Internet of Things!

Fall 2024

Where are we today?

We have the things … now we need to make it an Internet of Things!

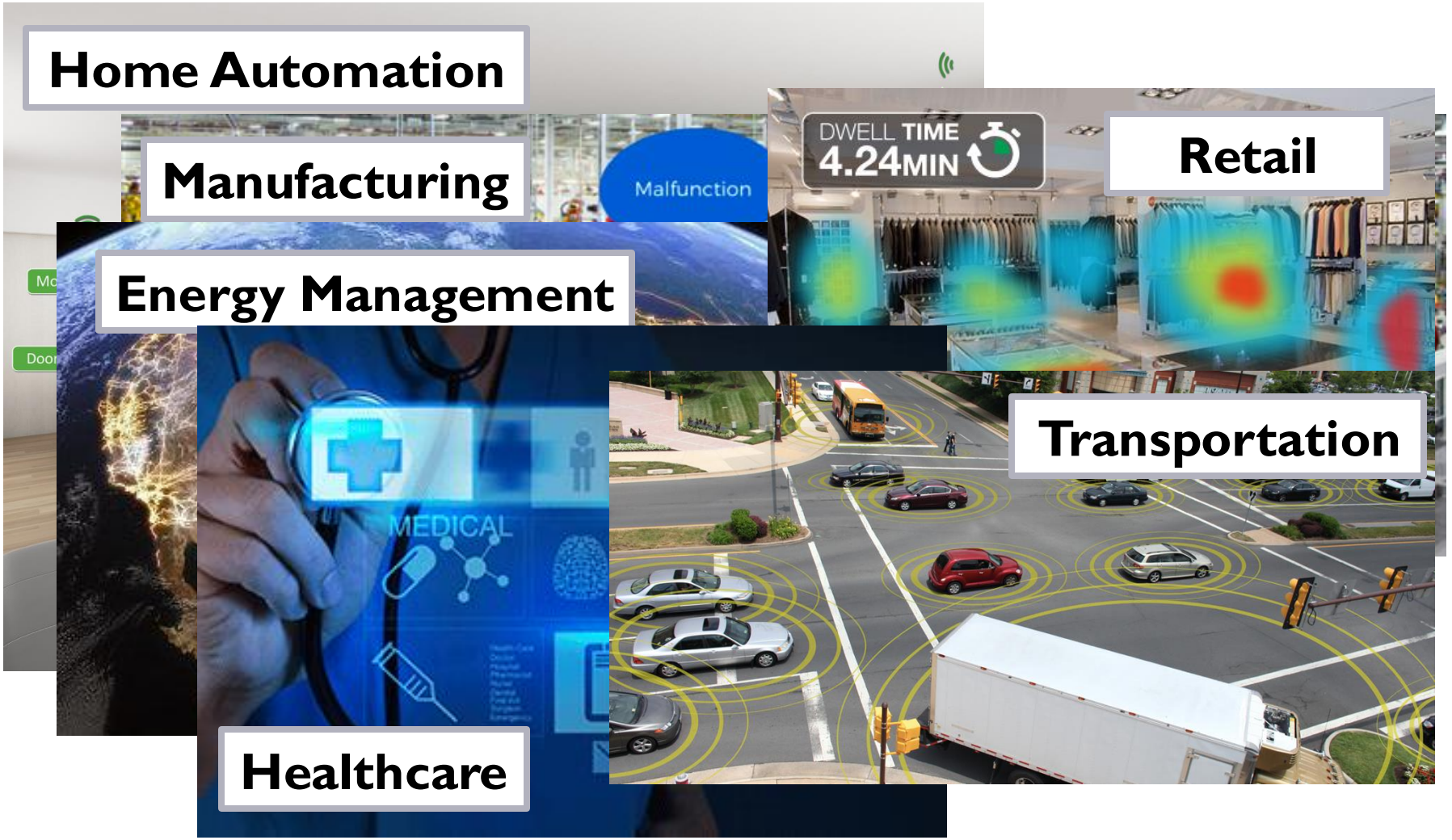
IoT Networks

IoT Network

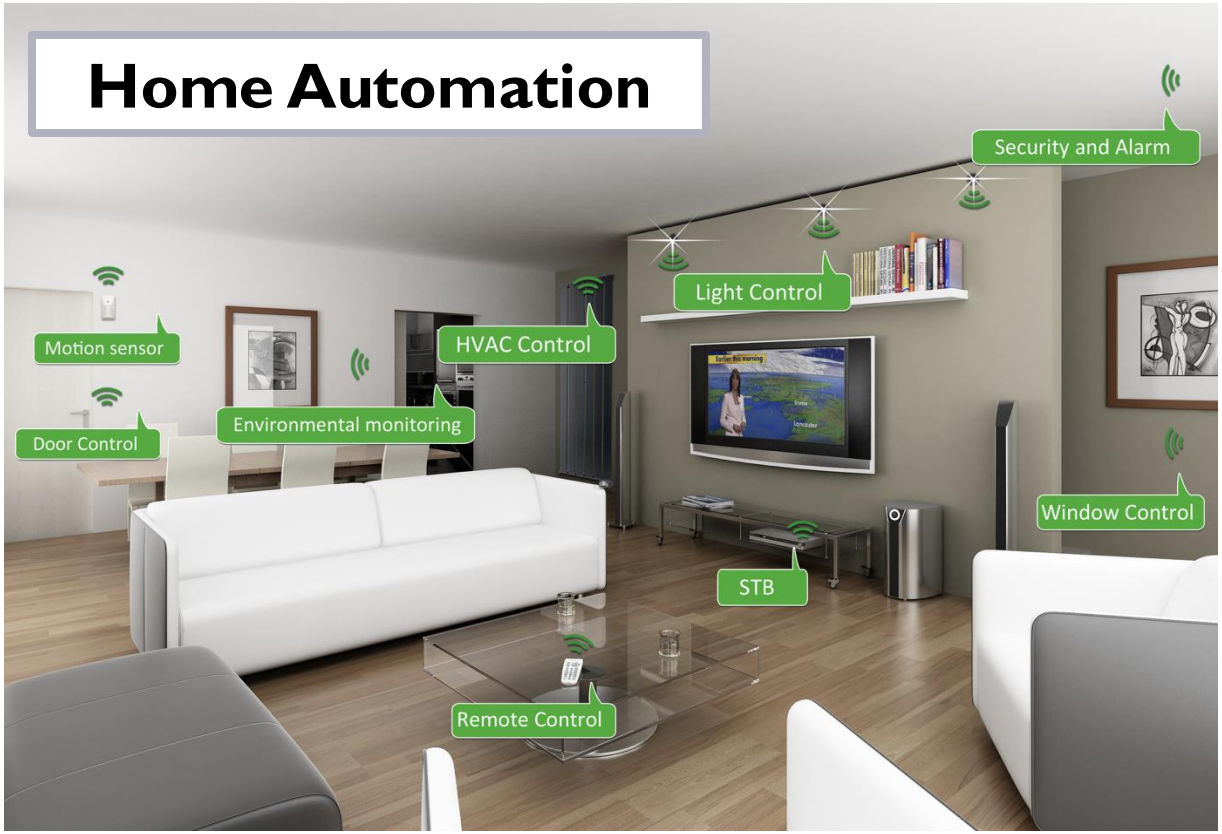
Goal

- Connecting users to the information around them

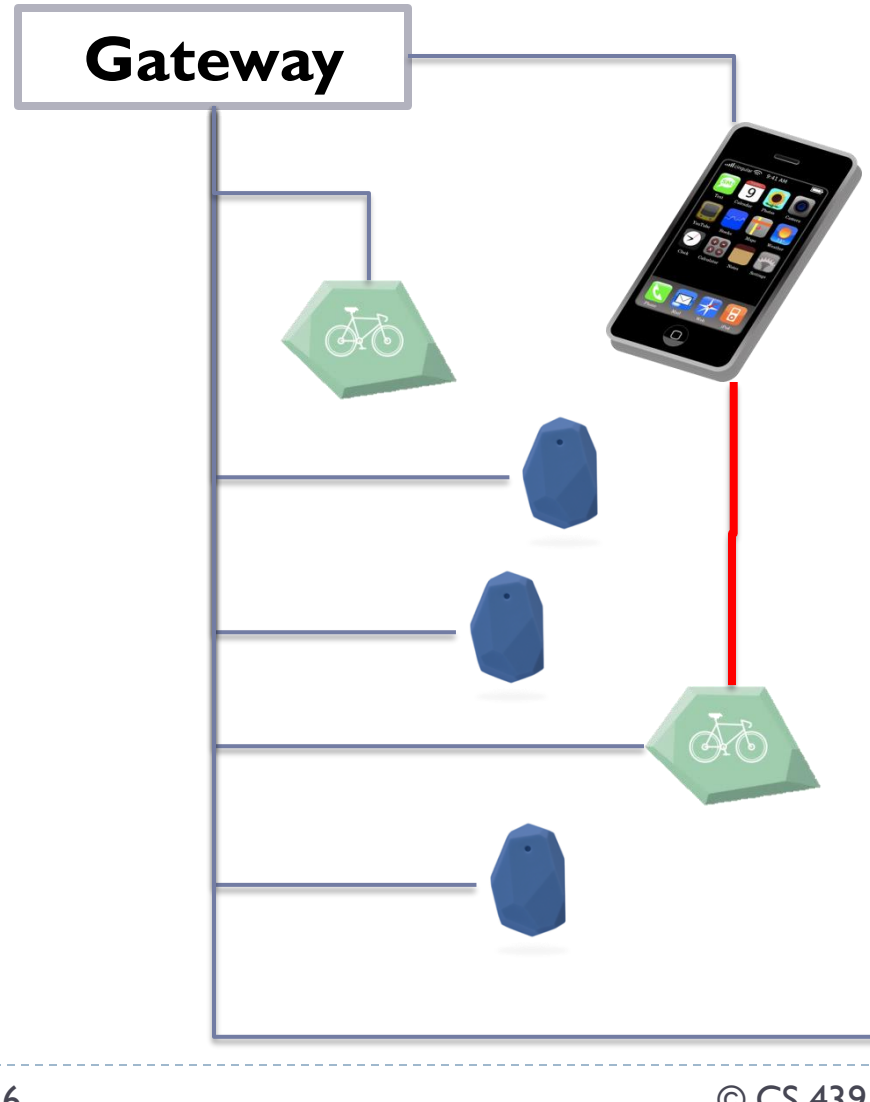
Targeted Solutions



IoT in Home Automation

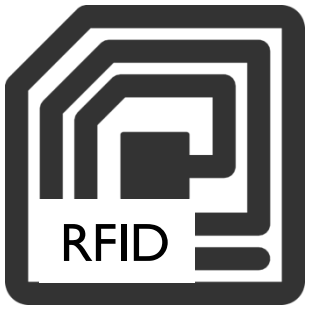


IoT in Retail



Connecting Devices

The Internet has IP to enable interoperability



