6.1820/MAS.453: Mobile and Sensor Computing

https://6mobile.github.io/

Lecture #5:

Network Connectivity for IoT Systems

Course Staff	Announcements
Lecturers Fadel Adib (fadel@mit.edu) Tara Boroushaki (tarab@mit.edu) TAs Waleed Akbar (wakbar@mit.edu) Jack Rademacher (jradema@mit.edu)	1- Lab 1 due tonight 2- PSet 1 Due March 6

Objectives of the Upcoming Three Lectures

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

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

NETWORKING: “GLUE” FOR THE IOT

IoT’s “technology push” from the convergence of

- Embedded computing
- Miniaturized sensing (MEMS)
- **Wireless network connectivity**

THE IOT CONNECTIVITY SOUP

Where would use use different technologies for?
Why not the same technology across use-cases?

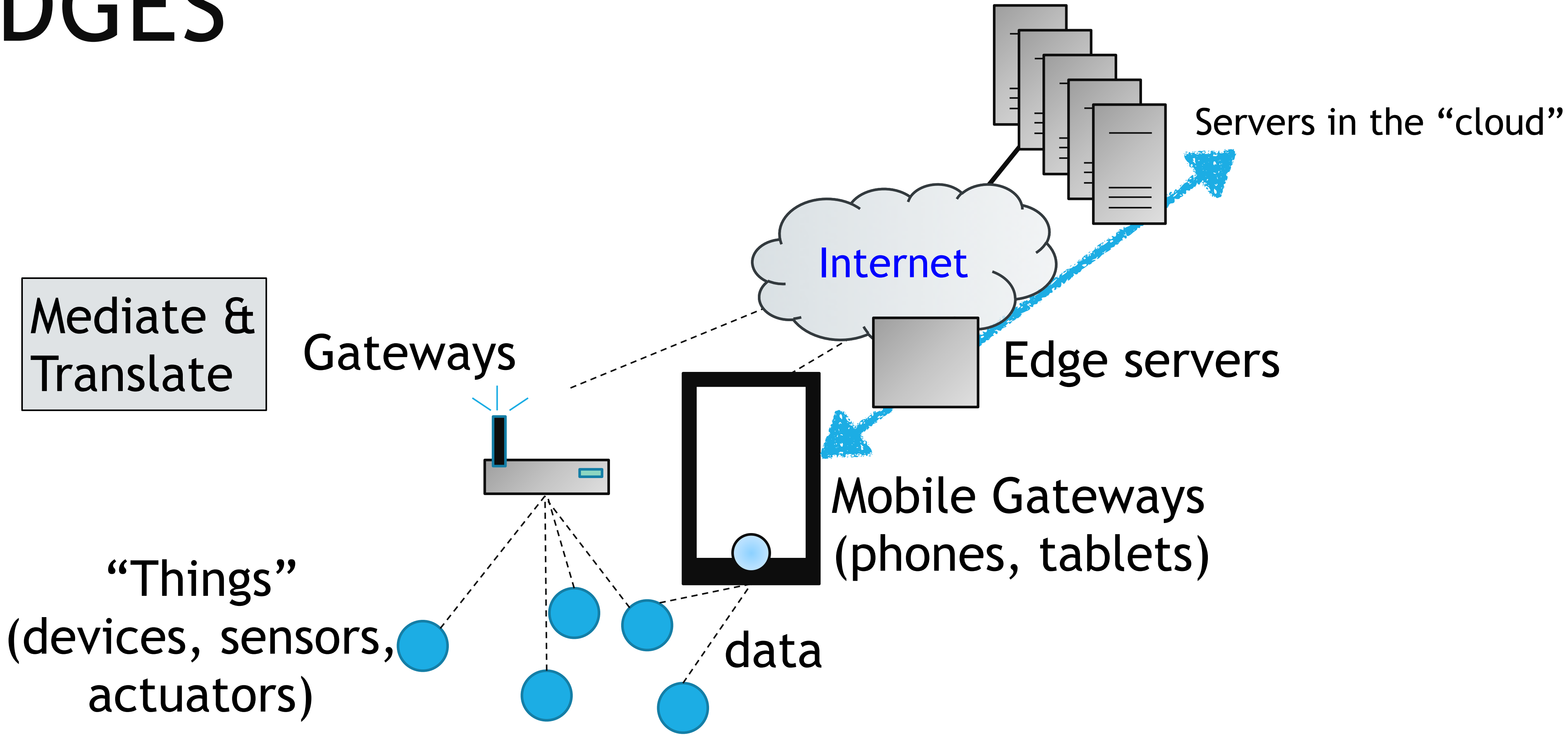
NETWORKING: “GLUE” FOR THE IOT

Many different approaches, many different proposed standards.
Much confusion

One size does not fit all: best network depends on application

What are the key organizing principles and ideas?

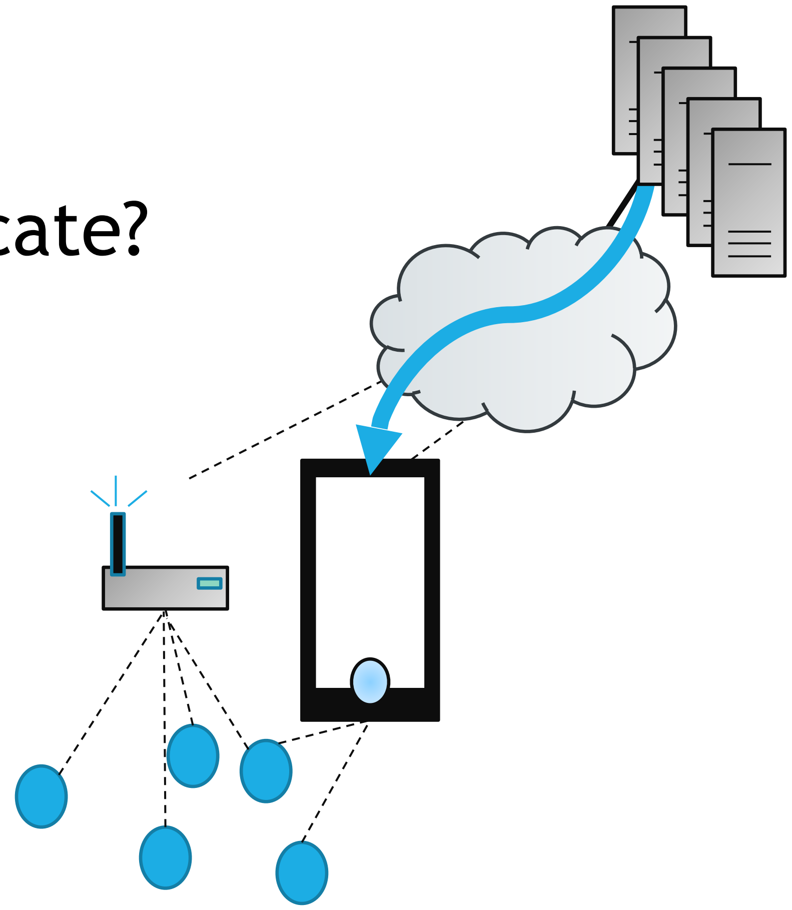
ARCHITECTURE:DIRECT, GATEWAYS EDGES



BUT, IN FACT, A RICH DESIGN SPACE

How should gateways and things communicate?

