6.1820/MAS.453: Mobile and Sensor Computing
aka IoT Systems

https://6mobile.github.io/

Lecture 7: Batteryless Sensors and Smart Cities

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

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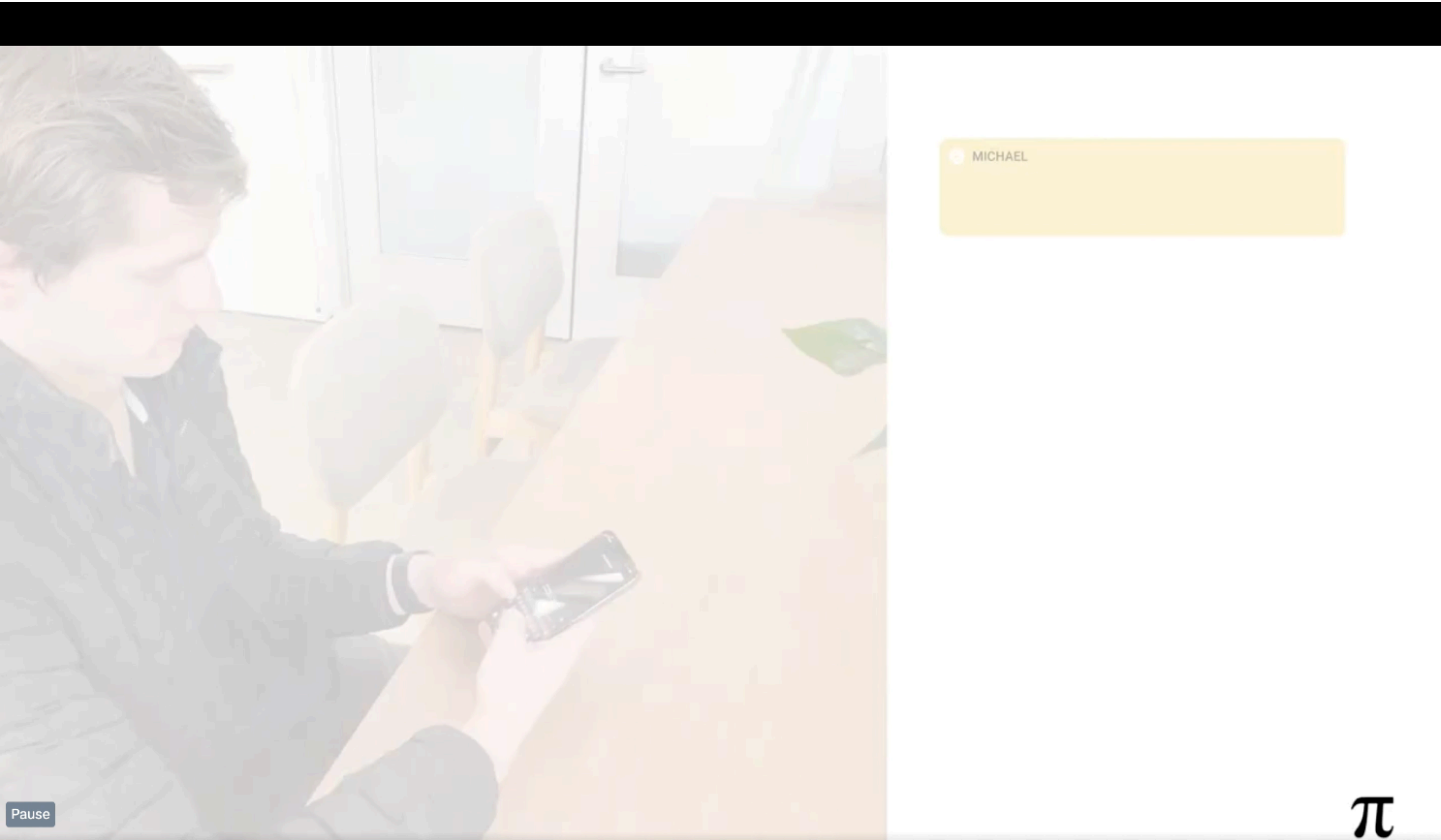
Announcements

1- PSet 1 due March 6

2- Lab 2 out; due March 11

Today in IoT +Robotics



Today in IoT +Robotics

What are we learning today?

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

1- What is an RFID? where are they used?

2- How does an RFID power up?

3- How does an RFID communicate?

4- What are the application that RFIDs enable?

5- How can we use E-toll transponders for sensing in cities?

6- How can we deal with collisions?

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

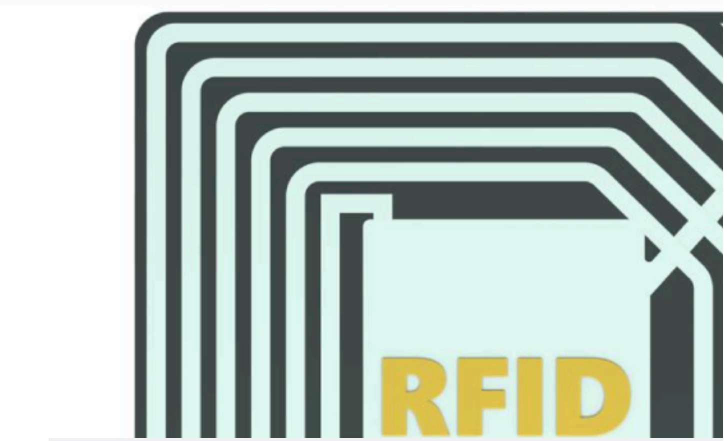
How RFID Helps Retail Companies Save Money

Walter Loeb

Walter Loeb Senior Contributor

Retail

I cover major developments in the retail industry.



NEWS

Using RFID, Airline Industry Making Progress to Reduce Baggage Mishandli Report

Published: June 6, 2024 Author: James Hickey, Managing Editor, RFIDJournal.com

TRENDS | DIGITAL TRANSFORMATION

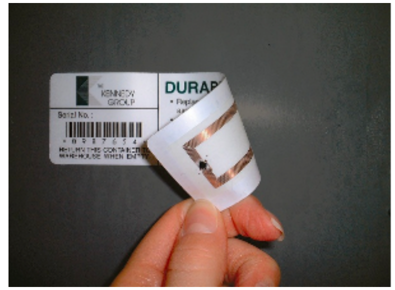
Guiding Brands Through Walmart's RFID Mandates

With Walmart's RFID mandates underway, Avery Dennison is helping companies navigate challenges in adopting the technology.

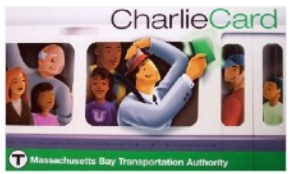
By — Casey Flanagan

Sep 13, 2024

RFID (Radio Frequency IDentification)



Access Control



Inventory control

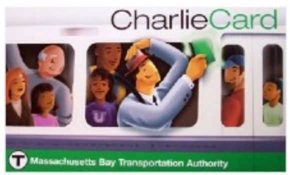
Security Sensitive Applications

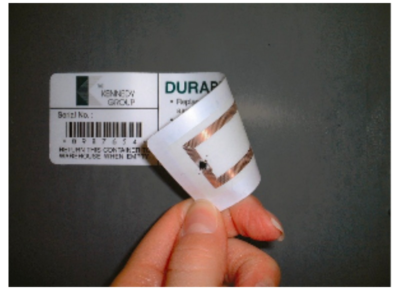
Tracking & Localization

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 ALL W

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)

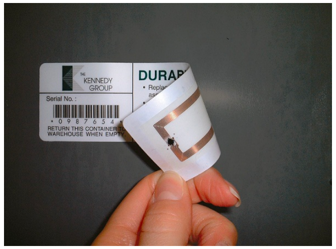
short range (few cm)

Range of Operation

"need to tap"

Power consumption

Where do these fall?