Is IP the right solution for IoT?

Connecting Devices

Many of these technologies target low power communication with very small payload

The Internet has IP to enable interoperability

Is IP really necessary?

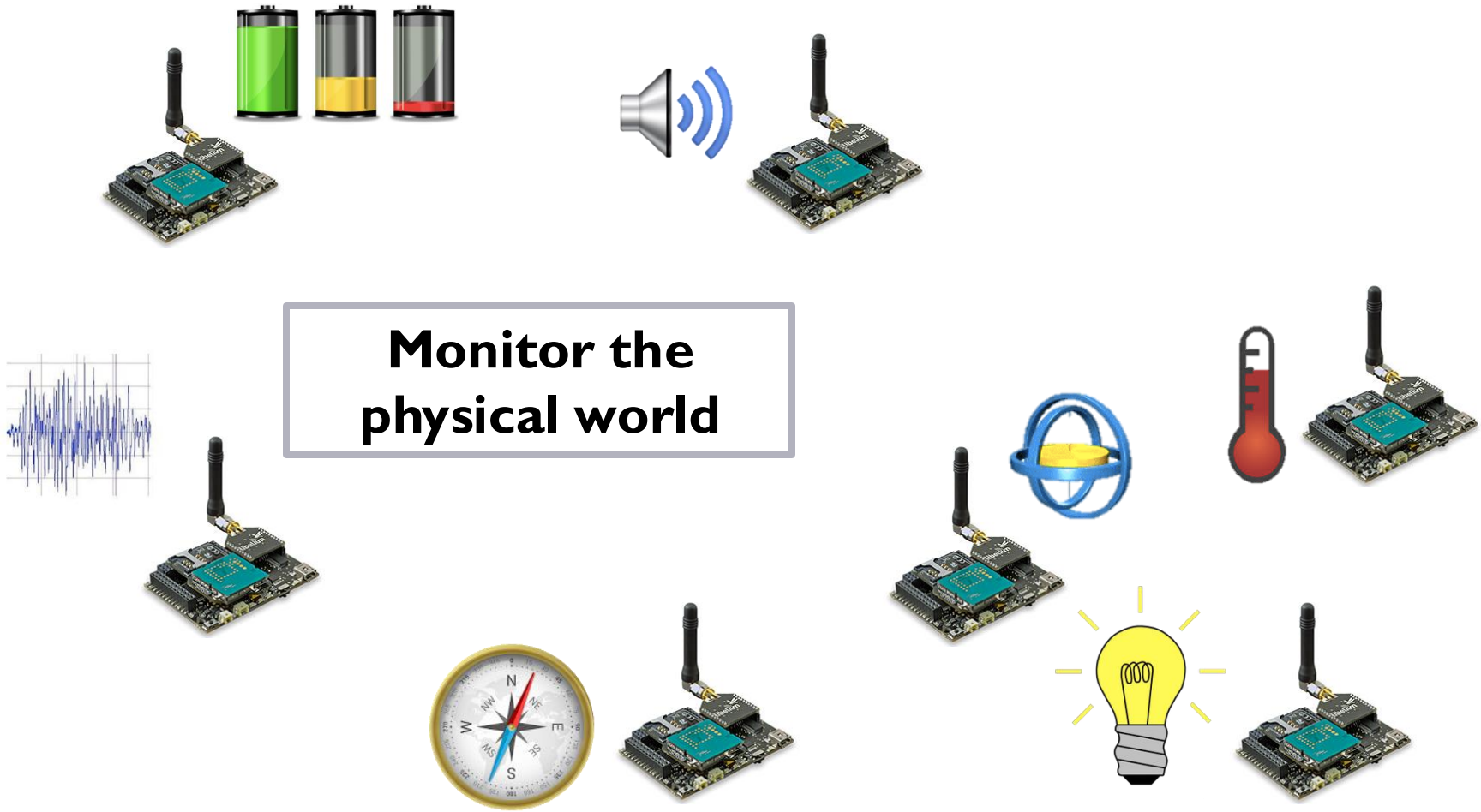
RFID

Do we need global addressing for every device?

Is IP the right solution for IoT?

Is an IoT Gateway good enough?

From Small Things …



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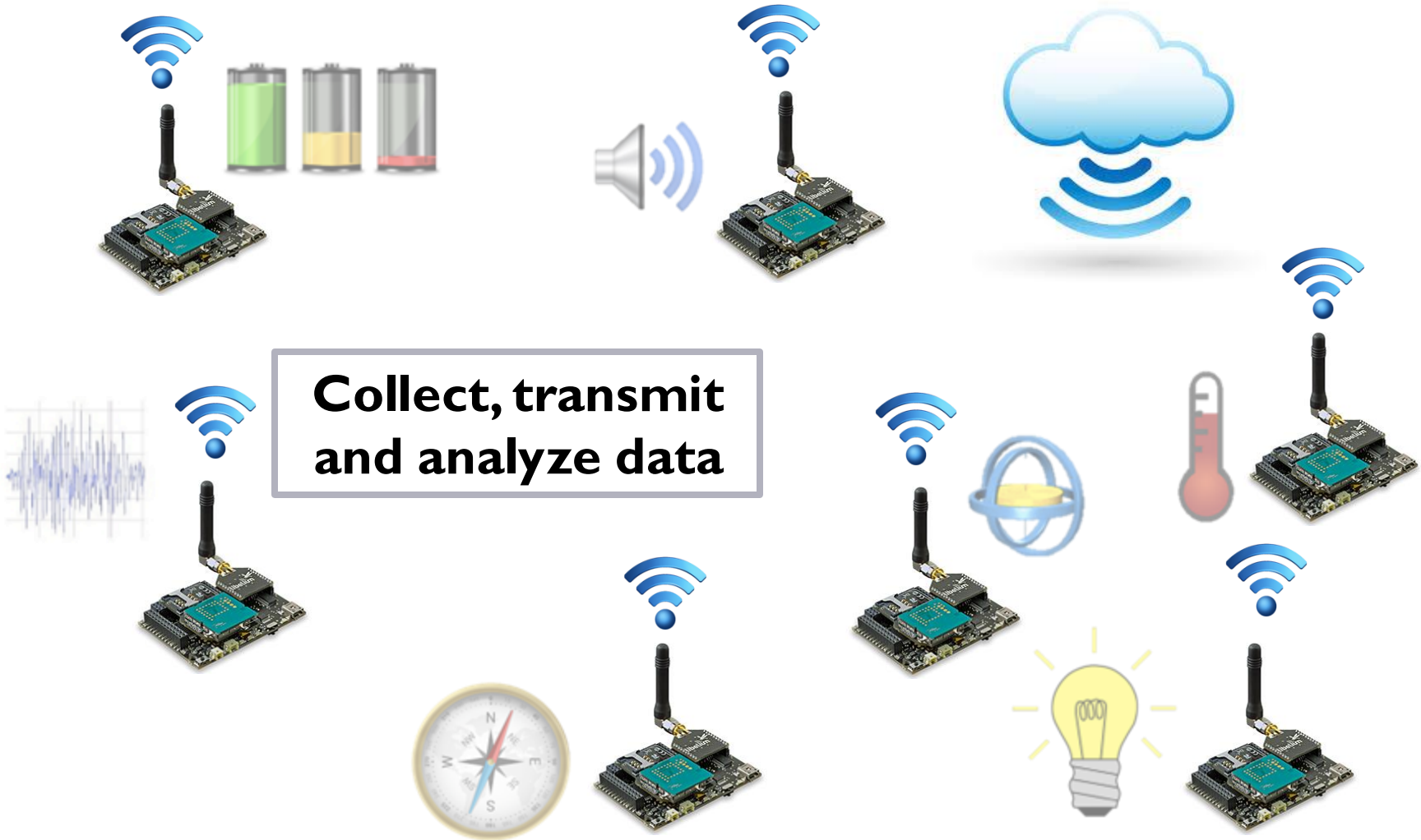

