MAS.S60

How to Wirelessly Sense Almost Anything

Lecture 9: LP-WANs

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This Week in Wireless Sensing

5G

Sateliot plans 5G IoT launch

By **Martha DeGrasse** • Nov 10, 2022 11:22am

Sateliot | Verizon | Qualcomm | Telefonica

After launching a test satellite last year with Open Cosmos, Sateliot will launch its first commercial nanosatellite with SpaceX. (Pixabay)

How to Wirelessly Sense Almost Anything

sensing the physical world & transmitting data wirelessly

sensing via the wireless signals themselves

Objective of Today's Lecture

Learn the fundamentals, applications, and emerging technologies in LP-WANS

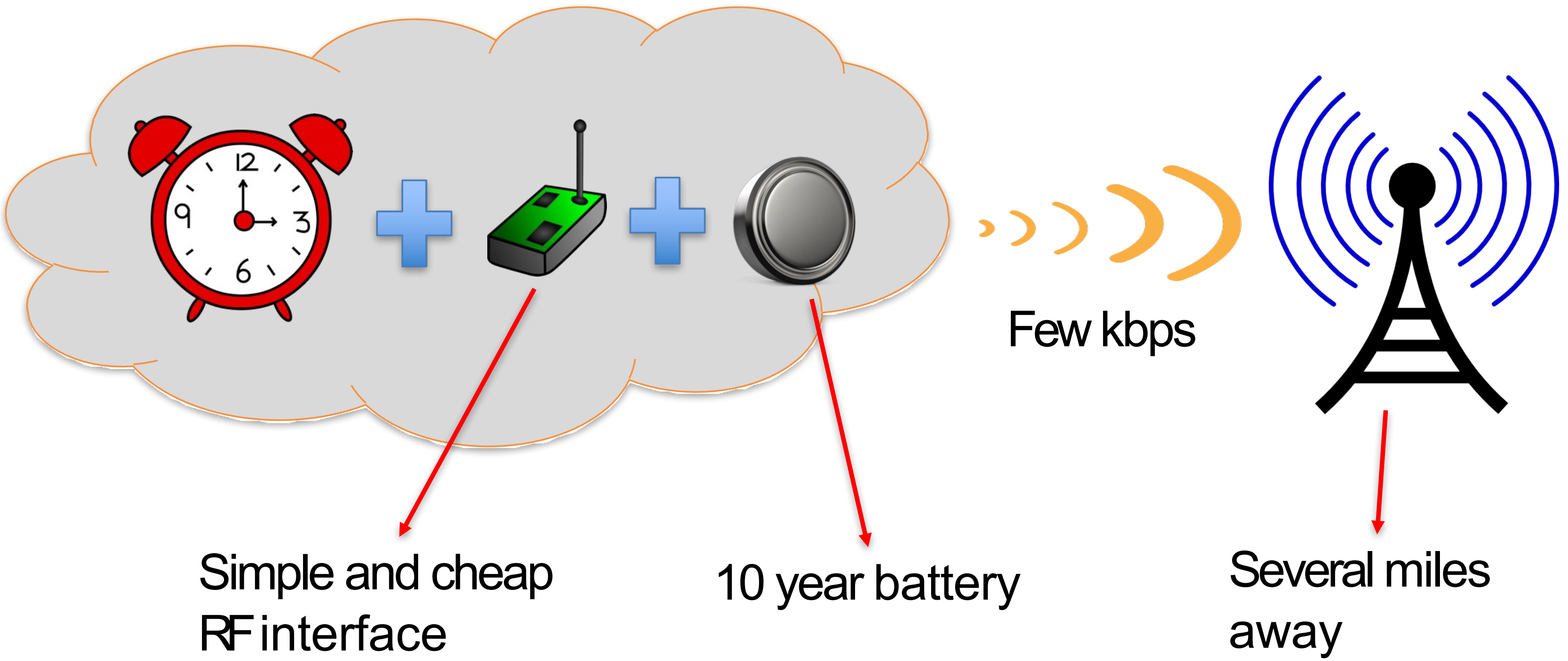
1. Why are LPWANs (low-power wide-area networks) and their applications?
2. What is LoRa and how does it work?
3. How can we increase the network throughout and range of LoRa?
4. How can we combine LoRa with backscatter?

Two Papers

Empowering Low-Power Wide Area Networks in Urban Settings, SIGCOMM’17

NetScatter: Enabling Large-Scale Backscatter Networks, NSDI’19

Imagine a world where every single object is connected to the Internet…

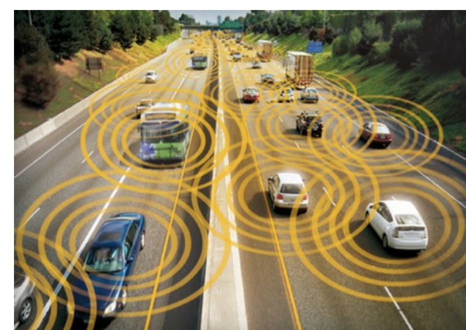


The building block for a city-scale Internet of Things...

Smart Infrastructure

Smart Homes

Smart Vehicles



Low-Power Wide-Area Networking (LP-WAN)

How is it different from other standards (WiFi, BLE, cellular)?

Low-Power Wide-Area Networking (LP-WAN)

How is it different from other standards (WiFi, BLE, cellular)?

Long Range	Low Data rate	Low Cost	Low Power
• Up to 10 KMs in rural areas	• Order of kilobits per second	• < $5	• Up to 10 years of battery life

Initiatives from Industry (LoRa, SIGFOX) and standardization bodies (3GPP LTEM, NBIoT)

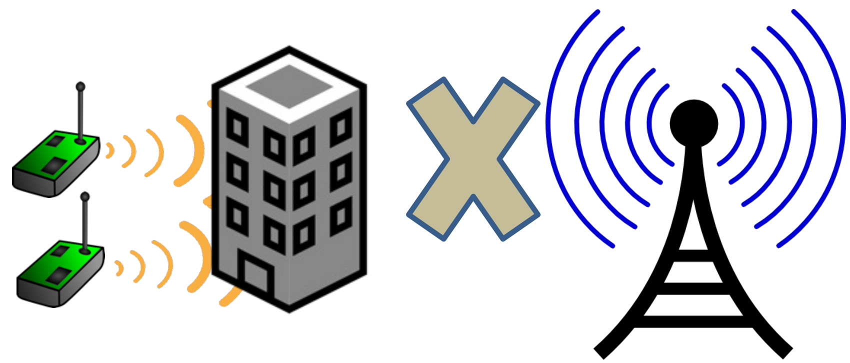
Key Challenges

Key Challenges

Interference

Collisions emerge from the **sheer** density of nodes and the **simplicity** of the current MAC protocols (e.g., transmit as soon as wakeup)

Range



LPWAN ranges drop by 10x in **urban** areas due to excessive multipath, shadowing, etc.

Choir

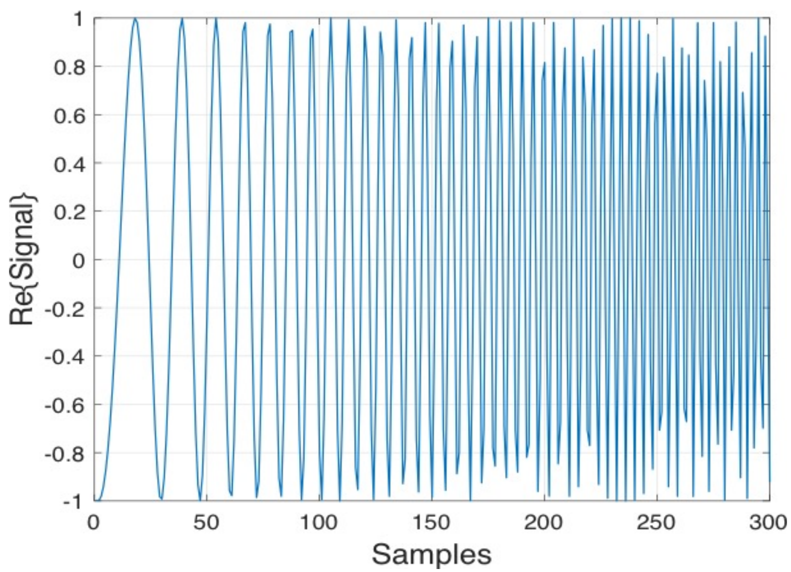
Scalability	Range	Preserving simplicity
• Decodes 10's of collided transmissions	• Extends the range of teams of cooperating nodes	• Fully implemented at a **single-antenna** base station

Fully implemented and evaluated on

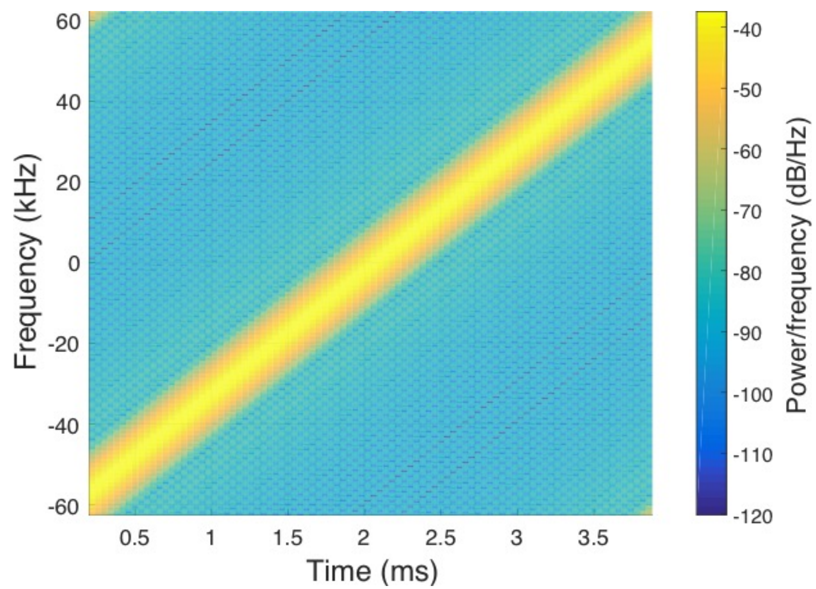
LoRaWAN™ base station over an area of 10 Km^2 in Pittsburgh

LoRaWAN™ : Chirps

Chirp in T.D.



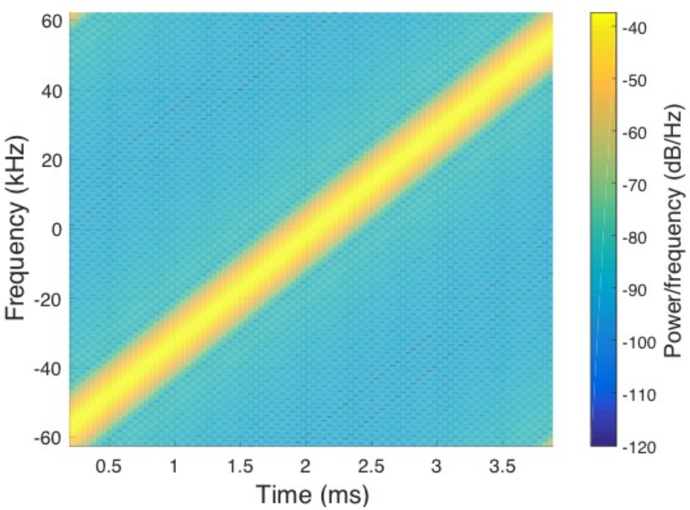
Chirp on a spectrogram



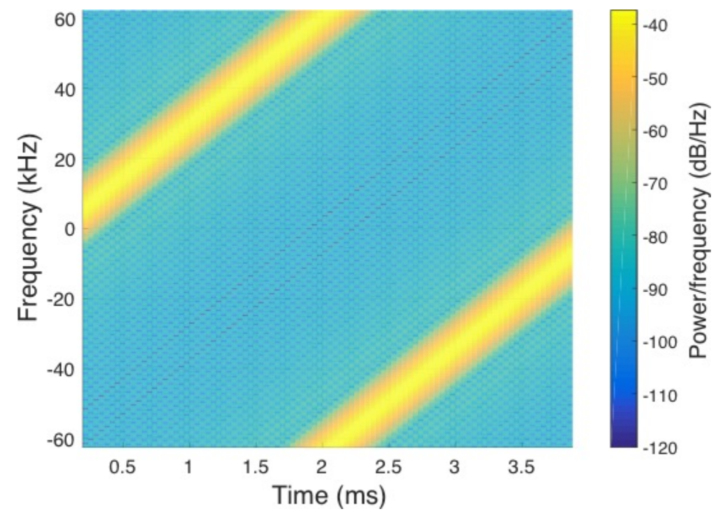
Data encoding

The initial frequency of the chirp

LoRaWAN™ : 1-bit encoding



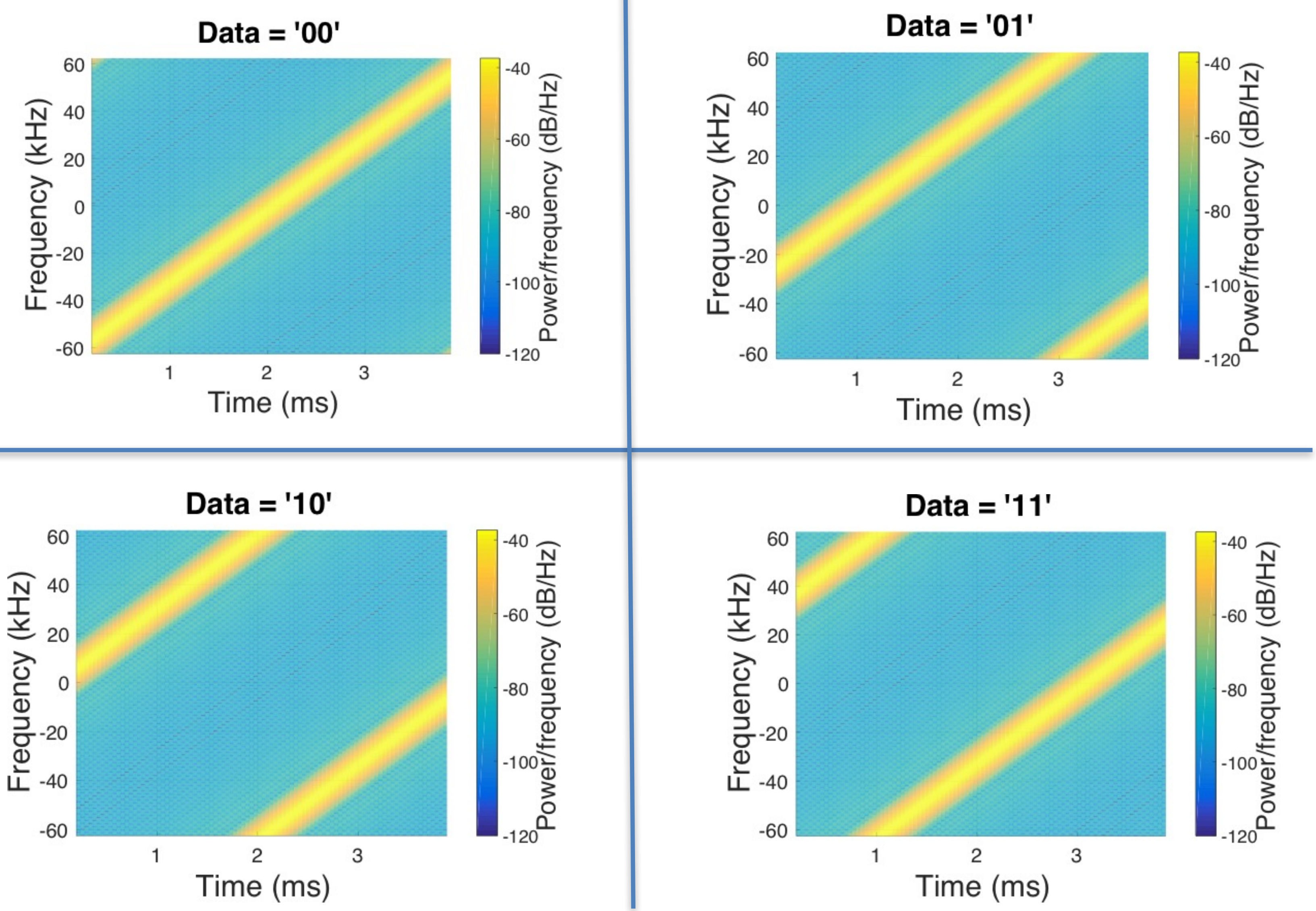
'0'



