

# Charm: Exploiting Geographical Diversity Through Coherent Combining in LPWANs

OR

# When They Go Low, We Go Lower (Power)

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# Low-Power Wide-Area Networking (LPWAN)



NB-IoT



# LPWAN's potential



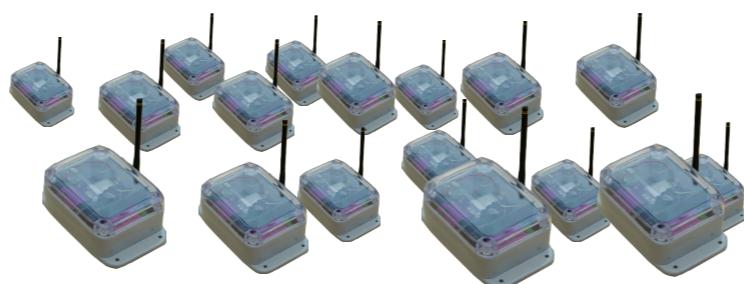
Sub-GHz ISM band  
chirp spread-spectrum (CSS)

10km range in line-of-sight

Low data rate  
(0.25 kbps – 27 kbps)



Thousands of devices  
per gateway



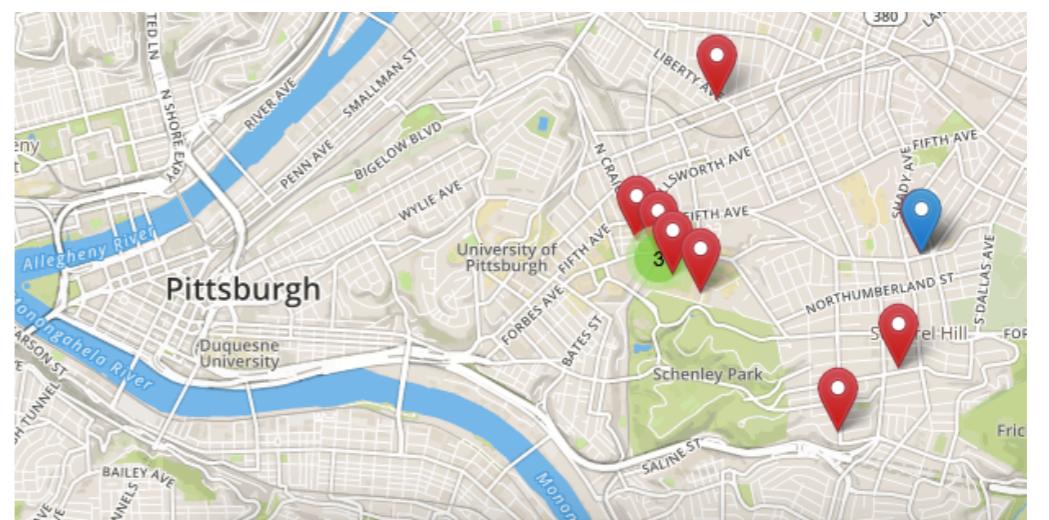
5+ year battery life