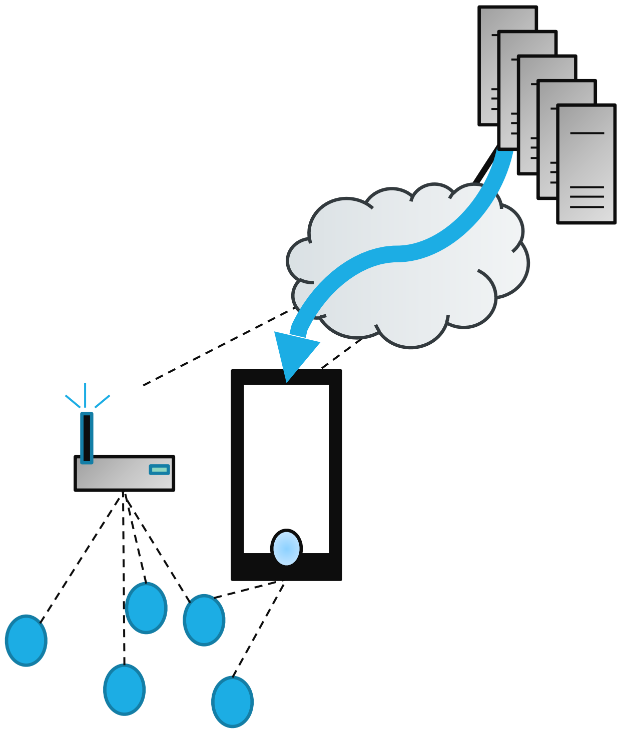
Many answers, many approaches



CAN'T WE JUST USE THE WIRELESS INTERNET?

Cellular and Wi-Fi

Yes, we can…
except when we can't!



WIRELESS INTERNET FOR IOT?

Cellular (5G, LTE/4G, 3G, 2G) and Wi-Fi are

+ Widely available (cellular in the wide-area and Wi-Fi for static uses)
+ High bandwidth (for most purposes), so can support high-rate apps

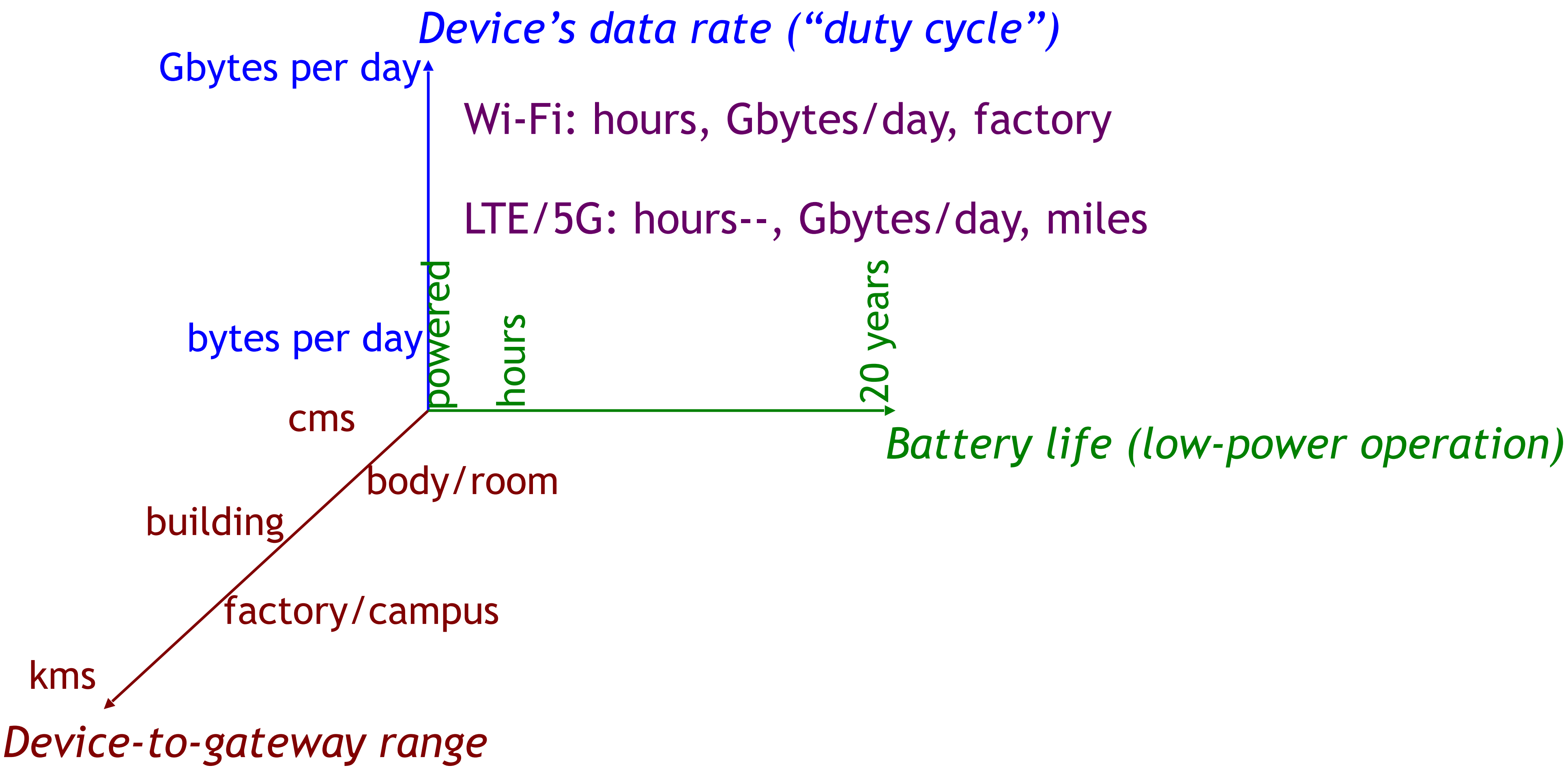
But, each has two big drawbacks

- **High power**: not ideal for battery-operated scenarios
- Cellular: often high cost (esp. per byte if usage-per-thing is low)
- Wi-Fi: OK in most buildings, but not for longer range

