6.808: Mobile and Sensor Computing
aka IoT Systems

http://6808.github.io

Lecture 7: Batteryless Sensors and Smart Cities

Some slides adapted from Haitham Hassanieh (UIUC) & Omid Abari (UCLA)

Course Staff	Announcements
Lecturers: Fadel Adib (fadel@mit.edu)	1- PSet 1 due Feb 28
Hari Balakrishnan (hari@csail.mit.edu)	2- Lab 2 out; due March 2
TAs: Maya Nielan (mnielan@mit.edu)	
Sayed Saad Afzal (afzals@mit.edu)	

Today in IoT

AXIOS　Sections　Local news　Axios Pro　About Axios　Sign up

8 hours ago - Technology

Ending 3G service sparks fears of an "alarmaggedon"

Margaret Harding McGill

Objectives of the Three Lectures Series

Learn the fundamentals, applications, and implications of

IoT connectivity technologies

Objectives of the Three Lectures Series

Learn the fundamentals, applications, and implications of
IoT connectivity technologies

1. What is the overall IoT system architecture?
2. What are the various classes of connectivity technologies? And how do we choose the "right" technology for a given application?
3. What are various routing architectures for wireless networks & IoT systems?
4. How does energy impact IoT device design? And how do batteryless IoT systems work?

this lecture

macy's

NIKE

ユニクロ UNIQLO

lululemon

H&M

ZARA

RALPH LAUREN

BURBERRY
LONDON

Forbes

Mar 8, 2021, 07:10am EST | 374 views

How RFID Helps Retail Companies Save Money

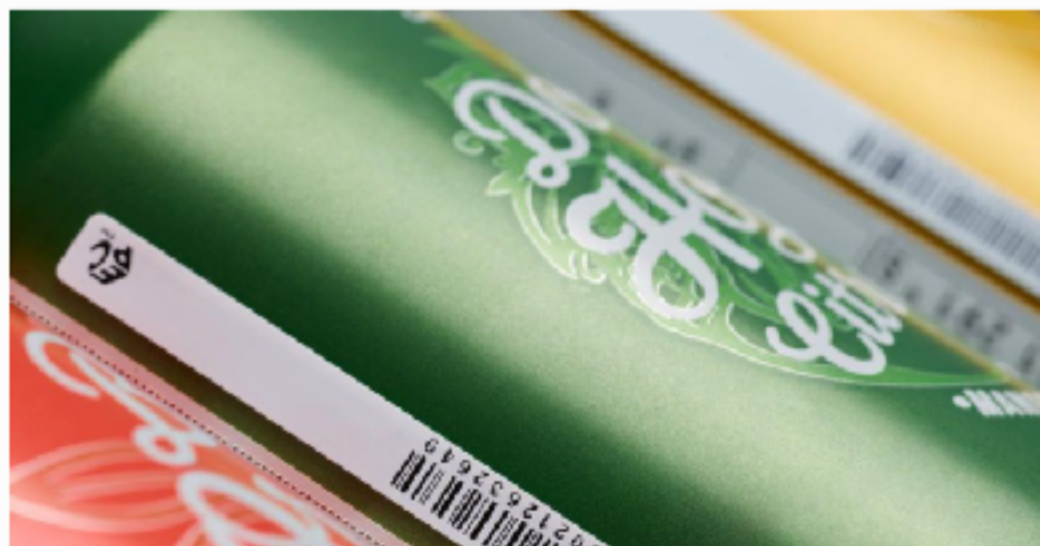
Walter Loeb Senior Contributor
Retail
I cover major developments in the retail industry.

Feb 26, 2018, 08:44pm EST | 7,451 views

Japan Aims To Automate All Convenience Stores By 2025 With A New RFID Technology

Akiko Katayama Contributor
Food & Drink

This article is more than 2 years old.



RFID (Radio Frequency IDentification)

Access Control

Inventory control

Security Sensitive Applications

Tracking & Localization

Long-Range Payment Systems

RFID (Radio Frequency IDentification)

Access Control

Inventory control

> 100 Billion in the world

ZDNet

VIDEOS WINDOWS 10 5G BEST VPNS CLOUD SECURITY AI MORE NEWSLETTERS

MUST READ: Everything you need to know about the Microsoft Exchange Server hack

PART OF A ZDNET SPECIAL FEATURE: CORONAVIRUS: BUSINESS AND TECHNOLOGY IN A PANDEMIC

Humble hero: How RFID is helping end the pandemic

A common technology takes on an uncommon mission: Distributing vaccines around the globe.

Basic Principle of Operation

RFID: cheap battery-free stickers

Reply to wireless reader with a unique identifier

History of RFIDs

- WWII: Aircraft IFF Transponder
  – Identify Friend or Foe, Transmitter-Responder

- 1945: “The Thing” or “The Great Seal Bug”
  - “Gift” given by the Soviets to American ambassador

- 1980s: development of E-Toll transponders

- 2004: Auto-ID lab at MIT led to the birth of modern battery-free RFIDs
  - Goal: supply chain chain optimization
  - Paper: “Towards the 5 cent tag”

Types of RFIDs

Frequency Range

UHF (~900MHz)

HF (13.56MHz)

LF (120-150kHz)

long range (few m)

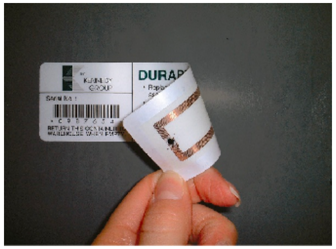
short range (few cm)

Range of Operation

"need to tap"

Power consumption

Where do these fall?



Types of RFIDs

Frequency Range

UHF (~900MHz)

HF (13.56MHz)

LF (120-150kHz)

the vast majority of RFIDs

Cost

few cents

10s to 100s of $

Power consumption

Passive (battery-free)	Semi-Passive or Semi-Active	Active (with battery)

Other less common versions: 2.4GHz, UWB (3-10GHz), etc.

How does an RFID power up?

Harvests Energy from Reader's Signal

<u>Inductive Coupling</u>

LF
(120-150kHz)

HF
(13.56MHz)

Magnetic
(Near Field)

Coil

<u>Radiative</u>

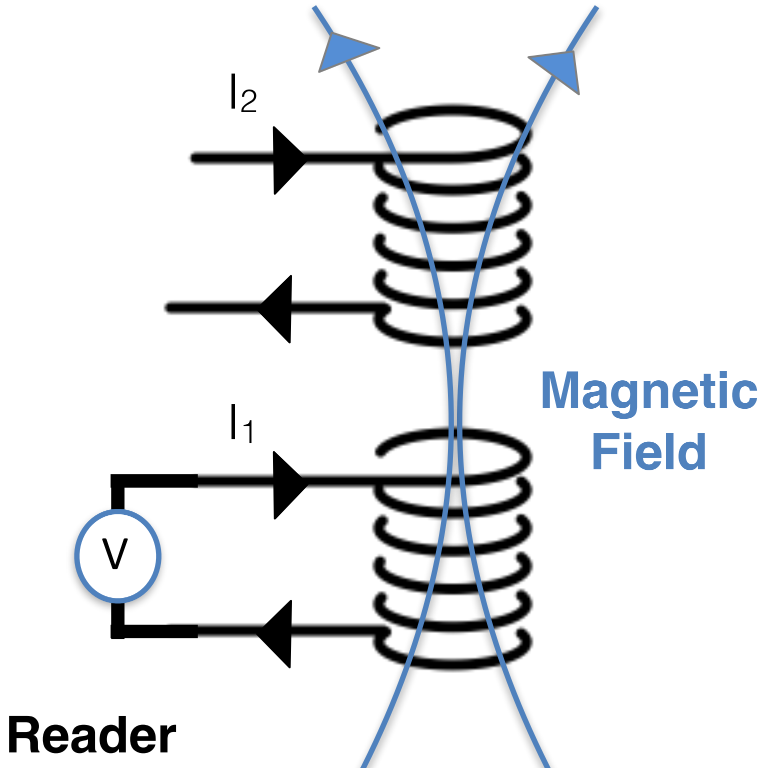
UHF
(~900MHz)

Electromagnetic
(Far Field)

Antenna

Inductive Coupling

How to power in HF/LF?



