ECE 598HH: Advanced Wireless Networks and Sensing Systems

Lecture 17: Low Power Wide Area Networks

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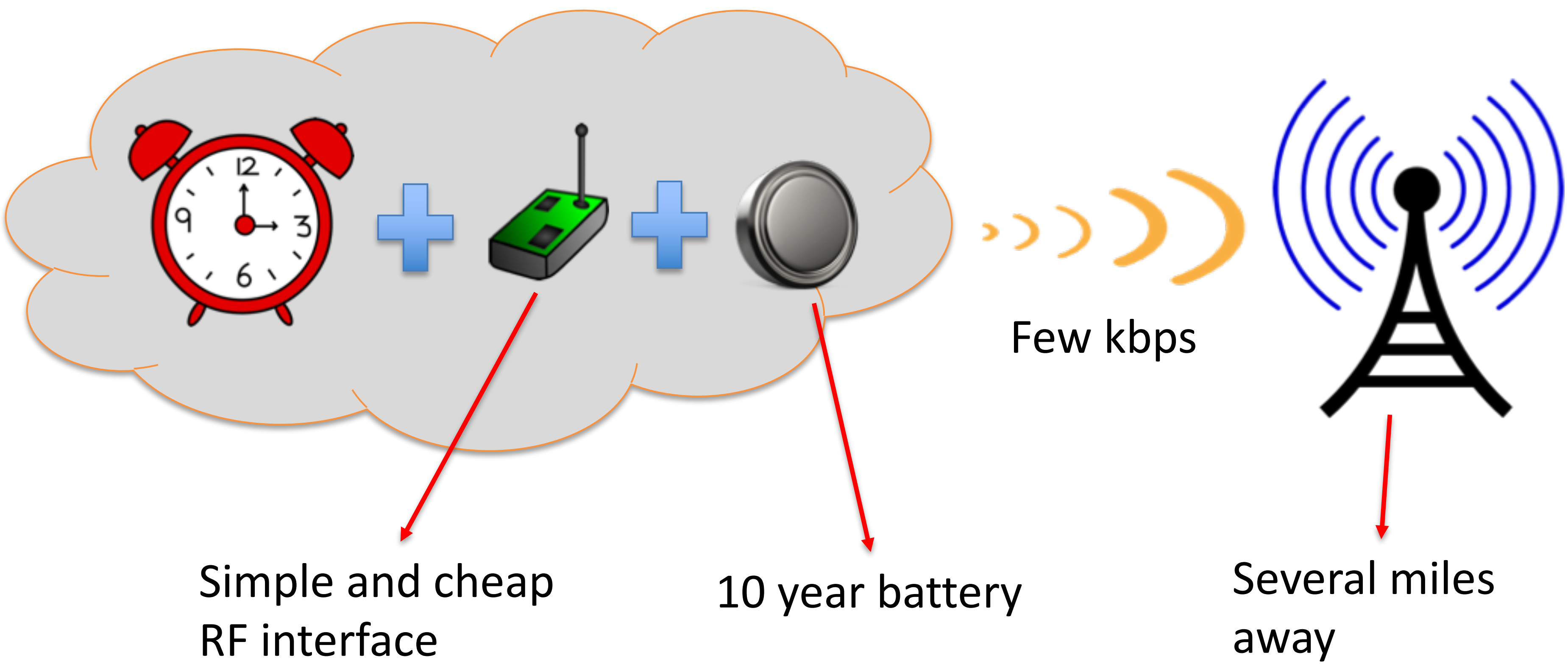
*These slides are courtesy of Swarun Kumar (CMU)

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)

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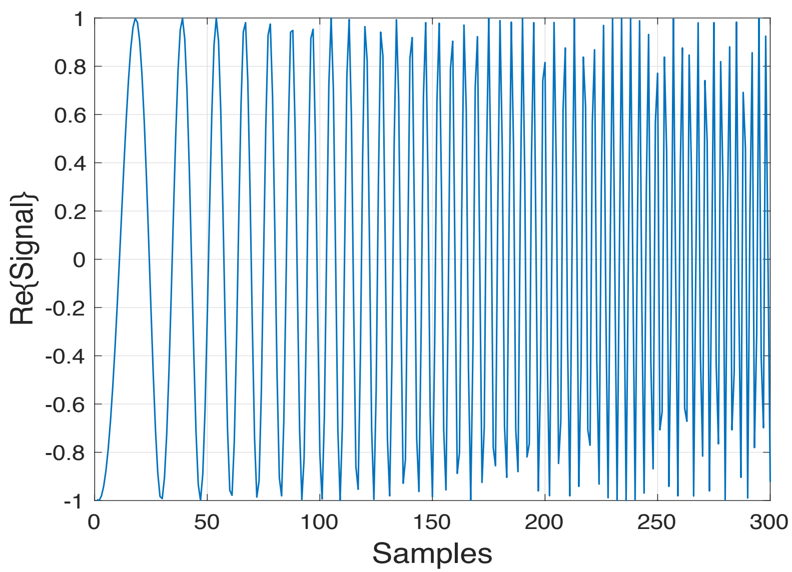
Long Range	Low Data rate	Low Cost	Low Power
• Up to 10 KMs in rural areas	• Order of kilobits per second	• < $5	• Up to 10 years of battery life

Initiatives from Industry (LoRa, SIGFOX)

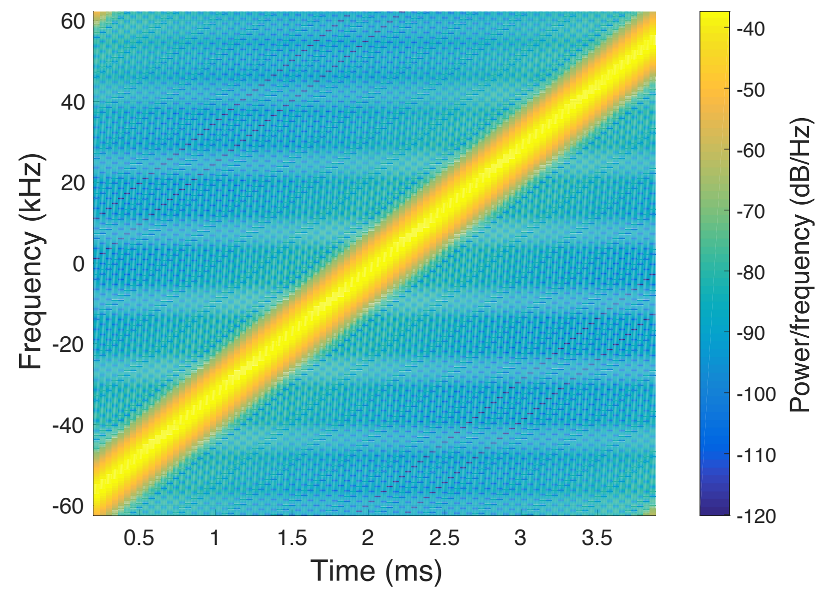
Low-Power Wide-Area Networking (LP-WAN)

LoRaWAN™ : Chirps

Chirp in T.D.



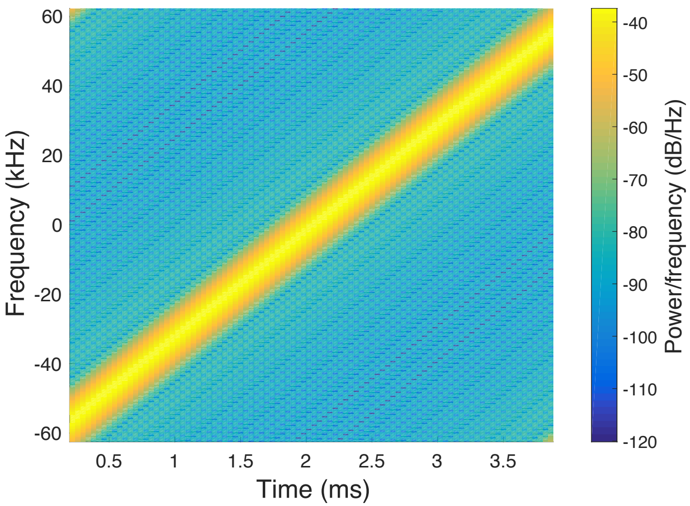
Chirp on a spectrogram



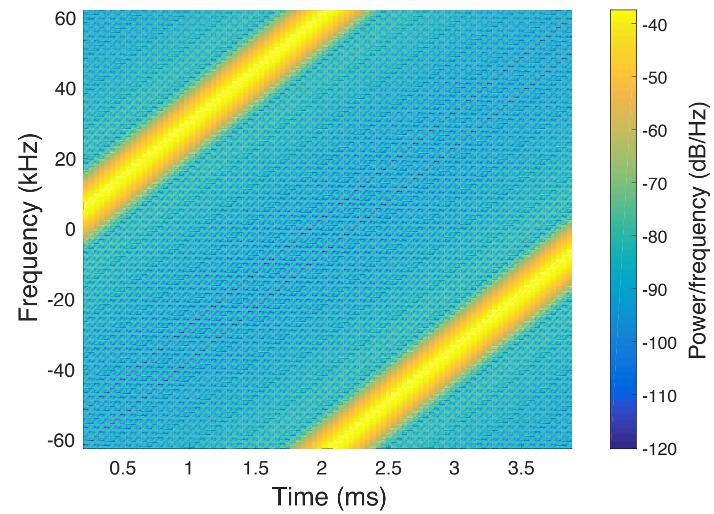
Data encoding

The initial frequency of the chirp

LoRaWAN™ : 1-bit encoding



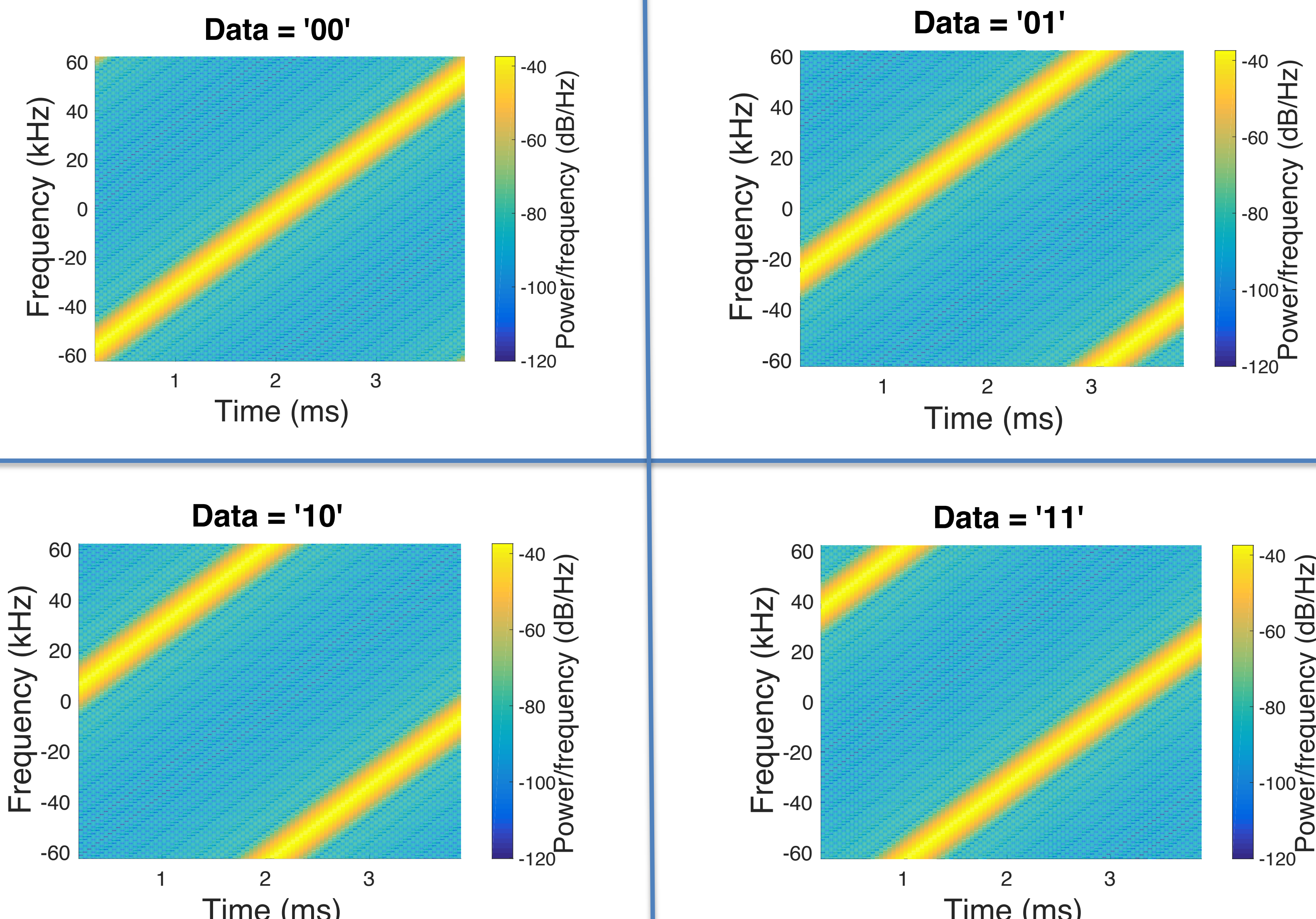
'0'