Types of RFIDs

Frequency Range

the vast majority of RFIDs

UHF (~900MHz)

HF (13.56MHz)

LF (120-150kHz)

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

Inductive Coupling

LF
(120-150kHz)

HF
(13.56MHz)

Magnetic
(Near Field)

Coil

Radiative

UHF
(~900MHz)

Electromagnetic
(Far Field)

Antenna

Inductive Coupling

- Powering

Inductive Coupling

- Magnetic field also induced in the reverse direction
- By modulating its impedance, the tag can communicate bits that are sensed due to the mutual coupling

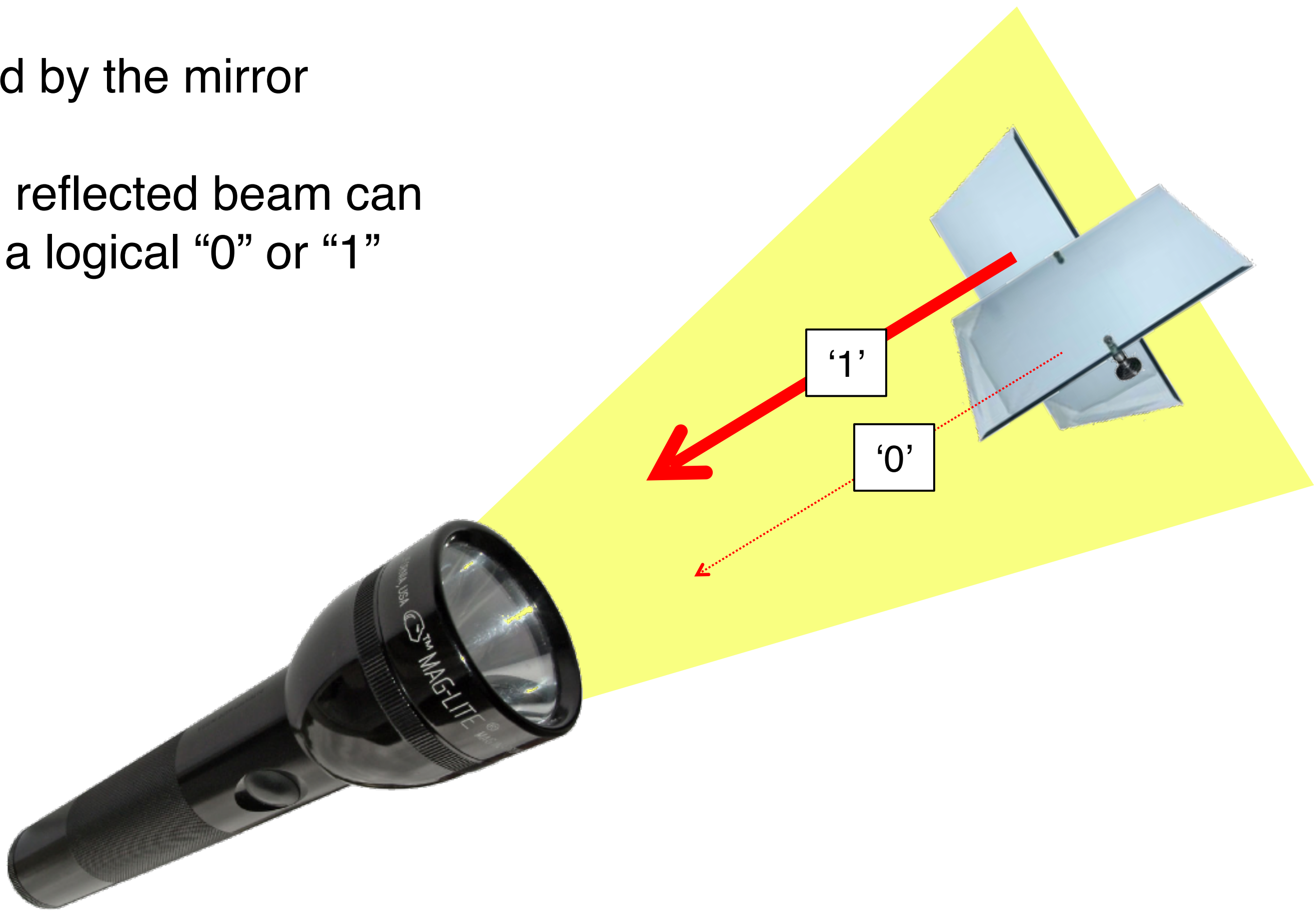
- Where else is this used?

How does the receiver decode?

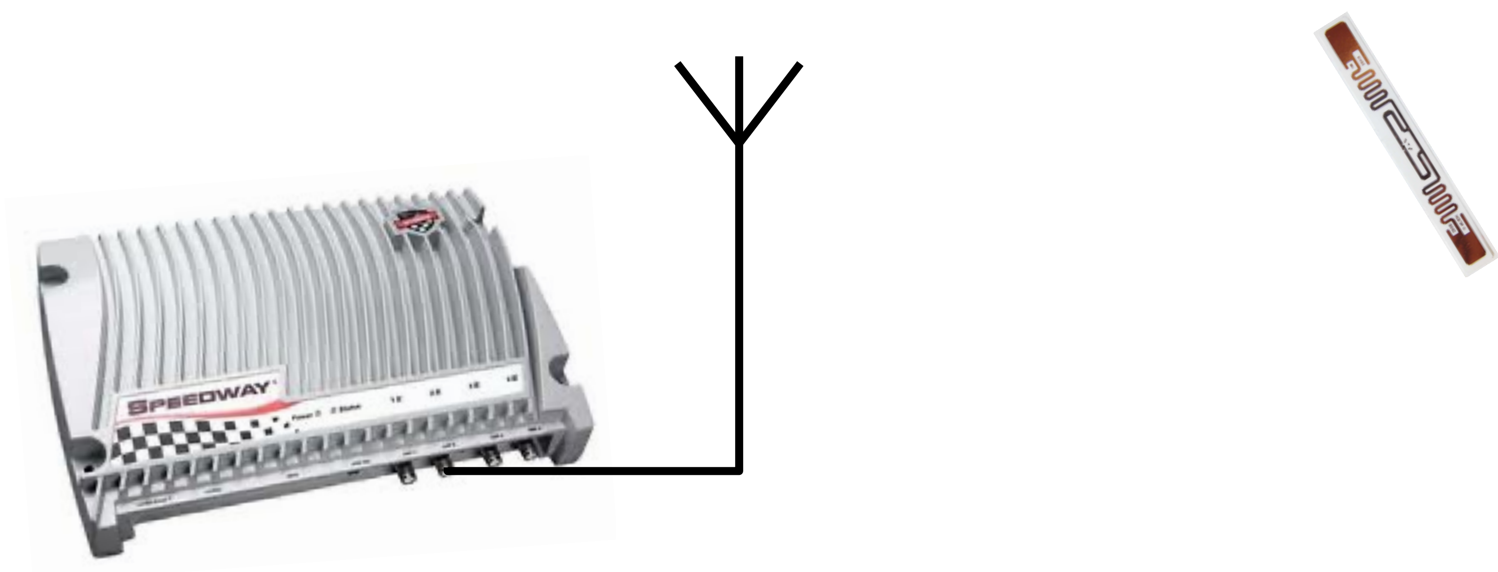
- How does it know whether the high or the low is zero or one?