Wi-Fi: In-building powered things (speakers, washers, refrigerators, …)

Cellular: High-valued powered things (e.g., “connected car”)

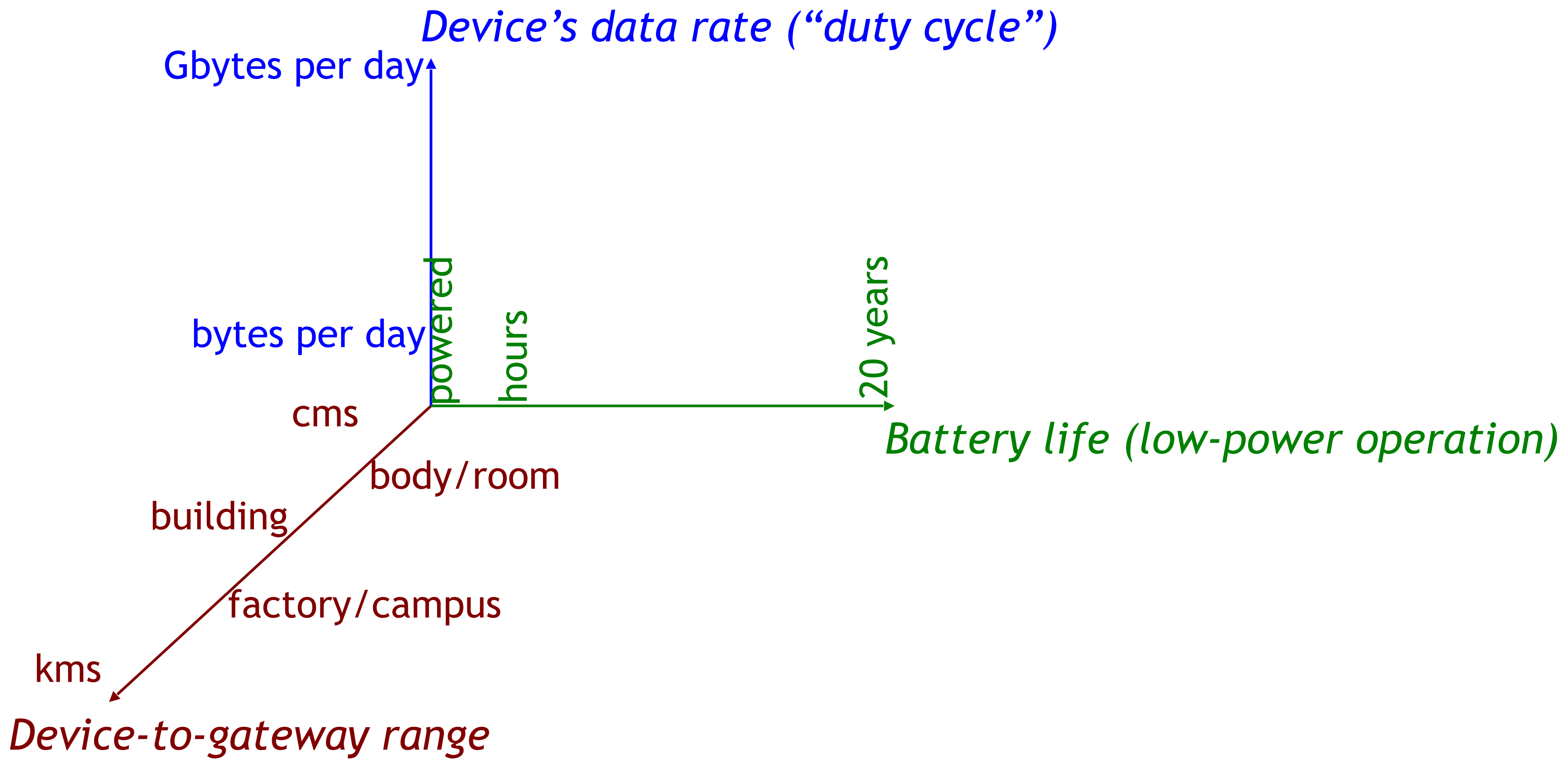
IOT NETWORK DESIGN SPACE



WHY SO MANY IOT NETWORKS?

Because engineers love inventing technologies!

