Choir: Empowering Low-Power Wide-Area Networks in Urban Settings

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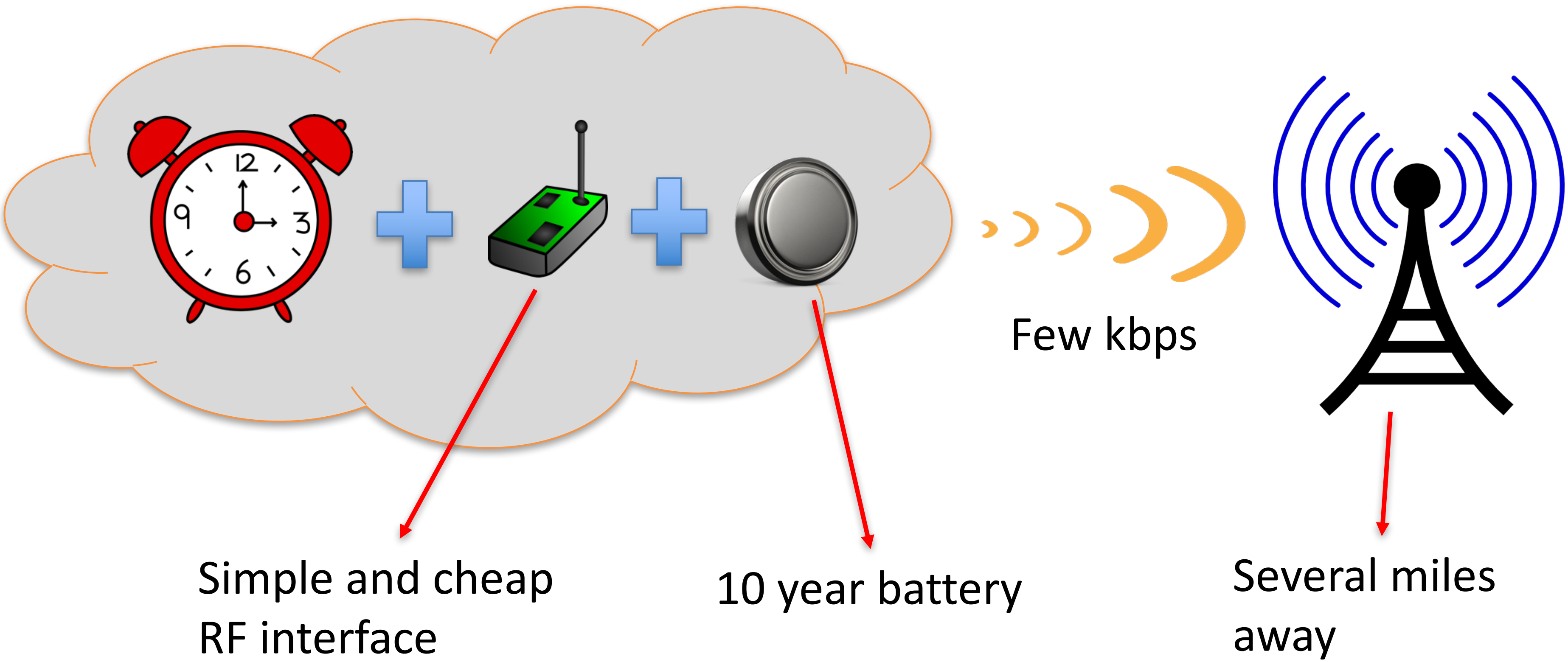
http://www.witechlab.com/LoRa/ChOIR.html