# OpenChirp In Pittsburgh

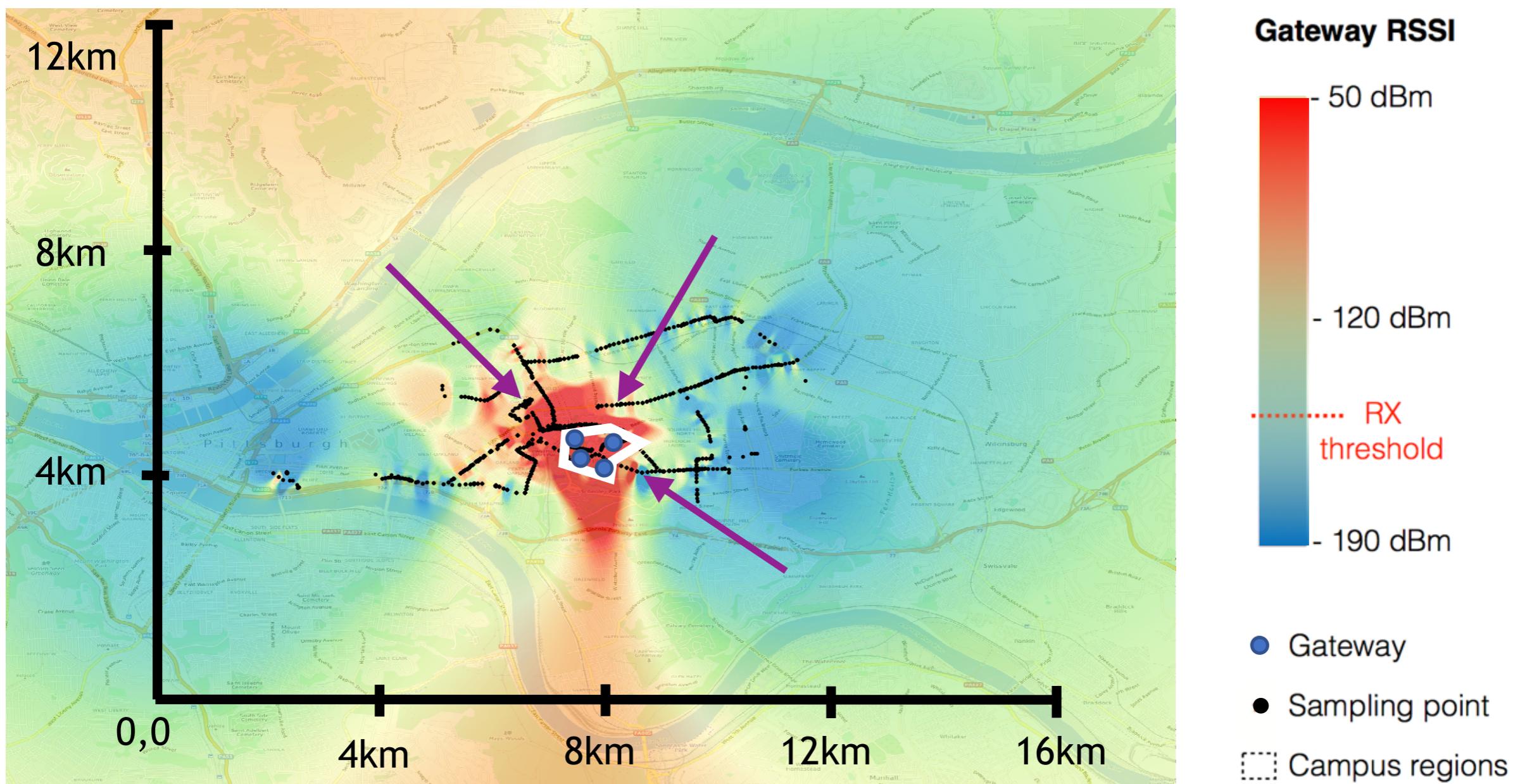


OpenChirp

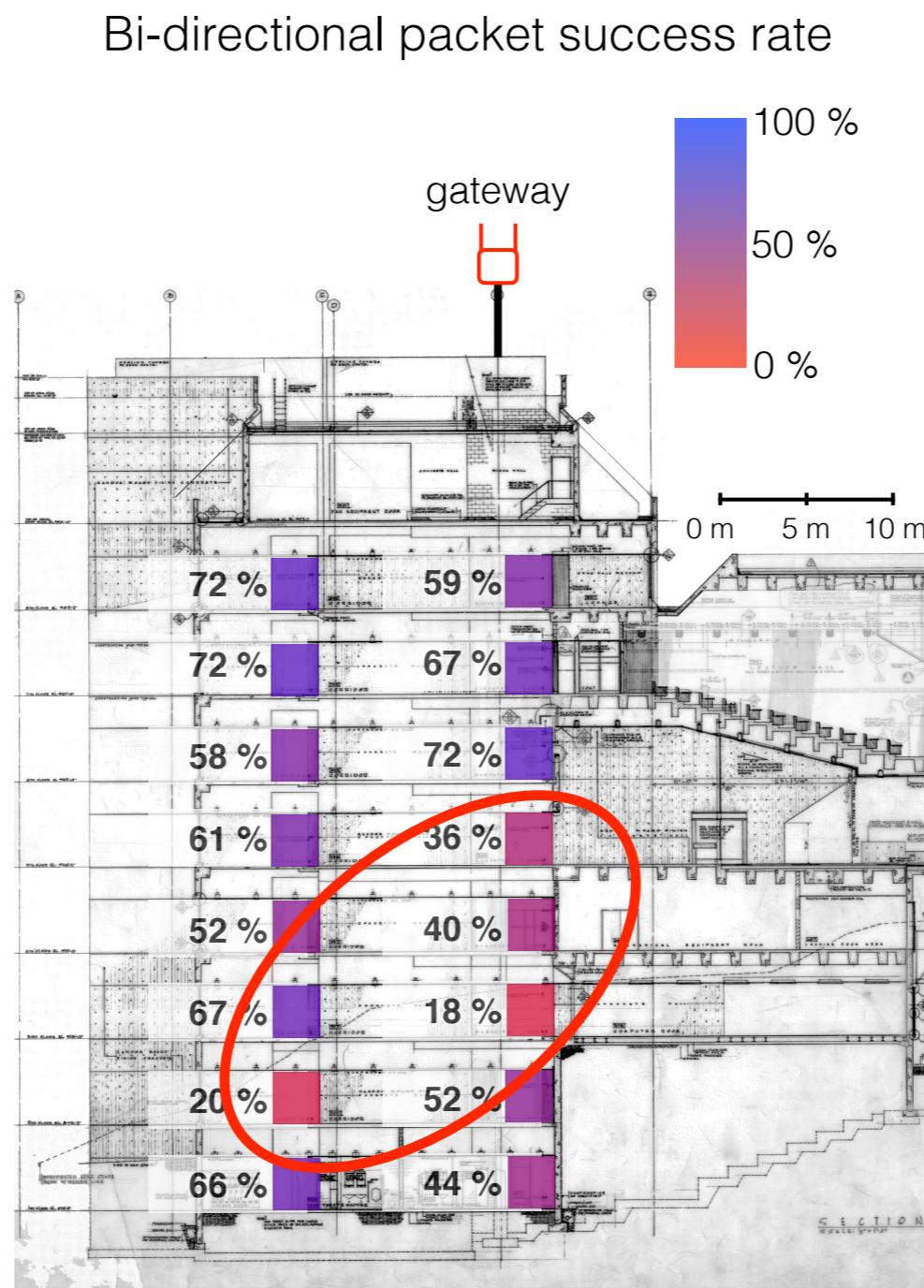
- [openchirp.io](https://openchirp.io)  
CMU's LoRaWAN network in  
Pittsburgh
- 4 outdoor gateways + multiple  
indoor gateways



# Coverage

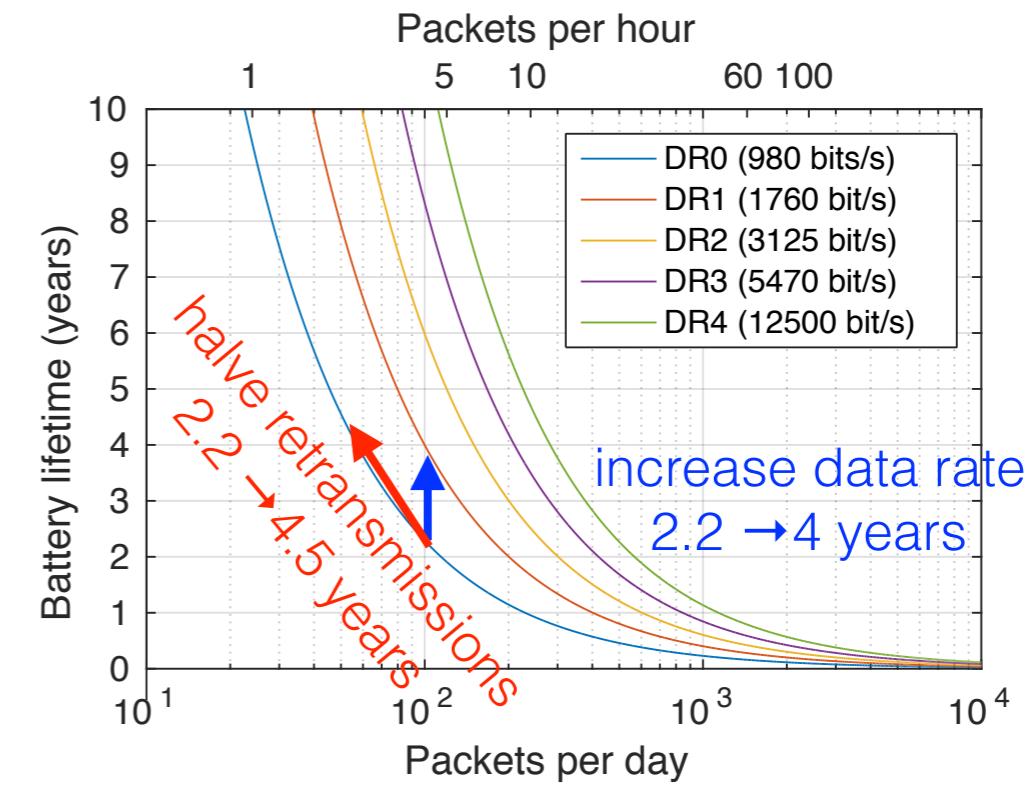
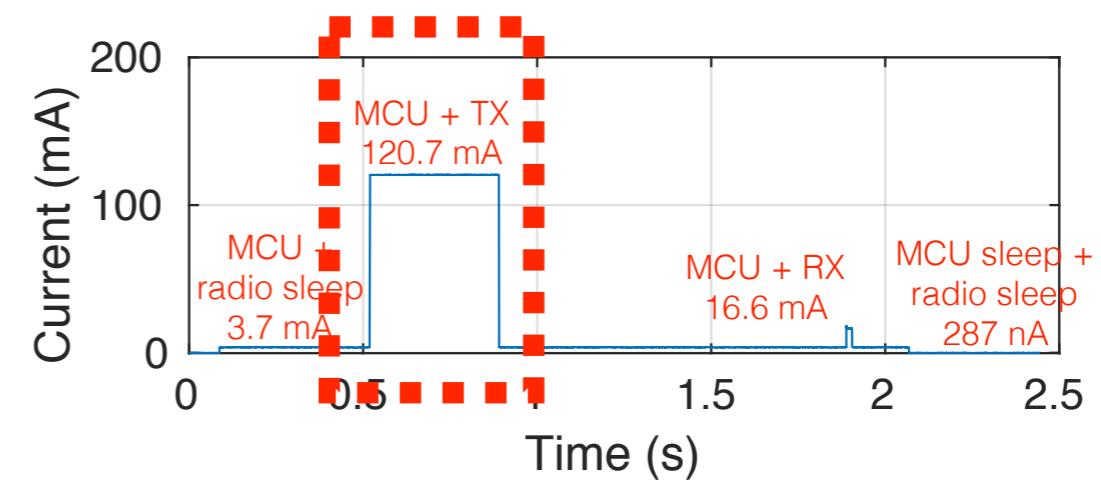


# Penetration Inside Buildings



# Client Device Battery Life

- Wireless transmissions dominate energy usage
- Increasing data rate and reducing retransmissions significantly improves battery life

