Lecture 13
Introduction to LPWANs

CS397/497 – Wireless Protocols for IoT

Branden Ghena – Winter 2021

Northwestern

Today’s Goals

- Introduction to the Wide-area communication space
- Apply knowledge from the course to understand LPWAN design
- Overview of unlicensed-band LPWANs
  - LoRaWAN

Resources

- Sigfox
  - Sigfox Technical Overview
  - IETF Descriptions
    - https://www.ietf.org/proceedings/97/slides/slides-97-lpwan-25-sigfox-system-description-00.pdf
    - https://tools.ietf.org/html/draft-zuniga-lpwan-sigfox-system-description-04
- LoRaWAN
  - LoRaWAN Specification version 1.1
  - LoRaWAN Regional Parameters version 1.0.2

Outline

- **Wide-Area Network Background**
- Design an LPWAN
- Unlicensed LPWANs
    - LoRaWAN

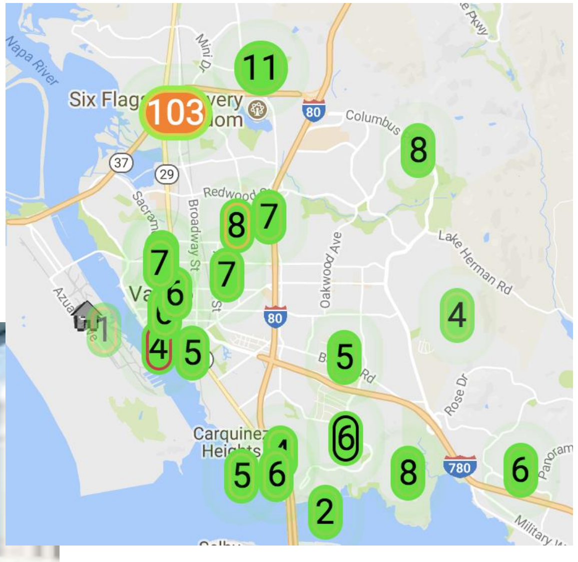
Wide area networks

- Communication at the region/city scale rather than the building/residence scale
  - Throughout cities
  - Agricultural deployments
  - Industrial facilities

- City-scale sensing is one very popular domain
  - What might we want to sense throughout a city?

Air quality monitoring

[2]



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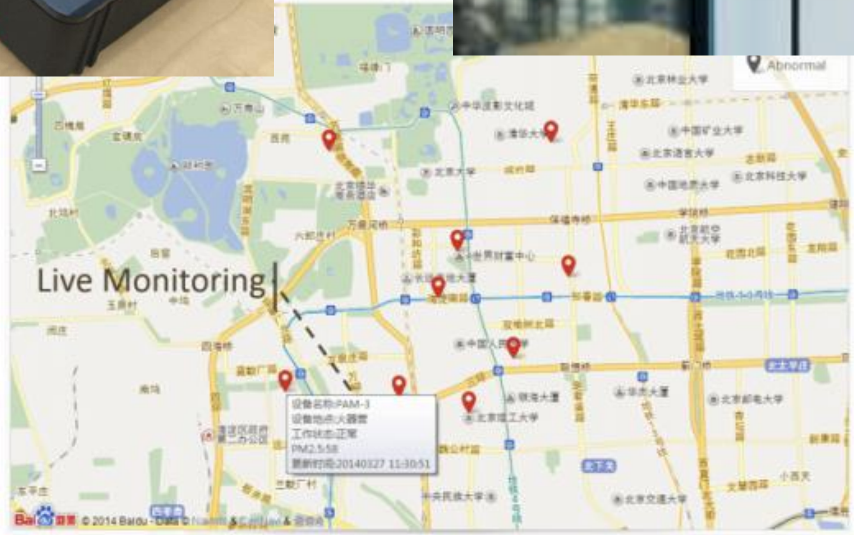

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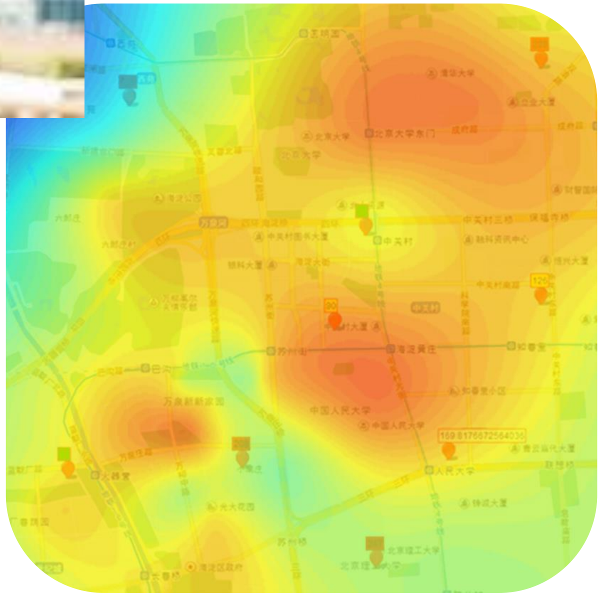
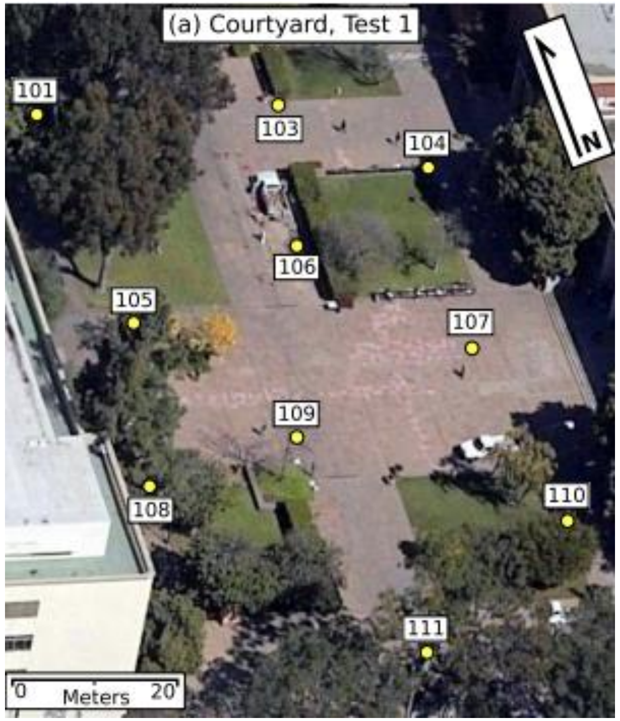


[1] Cheng et al. AirCloud: a cloud-based air-quality monitoring system for everyone. 2014.

[2] Purple Air. 2018.

Audio detection, classification, and localization



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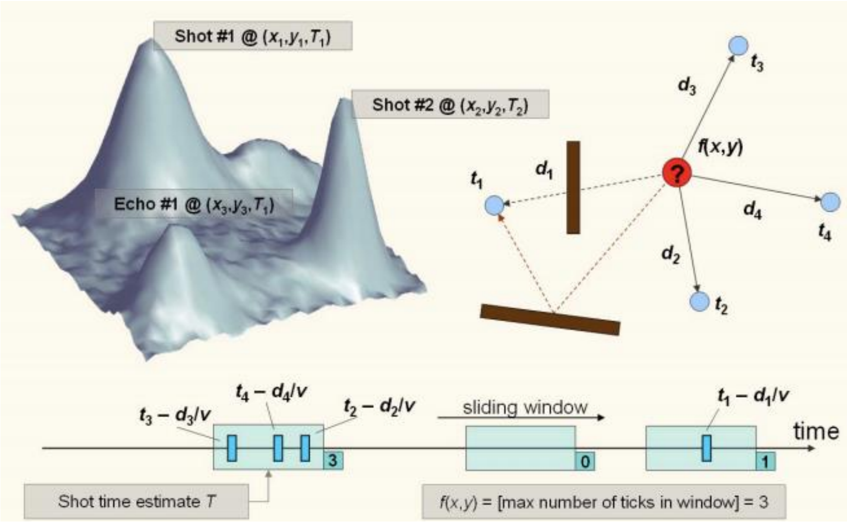

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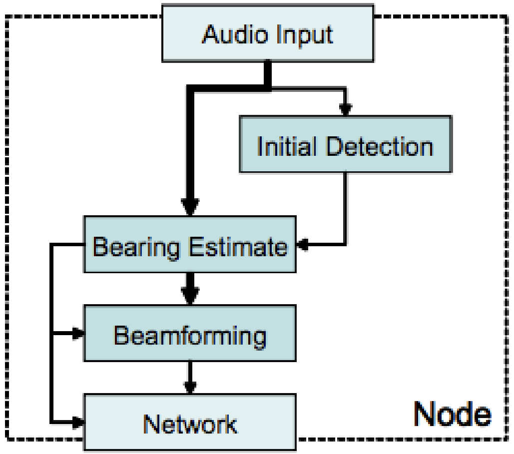

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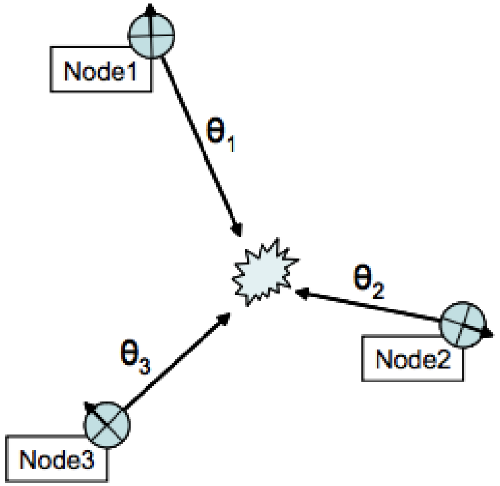
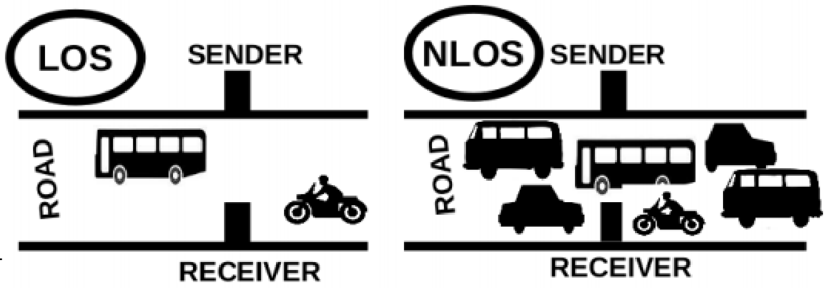


[1] Girod et al. The Design and Implementation of a Self-Calibrating Distributed Acoustic Sensing Platform. 2006.
[2] Lédeczi et al. Multiple Simultaneous Acoustic Source Localization in Urban Terrain. 2005.
[3] Sounds of New York City. 2016.