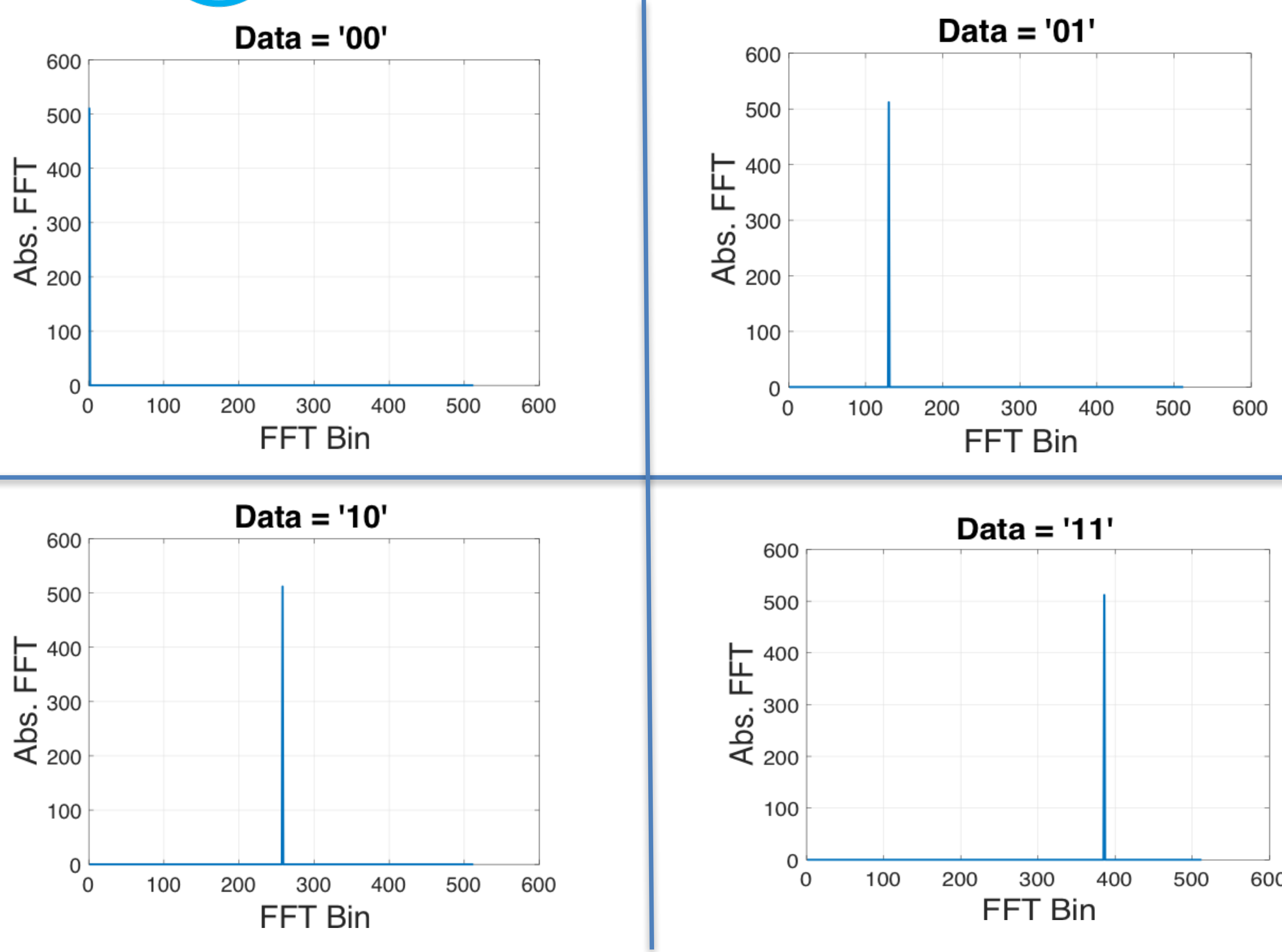
'1'