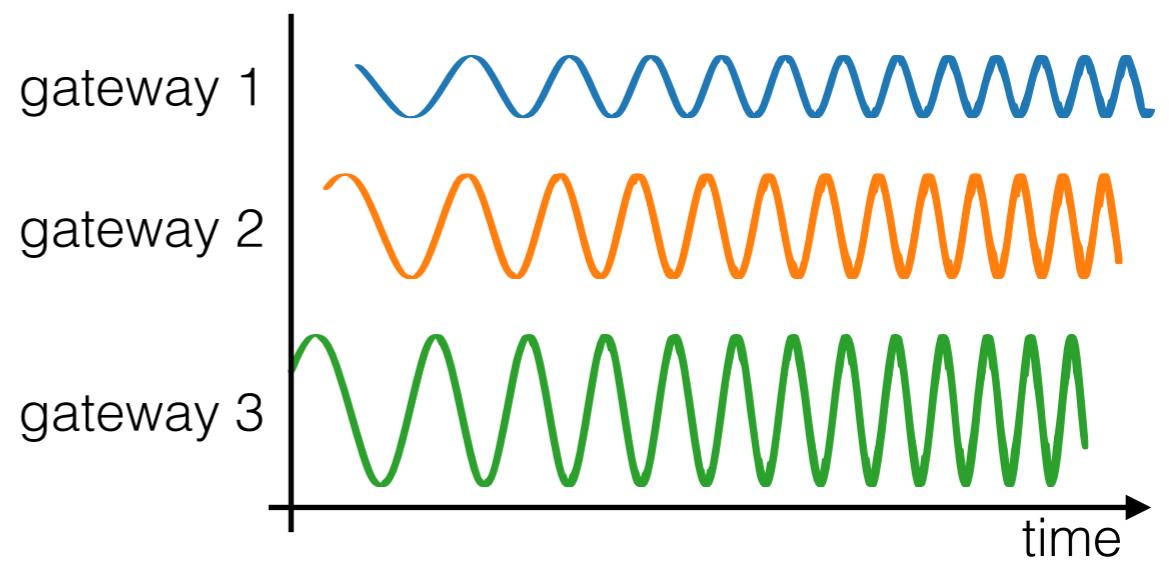
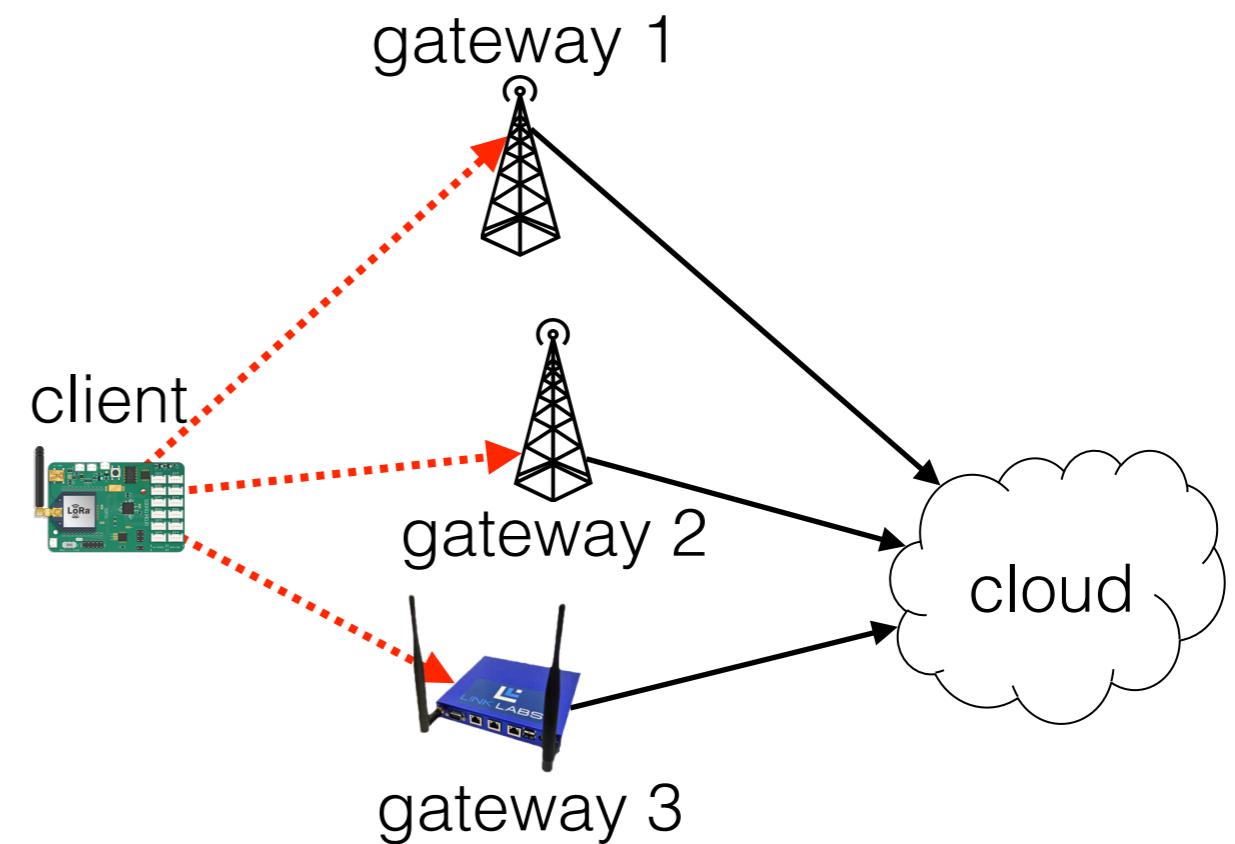


LPWANs have lots of gateways.....

Can we use them to improve network performance?

# Coherent Combining

- Multiple gateways hear the same weak transmission
- Coherent combining in the cloud
- e.g. Cloud Radio Access Networks (C-RAN) in cellular communication