Traffic queue sensing and congestion control

[1]



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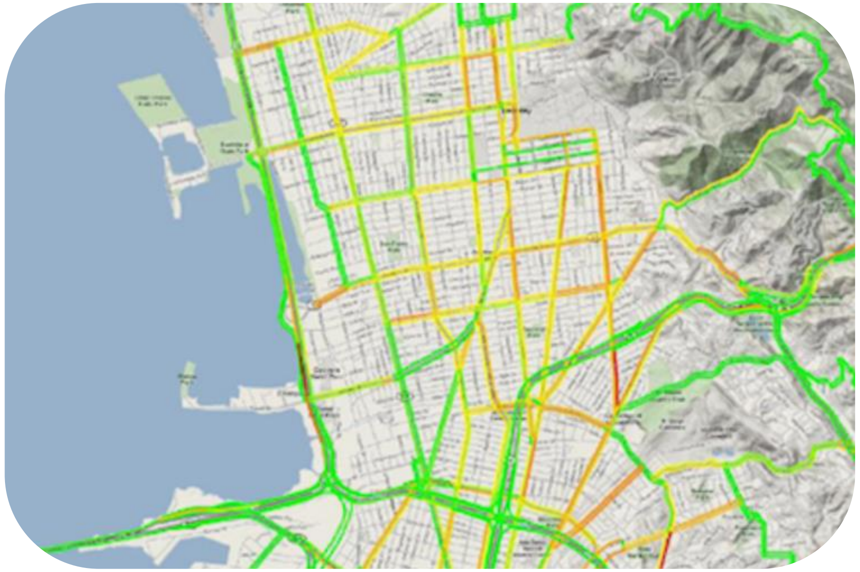

[1]

[1] Sen et al. Kyun Queue: A Sensor Network System To Monitor Road Traffic Queues, 2012

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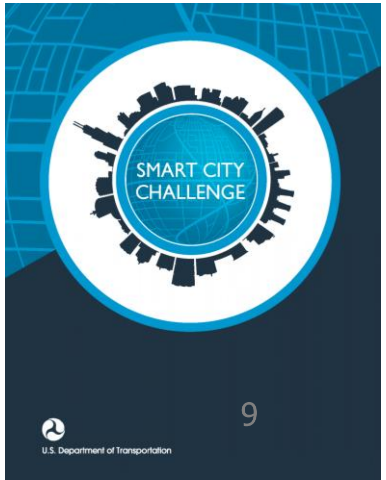


Smart Nation SINGAPORE

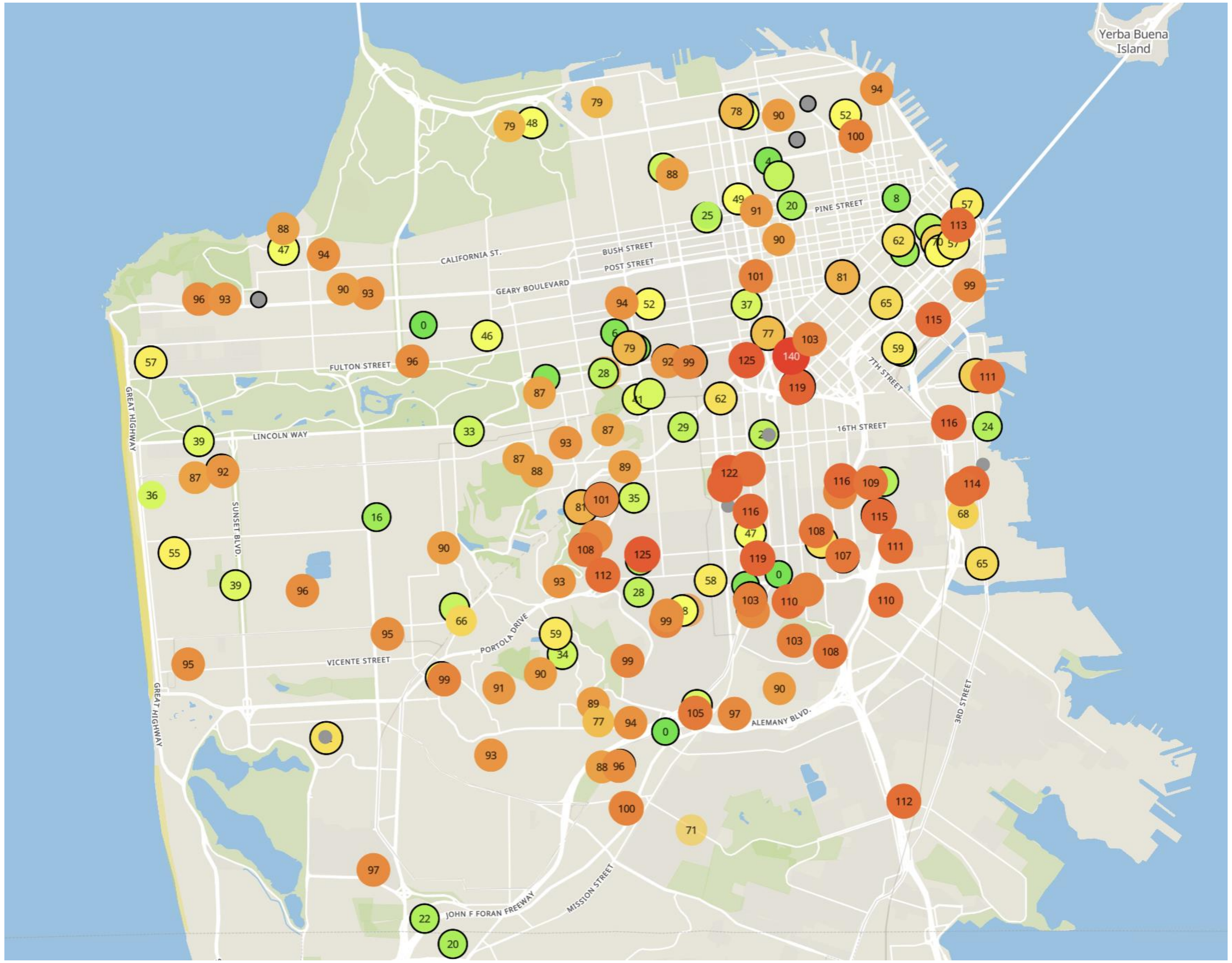
Many Smart Ideas • One Smart Nation

The City of SAN DIEGO

Example application: air quality monitoring

[1]

[2]