In general, n **bits -> divide the BW to** 2^n **initial frequencies**

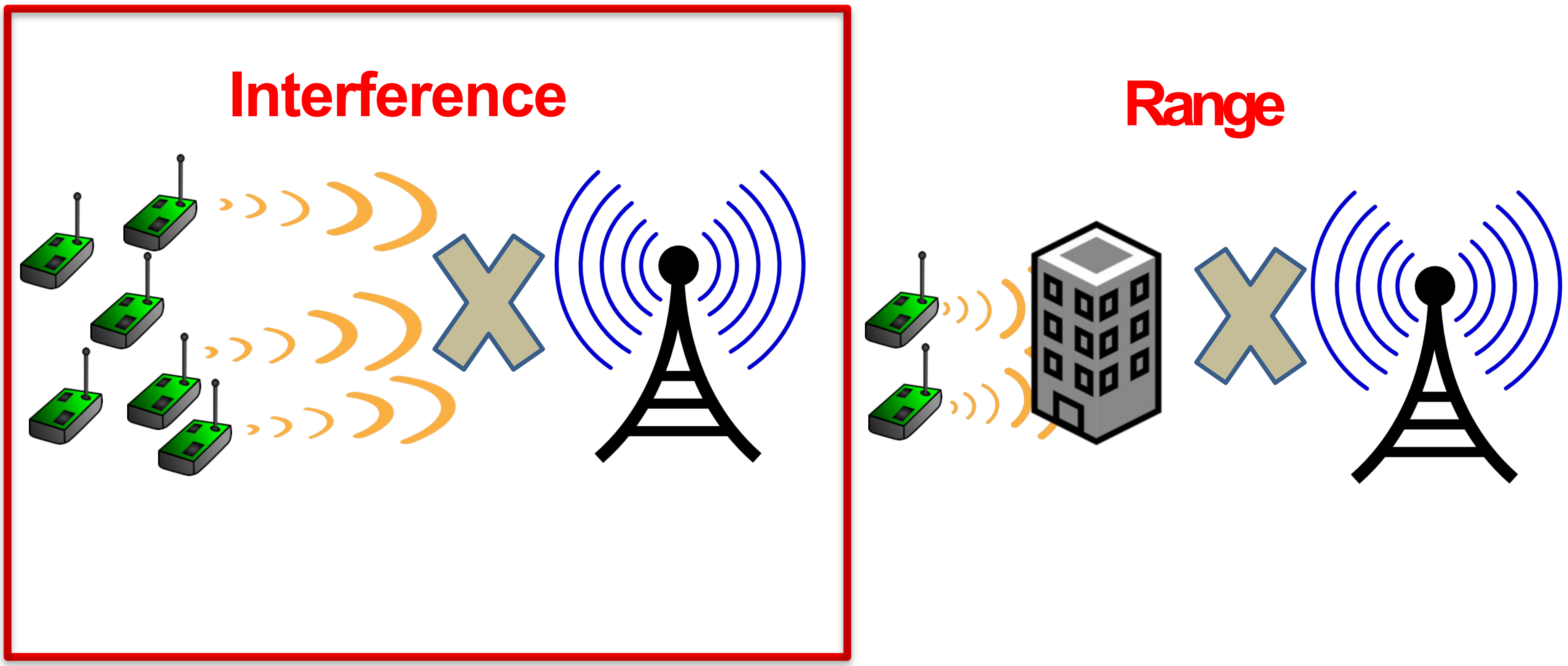
LoRaWAN™ : 2-bit encoding



LoRaWAN™ : 2-bit encoding

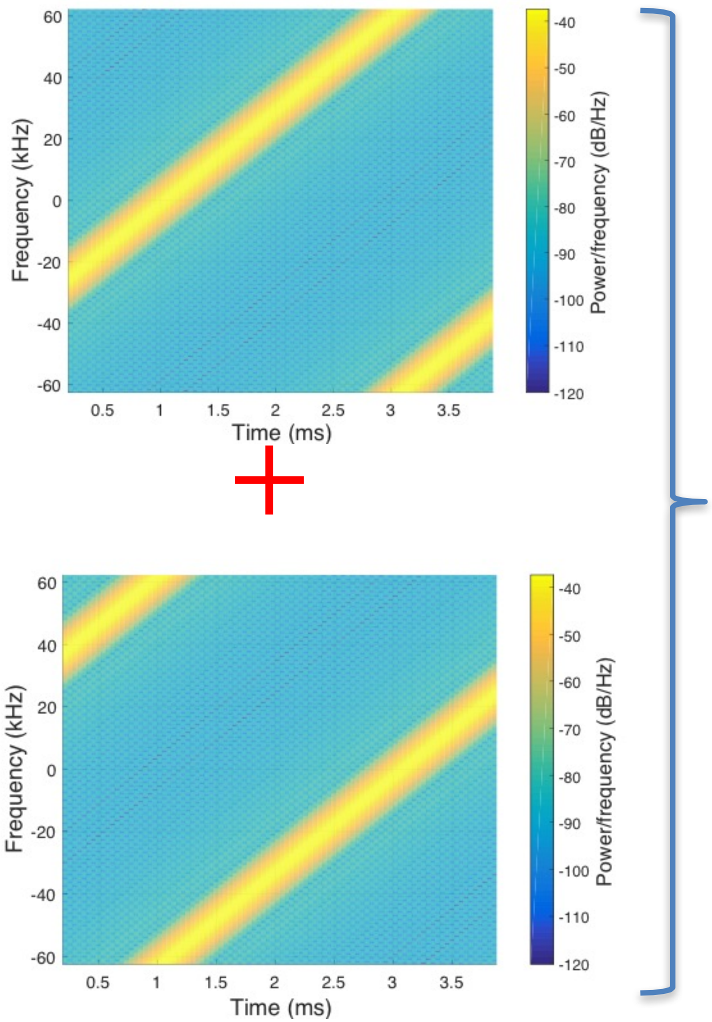


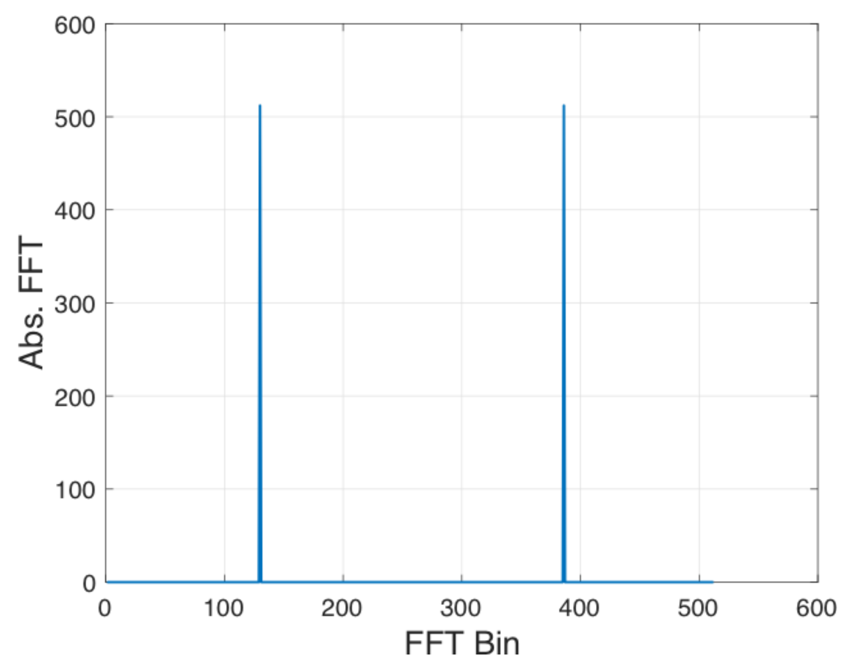
Choir in action



Collision of chirps

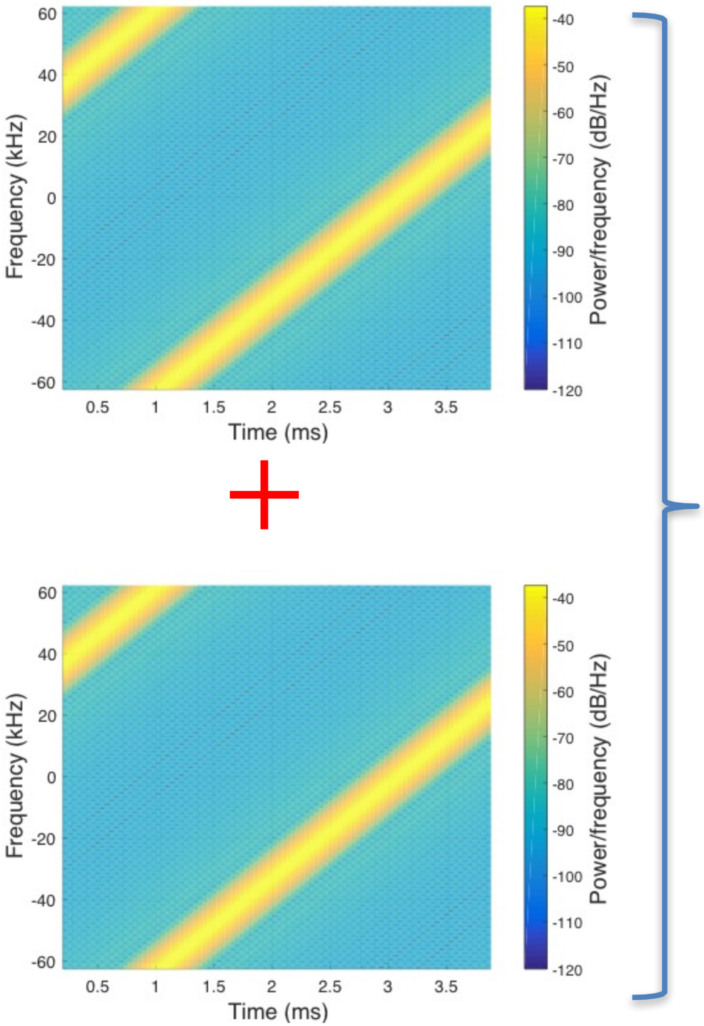
Different data

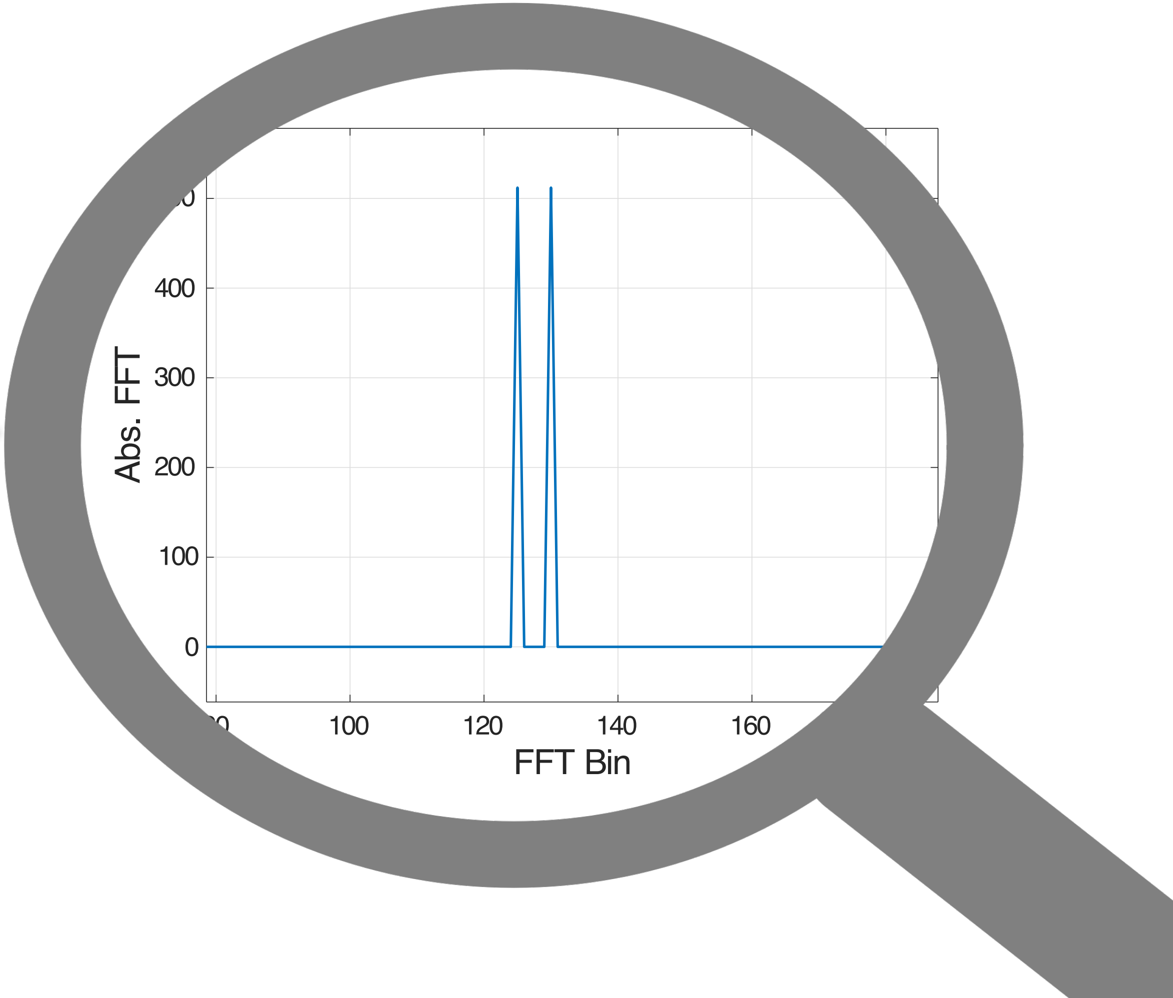




Collision of chirps

Same data





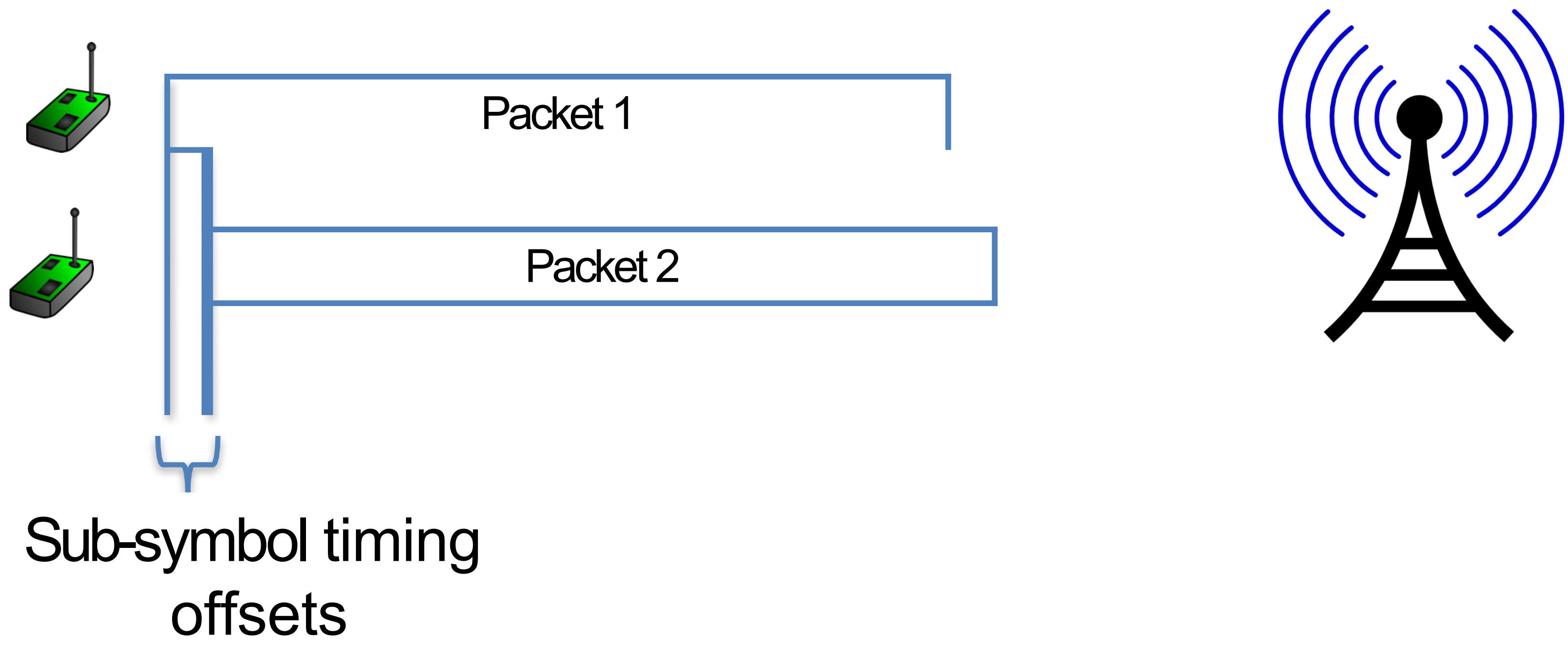
Hardware imperfections

Carrier frequency offsets (CFO)

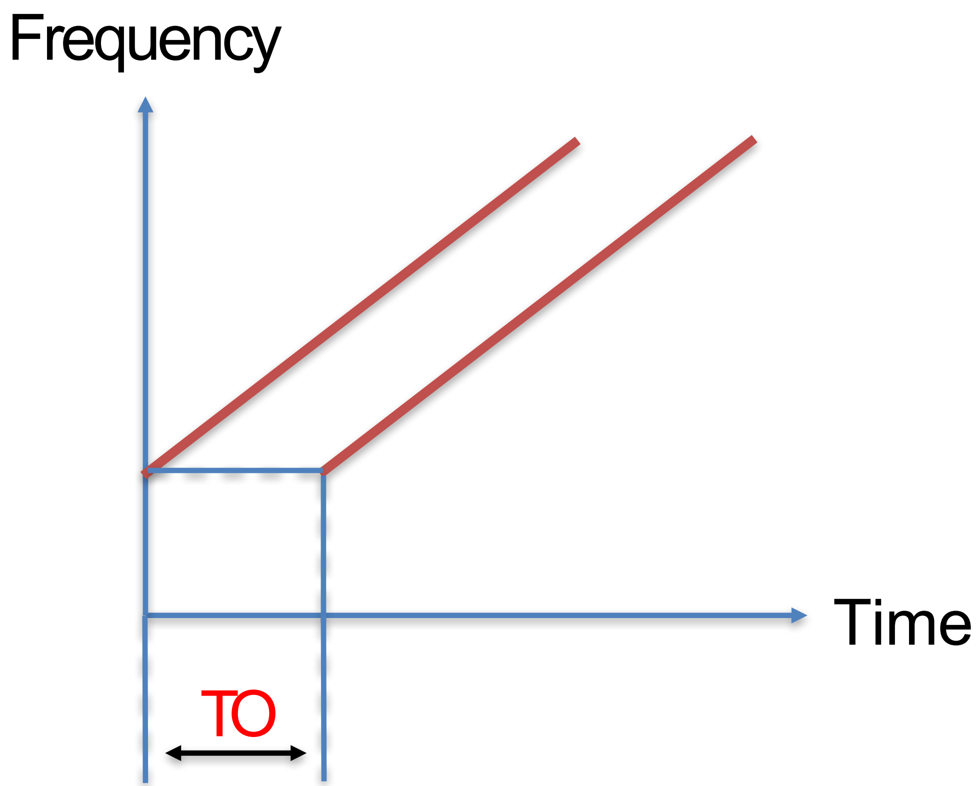
Local oscillator mismatch

Hardware imperfections

Timing offsets (TO)



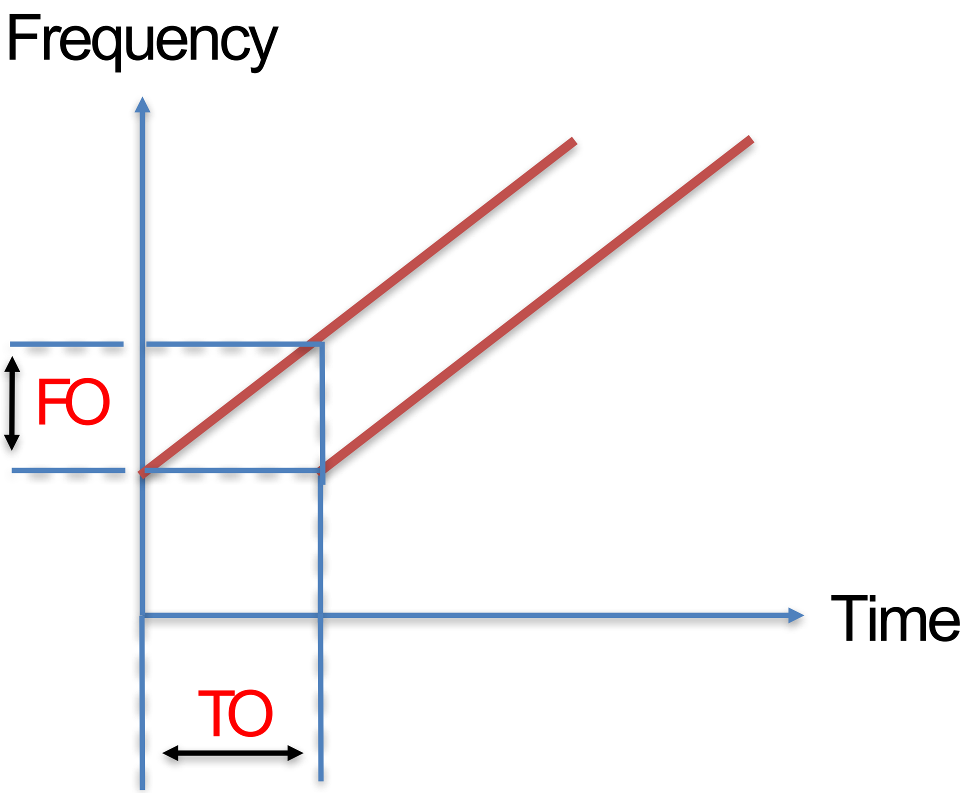
Timing offsets (TO)



Recall

Chirps are signals whose frequency increases linearly with time

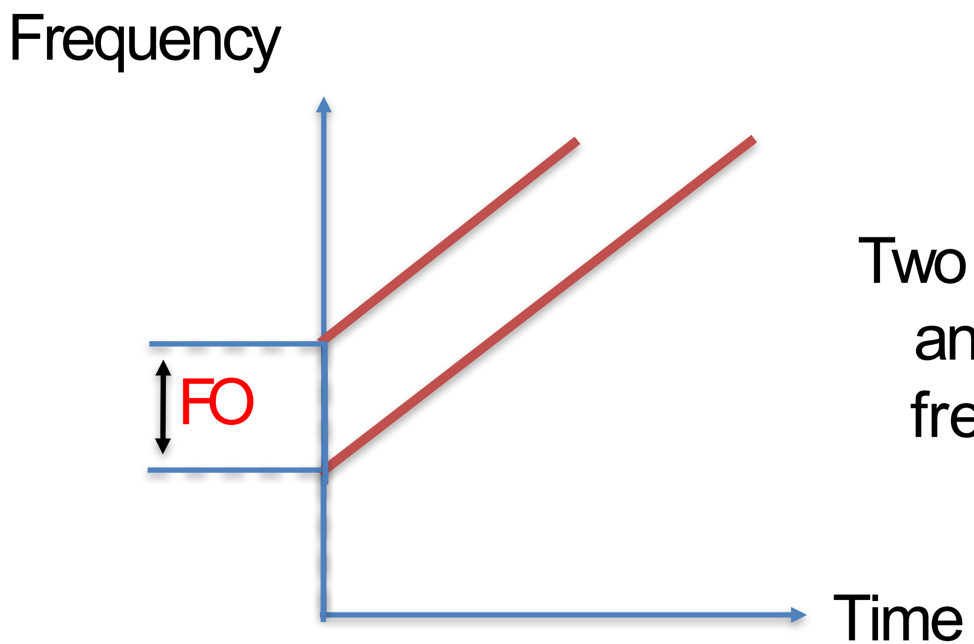
Timing offsets (TO)



Thus,

An offset in time maps to an offset in frequency!

Timing offsets (TO)

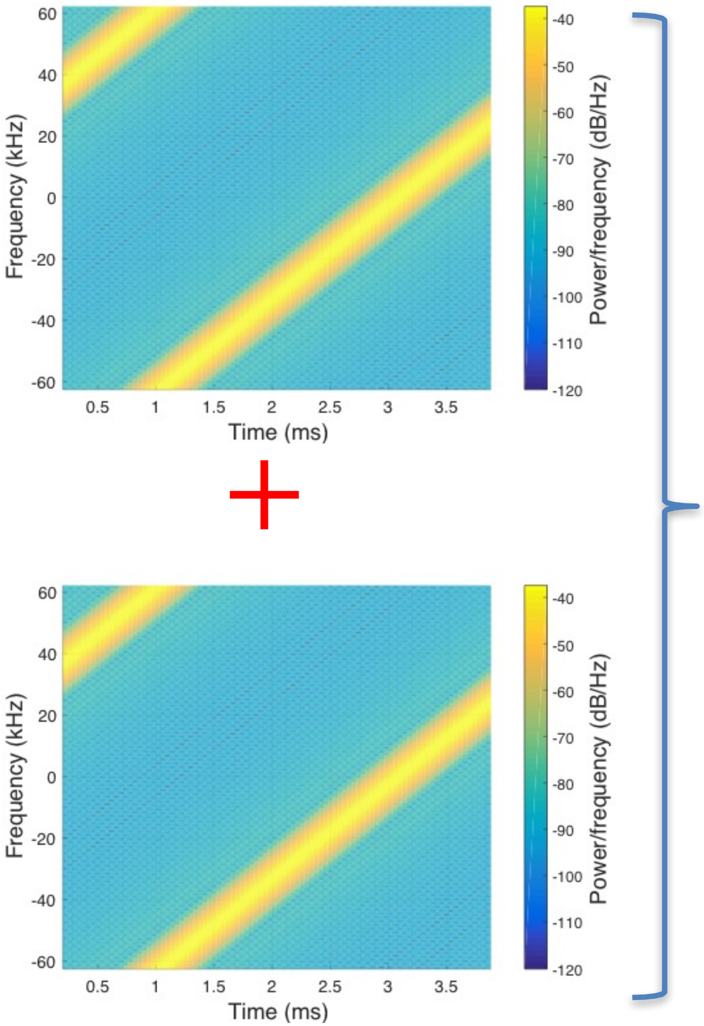


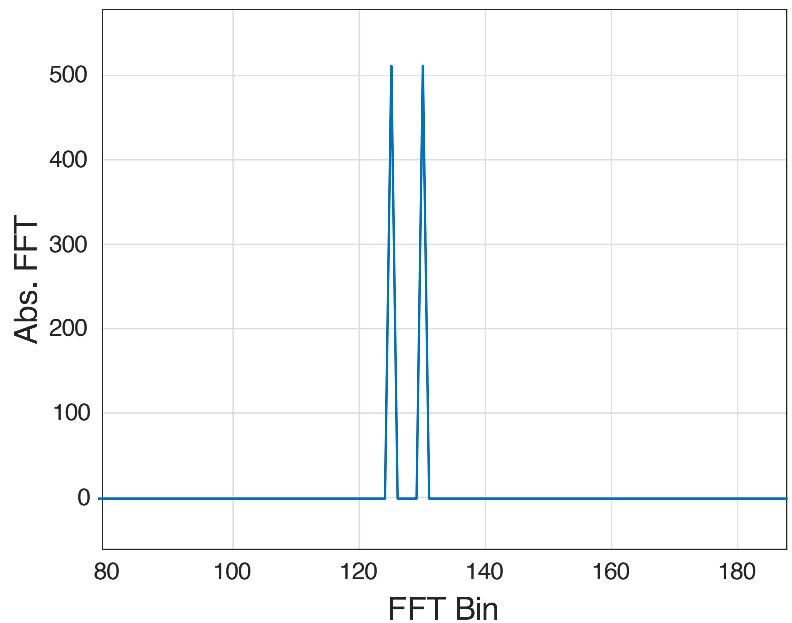
Two chirps with an offset in frequency!

Hardware offsets := { CFO + TO}

Collision of chirps

Same data





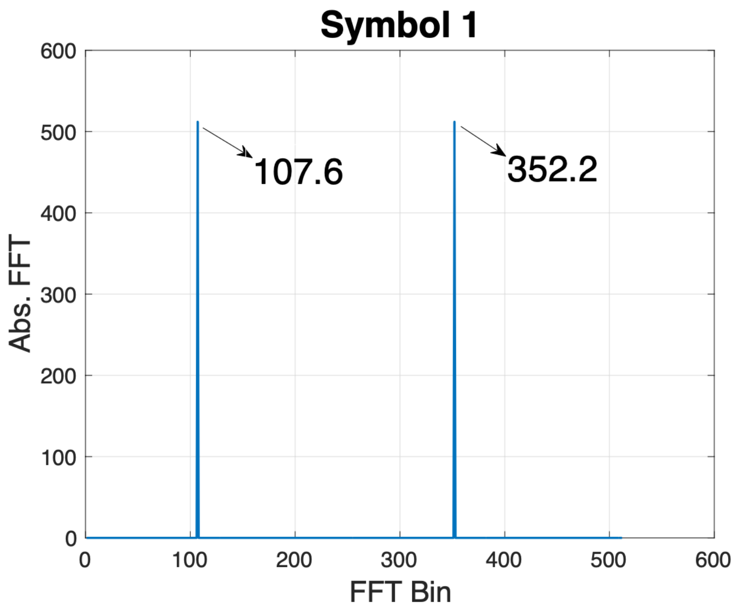
Hardware offsets!