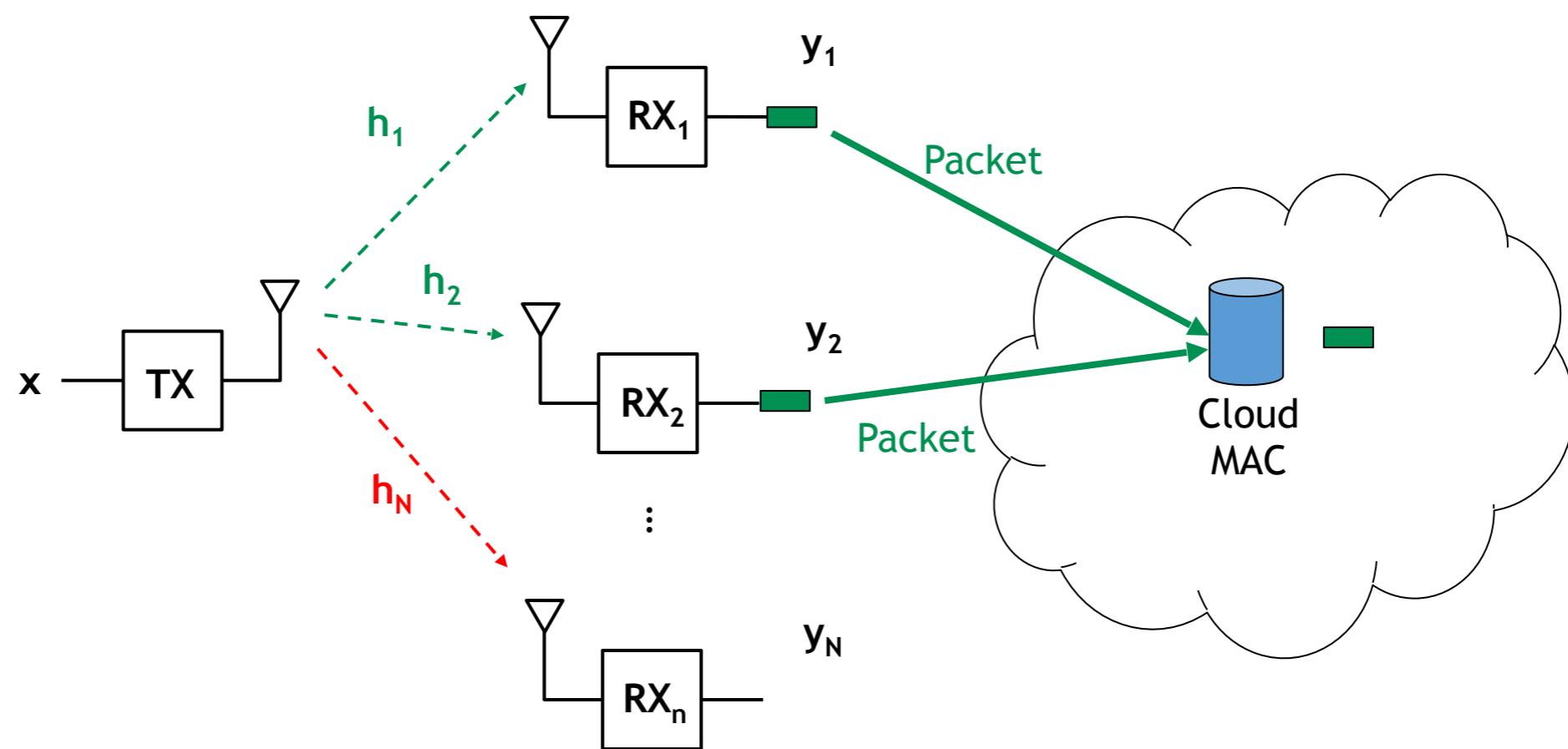
# Challenges

- High bandwidth connectivity to the cloud
- Nanosecond-scale synchronization
- Expensive computing resources for large number of streams
- Latency

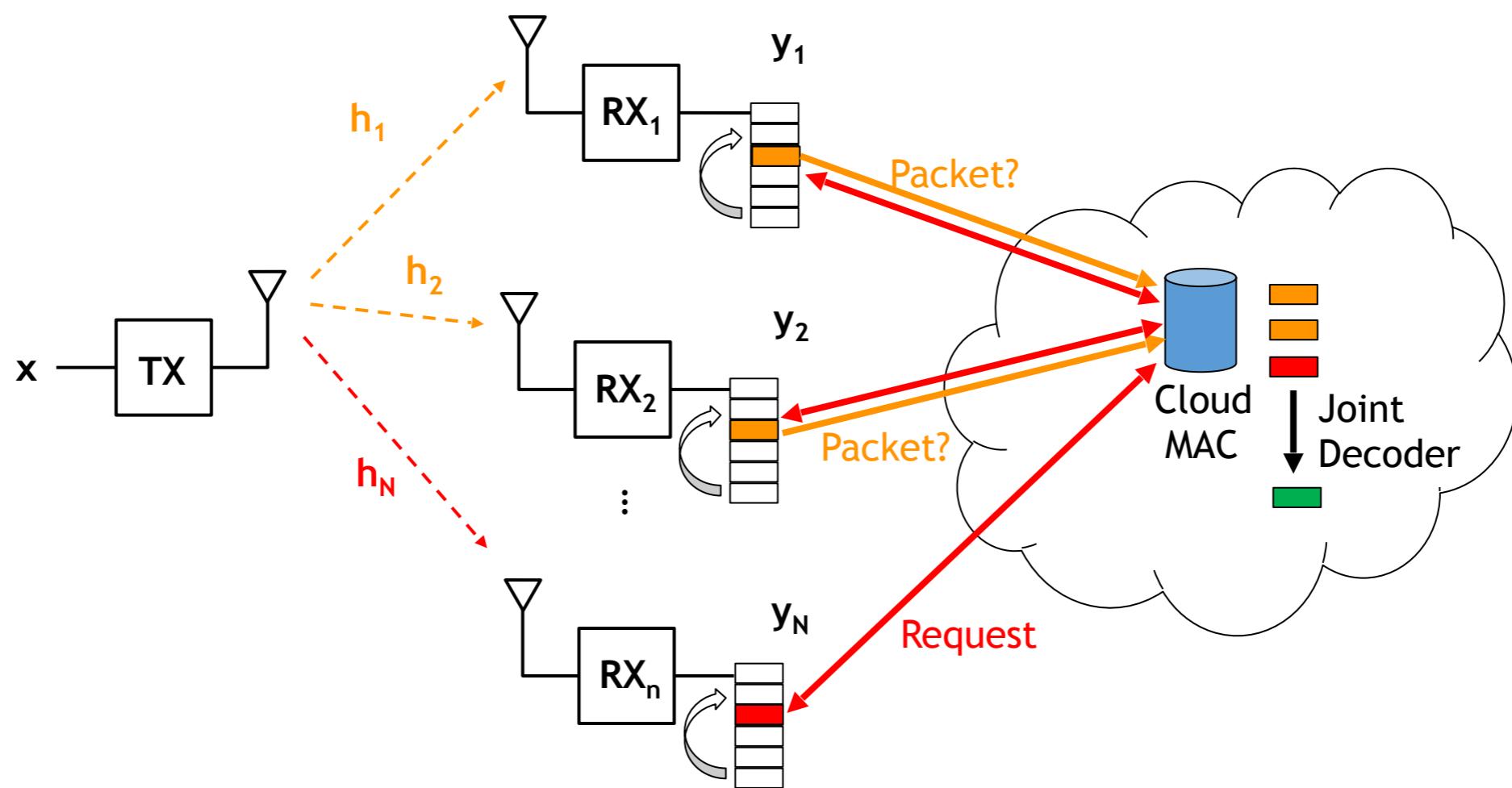
# Charm

- **Practical coherent combining**  
Leverage diversity from multiple gateway receivers
- **Software architecture**
  - Scalable two-phase protocol
  - Local packet detection
- **Hardware platform**  
Auxiliary low-cost SDR-like platform for gateways

