

Internet of Things!

Fall 2022

IoT: The Vision

**Connecting
users to the
information
around them ...**



IoT: The Vision

Connecting users to the information around them ...

to enable better recommendations, services and overall user experiences ...



IoT: The Vision



Connecting users to the information around them ...

to enable better recommendations, services and overall user experiences ...

IoT: The Reality

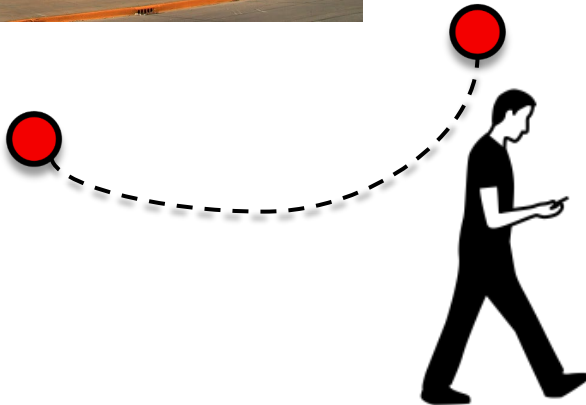
As we move through the world and interact with our environments ...



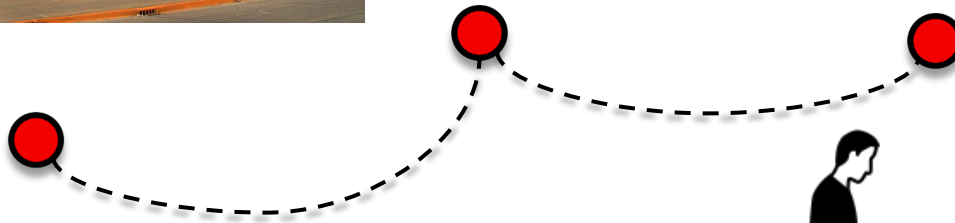
IoT: The Reality



**we leave behind
breadcrumbs**



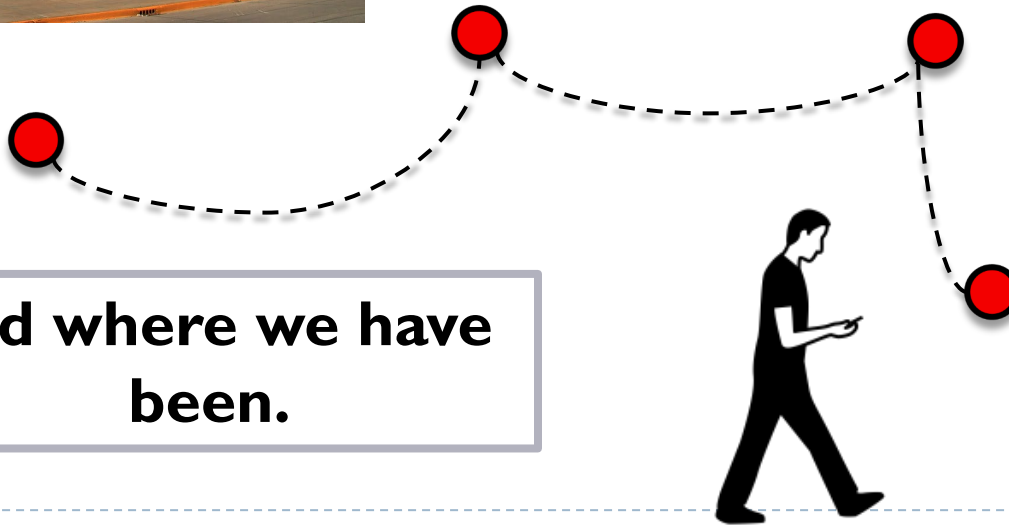
IoT: The Reality



**that can identify
who we are**



IoT: The Reality



**and where we have
been.**



IoT: The Problem

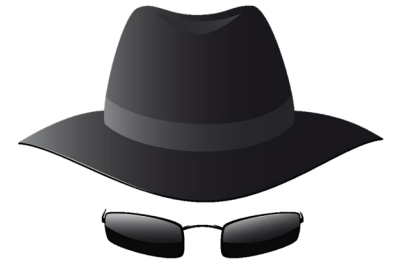
BuzzFeed NEWS

TECH

Exclusive: Hundreds Of Devices Hidden Inside New York City Phone Booths

Beacons can push you ads — and help track your every move. Update: Hours after BuzzFeed News exposed the devices, the city ordered the removal of the devices.

Anyone can now track the user!



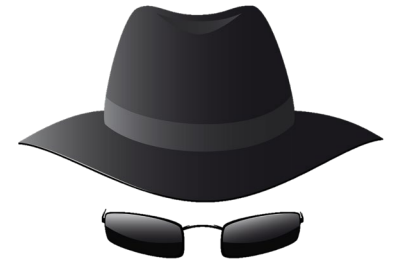
IoT: The Problem

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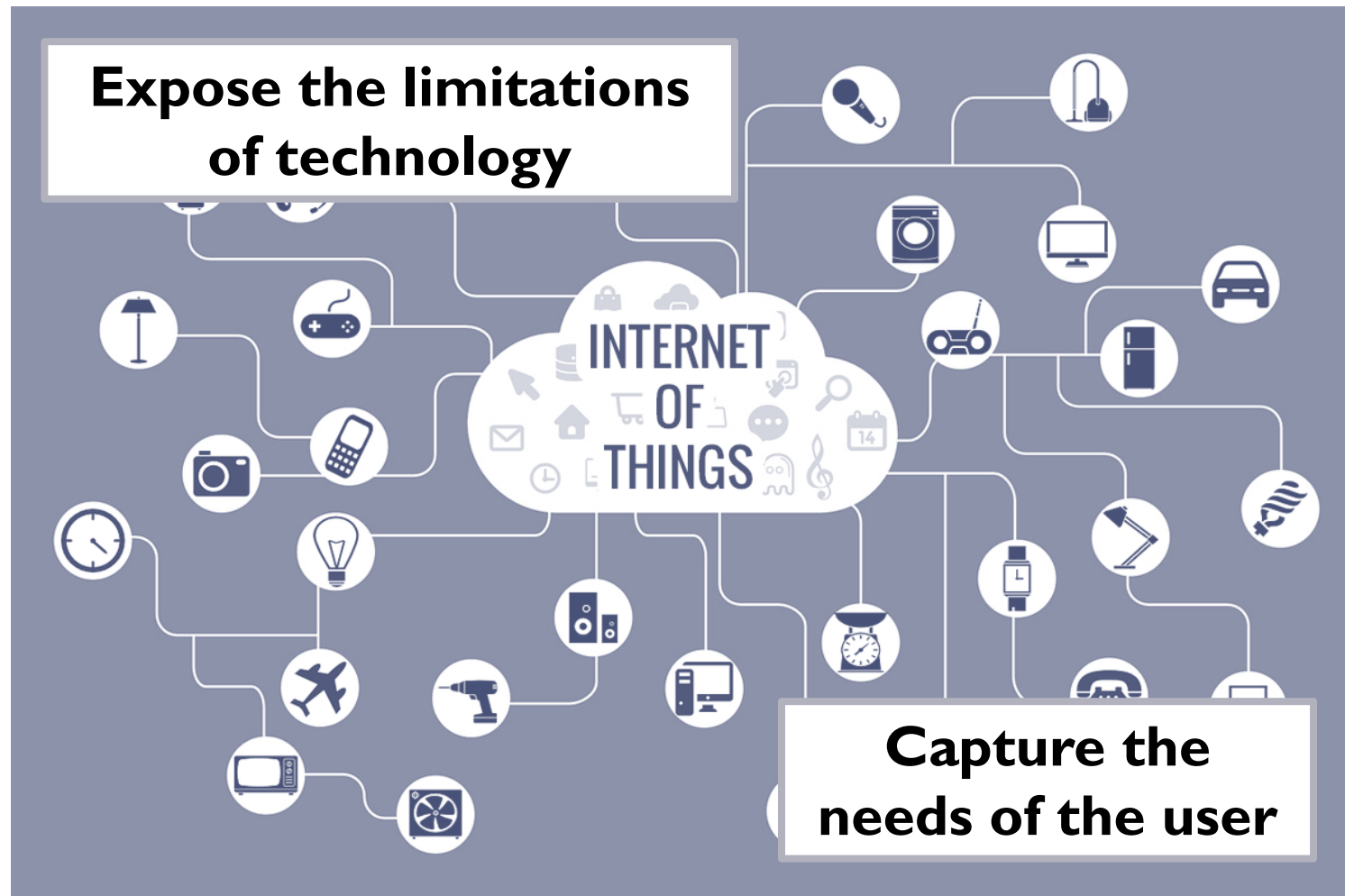
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No one should ever use IoT if we can't provide privacy



How to do this right ...