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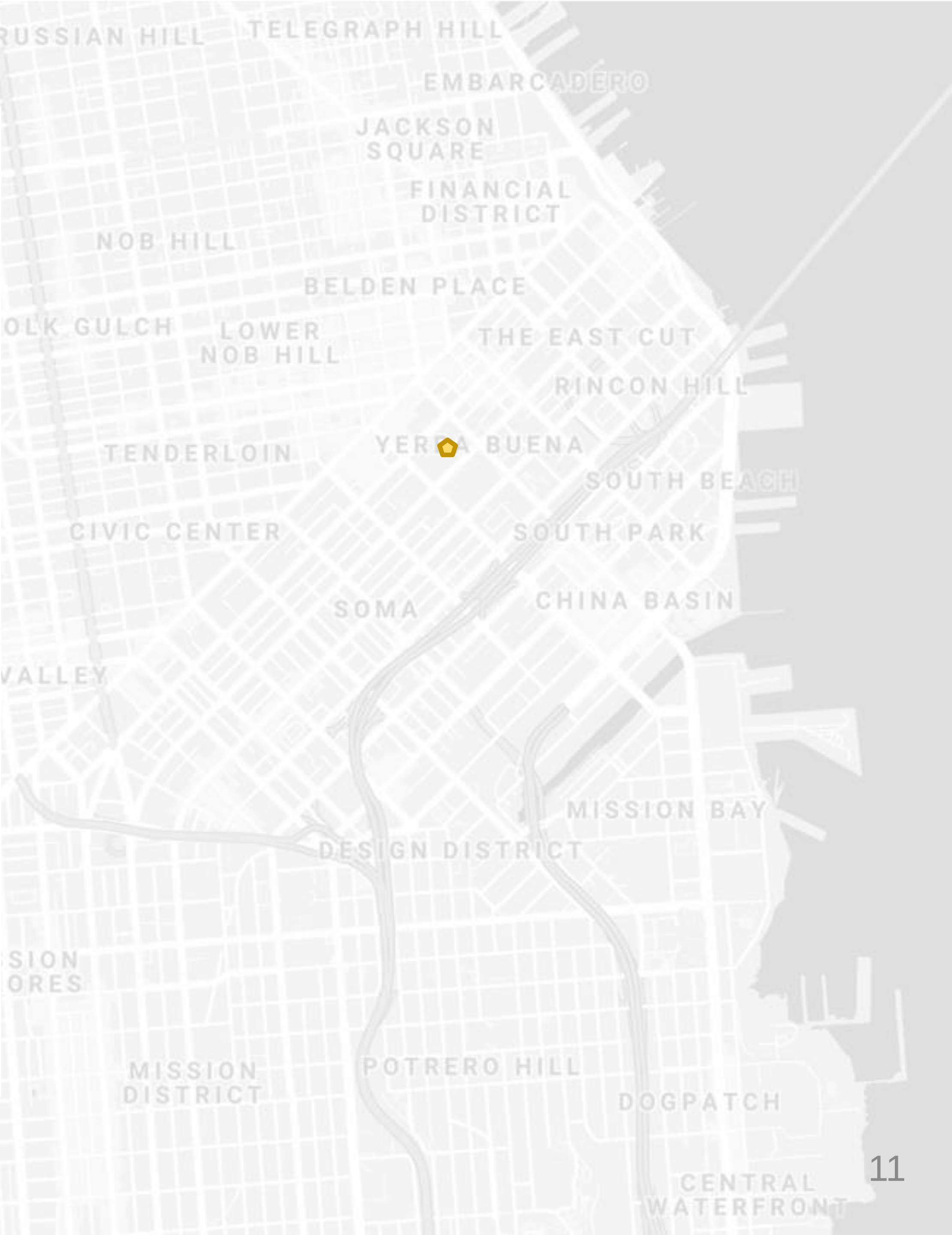
[1] Cheng et al. AirCloud: a cloud-based air-quality monitoring system for everyone. 2014. [2] Purple Air. 2019.

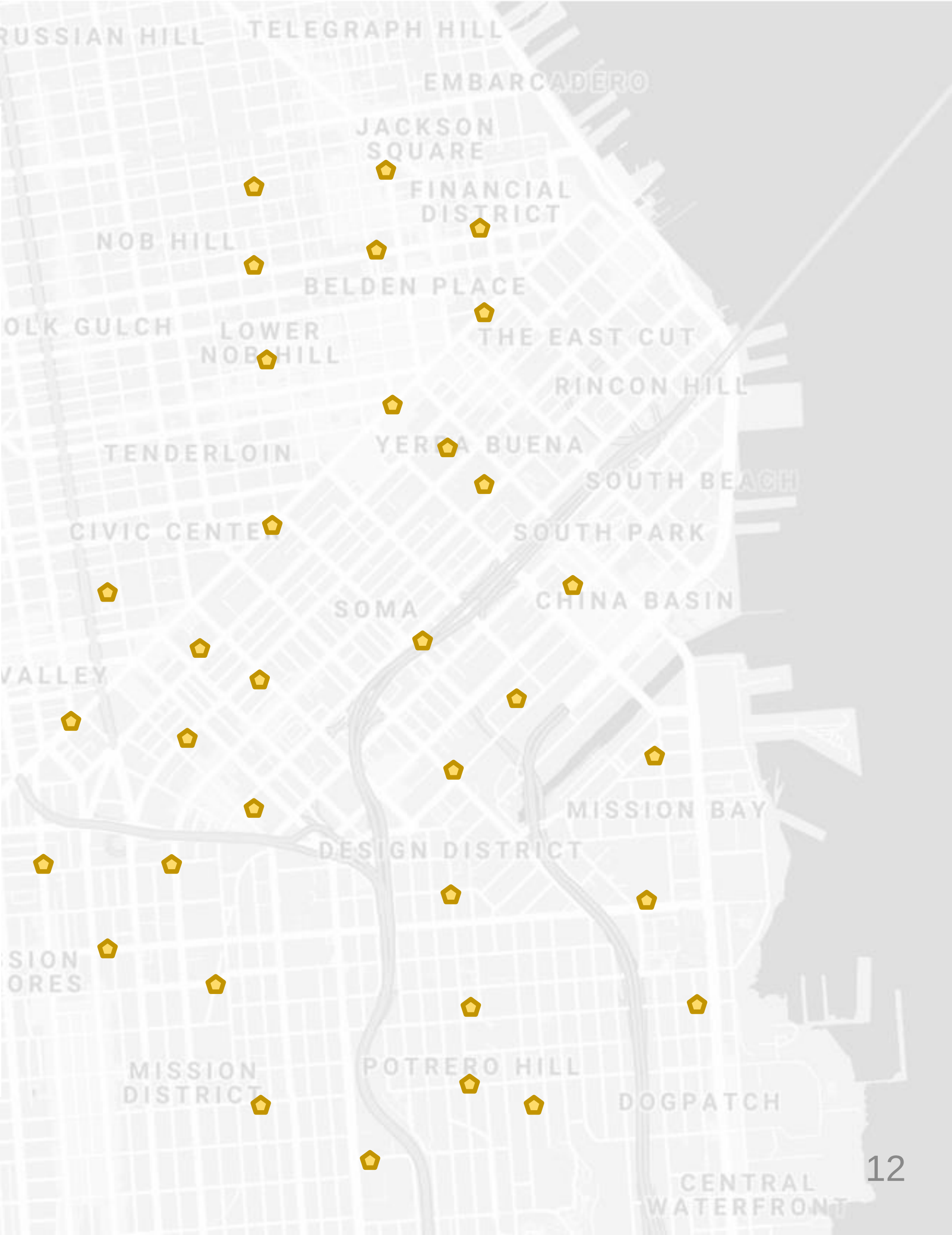
How do we collect data from a sensor?

- Manually collect measurements
- Connect it to WiFi (or Ethernet)
- Pay for cellular access



How do we collect data from MANY sensors?

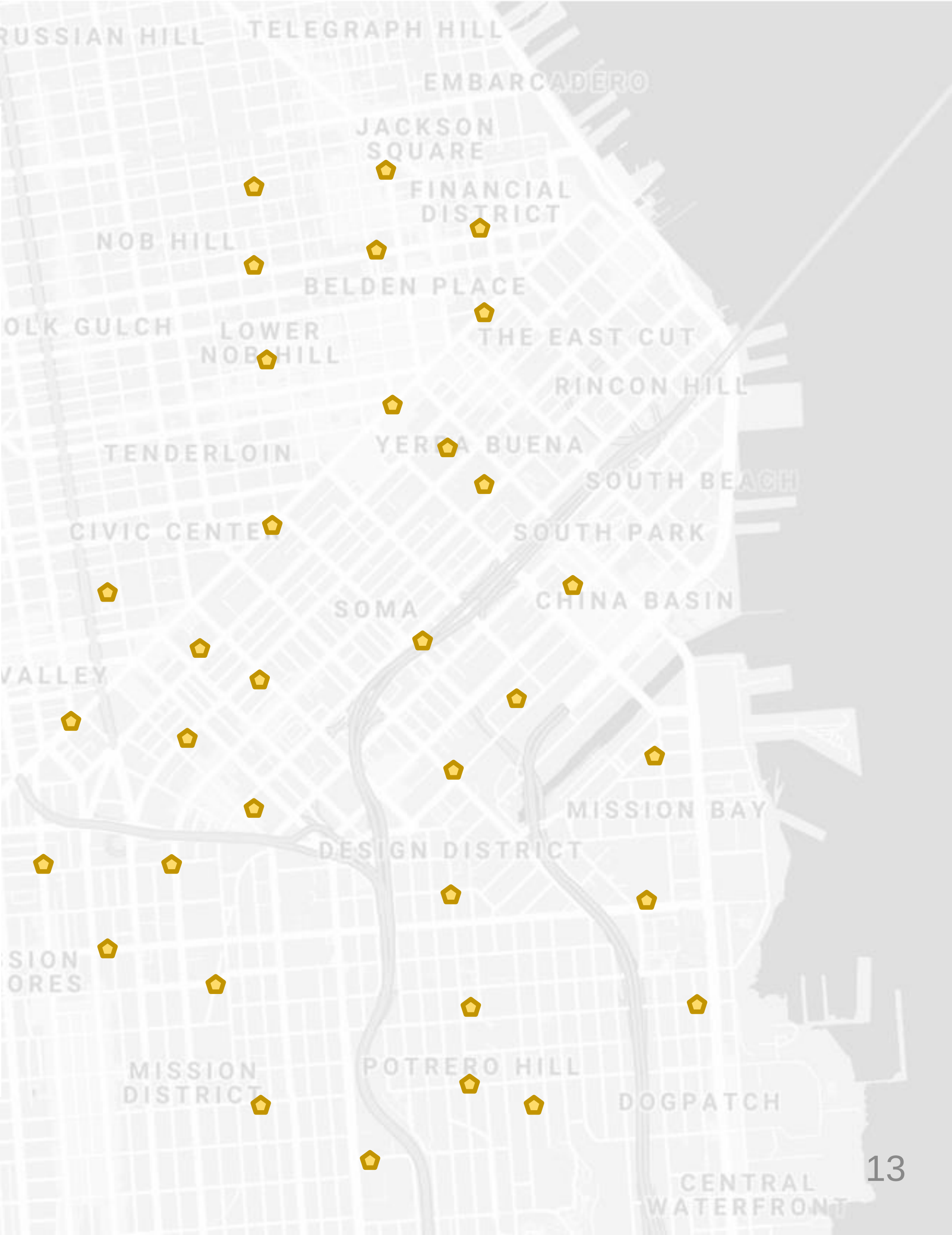
- Manually collect measurements
- Connect it to WiFi (or Ethernet)
- Pay for cellular access