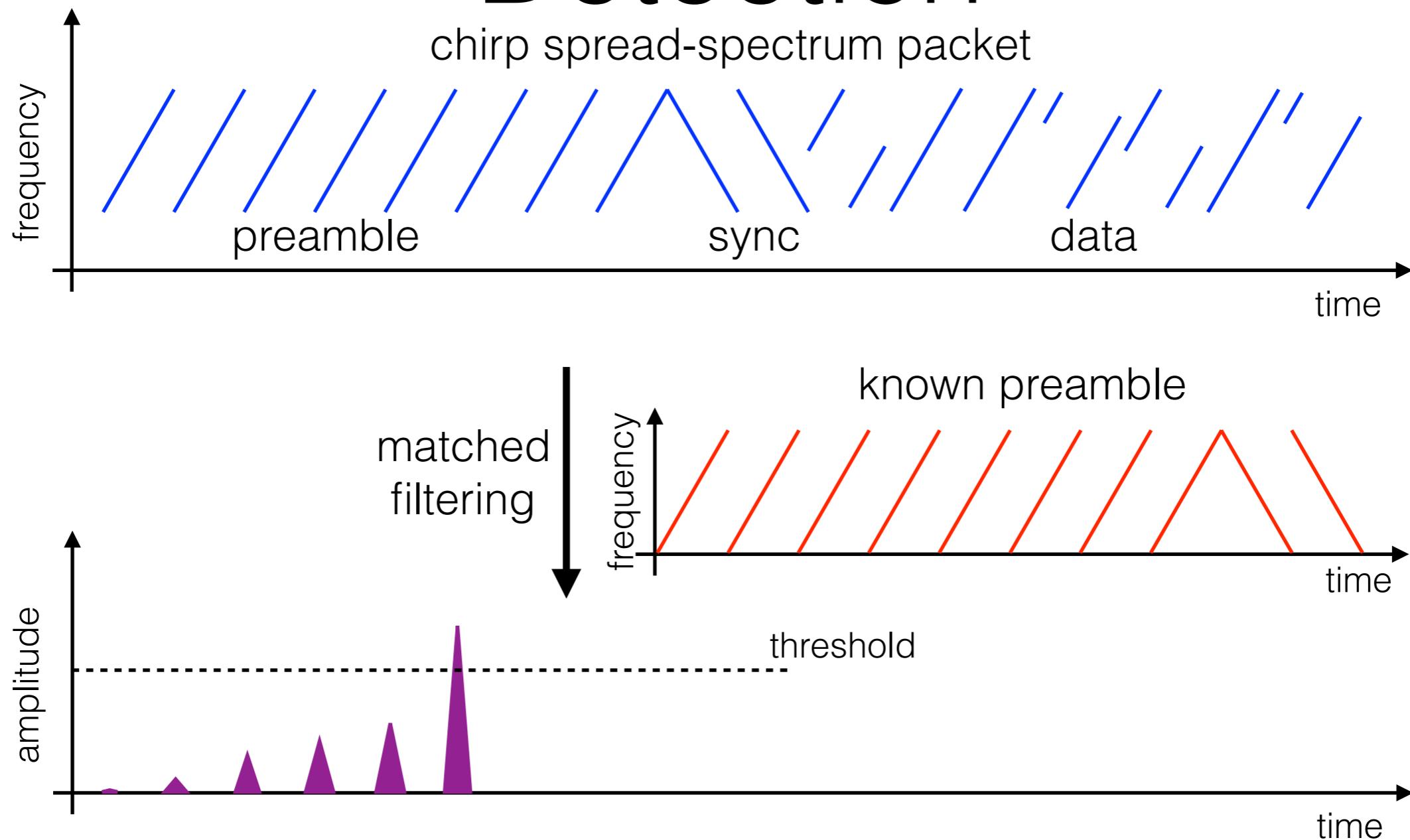
# LoRaWAN



# Charm: Two-Phase Protocol

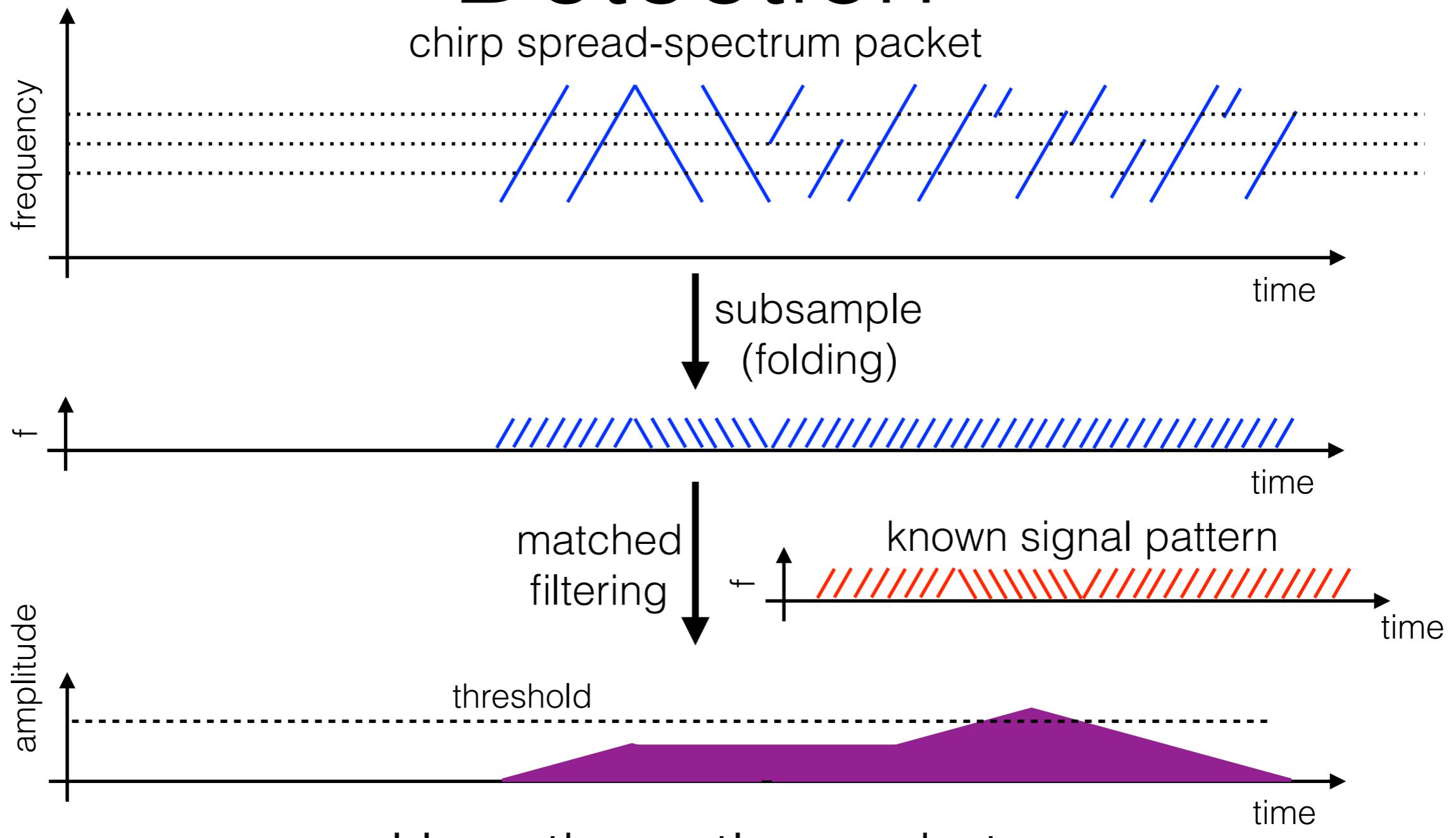


# Charm: Local Packet Detection



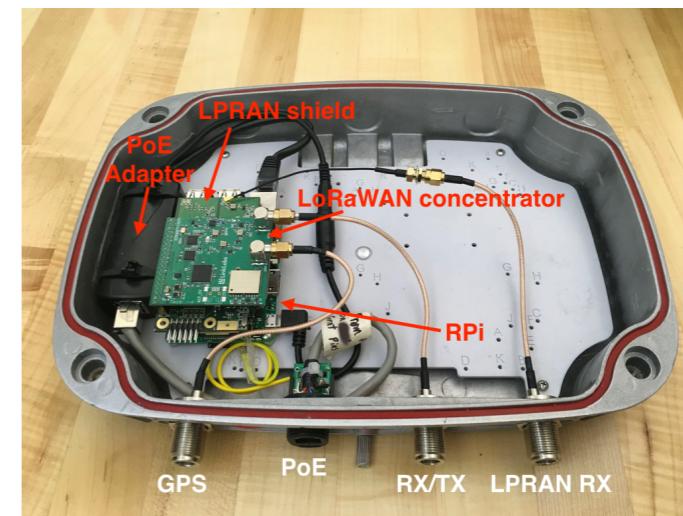
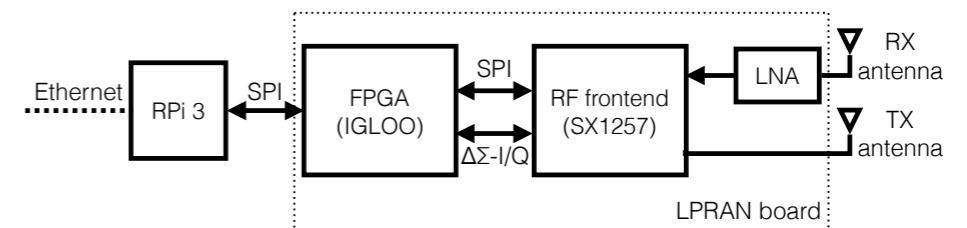
Uses only the preamble and sync header

