

# Internet of Things!

Fall 2024

# 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

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

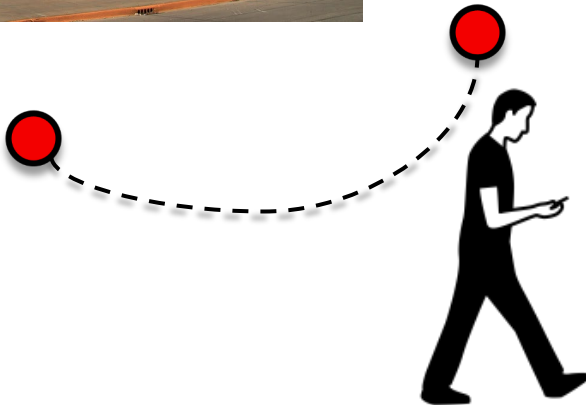


# IoT: The Reality

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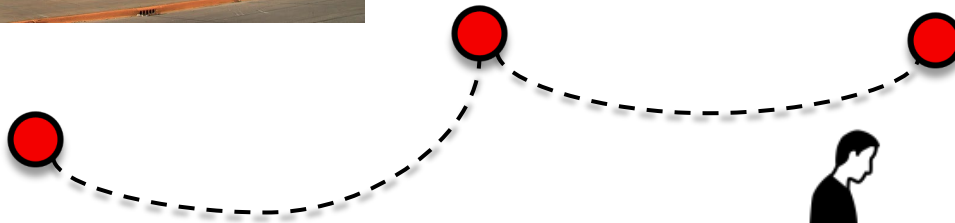


**we leave behind  
breadcrumbs**



# IoT: The Reality

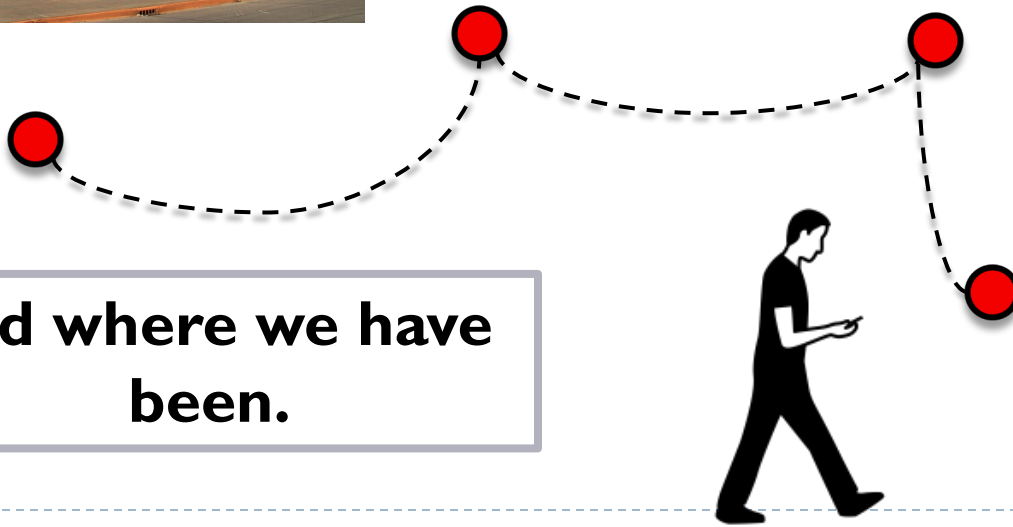
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**that can identify  
who we are**



# IoT: The Reality



**and where we have  
been.**





# IoT: The Problem

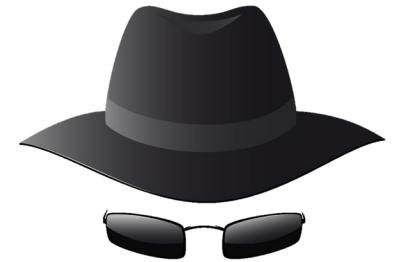
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## BuzzFeed NEWS

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

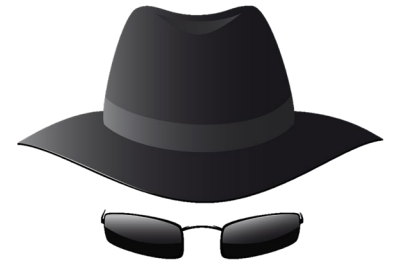
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## BuzzFeed NEWS

TECH

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

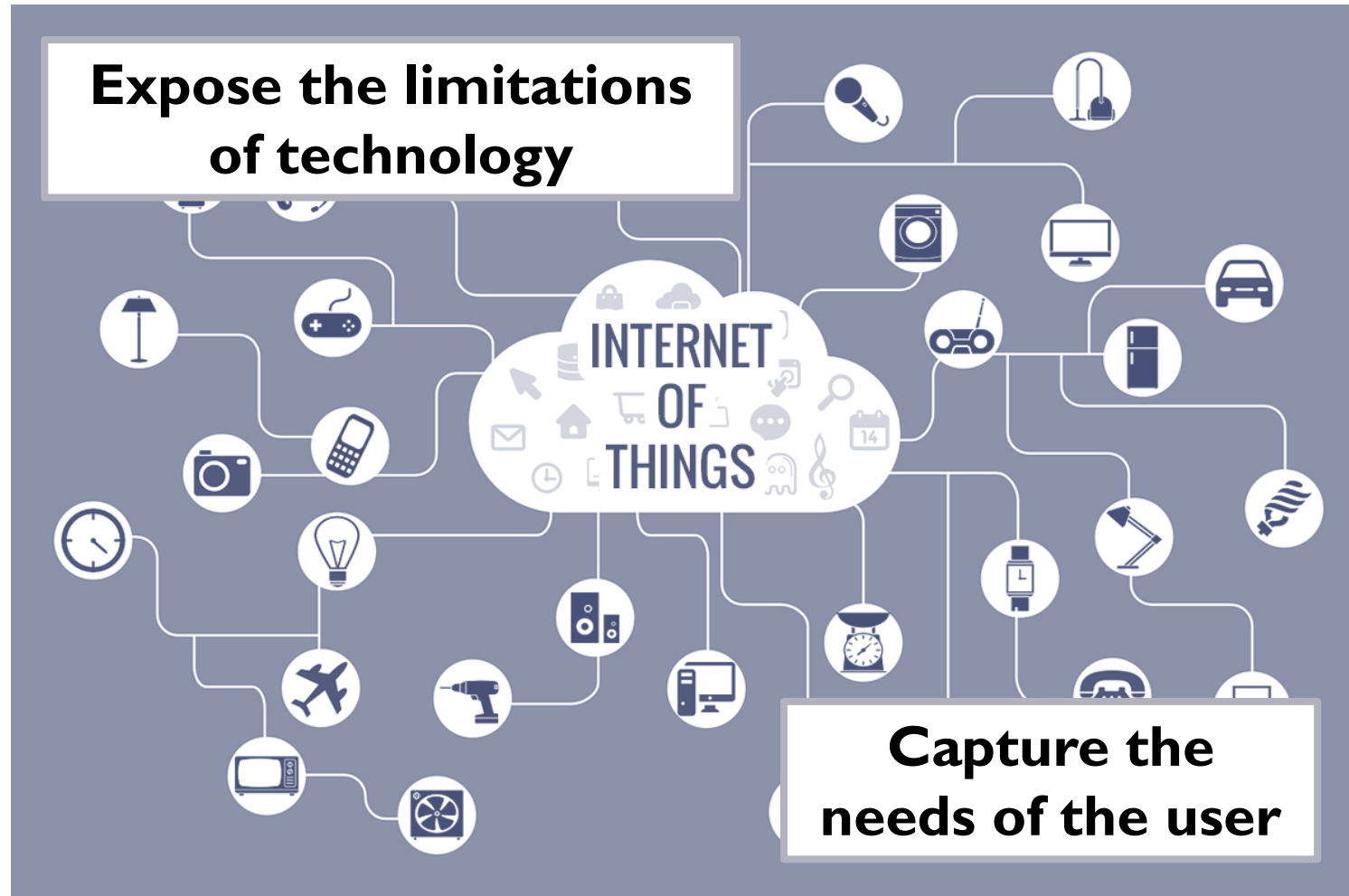
Beacons can push you ads — and help track your every move. Update: Hours after BuzzFeed News exposed the devices, the city ordered the removal of the devices.