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

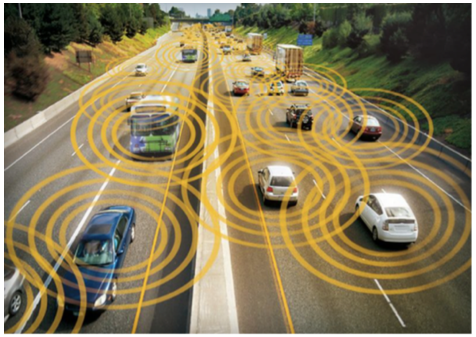


The building block for a city-scale Internet of Things…

Smart Infrastructure

Smart Homes

Smart Vehicles



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

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Long Range

- Up to 10 KMs in rural areas

Low Data rate

- Order of kilobits per second

Low Cost

- < $5

Low Power

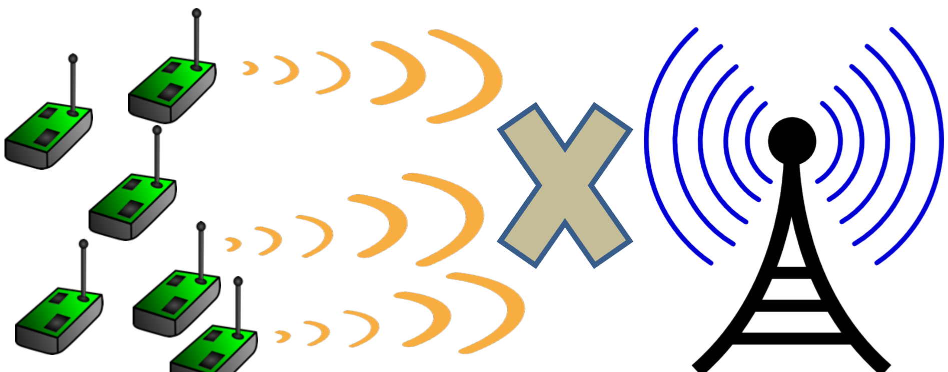
- Up to 10 years of battery life

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

Key Challenges

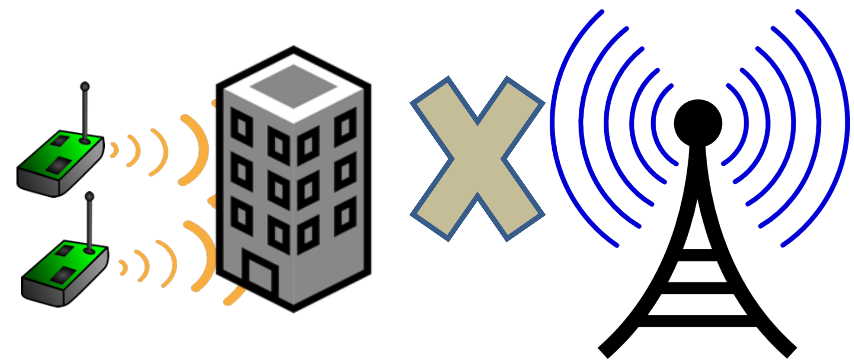
Key Challenges

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.

Past work

WiFi/Cellular	Wireless sensor networks	LPWANs
MegaMIMO	Glossy	LoRaWAN
SAM	ACR	Sigfox
ZigZag	….	….
….		

Choir

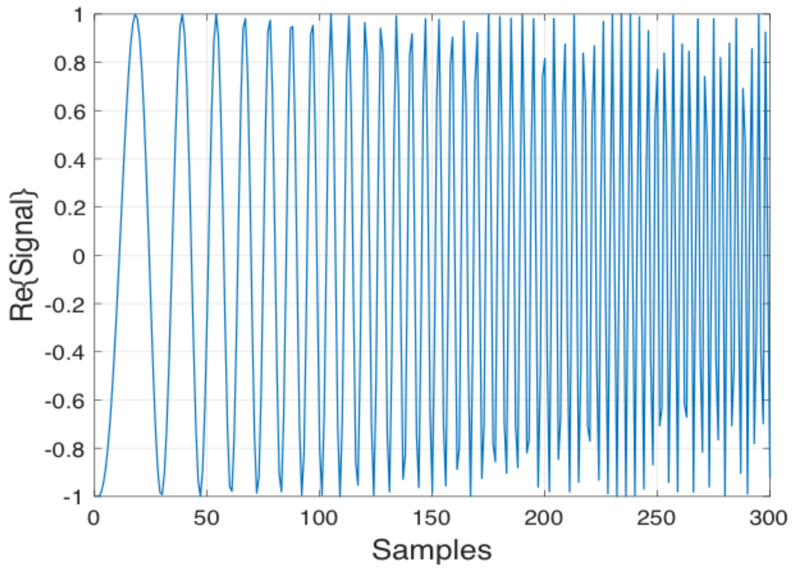
Scalability	Range	Preserving simplicity
• Decodes 10’s of collided transmissions	• Extends the range of teams of cooperating nodes	• Fully implemented at a **single-antenna** base station

Fully implemented and evaluated on

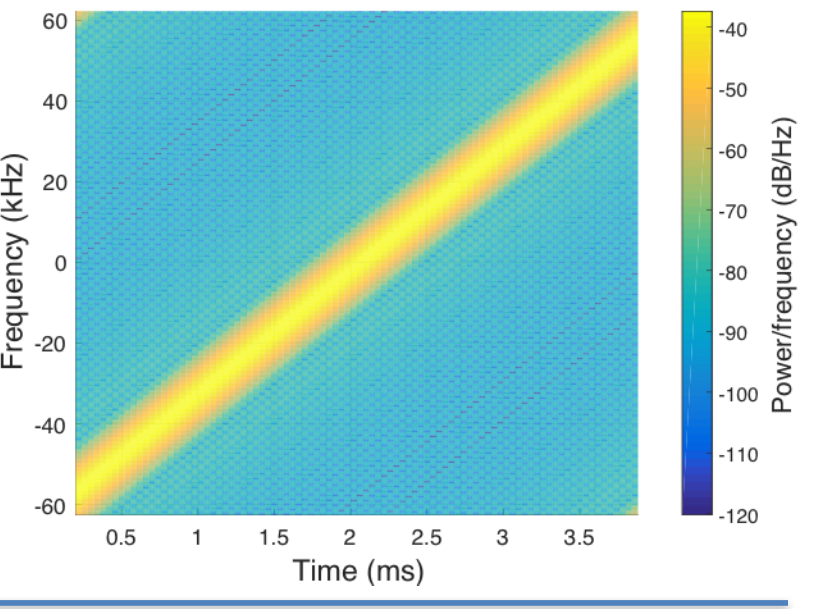
LoRaWAN™ base station over an area of 10 Km^2 in Pittsburgh

LoRaWAN™ : Chirps

Chirp in T.D.