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

Home Automation

Manufacturing

Malfunction

Energy Management

DWELL TIME
4.24MIN

Retail

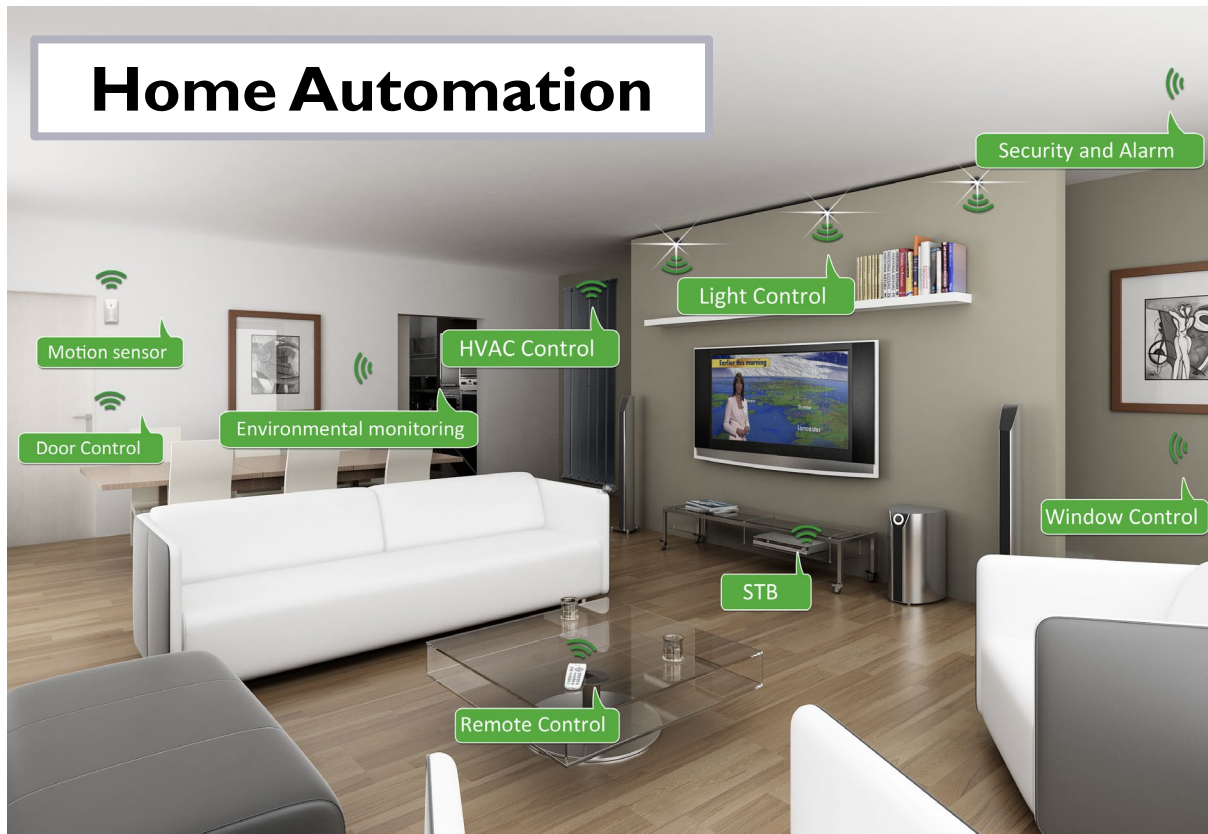
TOTAL FOOT TRAFFIC

Transportation

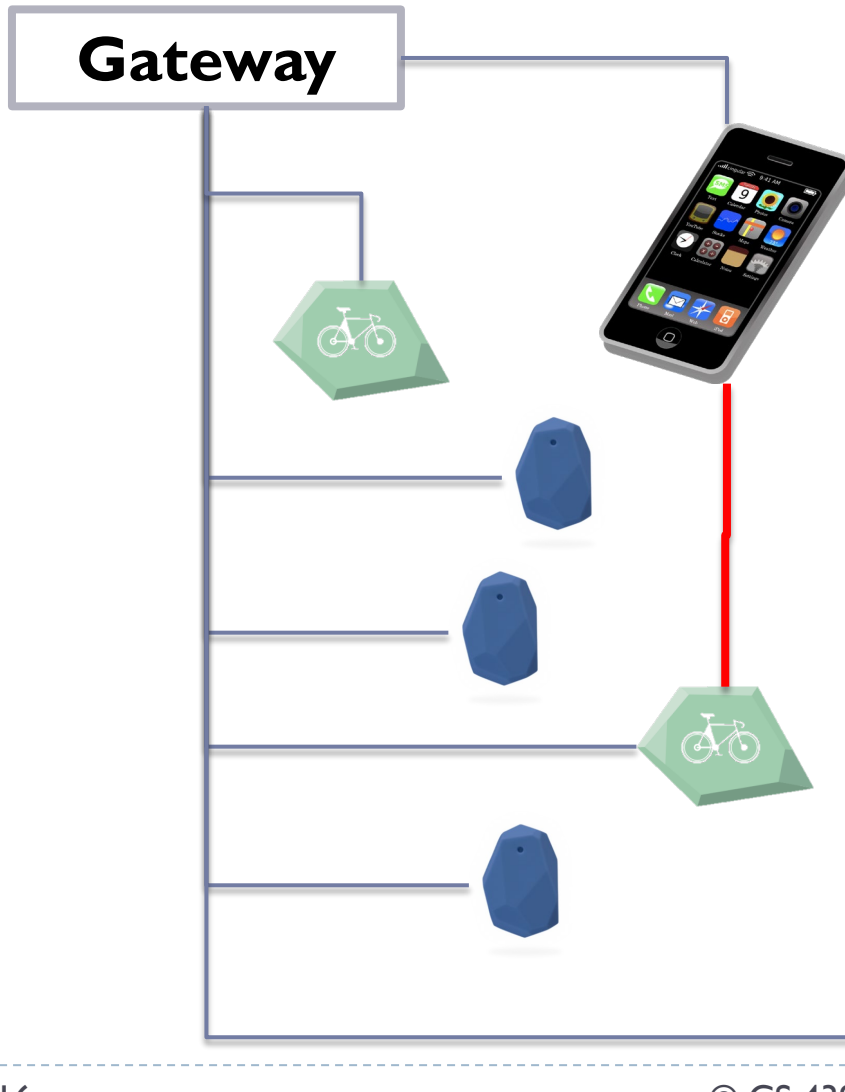
Healthcare



IoT in Home Automation



IoT in Retail



Connecting Devices



ZigBee®

The Internet has IP to enable interoperability



4G LTE



LoRa

Is IP the right solution for IoT?



Bluetooth®

Bluetooth®



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?

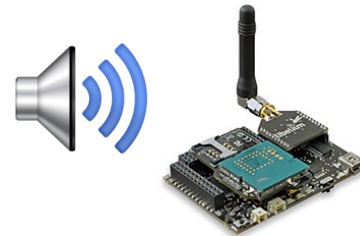
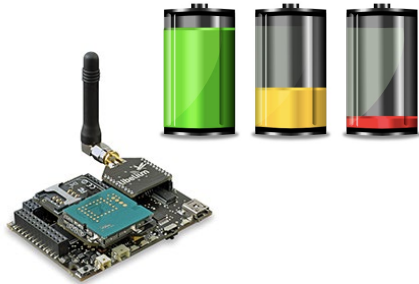
Do we need global addressing for every device?

Is IP the right solution for IoT?

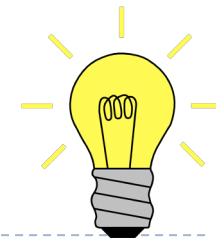
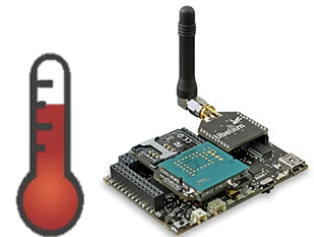
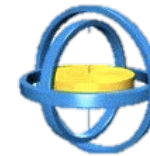
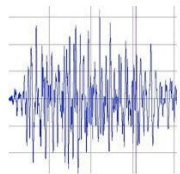
Is an IoT Gateway good enough?



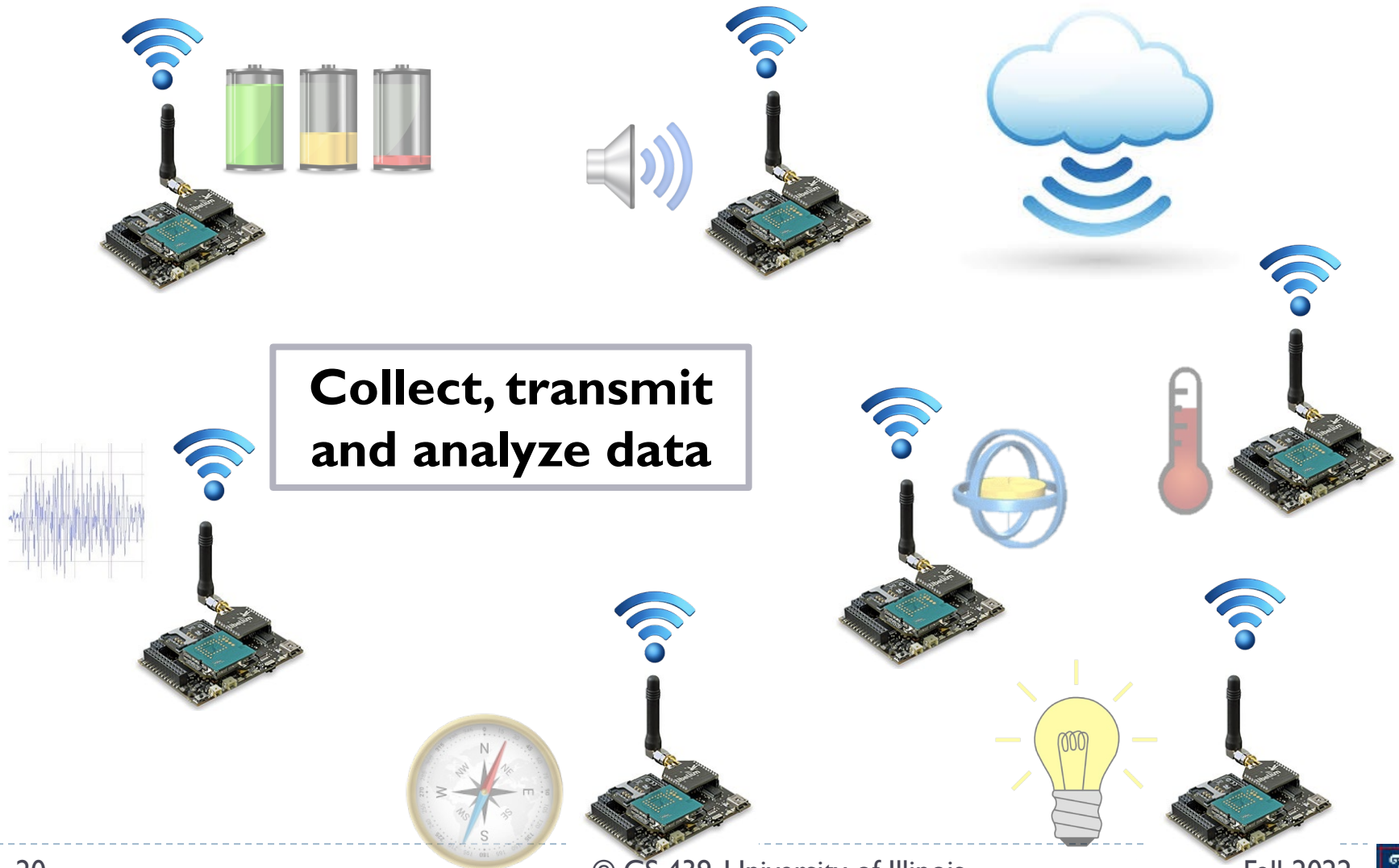
From Small Things ...



