OpenChirp
A Low-Power Wide-Area Networking Architecture

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City-Wide Sensing Applications

Infrastructure Monitoring

Flooding

Air quality

Volcano!

- Large number of sensors
- Hard to reach
- Wireless + harvesting or battery-powered
- Small amount of data

Existing Radios Don't Fit

- Limited Range
  - Bluetooth (~100 m)
  - 802.15.4 (~100 m)
- High power consumption
  - Wi-Fi (>500 mW)
- Optimized for mid-to-high data rates:
  All (>100 Kbit/s)

Cellular

- 2G is being phased out

~~2G~~ → 3G, LTE

- New protocols (3G, LTE)
  - Expensive hardware
  - Power-hungry
- Licensed spectrum
- Contracts

Ramiro Roman (http://littlezotz.com/)

For low power, low data-rate devices the last hop is still a problem!

Low-Power Wide-Area Networking (LPWAN)

sigfox

802.11ah HaLow

LoRa™

Bluetooth® 5

DASH7

LTE-M

NB-IoT

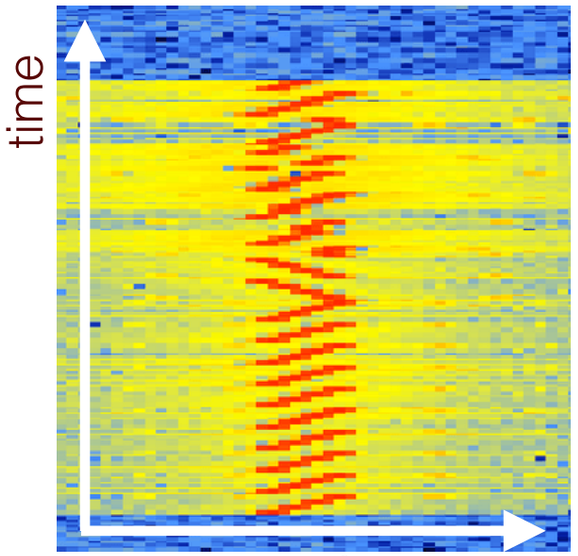
INGENU

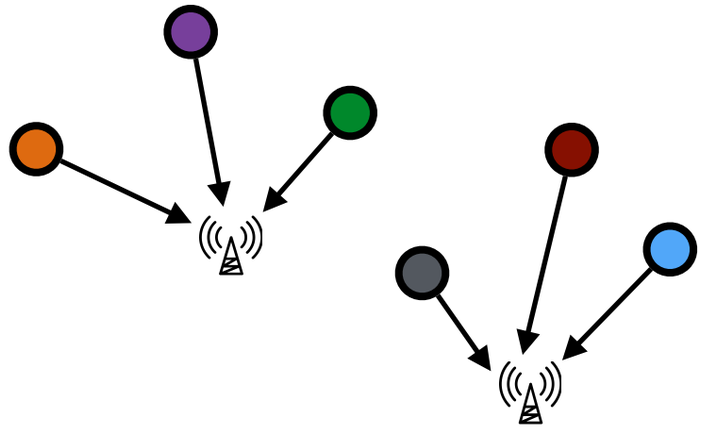
WEIGHTLESS™

- Compromise **low data rate** (e.g. Sigfox: 100 bits/s) for **long range** (>15 km)
- High penetration (using sub-GHz frequencies)

LoRa™

- LPWAN technology by Semtech (2014)
- Open Specification (PHY reverse engineered[1])
- Chirp Spread-Spectrum on 900 MHz ISM band
- Optimized for *asymmetric star topologies*
  - Low-power end-devices
  - Powerful base-stations
- Base-stations can *simultaneously listen* on multiple channels (frequency + coding)
- *Anyone* can deploy a base-station