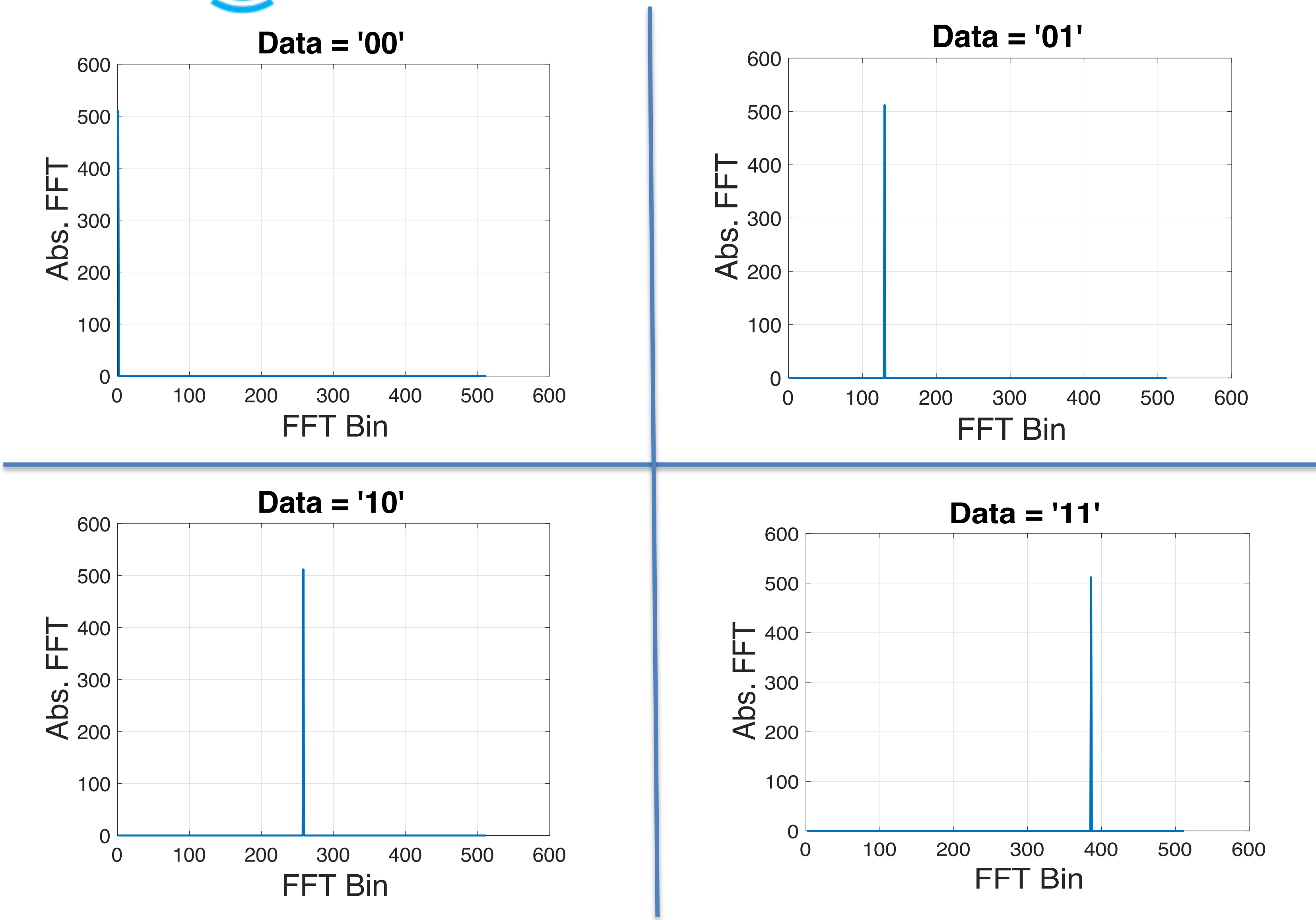
'1'

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

LoRaWAN : 2-bit encoding



LoRaWAN™ : 2-bit encoding



LoRaWAN™: Packet Structure

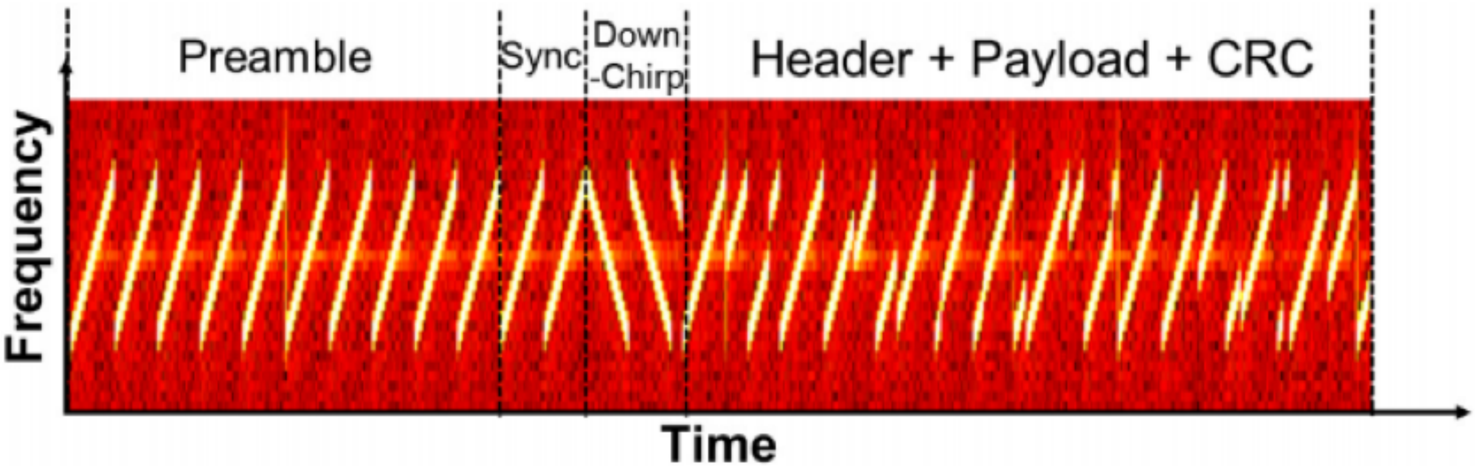


Figure 7: **LoRa packet structure.**

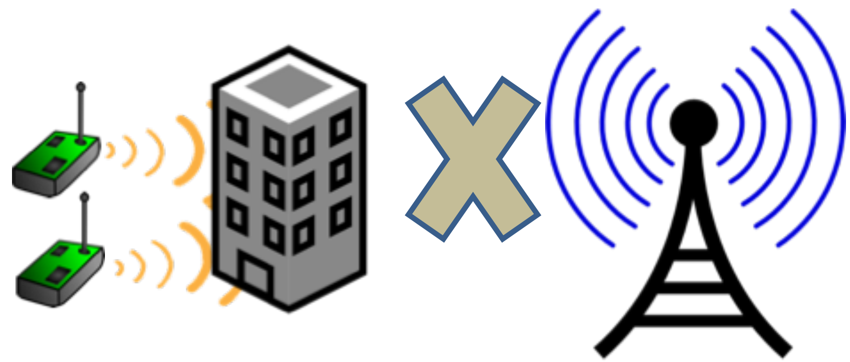
Key Challenges

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.

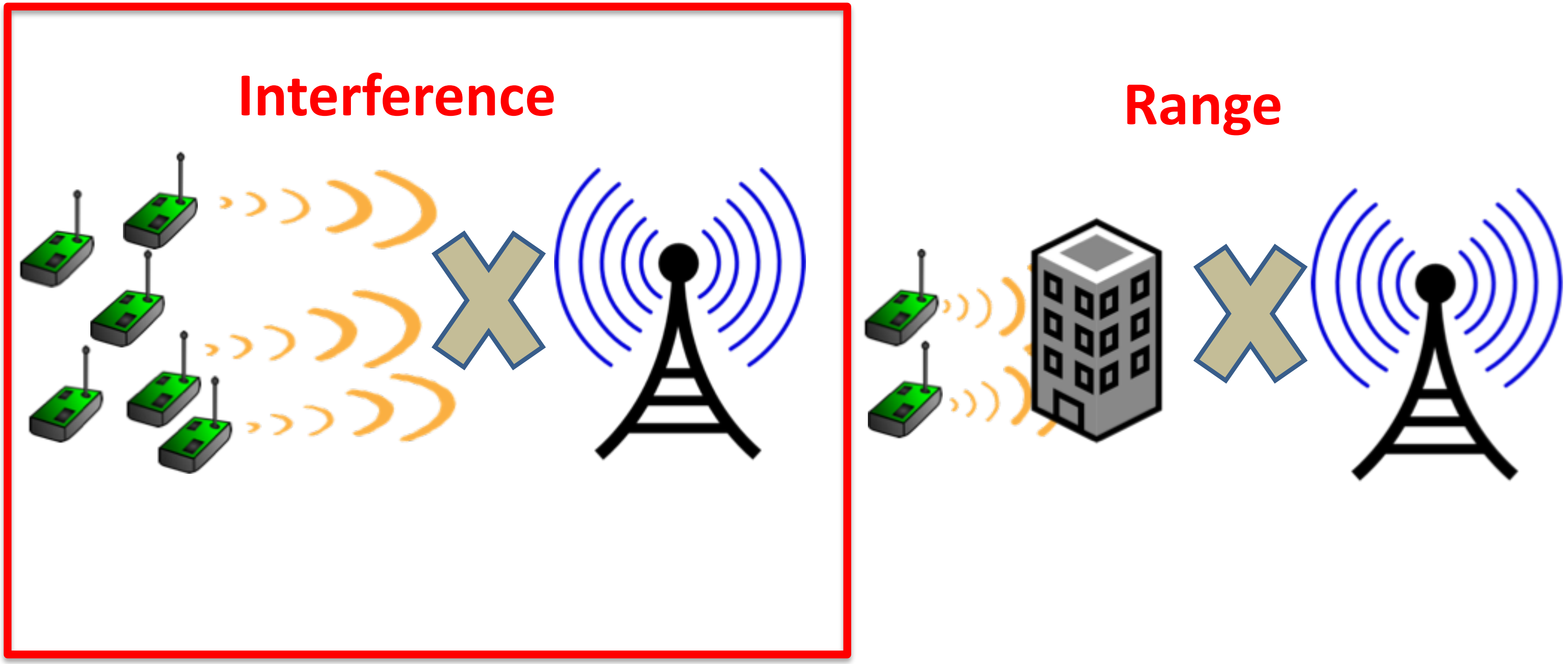
Choir

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

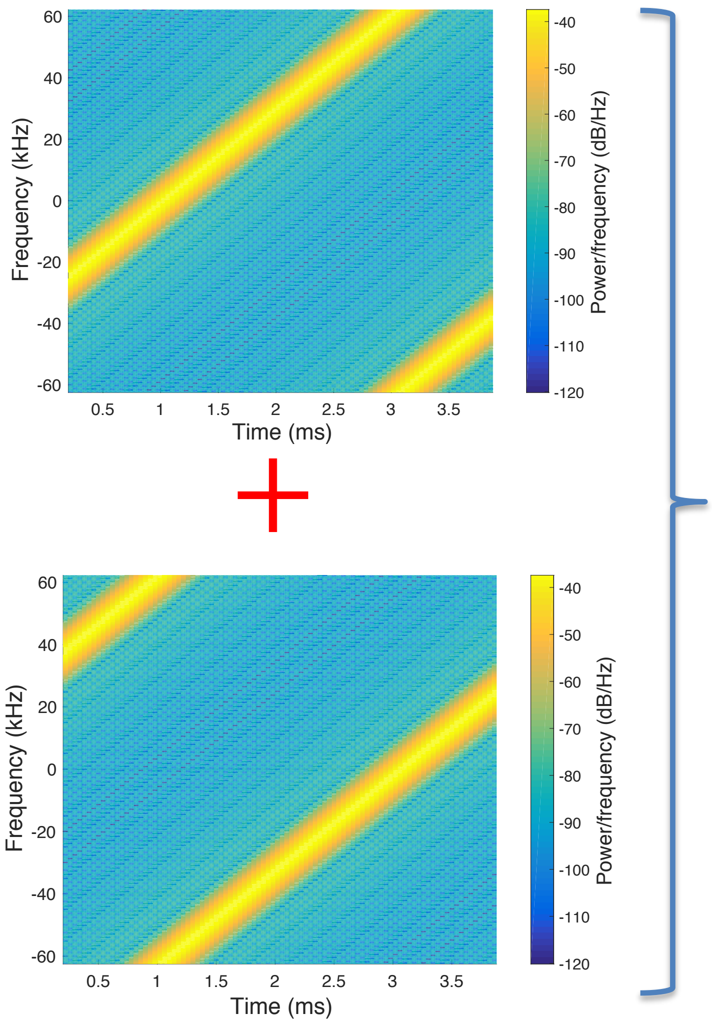
LoRaWAN™ base station over an area of 10 Km^2 in Pittsburgh