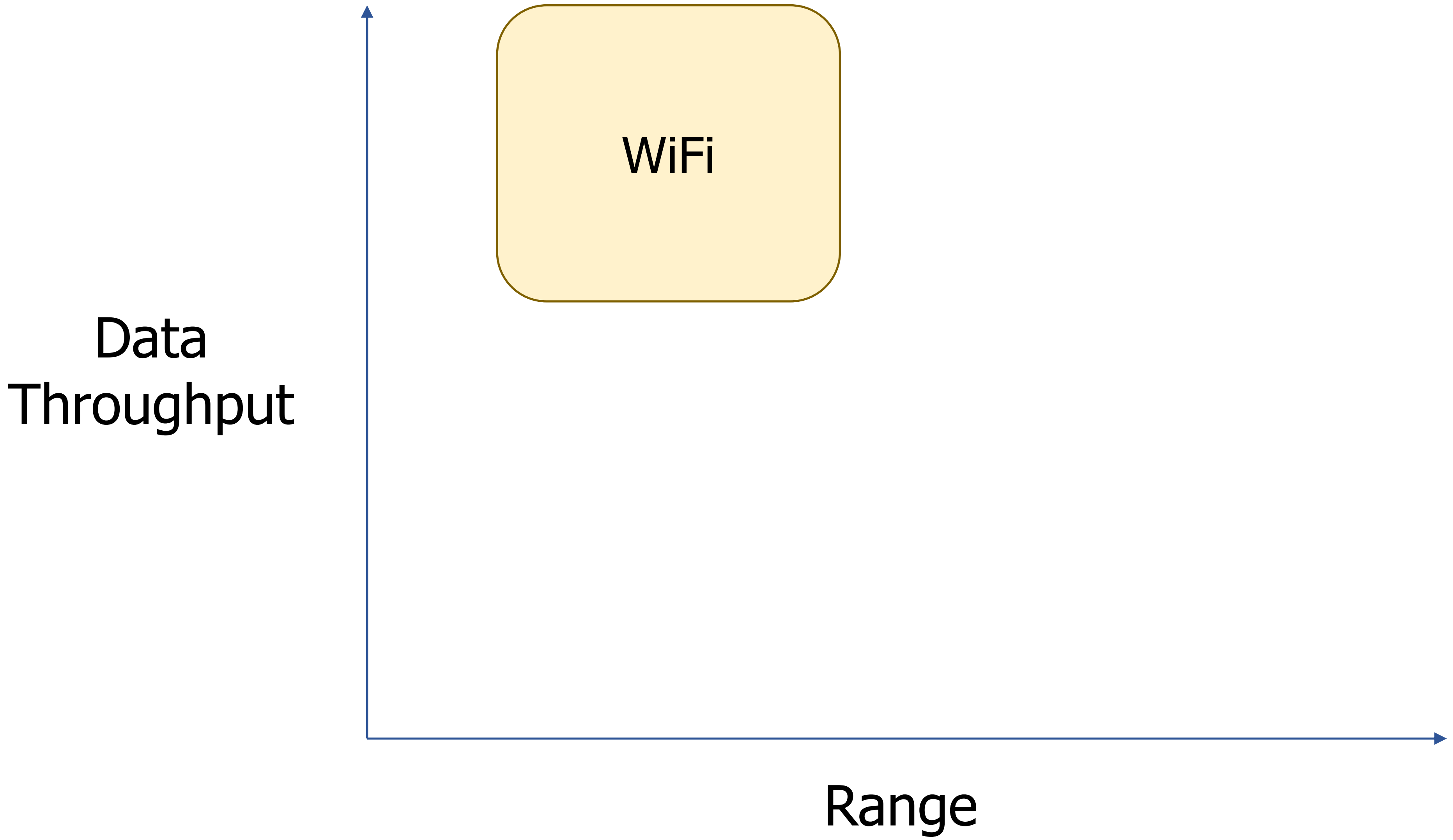
We need another network option

Requirements:

- Wide area of coverage
    - Deploy fewer gateways
- Low power
    - So we can deploy on batteries
- Doesn't need high throughput
    - Sensor data is relatively small



Long-range, low-data needs haven't historically been met



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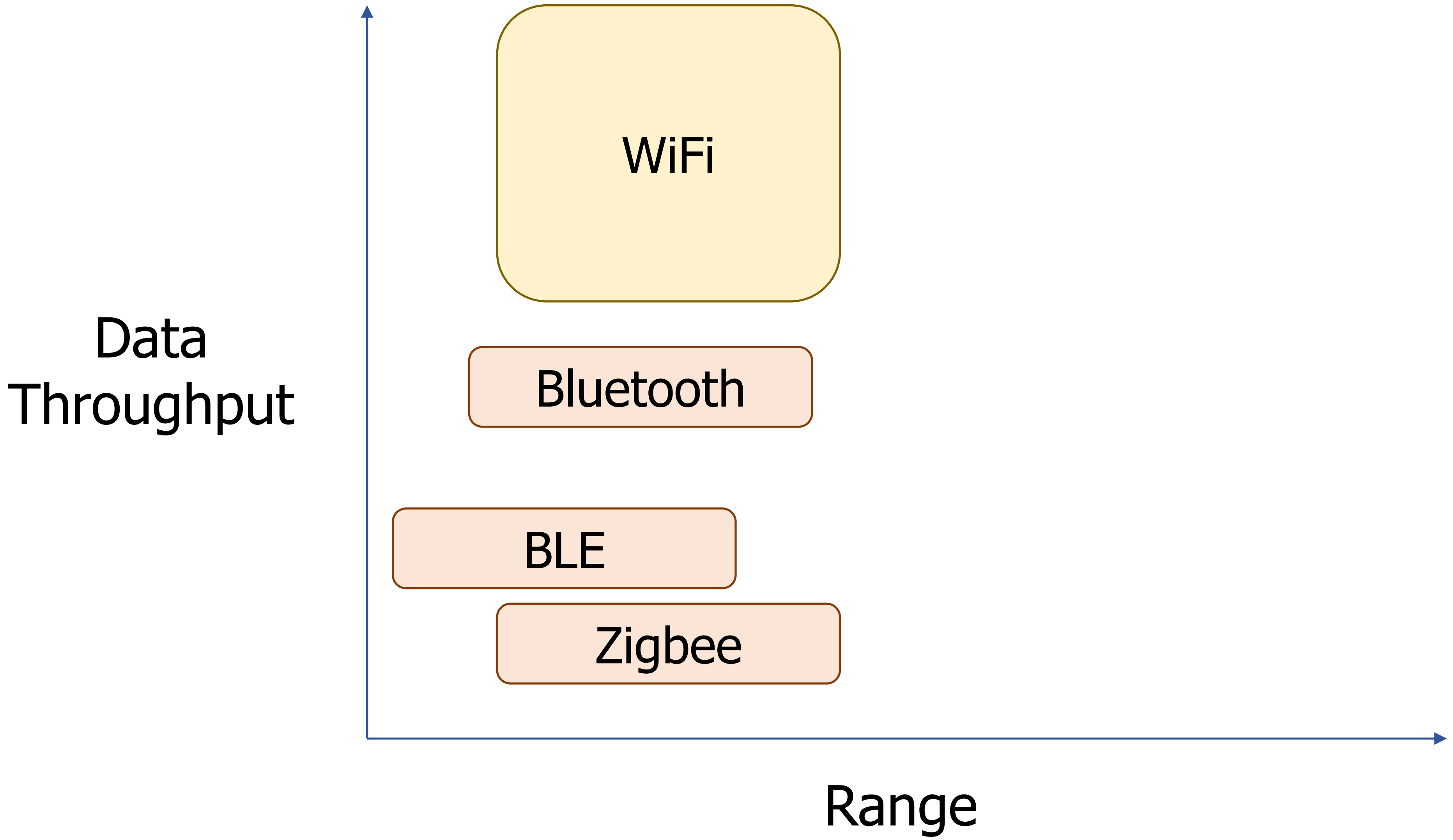