Because you can pick from this design space



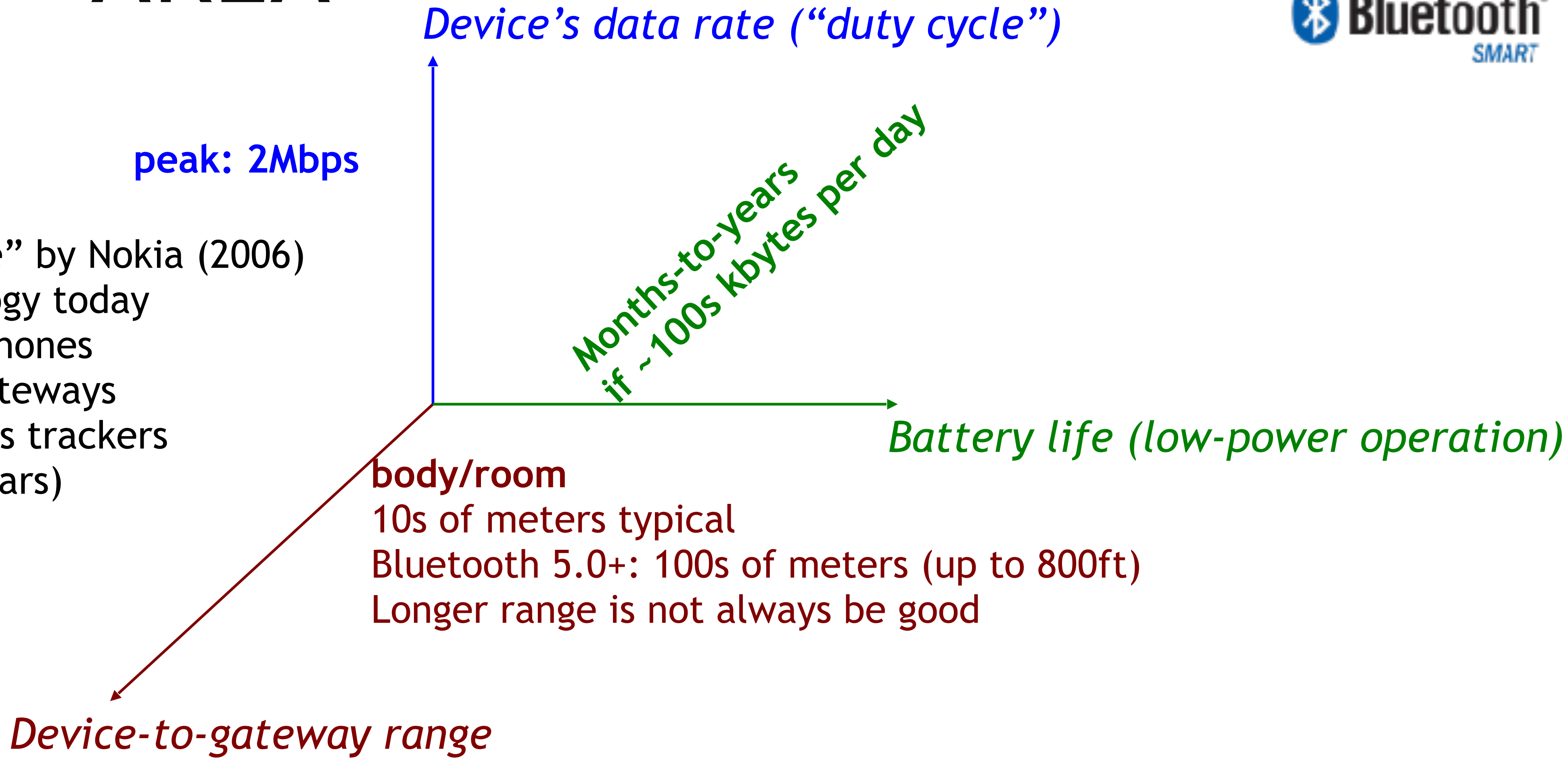
WHY SO MANY IOT NETWORKS?

- Note, axes aren’t independent
- And technology evolves fast
- And bundling into popular devices speeds-up adoption, changing the economics
  - Cf. Wi-Fi → laptops (without external cards)
  - Bluetooth classic → cell phones → wireless headsets
  - Bluetooth Low Energy (BLE) → iPhone then Android smartphones → “body/room” with months-to-years at low duty cycles

BLUETOOTH LOW ENERGY (BLE): “ROOM”-AREA

Bluetooth SMART

Started as “Wibree” by Nokia (2006)
Dominant technology today
Because of smartphones
Smartphones as gateways
- Wearables, fitness trackers
- Vehicles (bikes, cars)



HOW DOES BLE WORK?

Two parts:

1. Advertisements (aka “beaconing”) for device discovery
2. Connection phase to exchange data

Peripheral: device with data
Central: gateway

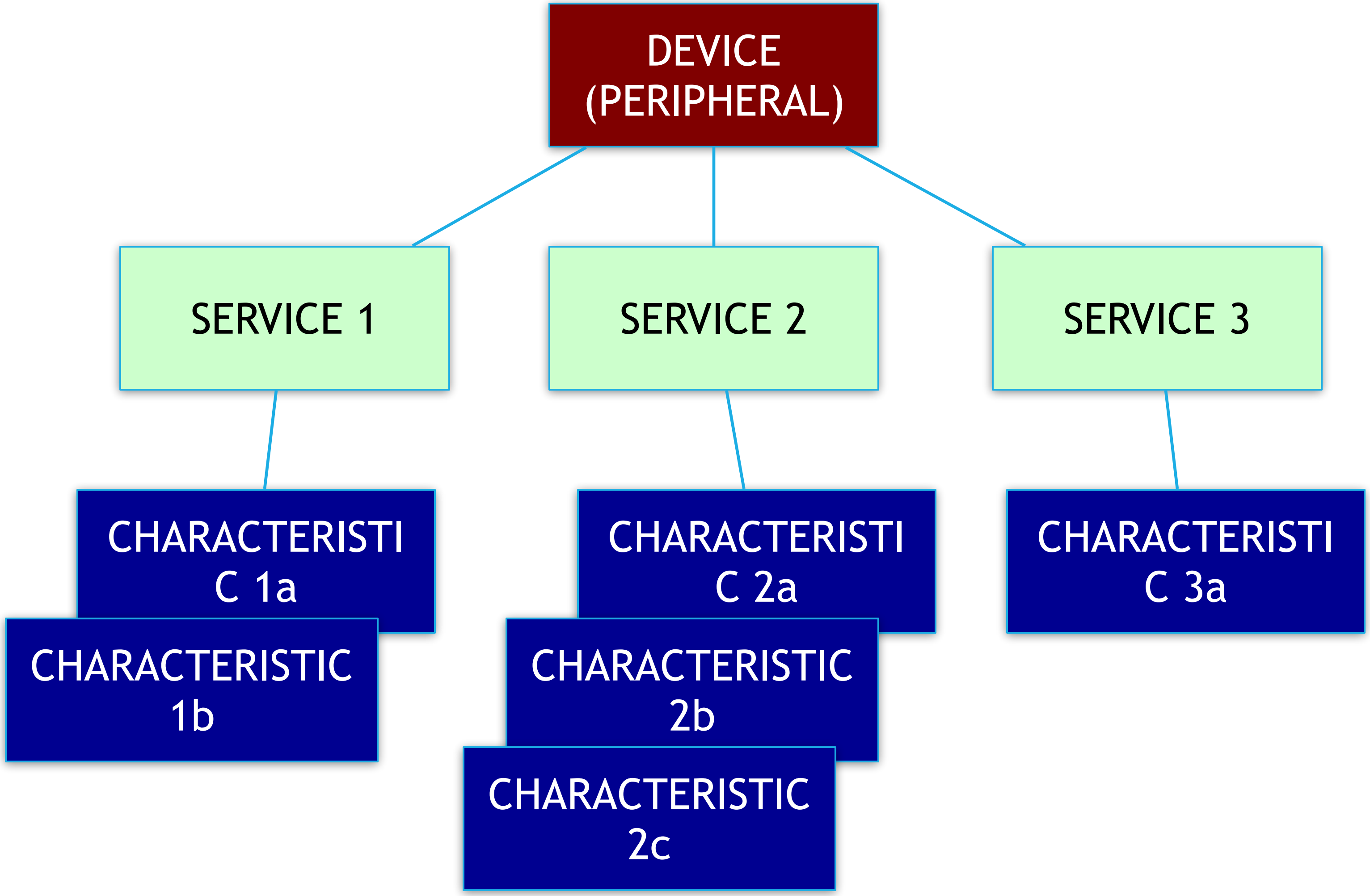
Should the central or peripheral scan? Why?