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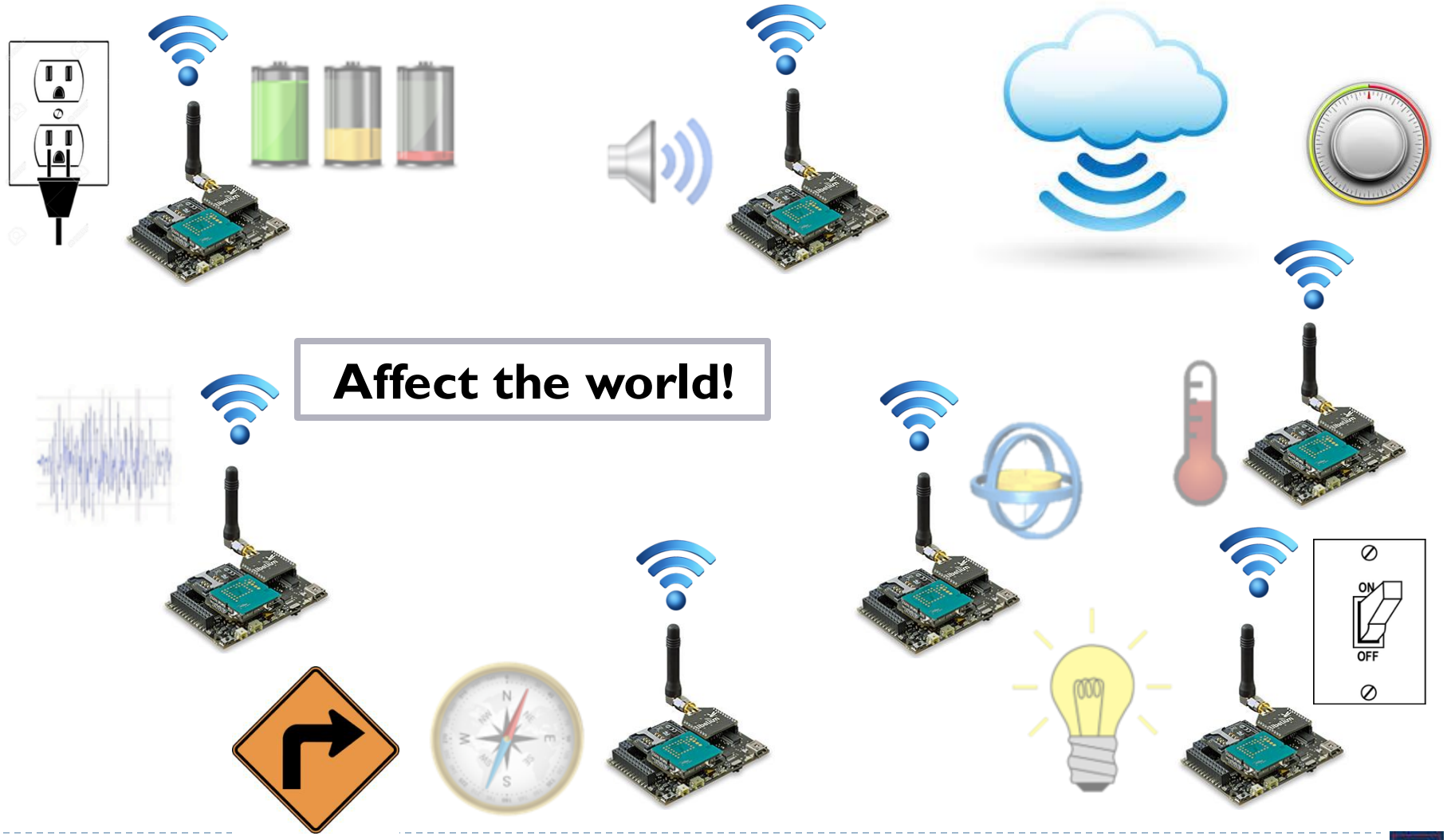
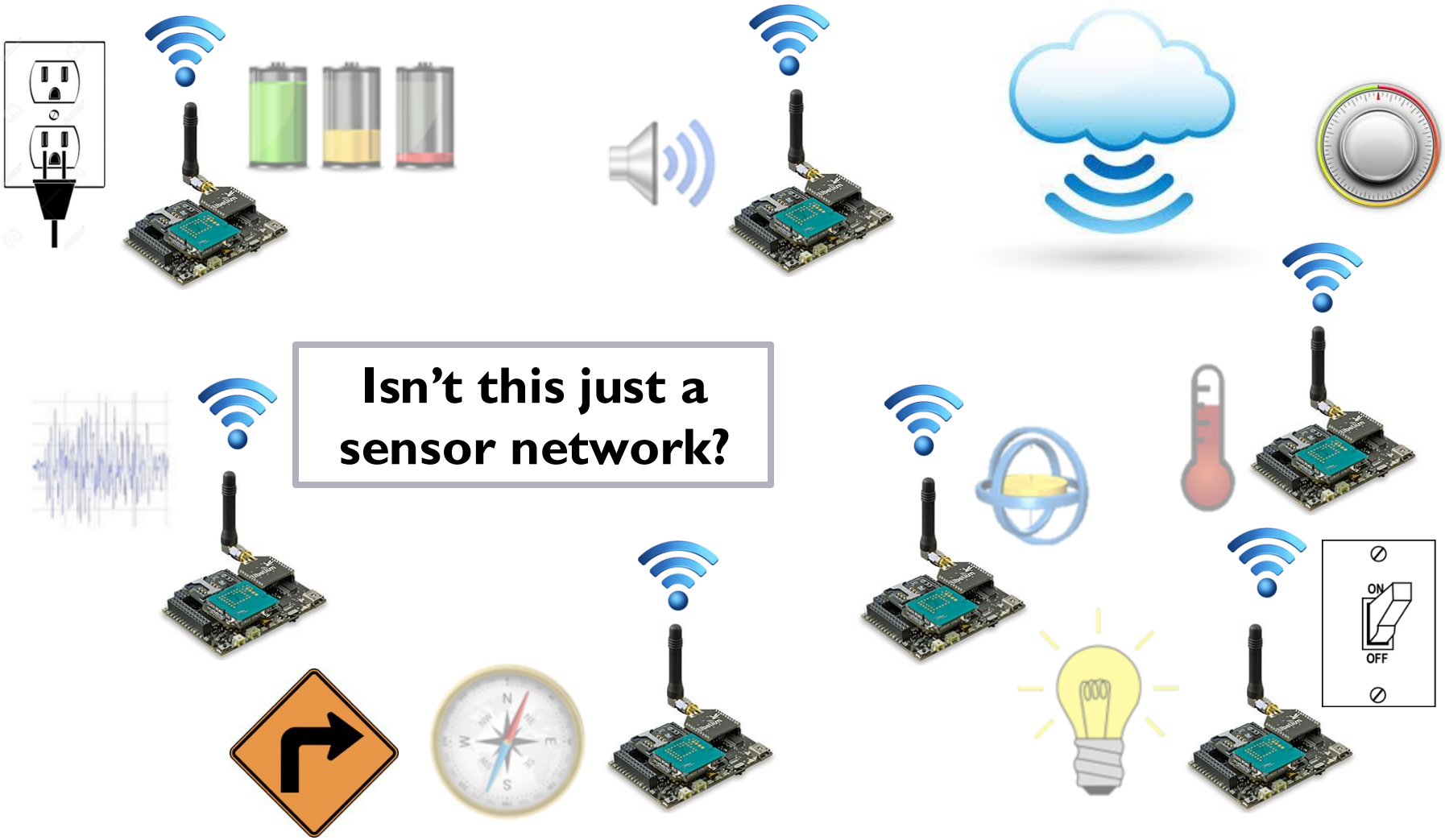