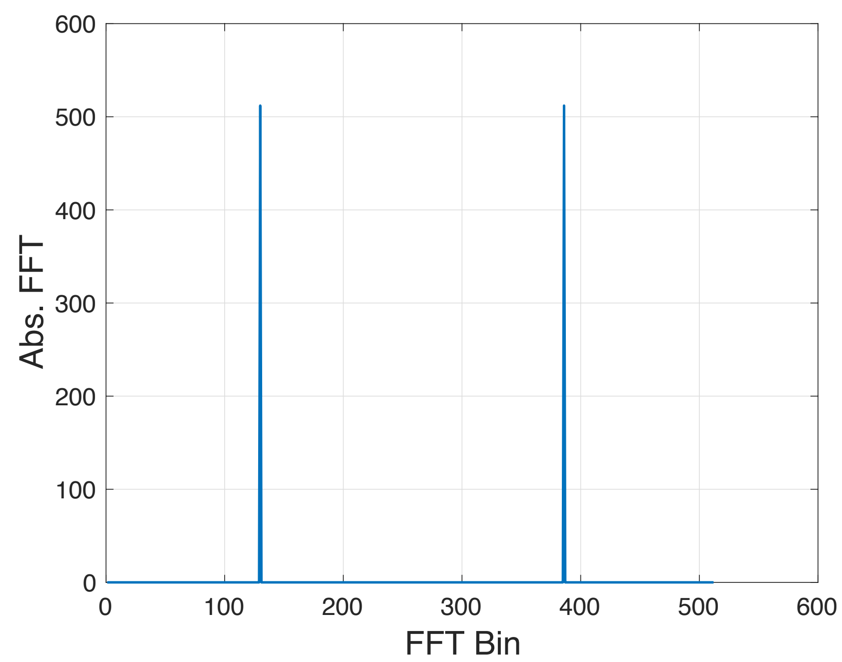
Choir in action



Collision of chirps

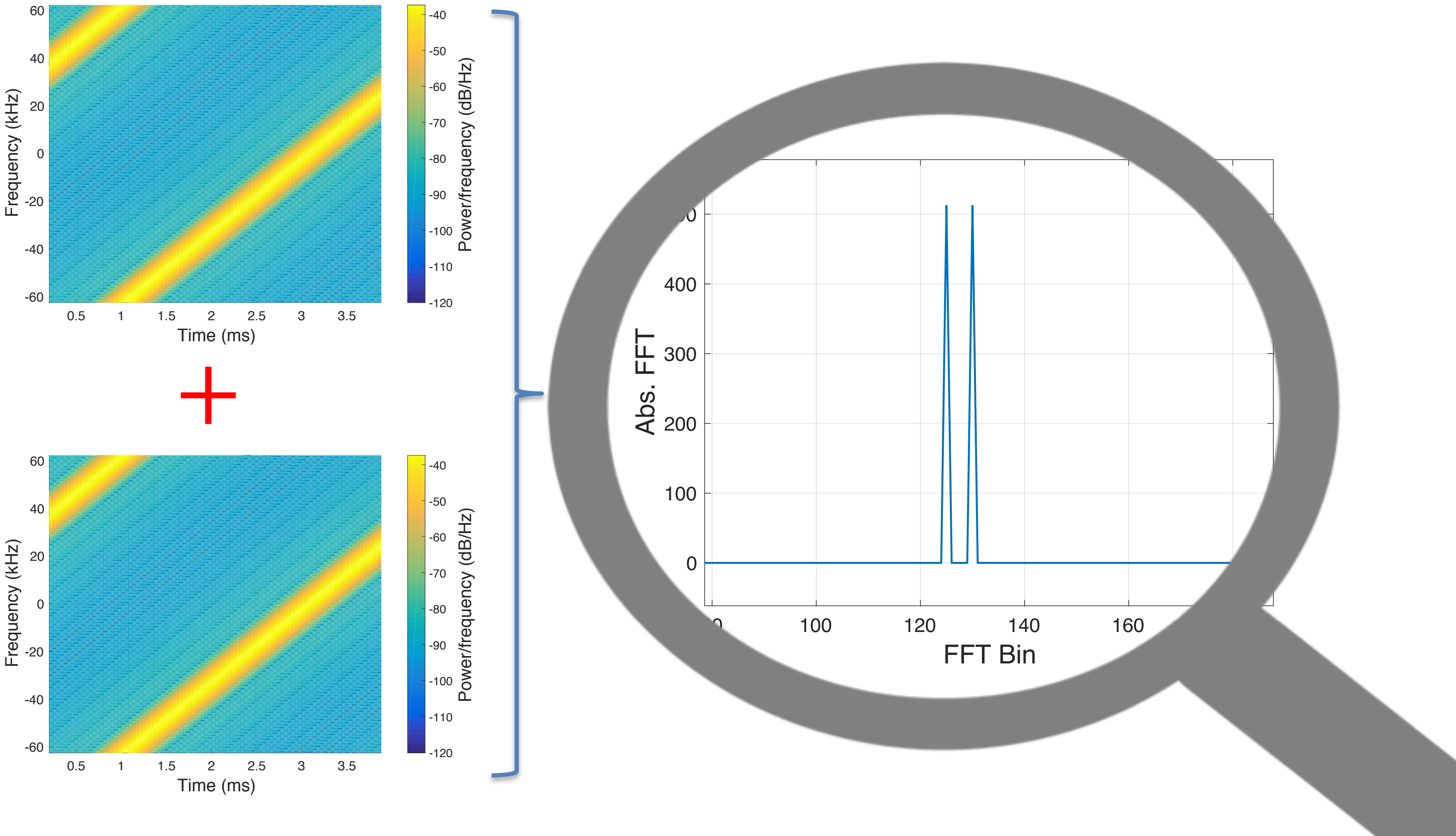
Different data



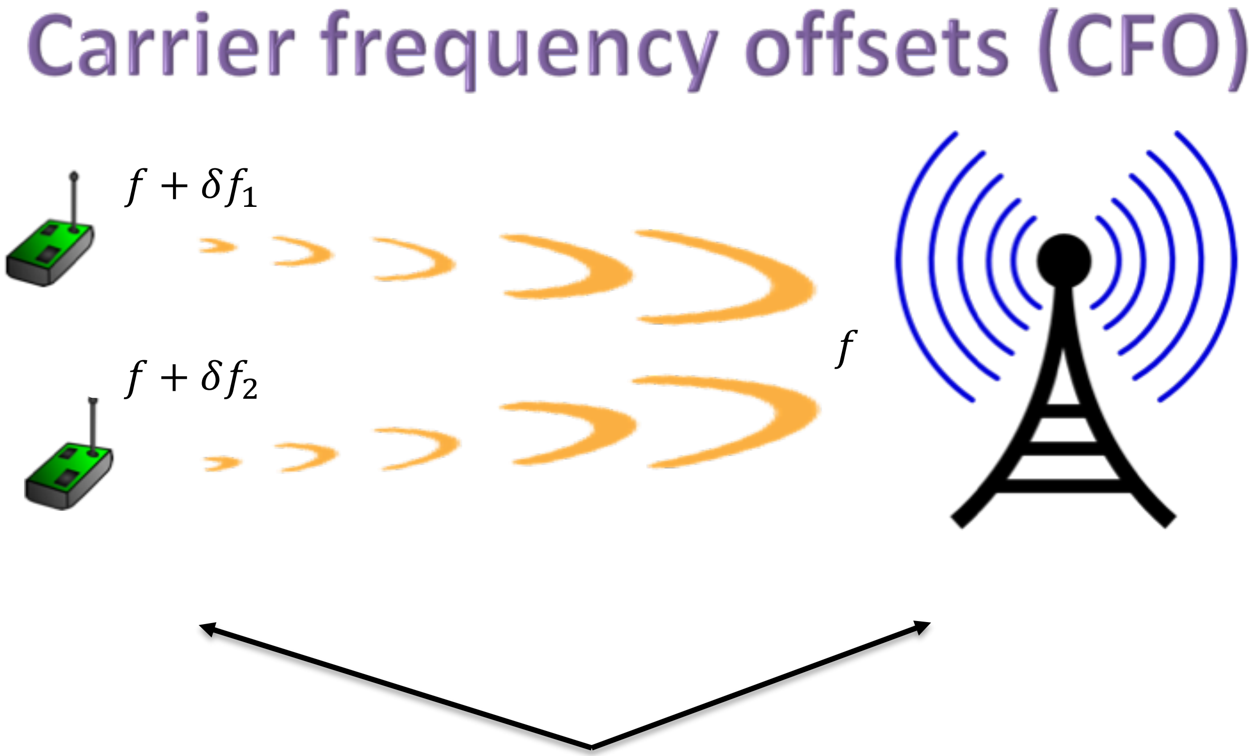


Collision of chirps

Same data



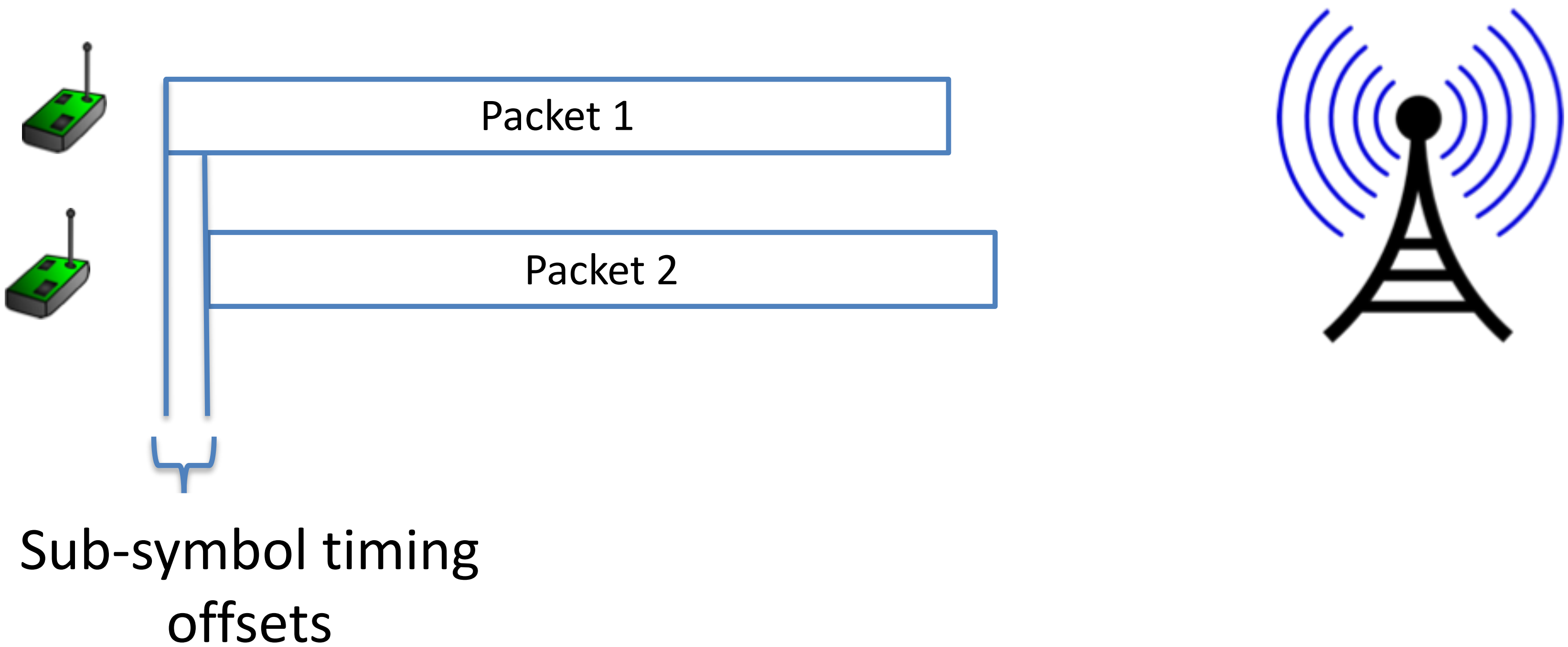
Hardware imperfections



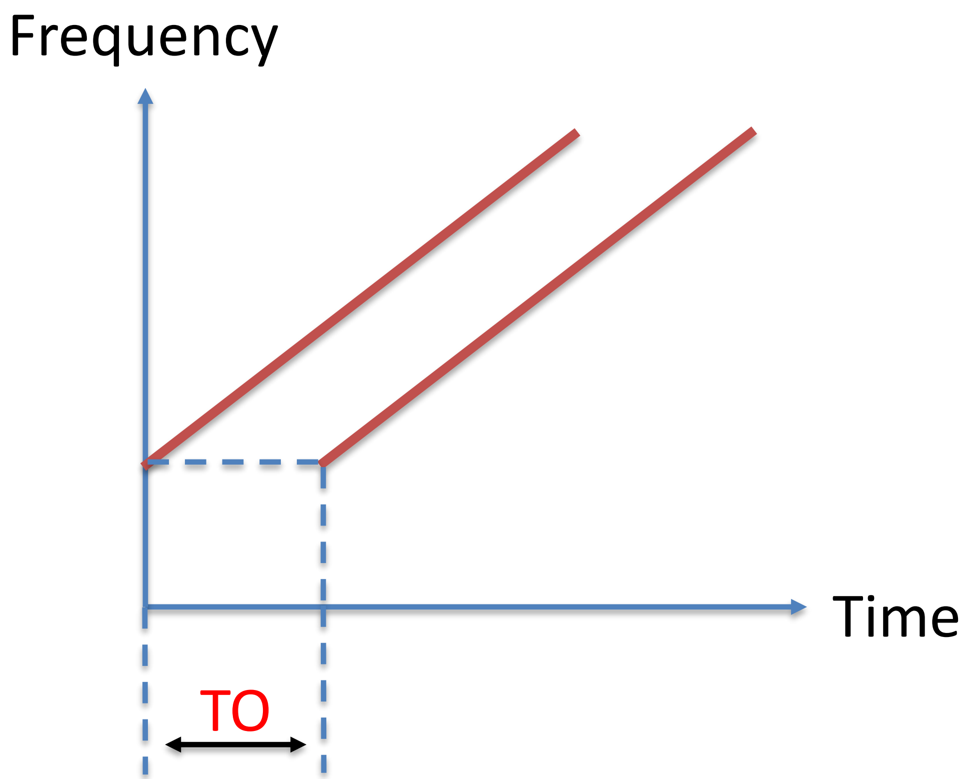
Local oscillator mismatch

Hardware imperfections

Timing offsets (TO)