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”



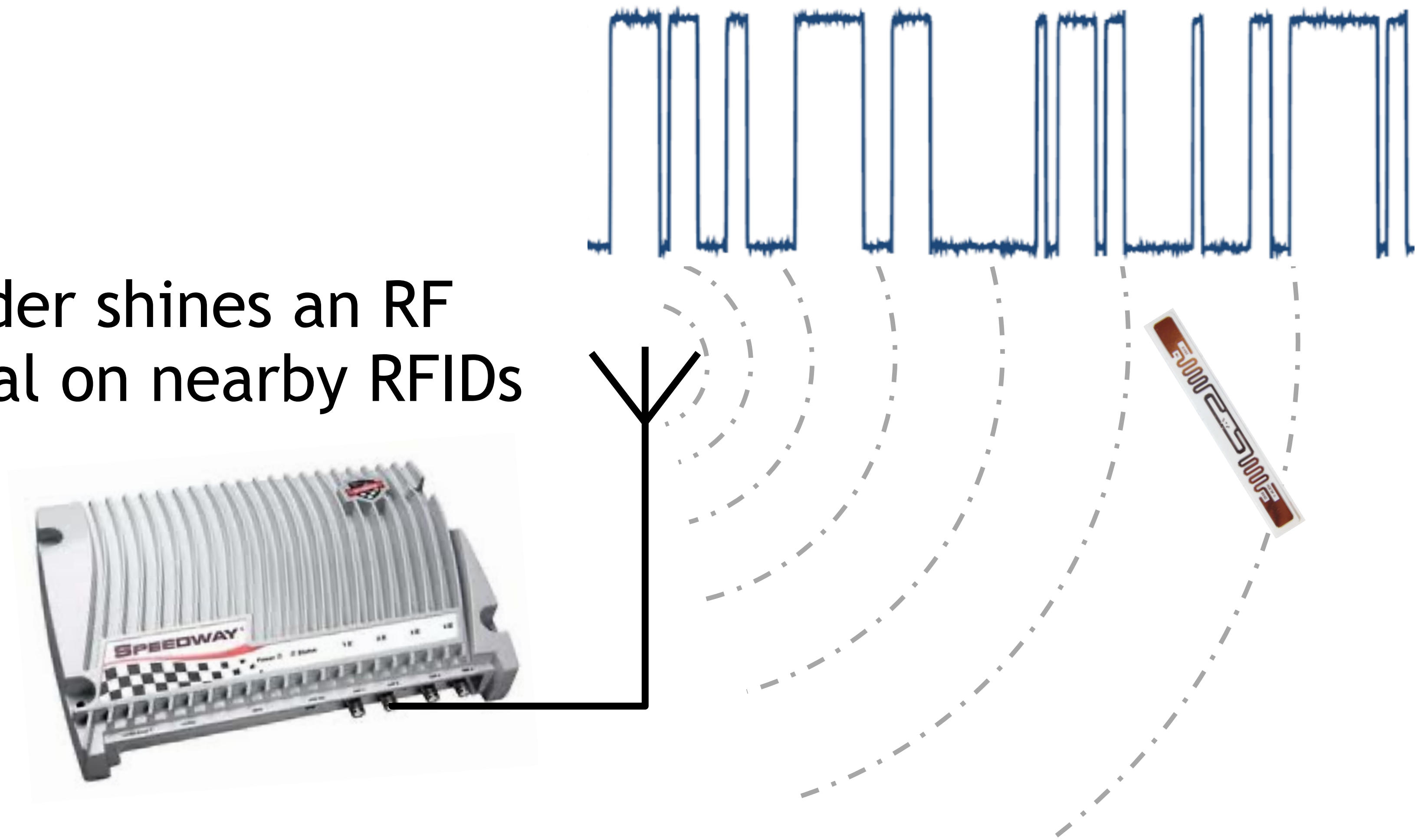
Backscatter Communication



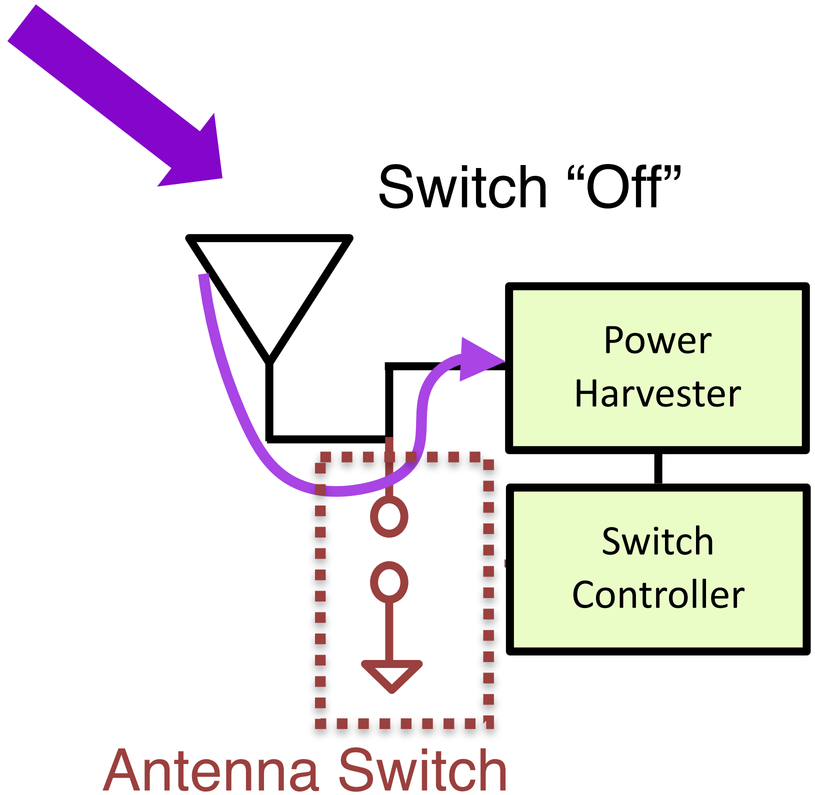
Backscatter Communication

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

Reader shines an RF signal on nearby RFIDs

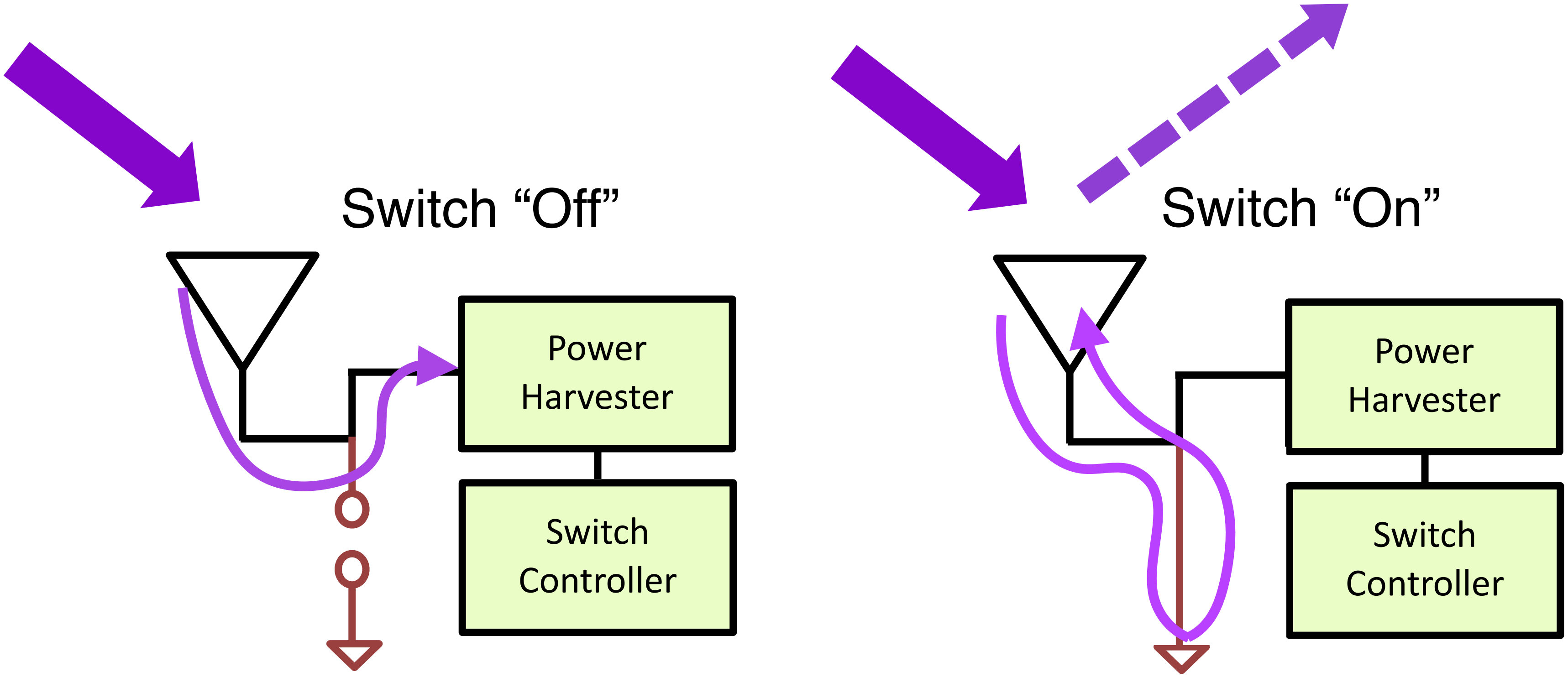


Uplink Communication

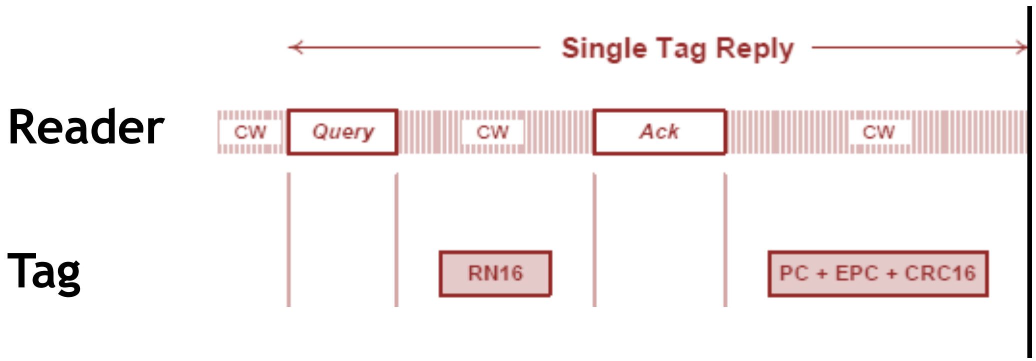