**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

DWELL TIME  
4.24MIN

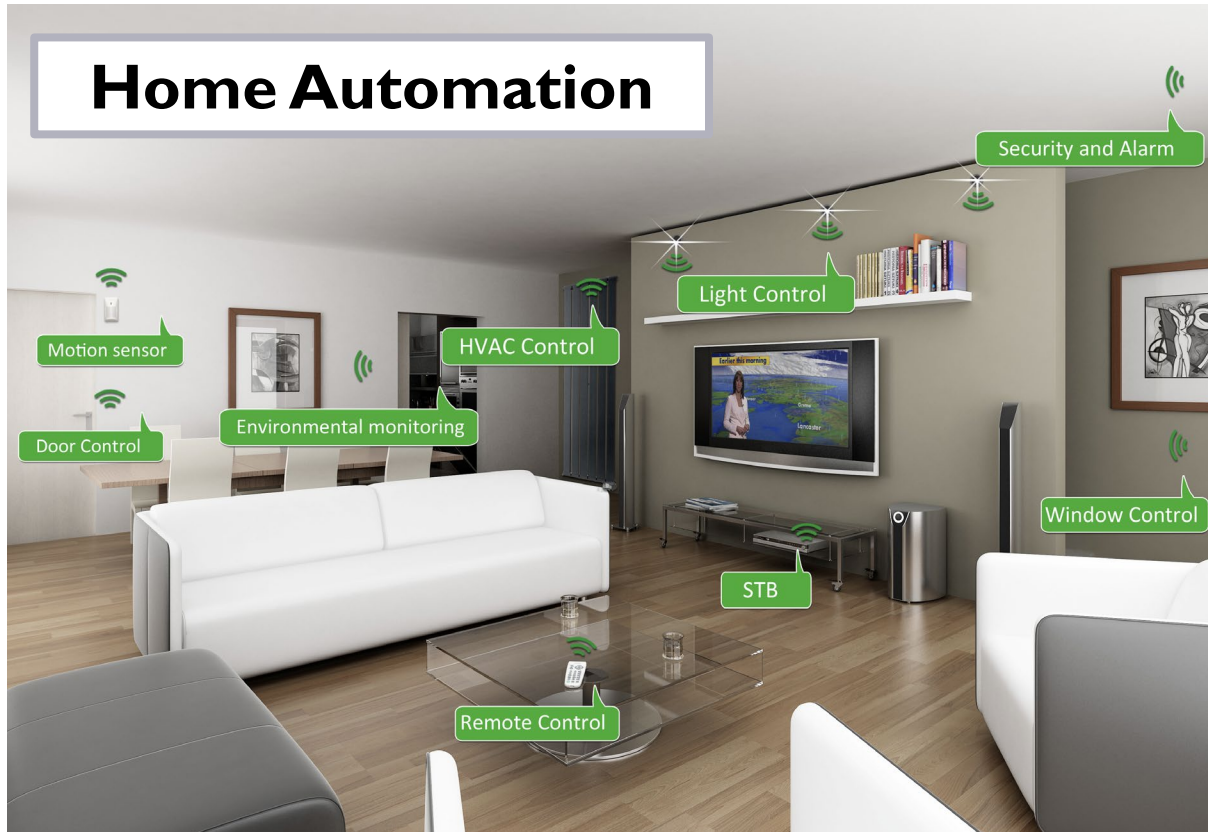
**Retail**

**Energy Management**

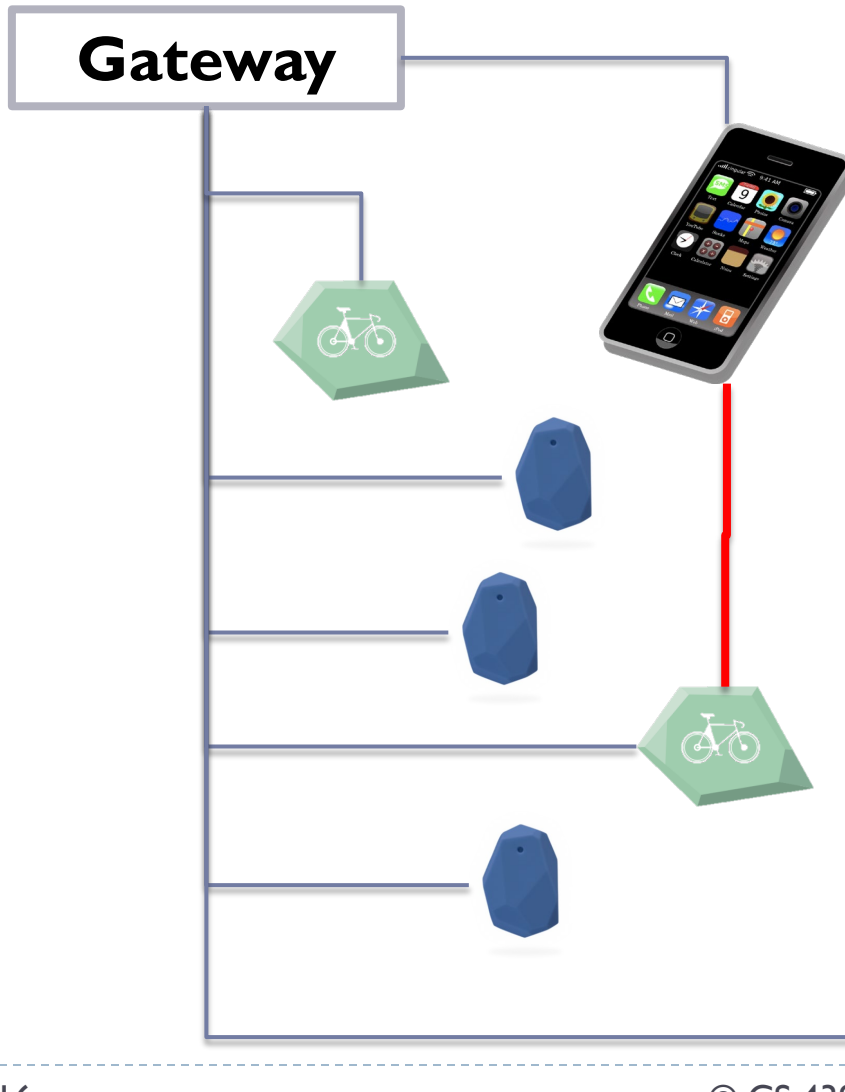
**Transportation**

**Healthcare**

# IoT in Home Automation



# IoT in Retail



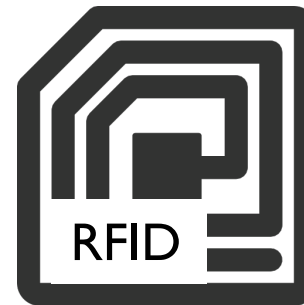


# Connecting Devices



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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?**