# Charm: Enhanced Packet Detection



# Charm: Gateway Hardware

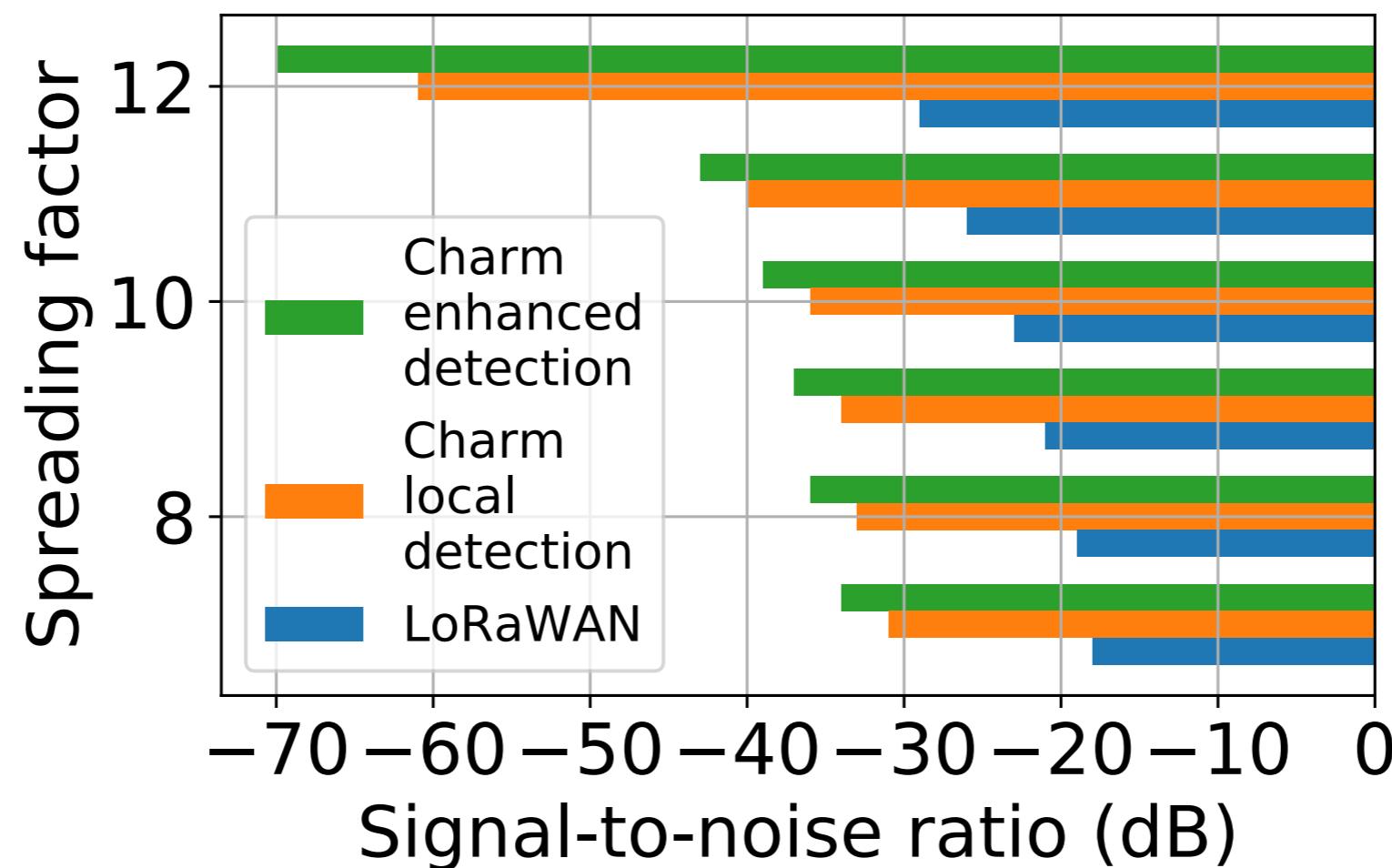
- Semtech SX1257 frontend with MicroSemi IGLOO FPGA
- Outputs radio I/Q stream like an SDR
- Auxiliary hardware for existing gateways and interfaces with raspberry Pi



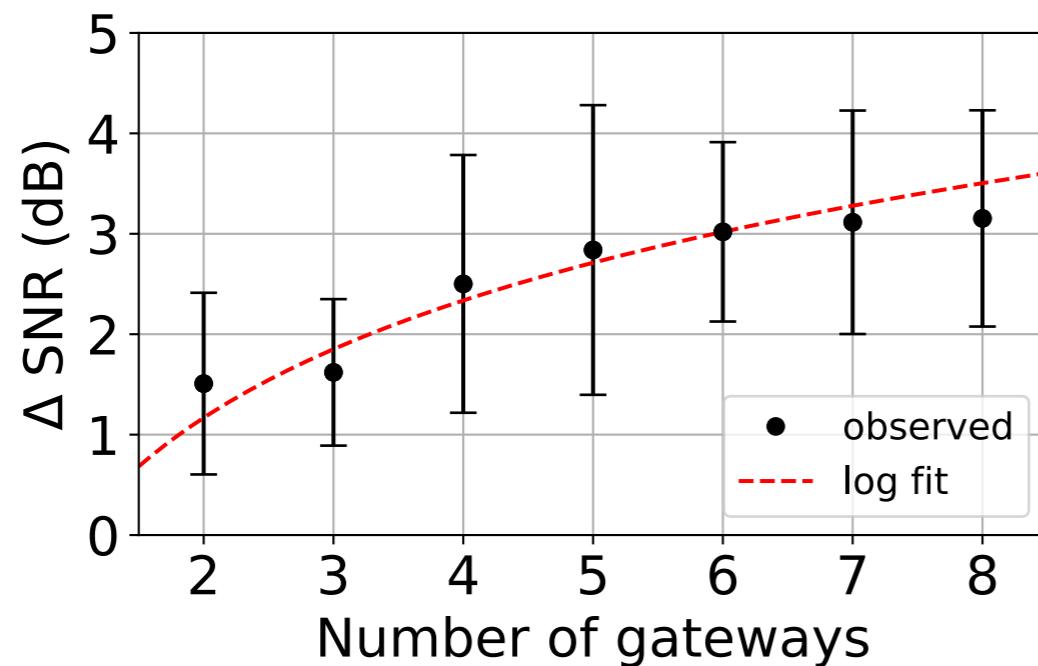
# Practical Coherent Combining With Charm

- High bandwidth connectivity to the cloud → **upload samples on request**
- Nanosecond-scale synchronization → **local packet detection  
simplifies synchronization**
- Expensive computing resources for large number of streams → **selective combination of sample streams**
- Latency → **LoRaWAN ~1 sec to ACK**