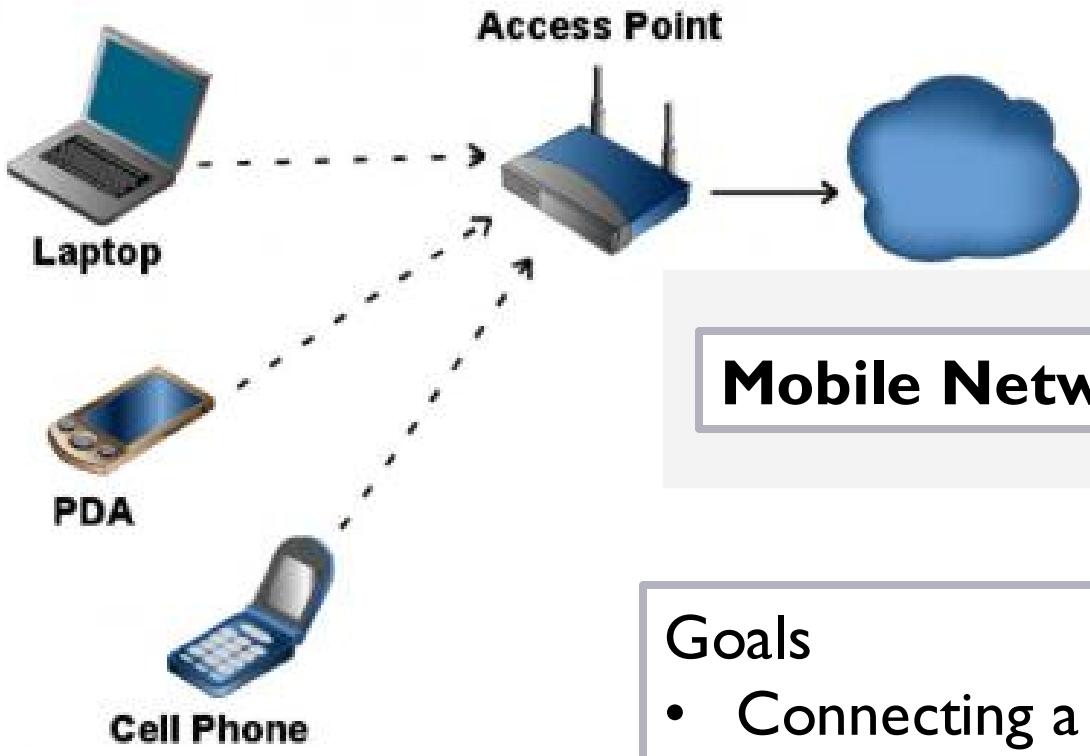
So we have lots of devices …



So we have lots of devices …

So we have lots of devices …

More than a Mobile Network



Device to Cloud

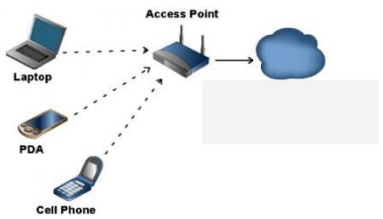
Device to Device

Mobile Network

Goals

- Connecting a mobile device to the Internet
- End-to-end communication

More than an Ad Hoc Network



Ad Hoc Network

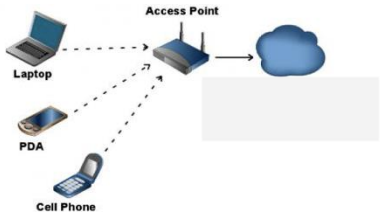
Device to Device

Goals

- Connecting a mobile device to another mobile device
- End-to-end communication

Does IoT require multihop wireless communication?

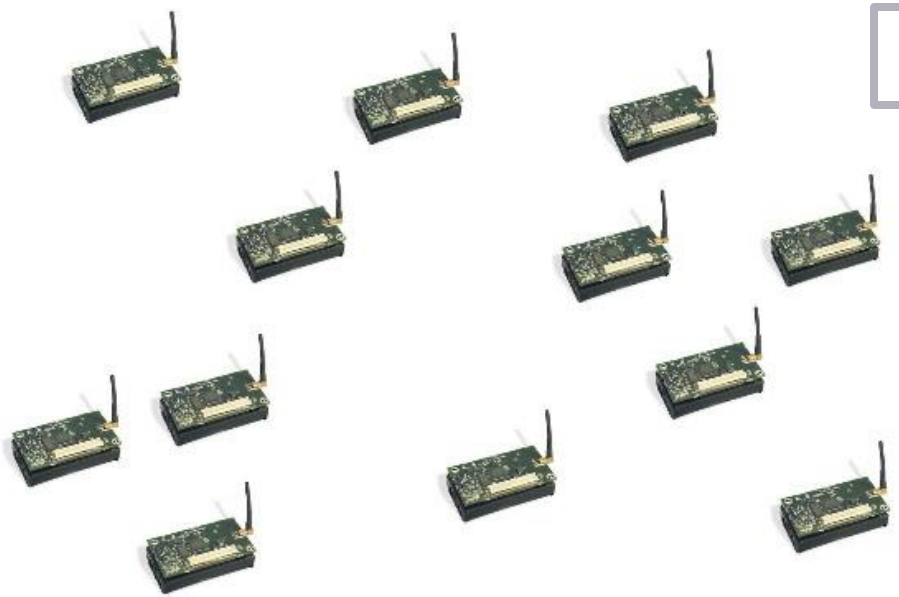
More than a Sensor Network



Sensor Network

Device to Cloud

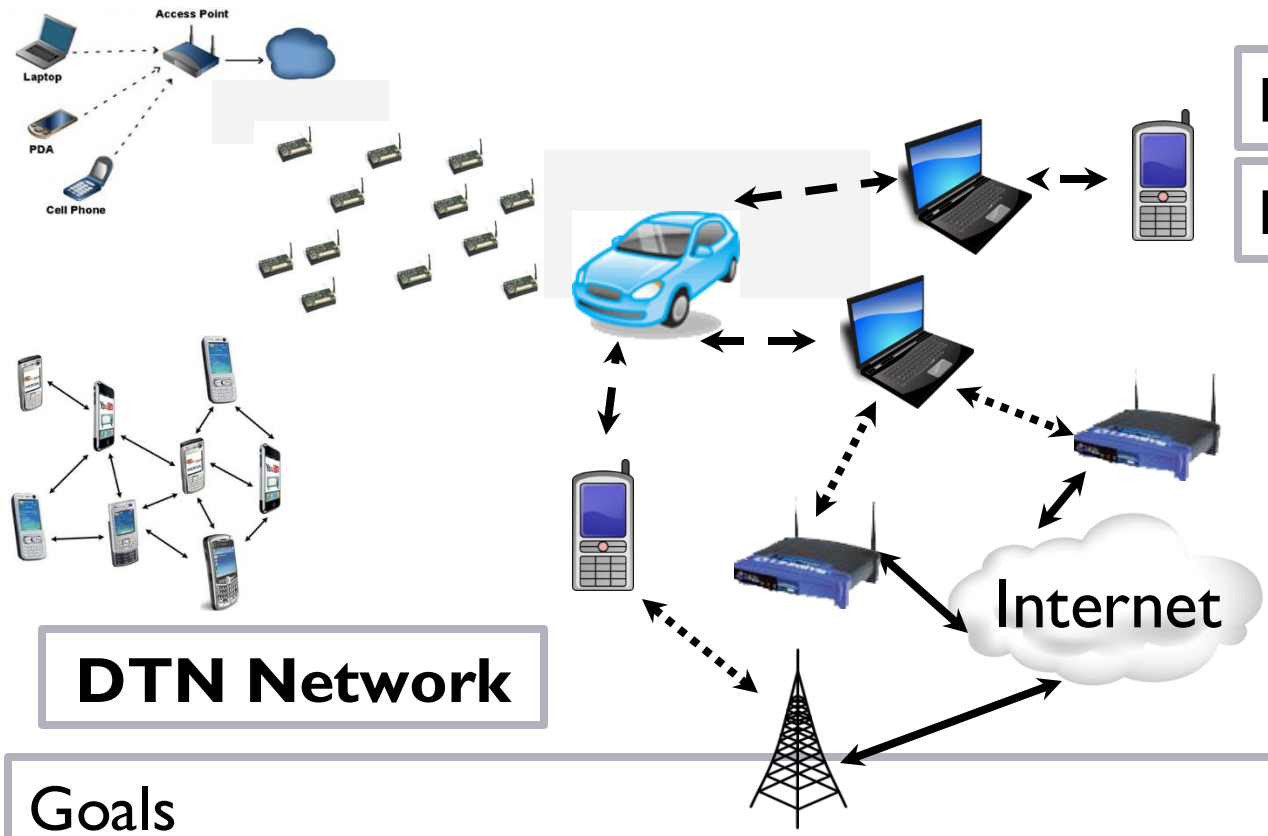
Device to Device



Goals

- Collecting data and connecting sensors to the cloud
- End-to-end communication

More than a DTN Network



Device to Cloud

Device to Device

DTN Network

Goals

- Collecting and moving data through a disconnected network
- End-to-end communication

Can we hide it all under IP?

Can we hide it all under IP?

Can we hide it all under IP?

The IoT Network

IoT Network

Goal

- Connecting users to the information around them
- Local point-to-point communication
- Cloud based end-to-end communication

The IoT Network

IoT Network

Proximity networking
- Discovery
- Localization

and

Cloud-based networking
- Service and data management

The IoT Network

IoT Network

Proximity ne
- Disco
- Lo

Cloud-based networking
- Ser

Driven by advances in technology

Supported by IP networks

The IoT Network

IoT Network

Proximity networking
- Discovery
- Localization

The IoT Network

IoT Network

Solutions must be:

Localized
Low bandwidth
Energy efficient
Privacy preserving

➔ Need to design from the bottom up

IoT from the Bottom Up

Wireless Networking

Low Power Computing

Sensors

Limited Power Source

Actuators

IoT from the Bottom Up

Wireless Networking

Privacy

Discovery

Which Technology?

IoT from the Bottom Up

Wireless Networking

Privacy

Discovery

Which Technology?

Which Technology best fits IoT?

Which Technology best fits IoT?

Need to understand the requirements and tradeoffs

Which Technology best fits IoT?

Connecting to the cloud

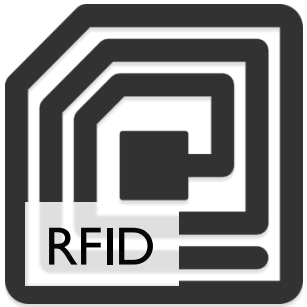
Large data transfers

High range
High BW
High energy

Which Technology best fits IoT?

Expensive for readers
Manufacturing

Low range
Medium BW



Good signal characteristics for localization
Not available on all phones

Medium range
Low BW

Slow discovery
Long-lived connections

Which Technology best fits IoT?

Proprietary solutions
Not available on phones

Long range
Very Low BW
Low Power

Simple standardized discovery and limited data transfer
Available on all phones

Short range
Low BW
Low Power

Which Technology best fits IoT?

ZigBee

They all have their place in IoT

IoT from the Bottom Up

Wireless Networking

Discovery

Privacy

Which Technology?

Discovery: Is anybody out there?