**Do we need global addressing for every device?**

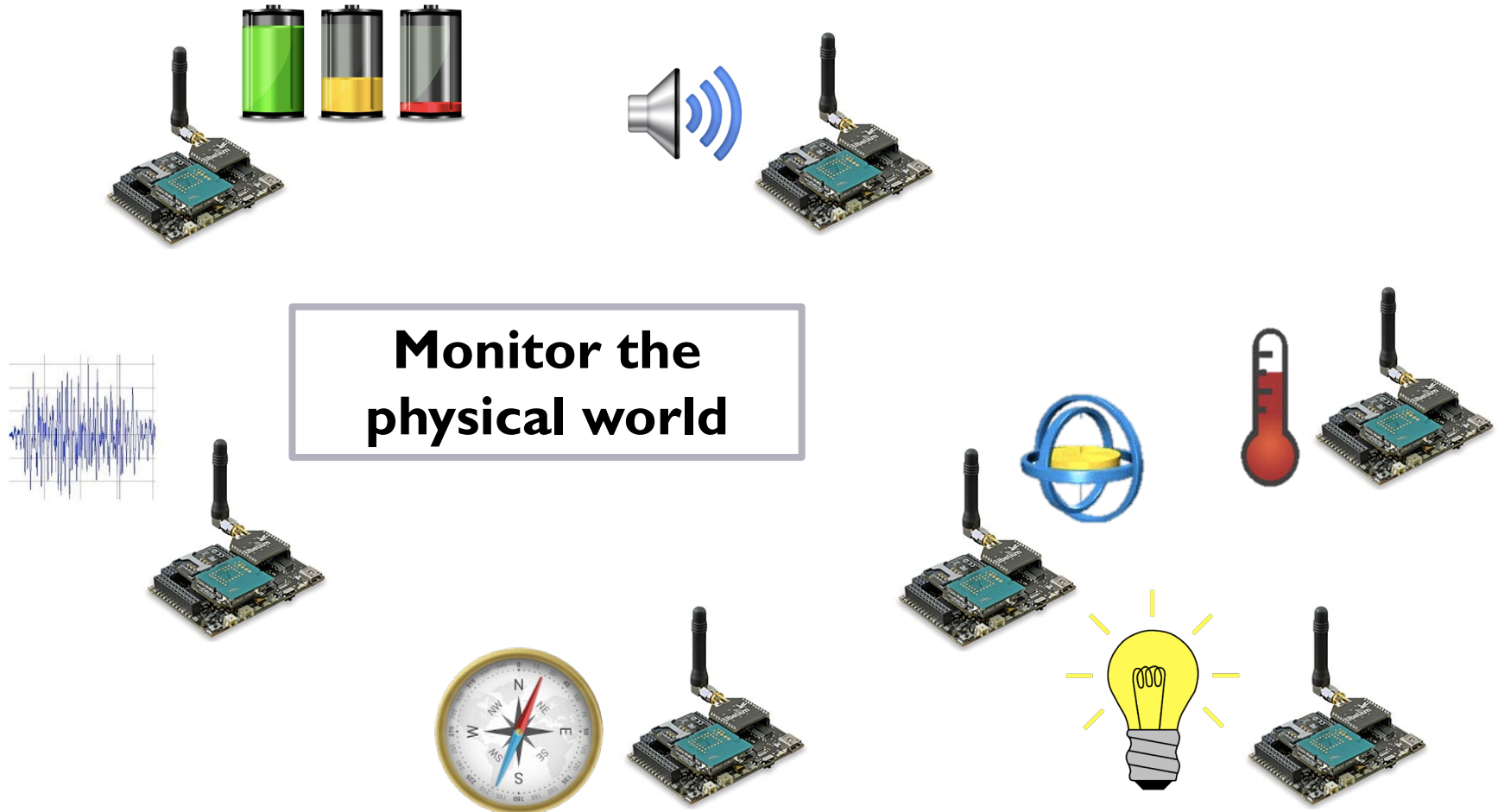
**Is IP the right solution for IoT?**

**Is an IoT Gateway good enough?**

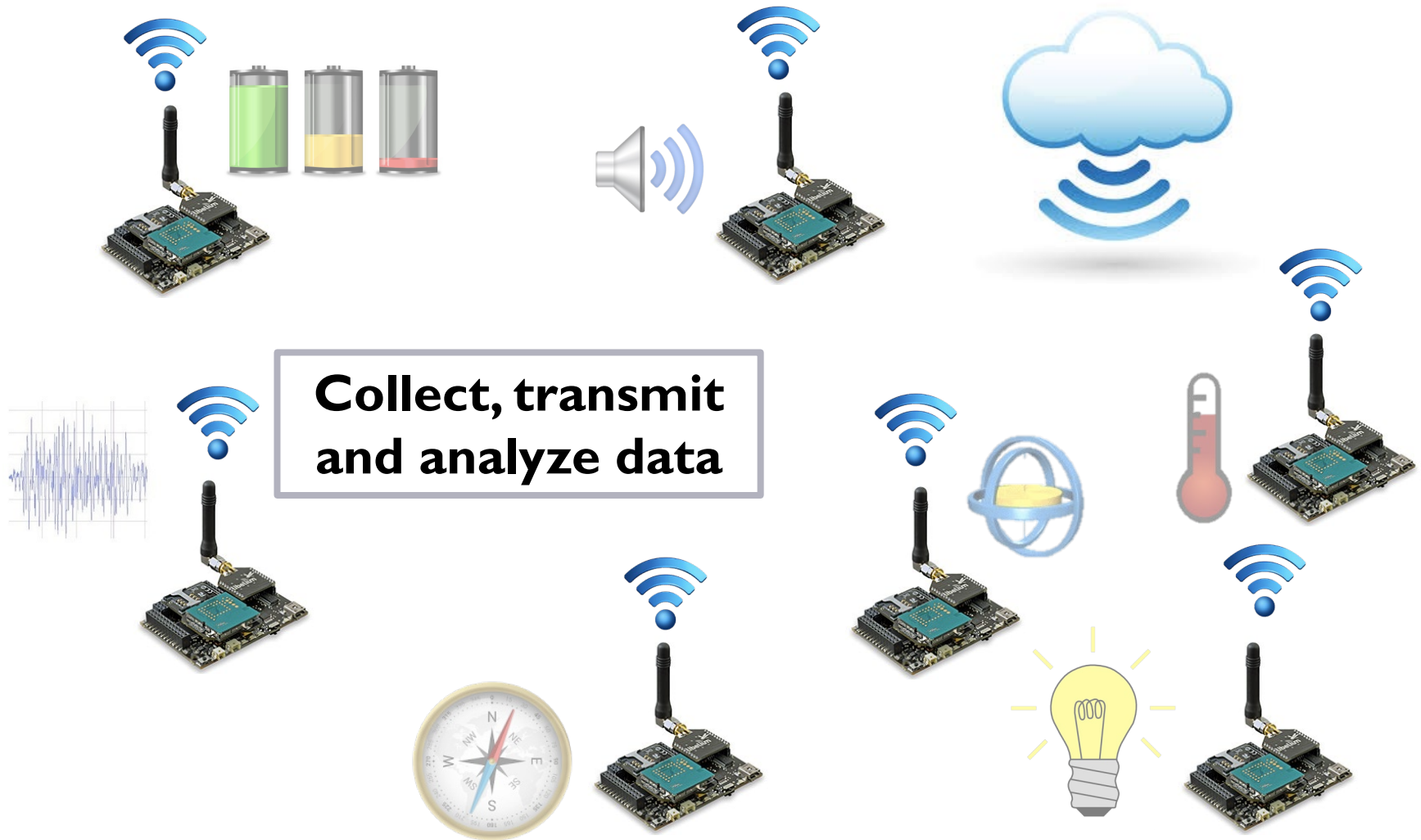


# From Small Things ...

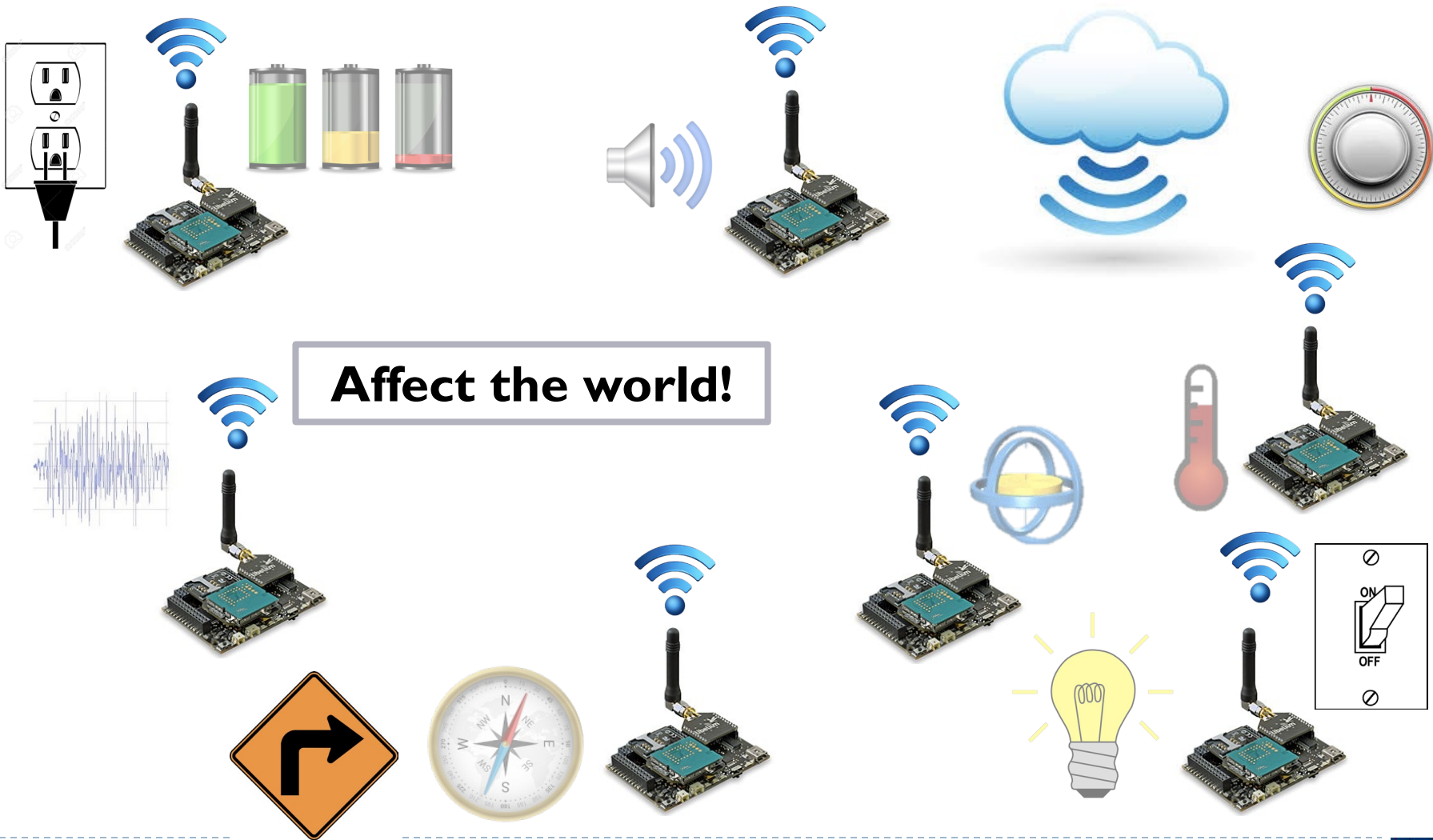
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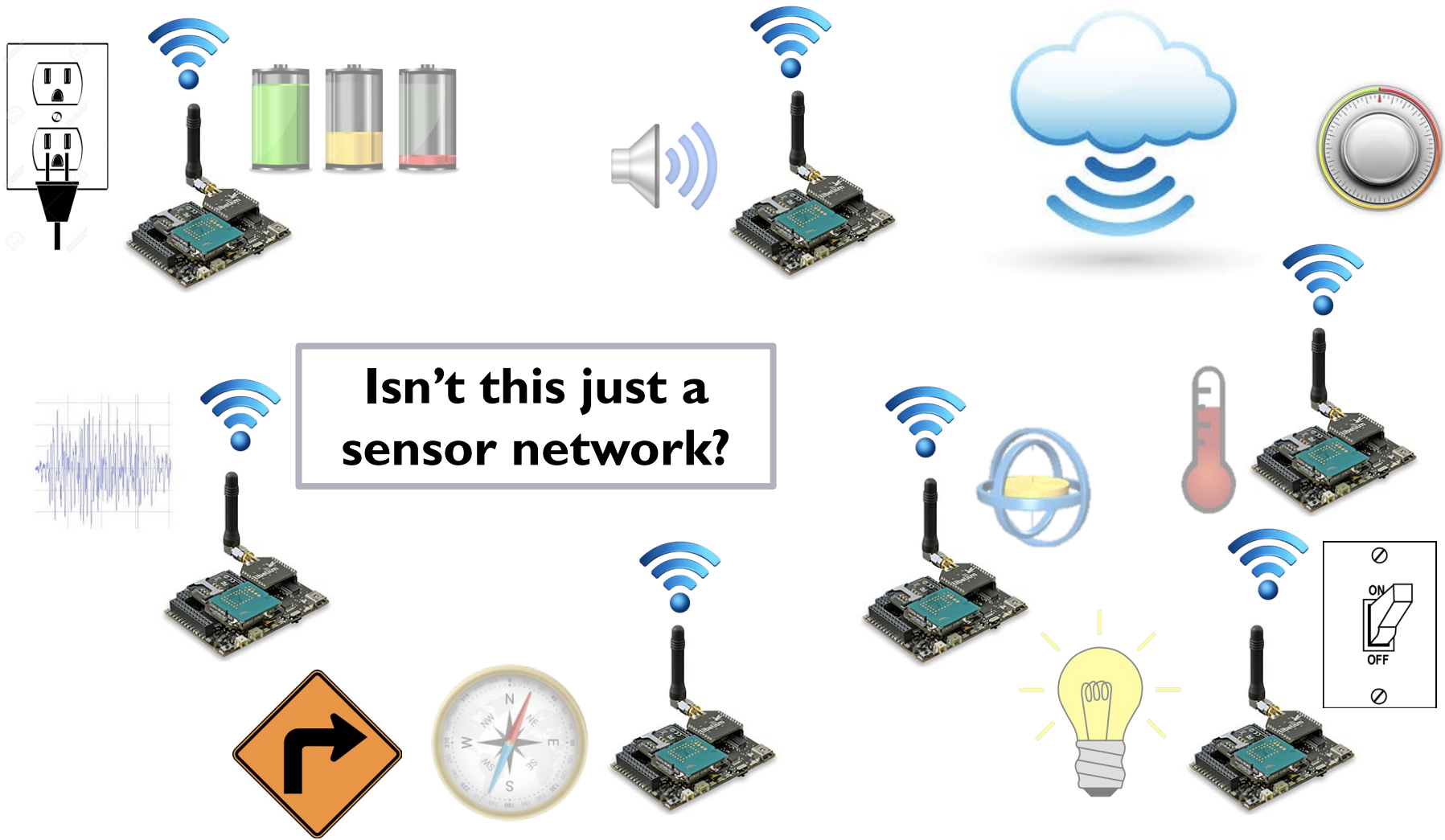
# From Small Things ...