BLE ADVERTISEMENTS ARE PERIODIC

Typical period: 100 ms (“iBeacon”)
Less frequent is fine
Triggered advertisements are often a good idea

Trade-off between energy consumed
and discovery latency

ON CONNECTION



READABLE
READ/WRITE
NOTIFICATIONS

Usually support OTA (over-the-air upgrades)

ON CONNECTION: MAC PROTOCOL

Central orchestrates data communication
Key idea: time-schedule to reduce energy consumption

On connect: exchange parameters

- Frequency hopping sequence
- Connection interval, i.e., periodicity of data exchange (T milliseconds)

Every T milliseconds, Central and Peripheral exchange multiple packets, alternating turns

Then Peripheral can go back to sleep until next interval

BATTERY LIFETIME CALCULATION

Consider an IoT system with coin-cell battery-powered nodes
Battery: 1000 mAh (milliamp-hours) capacity; 3 Volts
Recall that power = voltage * current and energy = power * time
So this battery has 3 amp-hour-volts = 3*3600 Joules = 10.8 kJ of energy

Example of BLE current draw:
Standby: 1 microAmp (typically in the 1-10 microAmp range)
Receive (RX): 3.3 mA
Transmit (TX): 4 mA

Suppose device transmits every second: how long does the battery last?

BATTERY CALCULATION (CONT.)

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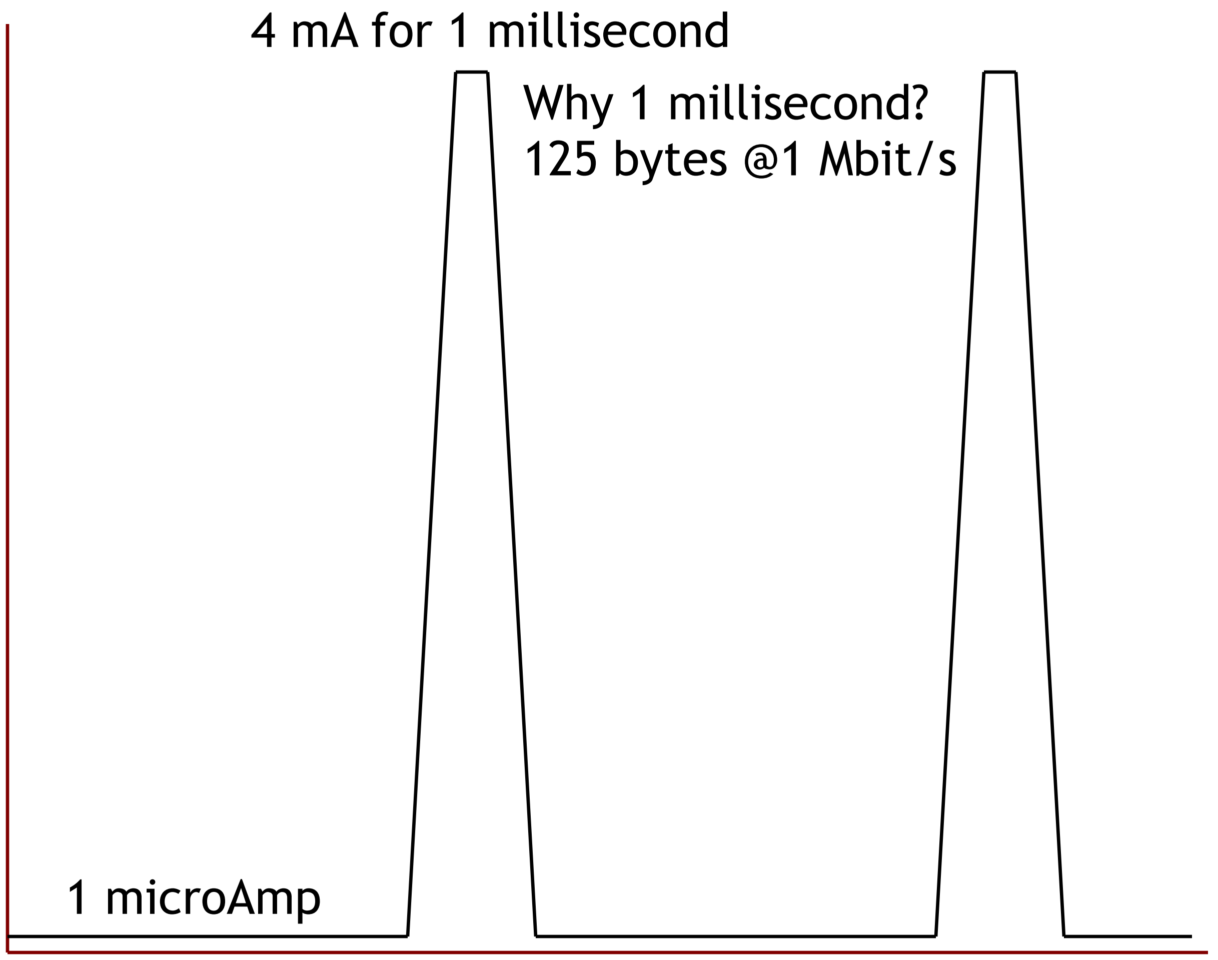
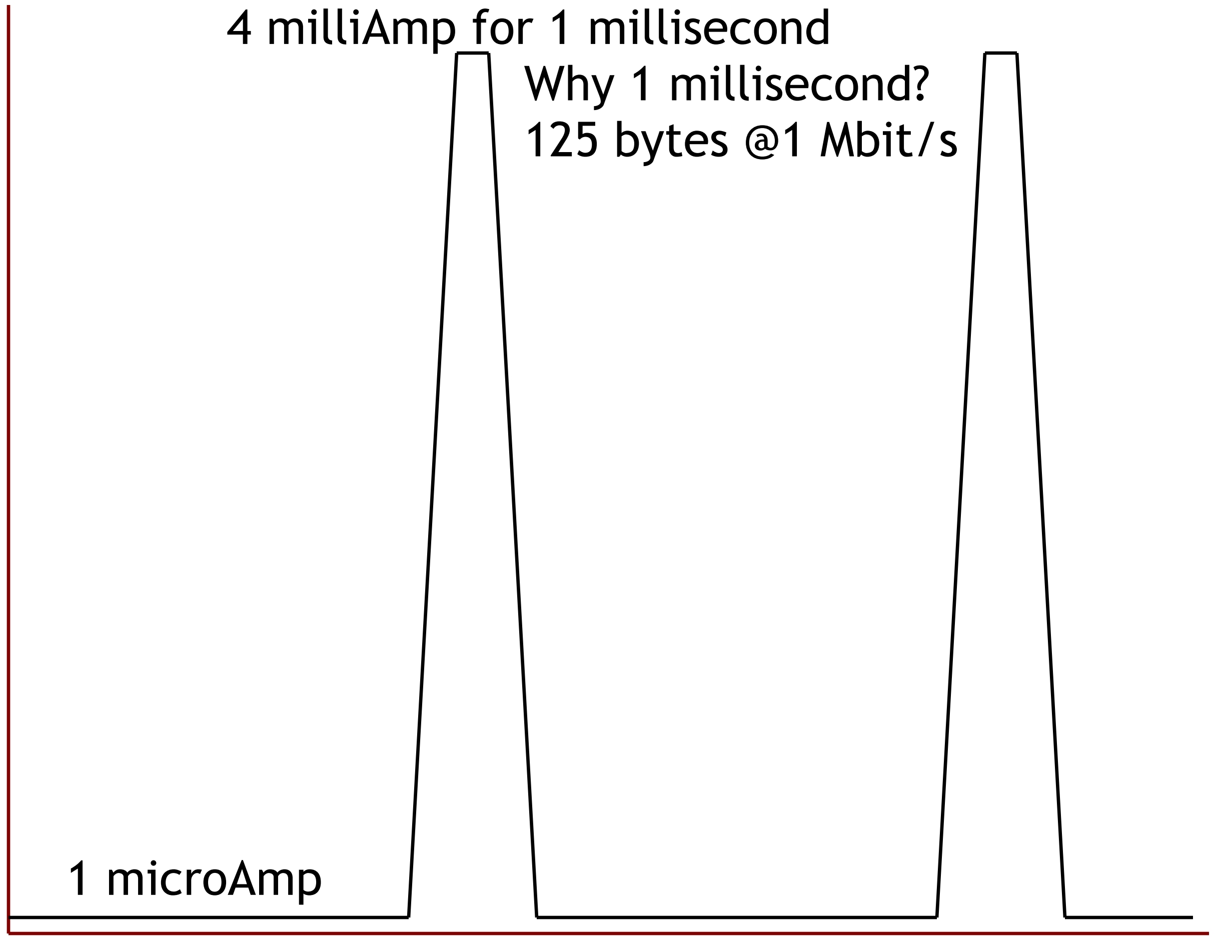
Transmit (TX): 4 mA
Ramping up and down (combined): 1 mA for 5 ms