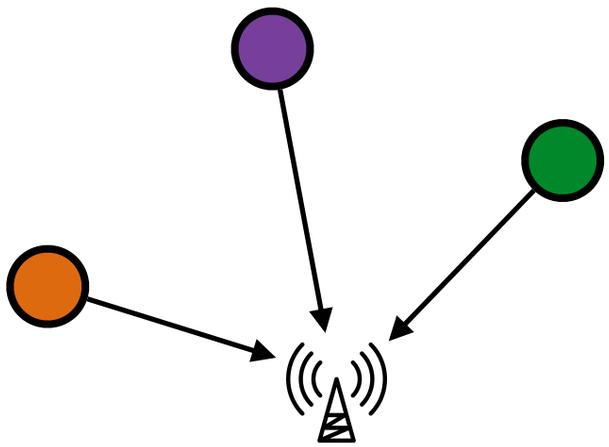




[1]Matthew Knight, LoRa PHY with SDR https://www.youtube.com/watch?v=-YNMRZC6v1s

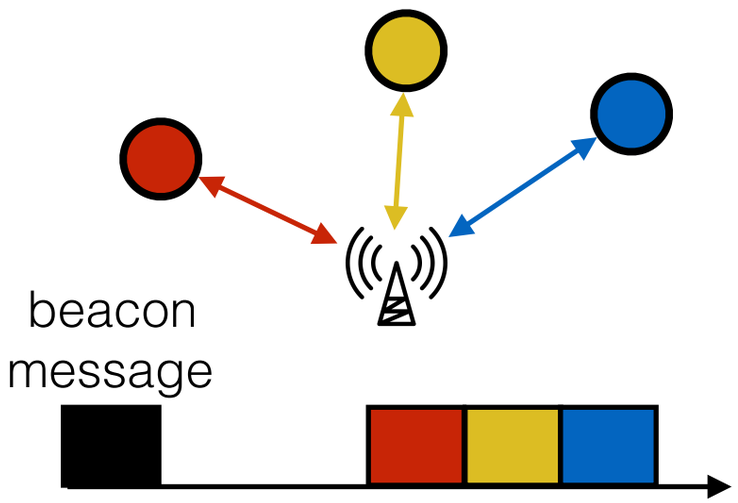
LoRaWAN

MAC layer in LoRa networks



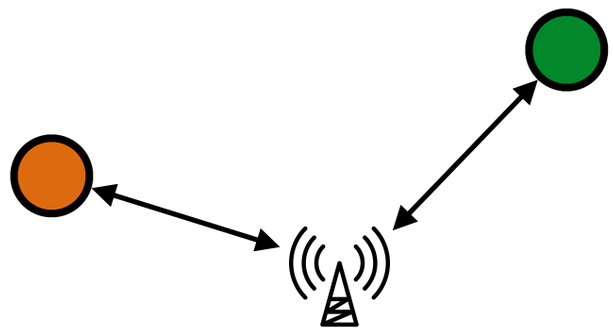
Class A
ALOHA + (optional) ACK

low-power sensor



Class B
Beacon + Time Slots

low-power actuator

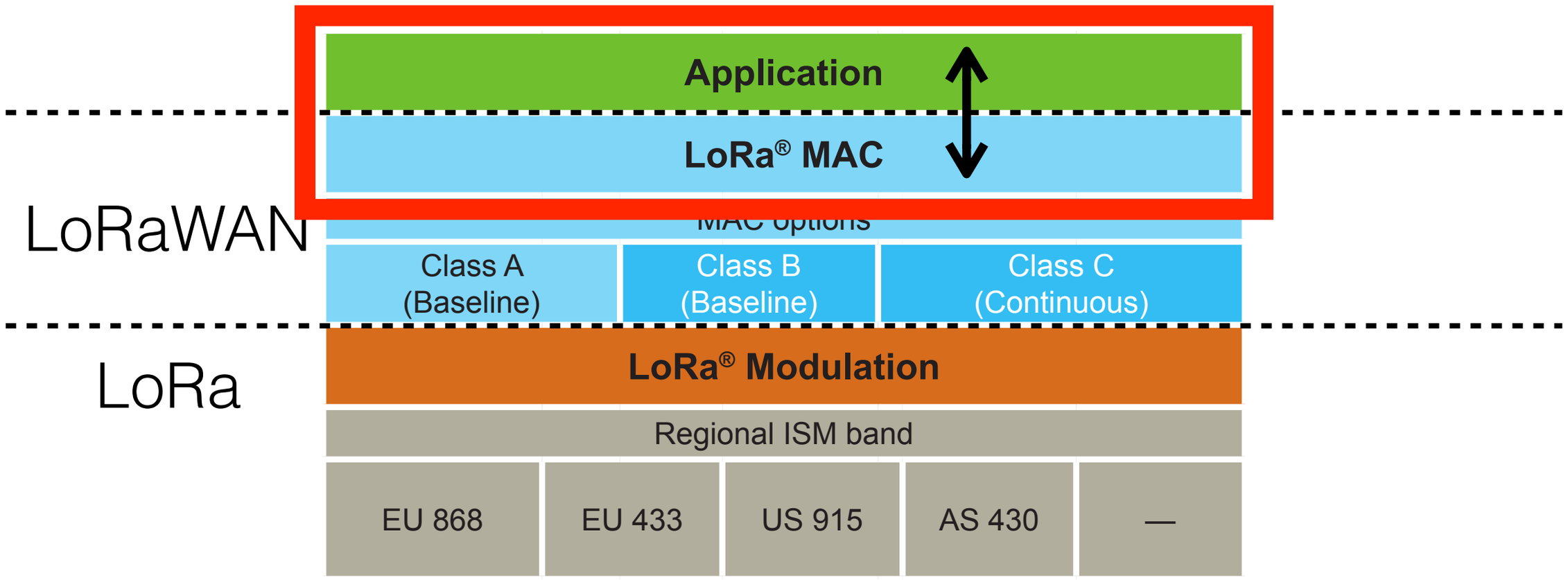


Class C
Always Listening

low-latency
applications

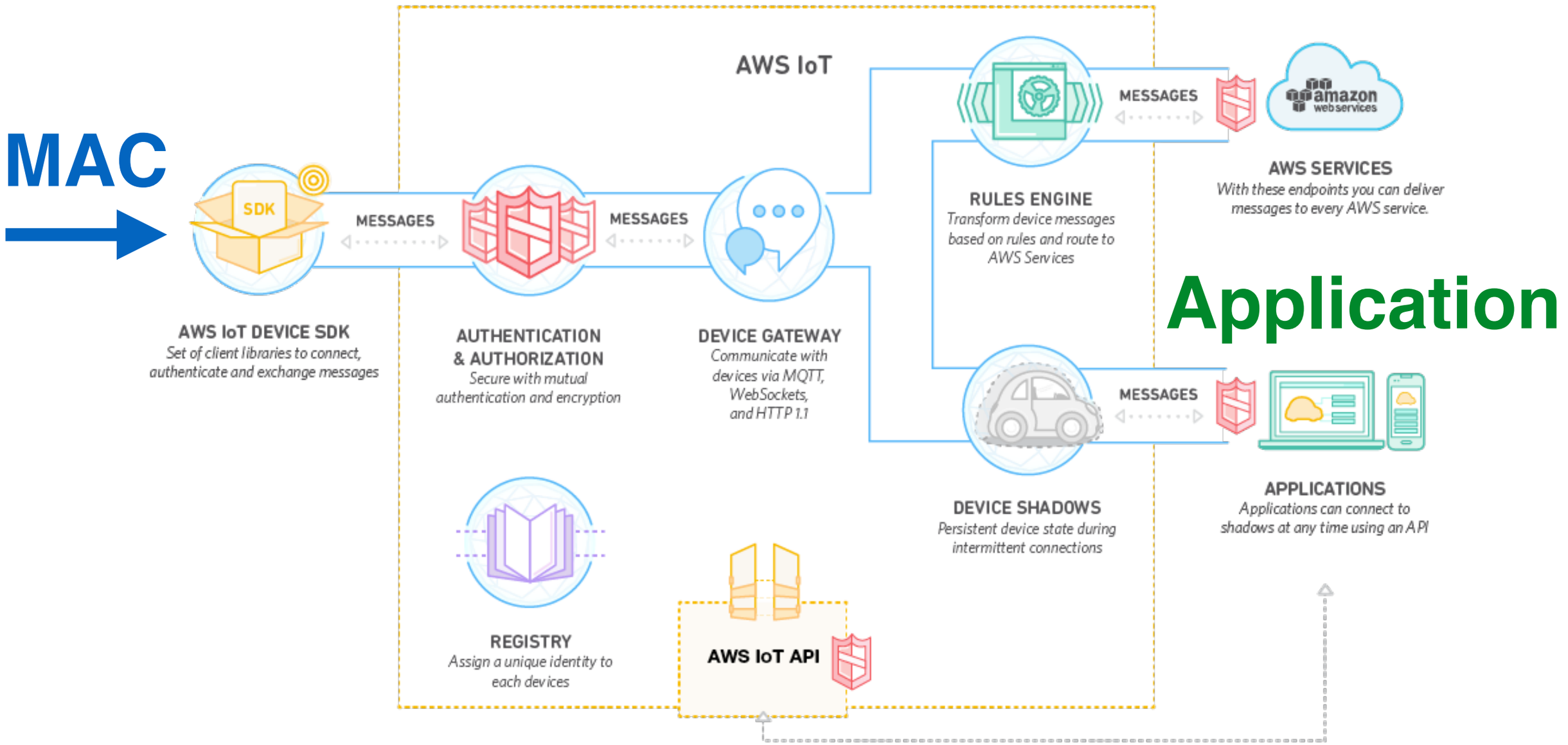
Base-stations are always listening

LoRa Network Stack



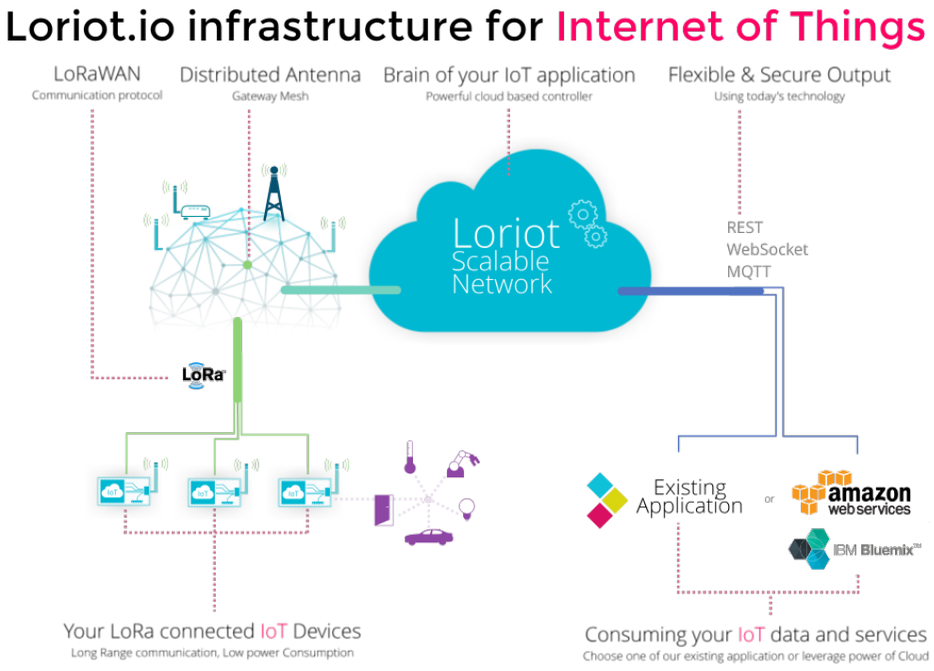
More components between MAC and application required for a scaleable network