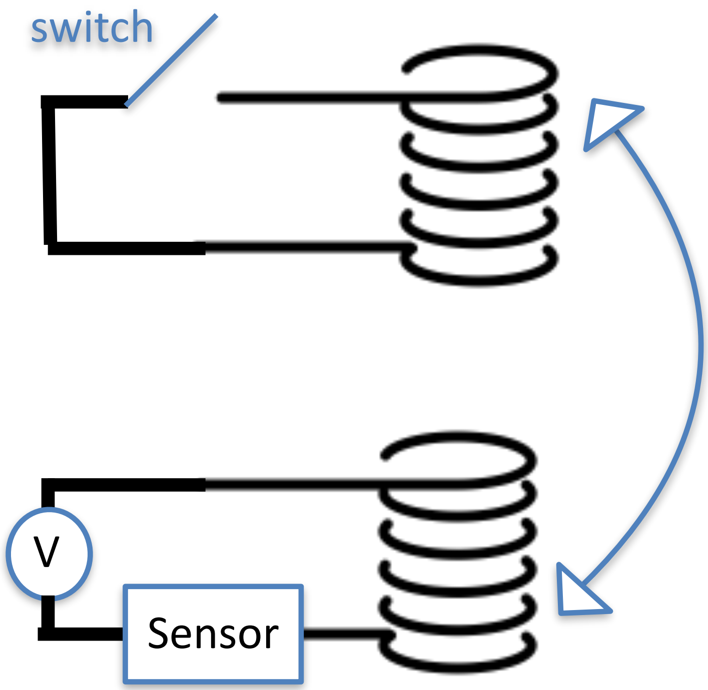
1.) Current in reader coil → a magnetic field
2.) Magnetic field passes through RFID's coil → current in the RFID
3.) RFID harvests energy & powers up

- *What happens if coils misaligned?*
  Magnetic field lines not aligned with RFID's coil → RFID doesn't power up
- Also, magnetic field decays quickly with distance → low operation range

What other technologies operate like this?

Inductive Coupling

- Magnetic field also induced in the reverse direction (mutual inductance)
- By turning a switch (transistor) on/off, the tag can communicate bits that are sensed due to the mutual coupling

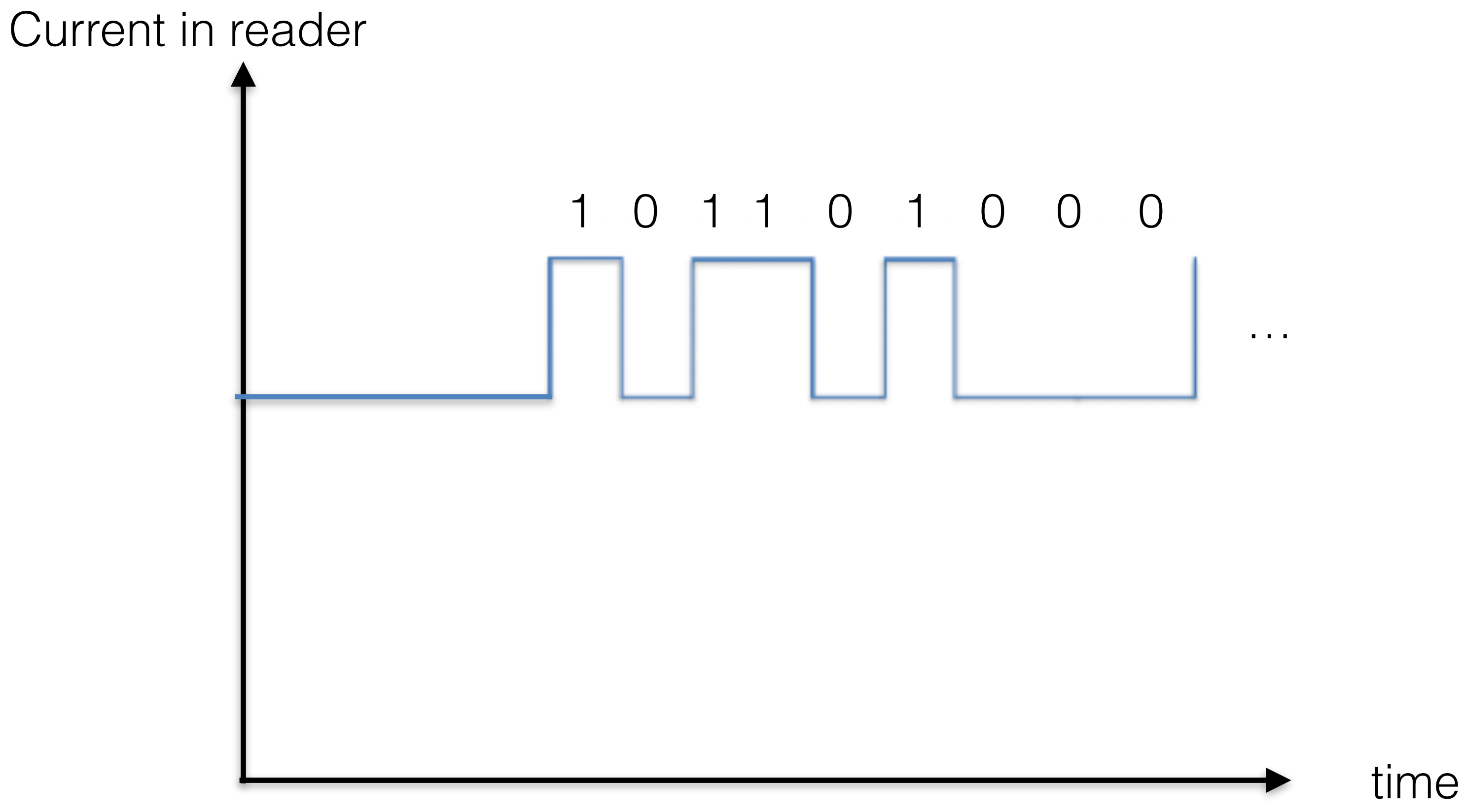


After powering up

1. RFID switch turns on/off (to communicate data in binary)
2. this impacts current in the reader (due to mutual inductance)
3. by sensing current change b/w two states, the reader cab decide the transmitted bits

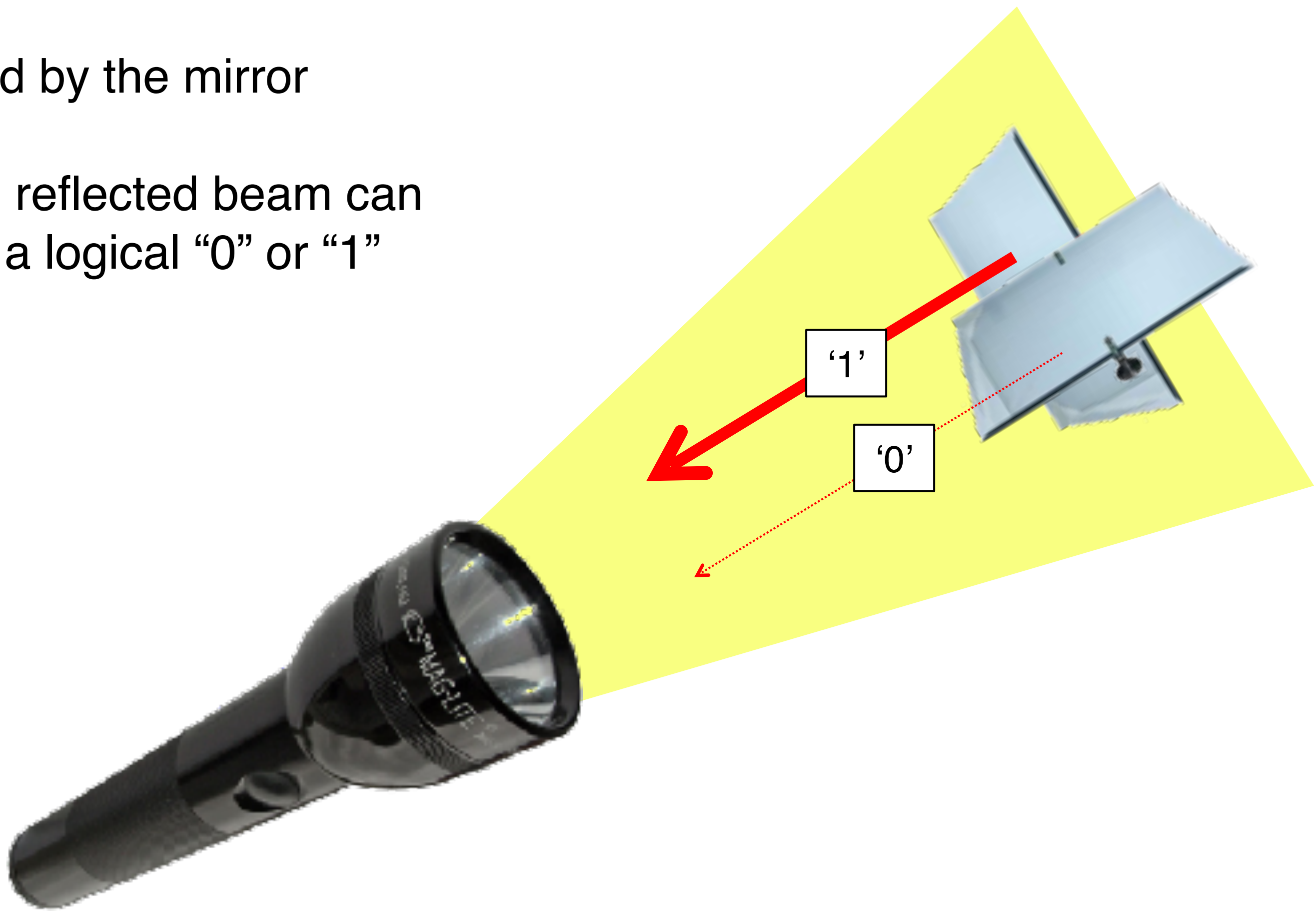
How does the receiver decode?