Device proximity is unplanned and unpredictable

Limited Resources
- Imbalance of power
  - Gateways have wall power
  - User devices are energy-constrained
  - Everything in-between
- Shared wireless bandwidth

Continuous beaconing/searching is not feasible
- User devices need to duty cycle wireless
- Global Synchronization is difficult

Solutions are technology-specific

Discovery: Is anybody out there?

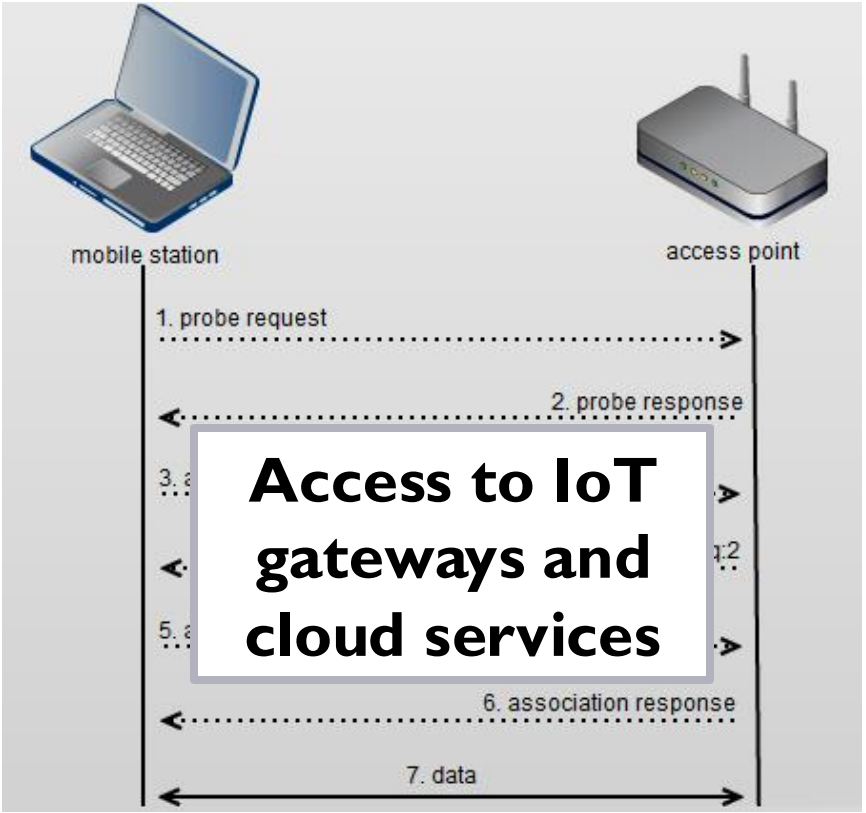
AP Discovery

Base station:

- No energy constraints
- Always on

Mobile

- Balance discovery delay with energy consumption

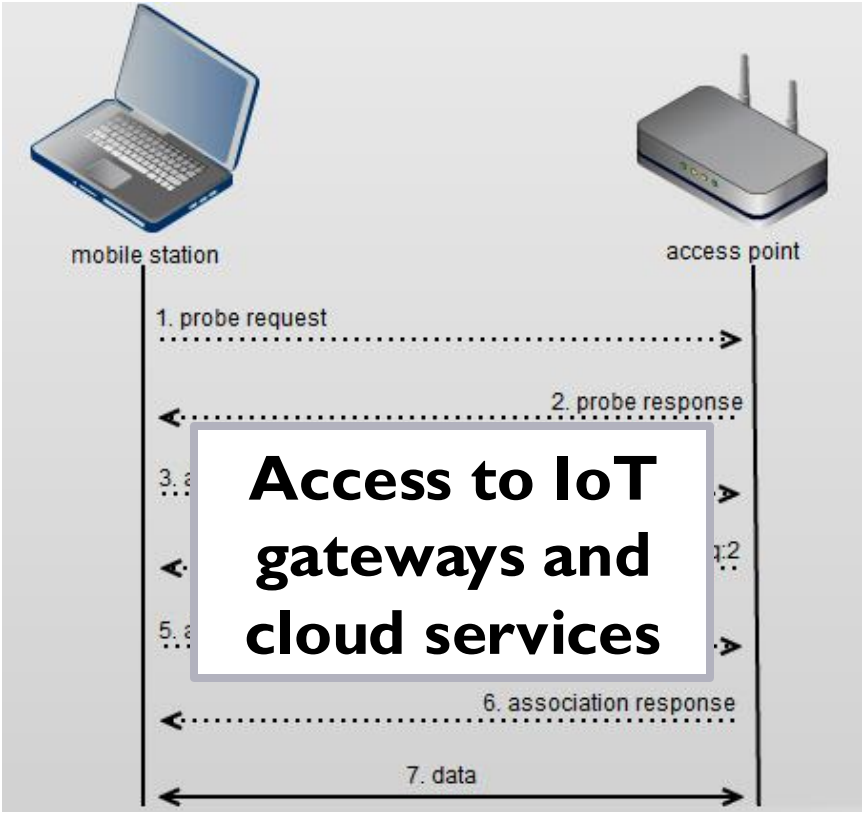


Discovery: Is anybody out there?

AP Discovery

Bandwidth constrains:

- Balance discovery delay with bandwidth overhead

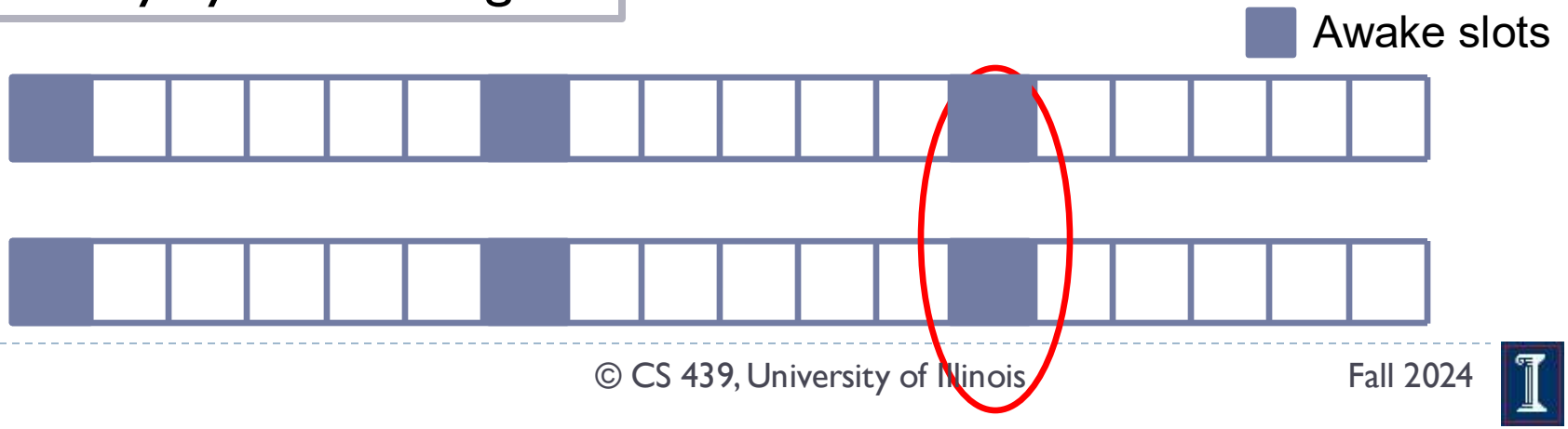


Discovery: Is anybody out there?

Device Discovery

Mobile
- Broadcast "beacon"
- Duty cycle listening

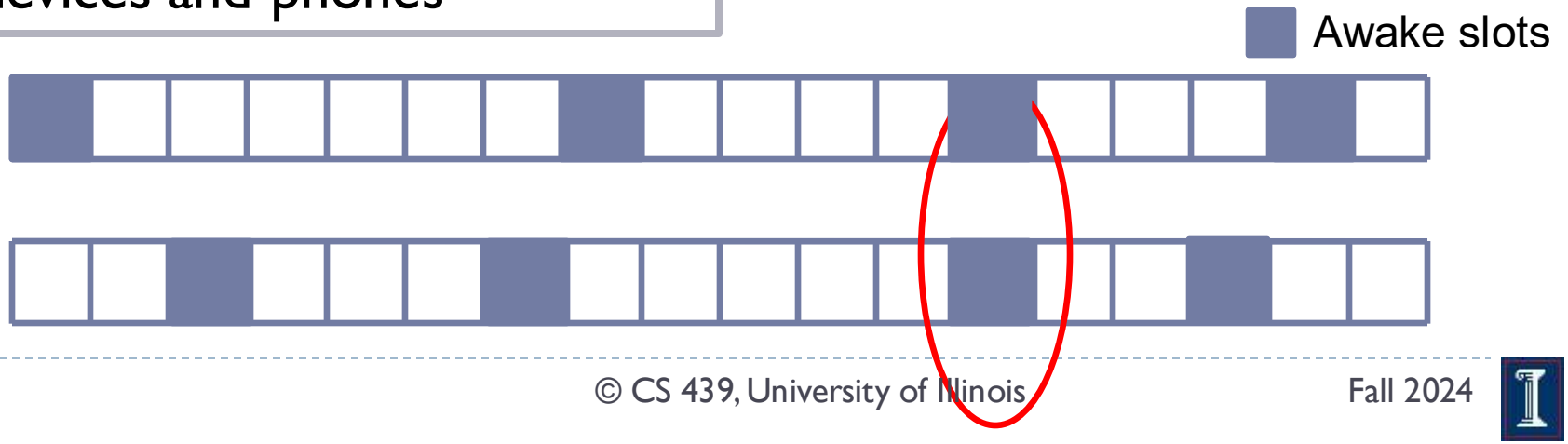
Local discovery
Specialized for environment



Discovery: Is anybody out there?

