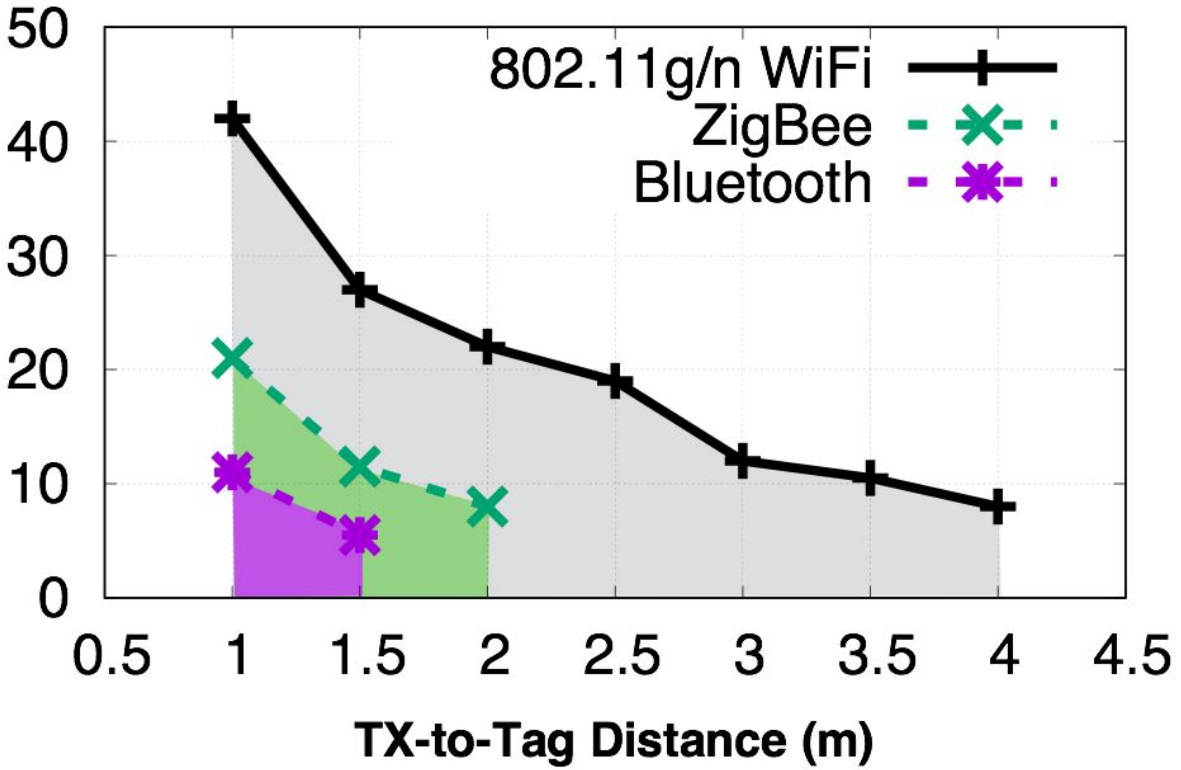
Operational regime



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FreeRider Summary

- First backscatter system capable of 802.11g, ZigBee and Bluetooth
- Excitation signal can be simultaneously used for productive communication
- 3-dimensional codeword translation
- First WiFi backscatter system to implement and evaluate multiple tags
- Source code available at: https://github.com/pengyuzhang/FreeRider