IoT Building Blocks

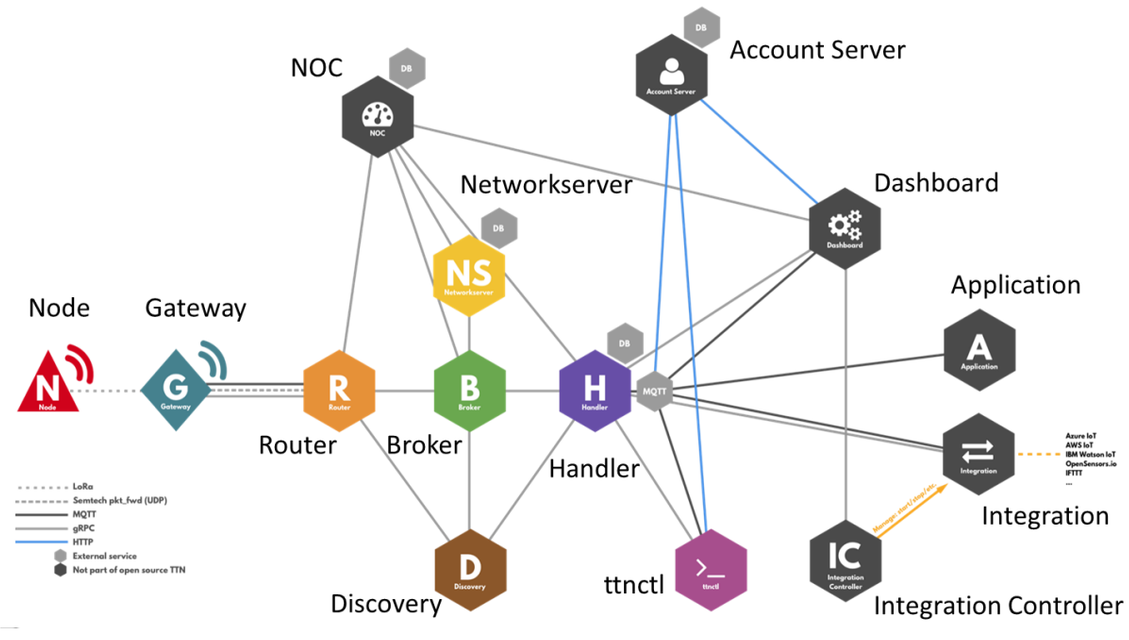


e.g. AWS IoT Cloud

Many Implementations



loriot.io



The Things Network

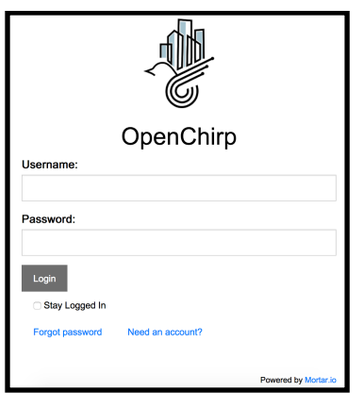
- Deliver binary blobs between end-device and cloud
- Not enough meta-data (units, precision, etc.)

OpenChirp

Layer on top of LoraWAN

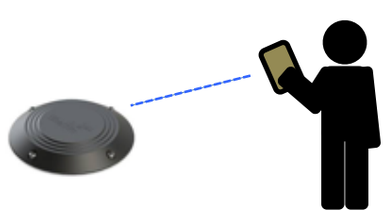
- Management
  - LoRa network (base-stations, devices, users)
  - Data flow
  - Access Control
- Additional Functionality
  - Meta-data
  - Authentication
  - Storage
  - Visualization
  - Sharing