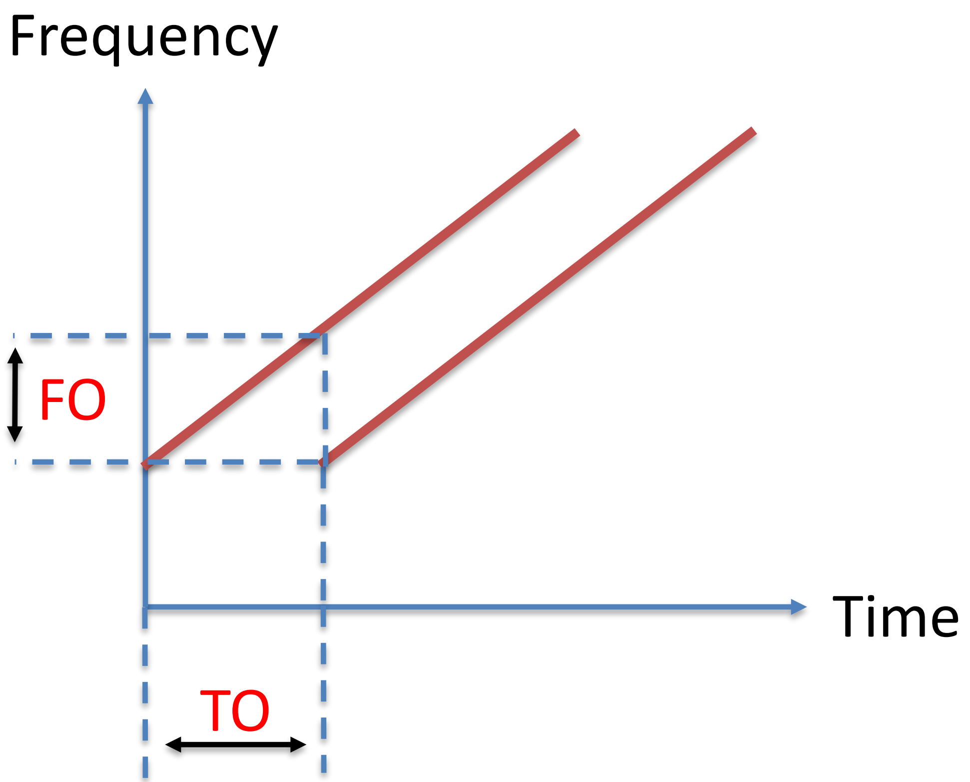
Timing offsets (TO)



Recall

Chirps are signals whose frequency increases linearly with time

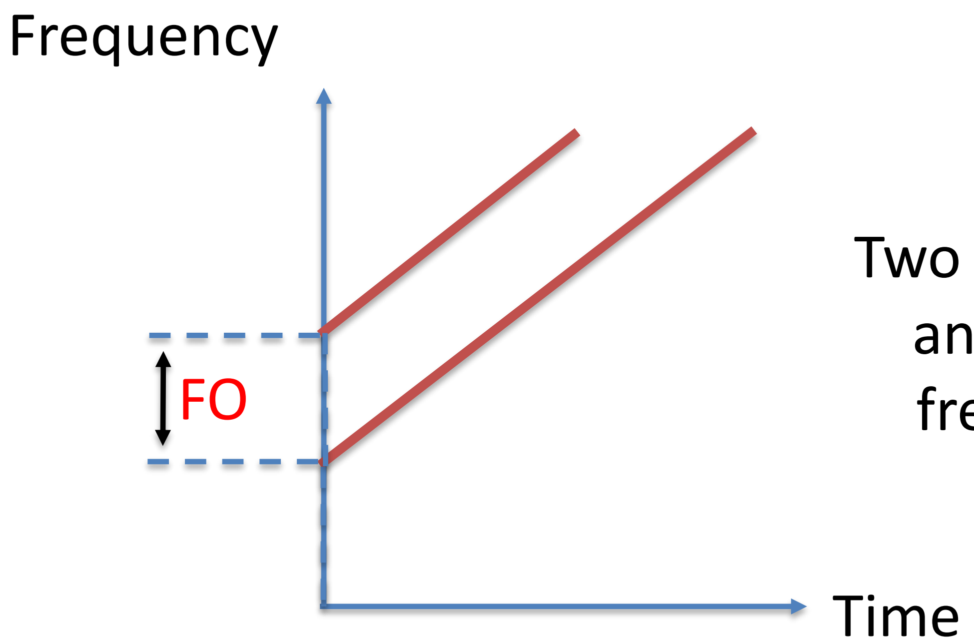
Timing offsets (TO)



Thus,

An offset in time maps to an offset in frequency!

Timing offsets (TO)

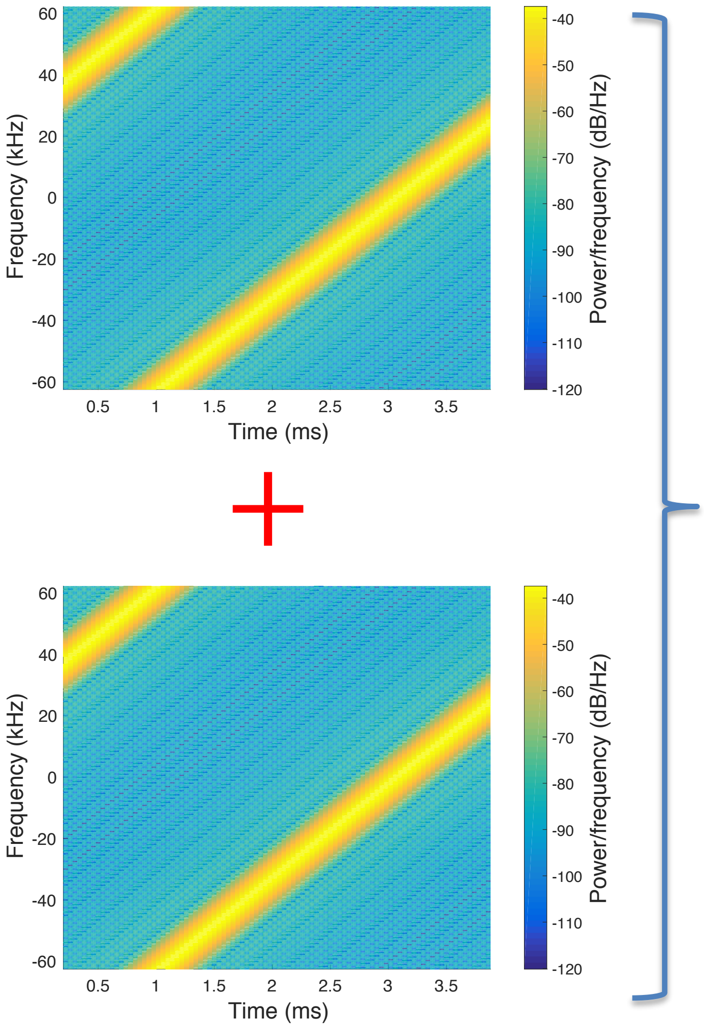


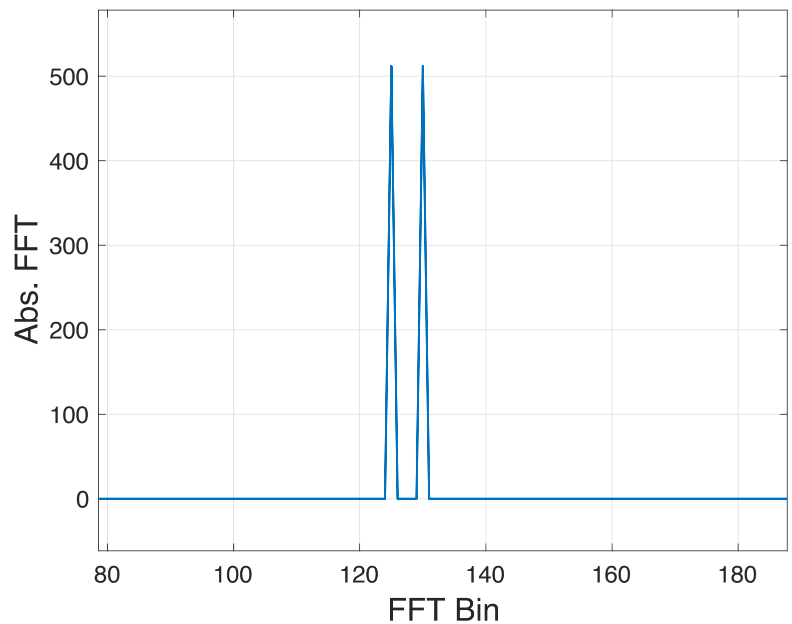
Two chirps with
an offset in
frequency!

Hardware offsets := { CFO + TO}

Collision of chirps

Same data

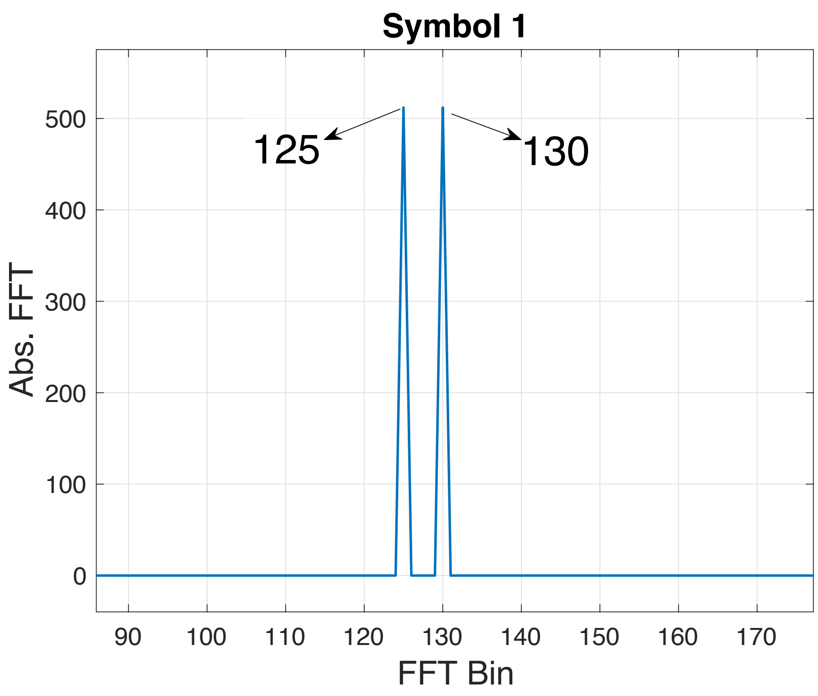




Hardware offsets!

Exploit hardware imperfections to resolve collisions!

Decoding data



U1 data: ✓ U2 data: ✓

U1 data + U1 hardware offsets = 125

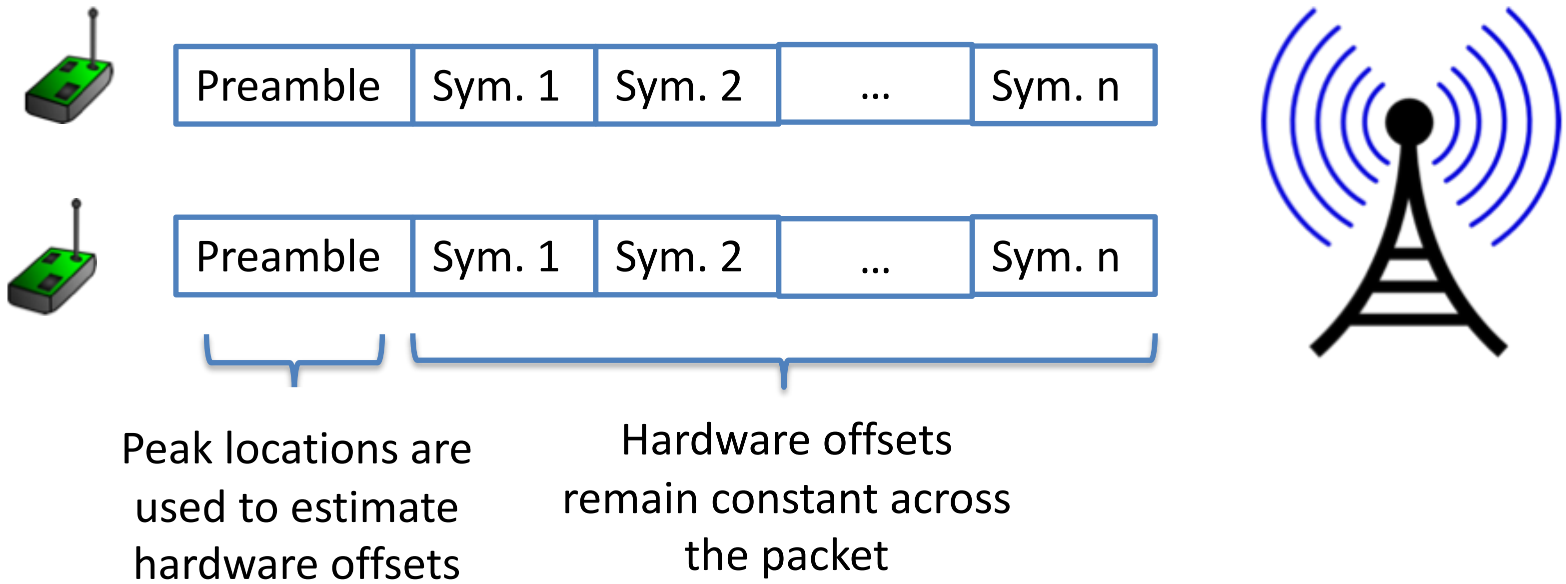
U2 data + U2 hardware offsets = 130

!

idea

Hardware offsets remain constant over a packet, data does not!