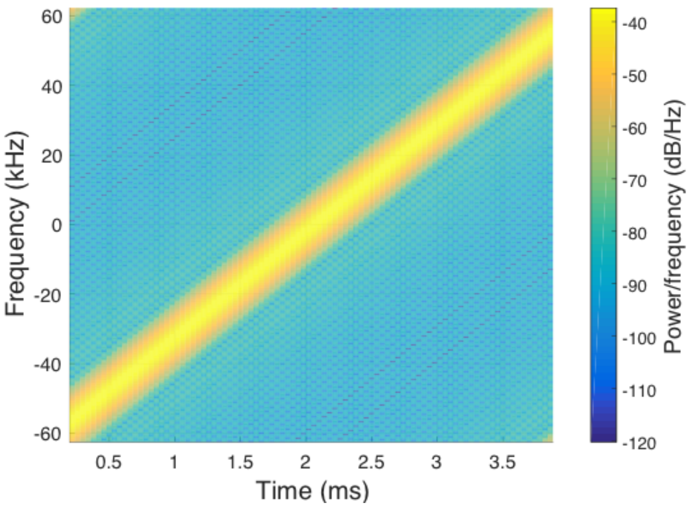
Chirp on a spectrogram



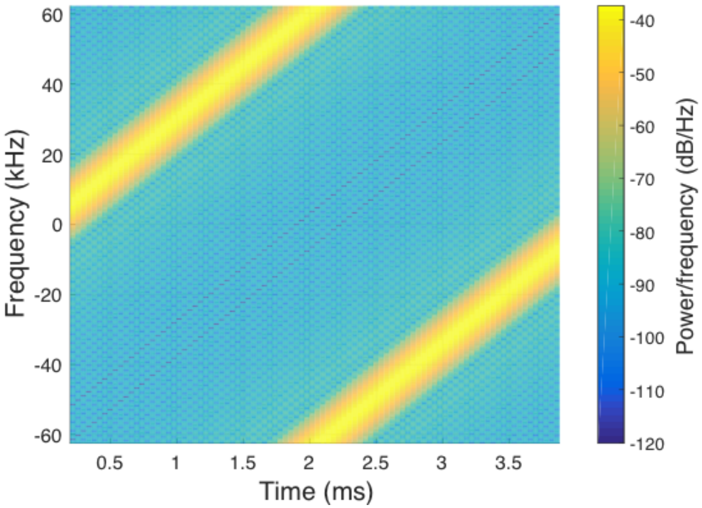
Data encoding

The initial frequency of the chirp

LoRaWAN™ : 1-bit encoding



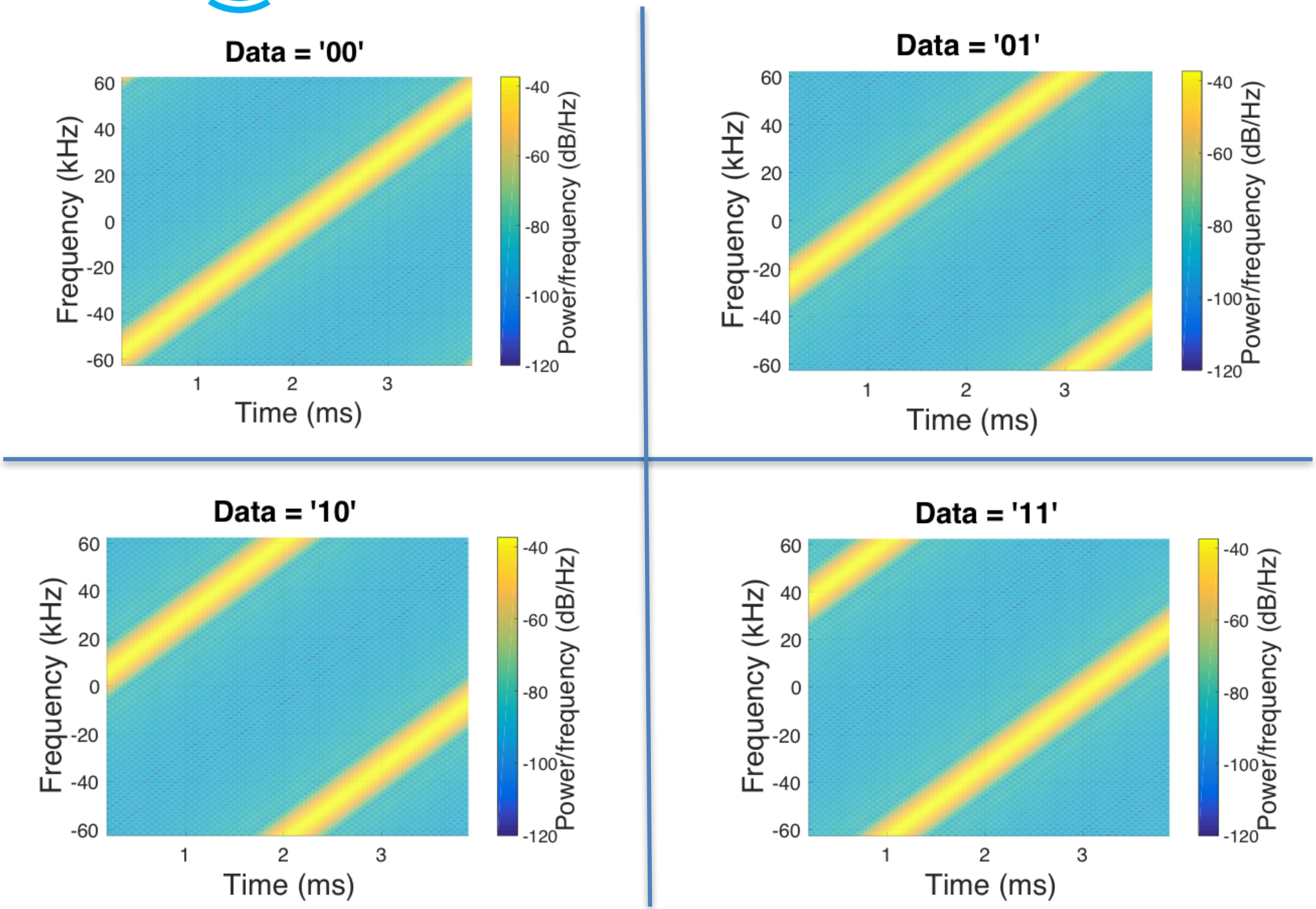
‘0’