OpenChirp As A User



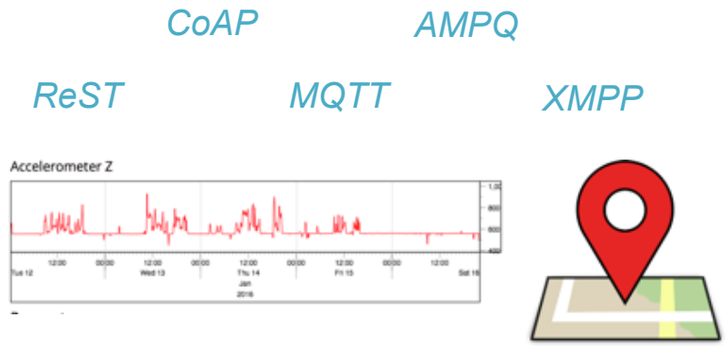
Step 1: Setup an account

Step 2: Grab a LoRa Device



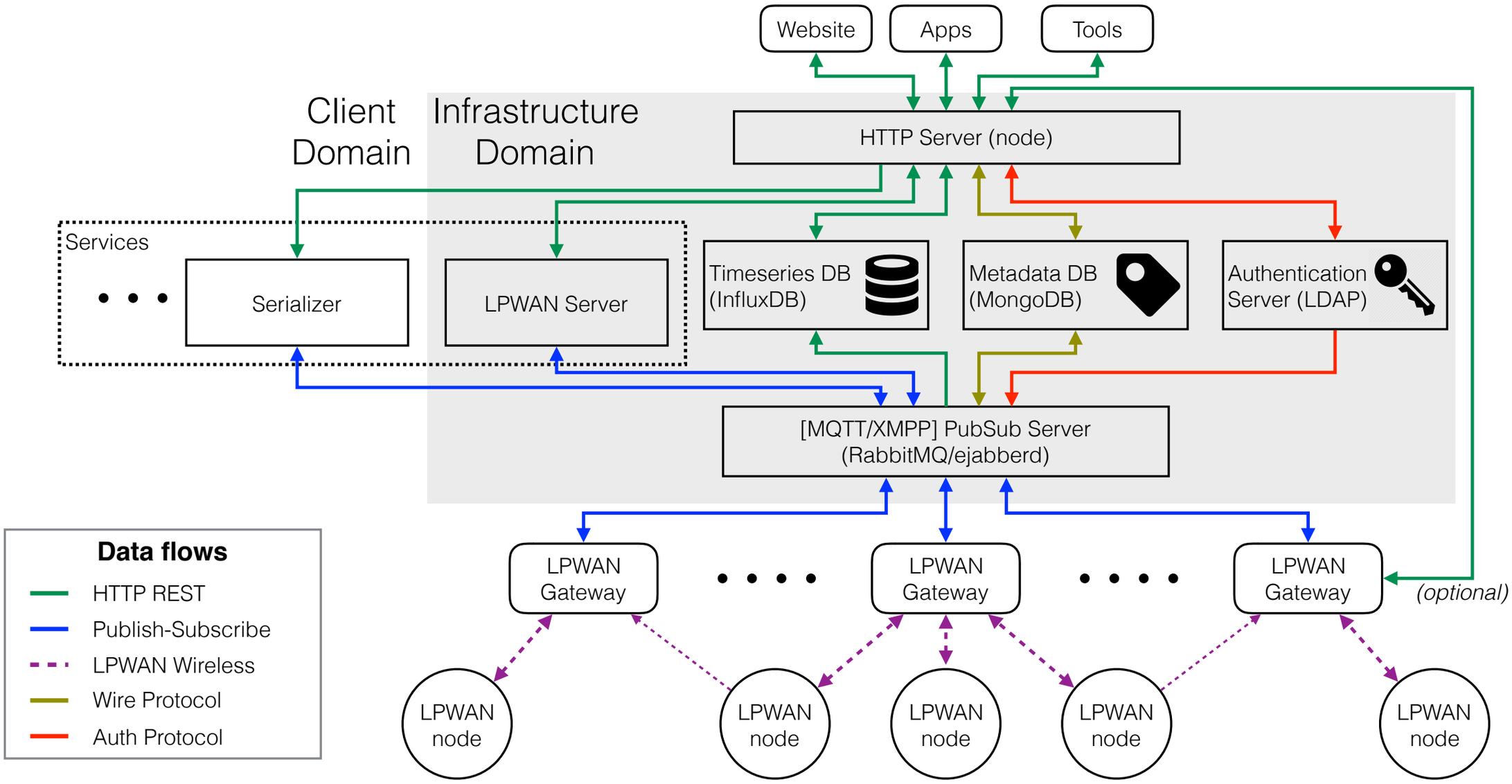
Step 3: Configure Devices

Step 4: Deploy the device



Step 5: Manage Devices

OpenChirp Architecture

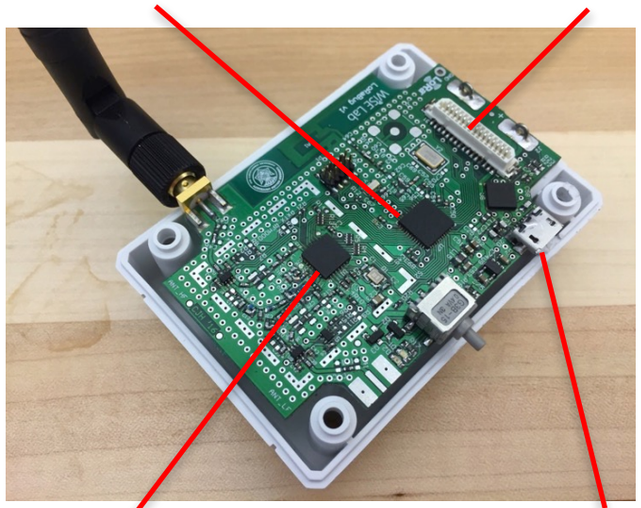


Deployment and Performance

LoRaBug Client

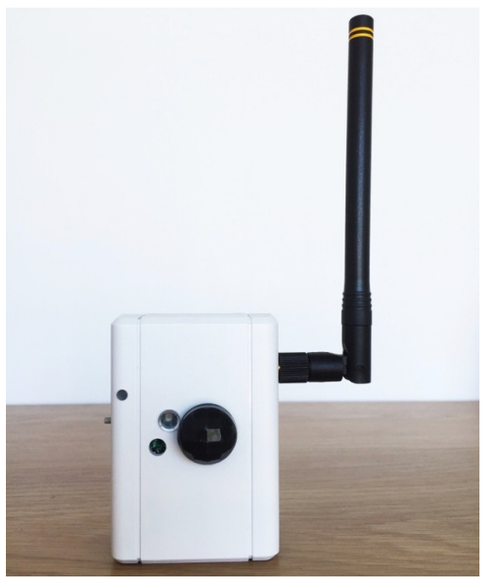