Decoding data

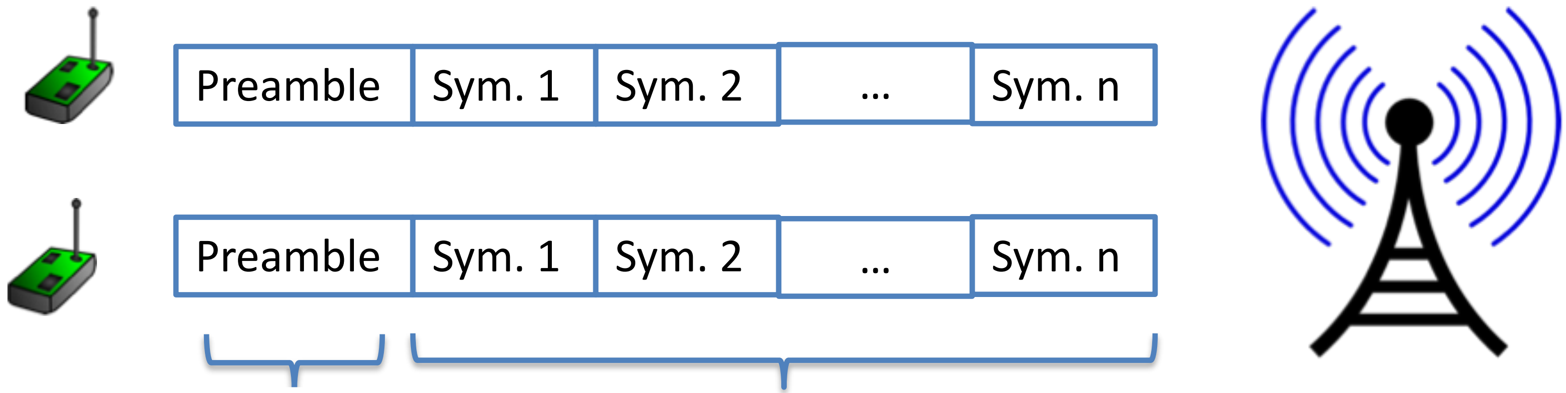


Symbol 1:

U1 data + U1 hardware offsets = 125

U2 data + U2 hardware offsets = 130 ✓

Decoding data



Peak locations are used to estimate hardware offsets

Hardware offsets remain constant across the packet

How to measure accurate hardware offsets across the preamble?

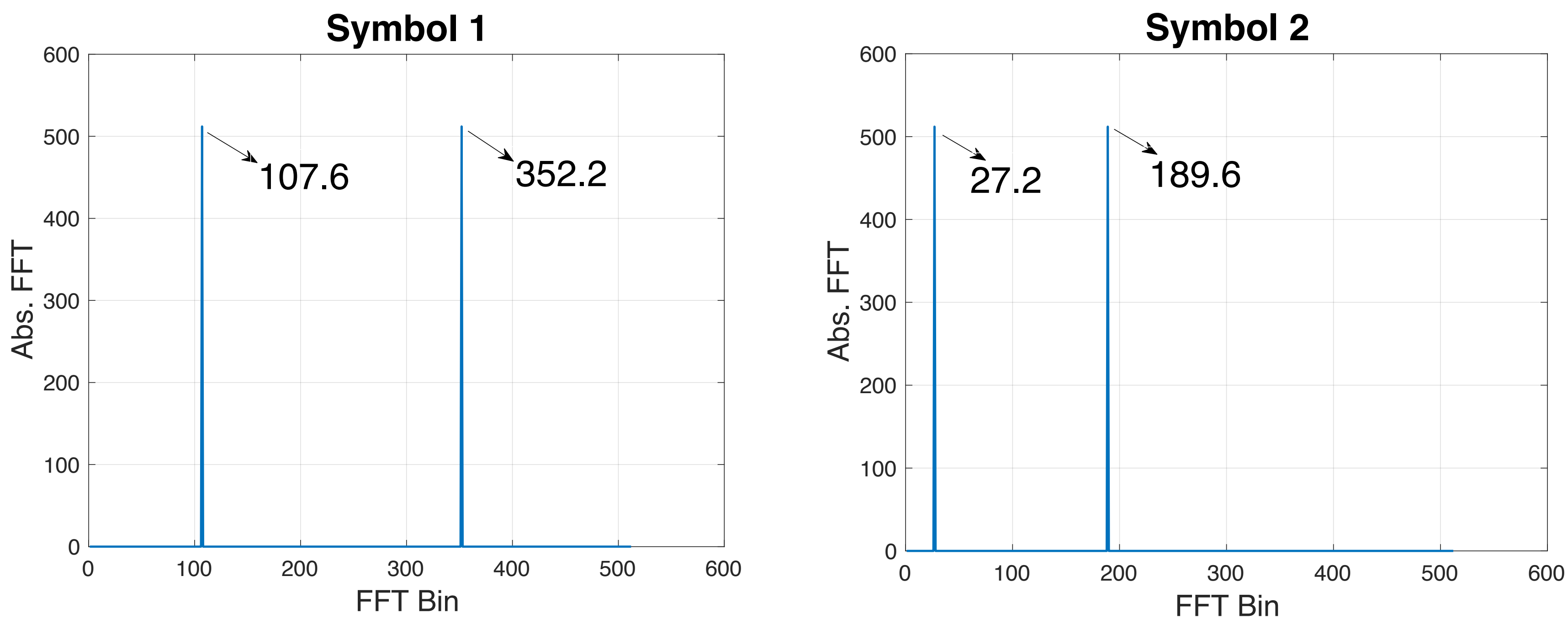
Decoding data

$$(f_1^*, f_2^*) = argmin_{\{f_1 \in (\overline{f}_1 - \Delta, \overline{f}_1 + \Delta), f_2 \in (\overline{f}_2 - \Delta, \overline{f}_2 + \Delta)\}} \left| yC^{-1} - \left(\overline{h}_1 e^{j2\pi \overline{f}_1 t} + \overline{h}_2 e^{j2\pi \overline{f}_2 t} \right) \right|^2$$

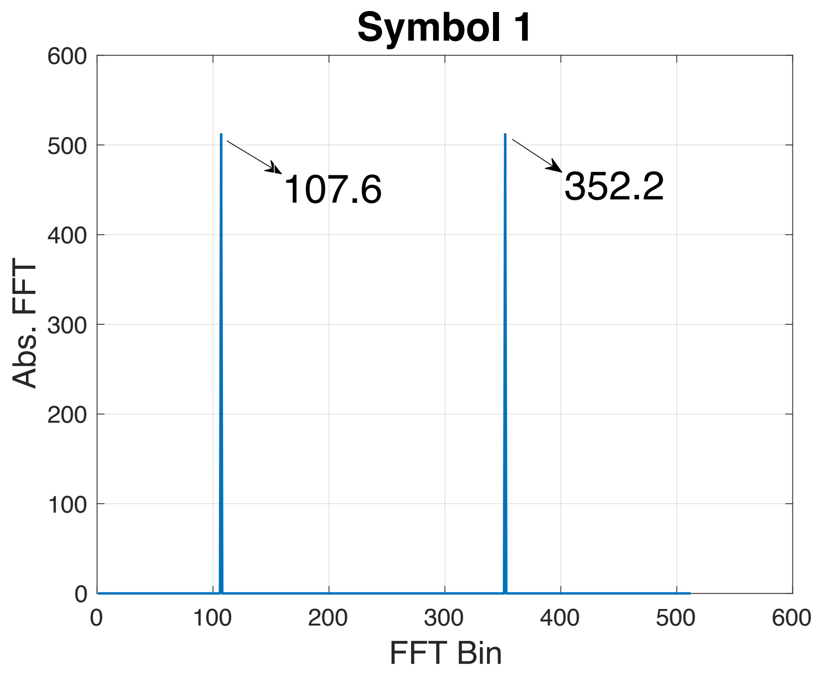
$\overline{f}_i$ -> initial frequency offset estimate of user i
$\overline{h}_i$ -> channel estimate of user i
Δ -> bin size of the FFT
C^{-1} -> conjugate nominal chirp
y -> received symbol
f_i^* -> correct frequency offset of user i

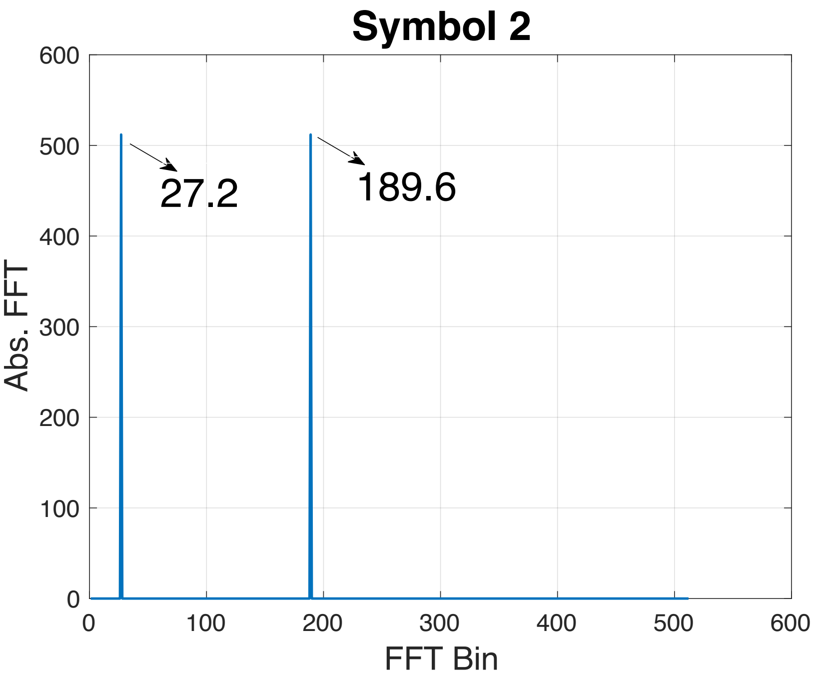
Which peak corresponds to which user?

Which peak corresponds to which user?



Which peak corresponds to which user?

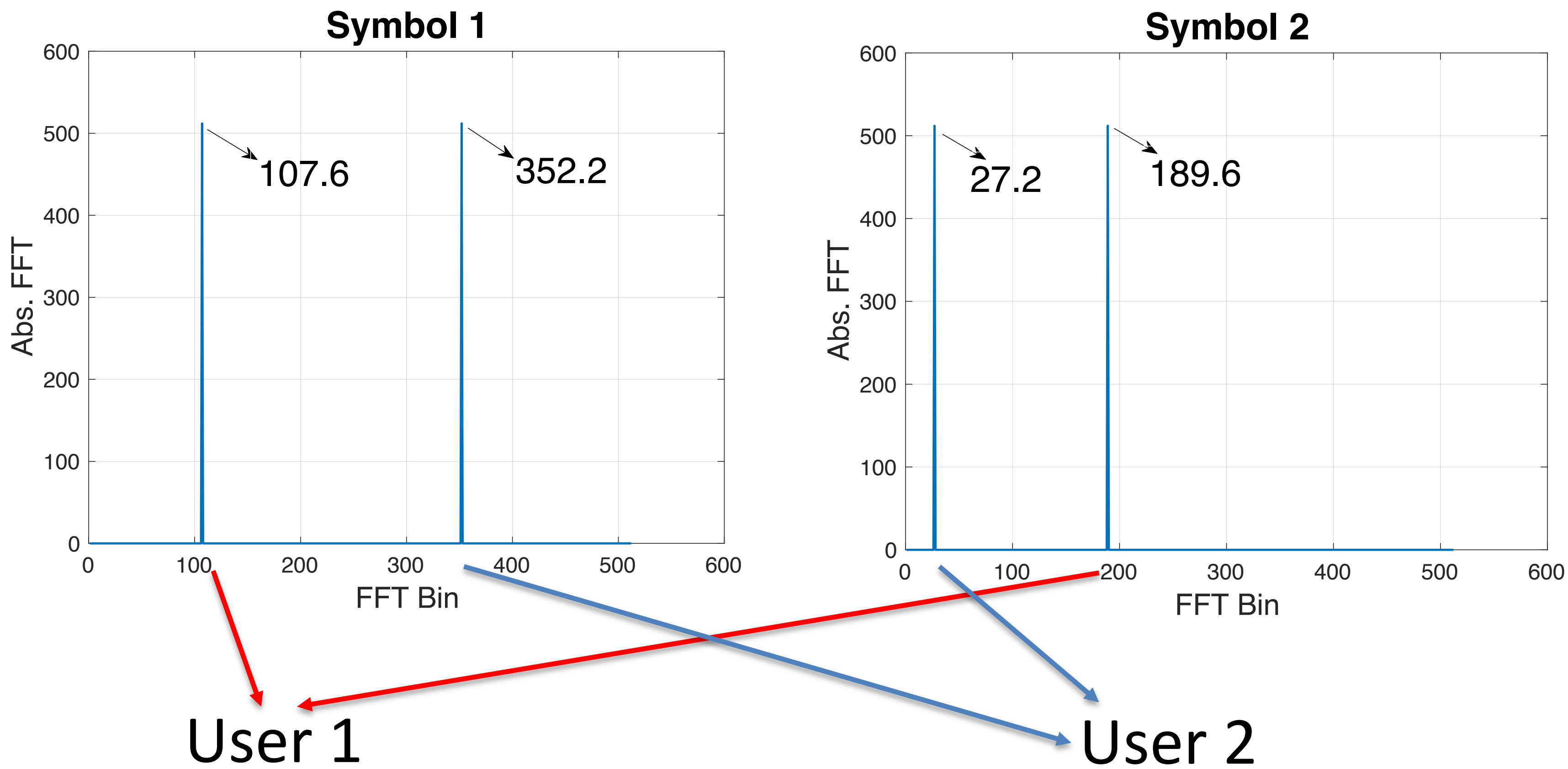




idea

Data bits are discrete, hardware offsets are continuous!