Simplified RFID schematic

Uplink Communication



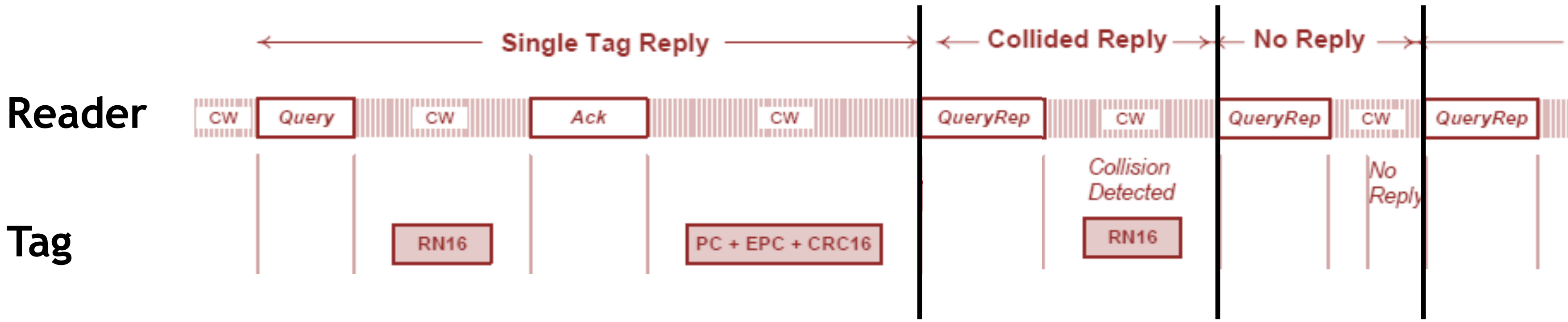
EPC Gen2 Standard - MAC



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

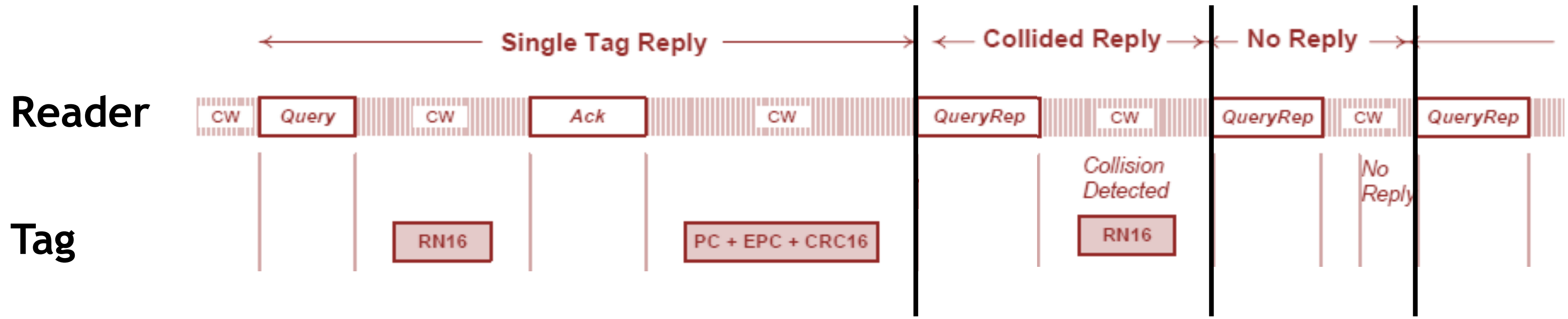
- To maximize E, set K = N

- 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

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

MobiCom 2018, New Delhi, India

Challenge: RFID Hacking for Fun and Profit