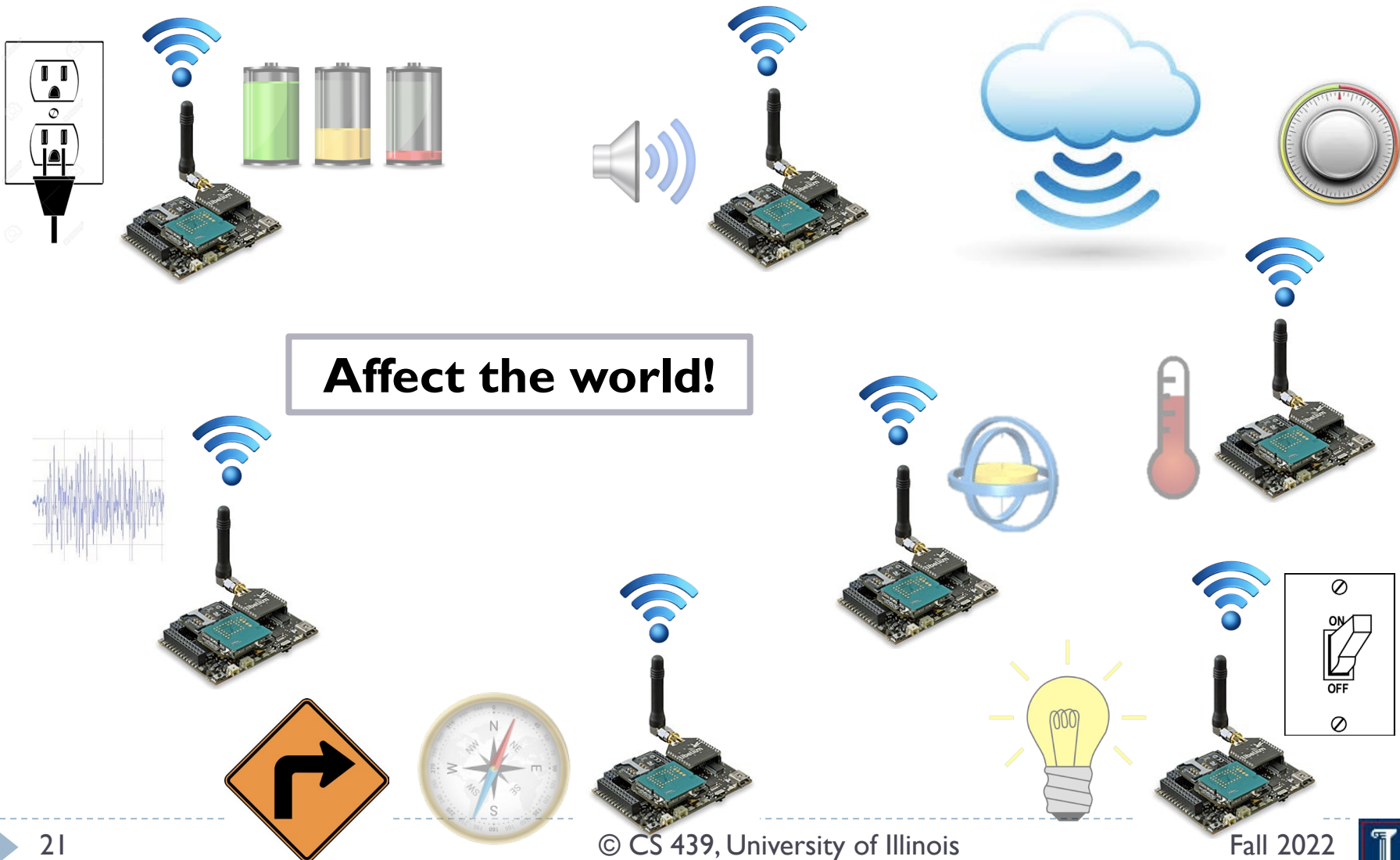
**Monitor the
physical world**



From Small Things ...



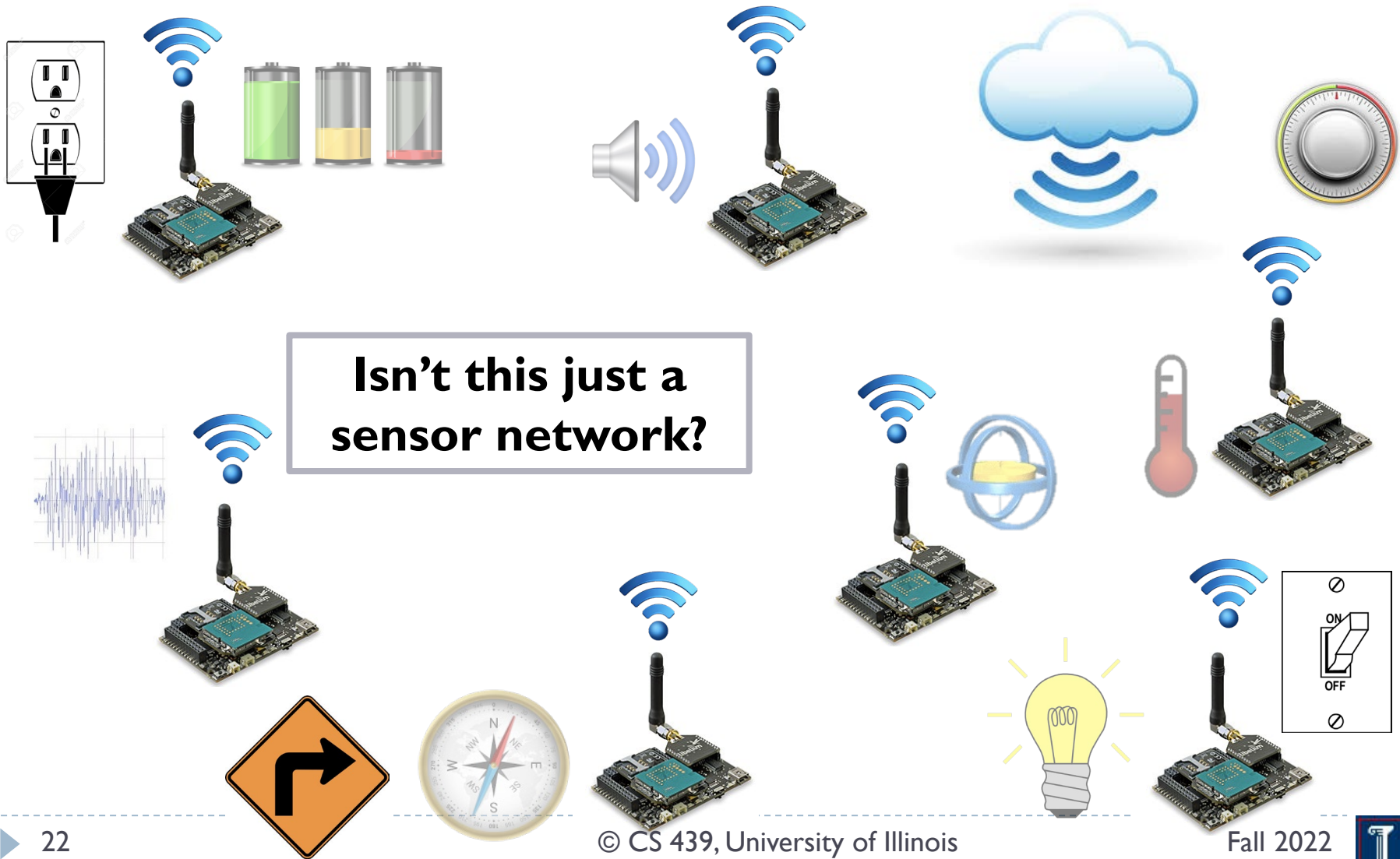
From Small Things ...



Affect the world!



So we have lots of devices ...



Isn't this just a sensor network?