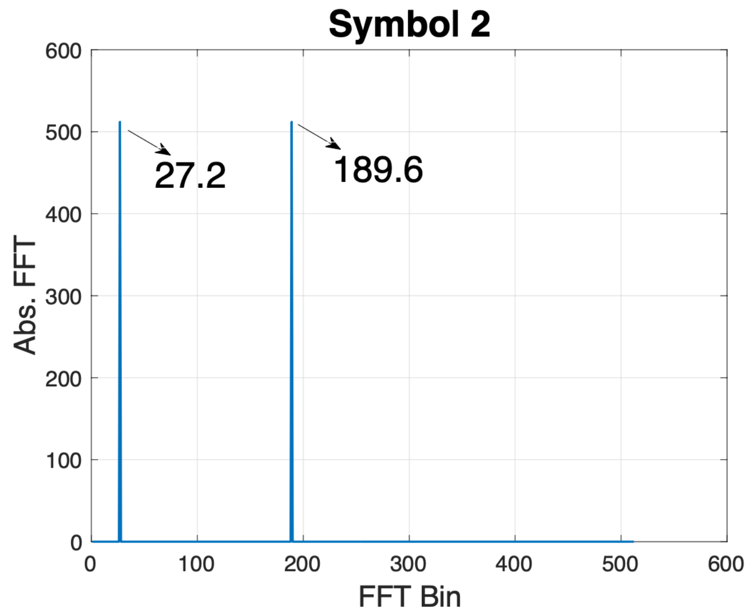
idea

Exploit hardware imperfections to resolve collisions!

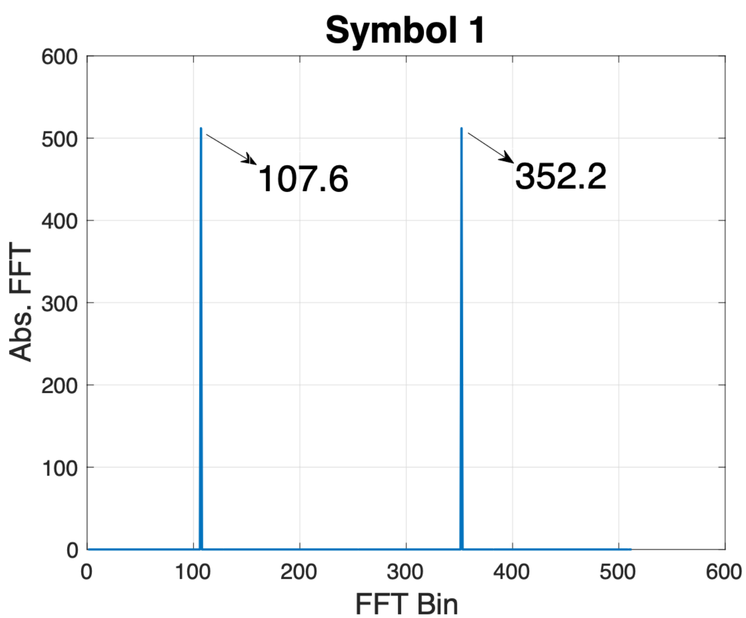
Which peak corresponds to which user?

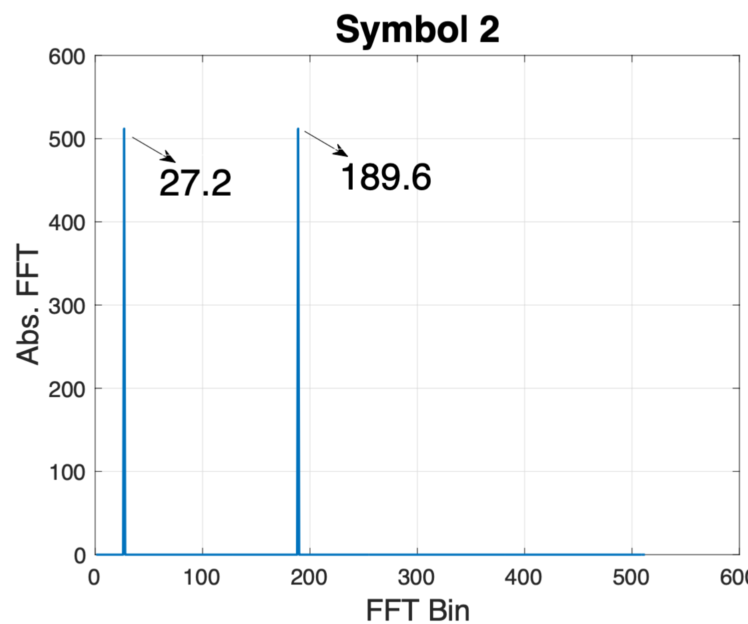
Which peak corresponds to which user?





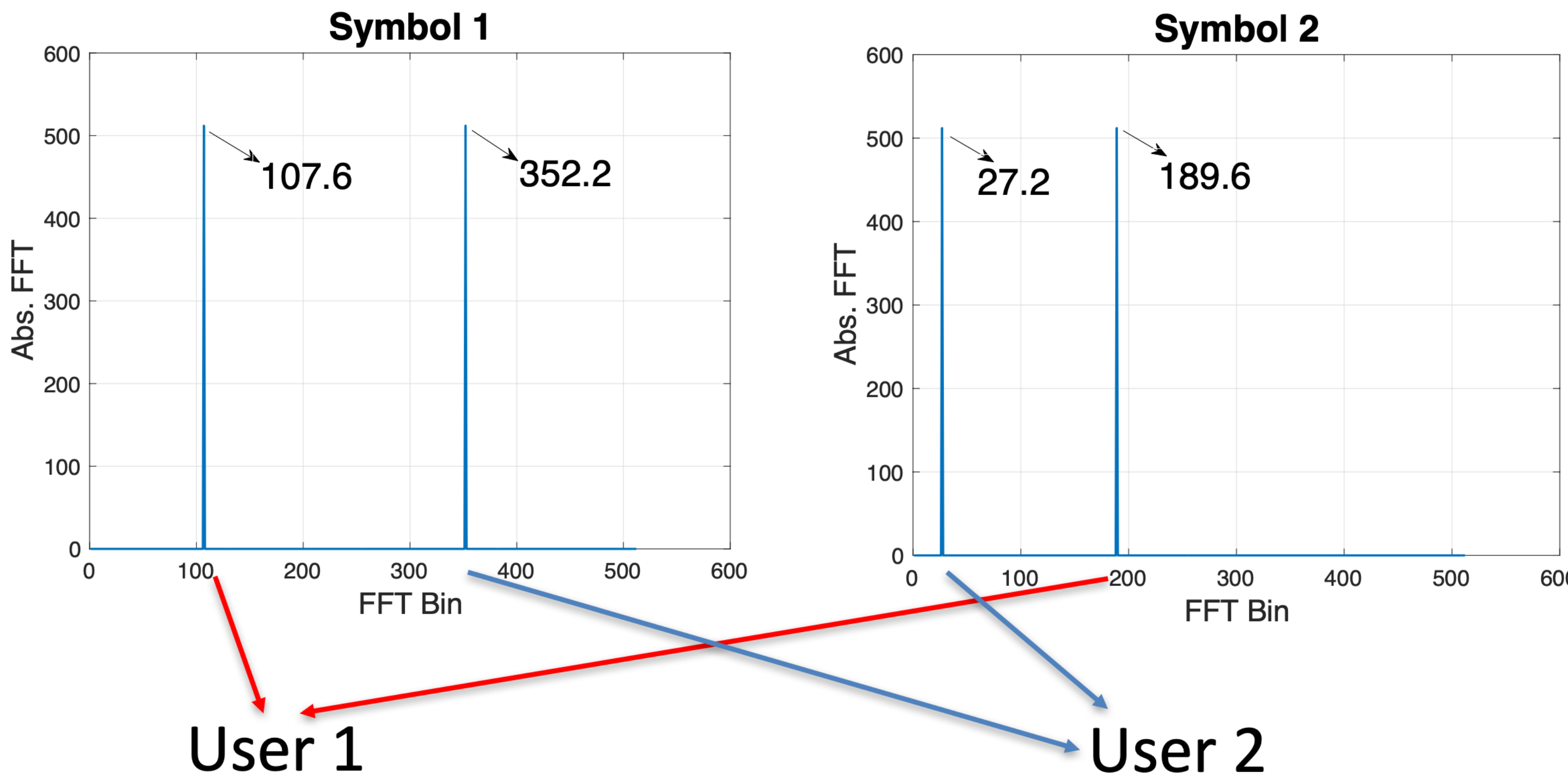
Which peak corresponds to which user?





Data bits are discrete, hardware offsets are continuous!

Which peak corresponds to which user?

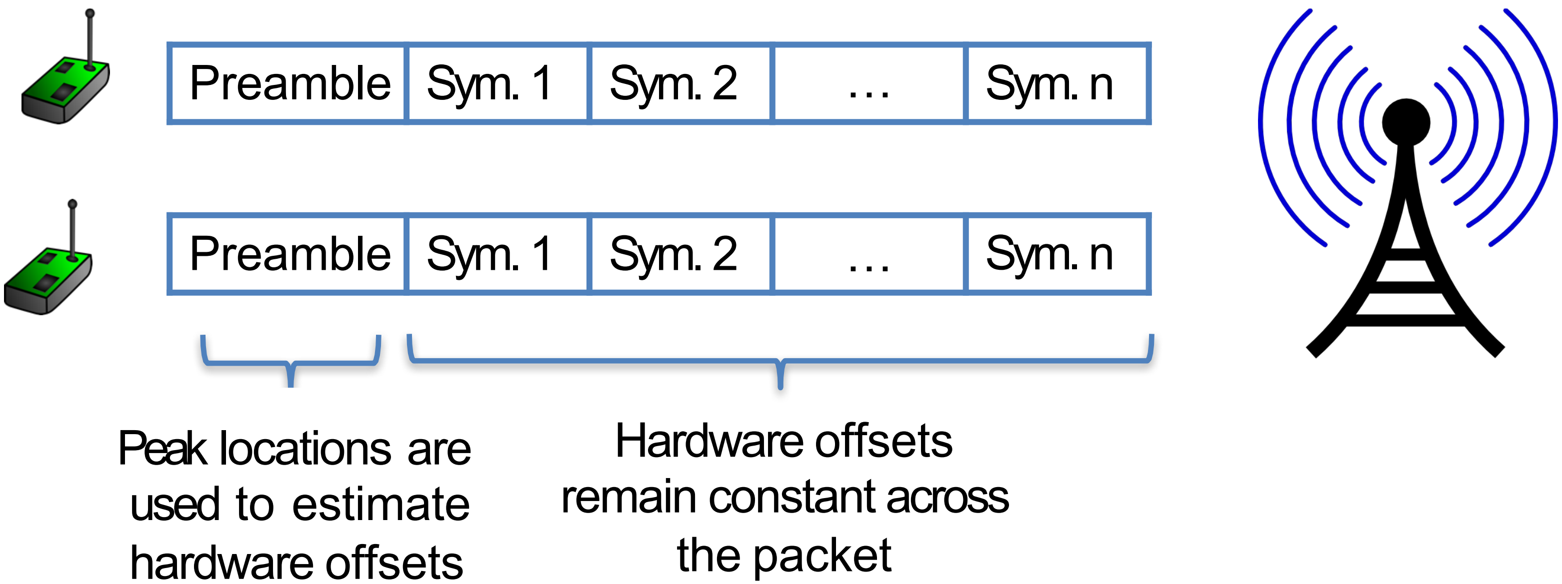


Integer part depends on both data and hardware offsets

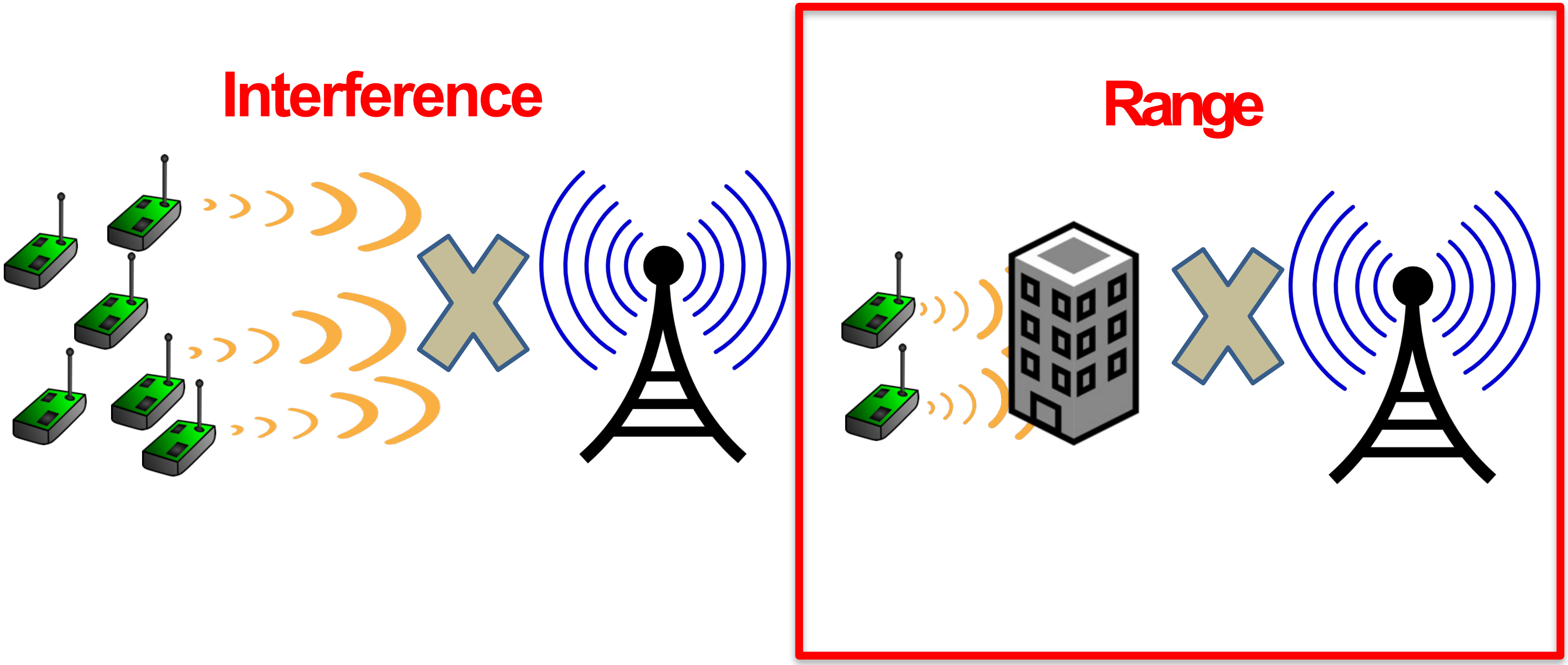
Fractional part depends only on hardware offsets

How to know which user is which?