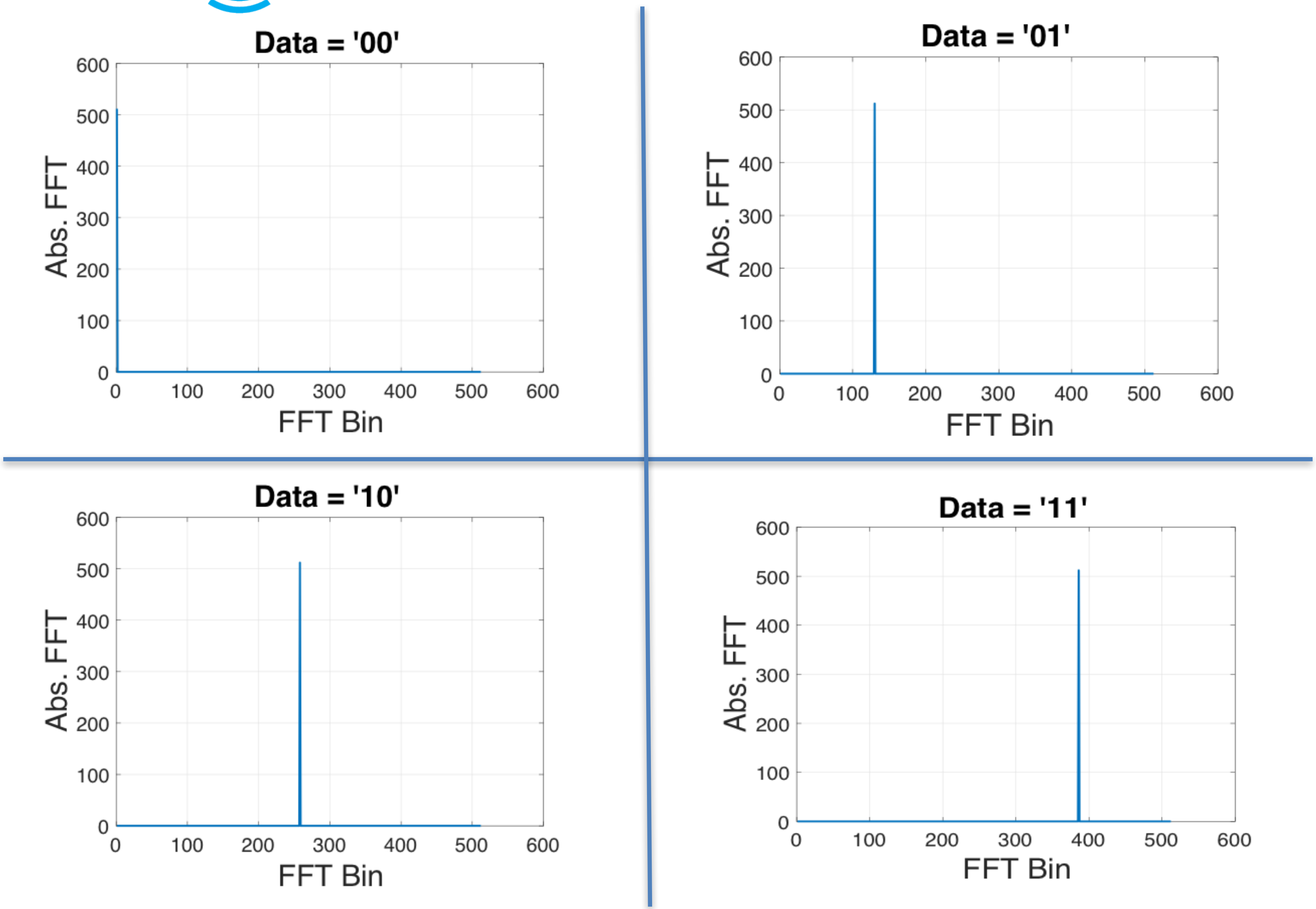
‘1’