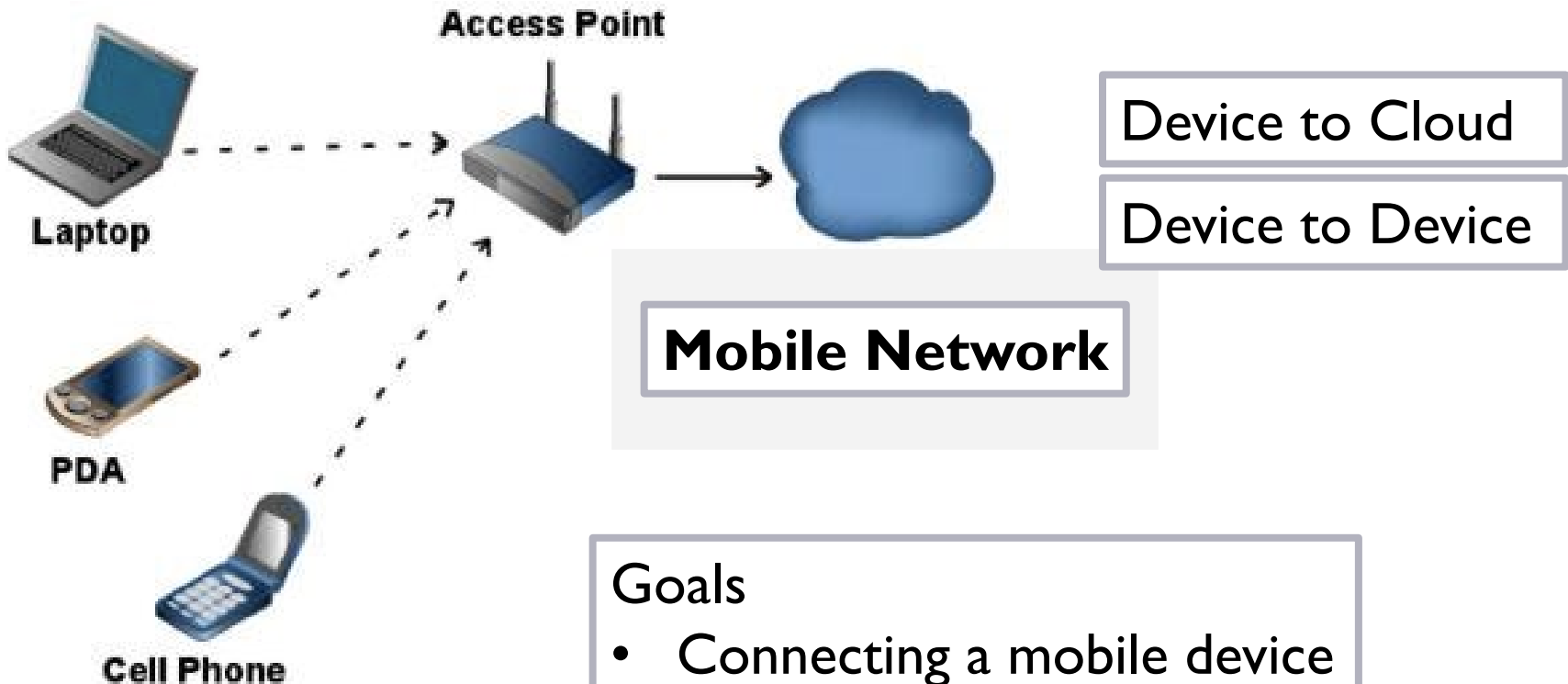
So we have lots of devices ...



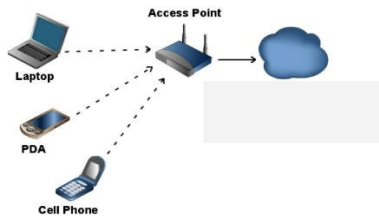
So we have lots of devices ...



More than a Mobile Network

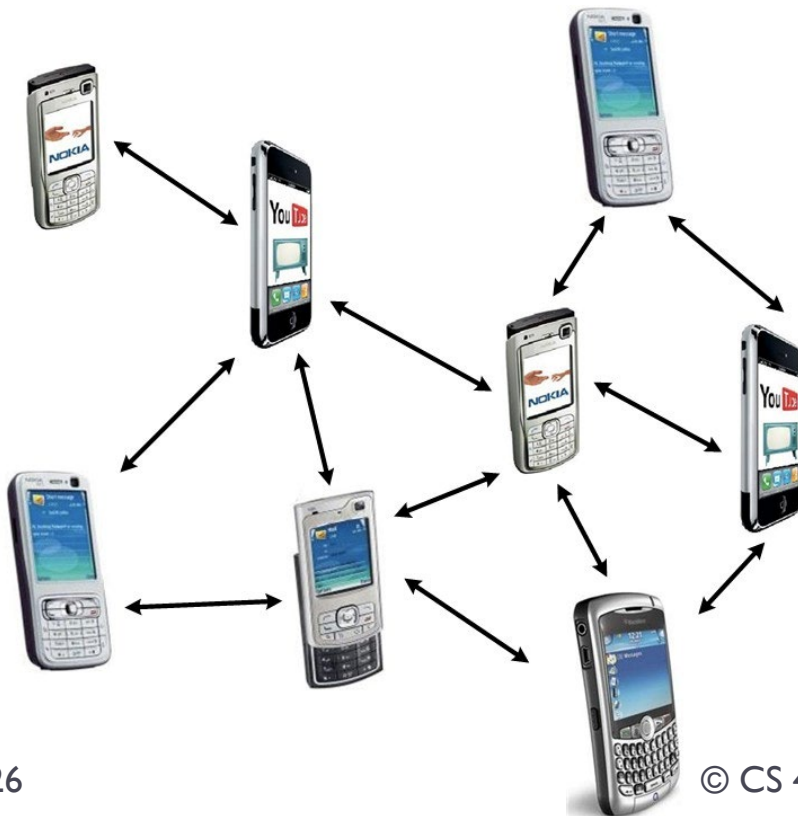


More than an Ad Hoc Network



**Ad Hoc
Network**

Device to Device

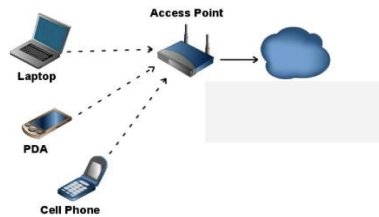


Goals

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

Does IoT require multihop wireless communication?

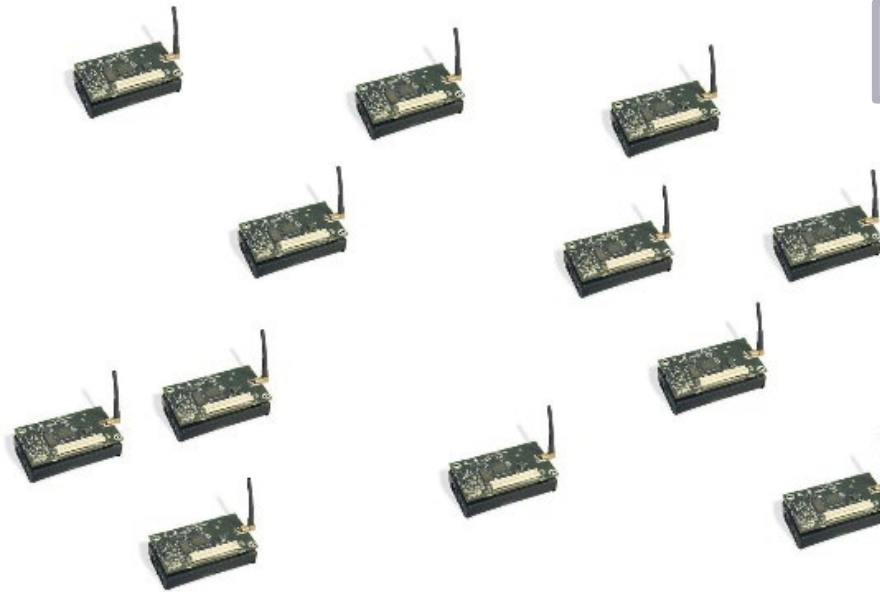
More than a Sensor Network



Sensor Network

Device to Cloud

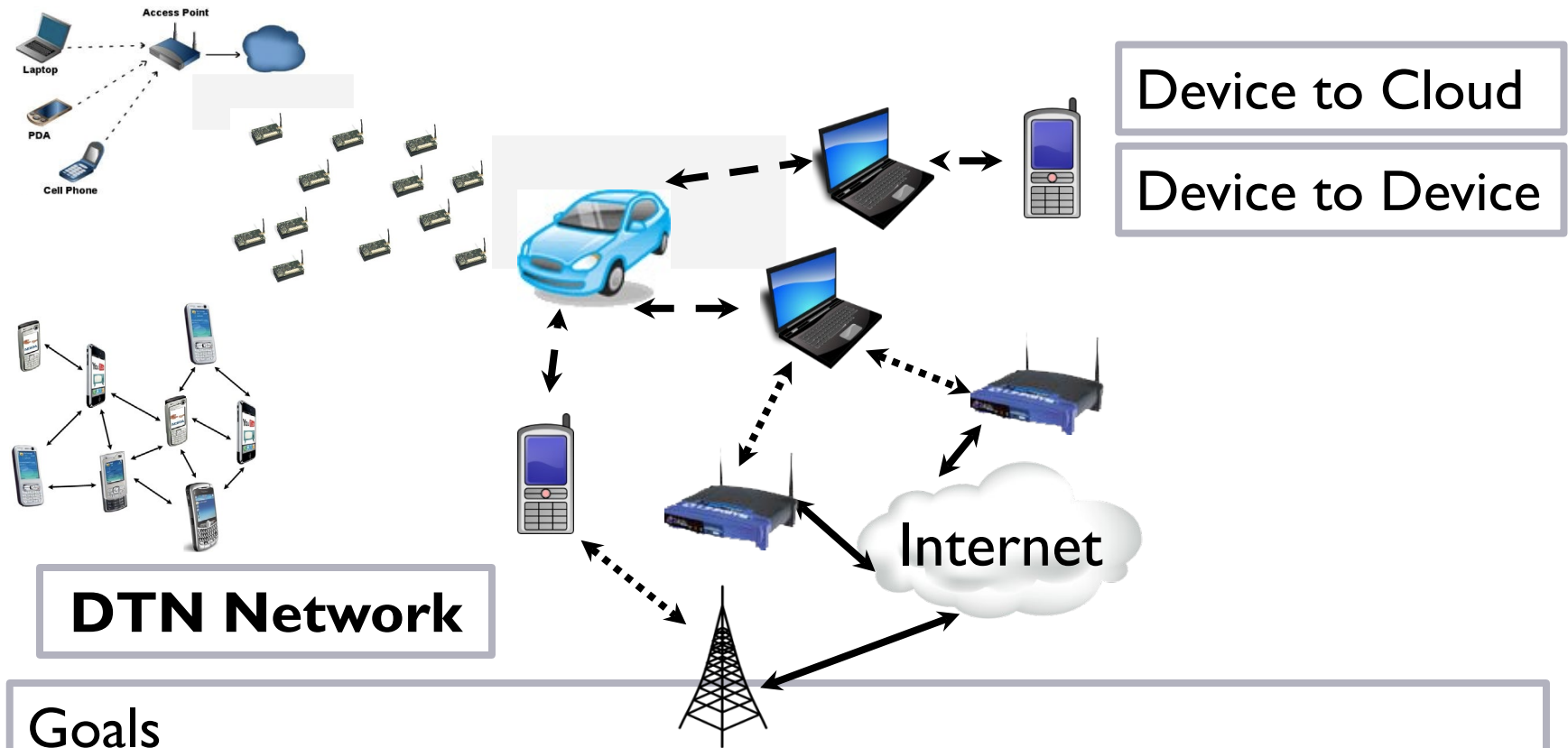
Device to Device



Goals

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

More than a DTN Network



Can we hide it all under IP?