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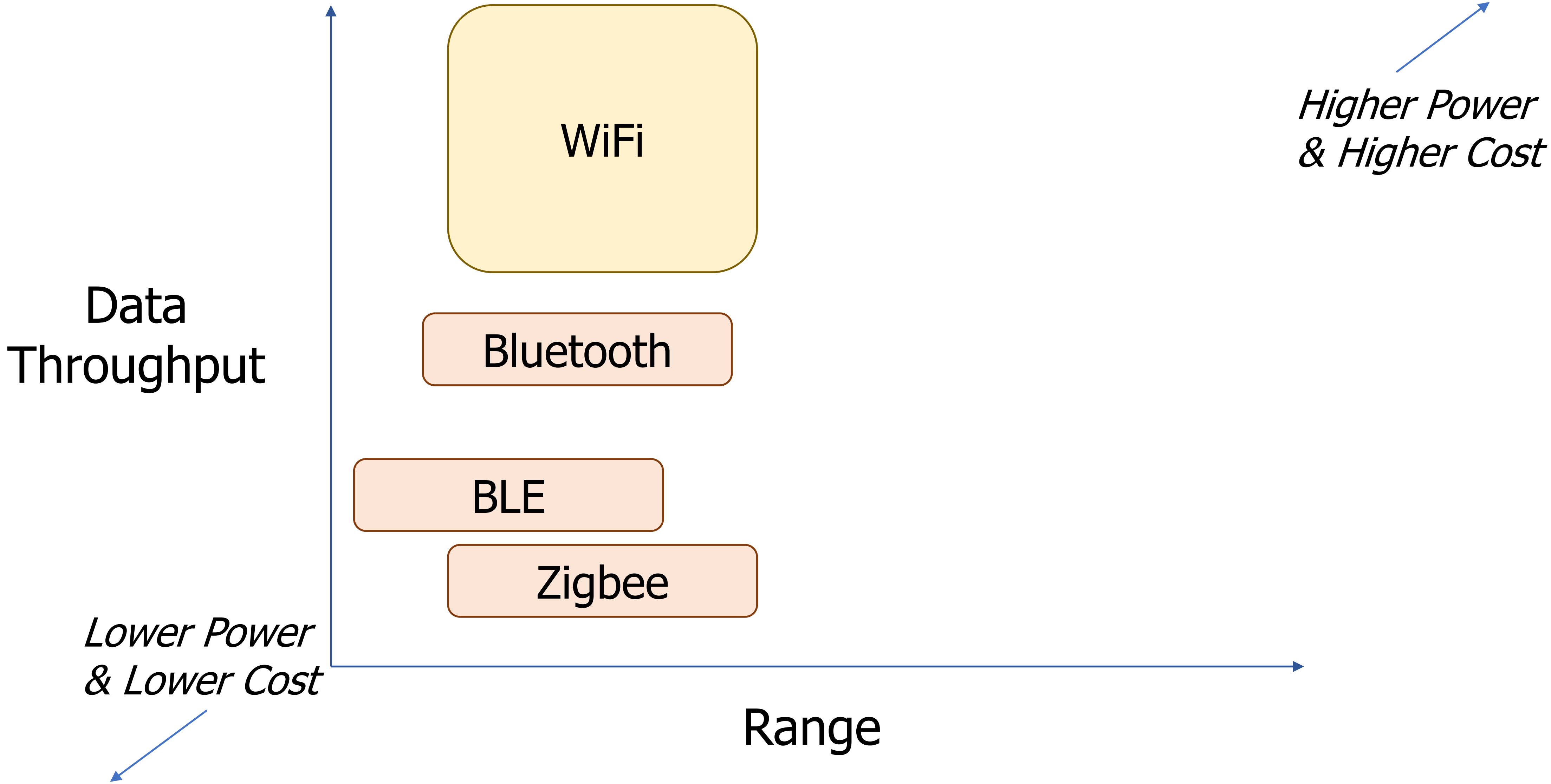

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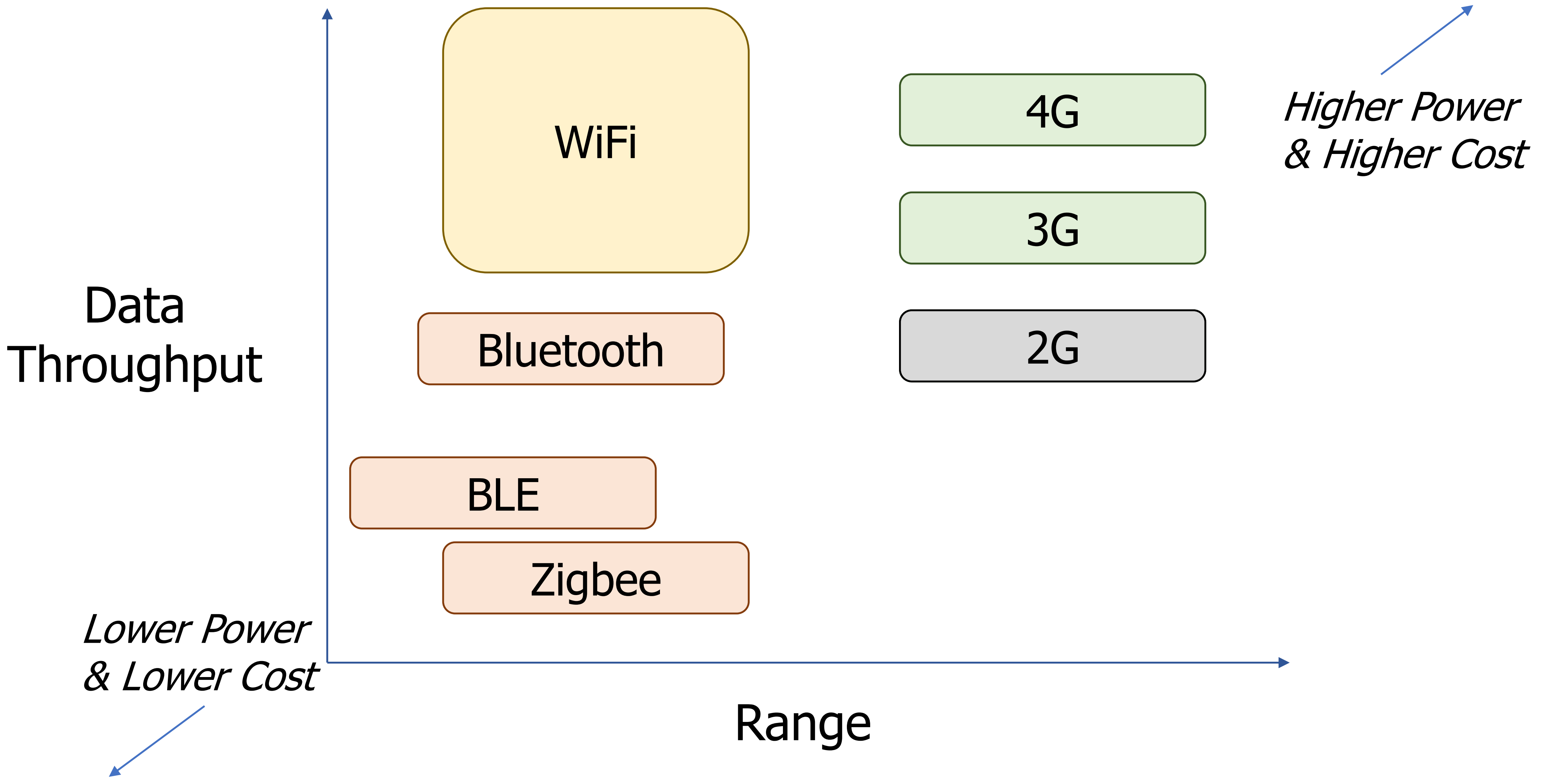

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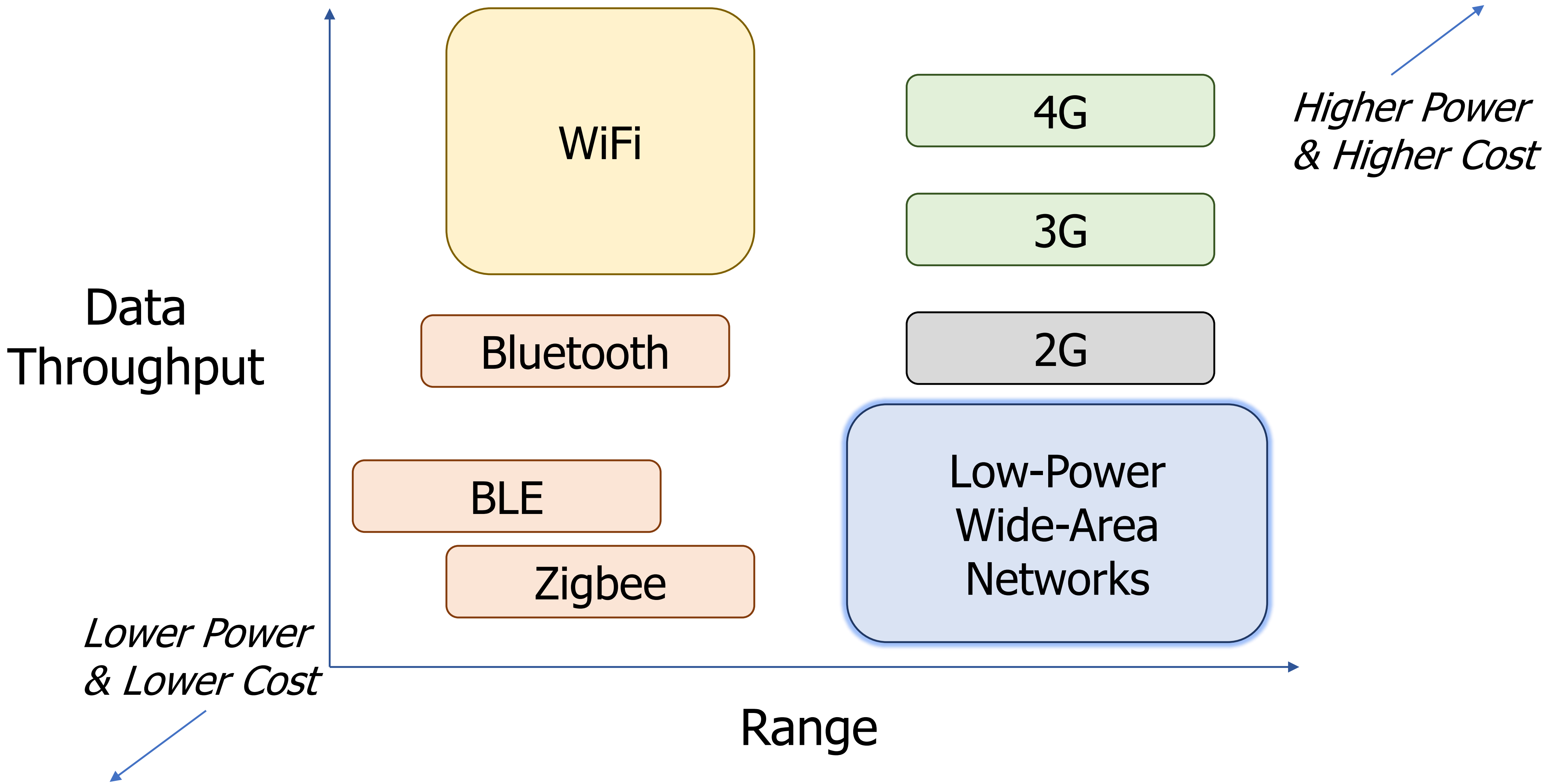