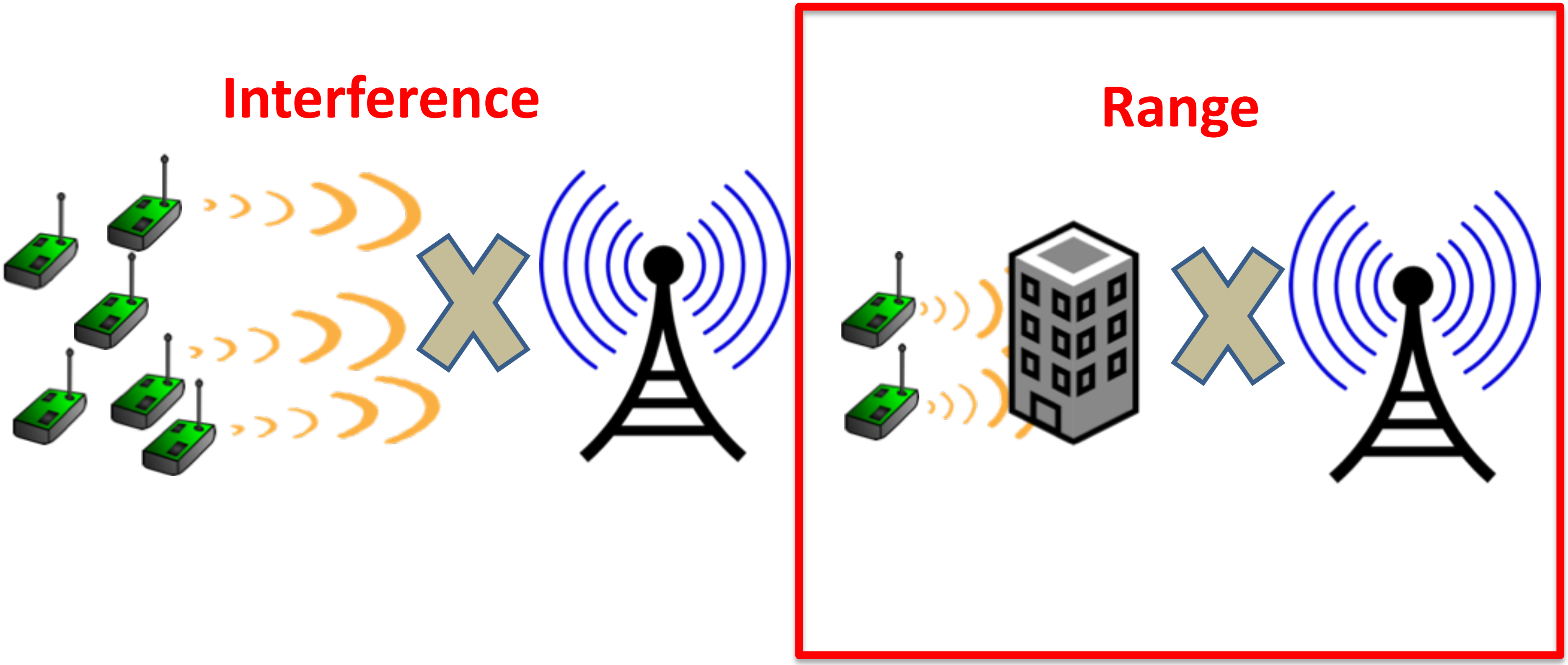
Which peak corresponds to which user?



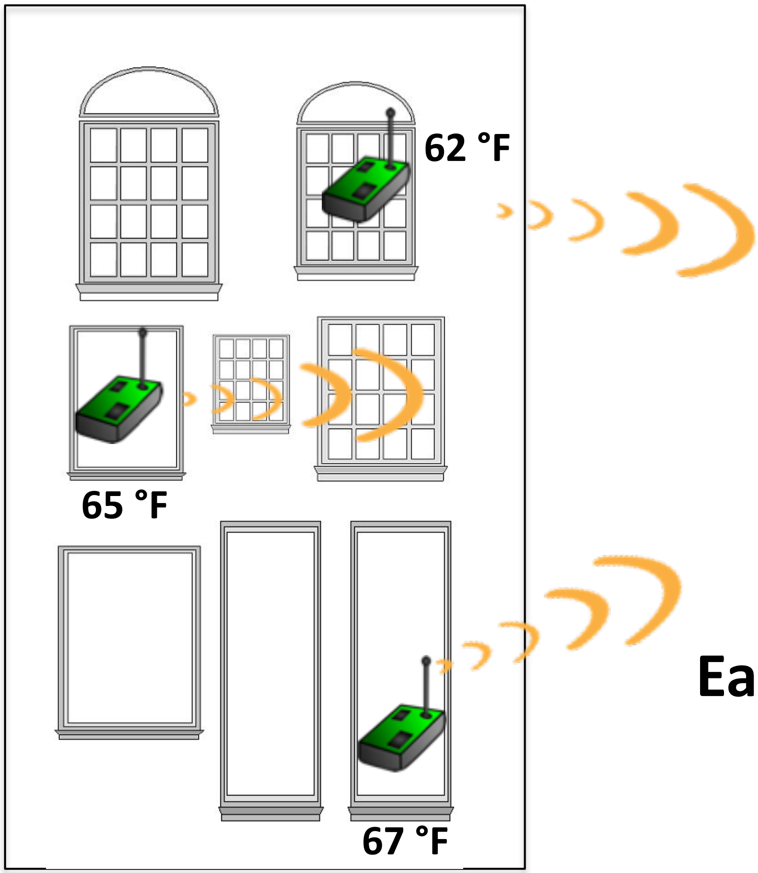
Integer part depends on both data and hardware offsets

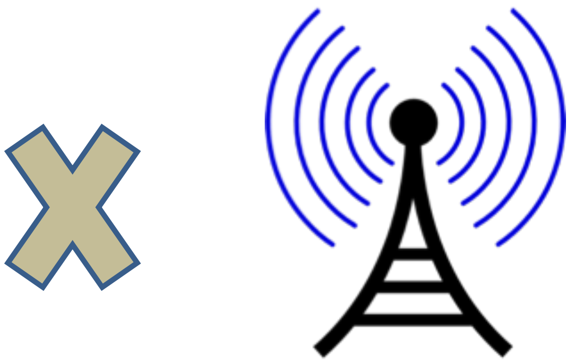
Fractional part depends only on hardware offsets

Choir in action



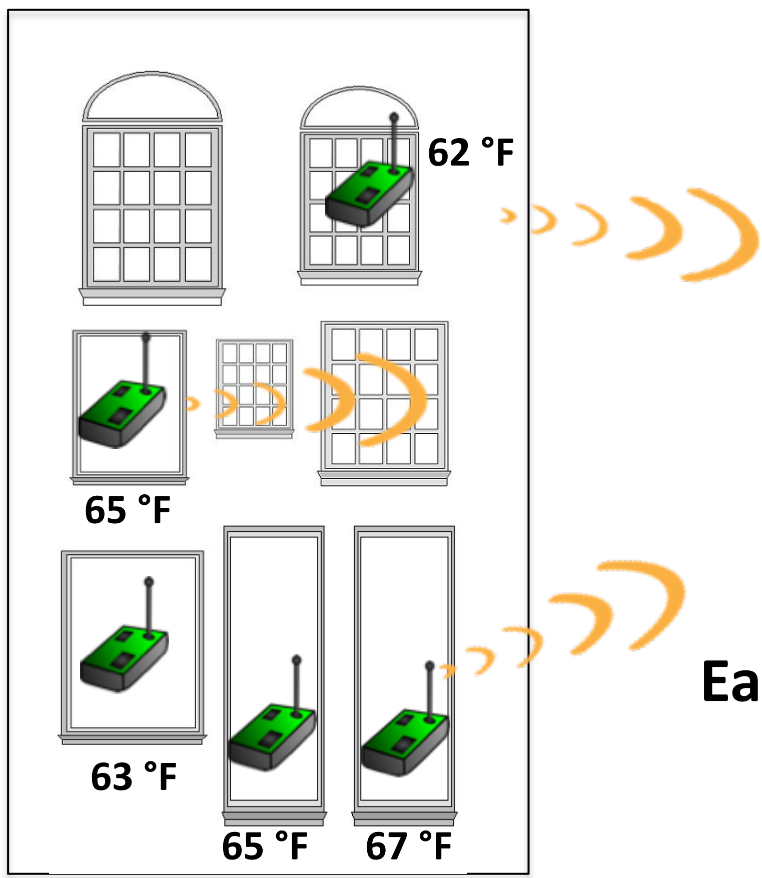
Range Extension

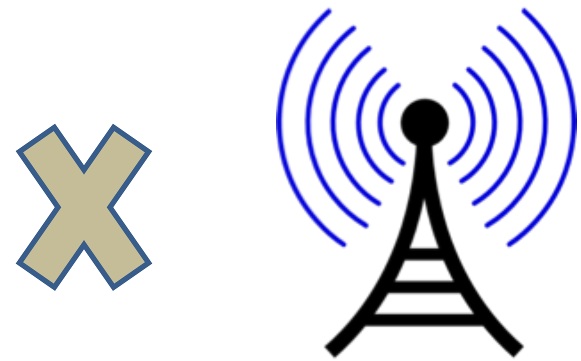




Each node is out-of-range!

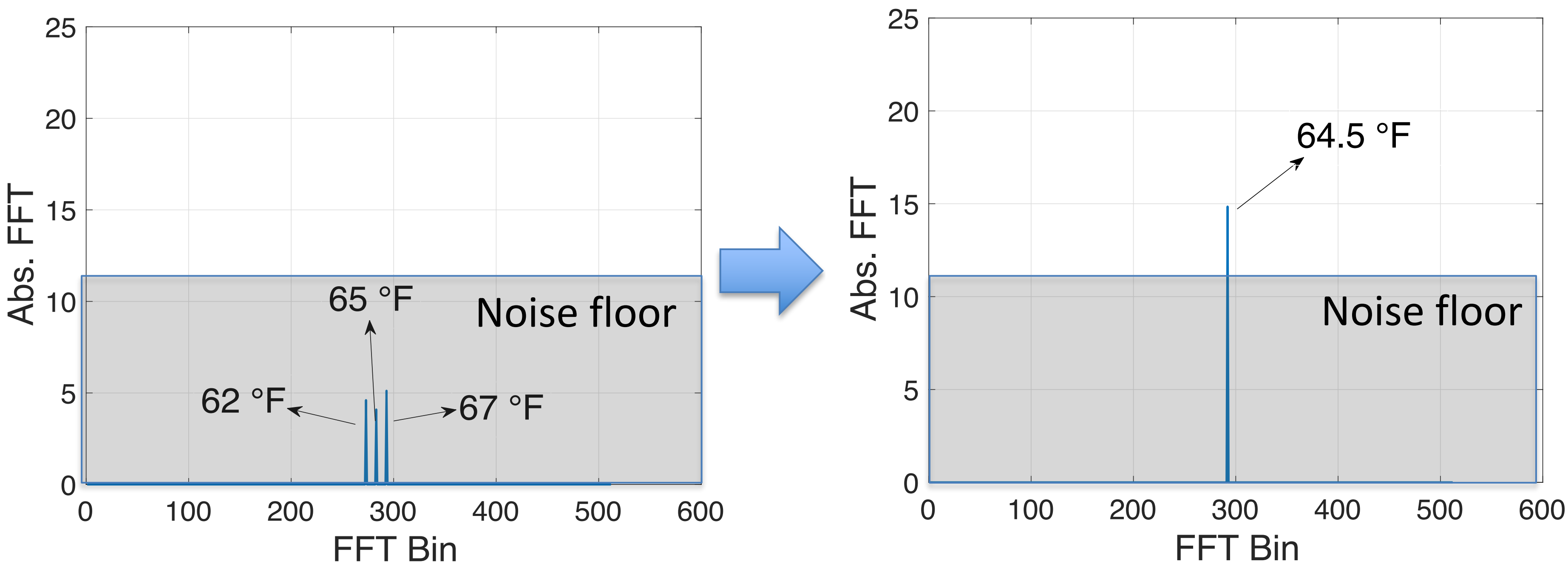
Range Extension





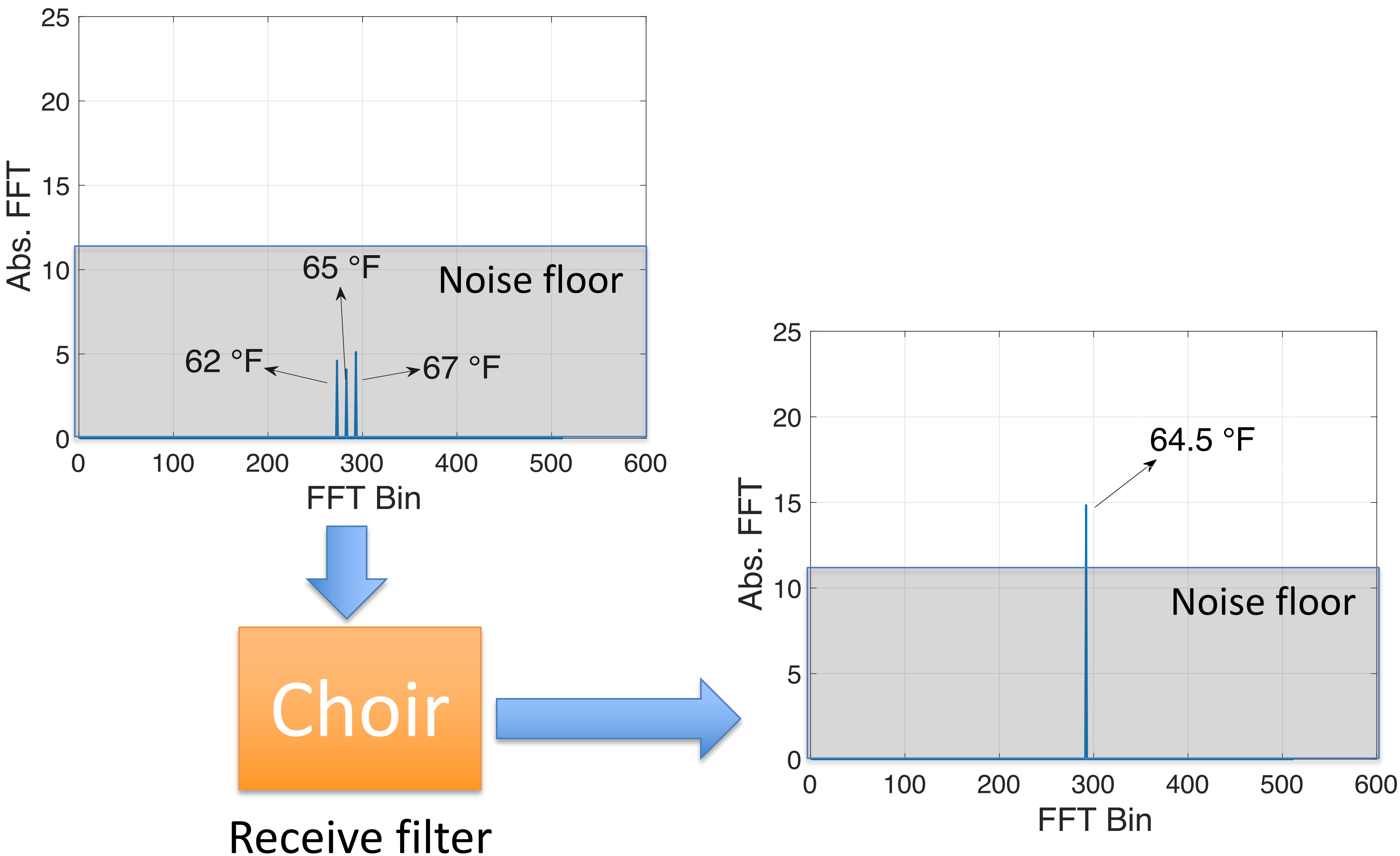
Each node is out-of-range!