Suppose device transmits every second: how long does the battery last?
Depends on how long the xmit lasts: let's assume 125 bytes at 1 Mbit/s (i.e. 1 ms)



BATTERY CALCULATION (CONT.)



Note: 1Watt = 1A x 1V
1Joule = 1Watt x 1s

Battery capacity: 1000 mAh (milliAmp-hours)
Ramp-up and down: 1 milliAmp for 5 milliseconds

Energy consumed in 1 second is:
(4*0.001 (xmit) +
1*0.005 (ramping) +
1 microAmp (standby)) x 3V
= 10 microAmps x 3V

Therefore, battery lifetime
= 1000 mAh / 10 microAmps
= 1000 mAh / 0.01 mA
= 100,000 hours
= 11+ years!

Saves energy because it's sleeping most of the time!

But of course an IoT device also does sensing,
some computation, perhaps some storage, etc.

I Used Apple AirTags, Tiles and a GPS Tracker to Watch My Husband's Every Move

A vast location-tracking network is being built around us so we don't lose our keys: One couple's adventures in the consumer tech surveillance state.

By Kashmir Hill and Photographs By Todd Heisler
Feb 11, 2022

“THE IOT GATEWAY PROBLEM”

Application-level gateways prevalent for IoT today
Usually need a smartphone app to interact with IoT data/devices
Problem: “Siloed” architecture

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Should smartphones become generic BLE gateways (with OS support)
Any phone talking with any peripheral device via BLE

- Should phones become IPv6 routers for peripheral devices?
- Should phone proxy a device’s Bluetooth profile to cloud servers?