**Not all services
need access to
the cloud**

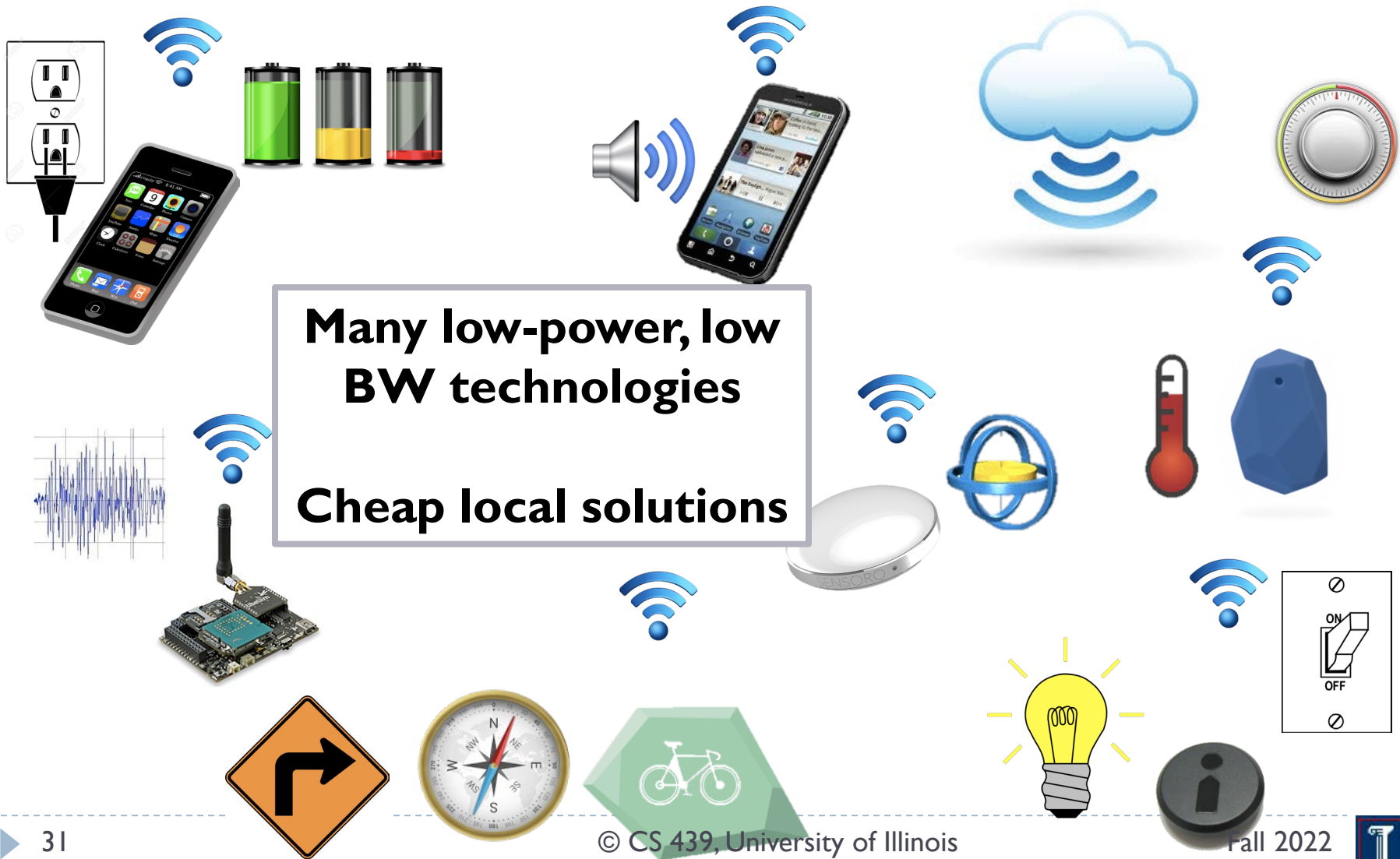
Can we hide it all under IP?



**Not all devices
need to be
globally
addressable**



Can we hide it all under IP?



**Many low-power, low
BW technologies**

Cheap local solutions



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
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

Low Power Computing

Sensors



Limited Power Source



Actuators

IoT from the Bottom Up

Wireless Networking



Privacy

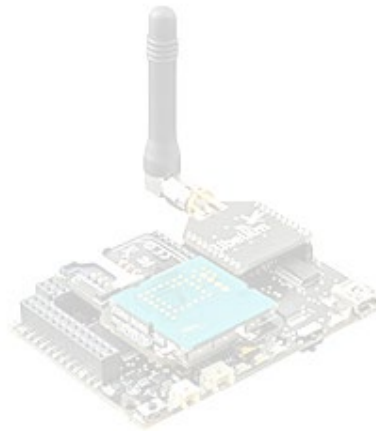
Discovery

Which Technology?



IoT from the Bottom Up

Wireless Networking



Privacy

Discovery

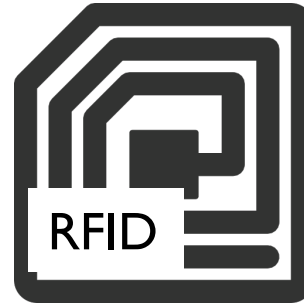
Which Technology?



Which Technology best fits IoT?



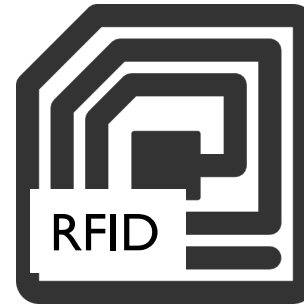
ZigBee[®]



Which Technology best fits IoT?



ZigBee[®]



**Need to understand
the requirements
and tradeoffs**



Which Technology best fits IoT?



ZigBee®

Connecting to the cloud

Large data transfers

THREAD



4G LTE



**High range
High BW
High energy**



Bluetooth®

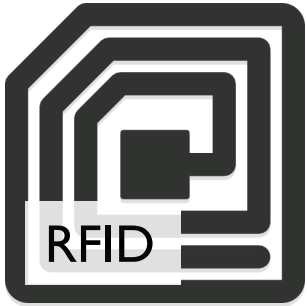
Bluetooth®



Which Technology best fits IoT?



Expensive for readers
Manufacturing



Low range
Medium BW

Medium range
Low BW

Good signal characteristics for localization
Not available on current phones



Slow discovery
Long-lived connections



Which Technology best fits IoT?

**Proprietary solutions
Not available on
phones**

THREAD



**Short range
Low BW
Low Power**



ZigBee



**Long range
Very Low BW
Low Power**



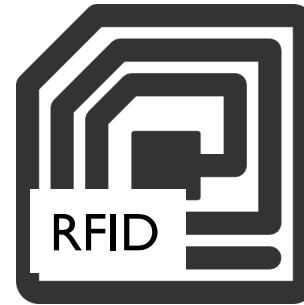
**Simple standardized
discovery and limited
data transfer
Available on all
phones**



Which Technology best fits IoT?



ZigBee[®]



They all have their place in IoT



IoT from the Bottom Up

Wireless Networking



Privacy

Discovery

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?



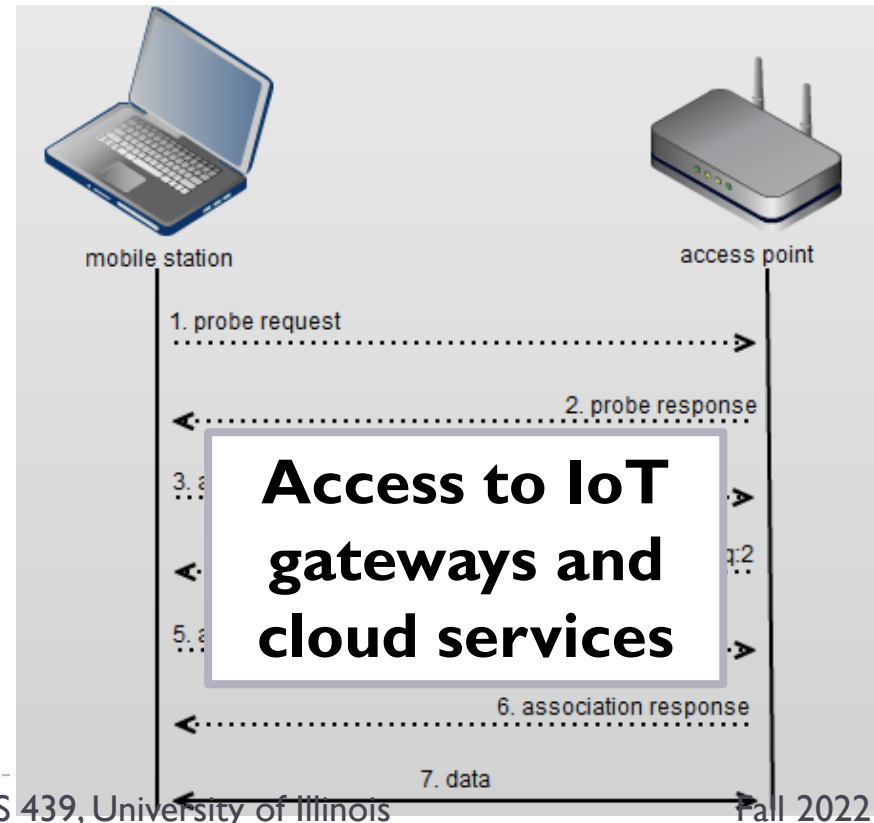
AP Discovery

Base station:

- No energy constraints
- Always on

Mobile

- Balance discovery delay with energy consumption



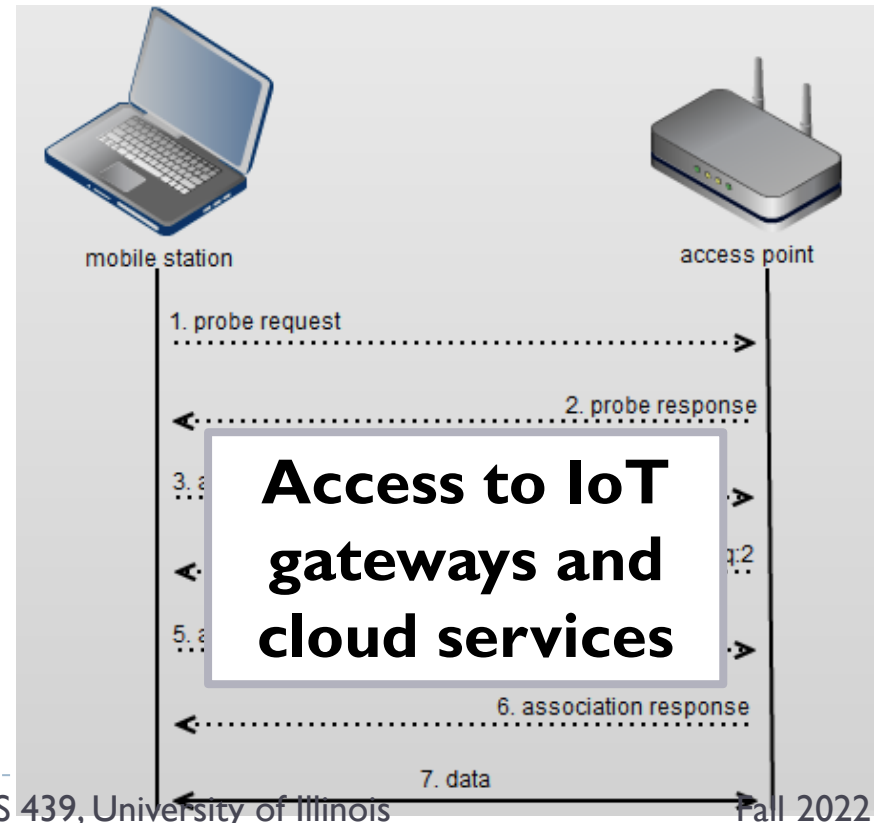
Discovery: Is anybody out there?



AP Discovery

Bandwidth constrains:

- Balance discovery delay with bandwidth overhead



Discovery: Is anybody out there?



ZigBee[®]

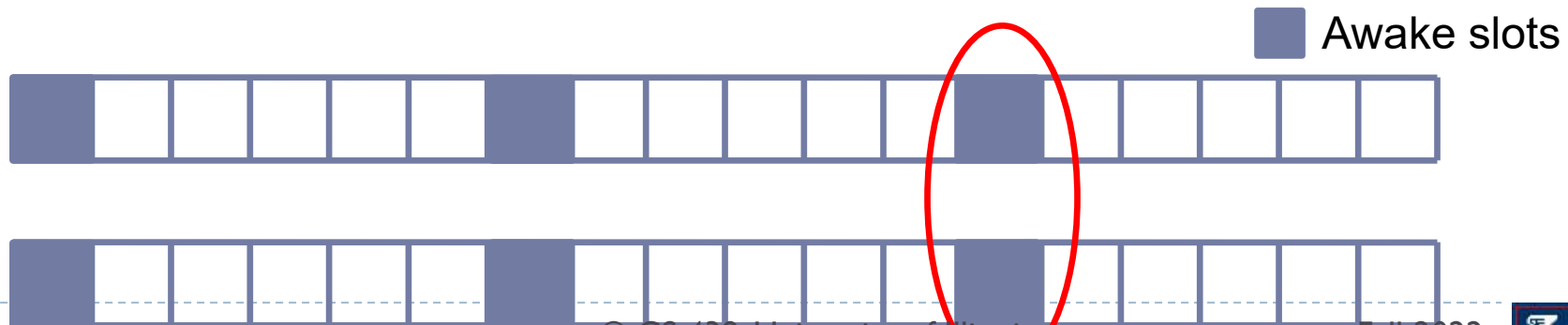


Device Discovery

Mobile

- Broadcast “beacon”
- Duty cycle listening

Local discovery
Specialized for
environment



Discovery: Is anybody out there?

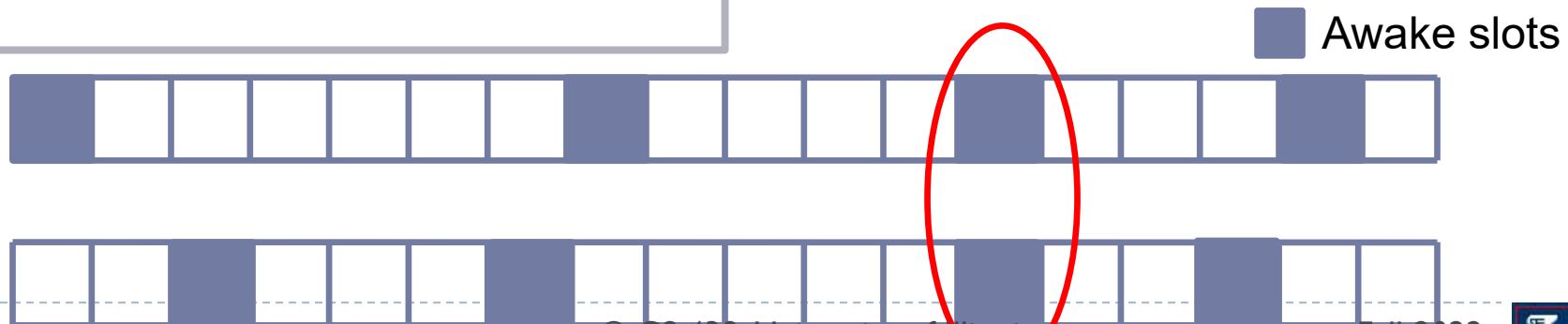


ZigBee®



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

Asynchronous Discovery

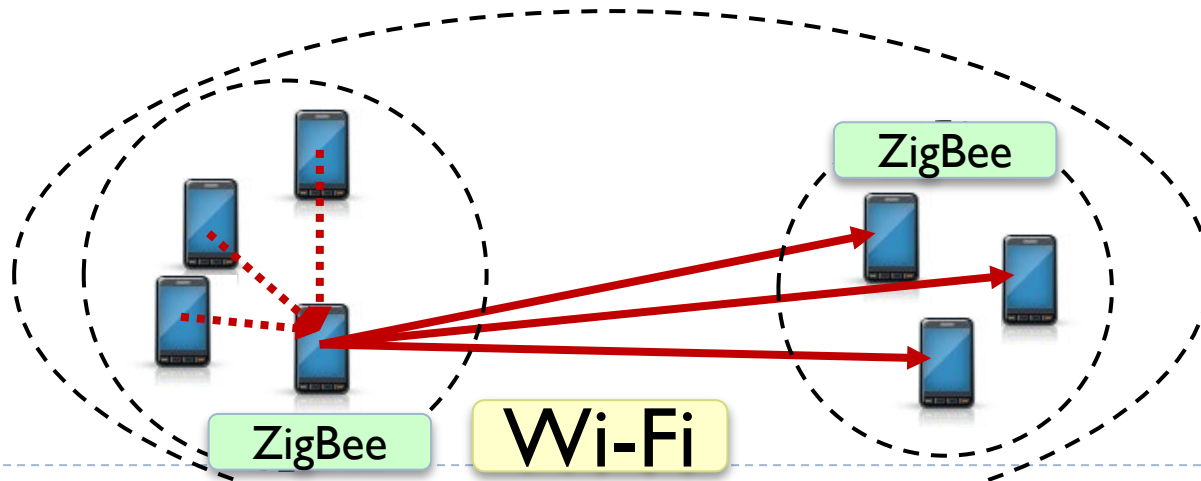


Discovery: Is anybody out there?



ZigBee®

Wi-Fi is expensive
ZigBee is low range



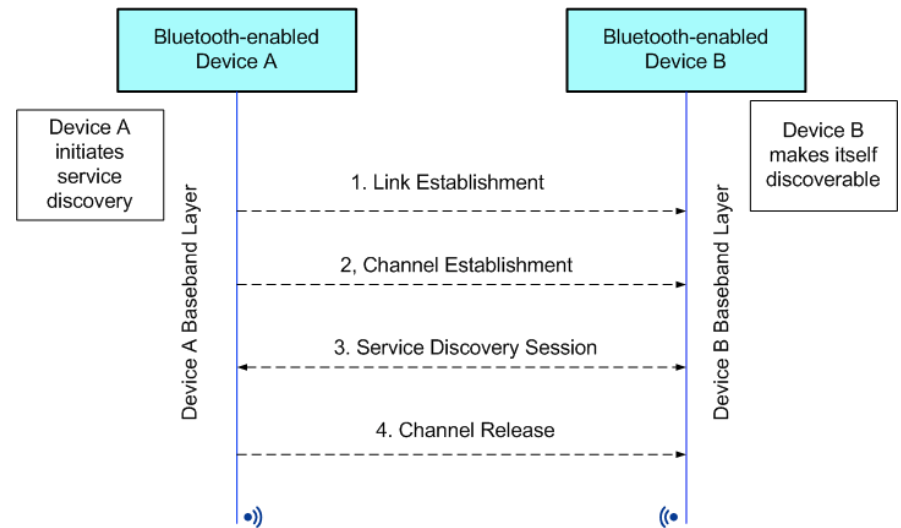
Discovery: Is anybody out there?



Asymmetric Discovery

Master-Slave:

- Complex
- Slow
- Requires user input



**OK for long-lived, low
BW connections**



Discovery: Is anybody out there?