- Senses changes in the current

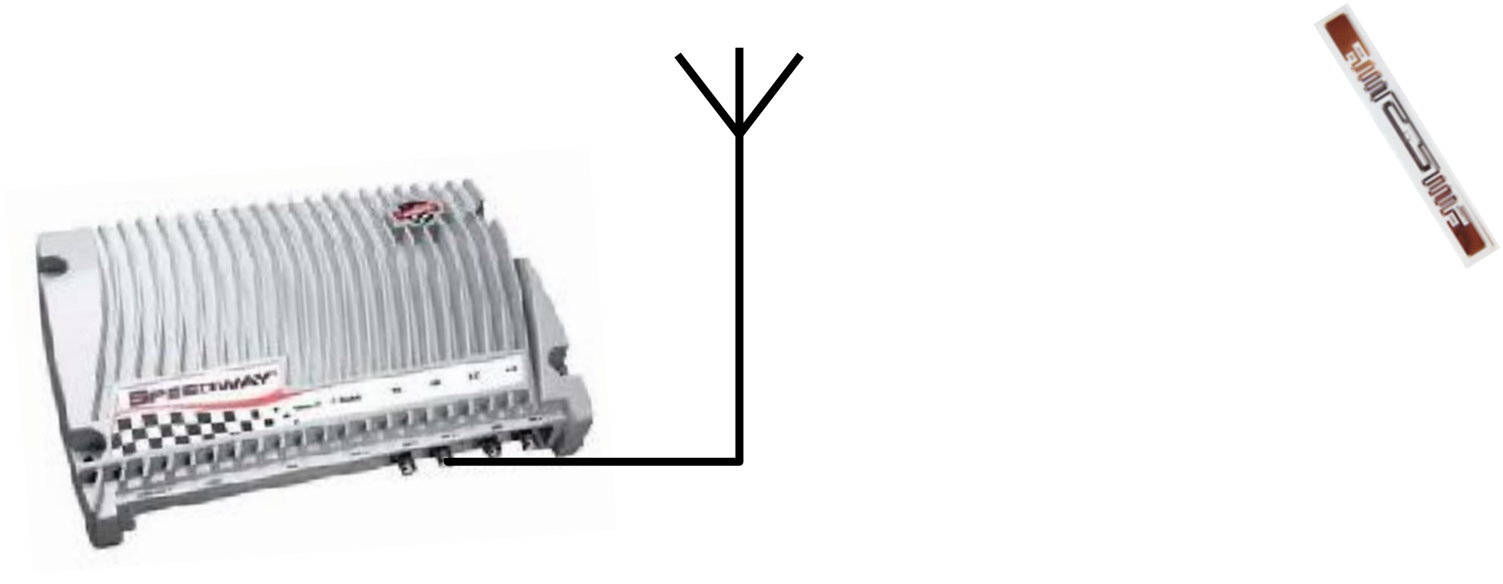


UHF Backscatter Communication

- 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”