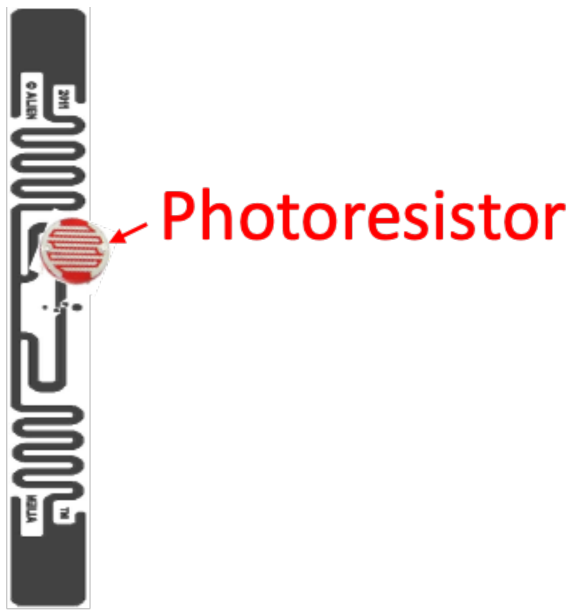
Ju Wang, Omid Abari and Srinivasan Keshav

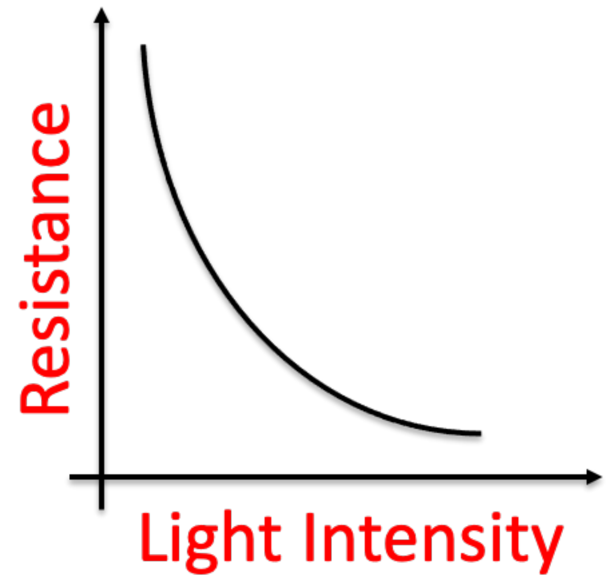
{ju.wang,omid.abari,keshav}@uwaterloo.ca

UNIVERSITY OF WATERLOO

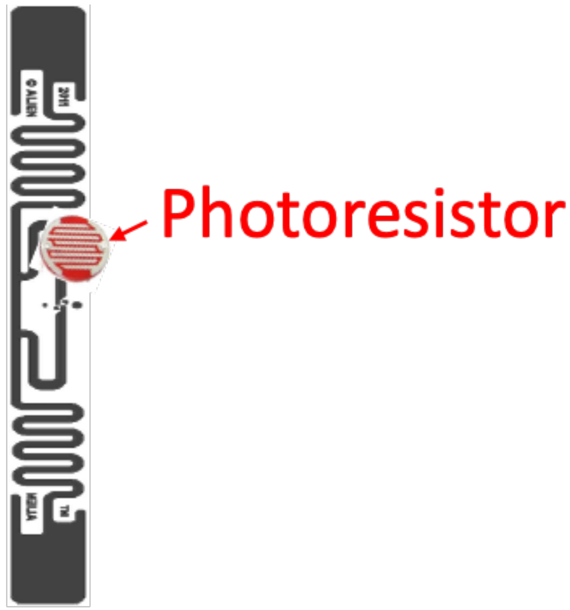
ICONLAB.ca

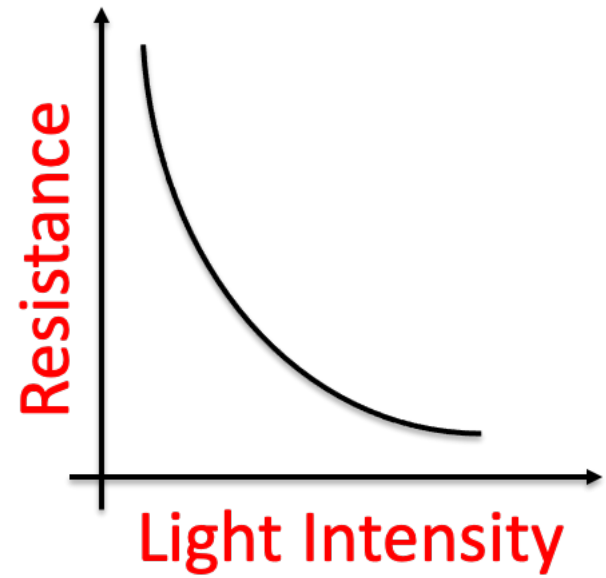
What’s the basic approach?





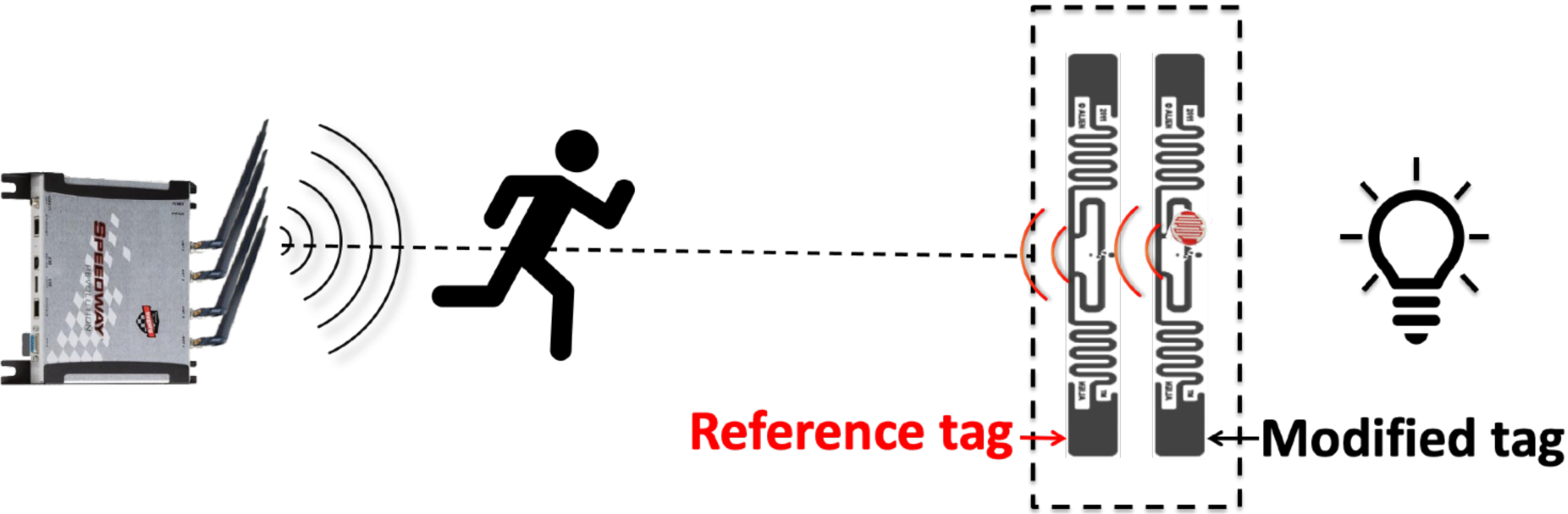
What’s the basic approach?