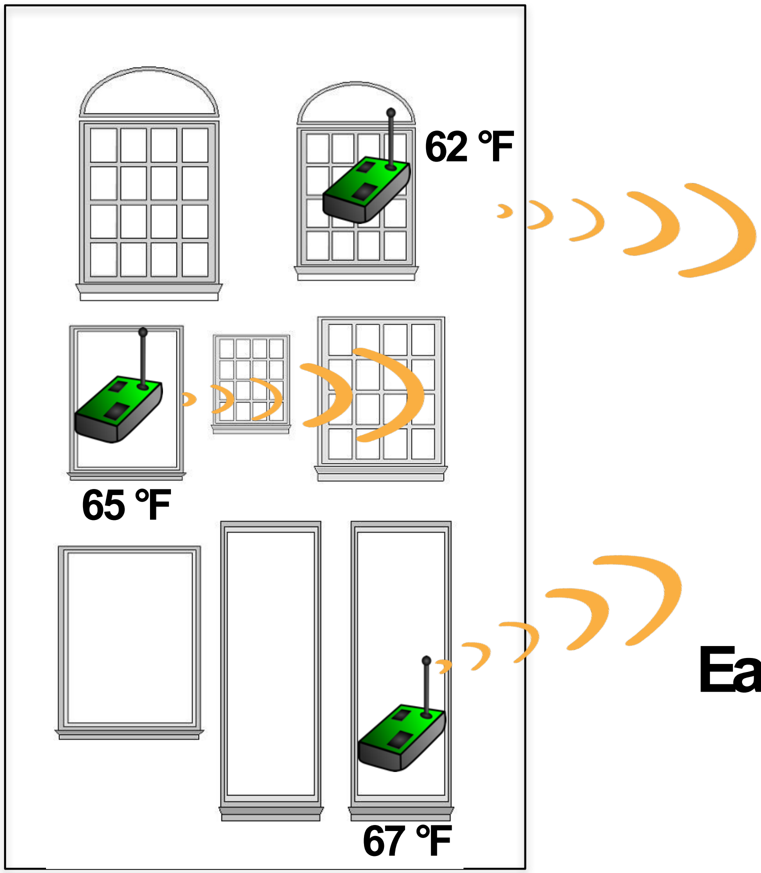
Use preambles with ID

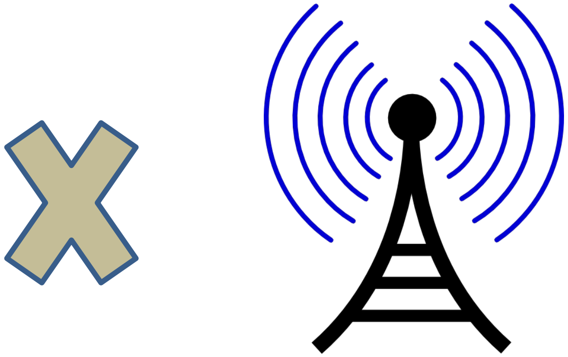


Choir in action



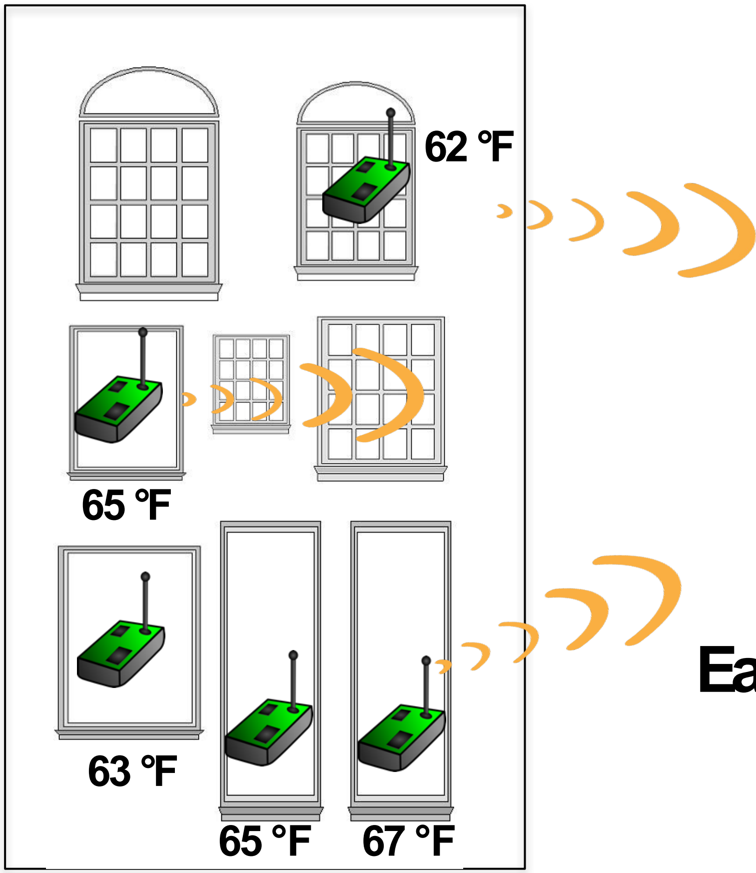
Range Extension

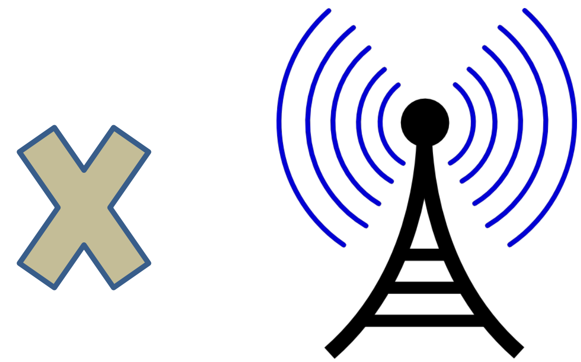




Each node is out-of-range!

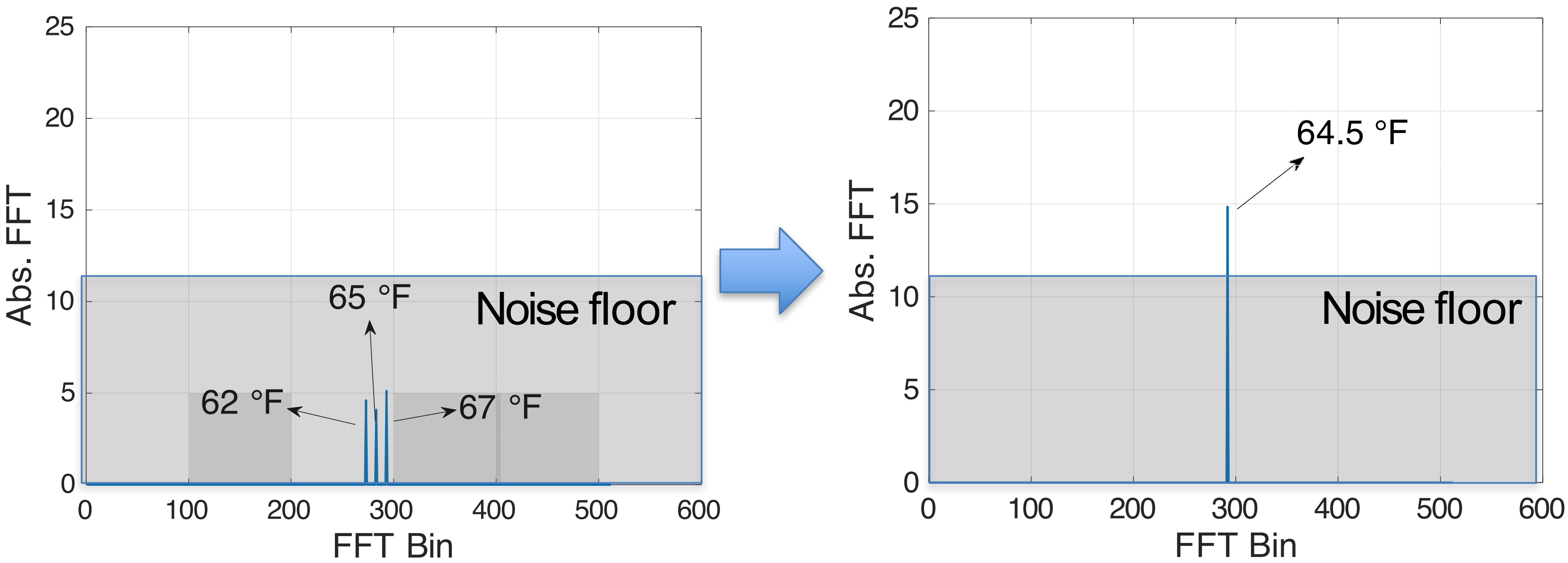
Range Extension





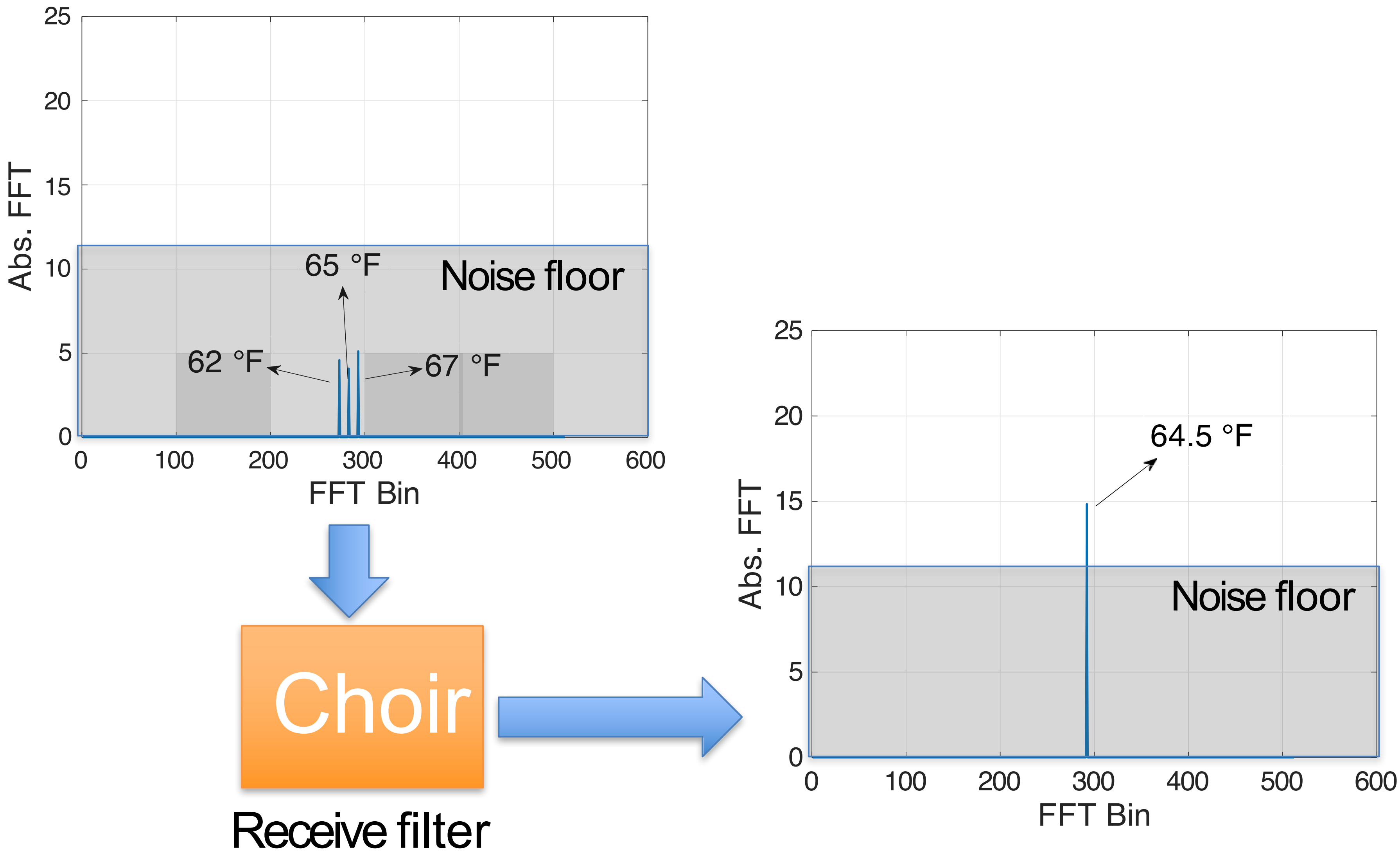
Each node is out-of-range!

Can we exploit data correlations to obtain a coarse-grained view of the sensed data?



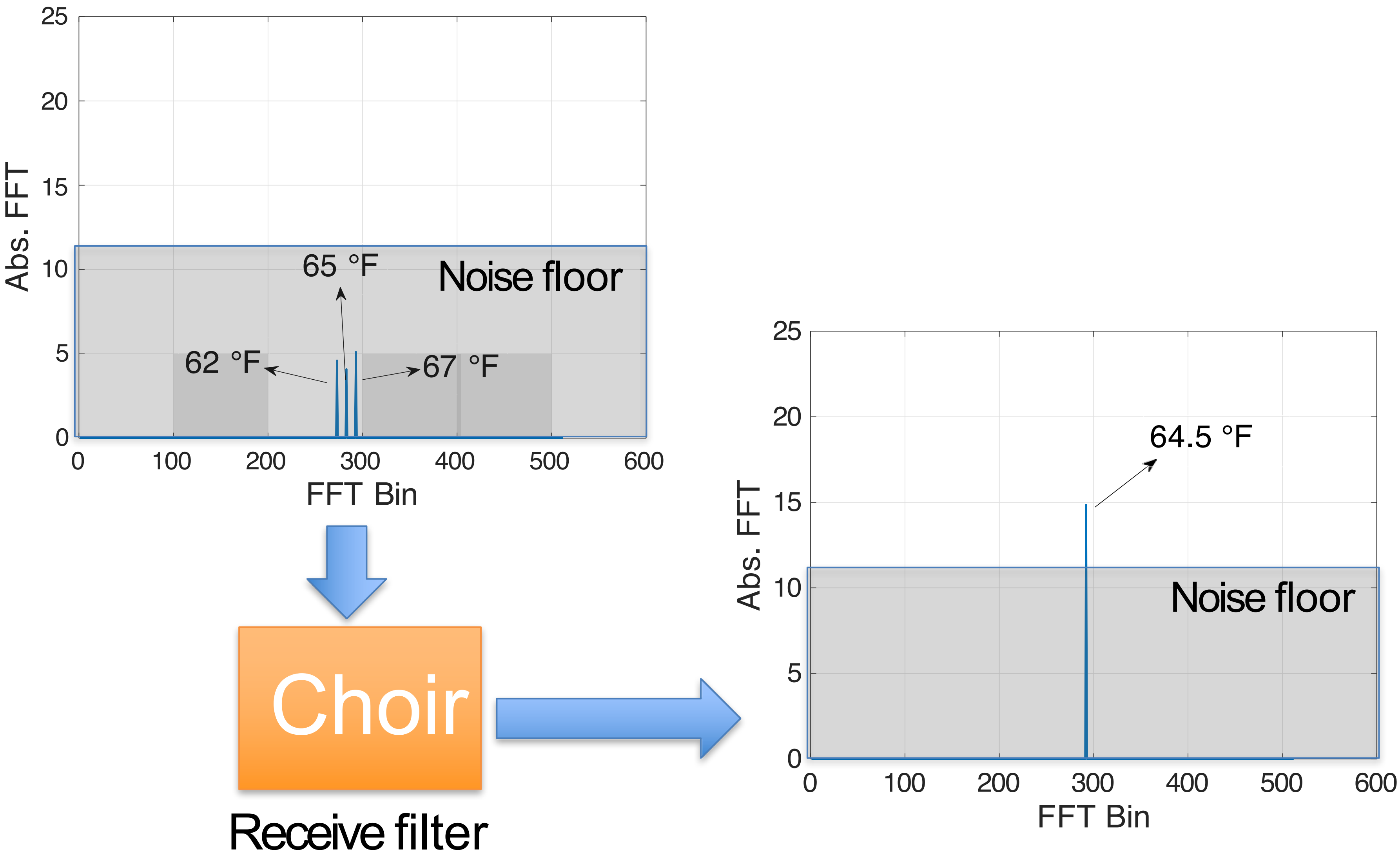
Objective

Coalesce these peaks around an aggregate value



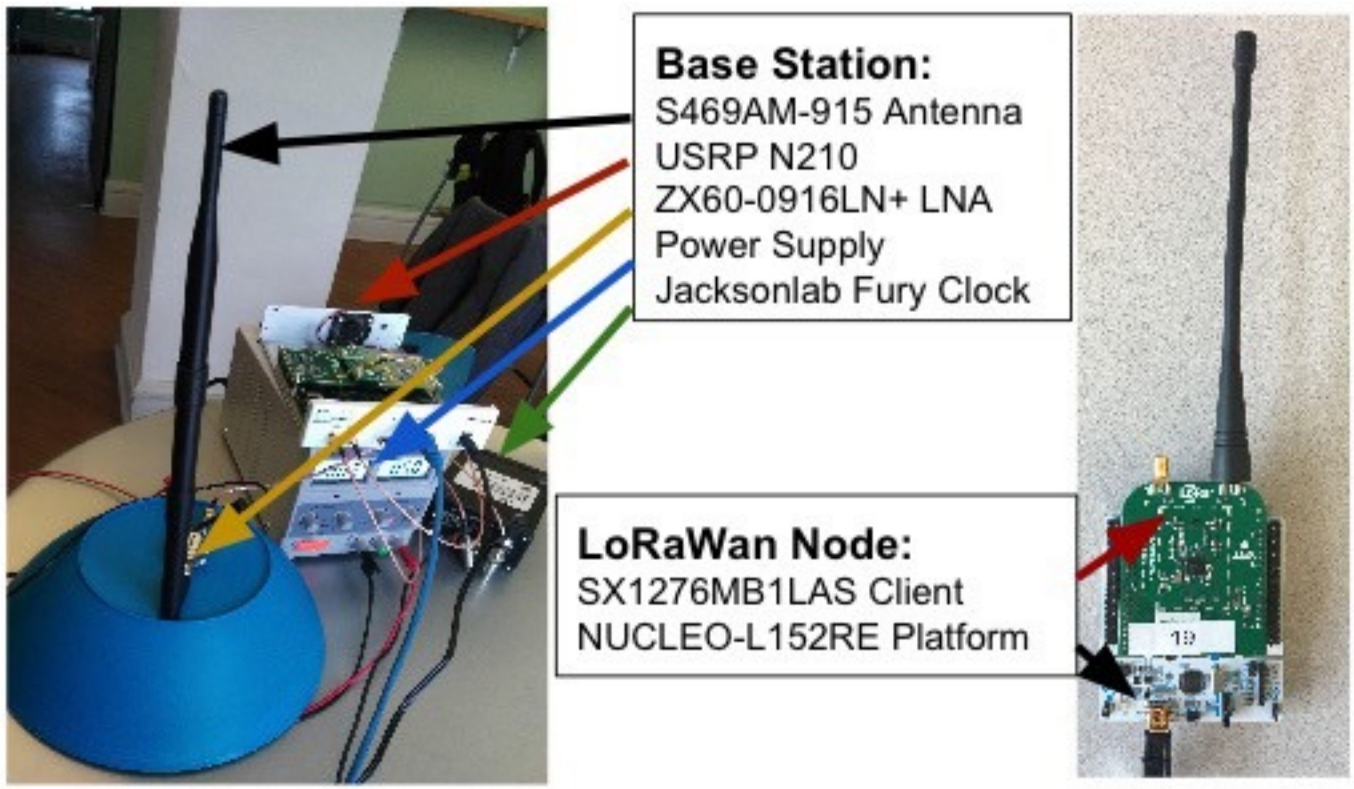
Approach

Signal processing based on exploiting frequency offsets to coalesce transmissions