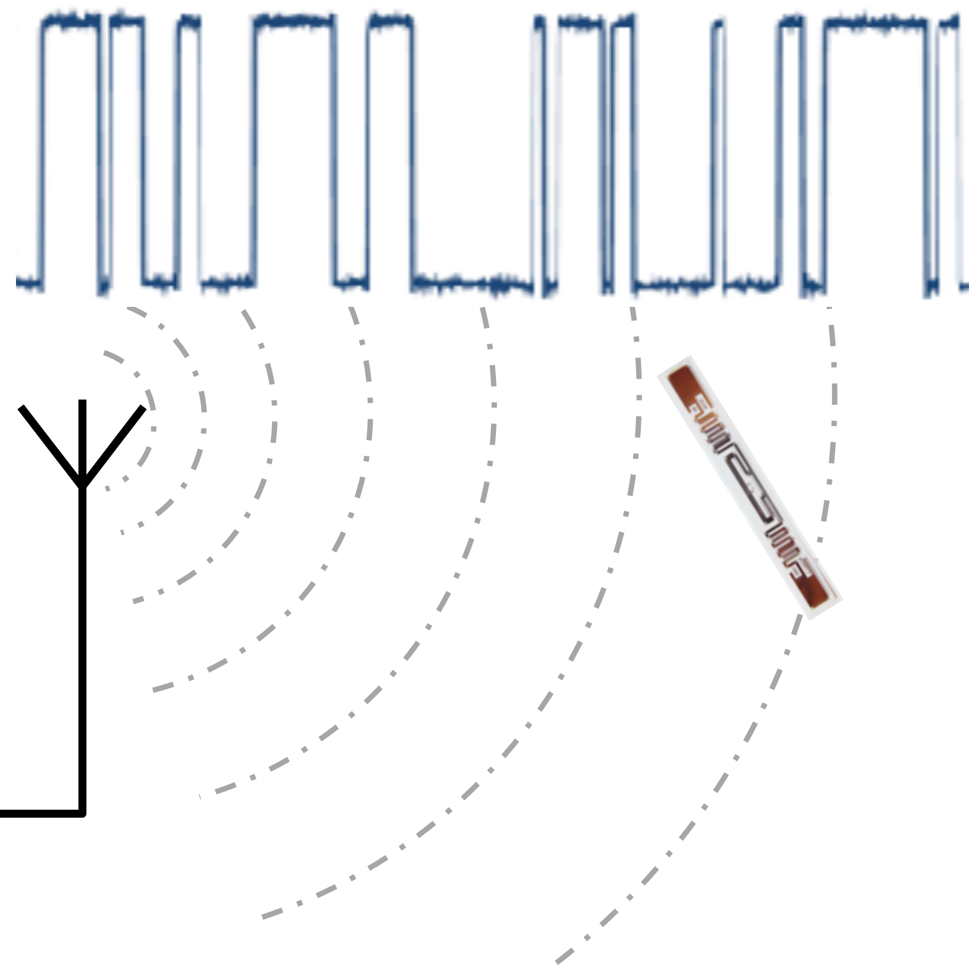


Backscatter Communication



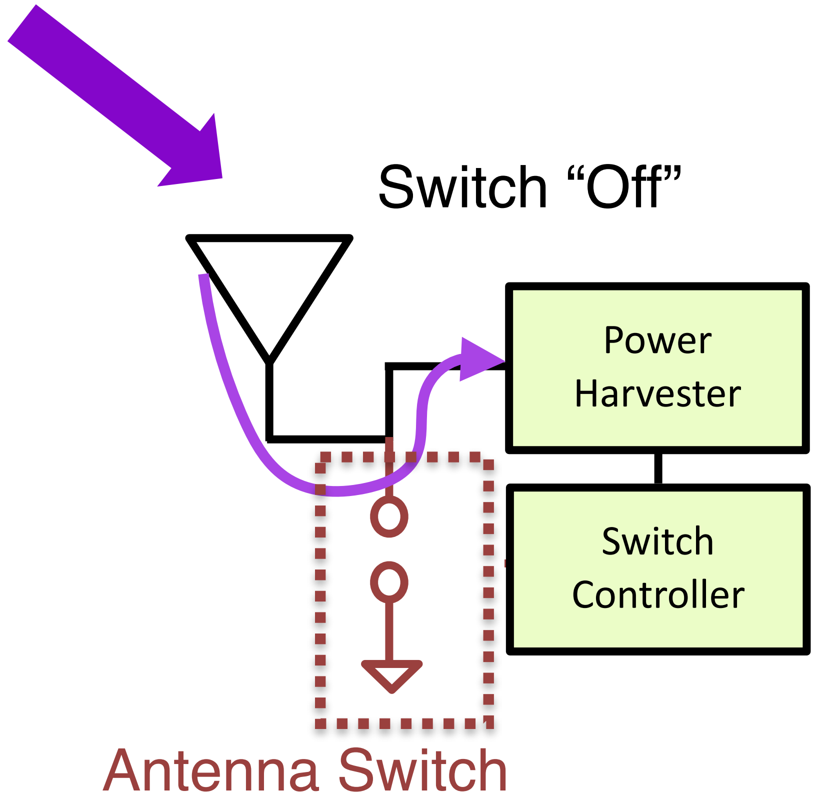
Backscatter Communication

Tag reflects the reader's signal using ON-OFF keying



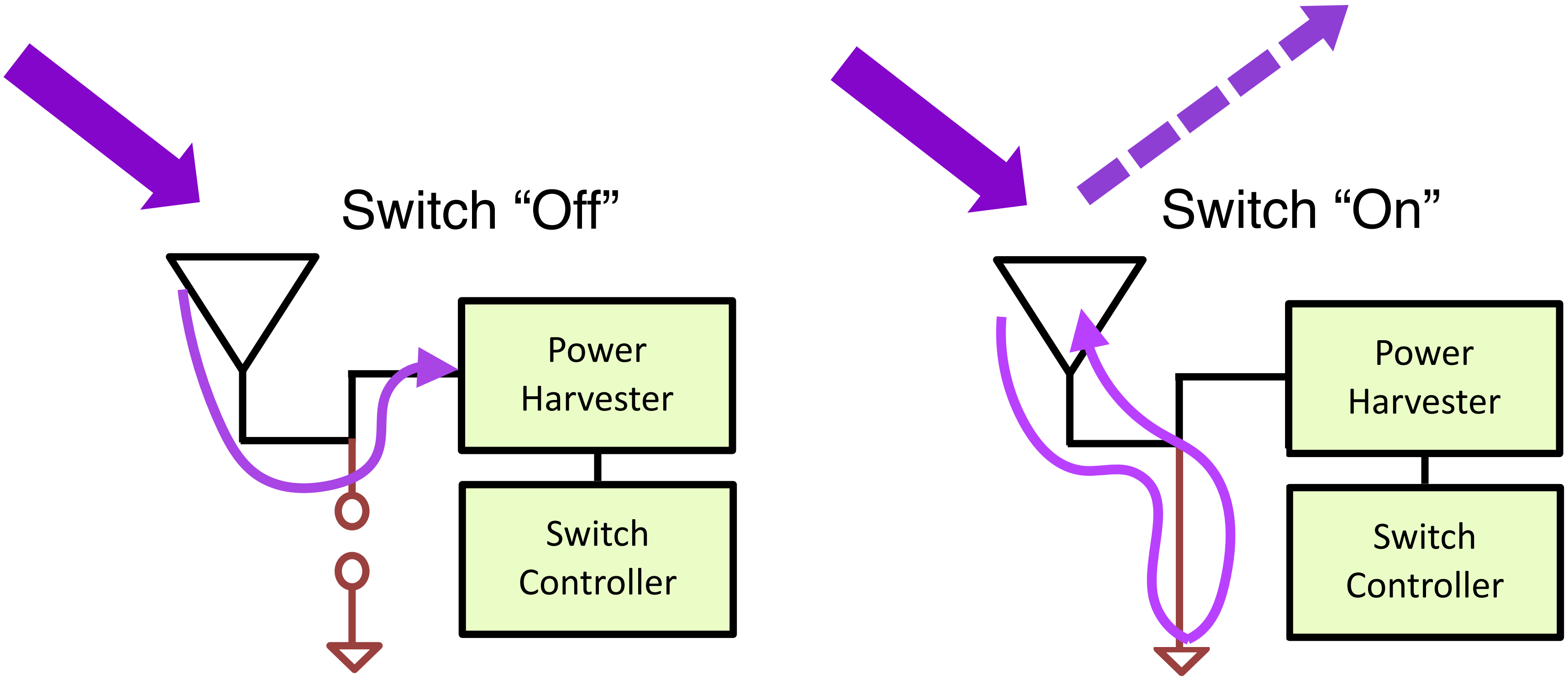
Reader shines an RF signal on nearby RFIDs

Uplink Communication

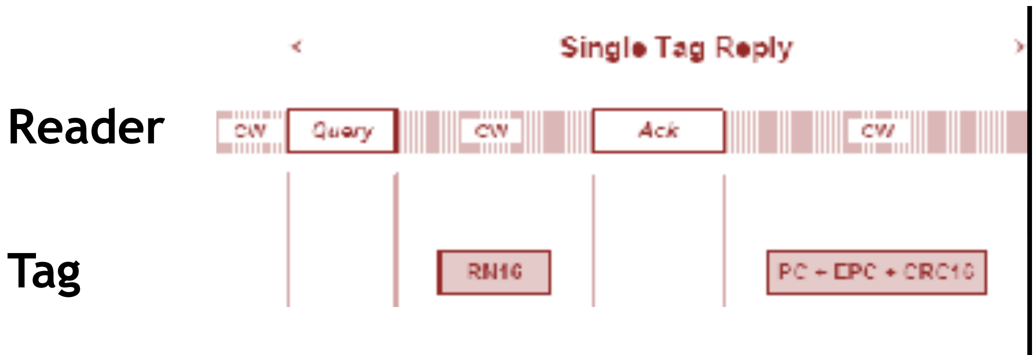


Simplified RFID schematic

Uplink Communication



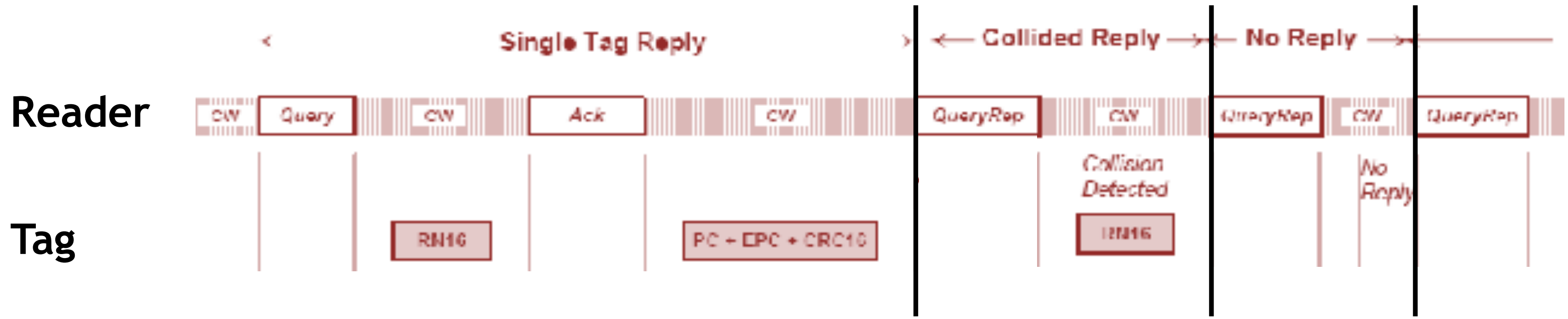
EPC Gen2 Standard - MAC



Slotted Aloha:

- Reader allocates Q time slots and transmits a query at the beginning of each time slot
- Each tag picks a random slot and transmits a 16-bit random number
- In each slot:
  - RN16 decoded → Reader ACKs → Tags transmits 96-bit ID
  - Collision → Reader moves on to next slot
  - No reply → Reader moves on to next slot

EPC Gen2 - MAC



Let’s consider an example with Q=4, no tag; and Q=4, 1 tag

Inefficient:

- If reader allocates large number of slots → Too many empty slots
- If reader allocates small number of slots → Too many collisions

EPC Gen2 – MAC: Minimizing Collisions

- N RFID Tags & K Time slots
- Each tag picks a slot uniformly at random to transmit in
- *Let's assume the reader knows the number of tags N; how should it set K? (And once we know it, what is the efficiency?)*

- Hint: goal is to maximize the number of "useful" slots
    - What is a useful slot?