# From Small Things ...



# So we have lots of devices ...



**Isn't this just a sensor network?**



# So we have lots of devices ...

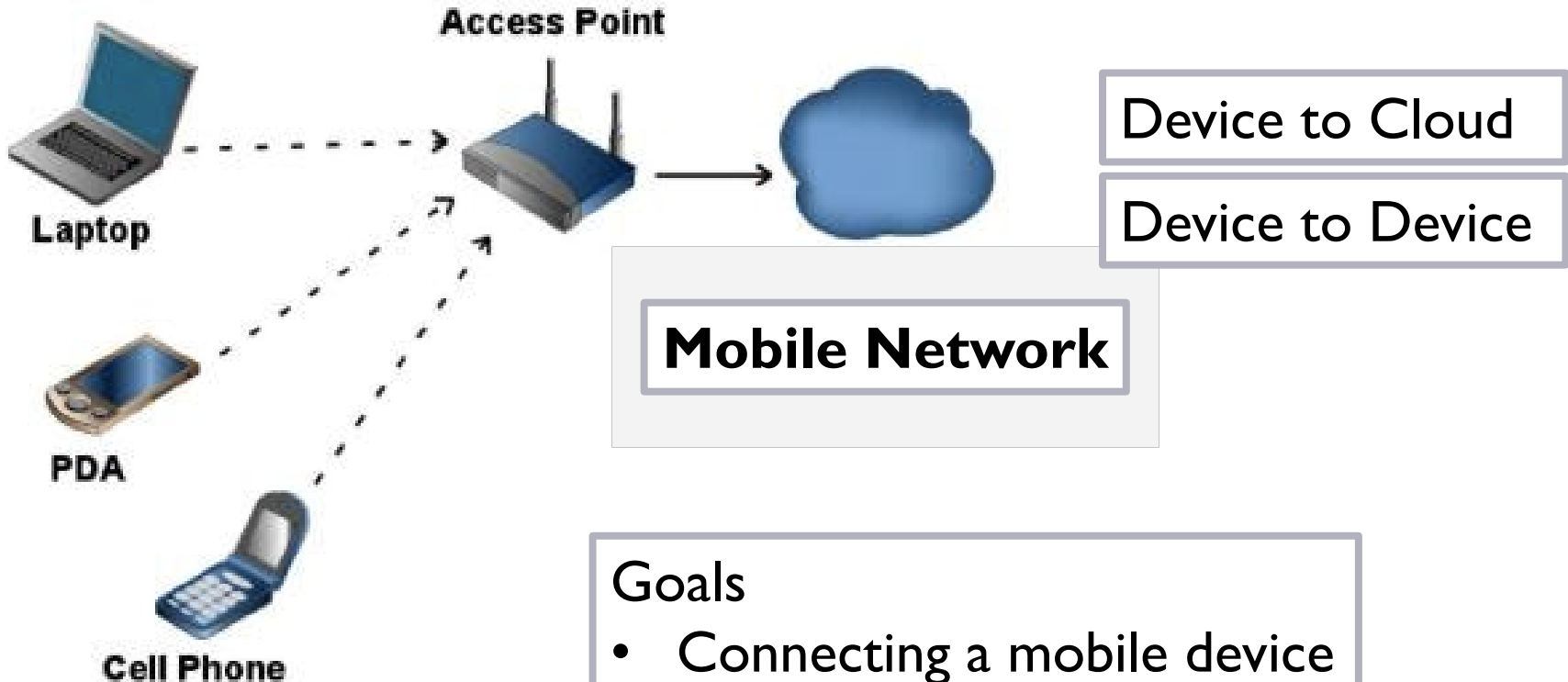


# So we have lots of devices ...





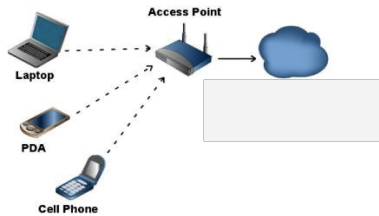
# More than a Mobile Network



## Goals

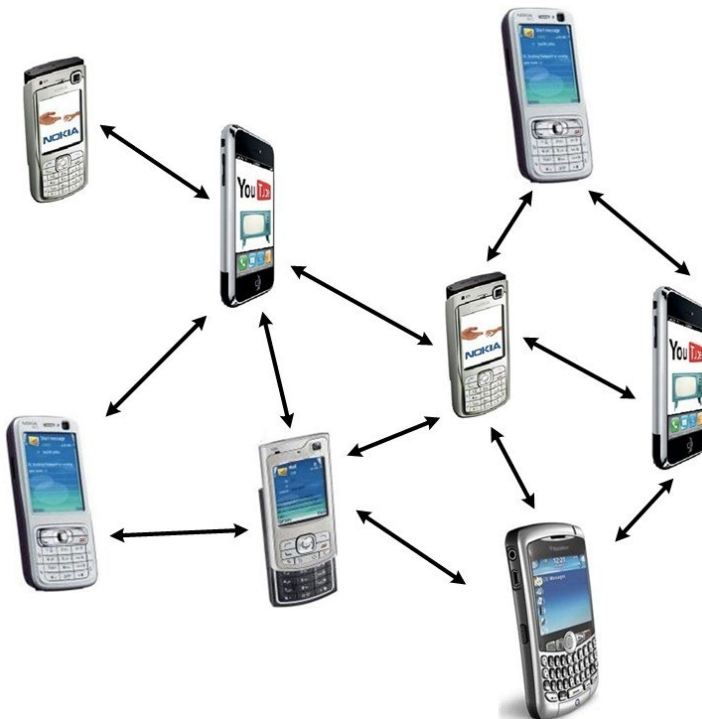
- Connecting a mobile device to the Internet
- End-to-end communication