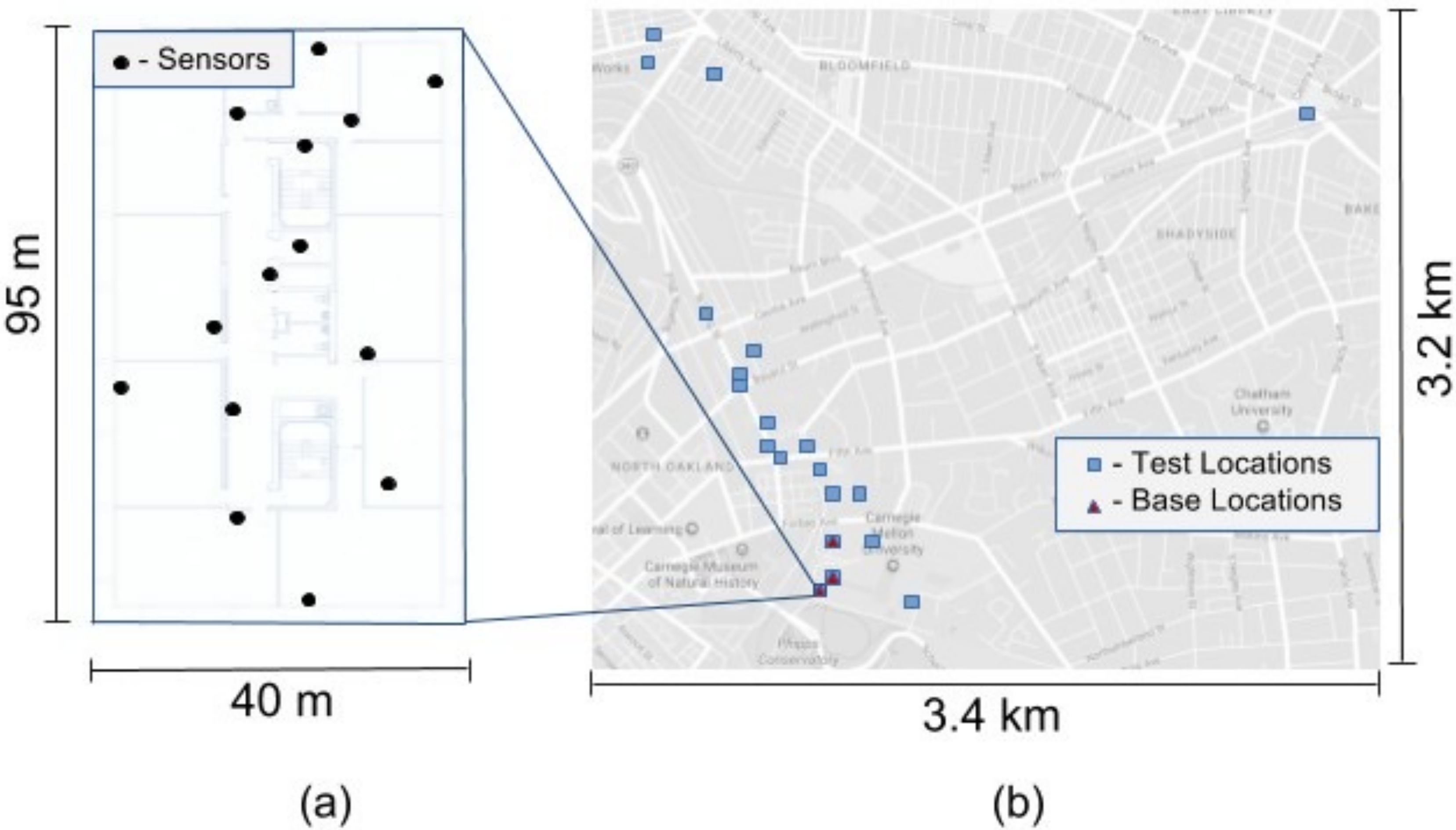


Details in the paper...

Implementation

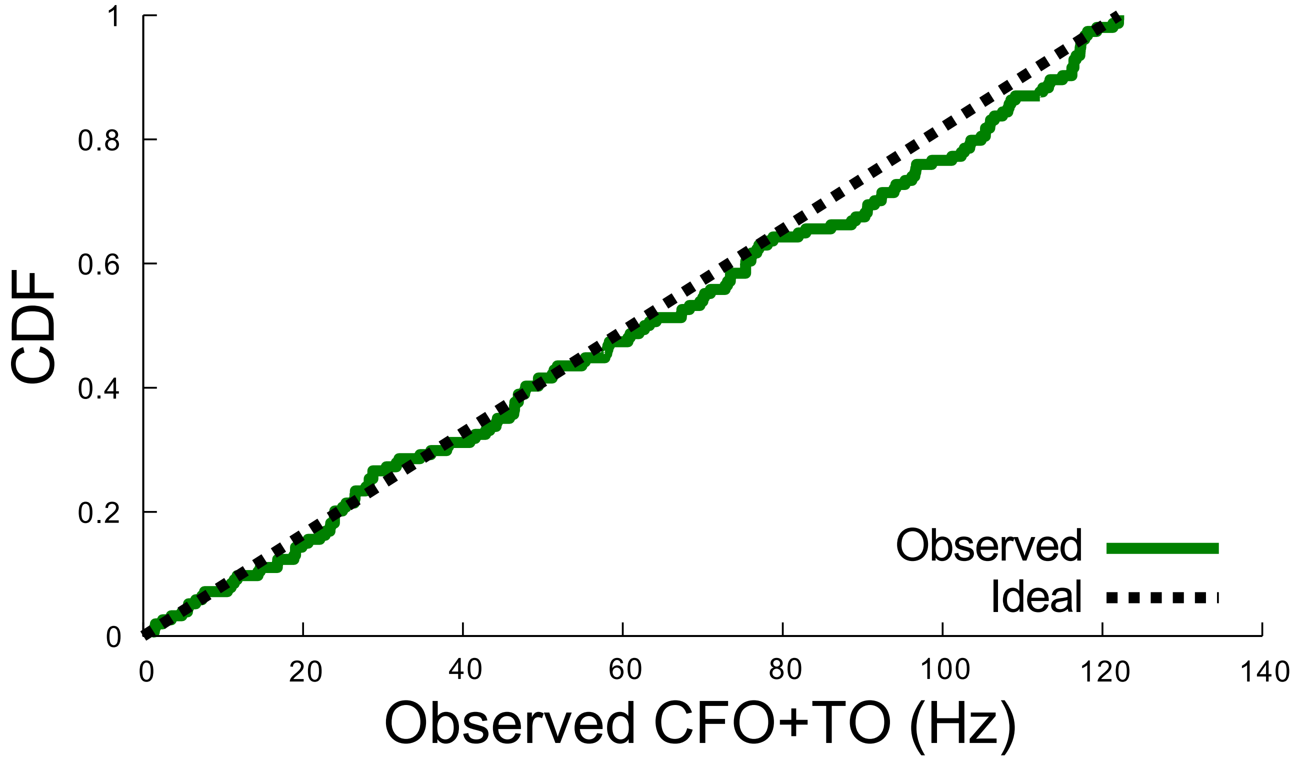


Evaluation



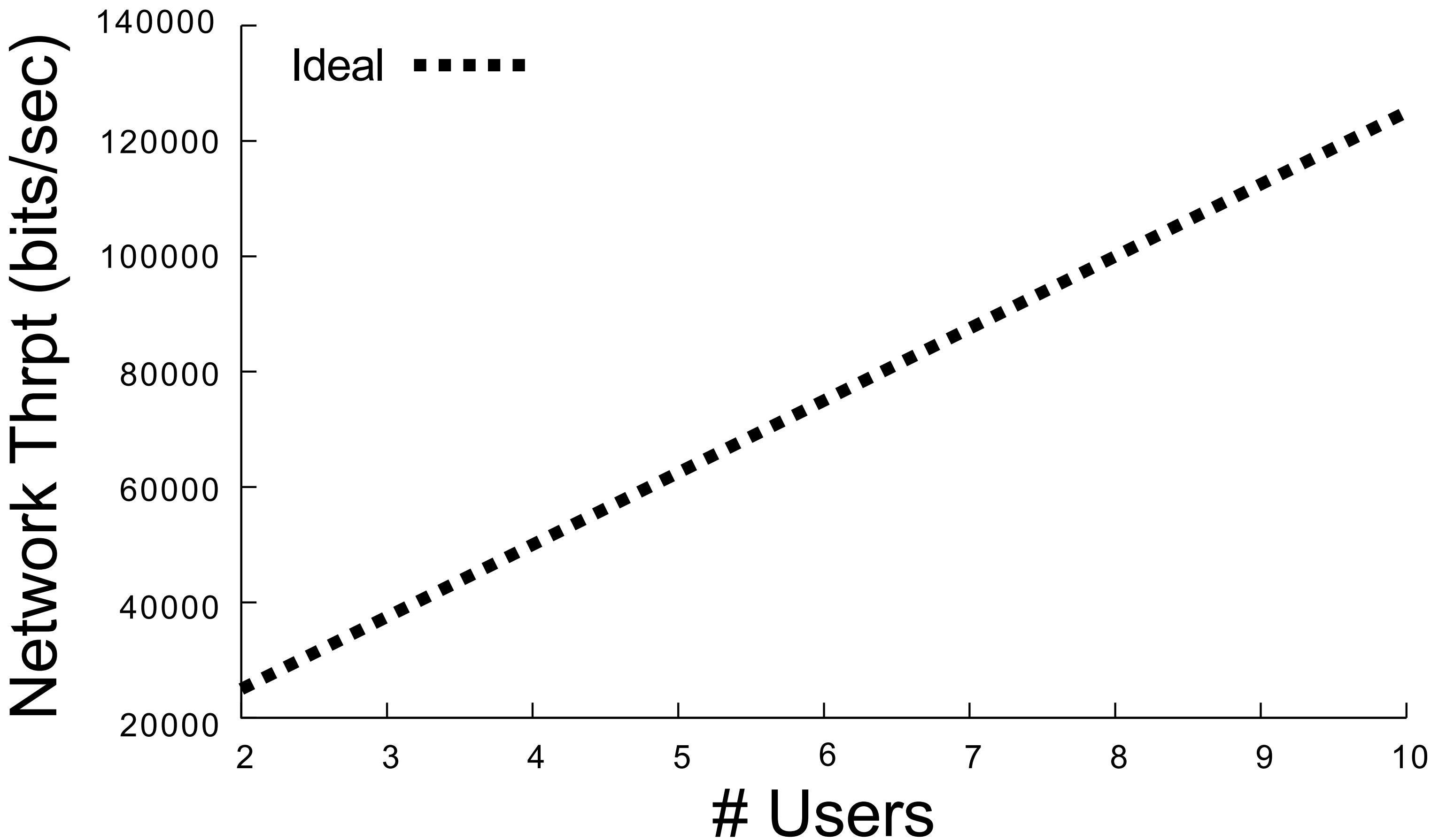
- Sensors
95 m
40 m
- Test Locations
- Base Locations
3.2 km
3.4 km
BLOOMFIELD
SHADYSIDE
NORTH OAKLAND
Carnegie Mellon University
Carnegie Museum of Natural History
Chatham University
(a)
(b)