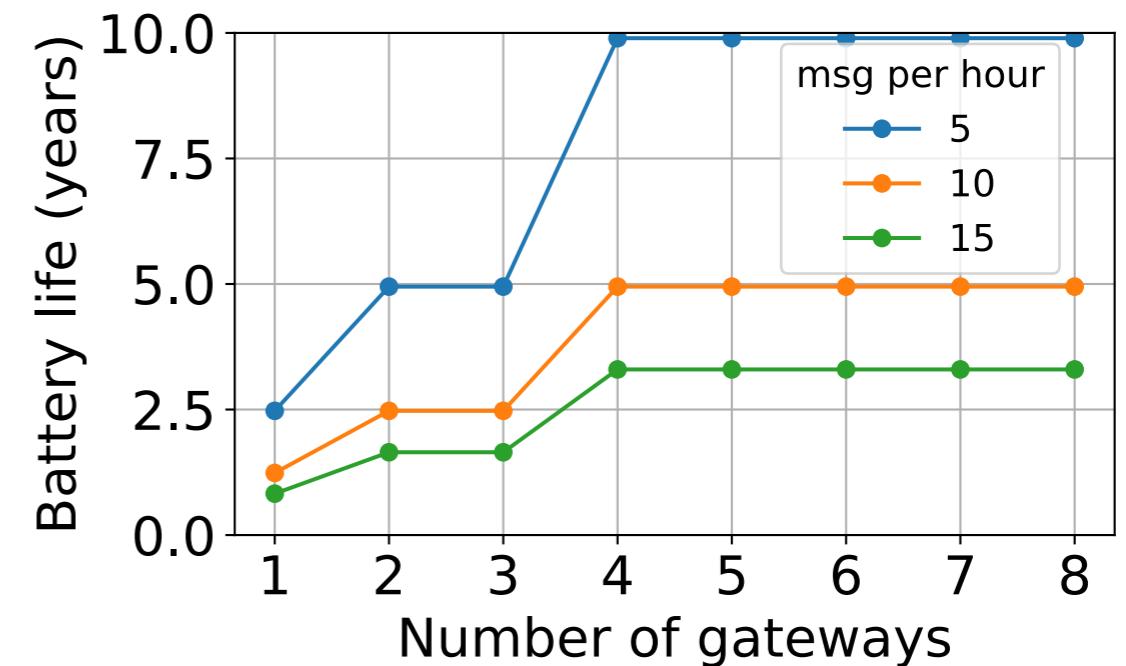
# Benchmark: Packet Detection



# Benchmark: Improved Network And Device Performance

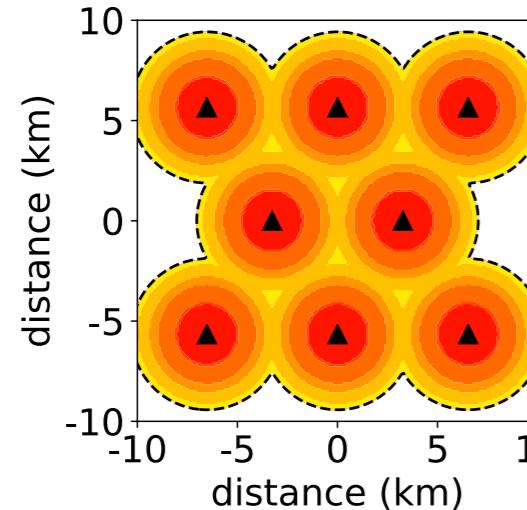


Combined signal SNR increases logarithmically

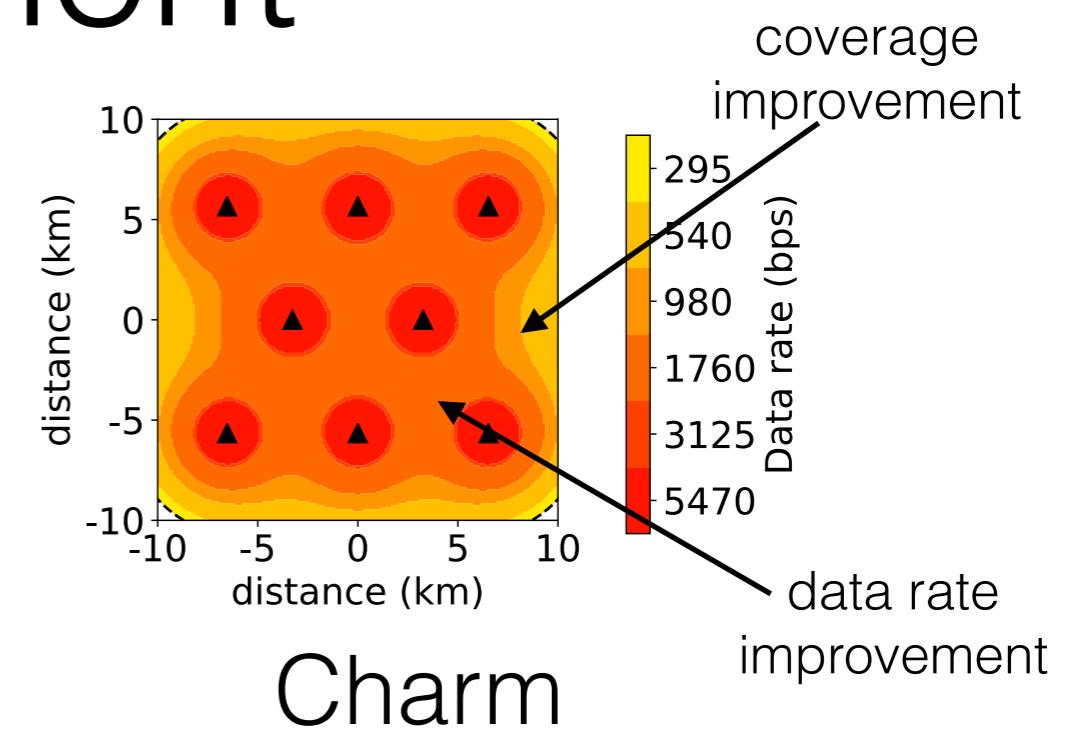


Results into improved battery life on client devices

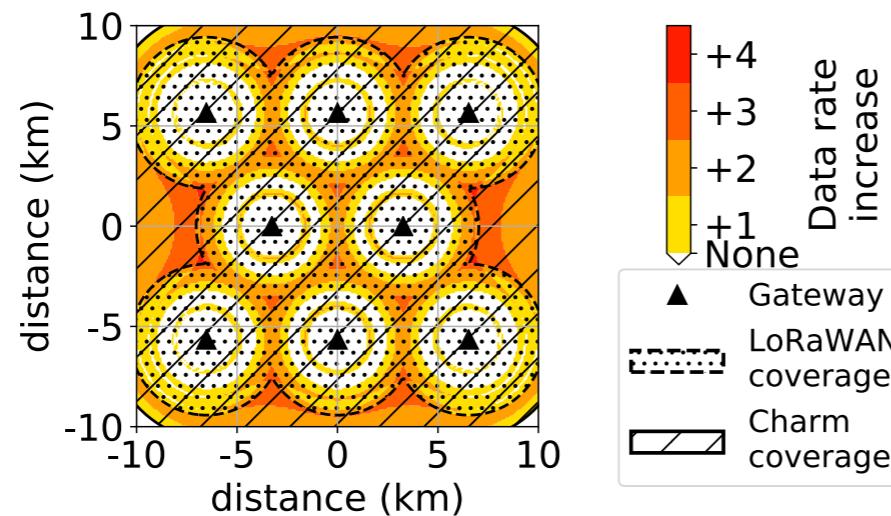
# Simulation: Dense Deployment



LoRaWAN



Charm

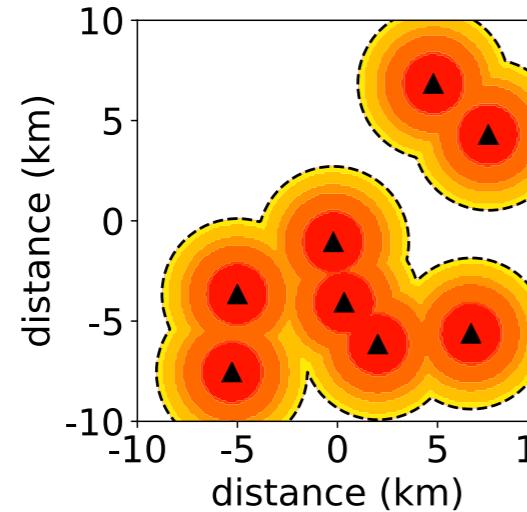


## Improvements

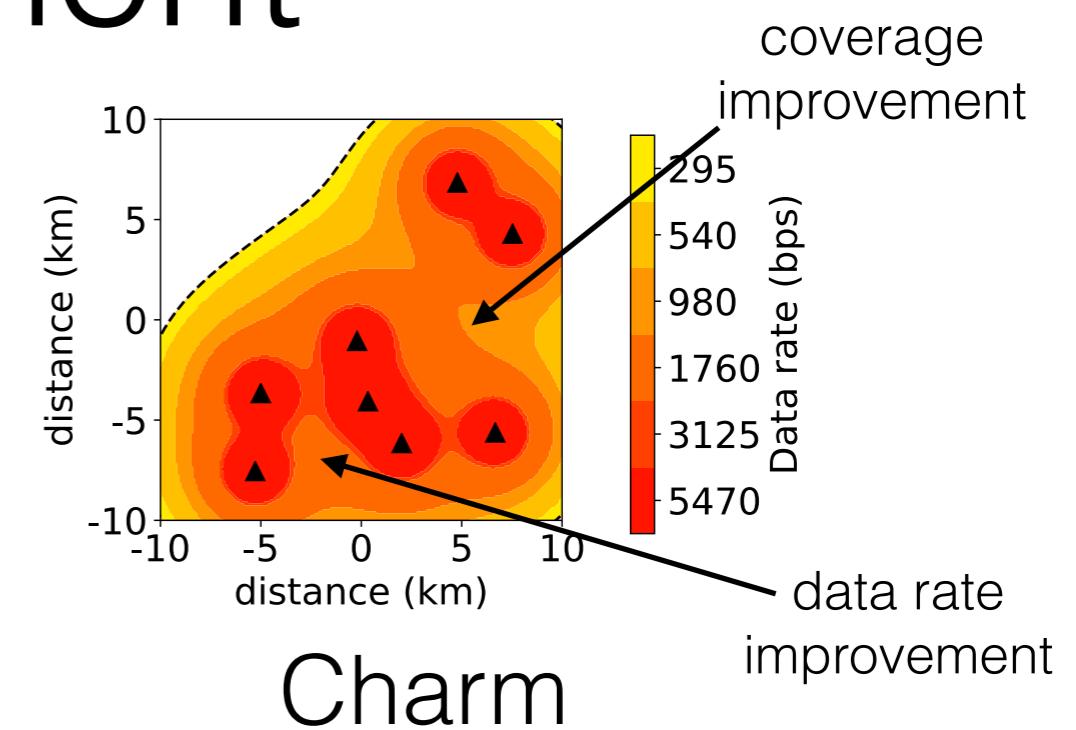
**Increase in coverage area:** 46.60%

Data Rate	Battery Life	Improved region (by area)
2x	2x	35.33%
4x	4x	22.30%
8x	8x	2.26%

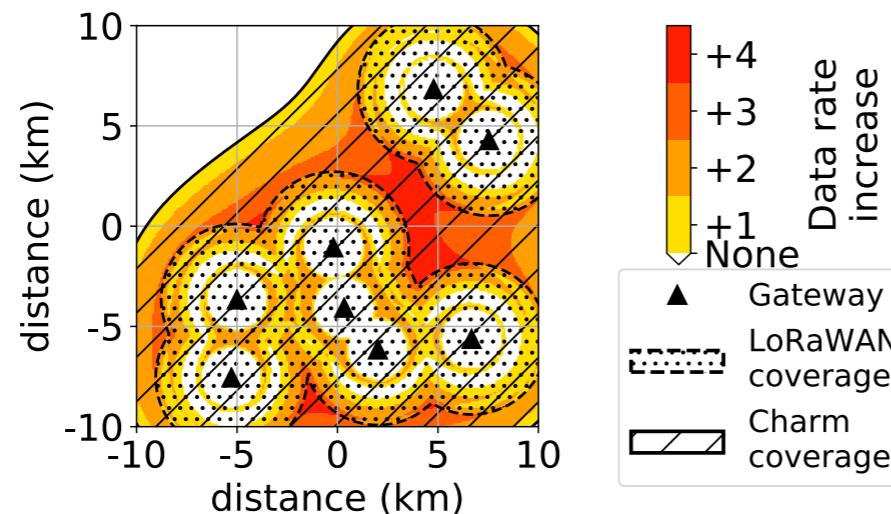
# Simulation: Random Deployment



LoRaWAN



Charm



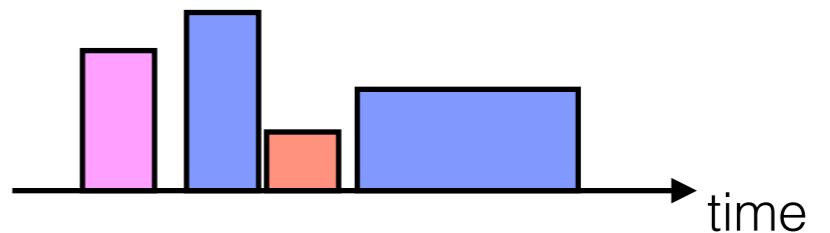
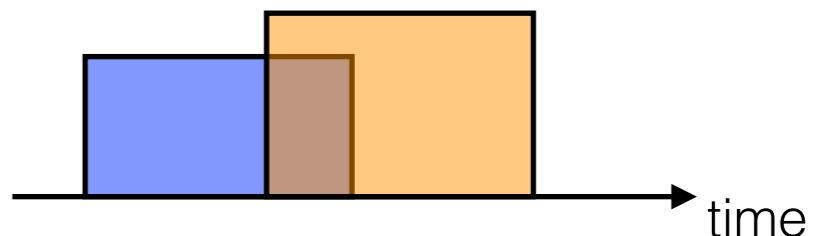
## Improvements

**Increase in coverage area:** 74.59%

Data Rate	Battery Life	Improved region (by area)