TI CC2650 ARM M3
BLE + 802.15.4

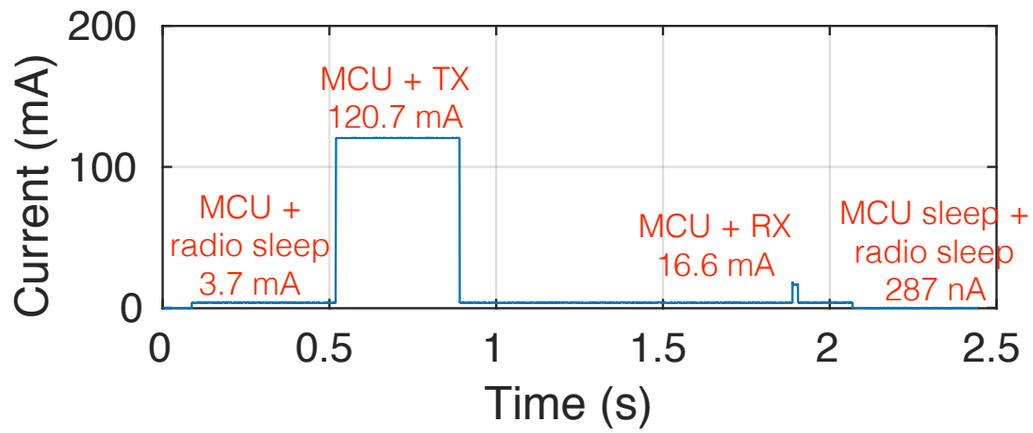
General Purpose
Sensor Header

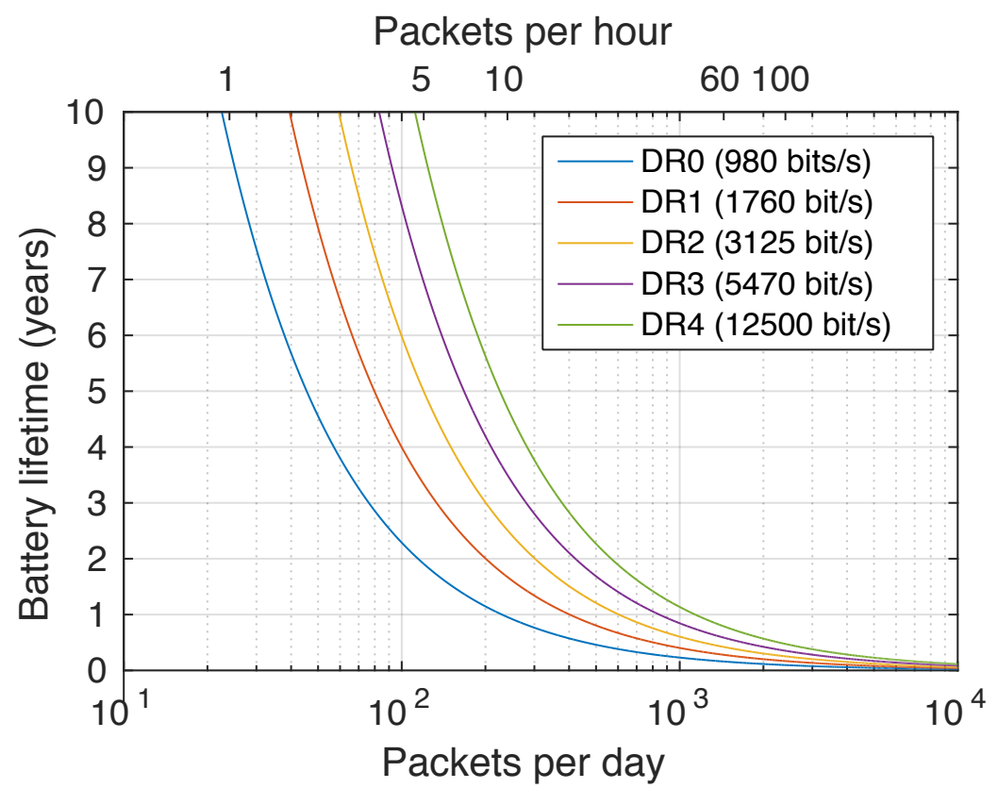


SX1276
LoRa Radio

USB



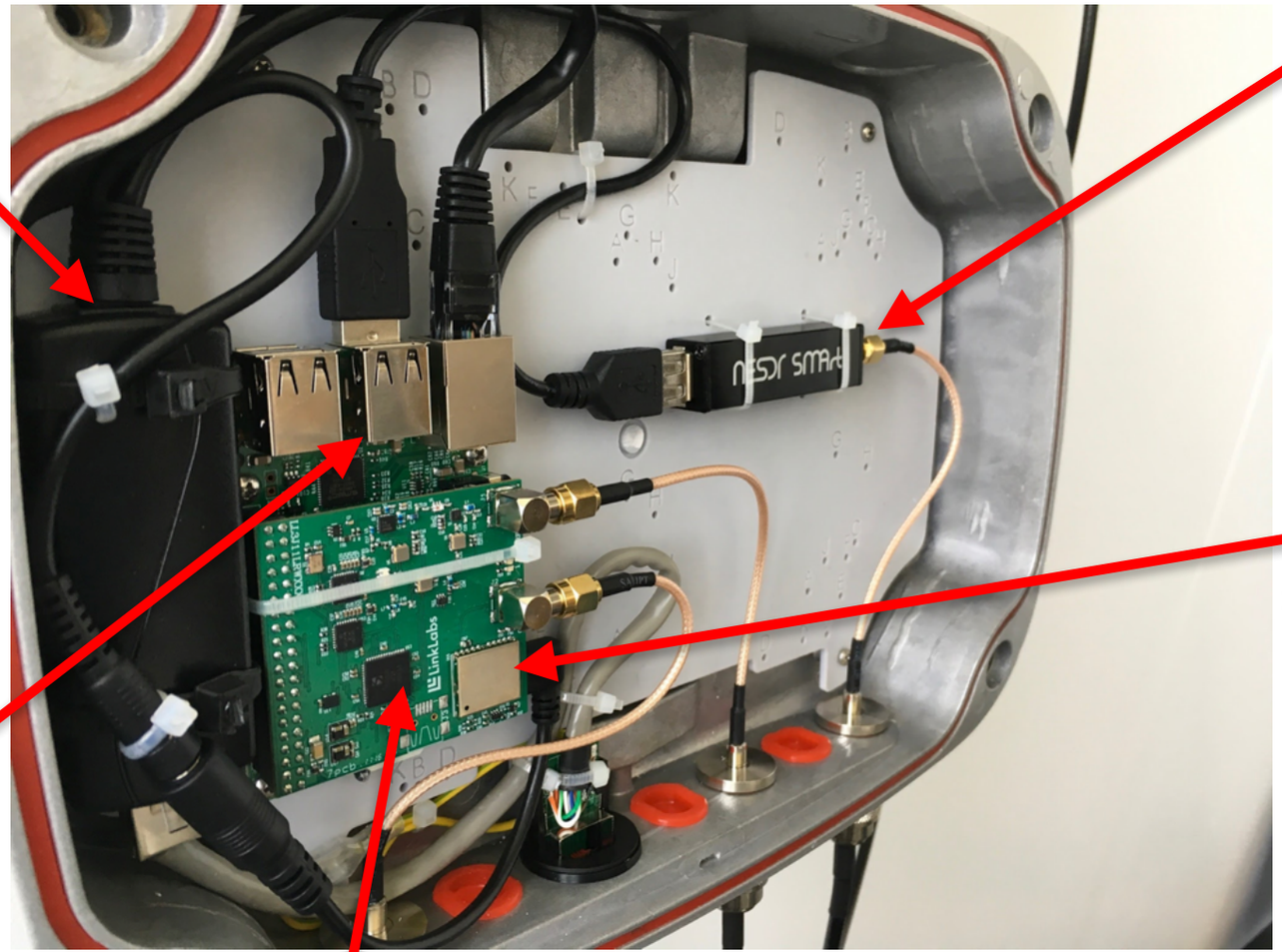




https://github.com/OpenChirp/LoRaBug

Custom Base-Station

PoE Supply



Software Defined Radio (spectrum scanning)

GPS (time sync)