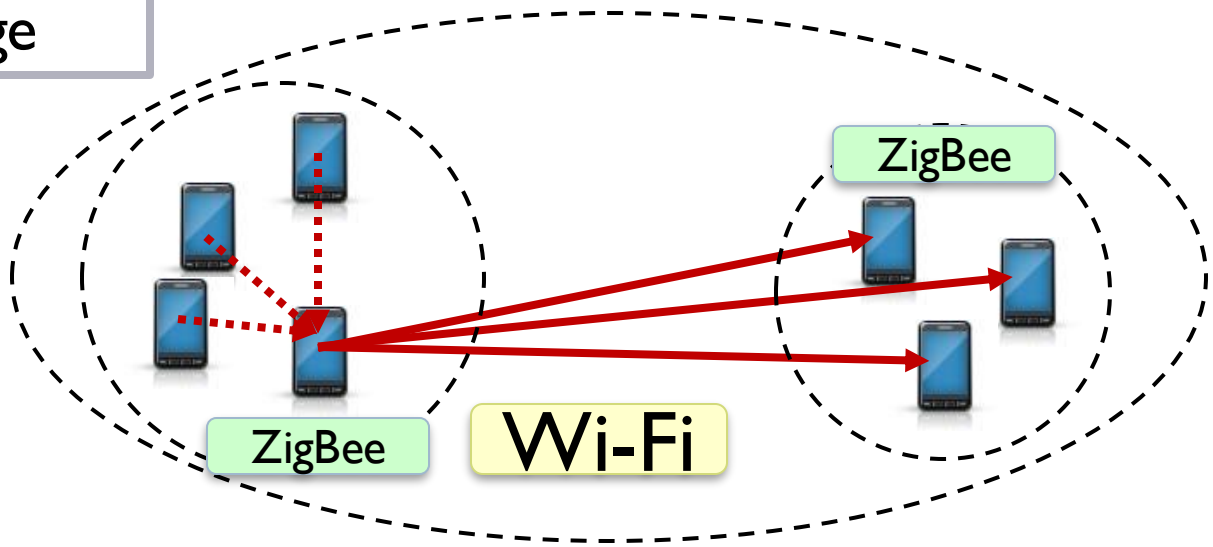
Attaining synchronization is complex and resource intensive … and hard to maintain on small, inexpensive devices and phones

Asynchronous Discovery



Discovery: Is anybody out there?

Wi-Fi is expensive
ZigBee is low range

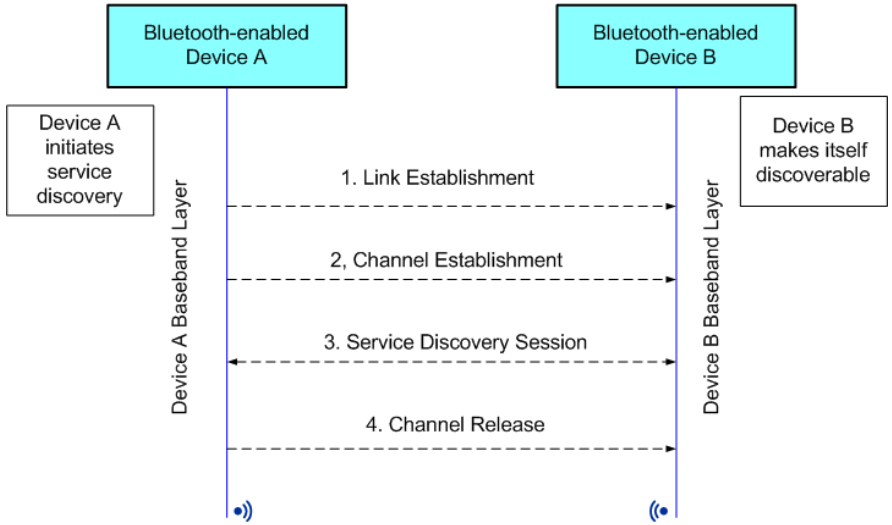


Discovery: Is anybody out there?

Asymmetric Discovery

Master-Slave:

- Complex
- Slow
- Requires user input



OK for long-lived, low BW connections

Discovery: Is anybody out there?

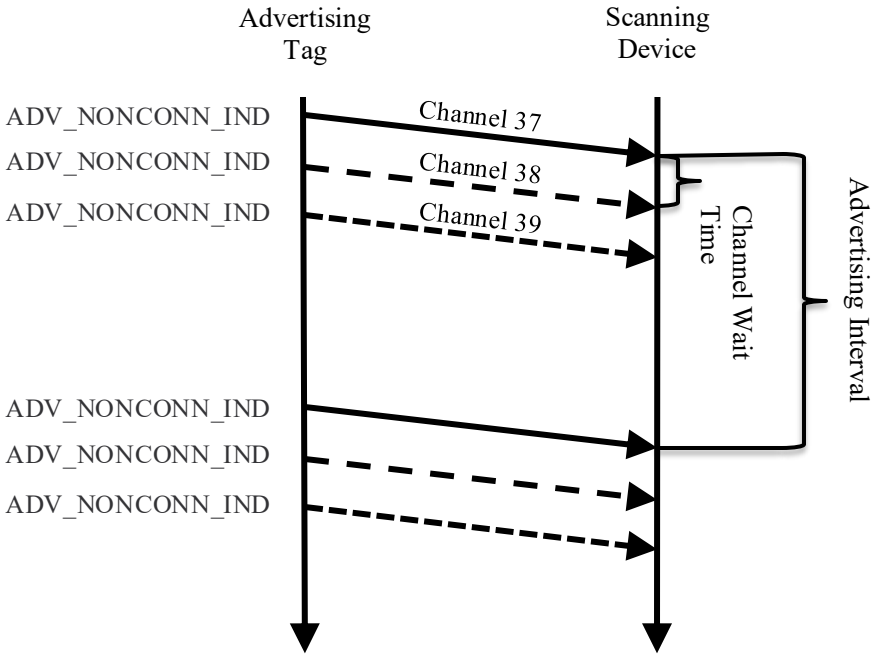
Bluetooth® SMART

Simplified Discovery

Beacon:

- Passive
- Active
- Client duty cycles listening

Small payload (31B)



Ultra-low power discovery

Discovery: Is anybody out there?

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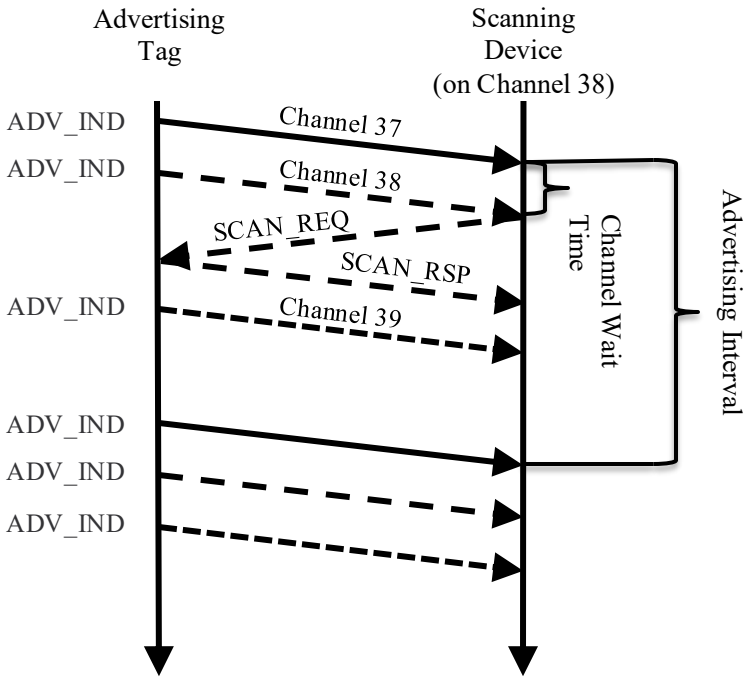


Ultra-low power discovery

IoT from the Bottom Up

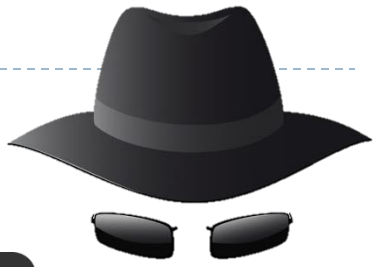
Wireless Networking

Privacy

Discovery

Which Technology?

Who has found me?