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

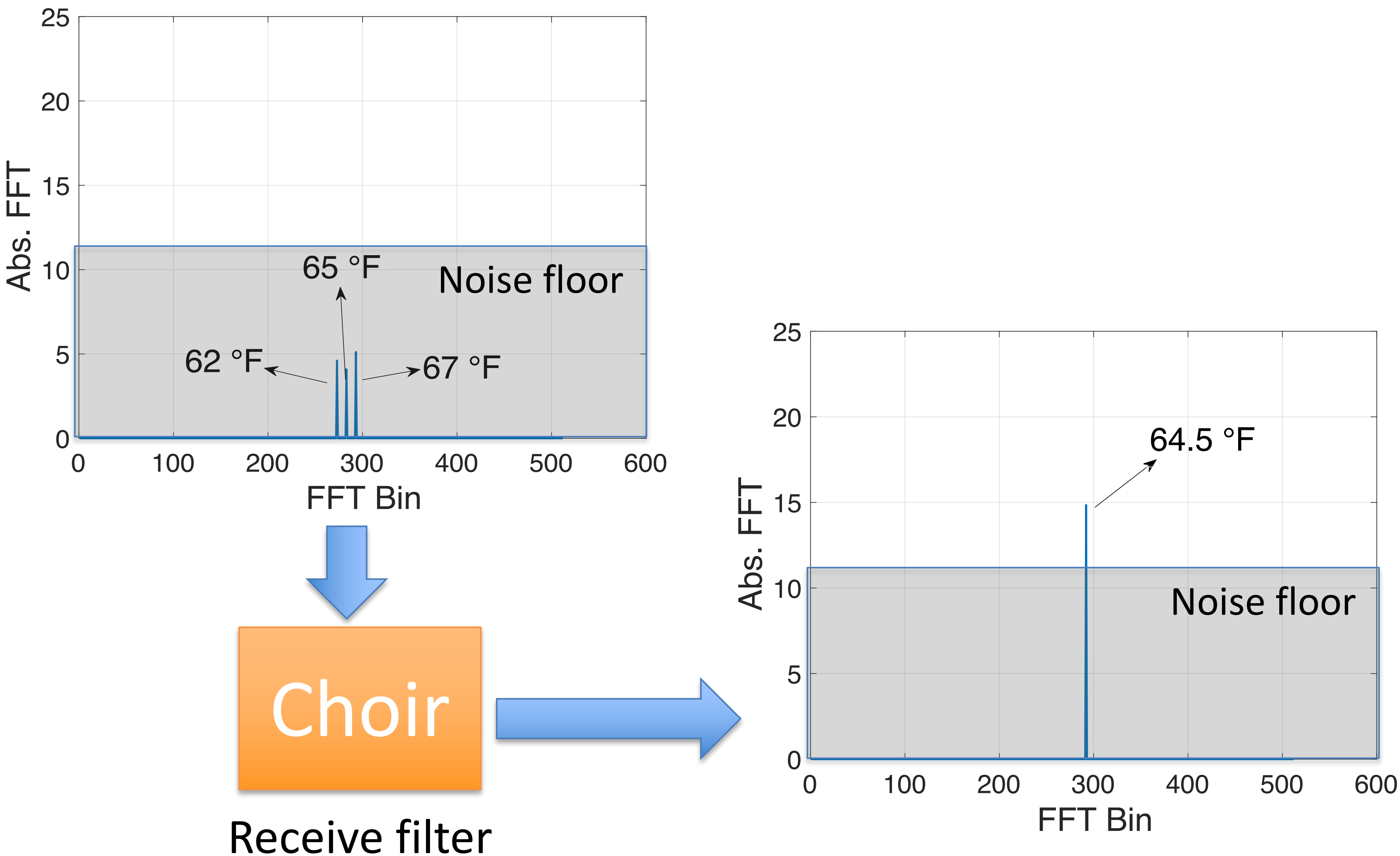


Objective

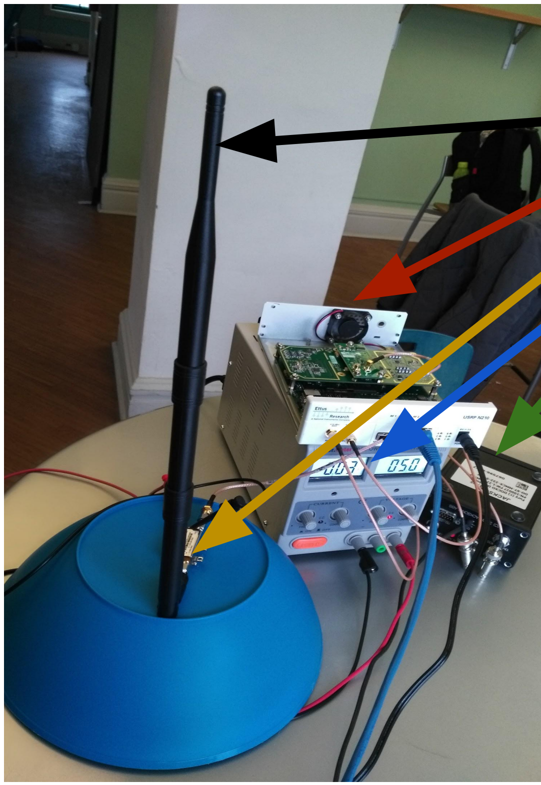
Coalesce these peaks around an aggregate value



Approach Signal processing based on exploiting frequency offsets to coalesce transmissions

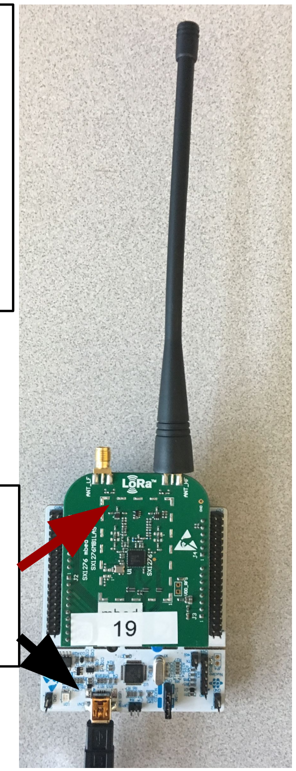

Abs. FFT
FFT Bin
Noise floor
65 °F
62 °F
67 °F
Choir
Receive filter
Abs. FFT
FFT Bin
Noise floor
64.5 °F

Implementation

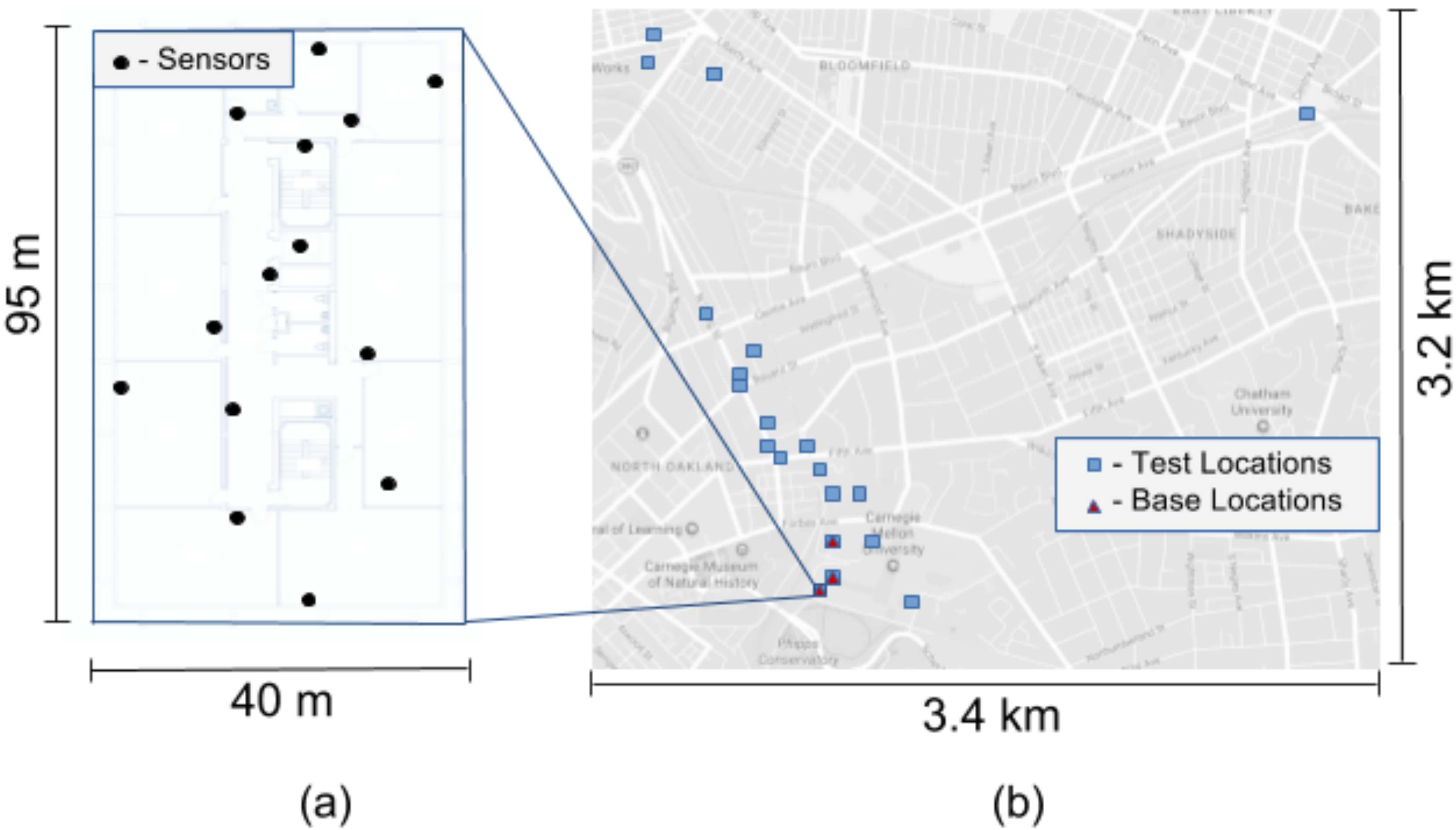


Base Station:
S469AM-915 Antenna
USRP N210
ZX60-0916LN+ LNA
Power Supply
Jacksonlab Fury Clock