# More than an Ad Hoc Network



**Ad Hoc  
Network**

**Device to Device**

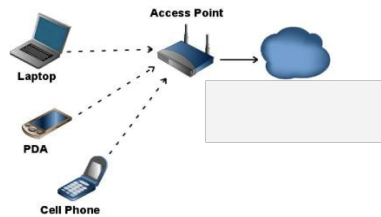


**Goals**

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

**Does IoT require multihop wireless communication?**

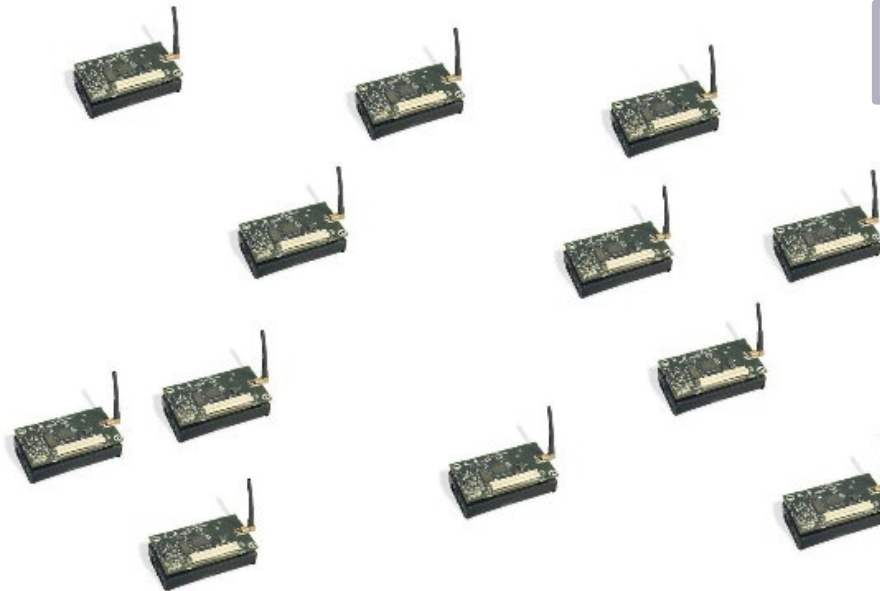
# More than a Sensor Network



**Sensor Network**

**Device to Cloud**

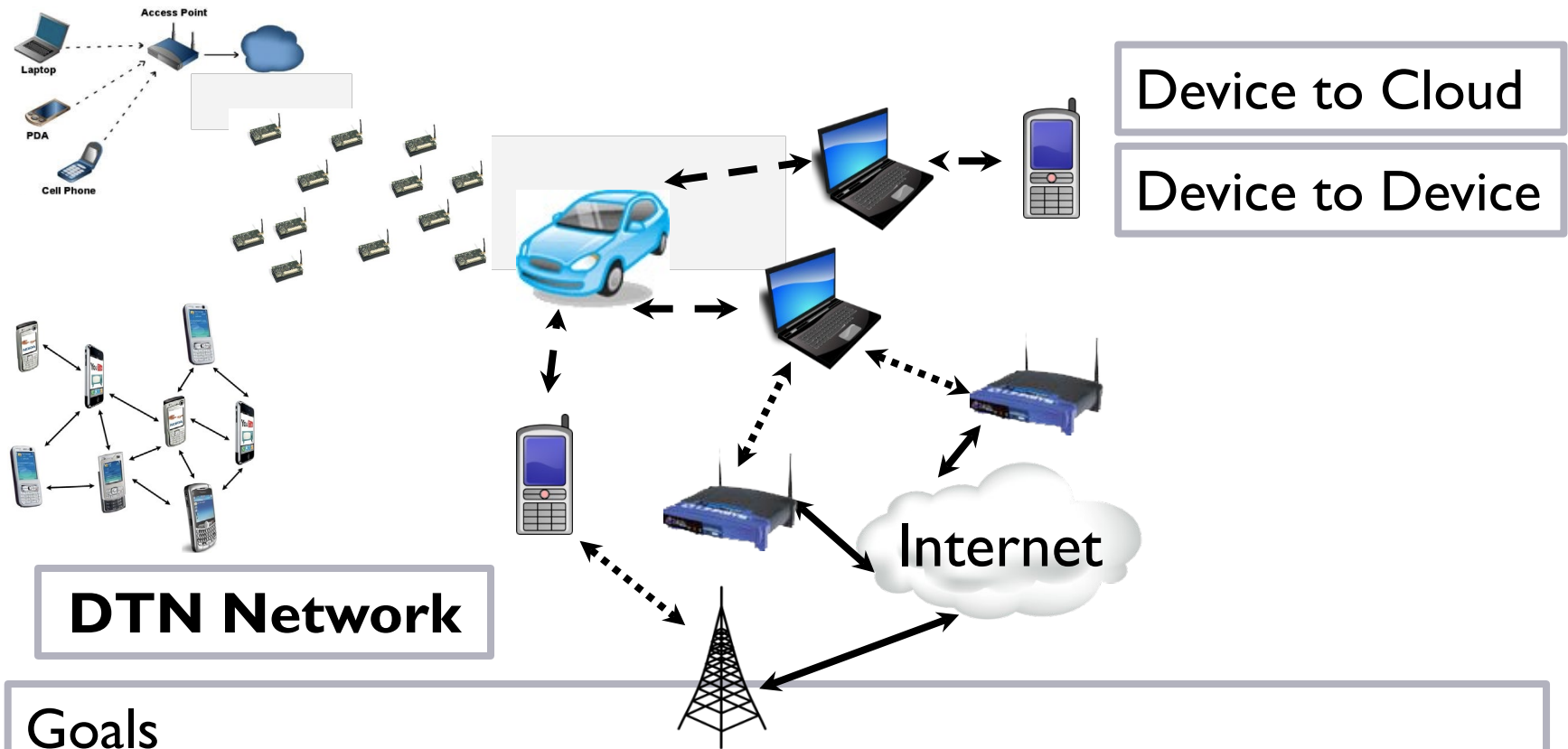
**Device to Device**



## Goals

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

# More than a DTN Network



- ## 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?



**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 networks

- Discovery
- Location

**Driven by advances in technology**

Cloud-based networking

- Service

**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

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**Wireless Networking**

**Low Power Computing**

**Sensors**



**Limited Power Source**

**Actuators**

# IoT from the Bottom Up

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**Wireless Networking**



**Privacy**

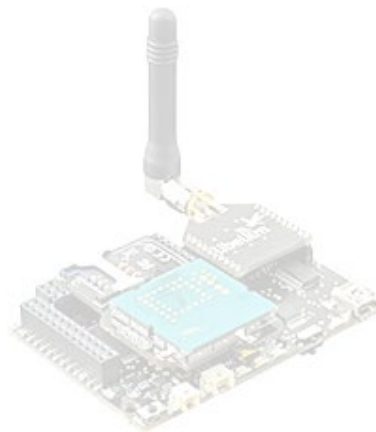
**Discovery**

**Which Technology?**

# IoT from the Bottom Up

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**Wireless Networking**



**Privacy**

**Discovery**

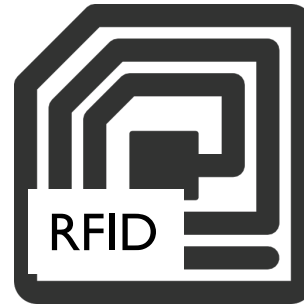
**Which Technology?**



# Which Technology best fits IoT?



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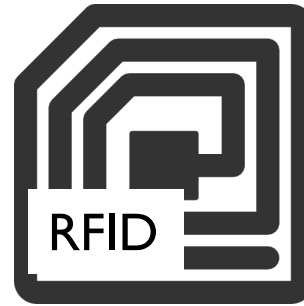




# Which Technology best fits IoT?



ZigBee®



**Need to understand  
the requirements  
and tradeoffs**



# Which Technology best fits IoT?



ZigBee®

**Connecting to the cloud**

**Large data transfers**

THREAD



**High range**  
**High BW**  
**High energy**



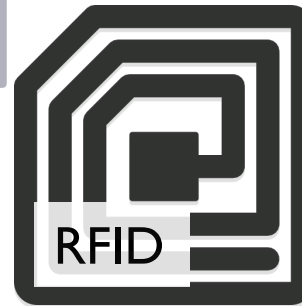
# Which Technology best fits IoT?



**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**

THREAD



**Long range**  
**Very Low BW**  
**Low Power**



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

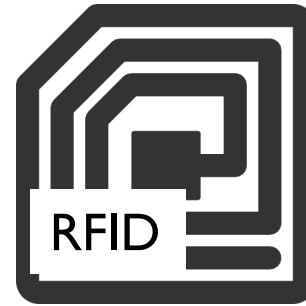
**Short range**  
**Low BW**  
**Low Power**



# Which Technology best fits IoT?



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**They all have their place in IoT**



# IoT from the Bottom Up

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**Wireless Networking**



**Privacy**

**Discovery**

**Which Technology?**



# Discovery: Is anybody out there?

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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?



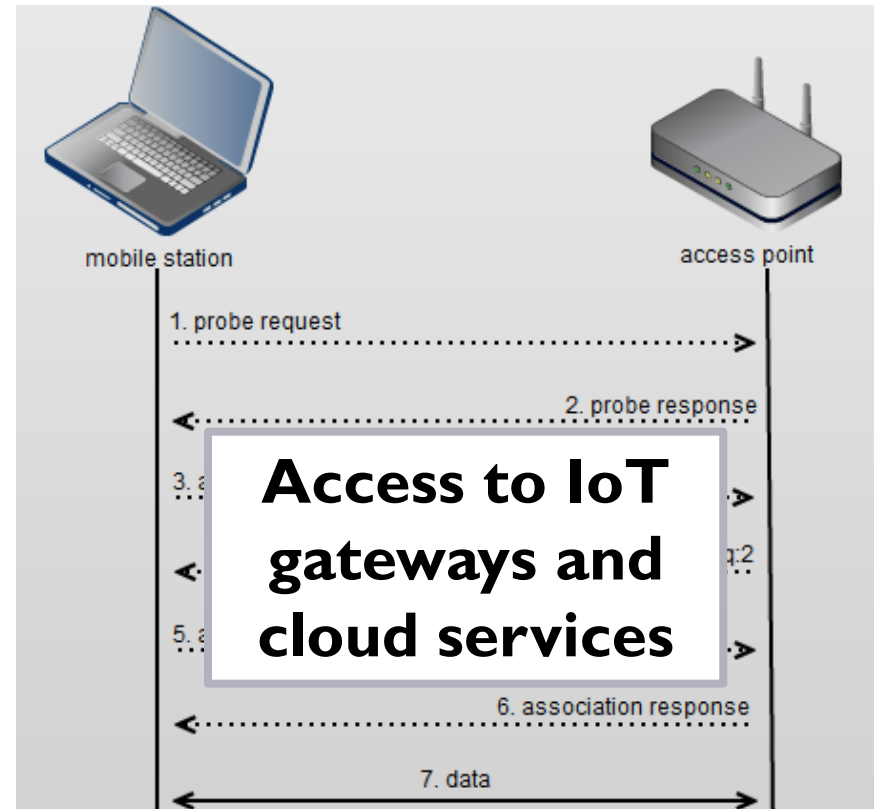
## AP Discovery

Base station:

- No energy constraints
- Always on

Mobile

- Balance discovery delay with energy consumption





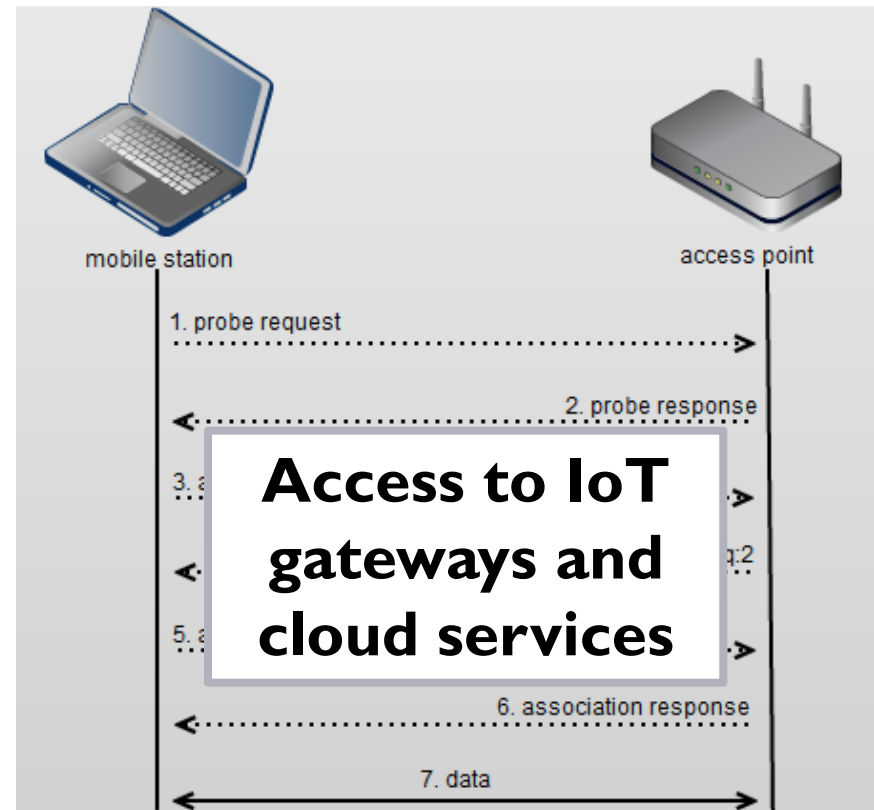
# Discovery: Is anybody out there?