EPC Gen2 – MAC: Minimizing Collisions

- N RFID Tags & K Time slots
- Each tag picks a slot uniformly at random to transmit in
- *Let's assume the reader knows the number of tags N; how should it set K?*

- Probability that a tag transmits in a given slot:

$$p = \frac{1}{K}$$

- Probability that any tag transmits in a given slot without collision:

$$E = Np(1-p)^{N-1}$$

- To maximize E, set:

$$\frac{dE}{dp} = 0$$

- p=1/N => K=N

EPC Gen2 – MAC: Minimizing Collisions

- N RFID Tags & K Time slots
- Each tag picks a slot uniformly at random to transmit in
- *Let's assume the reader knows the number of tags N; how should it set K?*

- Probability that a tag transmits in a given slot:

$$p = \frac{1}{K}$$

- Probability that any tag transmits in a given slot without collision:

$$E = Np(1-p)^{N-1}$$

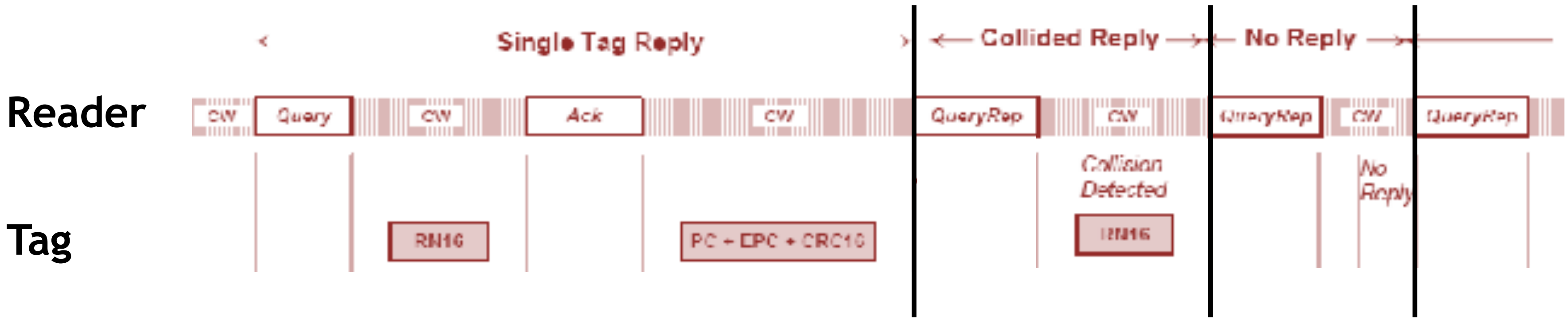
- To maximize E, set K = N

- Efficiency:

$$\text{Efficiency} = E = \left(1 - \frac{1}{N}\right)^{N-1}$$

$$\text{Efficiency} \leq lim_{N \to \infty} E = \frac{1}{e} = 0.37$$

EPC Gen2 - MAC



Inefficient:

- If reader allocates large number of slots → Too many empty slots
- If reader allocates small number of slots → Too many collisions
- If reader knows number of tags = N → Allocate K=N slots → 37% efficiency
- Downlink overhead

Significant work on "spanning trees", efficient scanning, decoding with collisions, etc.

MobiCom 2018, New Delhi, India

Challenge: RFID Hacking for Fun and Profit

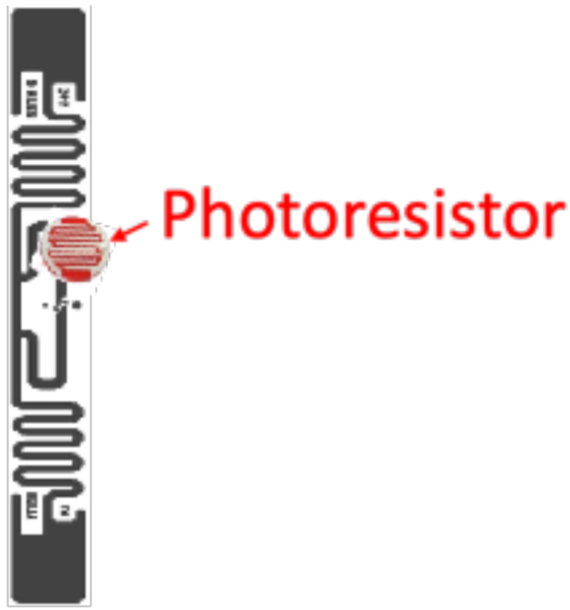
Ju Wang, Omid Abari and Srinivasan Keshav

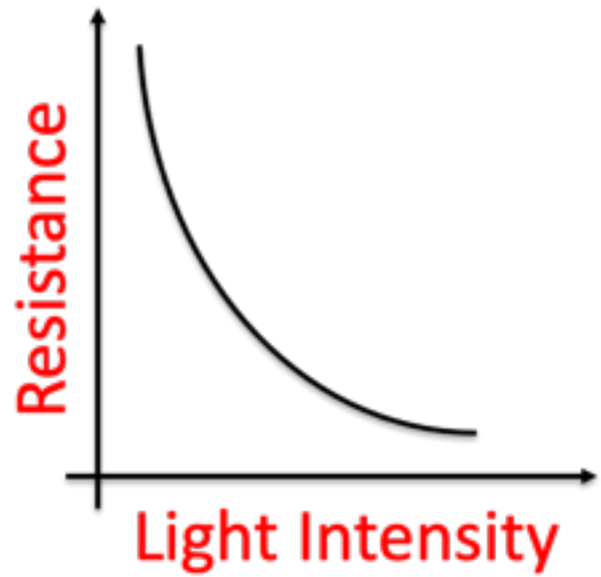
{ju.wang,omid.abari,keshav}@uwaterloo.ca

UNIVERSITY OF WATERLOO

ICONLAB.ca

What’s the basic approach?