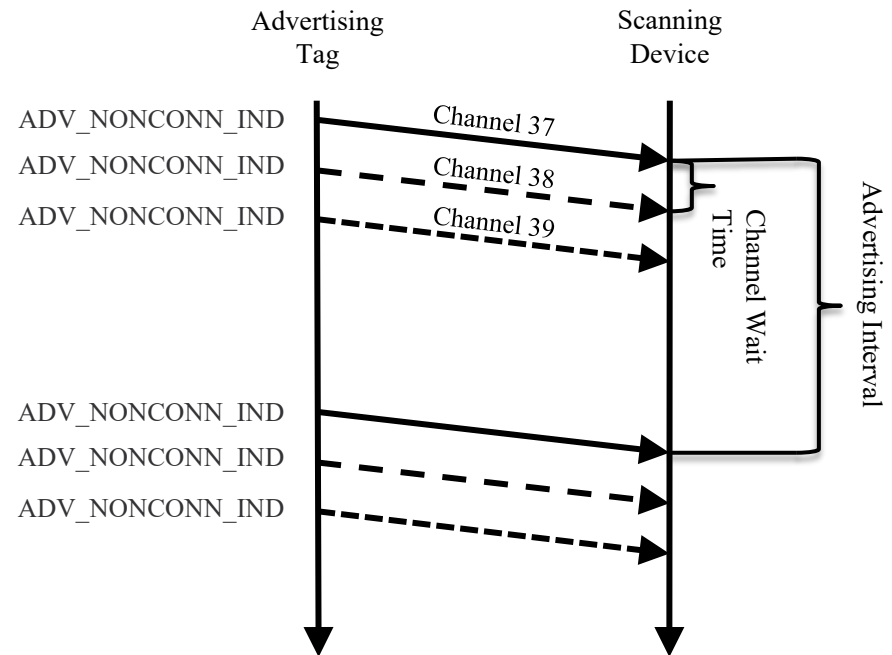


Simplified Discovery

Beacon:

- Passive
- Active
- Client duty cycles listening

Small payload (31B)



Ultra-low power discovery



Discovery: Is anybody out there?

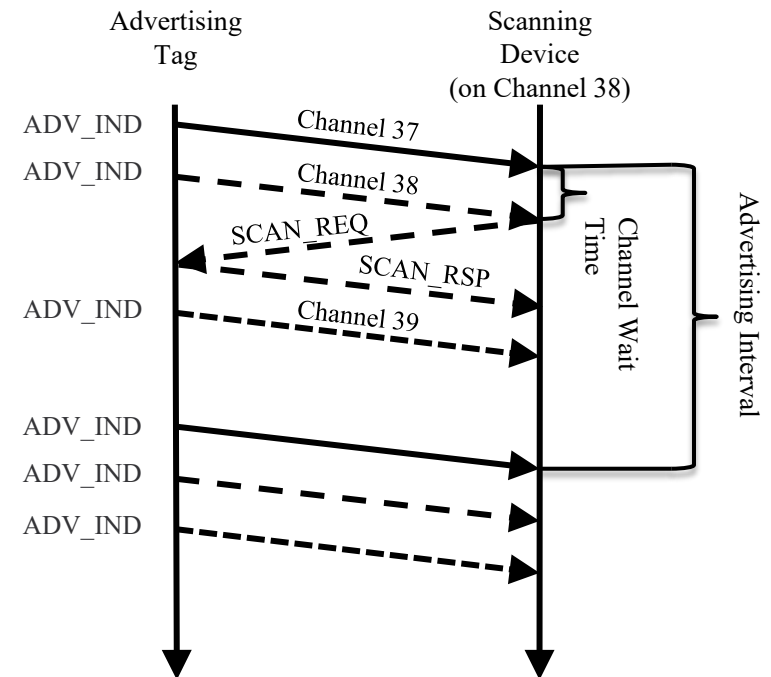


Simplified Discovery

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Small payload (31B)

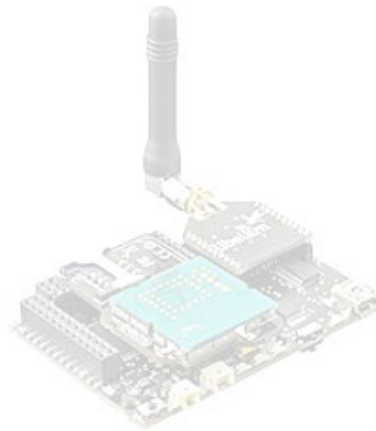


Ultra-low power discovery



IoT from the Bottom Up

Wireless Networking



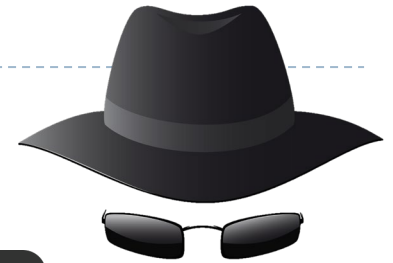
Privacy

Discovery

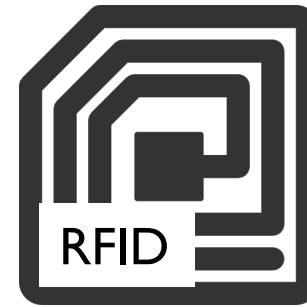
Which Technology?



Who has found me?



ZigBee®



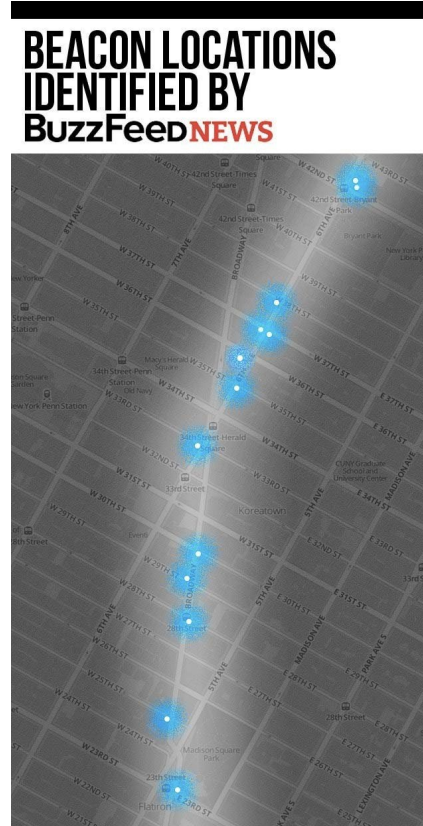
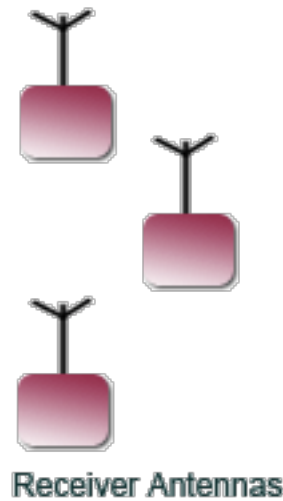
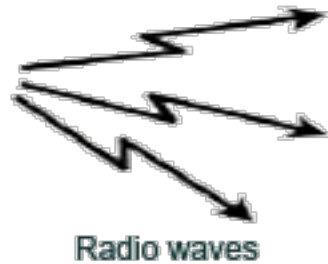
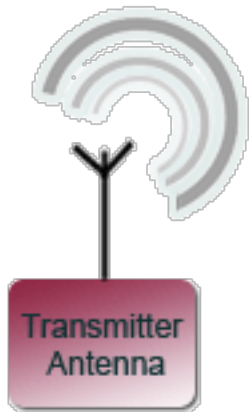
All of these protocols operate in the open

Discovery may reveal the user's identity!



Who has found me?

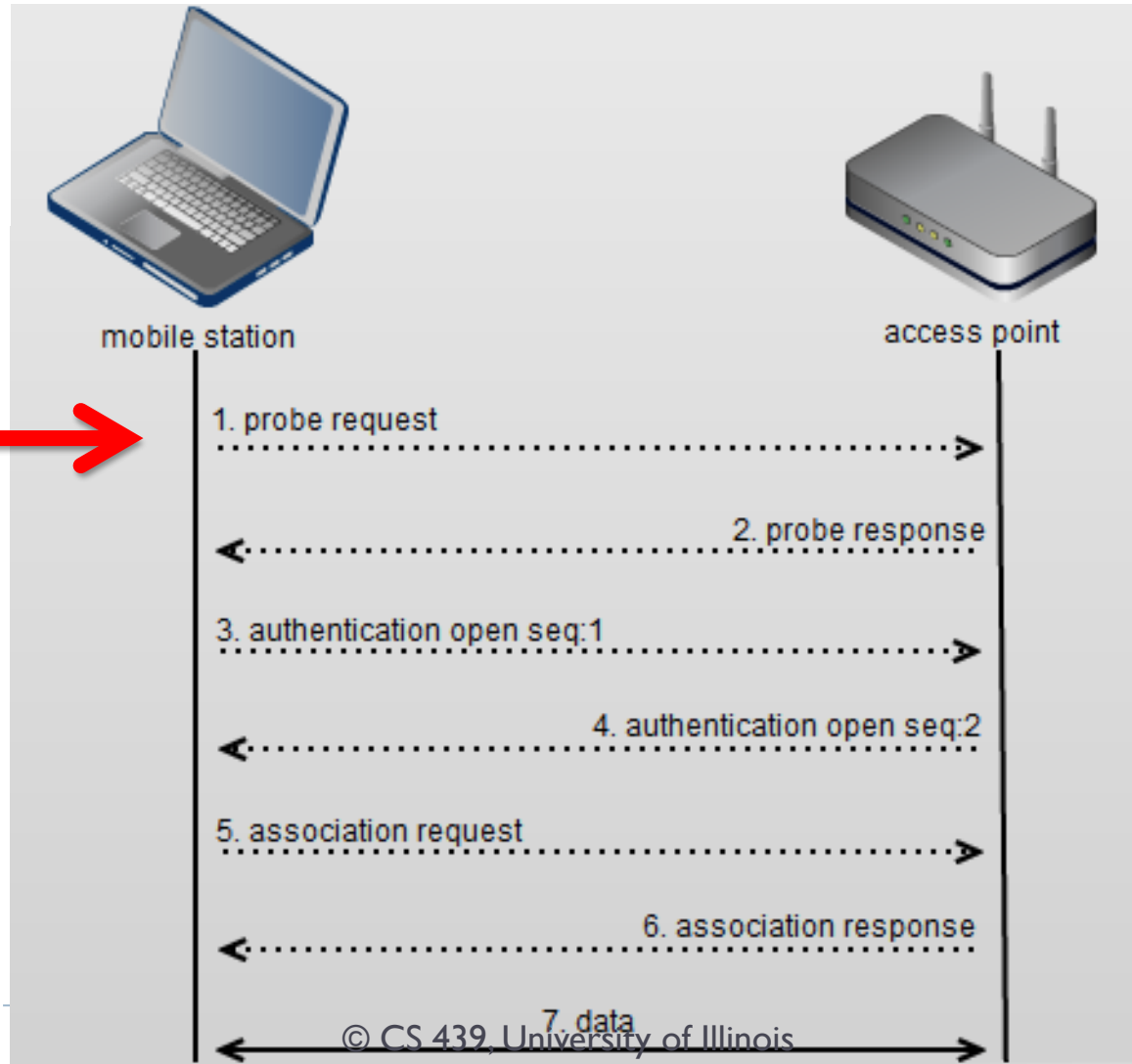
All transmission contain the identity of the sender (MAC address)