- How do they isolate the impact of the environment vs the photoresists on RSS?

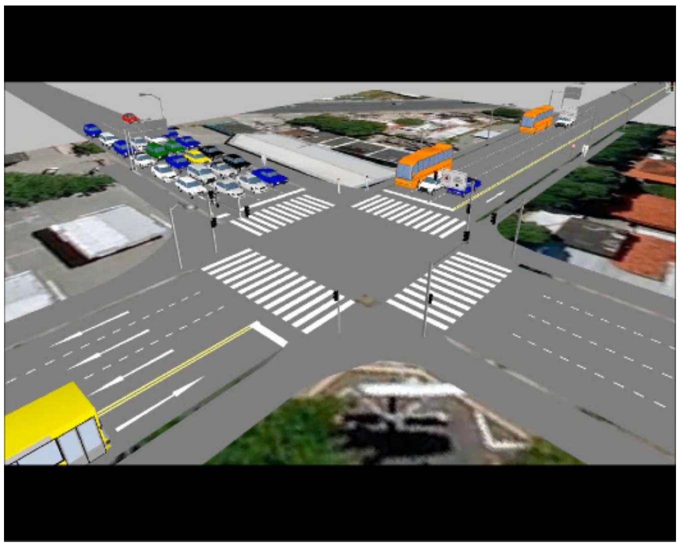
Solution: Differential Sensing to deal with environmental variations



- **Reference tag**: RSS1 ∝ Environment
- **Modified tag**: RSS2 ∝ Light + Environment
- **Differential: (RSS2 – RSS1) ∝ Light**

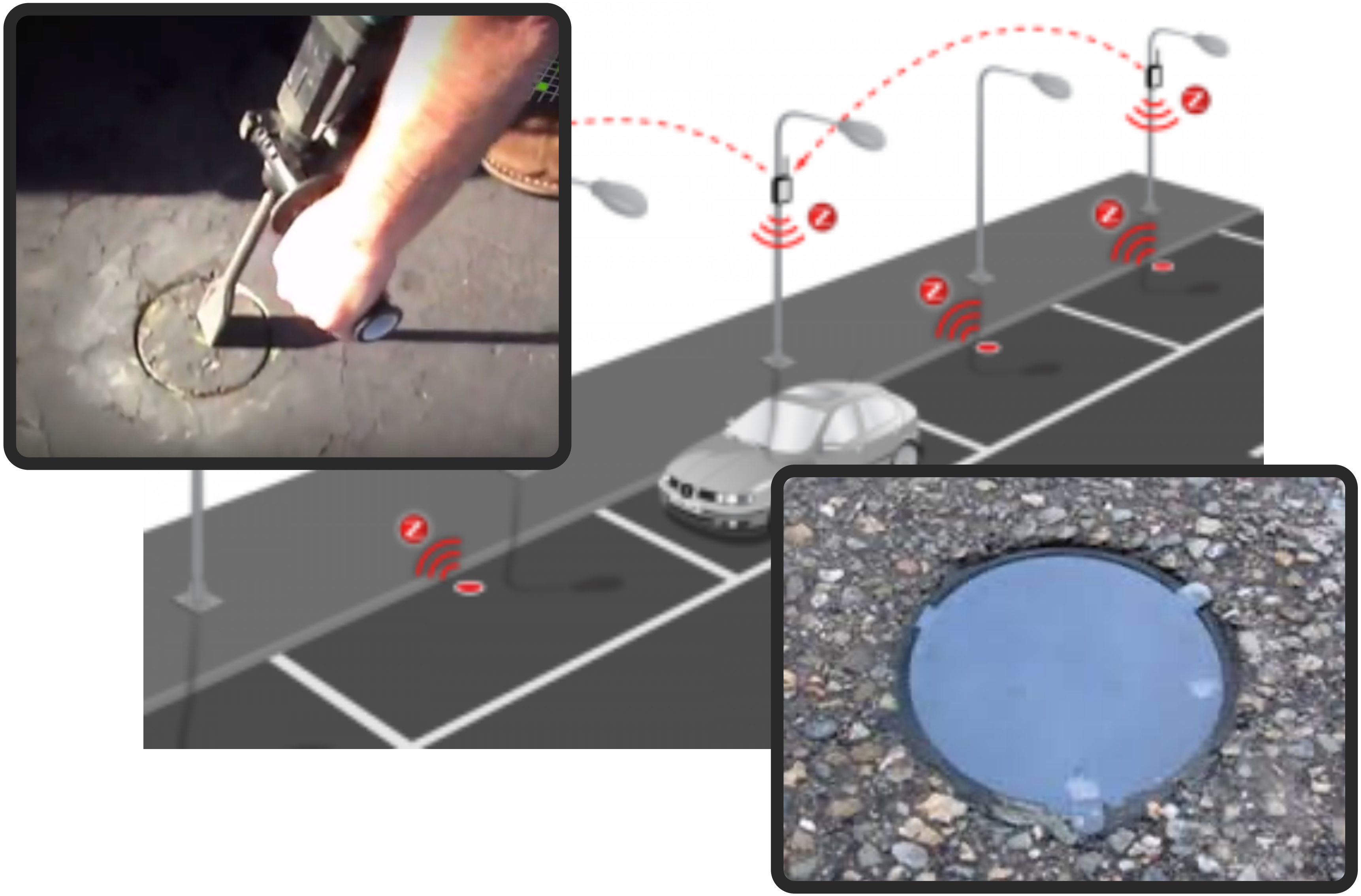
An E-Toll Transponder Network for Smart Cities