## AP Discovery

Bandwidth constrains:

- Balance discovery delay with bandwidth overhead



# Discovery: Is anybody out there?



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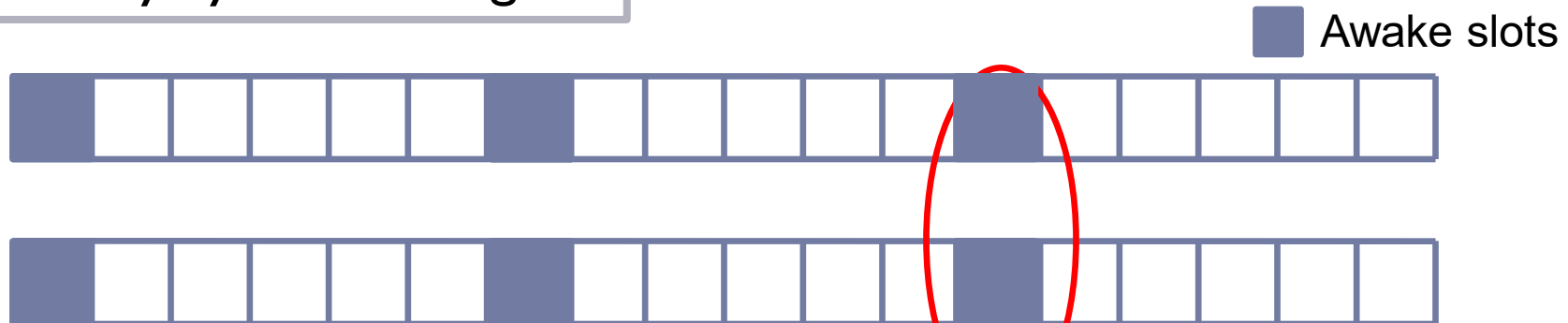


## Device Discovery

Mobile

- Broadcast “beacon”
- Duty cycle listening

**Local discovery**  
**Specialized for environment**



# Discovery: Is anybody out there?

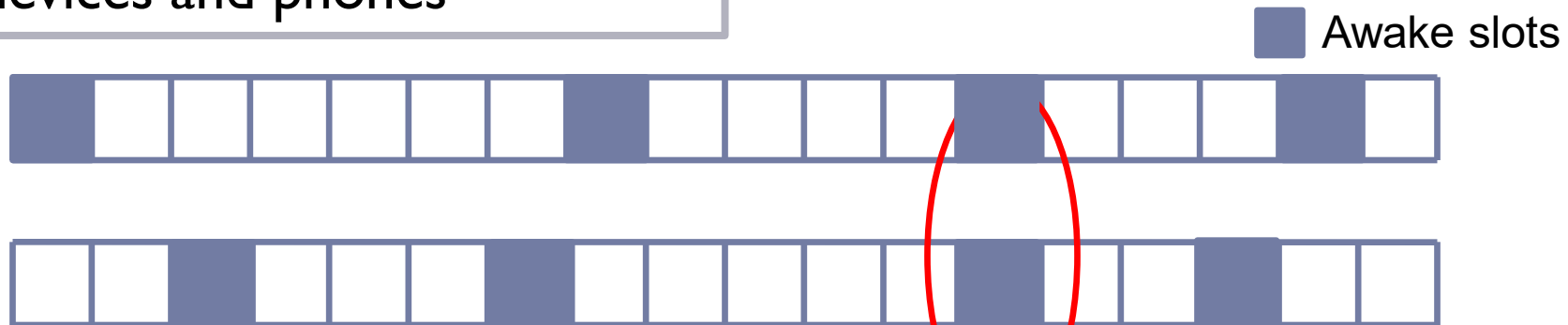


ZigBee<sup>®</sup>



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

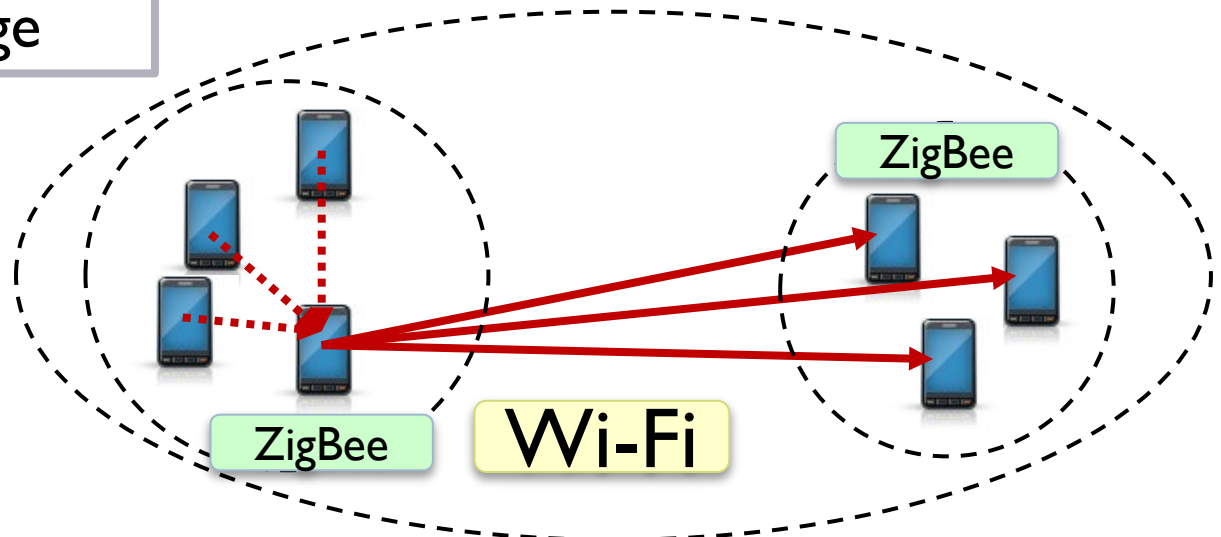
Asynchronous Discovery



# Discovery: Is anybody out there?



Wi-Fi is expensive  
ZigBee is low range



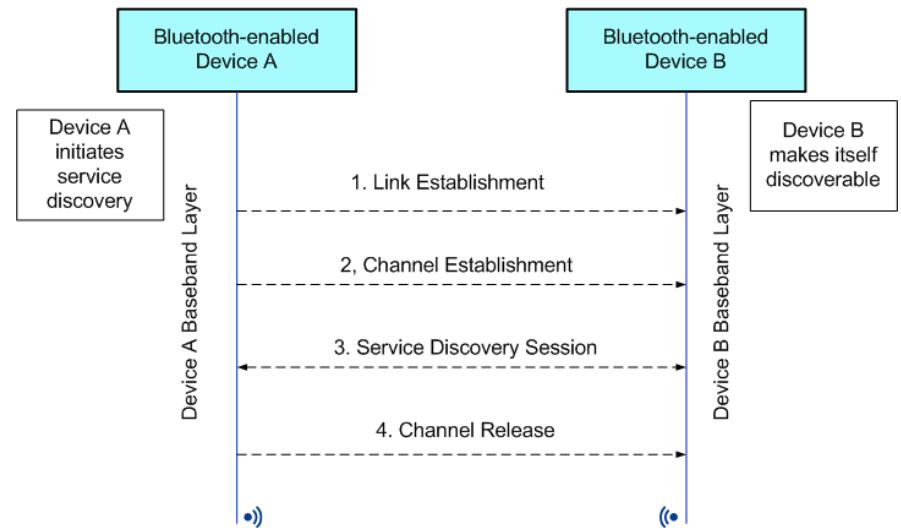
# Discovery: Is anybody out there?



## Asymmetric Discovery

Master-Slave:

- Complex
- Slow
- Requires user input



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



# Discovery: Is anybody out there?

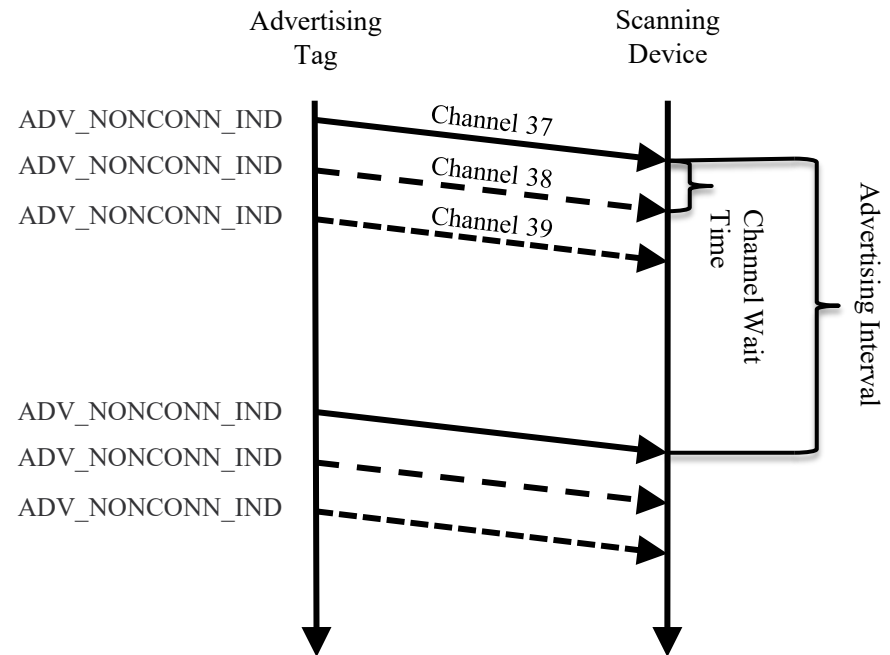


## Simplified Discovery

### Beacon:

- Passive
- Active
- Client duty cycles listening

Small payload (31B)