Anyone can listen and track the user



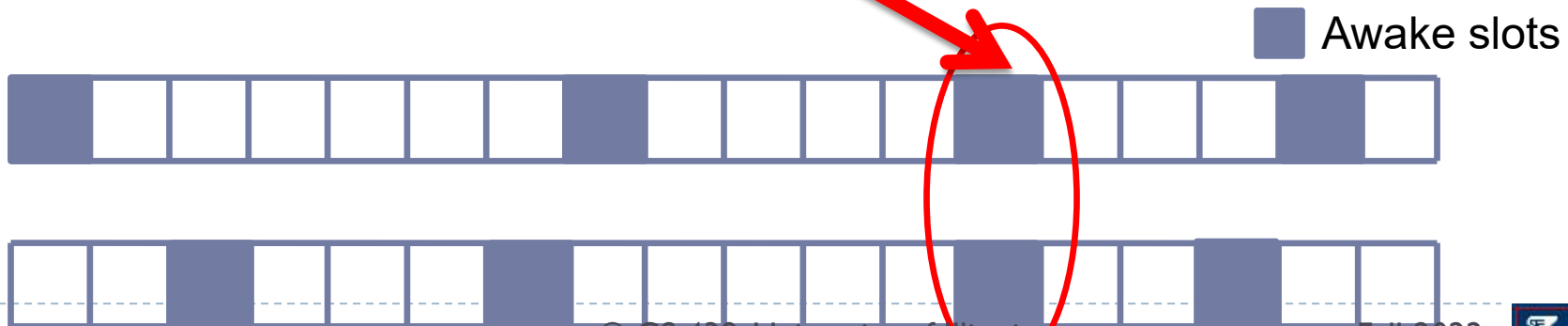
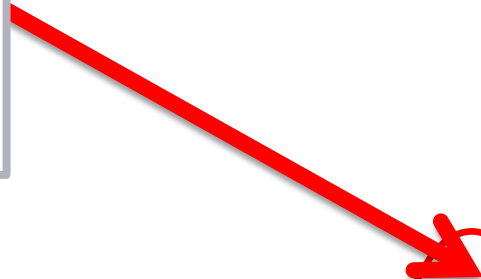
Who has found me?



Who has found me?



Any communication contains a MAC address!



Who has found me?



Advertising Tag

Scanning Device



ADV_NONCONN_IND
ADV_NONCONN_IND
ADV_NONCONN_IND

Channel 37

Channel 38

Channel 39

**Only if the user is
beaconing**

ADV_NONCONN_IND
ADV_NONCONN_IND
ADV_NONCONN_IND

Channel Wait Time

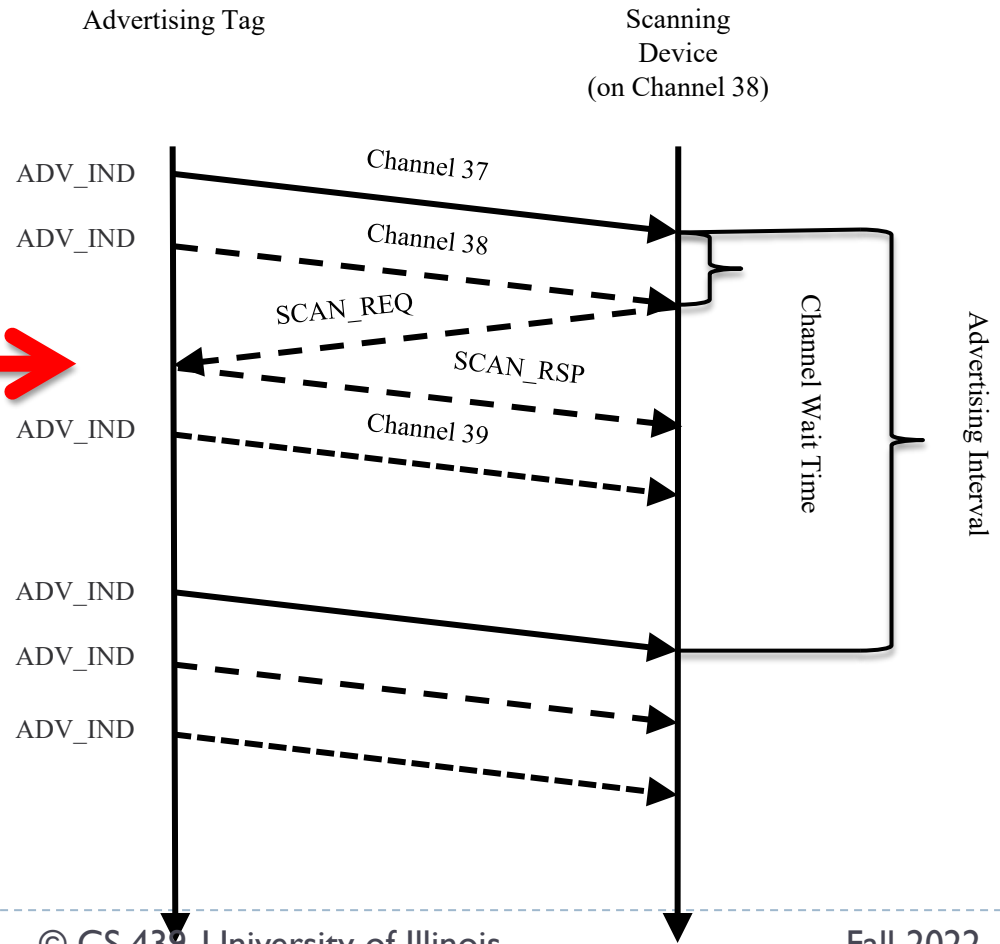
Advertising Interval



Who has found me?



Whenever a user's devices hears an active beacon!

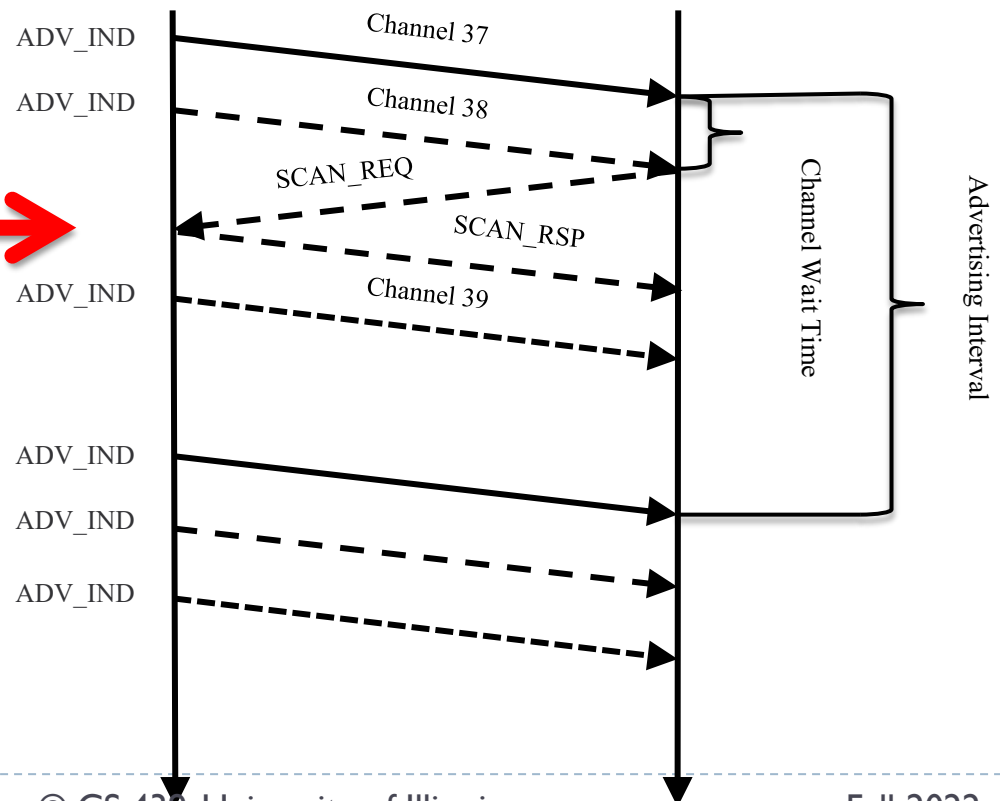


Who has found me?



Advertising Tag

Scanning Device
(on Channel 38)



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

Internet of Things

Home Automation

Manufacturing

Malfunction

Energy Management

Retail

DWELL TIME
4.24MIN

TOTAL FOOT TRAFFIC

Transportation

Healthcare