Raspberry Pi 3

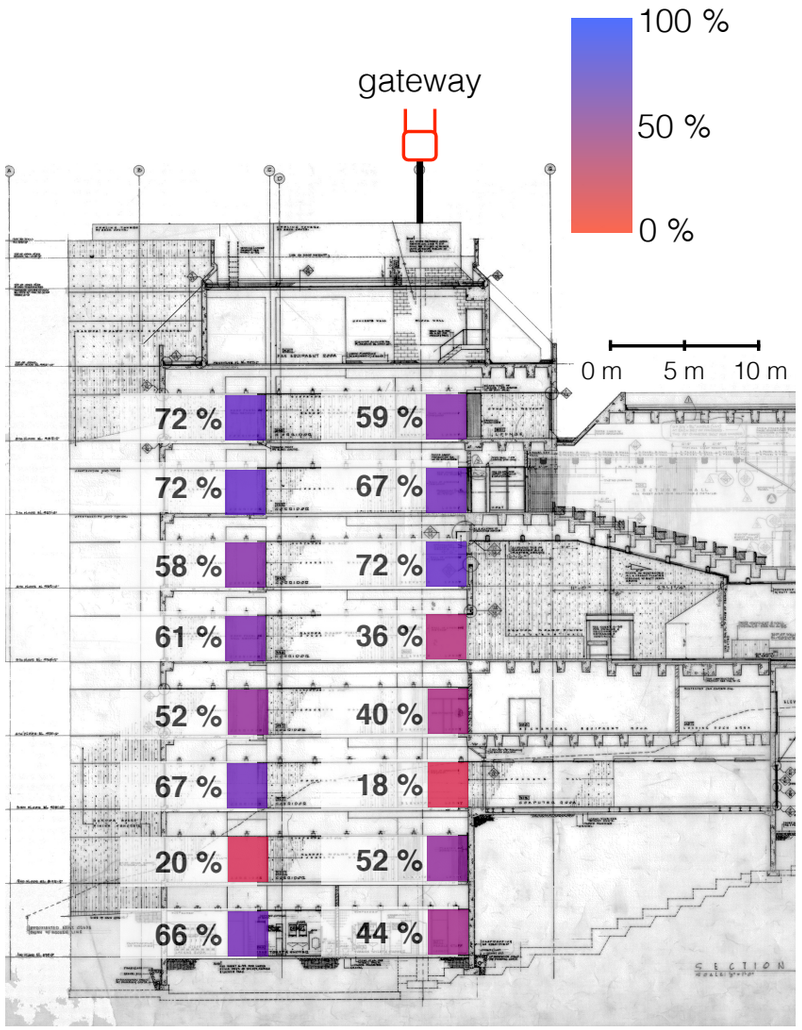
LoRa Concentrator Radio

Building Penetration: 1/2

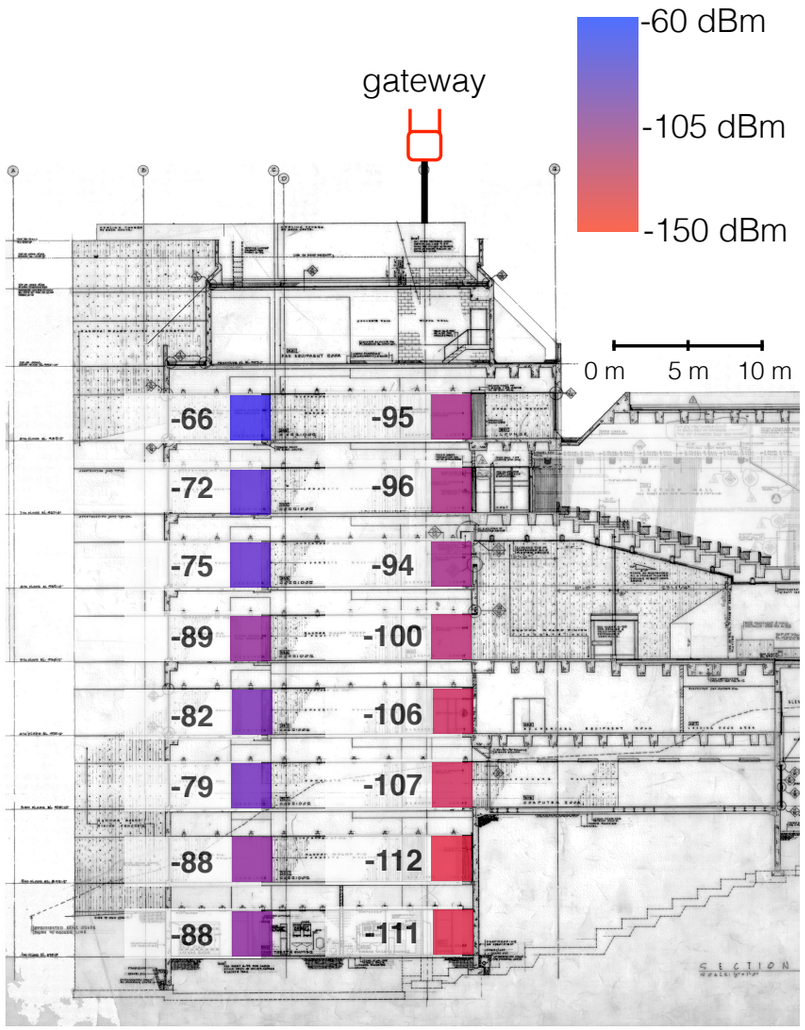
Wean Hall, CMU

Building Penetration: 2/2

Bi-directional packet success rate

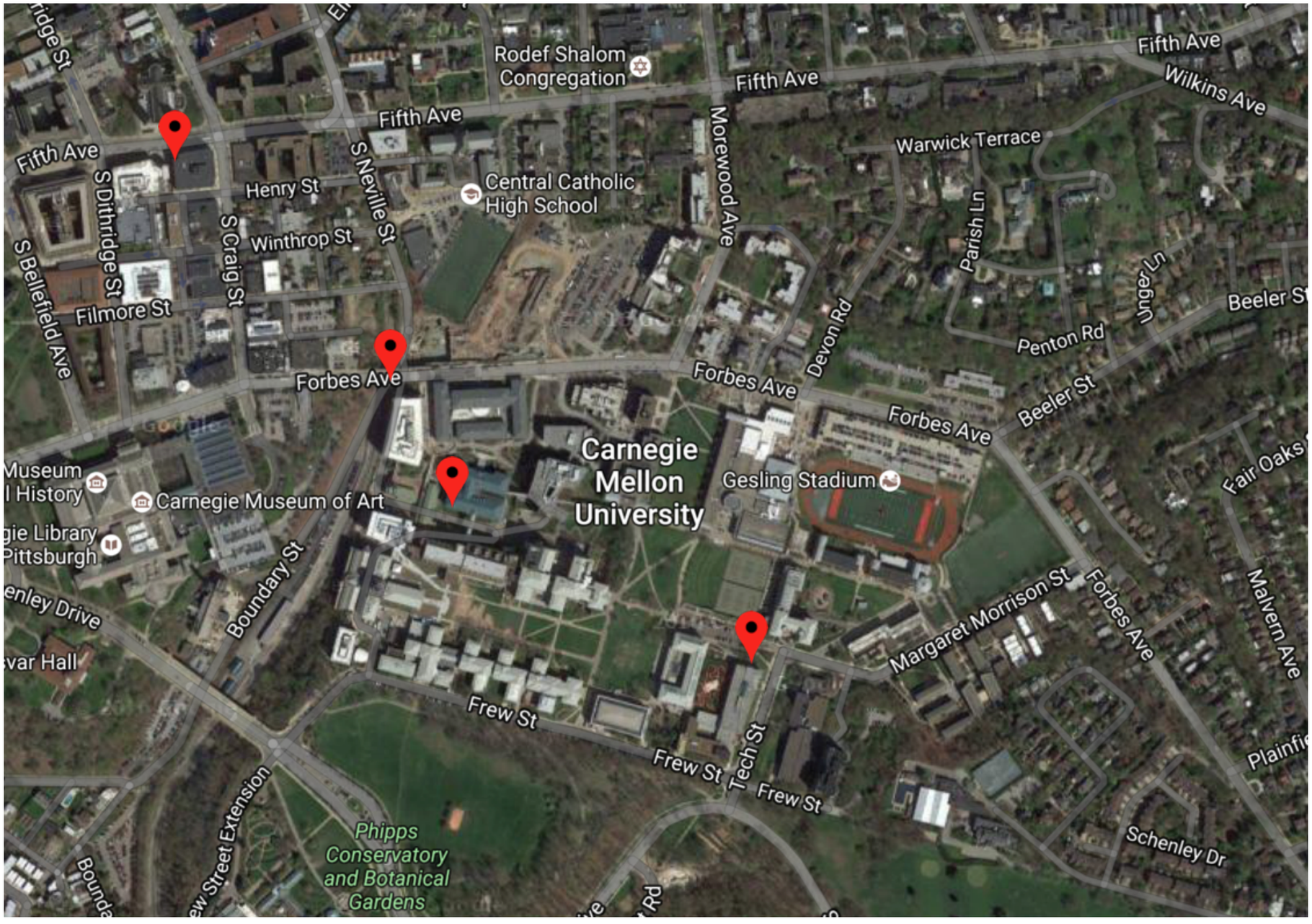


Gateway RSSI for successful packets

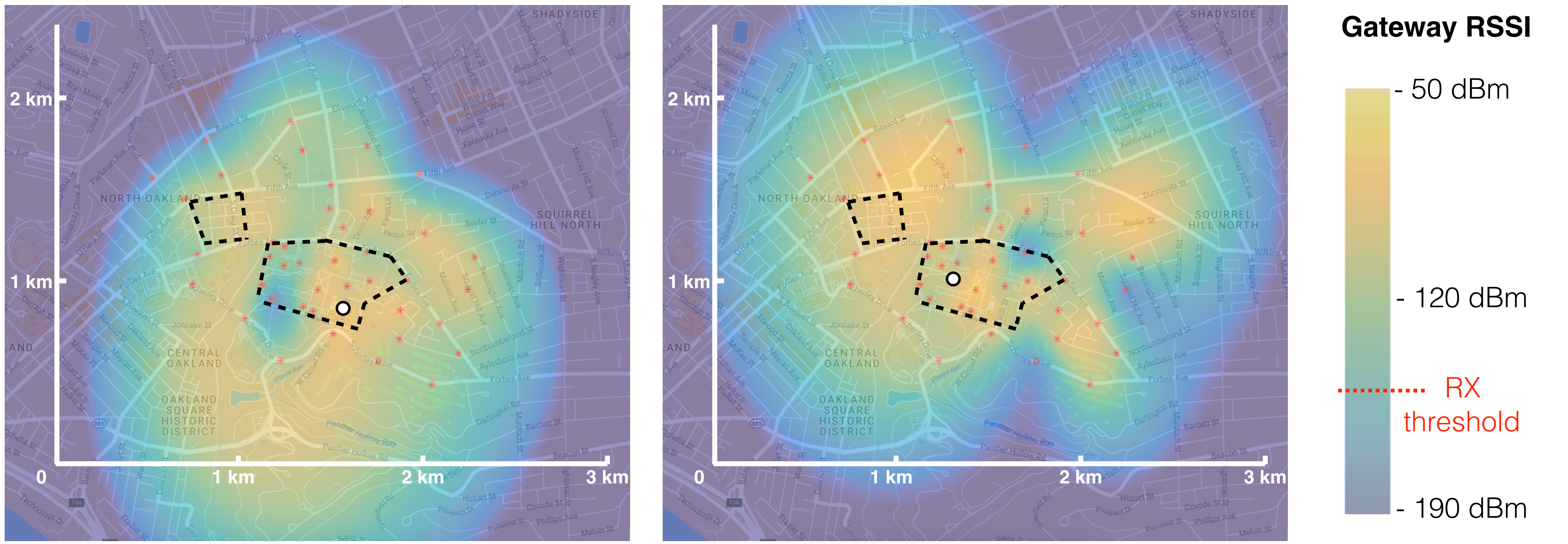


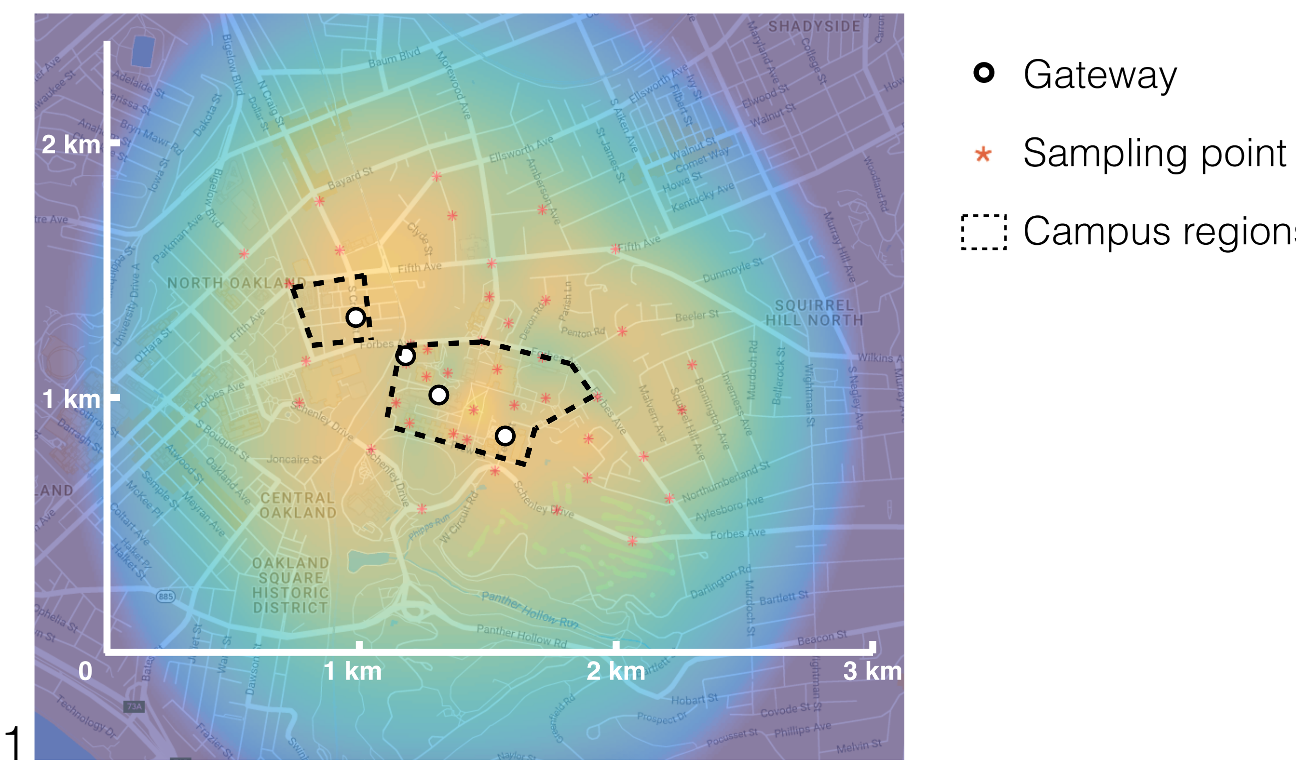
Devices can communicate through many layers of poured concrete (1 OpenChirp BS vs 150 WiFi APs)

Coverage: 1/2


Rodef Shalom Congregation
Fifth Ave
Wilkins Ave