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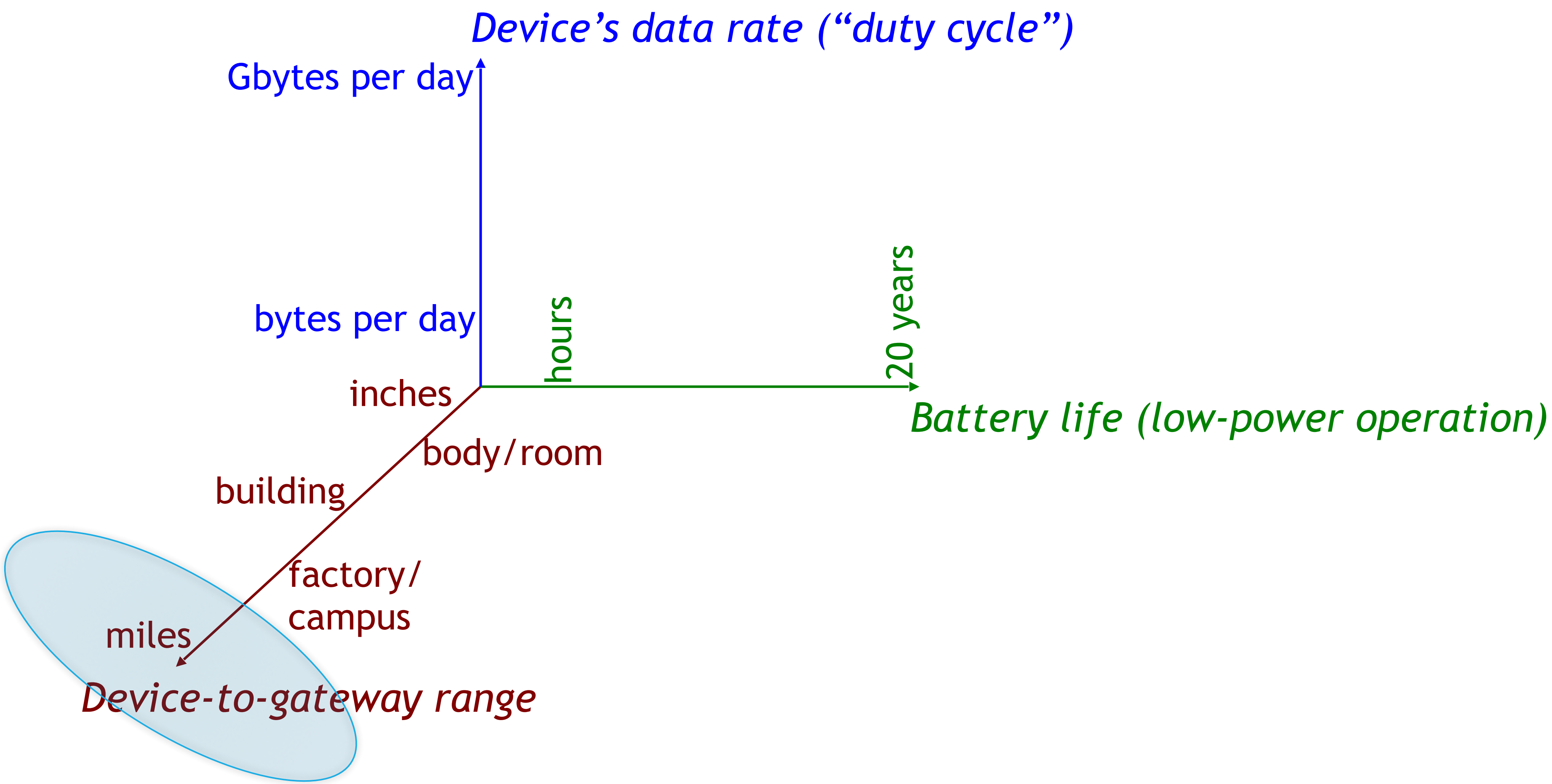
Is this a good idea? Will it work?

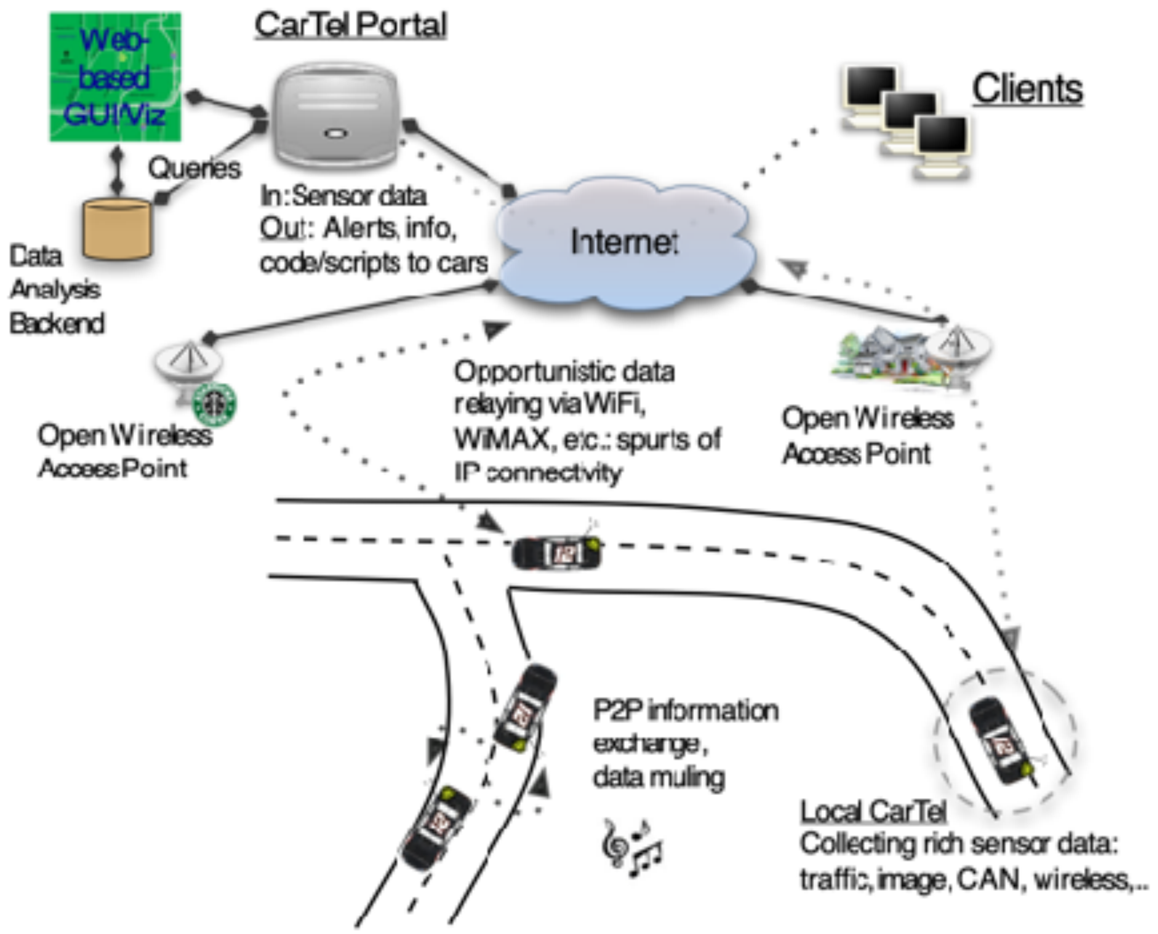
Value is in the data, not connectivity
Incentives are a problem

For device makers?
For app developers?
For smartphone users?

EVEN LONGER RANGE (CITY-SCALE)



WHEN THE INTERNET IS MILES AWAY



Use mobile devices as **data mules**

Trade-off: delay

Delay-tolerant network (DTN)

WHAT IF WE WANT LONG RANGE AND LOW DELAY?