Hardware offsets

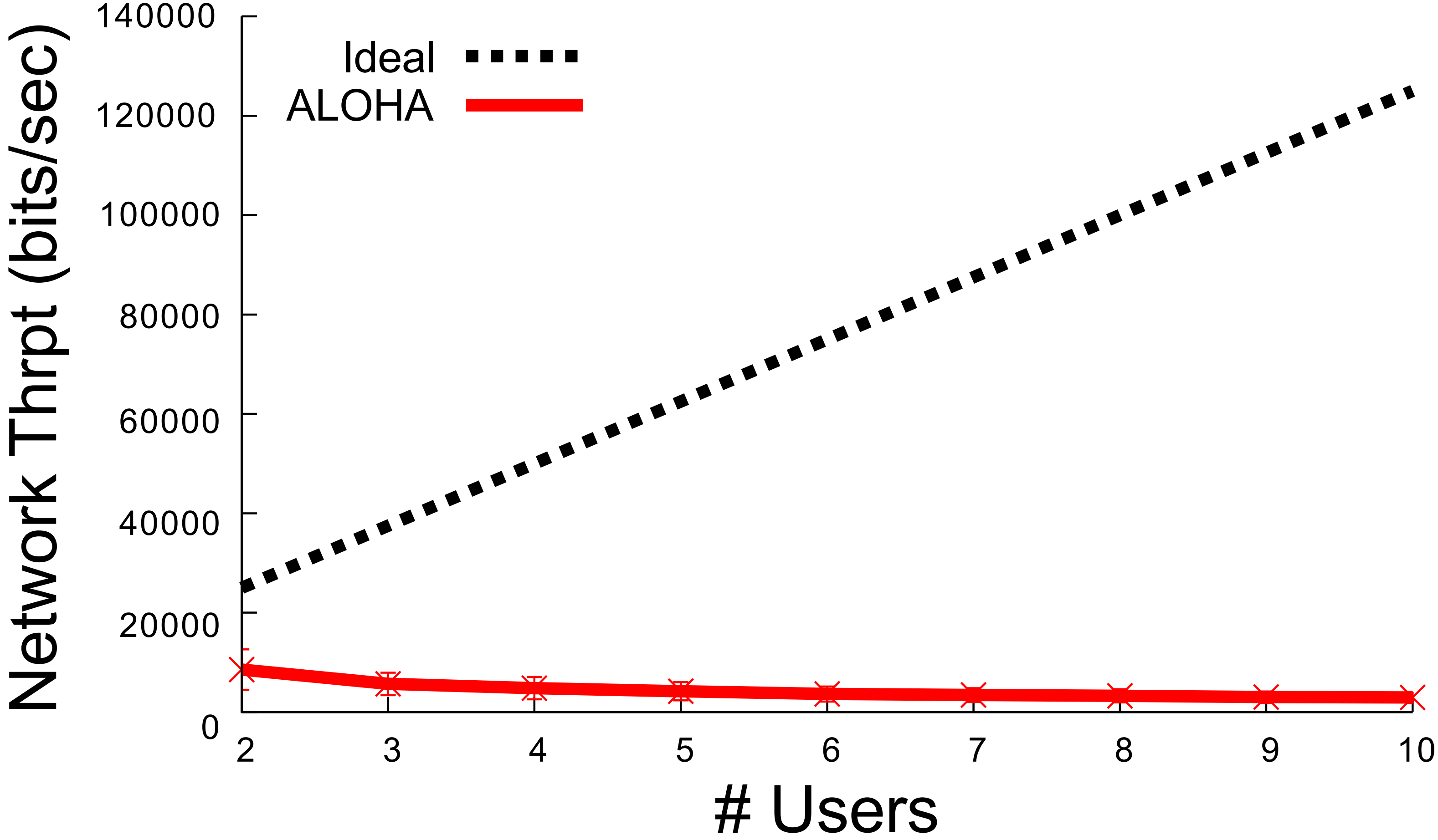


Hardware offsets are truly diverse across LPWAN radios

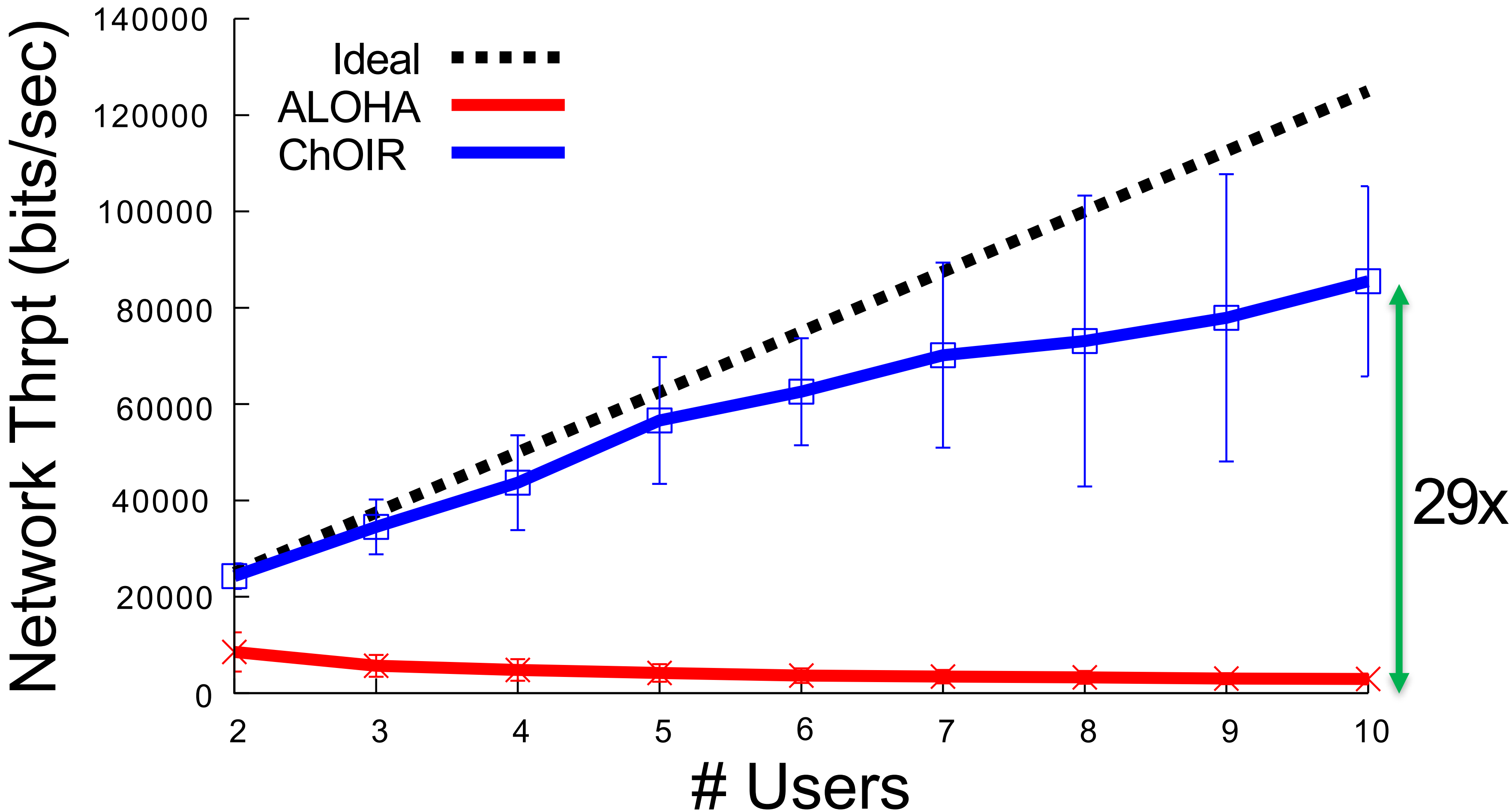
Resolving interference



Resolving interference



Resolving interference



Extending range

Number of collaborating nodes	Range
1	1 Km
10	2.5 Km
30	2.65 Km

2.65X

NetScatter

- First backscatter protocol supporting hundreds of concurrent transmissions

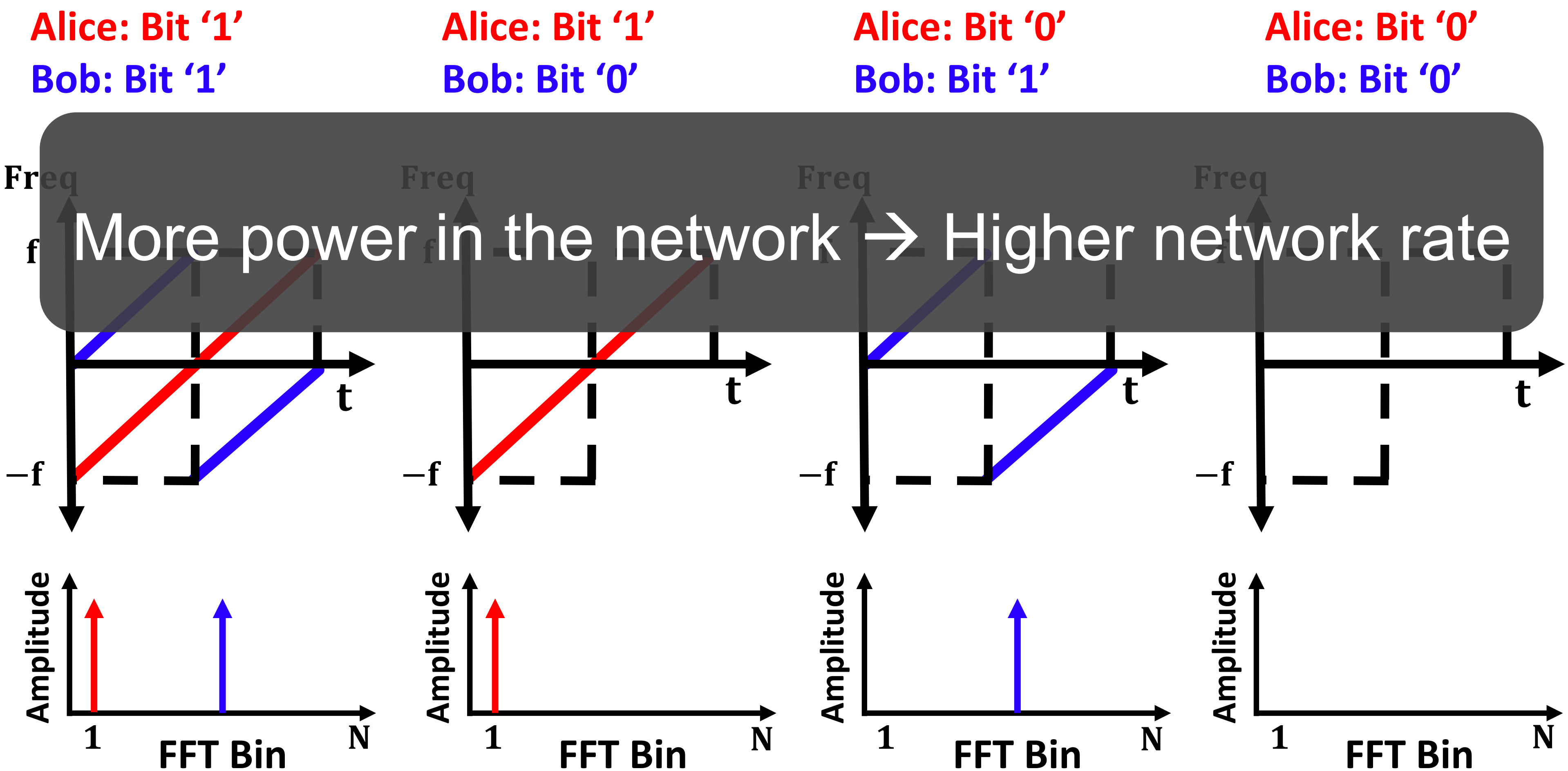
- Distributed coding mechanism which works below noise floor and can be decoded using a single FFT

- Network deployment of 256 devices using only 500 kHz
  - Improvements in PHY-layer data rate (7-26x), link-layer throughput (14-62x) and network latency (15-67x)

Core Idea: Distributed CSS

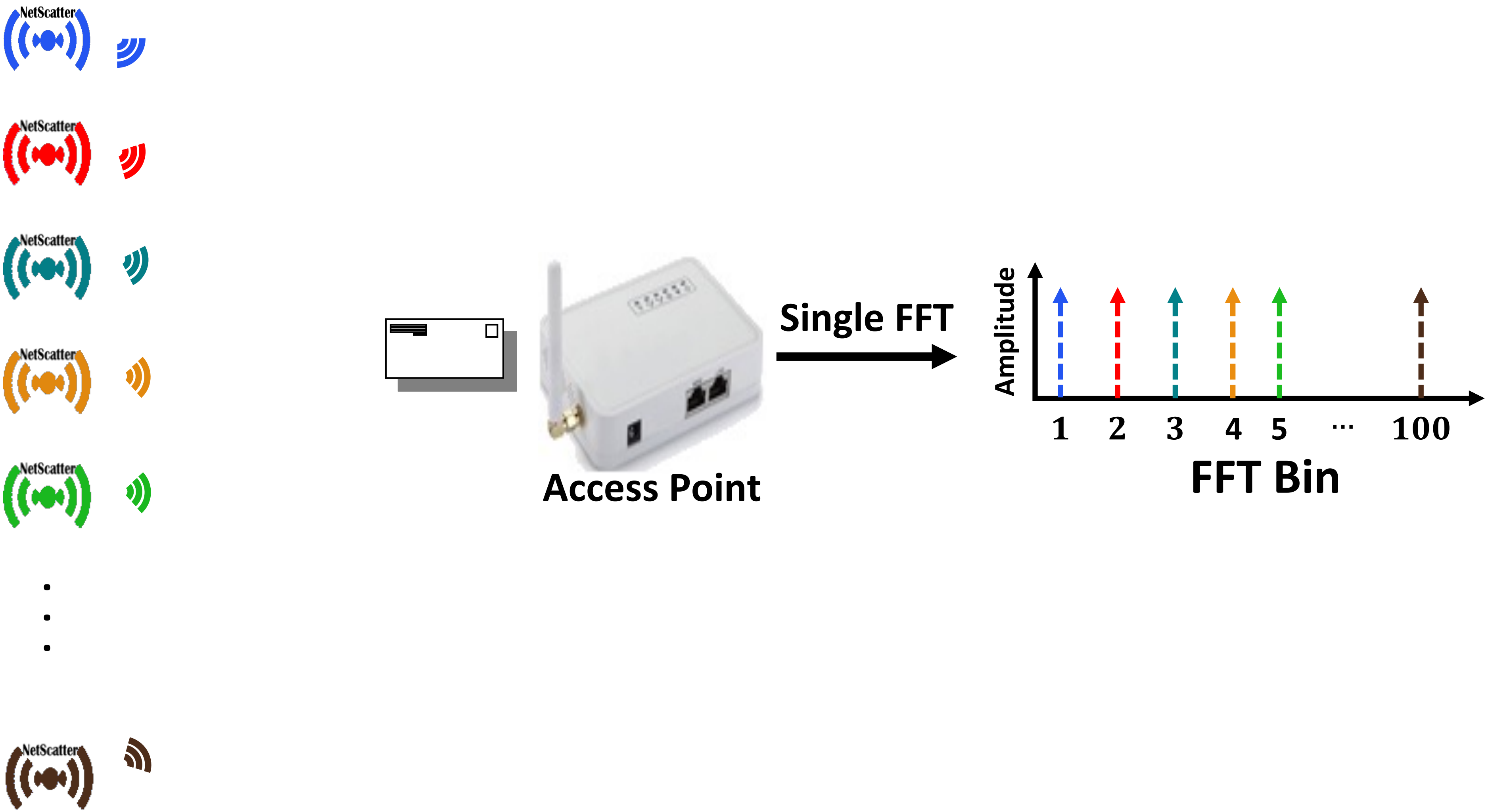
We assign each cyclic shift to a backscatter device

Each device uses ON-OFF keying on cyclic-shift to communicate



More power in the network → Higher network rate

Network of Hundred Backscatter Devices



How Many Concurrent Transmissions Can We Support?

Typical LoRa configuration

Uses 500 kHz BW

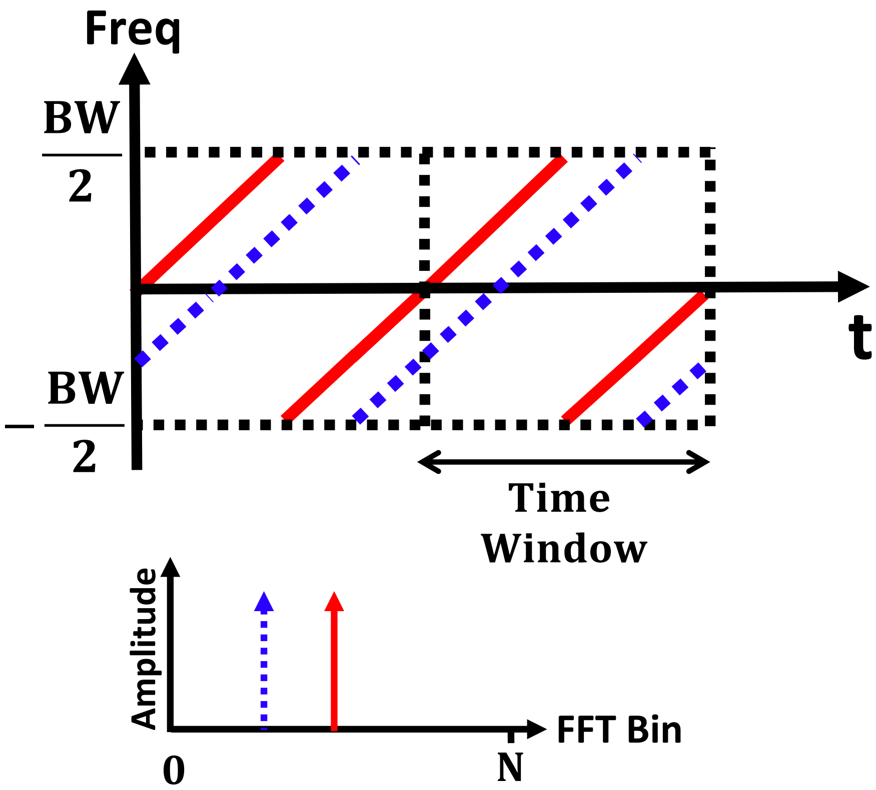
512 cyclic-shifts

Theoretically, can support 512 concurrent transmissions using only 500 kHz BW

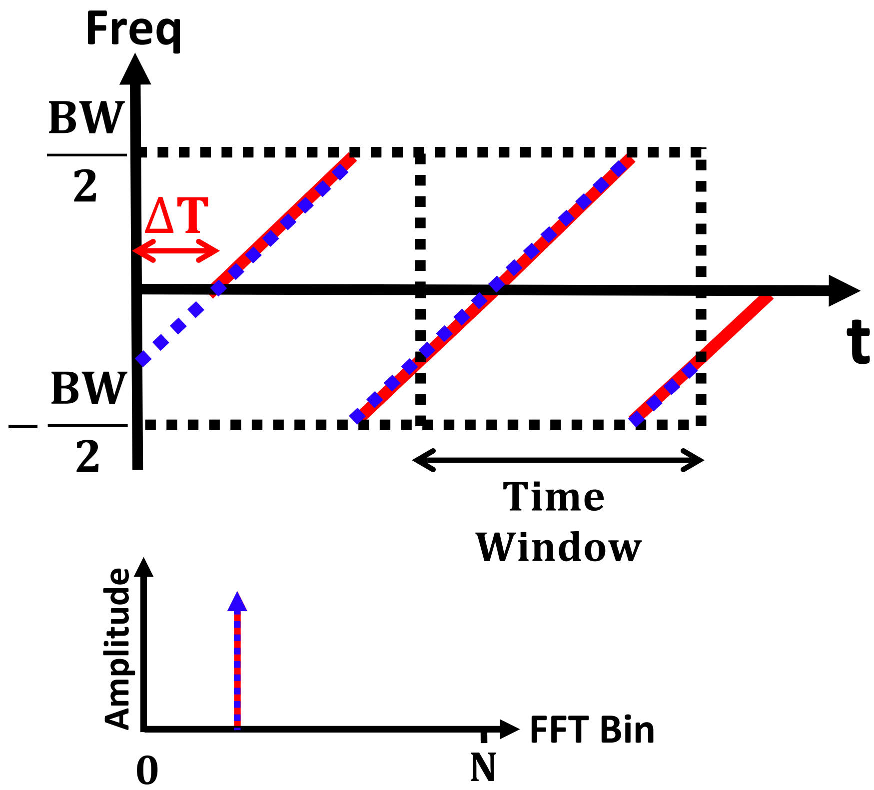
Practical Issues: Timing Synchronization