Warwick Terrace
Morewood Ave
Parish Ln
Unger Ln
Beeler St
Penton Rd
Devon Rd
Central Catholic High School
Henry St
Winthrop St
Filmore St
S Dithridge St
S Craig St
S Neville St
S Bellefield Ave
Forbes Ave
Carnegie Mellon University
Gesling Stadium
Carnegie Museum of Art
Boundary St
Margaret Morrison St
Malvern Ave
Frew St
Tech St
Schenley Dr
Phipps Conservatory and Botanical Gardens

Coverage: 2/2





4 base stations can cover CMU's campus

Challenges

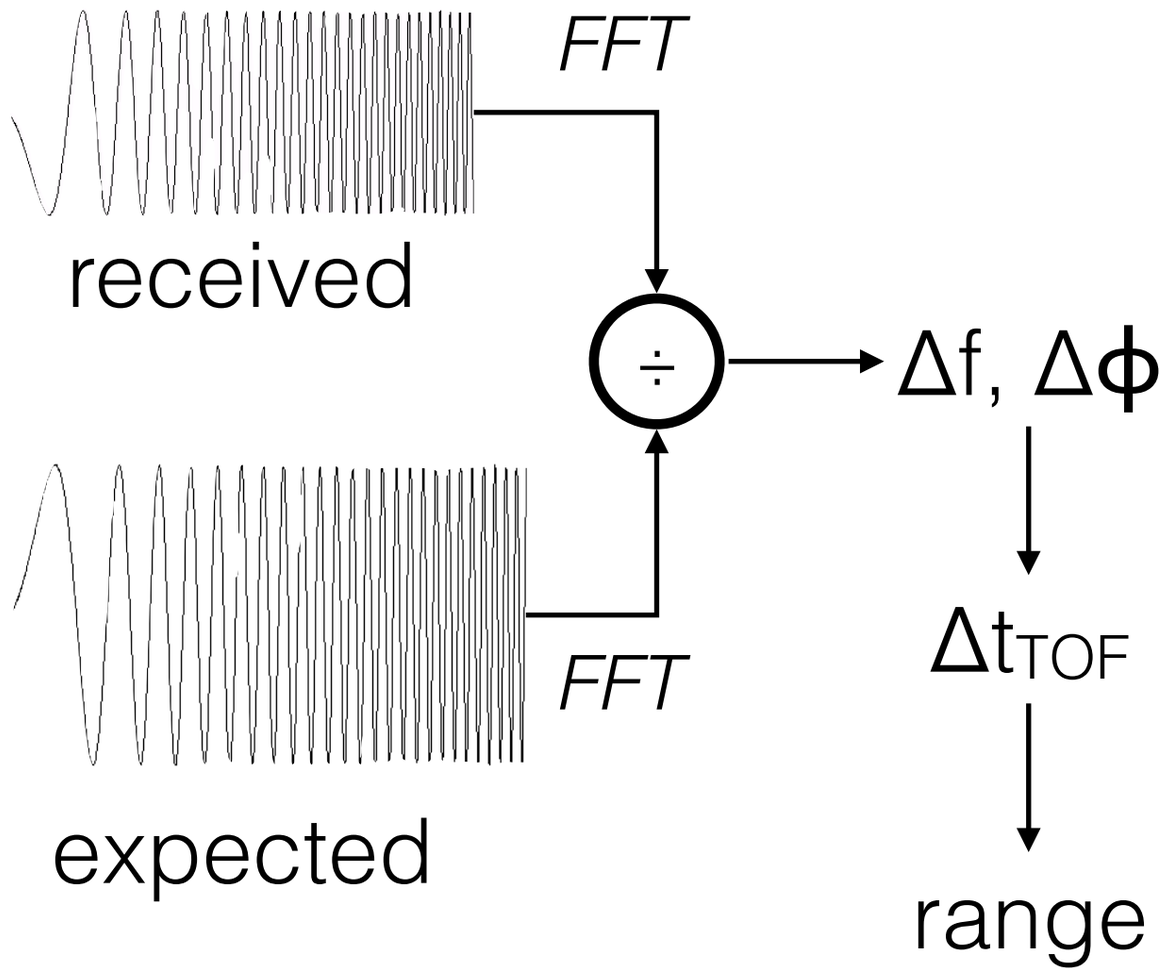
Localization

- GPS is expensive for LPWAN

Localization with LoRa?