Wi Fi

THREAD

ZigBee

RFID

UWB

Z-wave

All of these protocols operate in the open

NFC

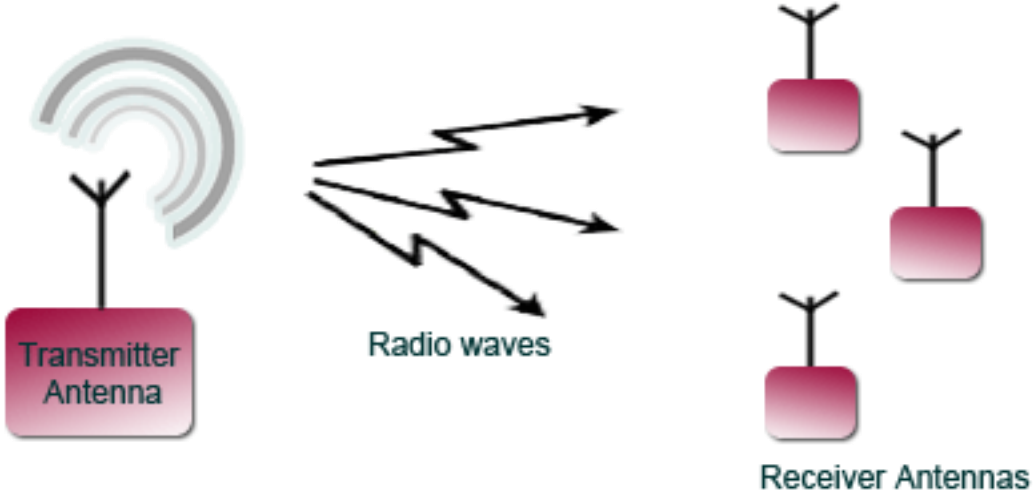
Bluetooth

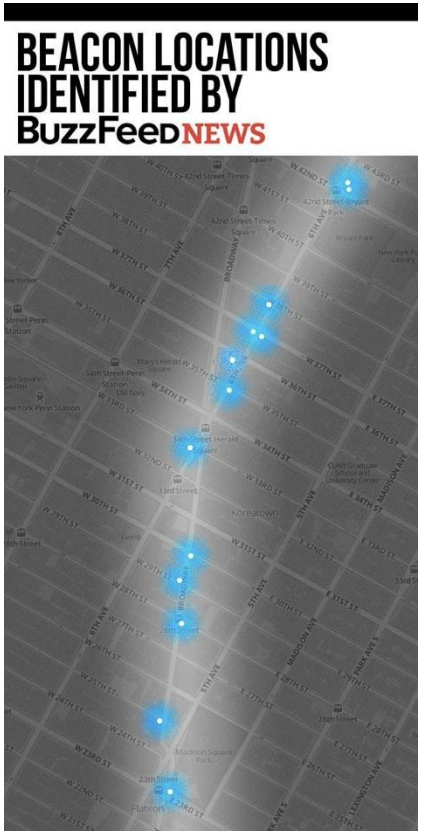
Bluetooth Low Energy

Discovery may reveal the user's identity!

Who has found me?

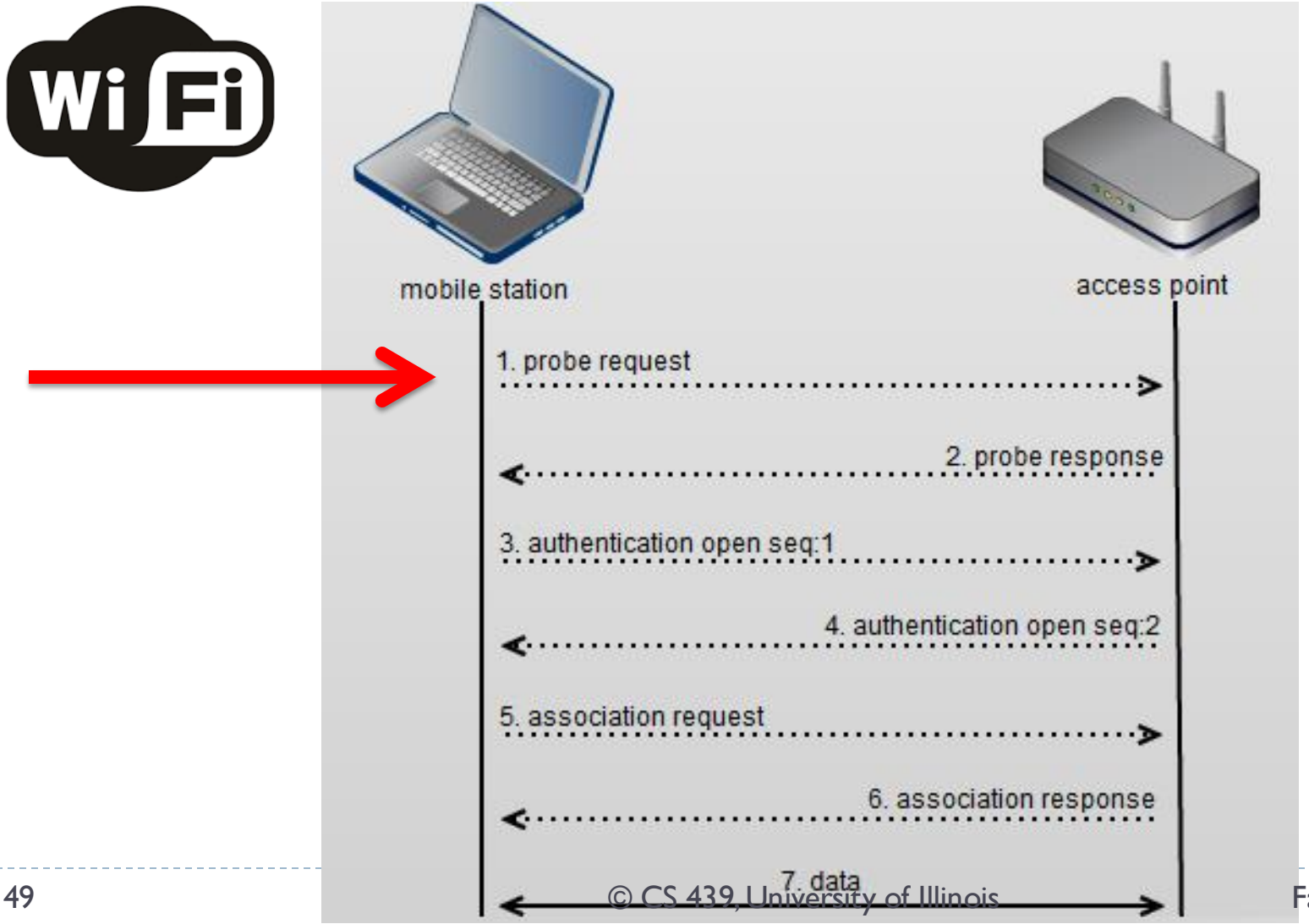
All transmission contain the identity of the sender (MAC address)





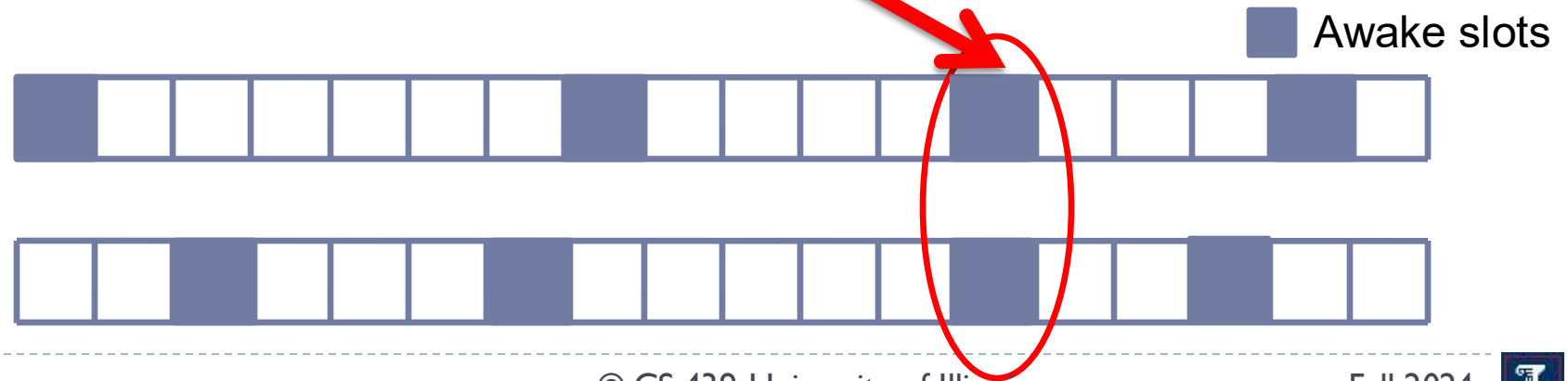
Anyone can listen and track the user

Who has found me?