"Long-range IoT networks"
Examples: Sigfox, LoRaWAN, cellular IoT proposals (narrowband LTE, etc.), 5G

Some of these are low-power designs (months to years of battery life)

Low or ultra-low throughput (a few bytes per day to achieve long-enough battery life at a rate of a few kbps)
Networks like LoRaWAN also include localization capabilities

These have seen growing deployment

WHAT IF WE WANT LONG RANGE AND LOW DELAY

Second choice: Cellular (of course!)
Examples: LTE/4G/5G, etc.

High-power consumption, so only when energy isn't an issue
Relatively high cost (>$10 per device today plus monthly usage cost)

Variable delay of cellular networks is still a concern for **data-intensive, latency-sensitive applications**

WHAT IS 5G? 6G?

"Unifying solution" offered by cellular providers

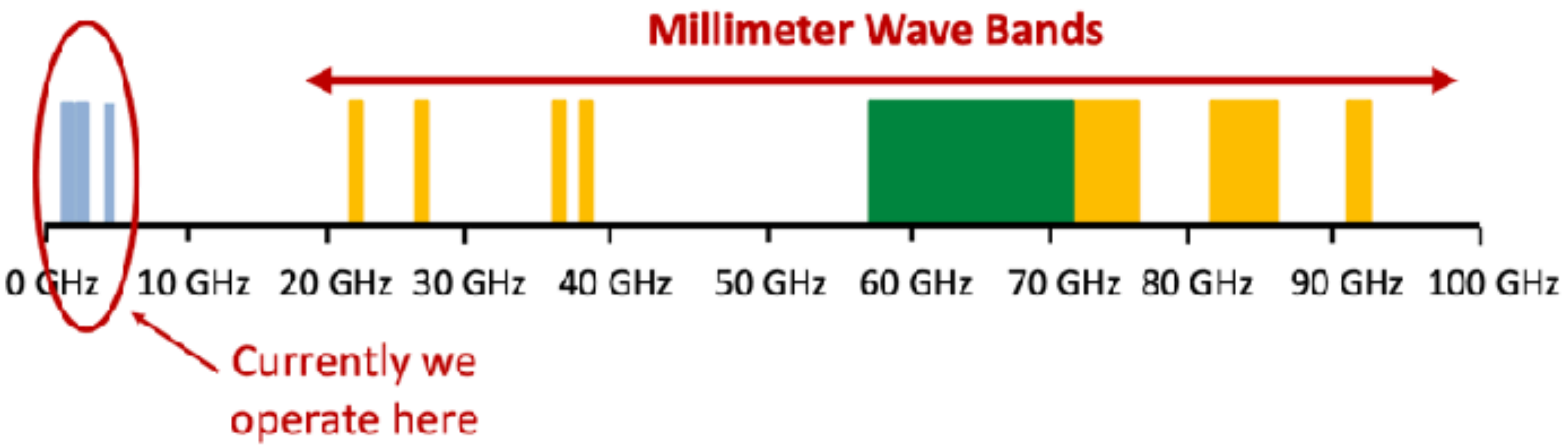
Usually means:

- higher speed
  - no significant difference between LTE & 5G
  - exception is millimeter-waves, which have seen slower adoption
- lower latency
  - e.g., safety critical applications; robotics; AR
- 6G also also joint comms + sensing (localization)

WHAT IS NEW IN 5G?

Millimeter Wave Technology

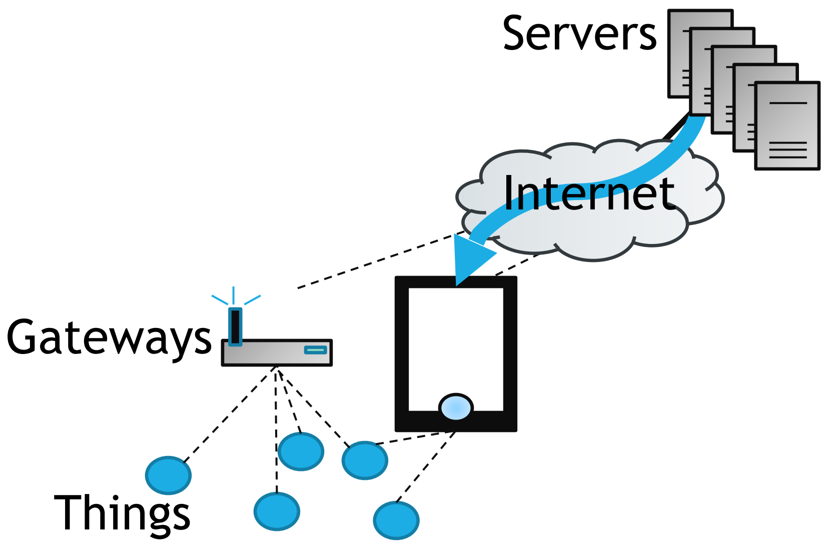
Huge bandwidth available at millimeter wave frequencies



Millimeter Wave can support data rates of multi-Gbps

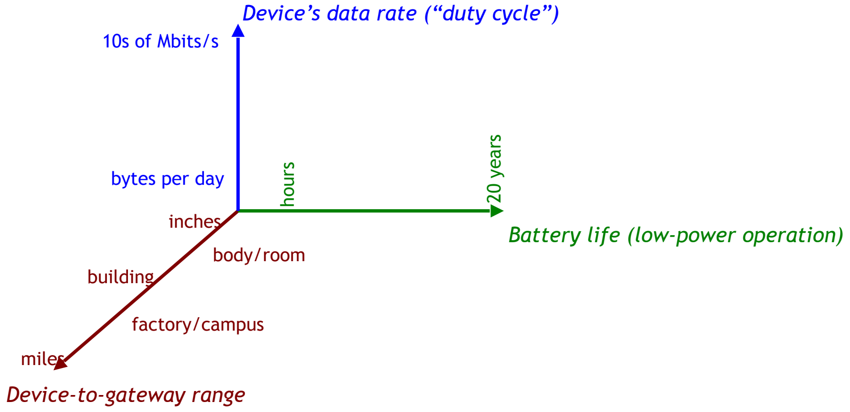
WHAT HAVE WE LEARNED?

Rich design space for things-gateway communication



Think along three dimensions:

1. data rate/duty cycle
2. battery
3. range



Examples:

1. Low-power design (Bluetooth LE): advertisement, time-scheduled MAC
2. Range extension techniques: muling & meshing (Zigbee, 6LoWPAN) [next lec]
3. Data-intensive IoT: continuous recognition [later in semester]

Objectives of the 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? **next lecture**
4. How does energy impact IoT device design? And how do batteryless IoT systems work?