## Ultra-low power discovery



# Discovery: Is anybody out there?

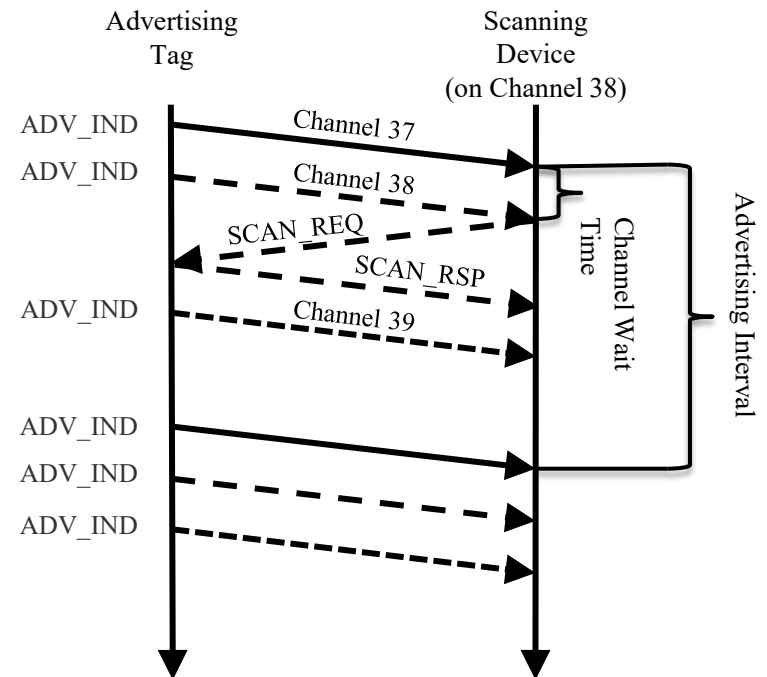


## Simplified Discovery

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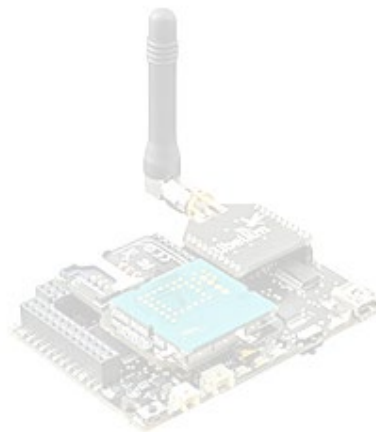
## Ultra-low power discovery



# IoT from the Bottom Up

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**Wireless Networking**



**Privacy**

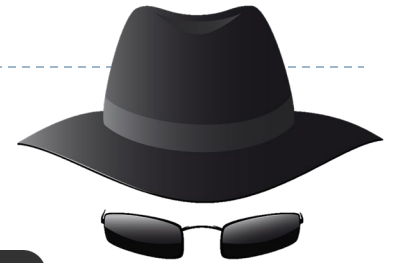
**Discovery**

**Which Technology?**

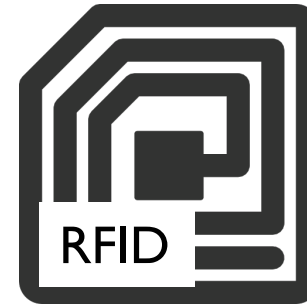




# Who has found me?



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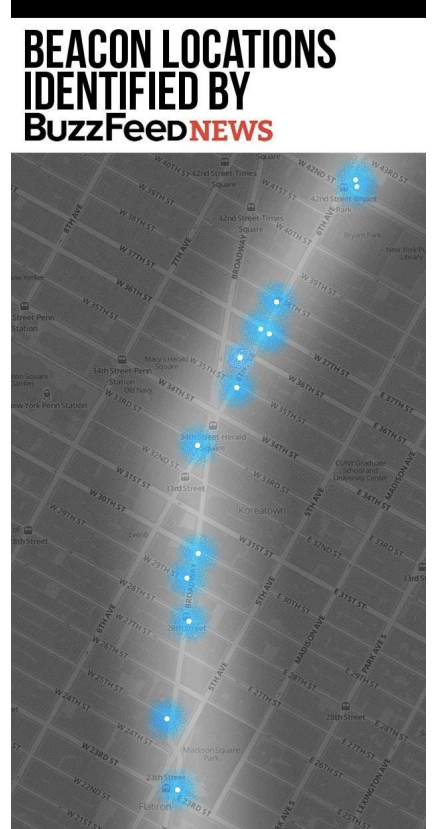
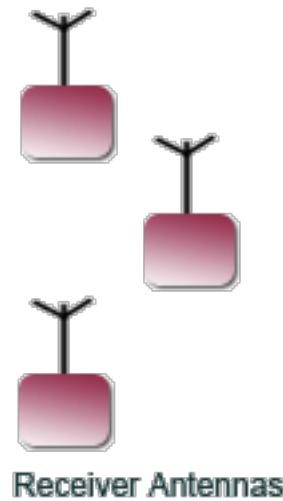
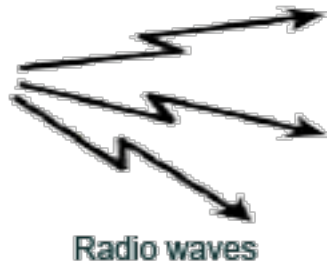
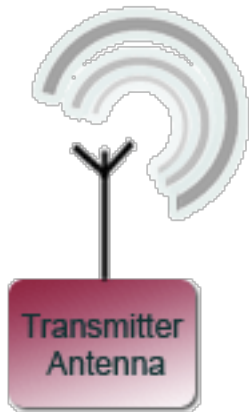
All of these protocols operate in the open

Discovery may reveal the user's identity!



# Who has found me?

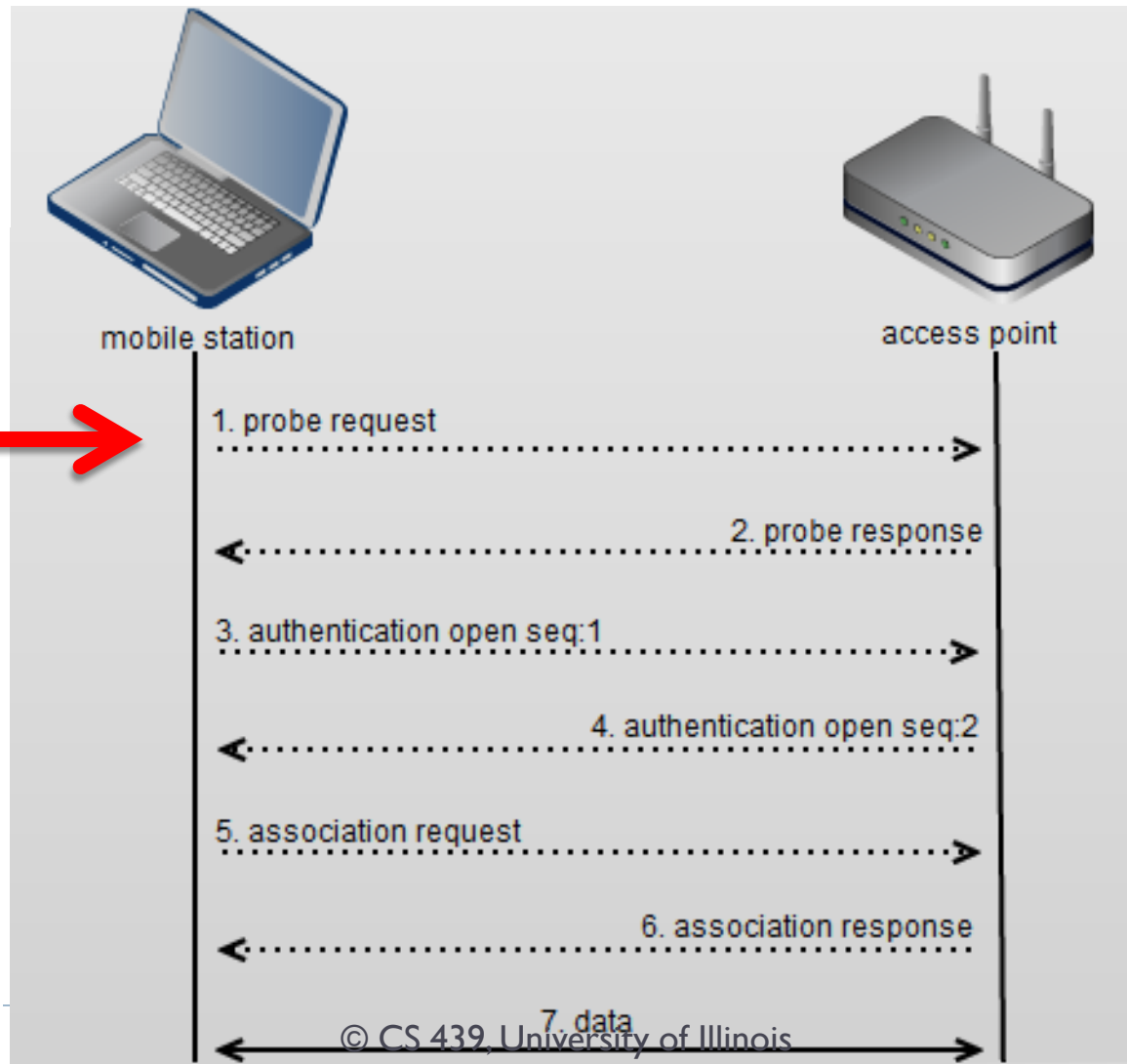
**All transmission contain the identity of the sender (MAC address)**