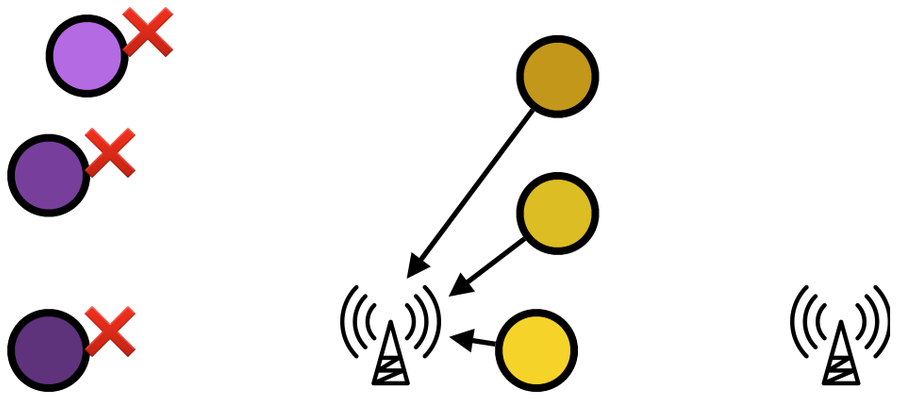
- Expected 10 m accuracy with channel-stitching

1. **Time-Difference-of-Arrival**
   - Synchronous base-station RX
2. **Time-of-Flight**
   - Peer-to-peer ranging
   - Needs phase on end-nodes

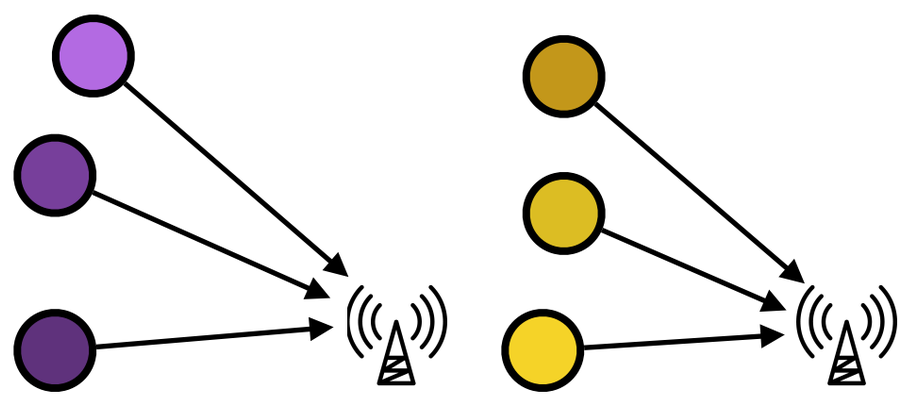


Phase-based ranging

Scalability

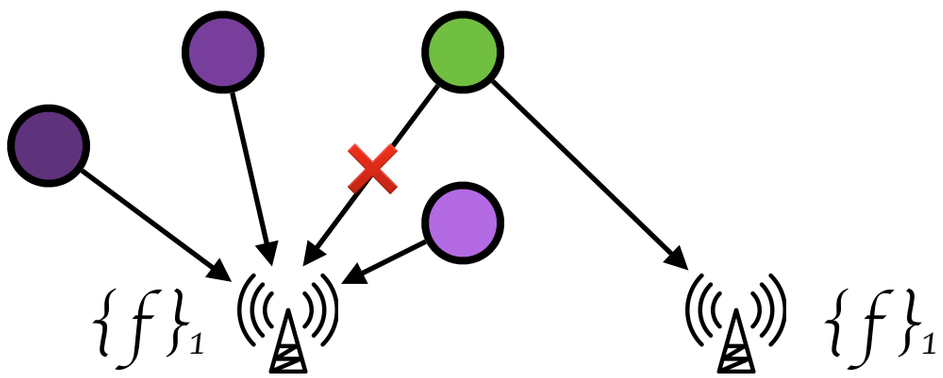


Greedy

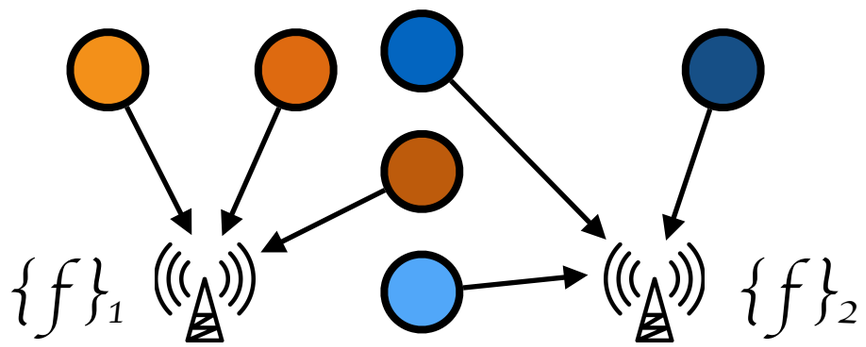


Intelligent

Naive greedy solutions *not* good enough. Leverage location?



Resilience



Orthogonality

What is the right operating point between resilience and orthogonality for this network?

Bring Your Own Base-Station

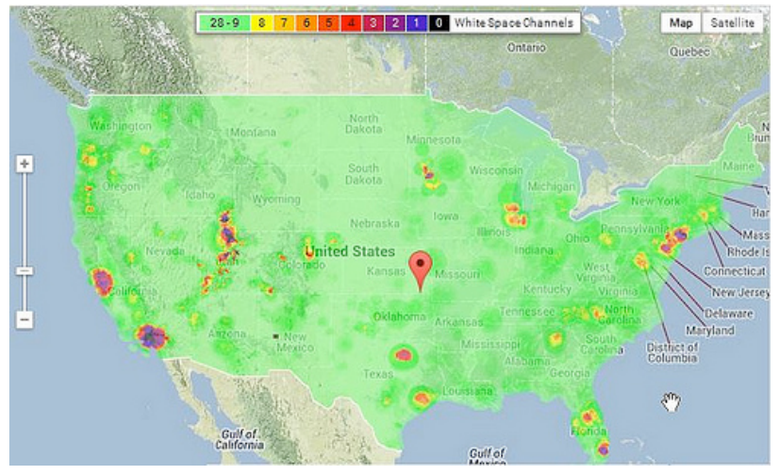
- *Anyone* can deploy a base-station
- How to manage a network with unreliable user-controlled base-stations?
- Convince other LoRa networks to collaborate

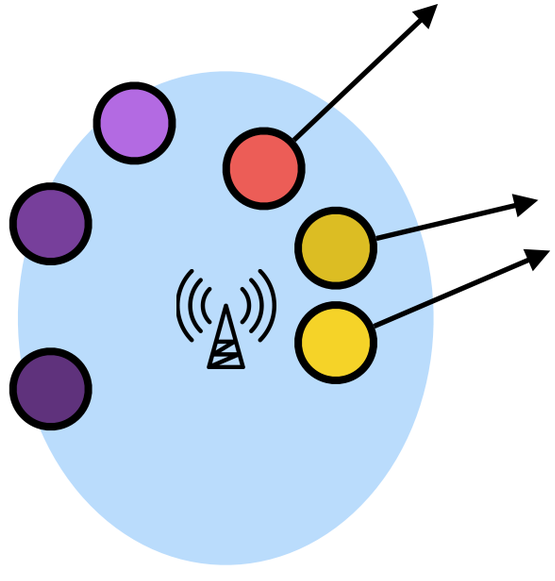
Security and Privacy

- Devices are easy to compromise
- Managing shared application and network keys
- Anti-spoofing using radio multi-lateration
- Accountability

Spectrum

- 900 MHz ISM band is limited (BW = 26 MHz)
  - Use of white spaces
  - How do devices identify usable channels?
  - Efficient RF front-end for usable frequencies
- ISM band is unlicensed
  - Interference from other communication
  - Leverage spectrum sensing at base-station





Conclusion

- LPWANs for long range, low power and low data-rate applications
- OpenChirp is our architecture built over LoRaWAN and adds network management, access control, meta-data, storage, visualization tools, etc.
- LoRaBug and Custom Gateway hardware for added functionality and ease of deployment.
- Many interesting challenges ahead:
  Localization, scalability, user base-stations, security and privacy, spectrum usage

Thanks!