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

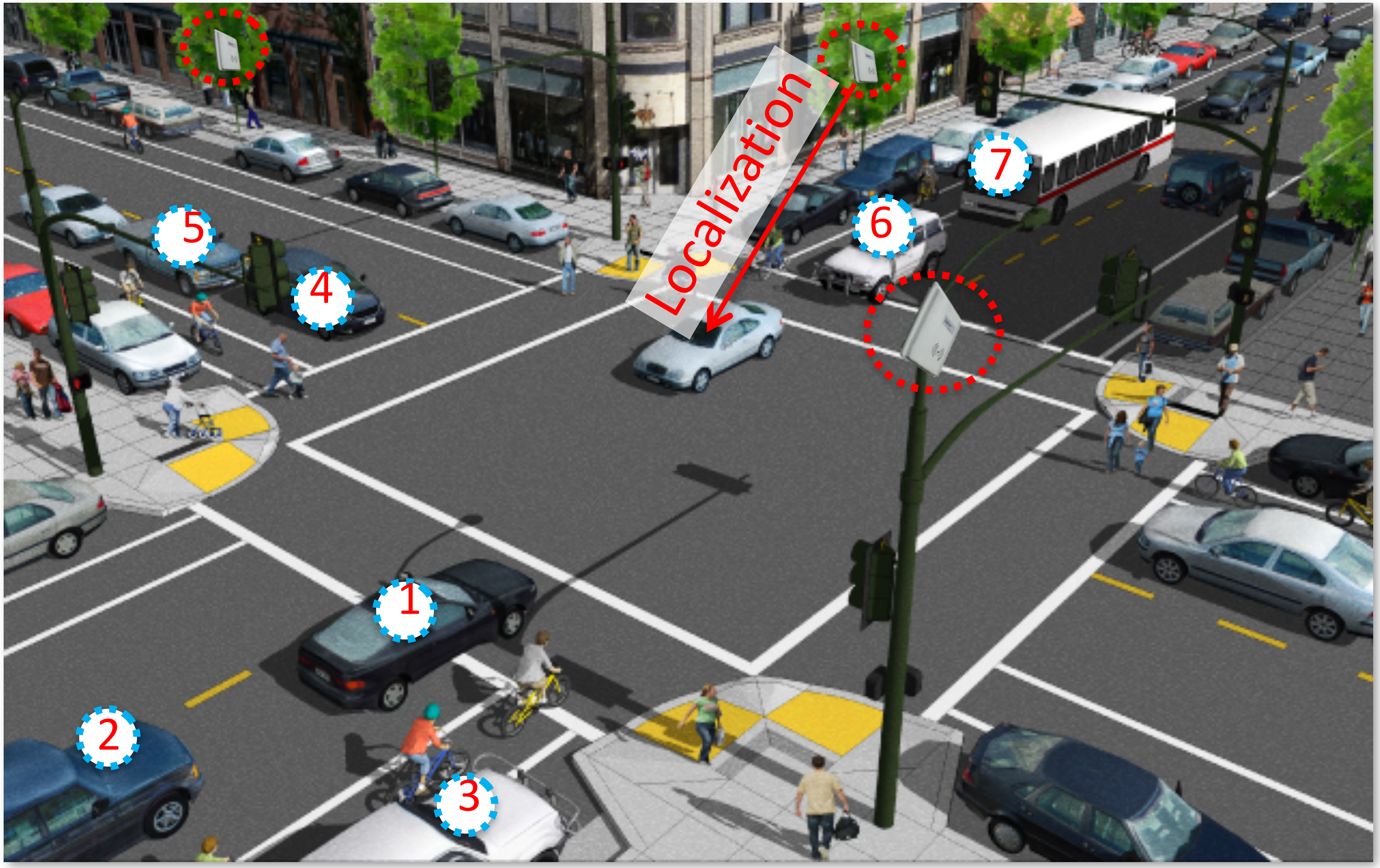
2) Ease of Maintenance

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

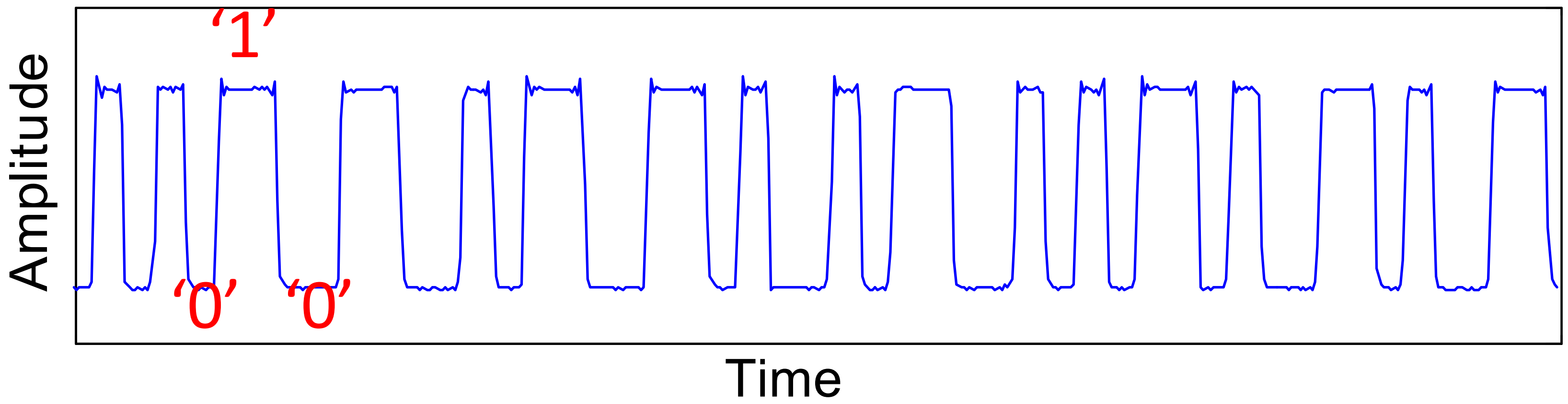
↓

All cars respond

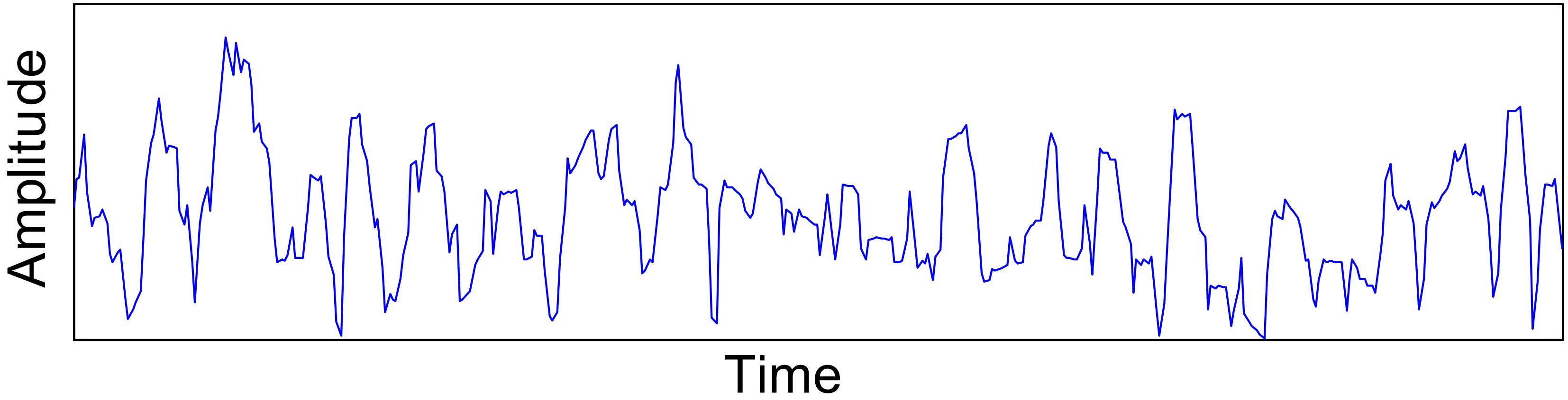
How can we decode transponders despite Interference?

How can we decode transponders despite Interference?

One Transponder Responds → Decodable



Multiple Transponders Respond



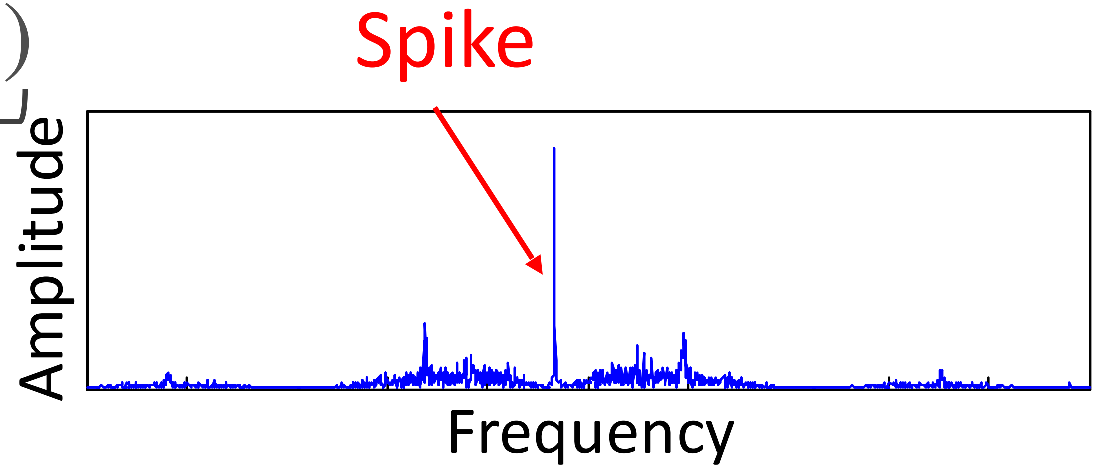
Count cars: How to count despite interference?