**Anyone can listen and track the user**



# Who has found me?

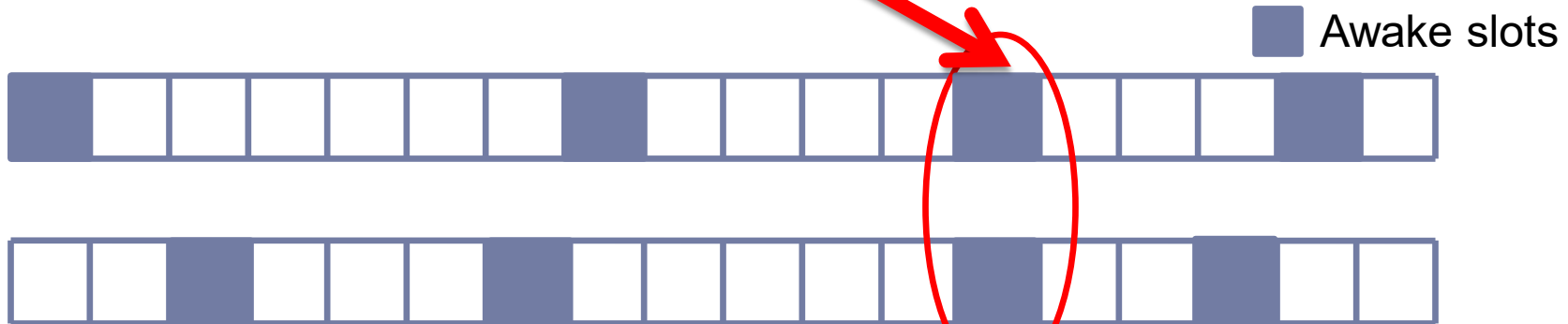


# Who has found me?



ZigBee®

**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

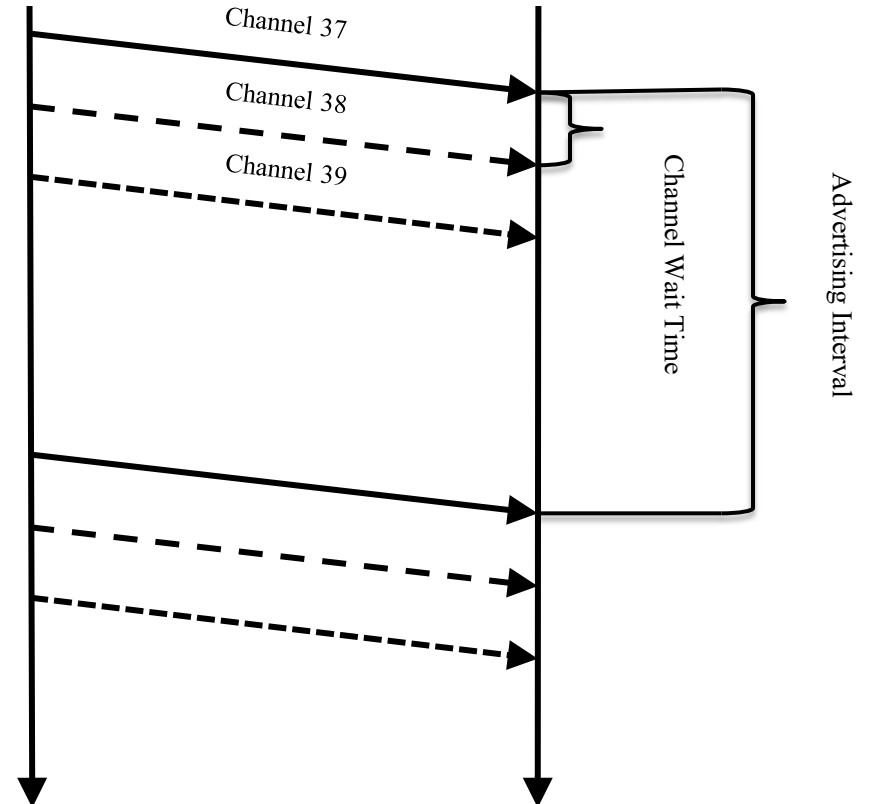
Channel 39

**Only if the user is  
beaconing**

ADV\_NONCONN\_IND  
ADV\_NONCONN\_IND  
ADV\_NONCONN\_IND

Channel Wait Time

Advertising Interval

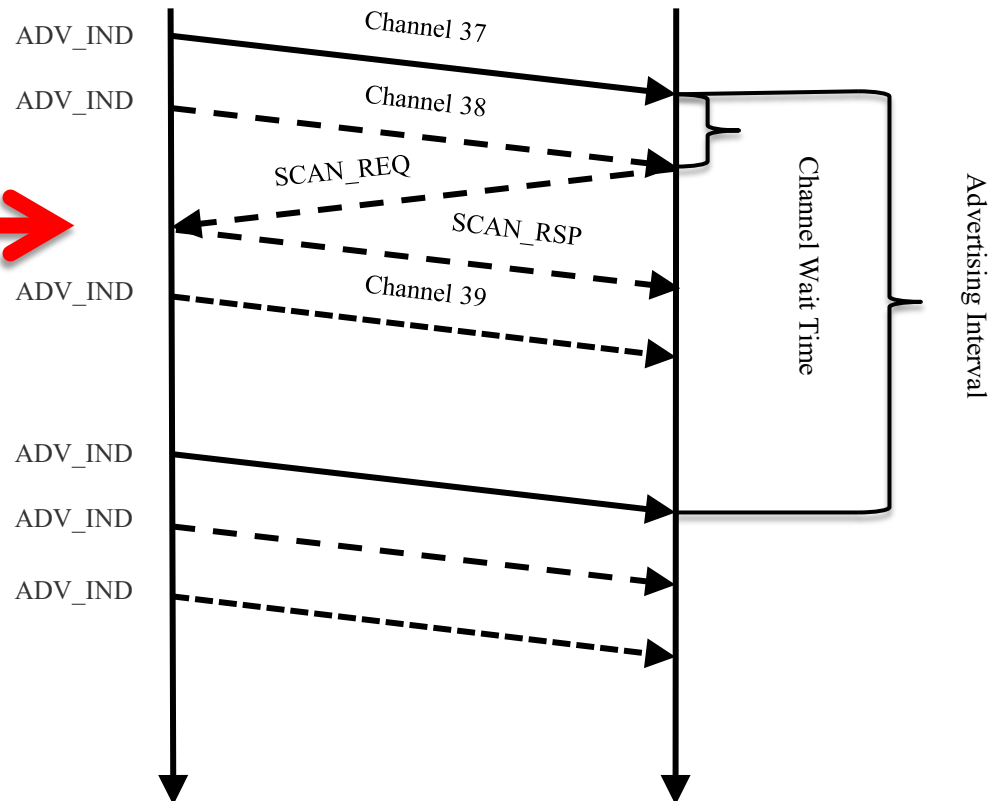


# Who has found me?



Advertising Tag

Scanning Device  
(on Channel 38)



**Whenever a user's devices hears an active beacon!**

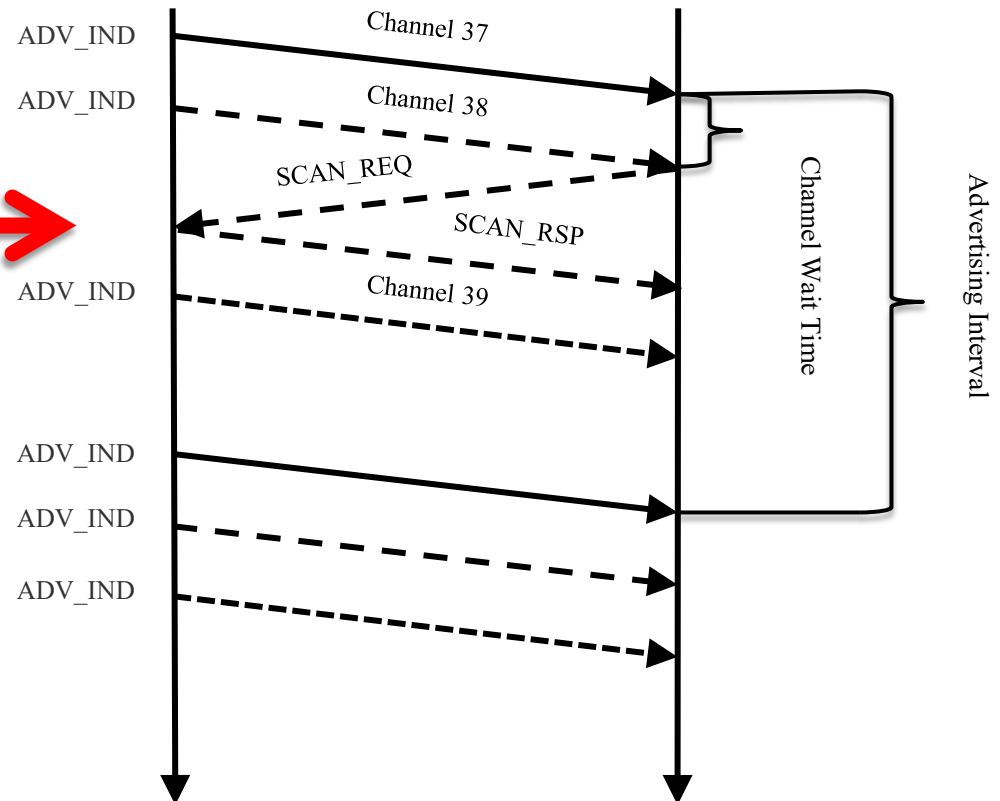


# Who has found me?



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