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

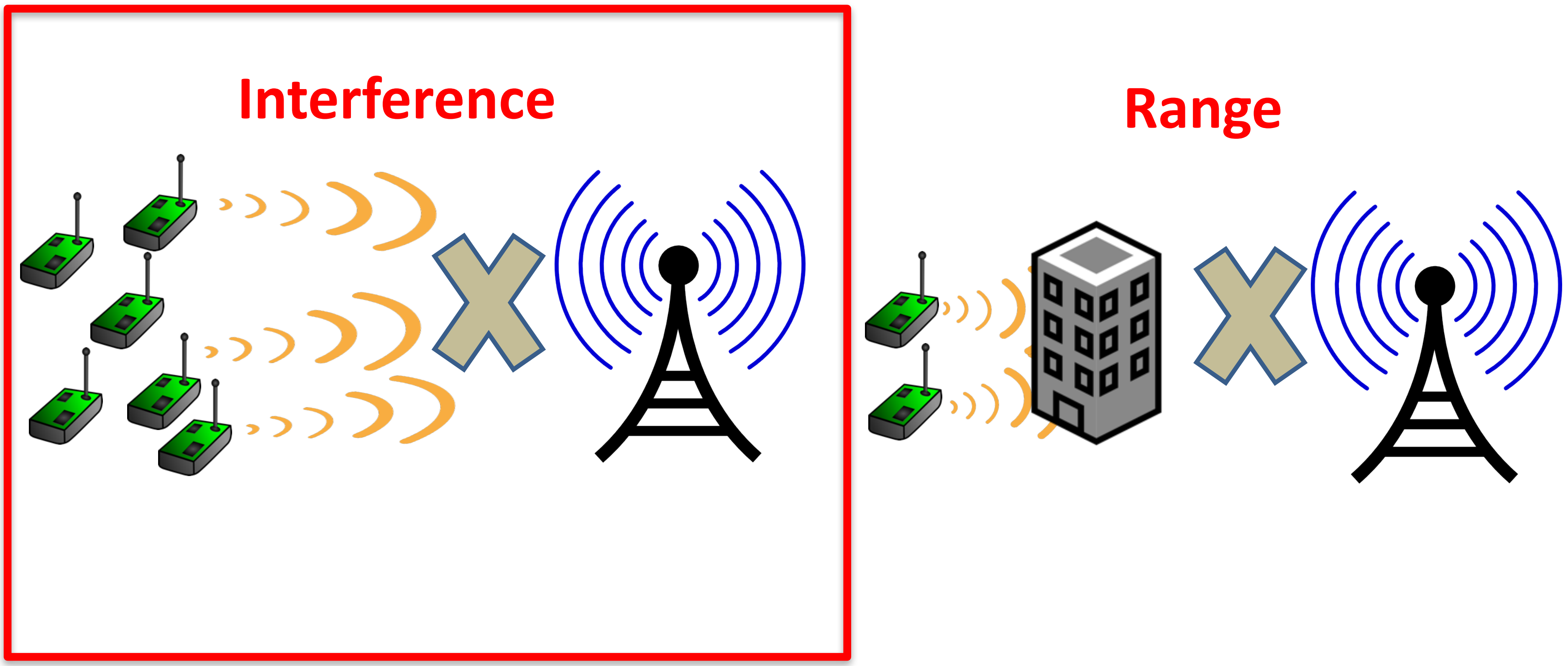
LoRaWAN™ : 2-bit encoding



LoRaWAN : 2-bit encoding