Structure of the Signal

Time-Domain

 x $\underbrace{(\sin 2\pi f_c t)}_{\text{Carrier}}$

Freq-Domain



Variability due to manufacturing process

Structure of the Signal

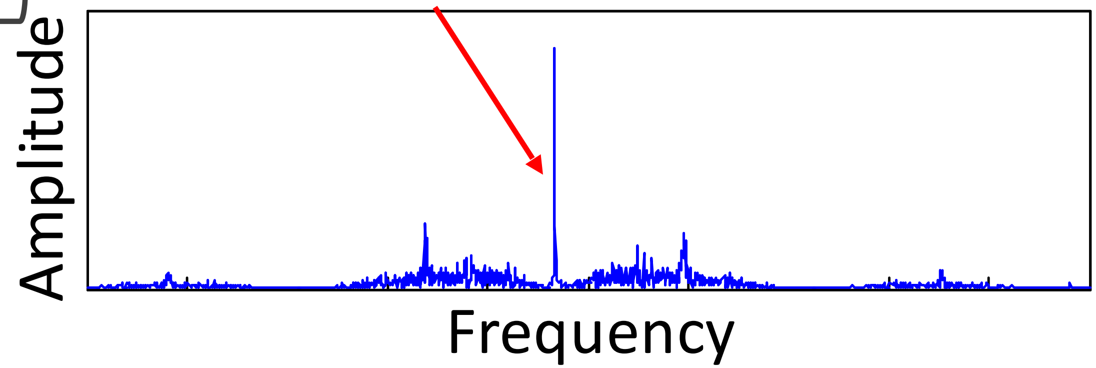
Time-Domain

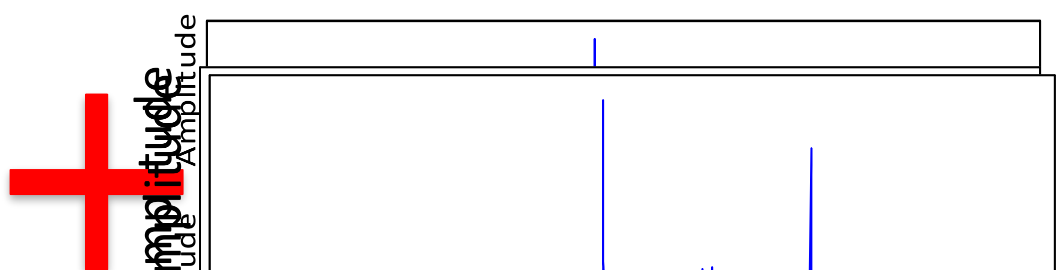
Freq-Domain

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

Carrier

Spike



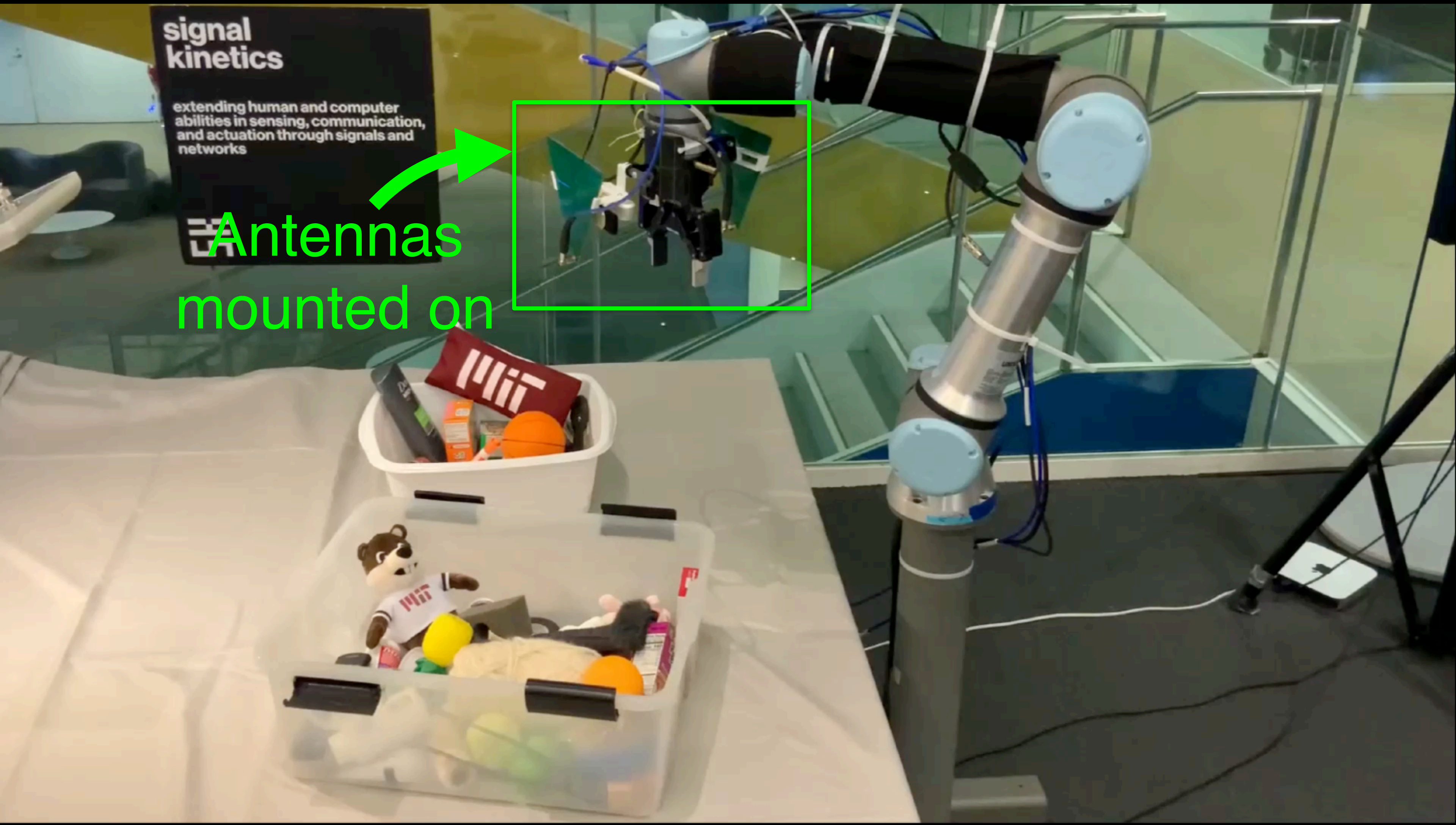


Can count despite interference

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


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

What did we cover today?

Learn the fundamentals, applications, and implications of

IoT connectivity technologies

1- What is an RFID? where are they used?

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3- How does an RFID communicate?

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