Outline

- Wide-Area Network Background
- **Design an LPWAN**
- Unlicensed LPWANs
  - LoRaWAN

Design a wide-area network (ignore low-power for now)

- **What PHY choices would you make?**

Design a wide-area network (ignore low-power for now)

- **What PHY choices would you make?**
  - Modulation
  - Tx Power
  - Carrier Frequency Band
  - Data Throughput
  - Channel Bandwidth

Design a wide-area network (ignore low-power for now)

- **What PHY choices would you make?**
  - Modulation
    - Unclear. Can't be too crazy for cheap devices.
  - Tx Power
    - High (much higher than 0 dBm)
  - Carrier Frequency Band
    - Low (something lower than 2.4 GHz, 915 MHz or lower?)
  - Data Throughput
    - Low (much lower than 1 Mbps)
  - Channel Bandwidth
    - Unclear. Likely smaller for lower frequency carrier.

Design a low-power wide-area network

- **Any particular MAC choices for lower power?**

Design a low-power wide-area network

- **Any particular MAC choices for lower power?**
  - Diversity of devices in network
    - High power gateway, low power devices in star topology
  - Devices should be off whenever possible
    - Listen-after send for downlink
  - Remove requirements for synchronization
    - No TDMA access control if it can be avoided
    - Aloha, ~~CSMA~~

Long-range CSMA is problematic

- Long-range makes everything more challenging
  - Kilometers of range mean kilometers between devices
- Detection of channel use is less reliable
  - Active research in clear channel assessment for LPWANs
- Hidden terminal problem has a wider range
  - Might make RTS/CTS more important
- Result: CSMA doesn’t dominate LPWANs like it does WLANs

LPWANs overview (common qualities)

- Unlicensed 915 MHz band (902-928 MHz)
- Higher power transmissions: ~20 dBm (100 mW)
- Low data rate 100 kbps or less
- Range on the order of multiple kilometers
- Simple Aloha access control

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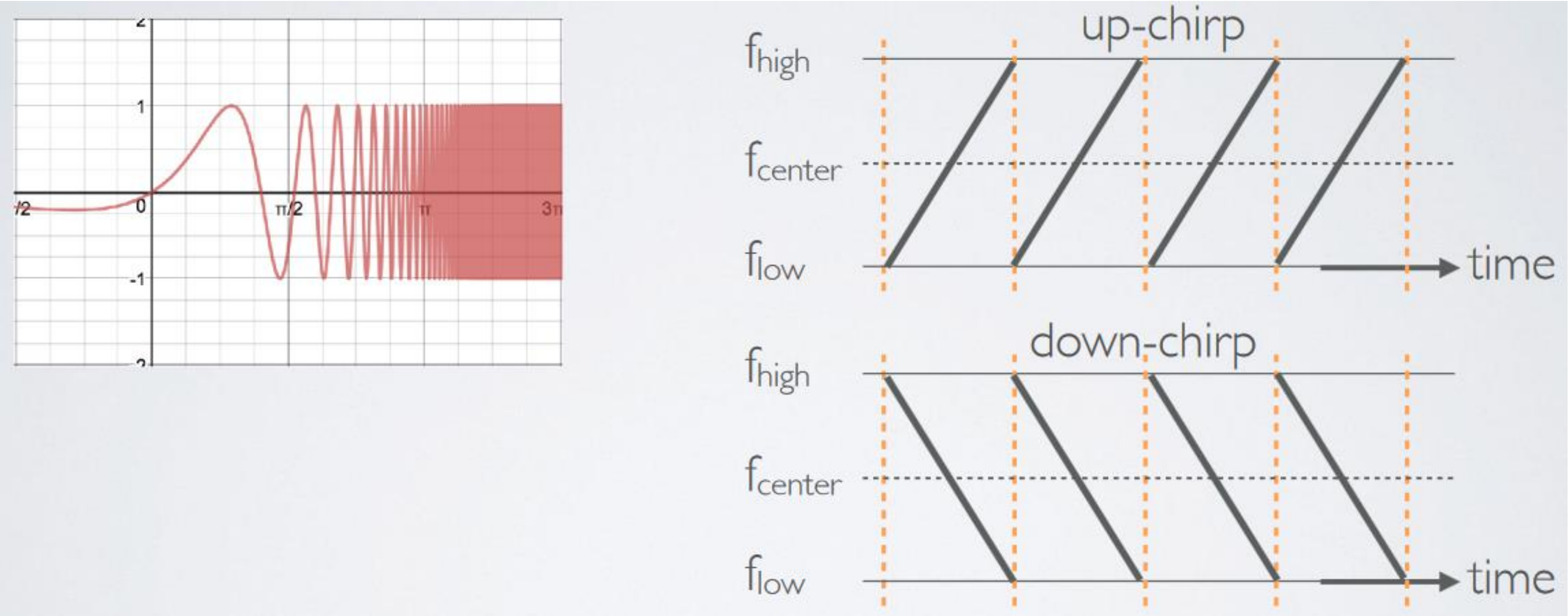
LoRaWAN

- Open communication standard built with proprietary LoRa PHY
- Low rate (1-20 kbps) and long range (~5 km)
  - Shorter range than Sigfox but much higher bit rate
- Most popular LPWAN protocol
  - Target of academic research
  - Industry involvement in hardware and deployments

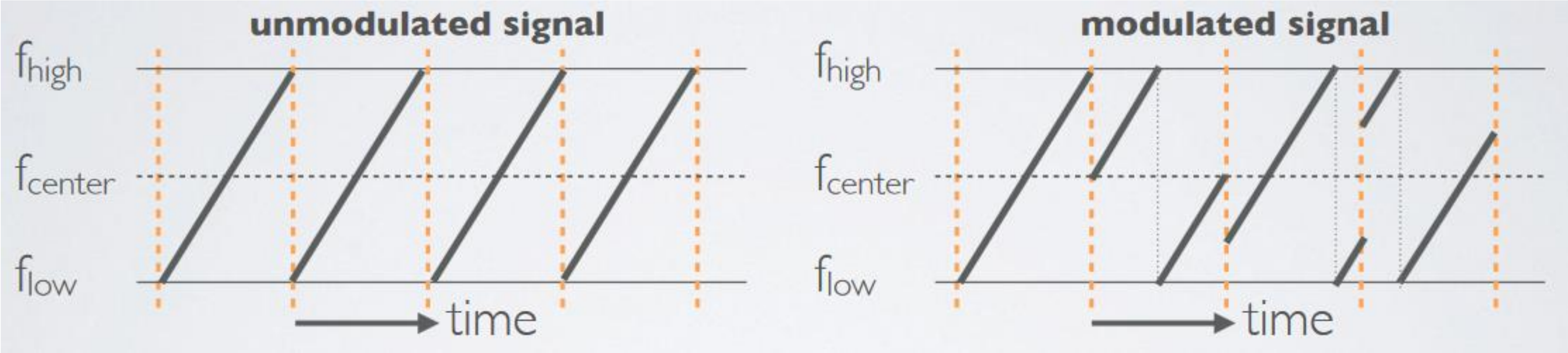
LoRa PHY uses a different modulation

- Chirp Spread Spectrum (CSS)
  - Modulation technique where frequency is varied linearly from lowest to highest within a channel