Alice and **Bob**

Synchronized



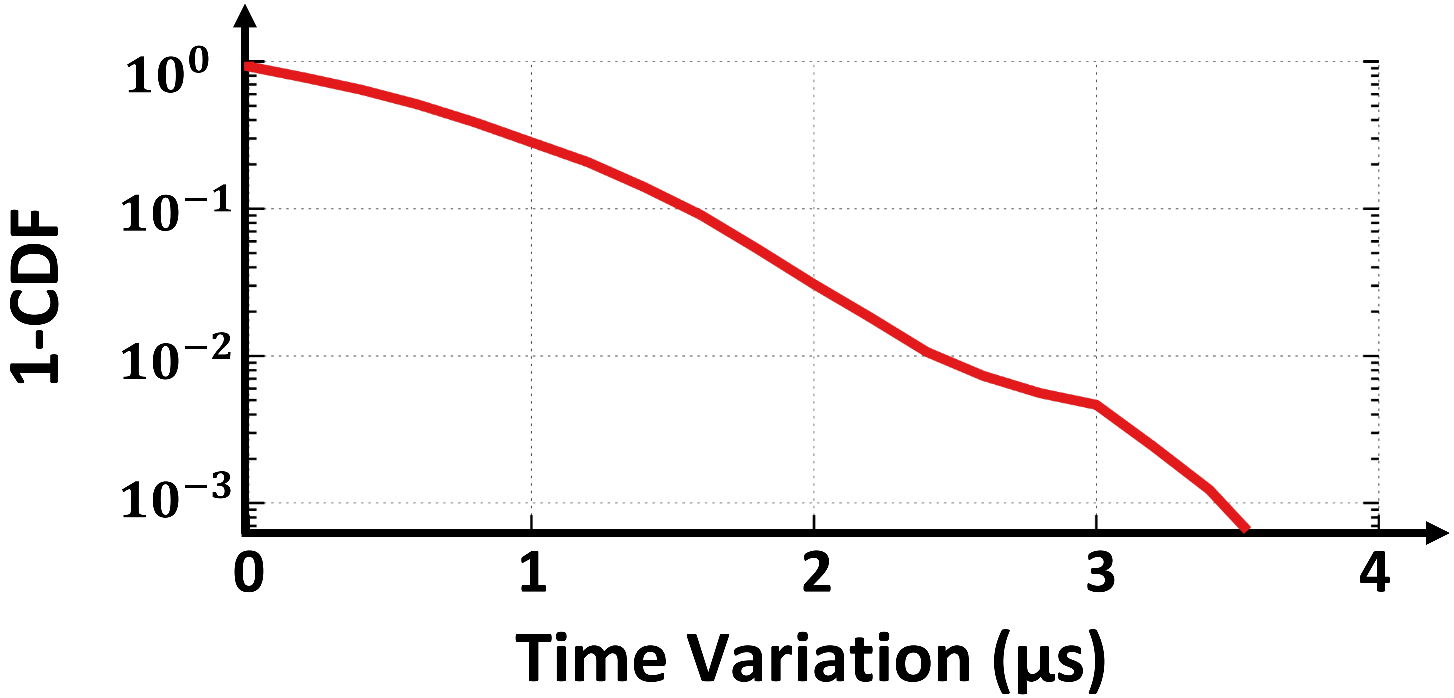
Not synchronized



Causes interference between Alice and Bob

Timing Variation Across Devices

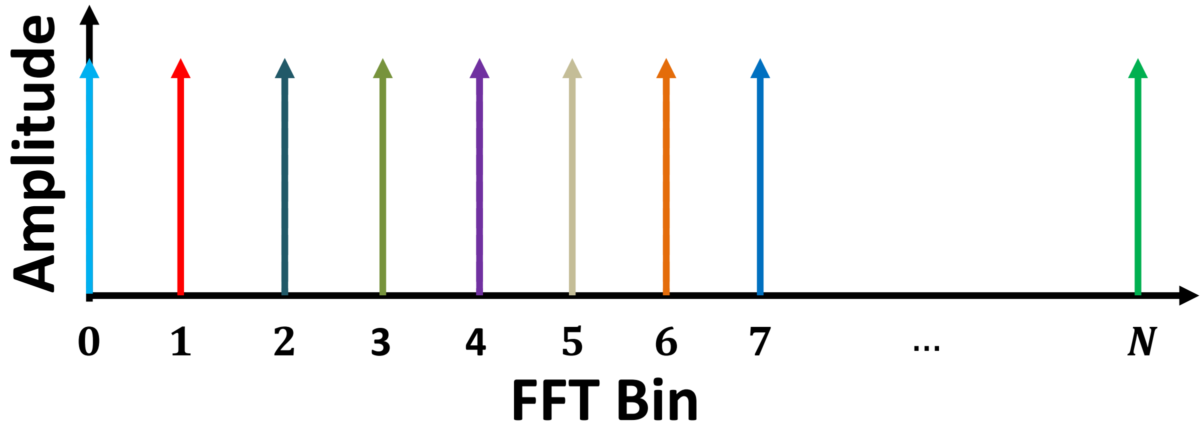
Hardware delay variations cause timing mismatch



2 µs delay translates to 1 FFT bin with 500kHz BW

Timing Synchronization Solution

We use every other cyclic-shift



Reduces concurrent transmissions from 512 to 256

Practical Issues: Near-Far Problem

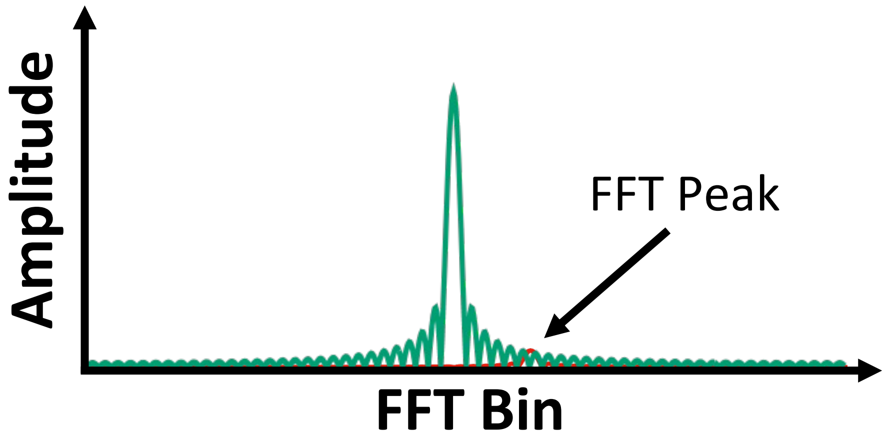
Access Point

NetScatter

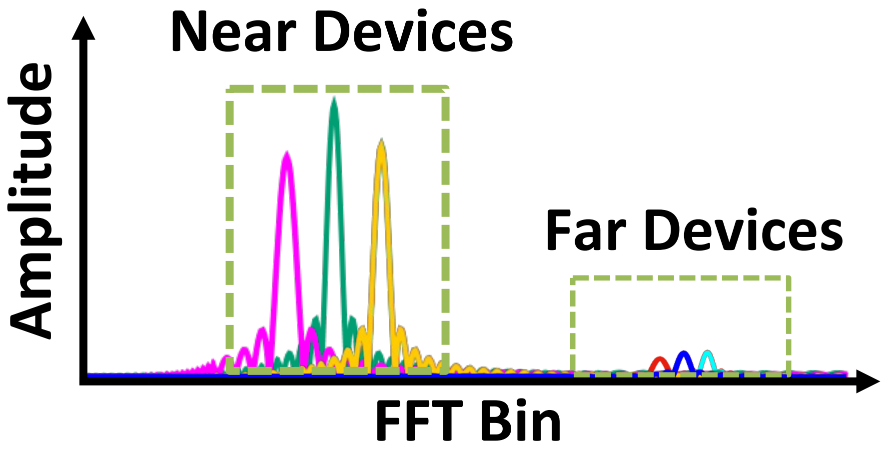
Bob

NetScatter

Alice



Solution: Power-Aware Cyclic Shift Assignment

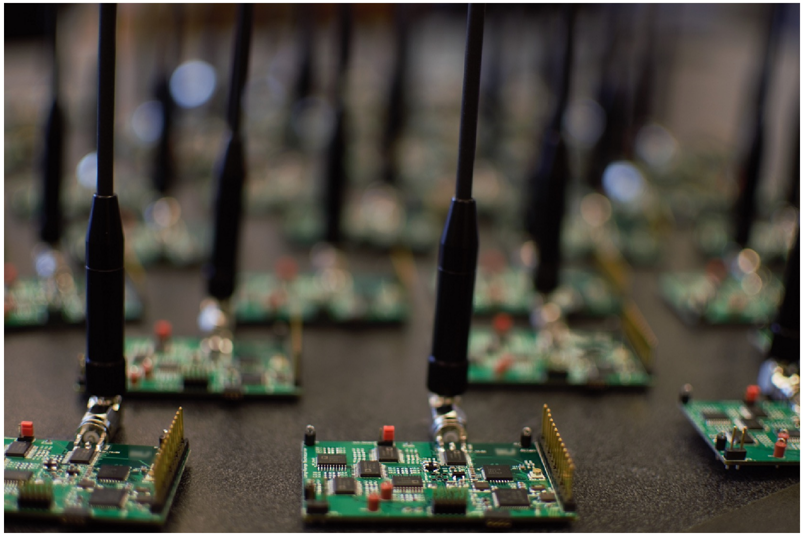


Similar power devices are clustered together

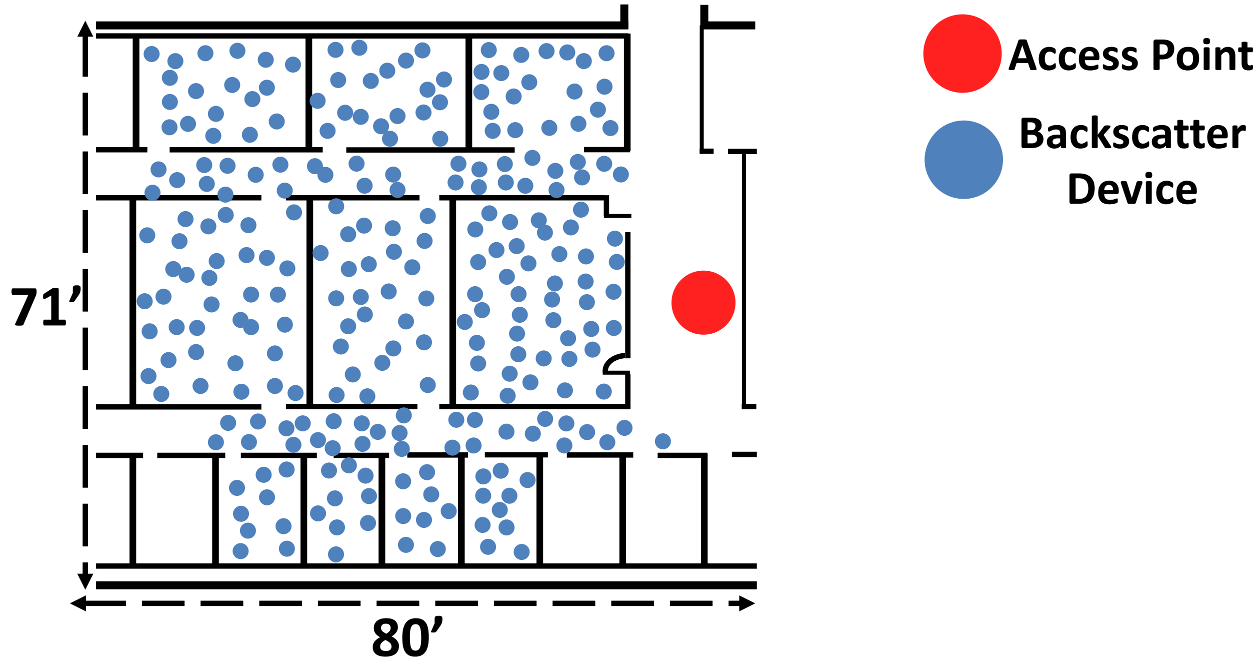
Implementation

Backscatter device
- Baseband: IGLOO nano FPGA
- Downlink: envelope detector
  and MSP430
- RF switch: ADG904
- Three levels power adjustment

Access point
- USRP X-300 with UBX-40 daughterboard
- Co-located RX/TX antennas separated by 3 feet



Evaluation: Large-Scale Deployment



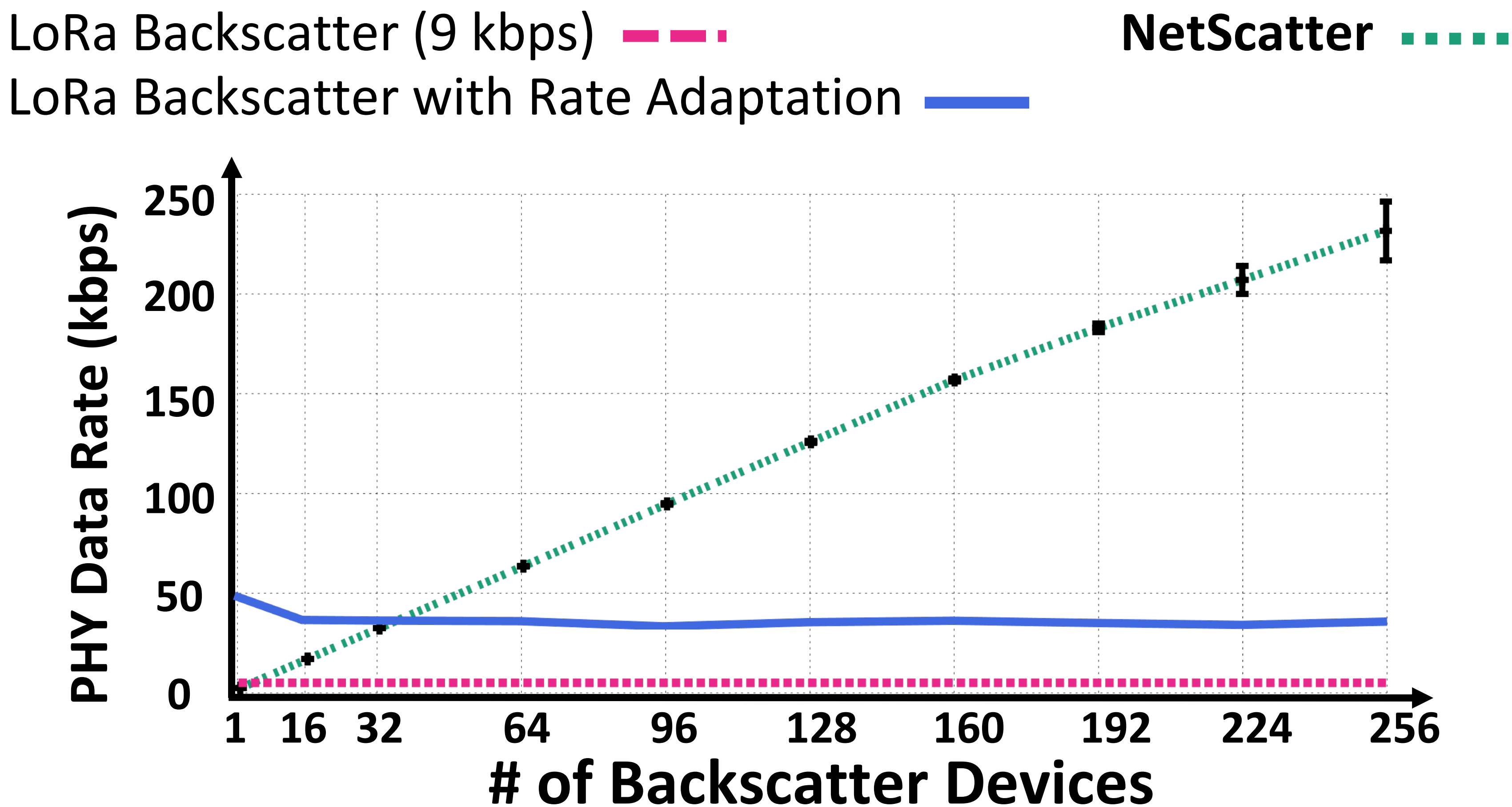
We deployed a network of 256 devices in an office building

Evaluation

We compared NetScatter with:

- LoRa-Backscatter (9 kbps)
- LoRa-Backscatter with rate adaptation

Evaluation: Network PHY Data-Rate



PHY data-rate improves by 7x - 26x

Objective of Today's Lecture

Learn the fundamentals, applications, and emerging technologies in LP-WANS

1. Why are LPWANs (low-power wide-area networks) and their applications?
2. What is LoRa and how does it work?
3. How can we increase the network throughput and range of LoRa?
4. How can we combine LoRa with backscatter?

Next Class: Smart Surfaces & Metamaterials

1) Required

- Programmable Radio Environments
- Metamaterials for Satellites

2) Optional

- Large Inexpensive Arrays
- Rfocus
- Metasurface IoT