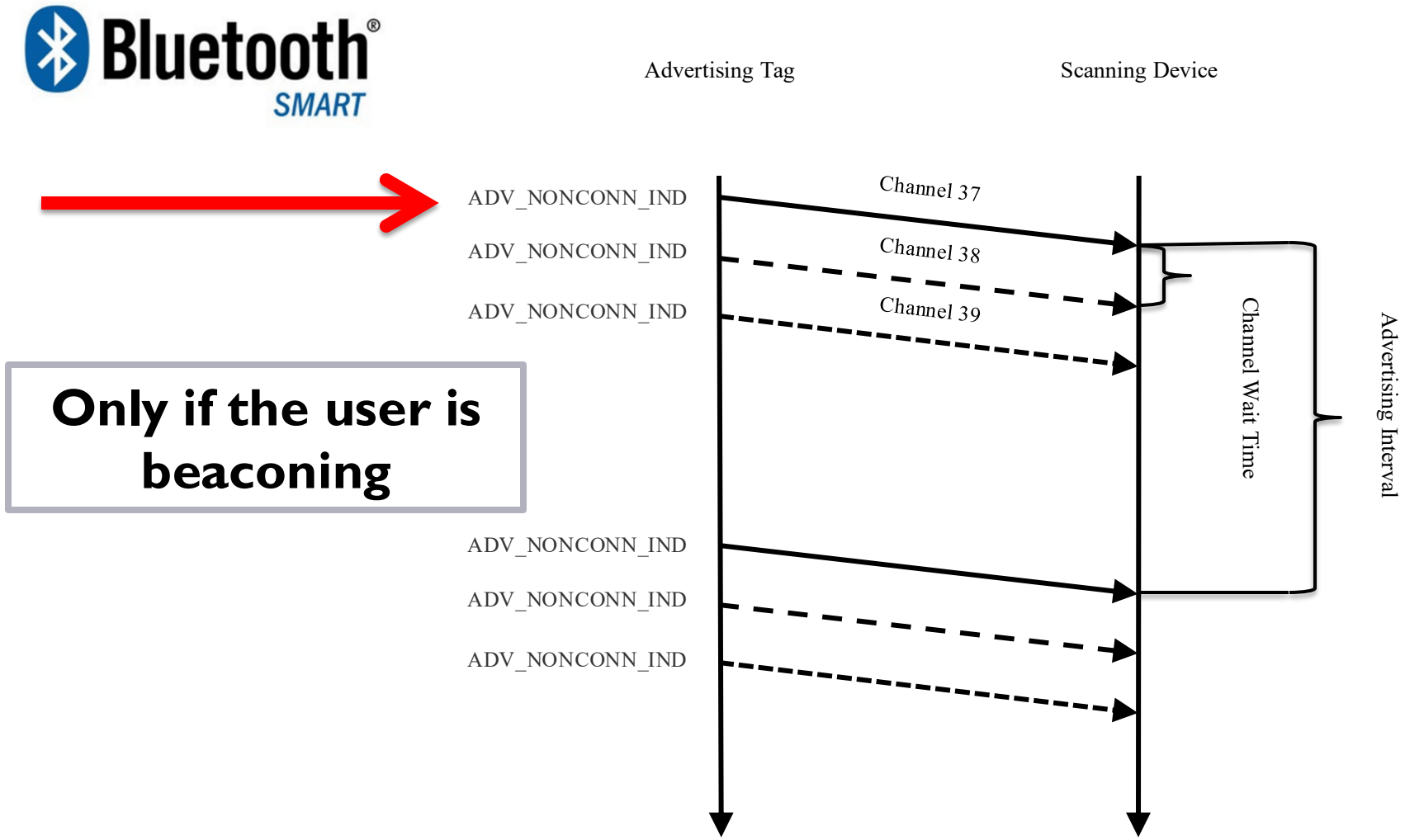


Who has found me?

Any communication contains a MAC address!

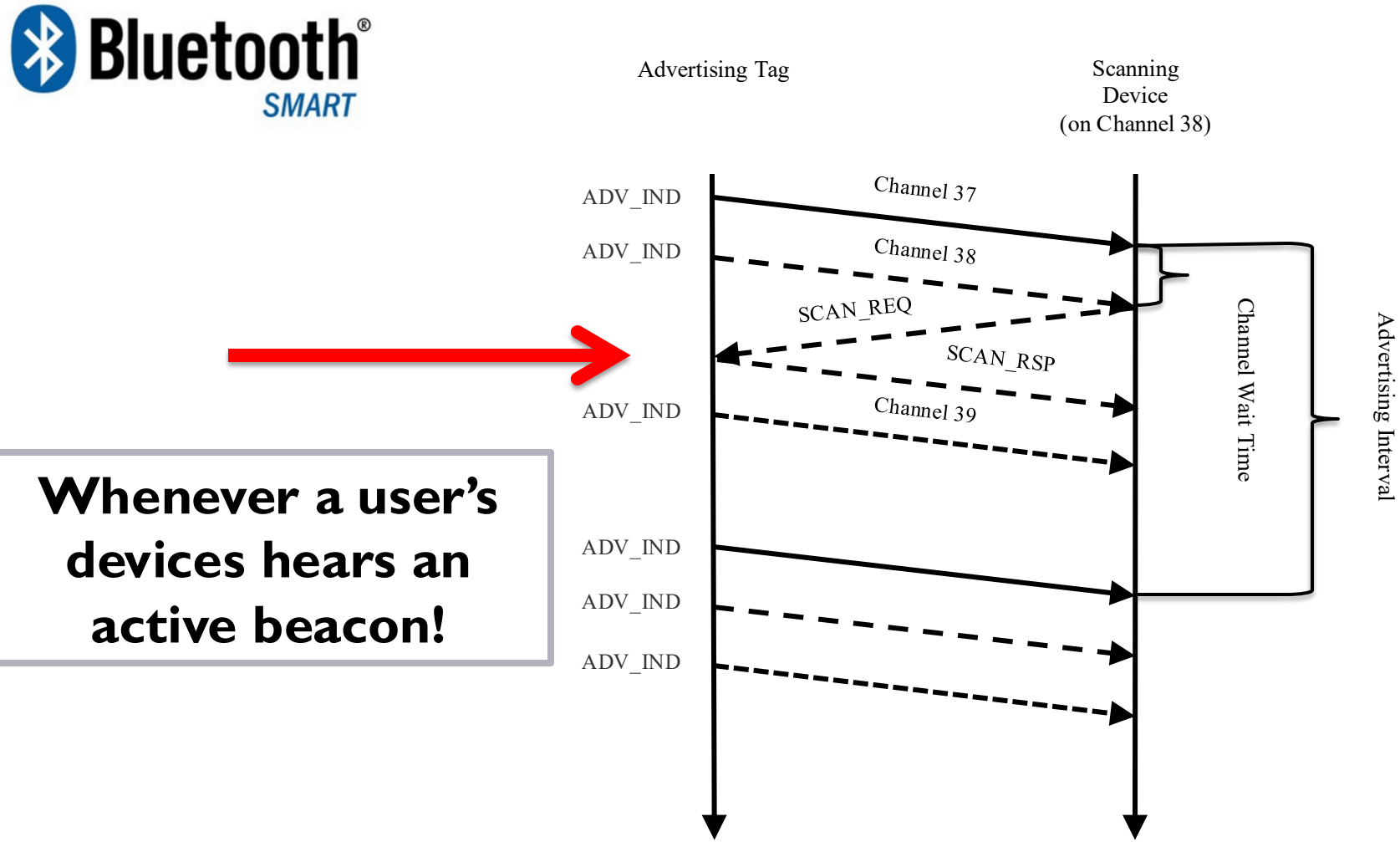


Who has found me?



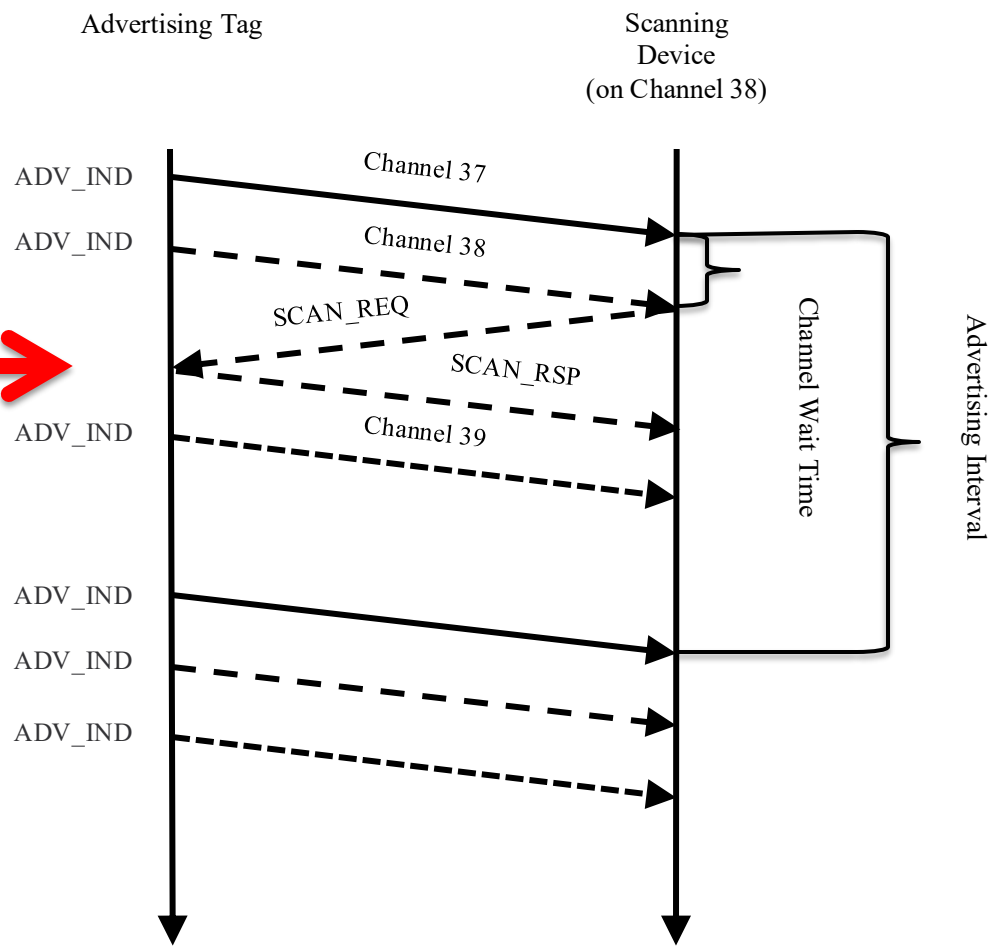
Only if the user is beaconing

Who has found me?



Whenever a user's devices hears an active beacon!

Who has found me?



Whenever a user's devices hears an active beacon!

The privacy hole from NYC!

Where do we go from here?

IoT is not one thing

There is no "on-size-fits-all" solution