An E-Toll Transponder Network for Smart Cities

Smart City Services

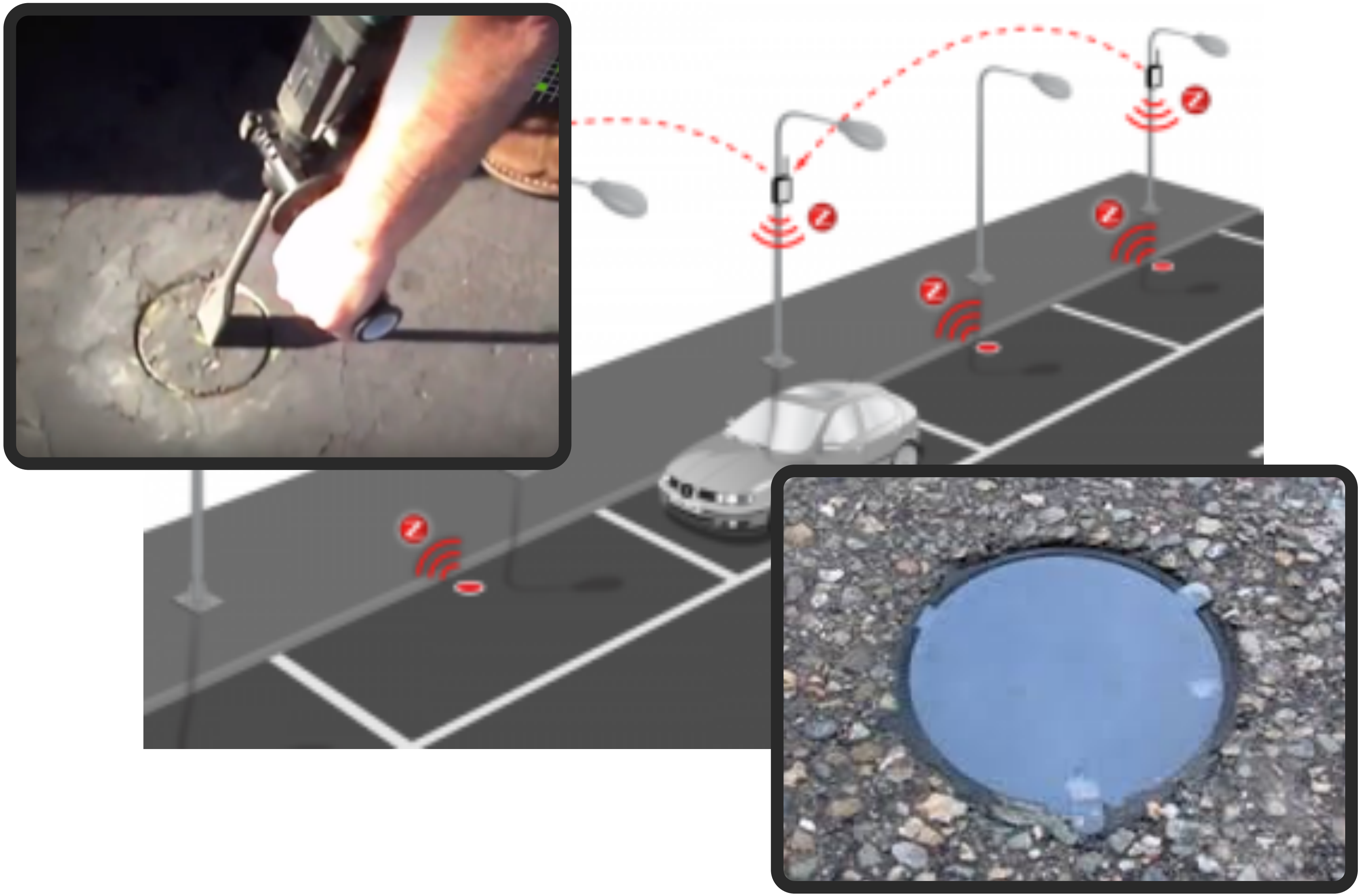
Traffic Management

Detect Red-Light Runner

Smart Parking

<u>Key Problem</u>: each service needs a new infrastructure

Smart Parking



Traffic Management

Ideally…

1) ONE Infrastructure

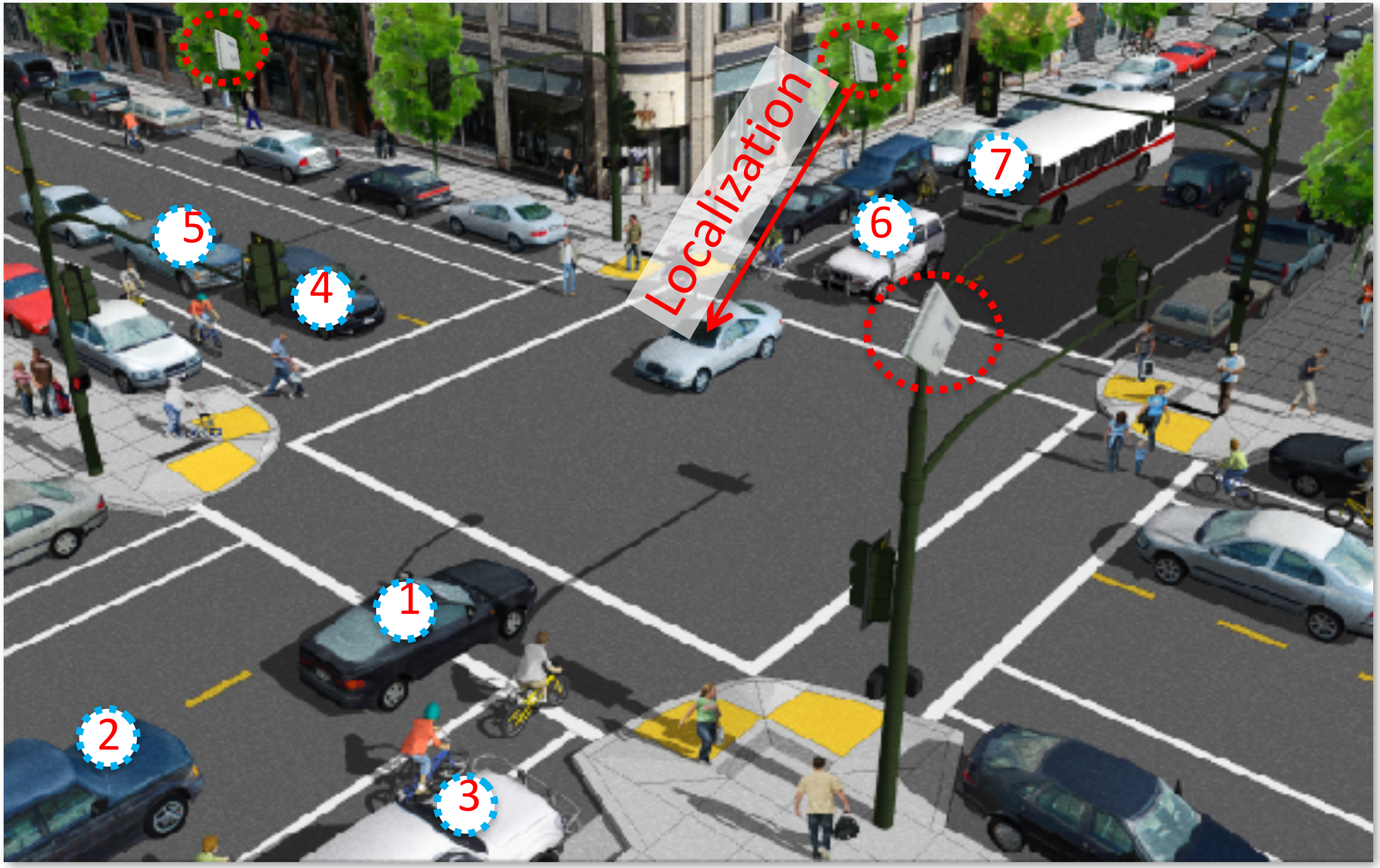
2) Ease of Maintenance

3) We don’t want to add new devices to cars

Electronic Toll Transponders

Some states have made it mandatory

Opportunities



One infrastructure for many smart services

Challenge: Interference

Wireless query

One car responds

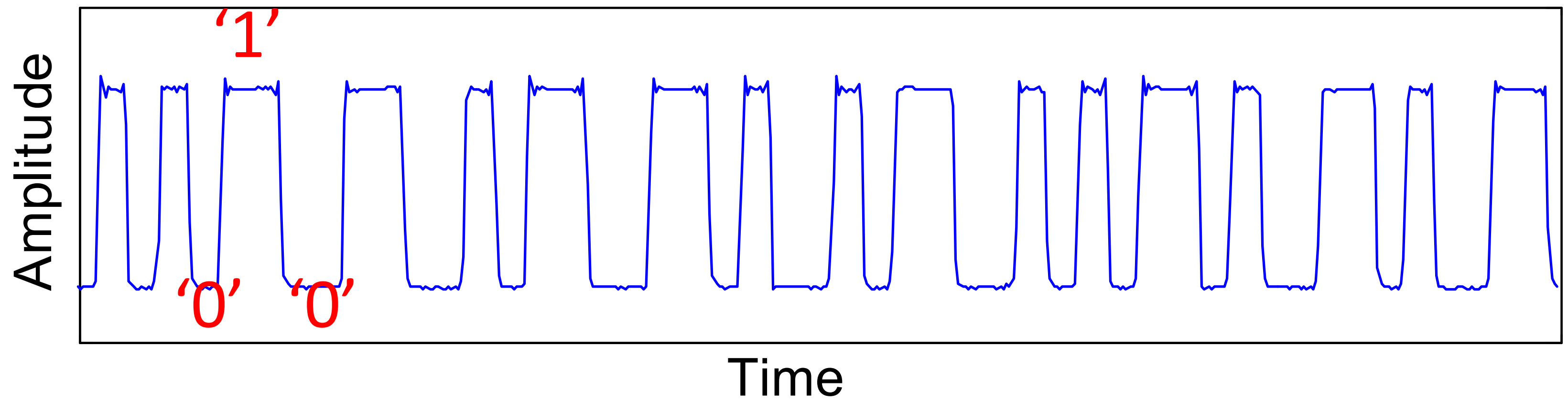
Wireless query

All cars respond

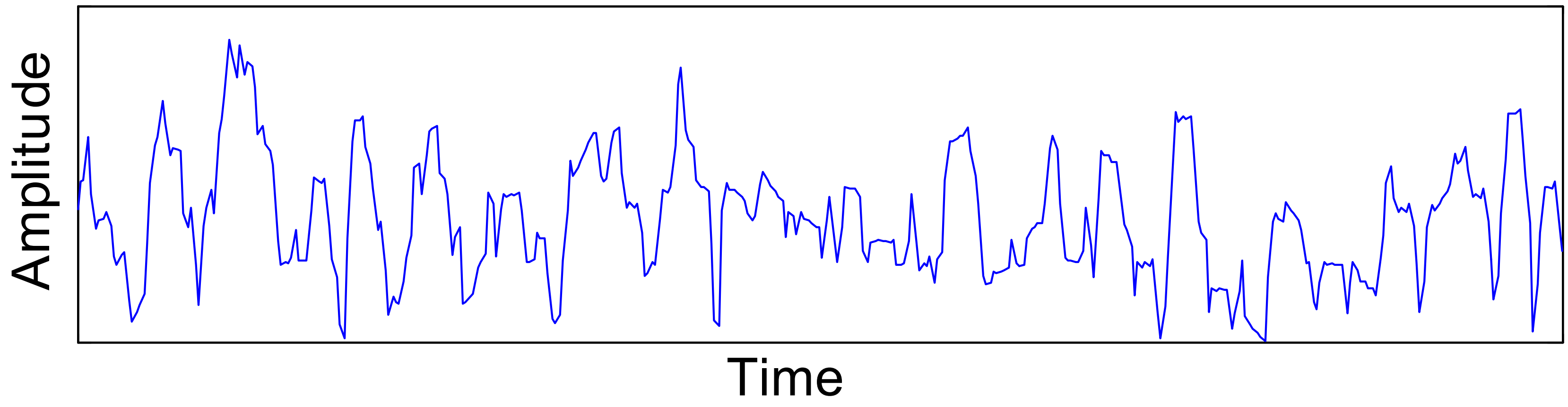
How can we decode transponders despite Interference?

How can we decode transponders despite Interference?

One Transponder Responds → Decodable



Multiple Transponders Respond



Count cars: How to count despite interference?