2x	2x	33.70%
4x	4x	25.82%
8x	8x	3.48%

# Future Work

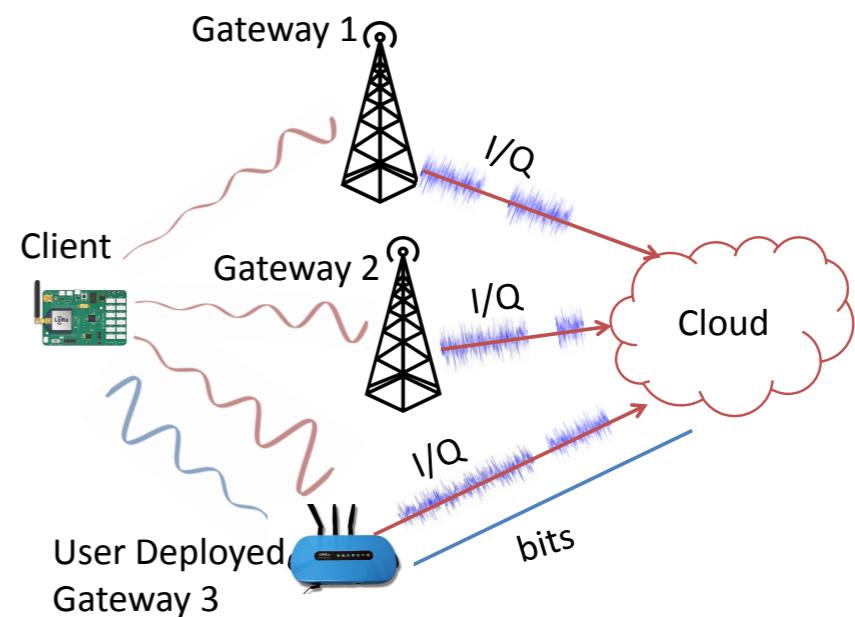
- **Collisions:** can we decode collisions?
- **Scalability:** can we avoid continuously streaming to the cloud?
- **Hardware Architecture:** how can we leverage new radio front-ends



Analog Devices  
ADALM-Pluto

# Conclusions

- Decode weak transmissions through coherent combining
  - Charm's two-phase protocol
  - On-demand upload - save bandwidth
  - Local packet detection - simplify synchronization requirements and computation
  - Selective combination - better scalability
- SDR-like auxiliary hardware to capture I/Q streams
- Performance
  - Improve coverage up to 98%
  - Improve battery life up to 8x
  - Effectively reduce coverage holes
  - No changes on low-power devices



# Thank you!

## Q&A

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