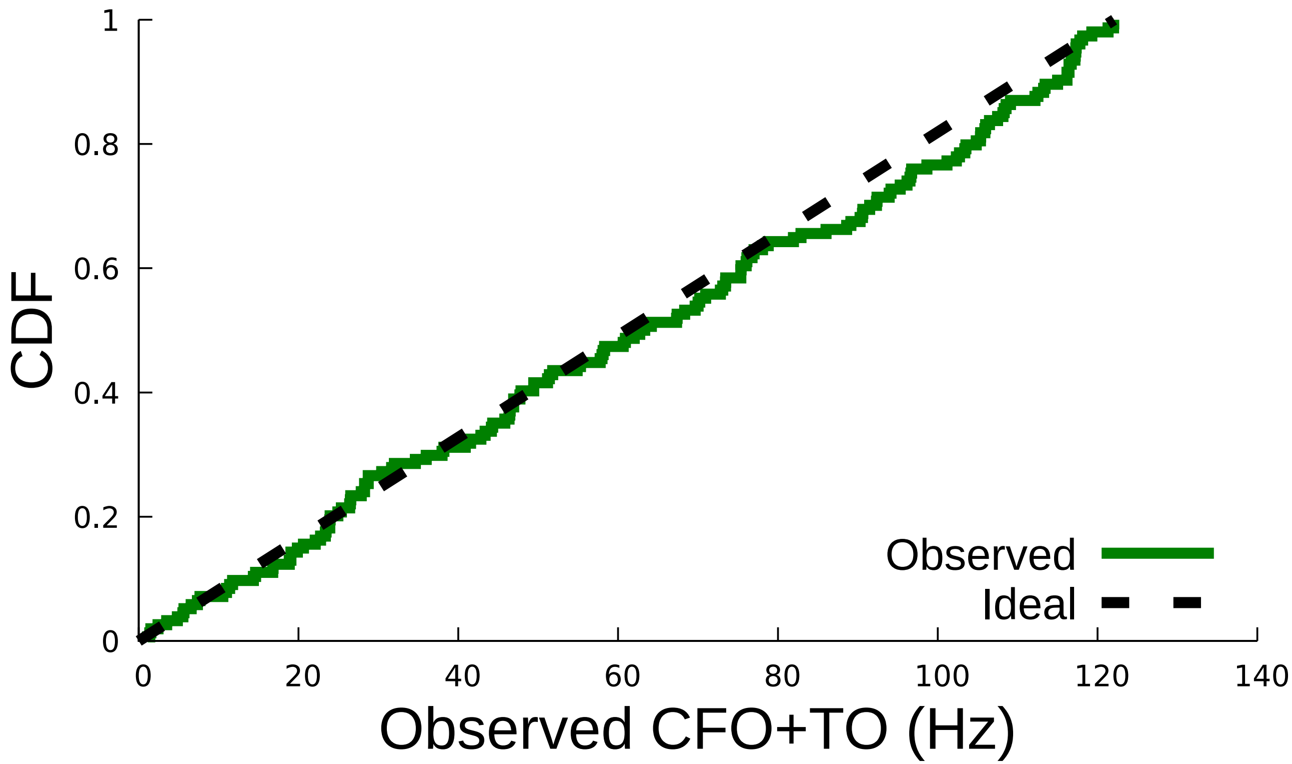
LoRaWan Node:
SX1276MB1LAS Client
NUCLEO-L152RE Platform



Evaluation

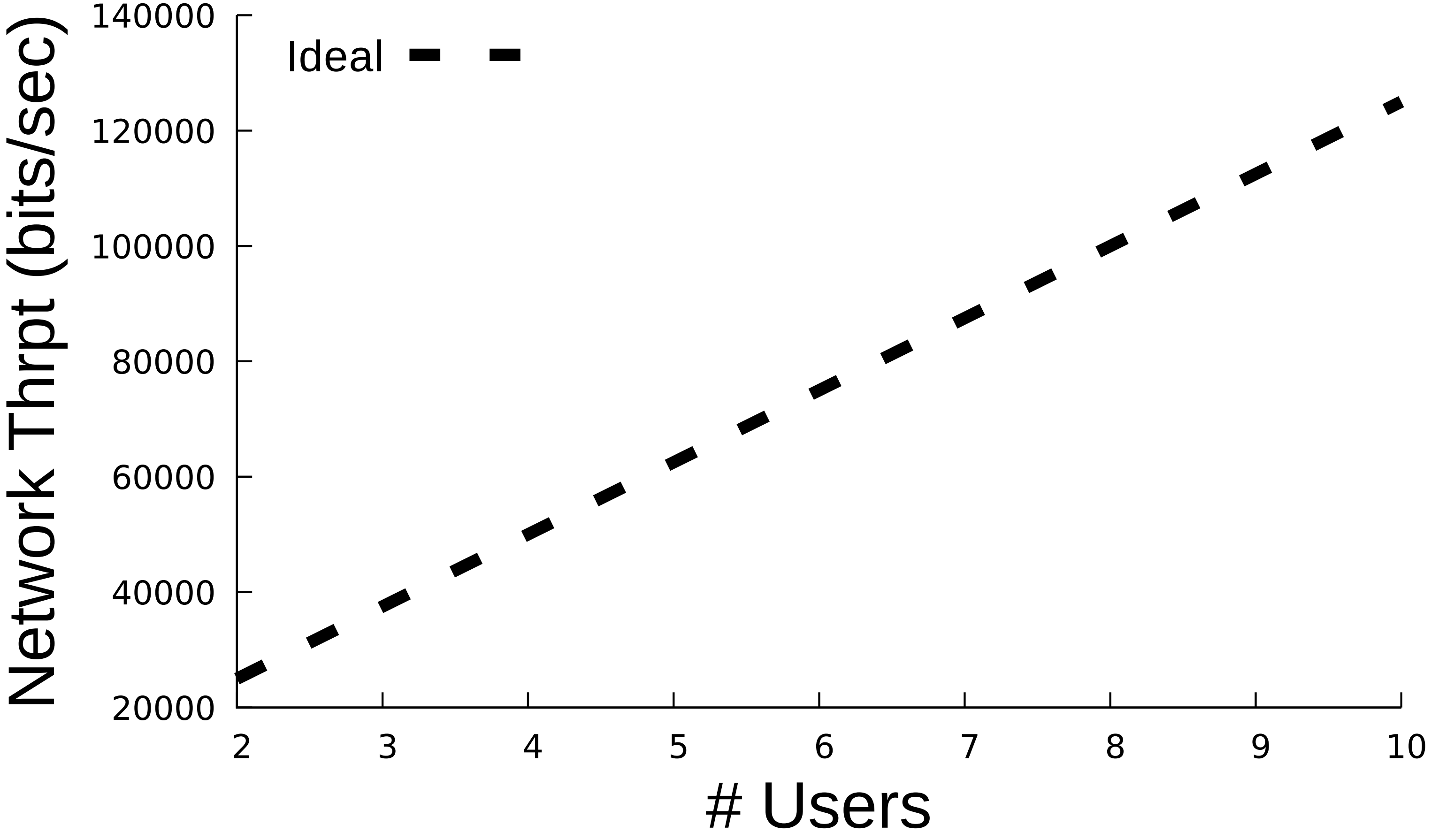


Hardware offsets

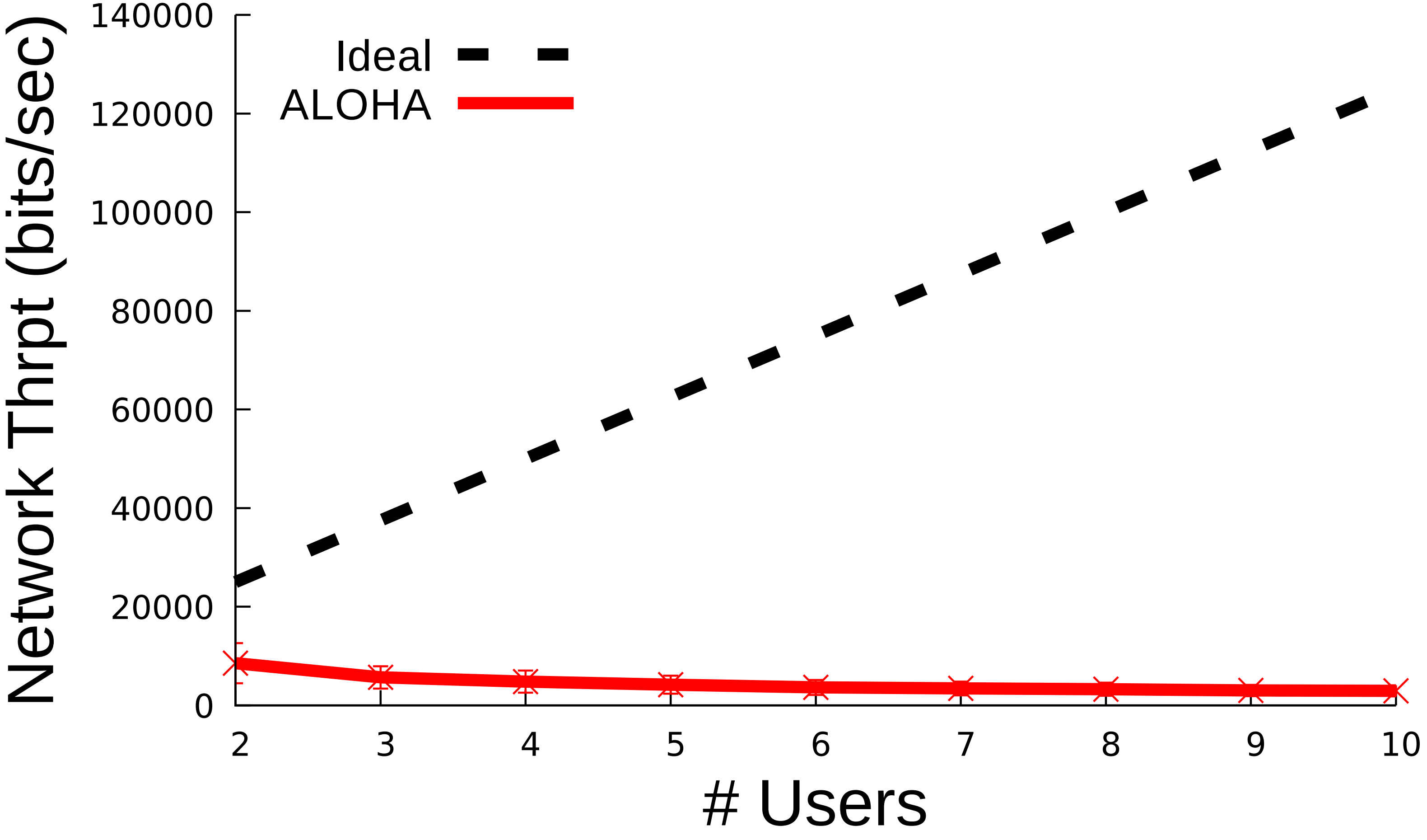


Hardware offsets are truly diverse across LPWAN radios

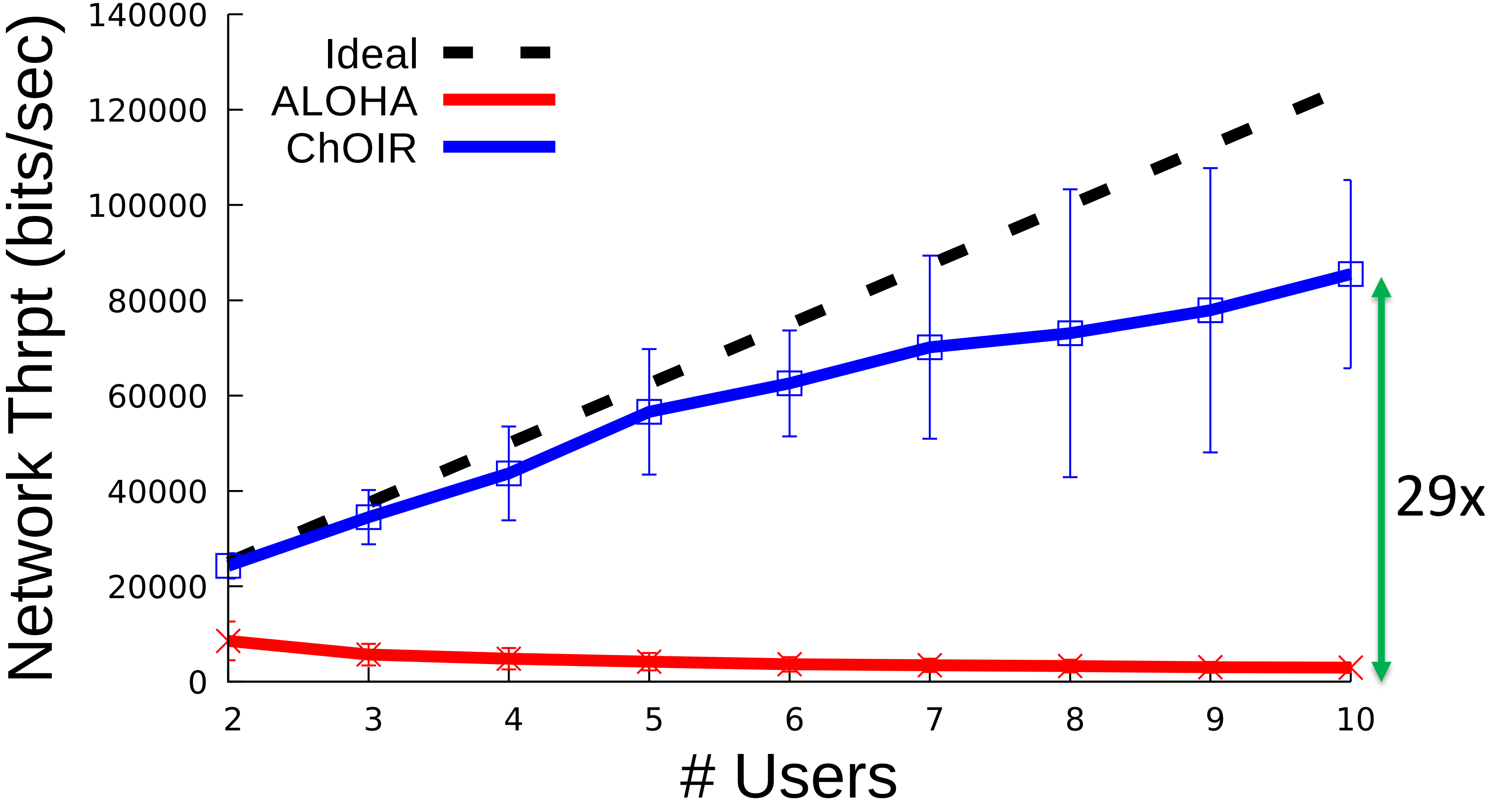
Resolving interference



Resolving interference



Resolving interference



Extending range

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

2.65X

Conclusion

Objective Improving the throughput and range of LPWANs in urban environments

idea Exploiting hardware imperfections!

Platform Commodity LoRaWAN LPWAN radios

Results

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