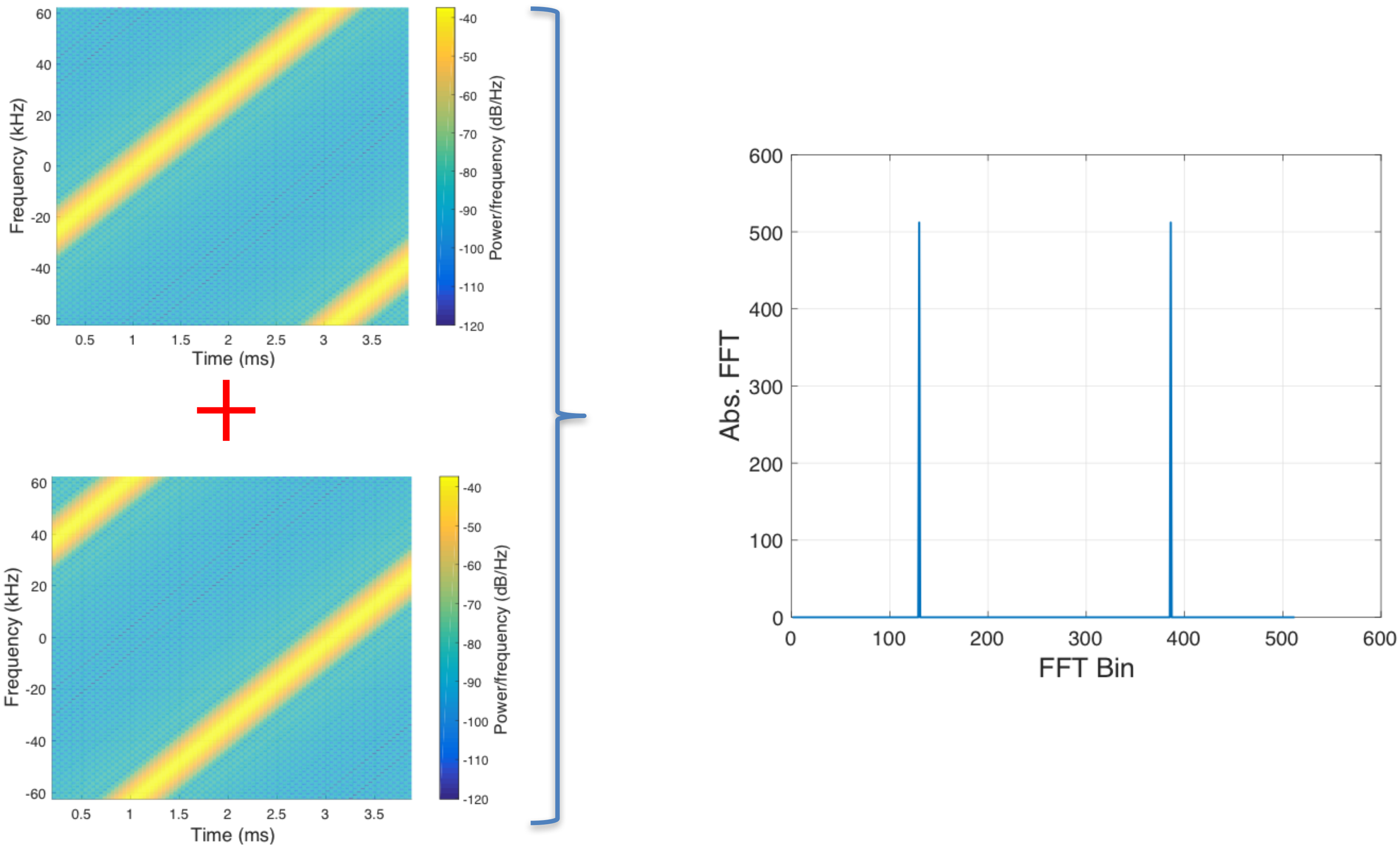


Choir in action



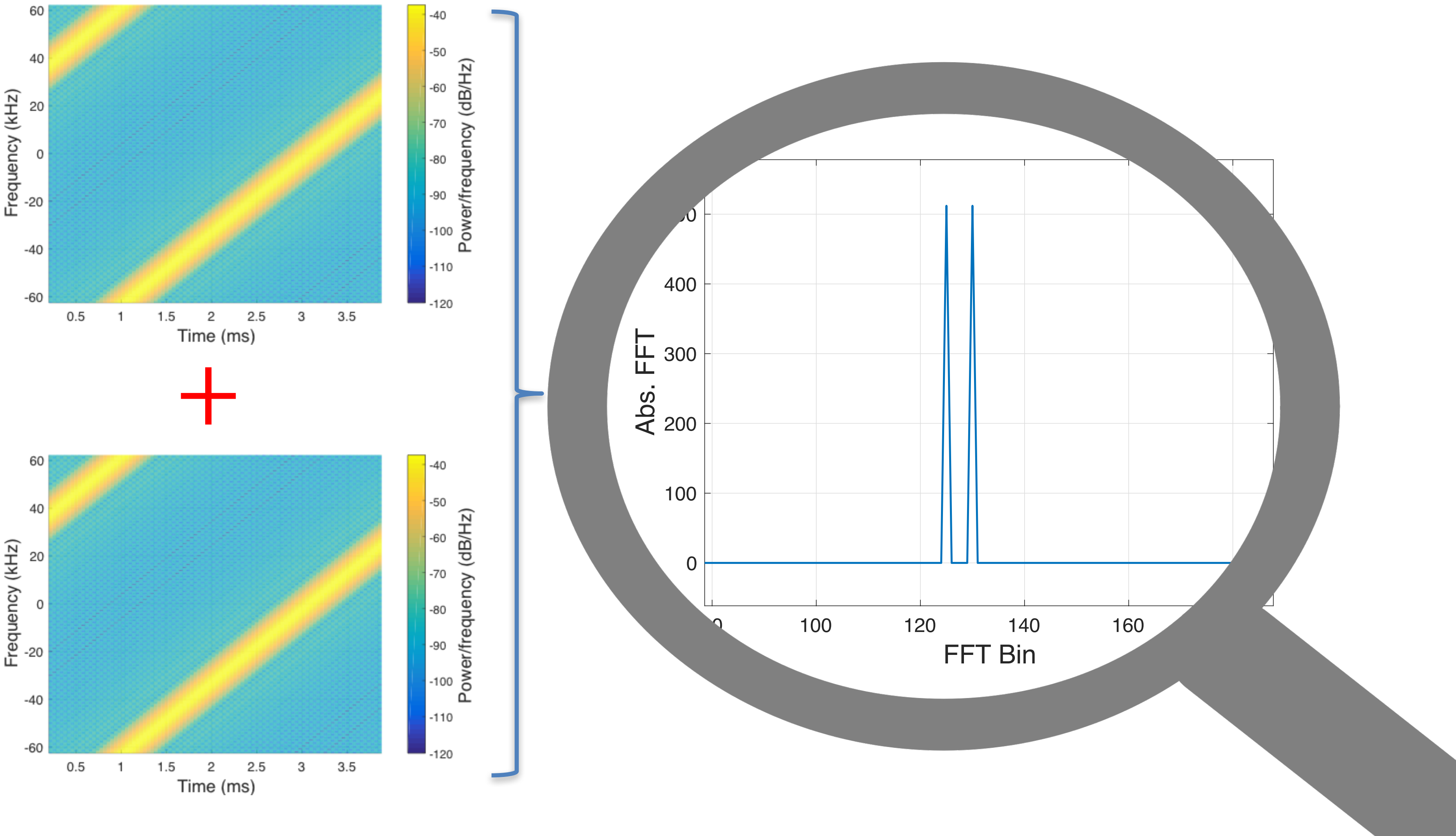
Collision of chirps

Different data