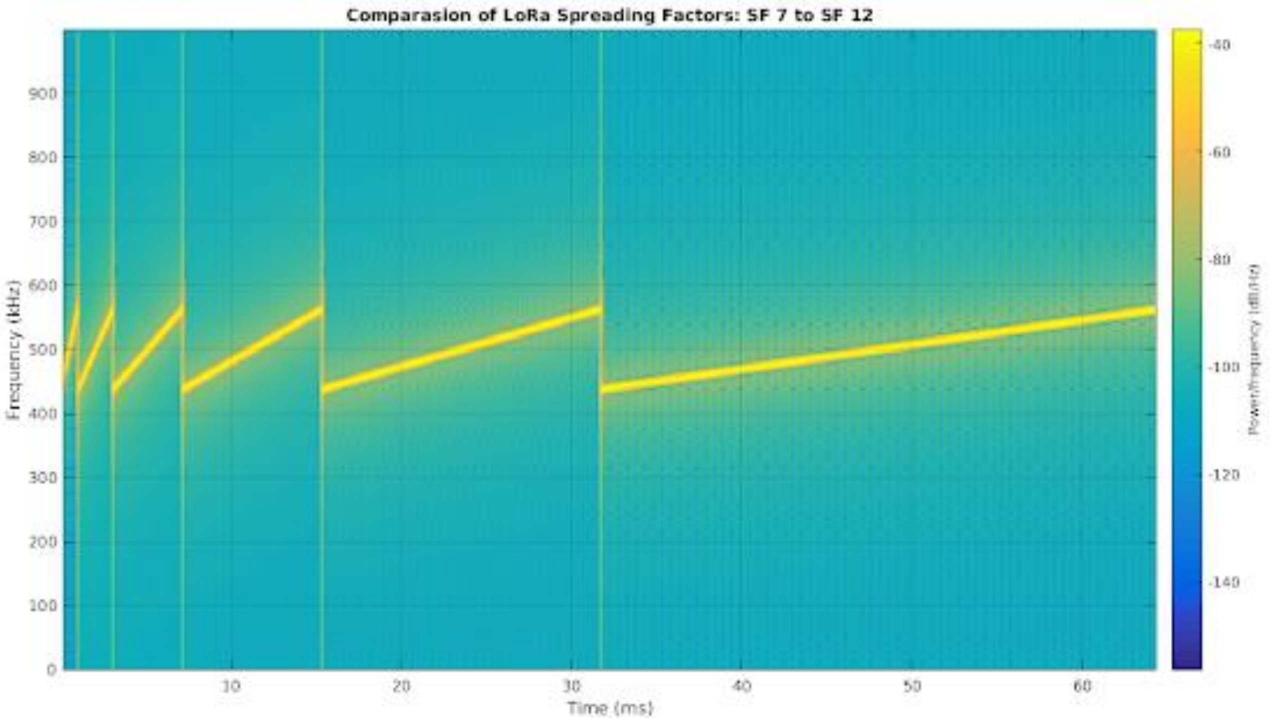
Chirp Spread Spectrum

- Data is modulated in the starting and ending points of chirp
  - Frequency increases linearly, modulo bounds of the channel

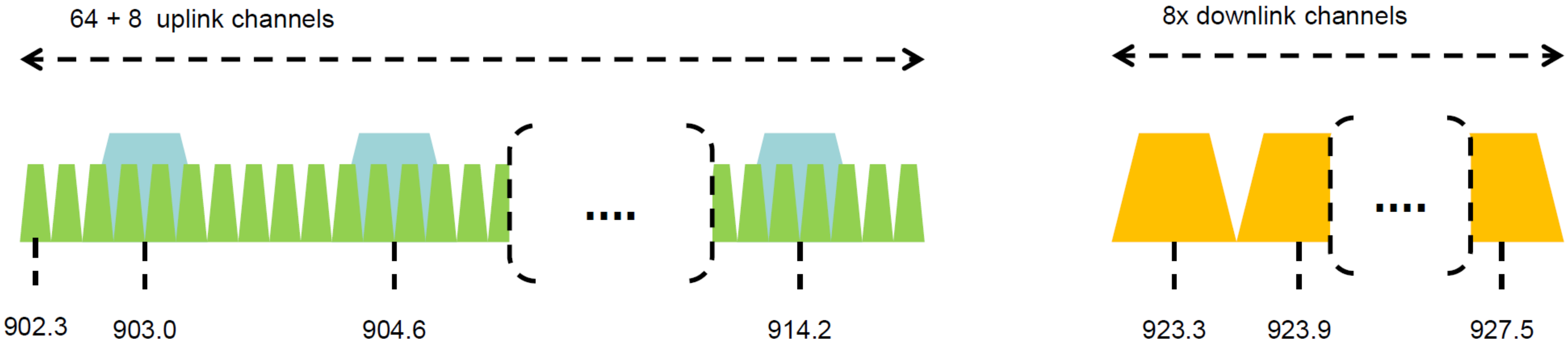


CSS has a Spreading Factor which determines bit rate

- Spreading Factor is essentially the rate-of-change of frequency
  - Slope of the line
  - Lower values of spreading factor (steeper slope) are faster data rate
- Important: different spreading factors are (mostly) orthogonal!
  - Two can overlap in time, space, and channel without a collision



LoRaWAN channels



- Sixty-four, 125 kHz uplink channels
  - Frequency Hopping over the 64 uplink channels
  - Plus eight, 500 kHz overlapping uplink channels (not well used in practice)

- Eight, 500 kHz downlink channels

LoRaWAN gateways

- No synchronization with end devices

- Instead listen to entire bandwidth simultaneously
  - Only 12 MHz total
  - Recognize preambles and allocate a hardware to decode packet
    - Normal gateways: 8 decoders
    - Good gateways: 64 decoders

LoRaWAN data rates

- Data rate options depend on channel in use
  - Unbalanced uplink and downlink
- 64-channel uplink
  - 1-5 kbps data rate
- Allowable rates based on dwell time restriction (400 ms)

Data Rate Index	**Spreading Factor**	**Bit Rate**
125 kHz Uplink Rates		
0	SF10, 125 kHz	980 bps
1	SF9, 125 kHz	1760 bps
2	SF8, 125 kHz	3125 bps
3	SF7, 125 kHz	5470 bps
500 kHz Uplink Rates		
4	SF8, 500 kHz	12500 bps
500 kHz Downlink Rates		
8	SF12, 500 kHz	980 bps
9	SF11, 500 kHz	1760 bps
10	SF10, 500 kHz	3900 bps
11	SF9, 500 kHz	7000 bps
12	SF8, 500 kHz	12500 bps
13	SF7, 500 kHz	21900 bps

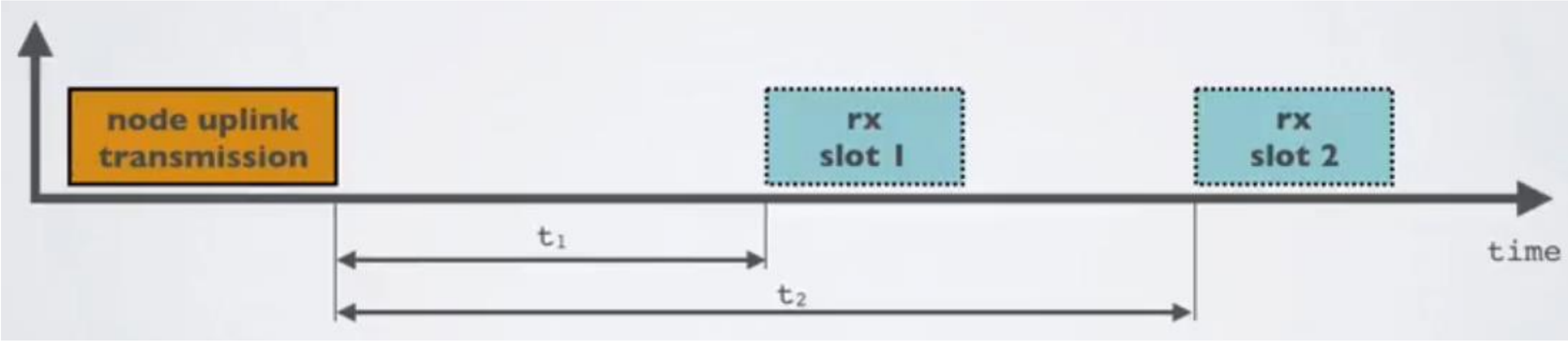
LoRaWAN link budget

- Typical TX power 20 dBm
  - Up to 30 dBm for 64-channel hopping
  - Up to 26 dBm for 8-channel hopping
- Receive sensitivity -119 dBm
  - Compare to -100 dBm for 802.15.4 and -95 dBm for BLE
- Resulting range is about a kilometer in urban environments

LoRaWAN MAC

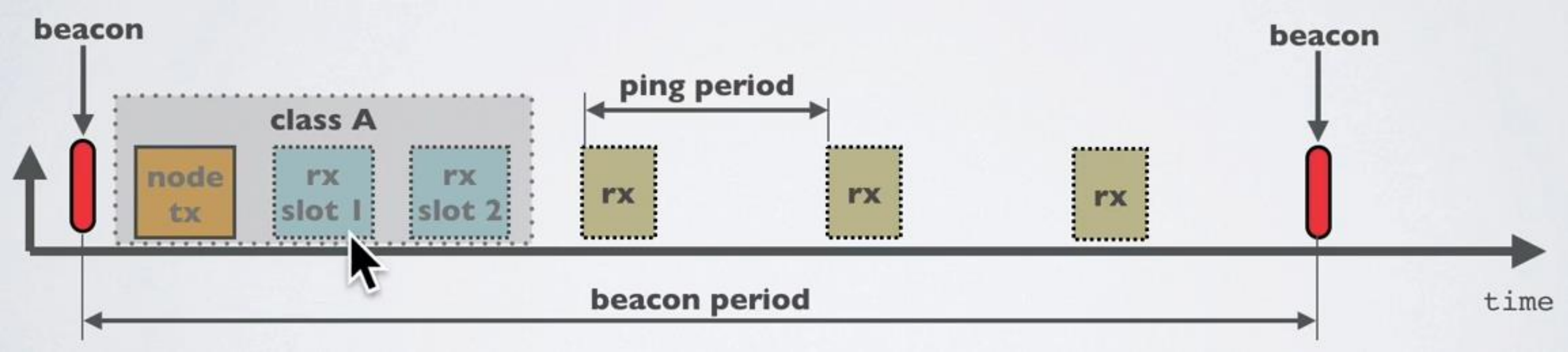
- Uplink: Aloha - transmit whenever
  - Randomly split across 64 uplink channels (reduced odds of collision)
  - Devices a different spreading factors also do not collide
  - Packets are very long though: up to 400 ms in duration