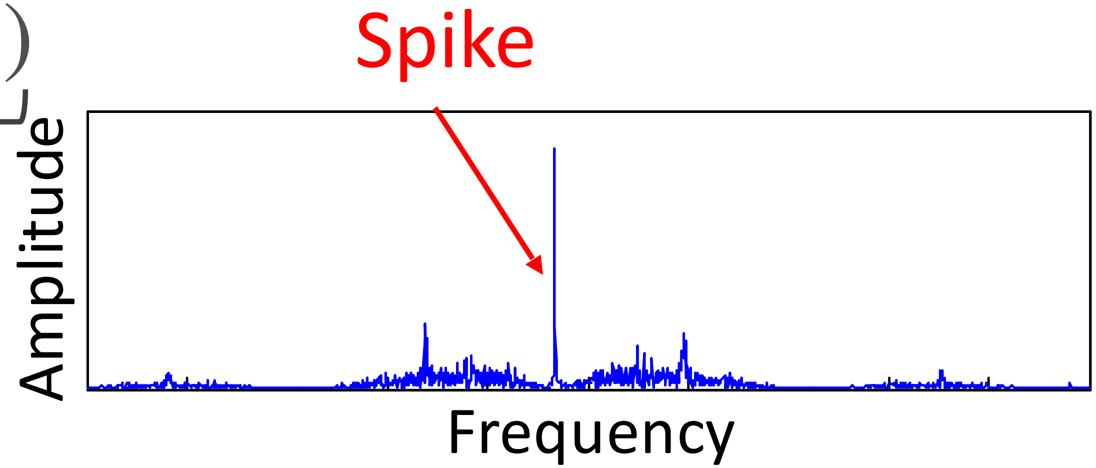
Structure of the Signal

Time-Domain

x $(\sin 2\pi f_c t)$

Carrier

Freq-Domain



Variability due to manufacturing process

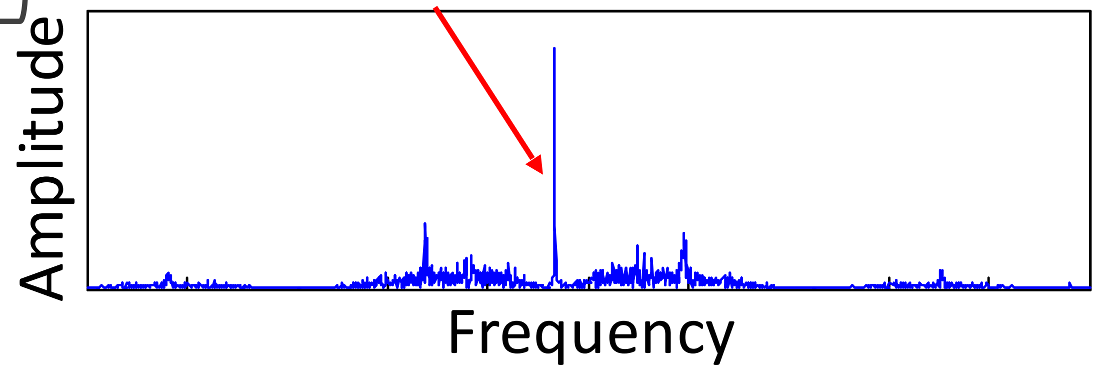
Structure of the Signal

Time-Domain | **Freq-Domain**

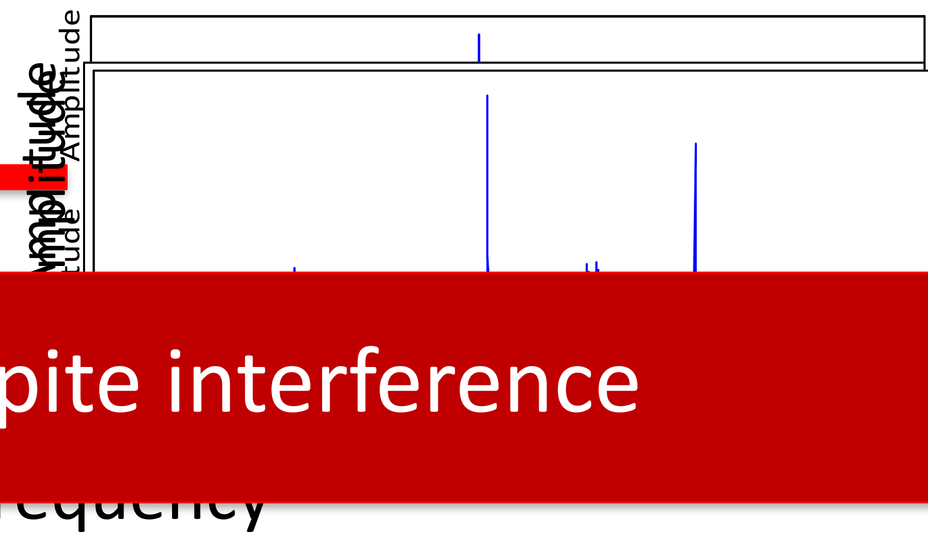
 x $(\sin 2\pi f_c t)$

Carrier

Spike



+

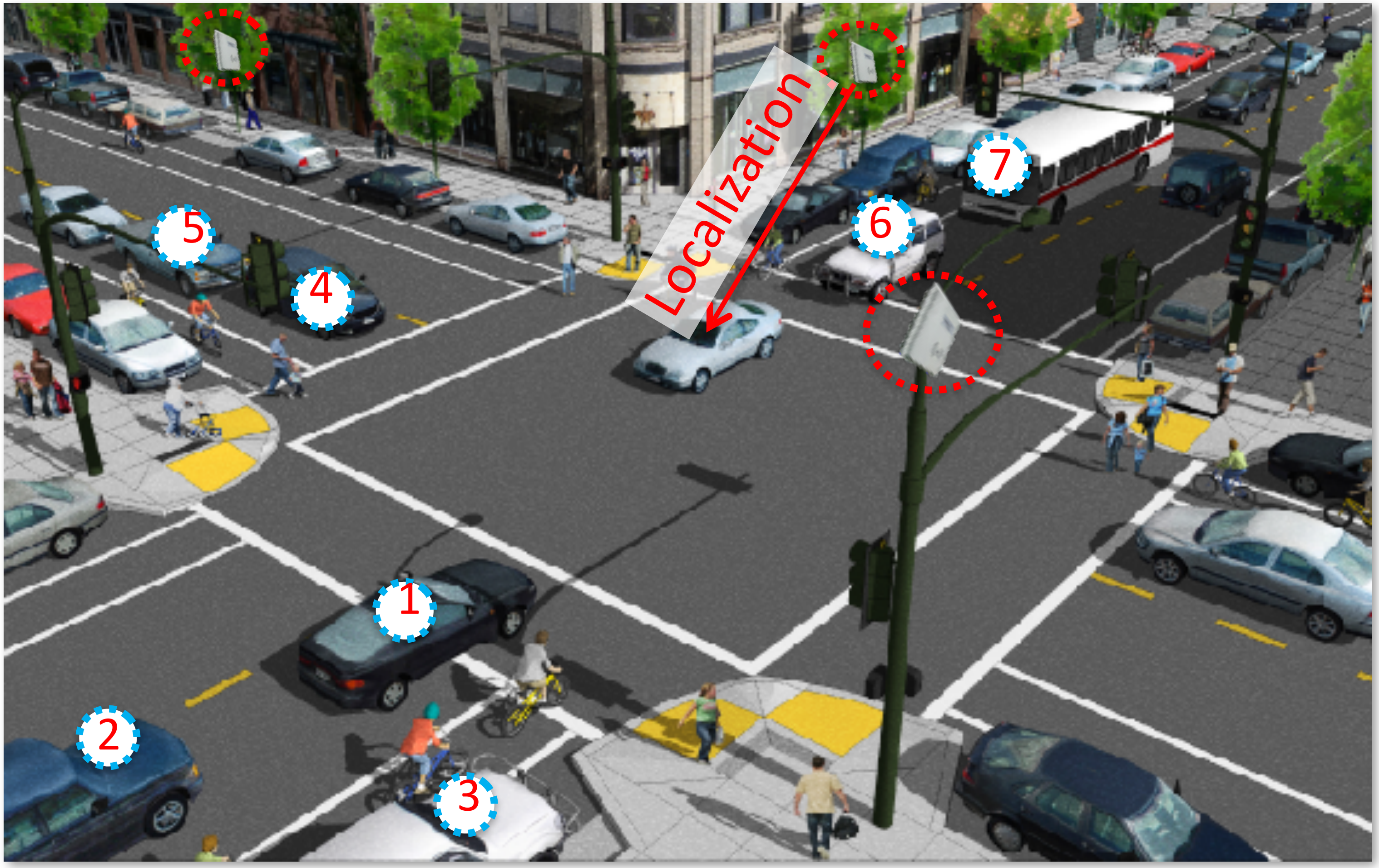


Can count despite interference

Evaluation

- MIT campus- four streets
- Caraoke readers were placed on 12.5-feet poles
- Standard E-ZPass transponders on the cars

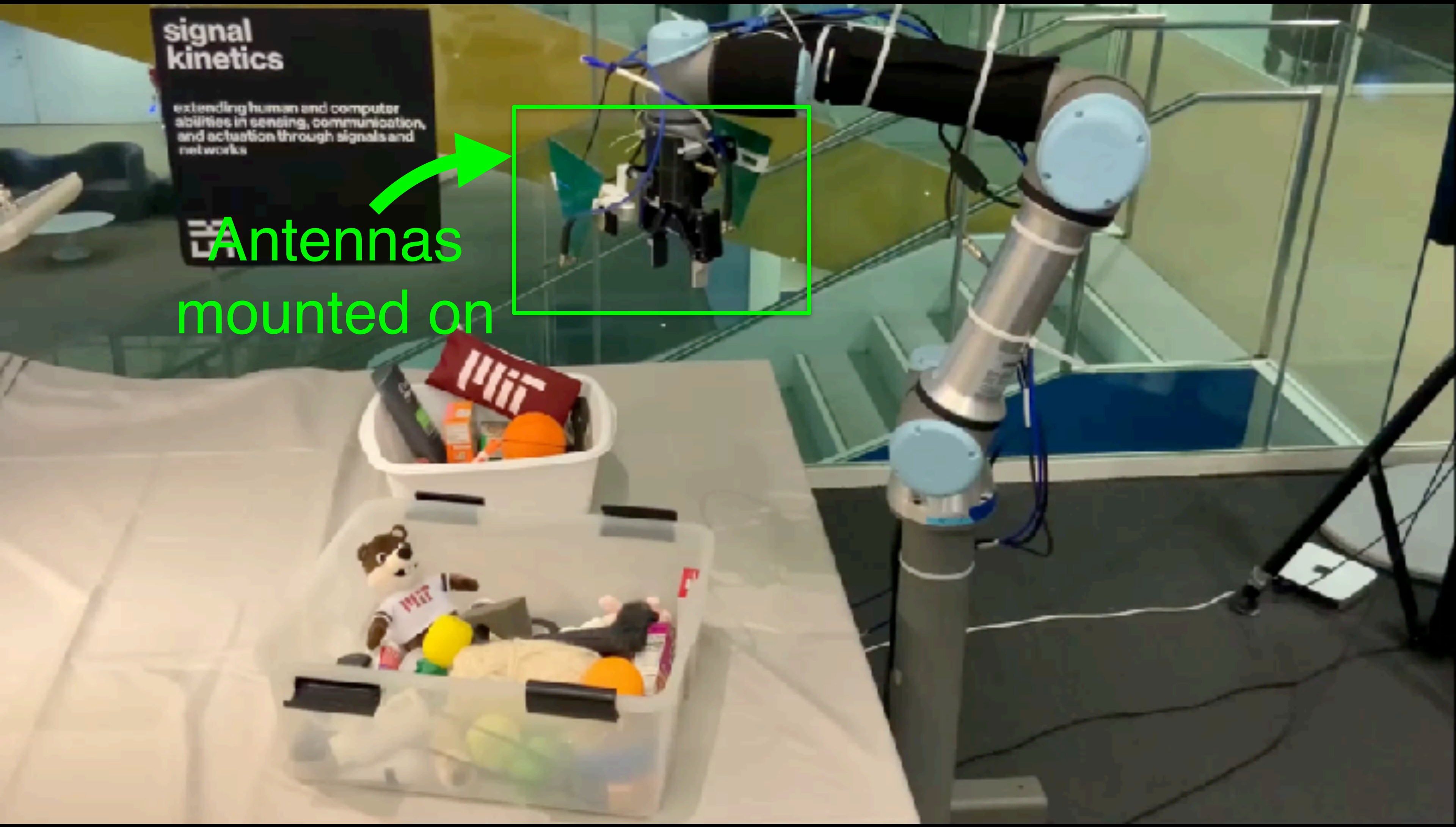
One infrastructure for many smart services



Caraoke

- A system for delivering smart services using existing e-toll transponders
- Can count, localize and decode transponders in the presence of interference
- Built into a small PCB

Bonus:
Application of Batteryless RFID Localization to Robotic Picking


signal kinetics
extending human and computer abilities in sensing, communication, and actuation through signals and networks
Antennas mounted on

Summary of Lecture

- RFID background, history, and applications
- Types of RFIDs (LF, HF, UHF. Passive, Active)
- Principles of operation: energy harvesting & backscatter communication
- Etoll transponders for smart cities
- Dealing with interference
- Localization by leveraging known constraints

Objectives of the Three Lectures Series

Learn the fundamentals, applications, and implications of

IoT connectivity technologies

1. What is the overall IoT system architecture? ✓
2. What are the various classes of connectivity technologies? And how do we choose the "right" technology for a given application? ✓
3. What are various routing architectures for wireless networks & IoT systems? ✓
4. How does energy impact IoT device design? And how do batteryless IoT systems work? ✓

TODO:

1- PSet 1 Due Feb 28

2- Lab 2 due March 2