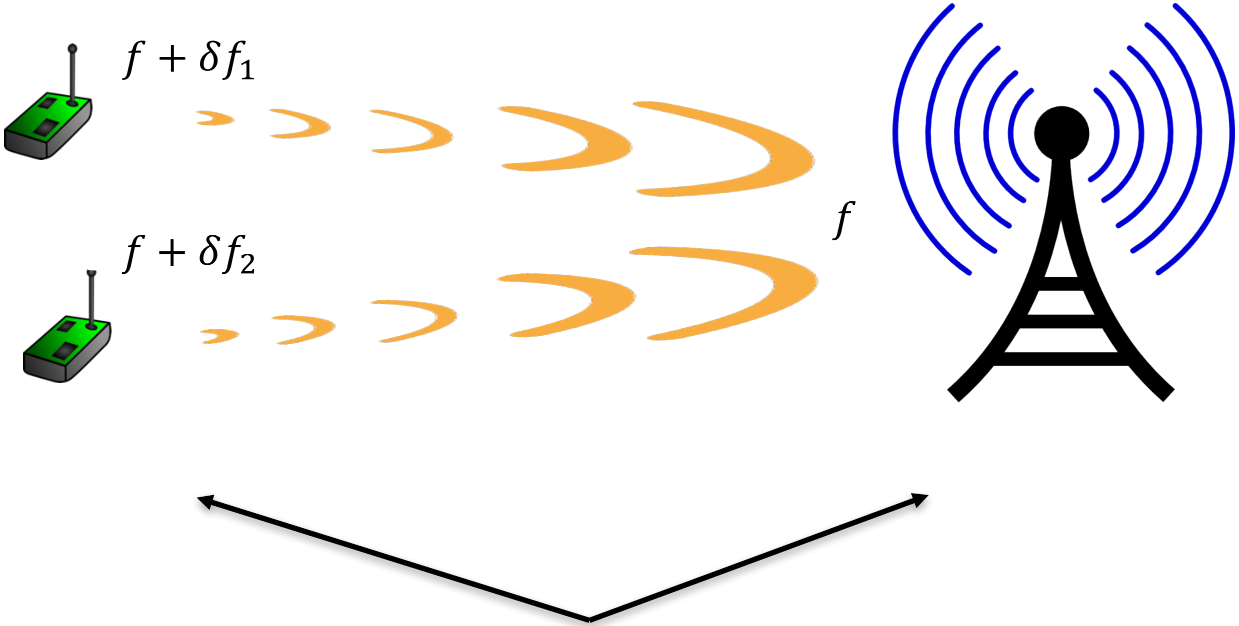
Collision of chirps

Same data



Hardware imperfections

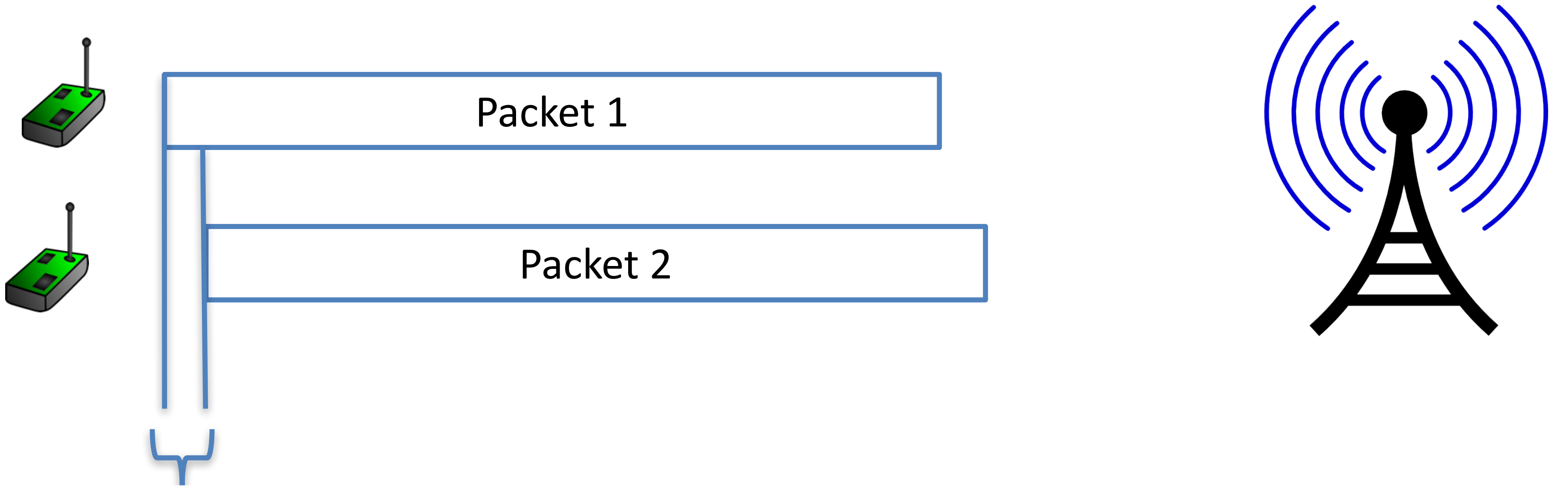
Carrier frequency offsets (CFO)