- Downlink: listen-after-send (class A device)
  - Two windows for RX on different channels



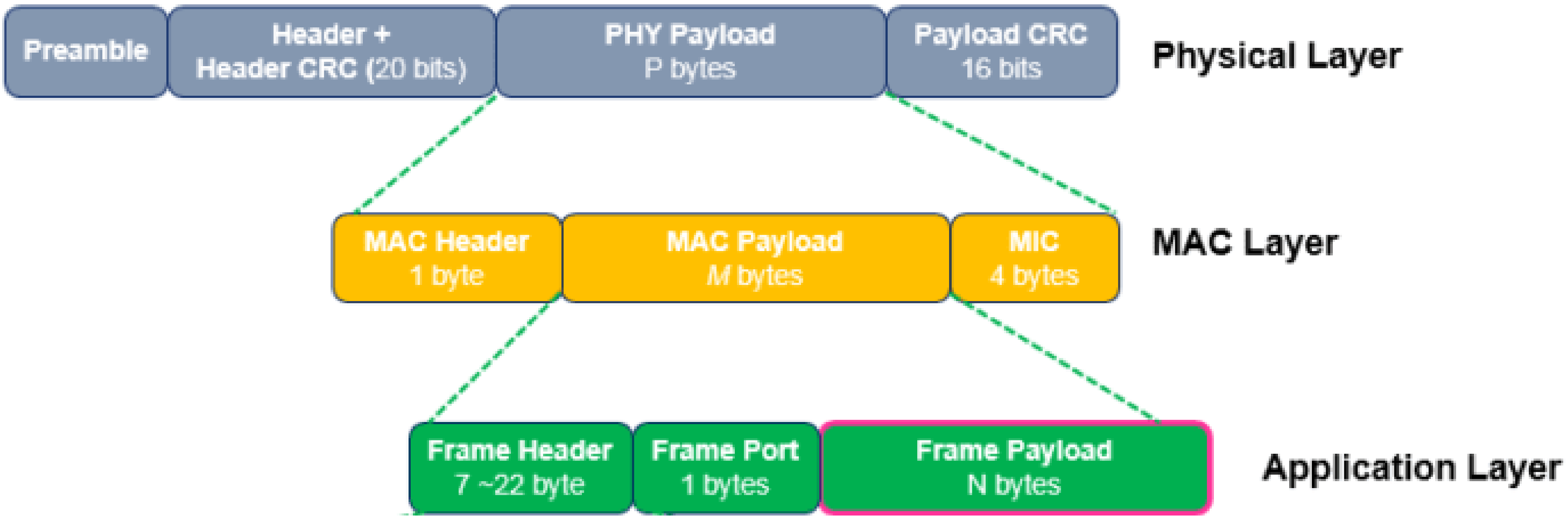
Optional downlink mechanisms

- Periodic listening (class B device)
  - Synchronized with periodic beacons
    - TX still unsynchronized Aloha
  - Mostly unused



- Continuous listening (class C device)
  - Always-on receivers

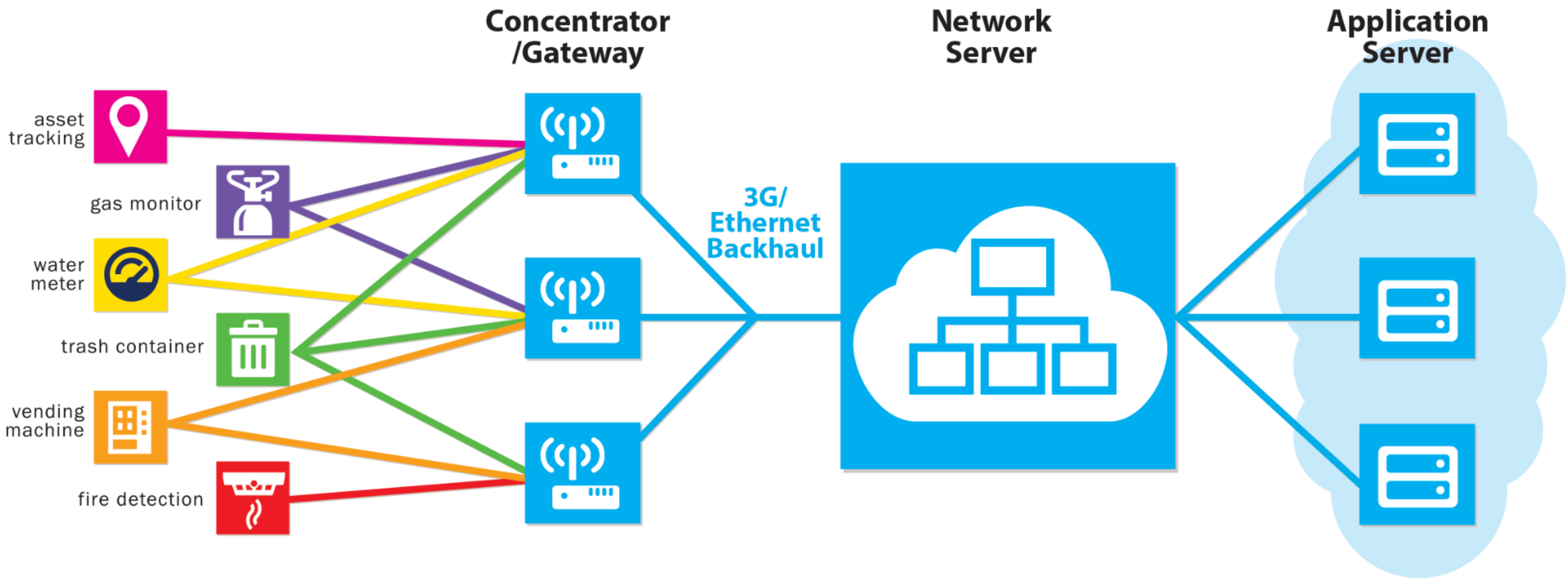
LoRaWAN packet format



- Frame header includes device address
- MAC Payload maximum size depends on data rate
  - Again based on dwell time in the US

Data Rate Index	MAC Payload Size
0	19 bytes
1	61 bytes
2	133 bytes
3	250 bytes
4	250 bytes

LoRaWAN network details



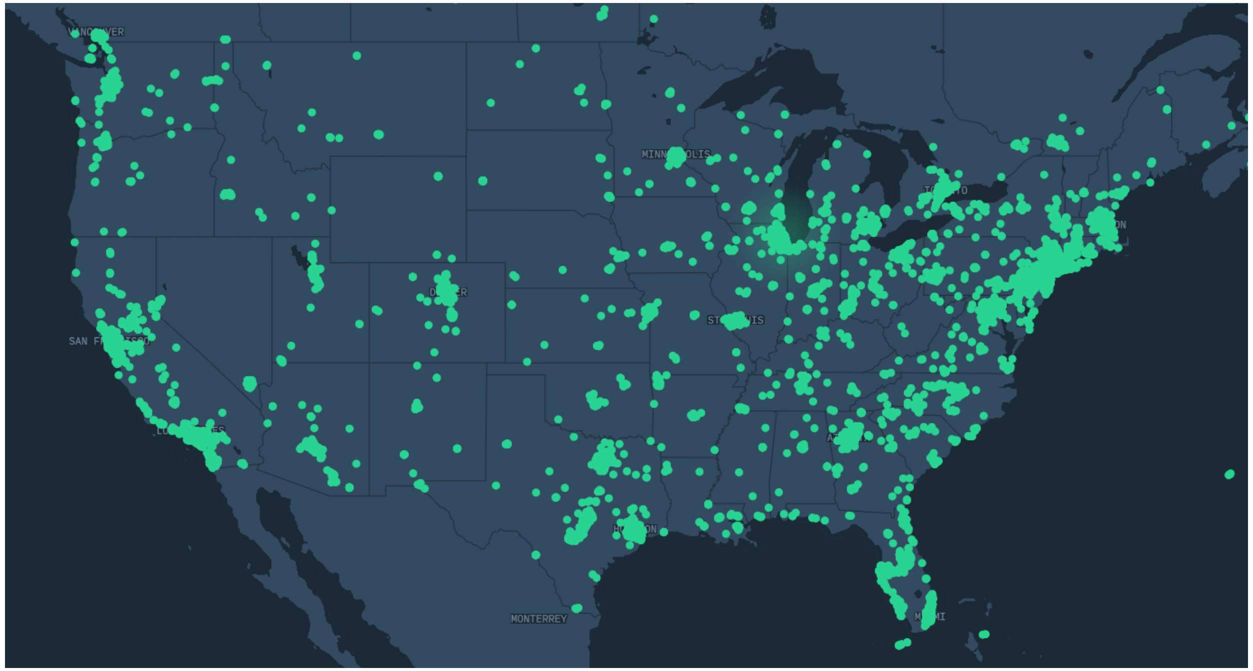
LoRaWAN hardware

- Numerous hardware modules and development kits
  - Almost all use Semtech radio chips (Semtech owns LoRa PHY)

- Recent addition: STM32WLE5 LoRa SoC
  - Cortex-M4 + LoRa radio (analogous to nRF52840)

LoRaWAN network providers

- Somewhat-managed network providers
  - The Things Network (predominantly in Europe)
  - Helium
    - Any can buy and install their own gateway, which serves everyone
    - Microtransactions to pay for communication



LoRaWAN interested parties

- MachineQ is a subsidiary of Comcast providing LoRaWAN networks

- Long-term goal
  - Indoor-to-outdoor LoRaWAN gateways combined with WiFi
  - Tune down power for 100-200 meter range

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