Local oscillator mismatch

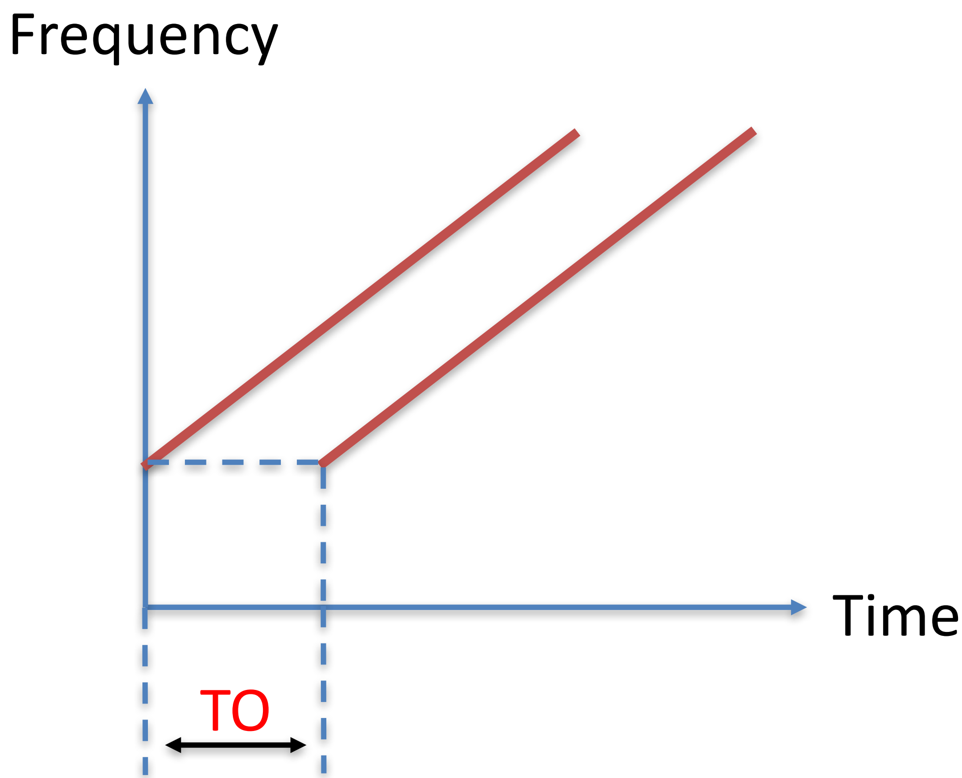
Hardware imperfections

Timing offsets (TO)



Sub-symbol timing offsets

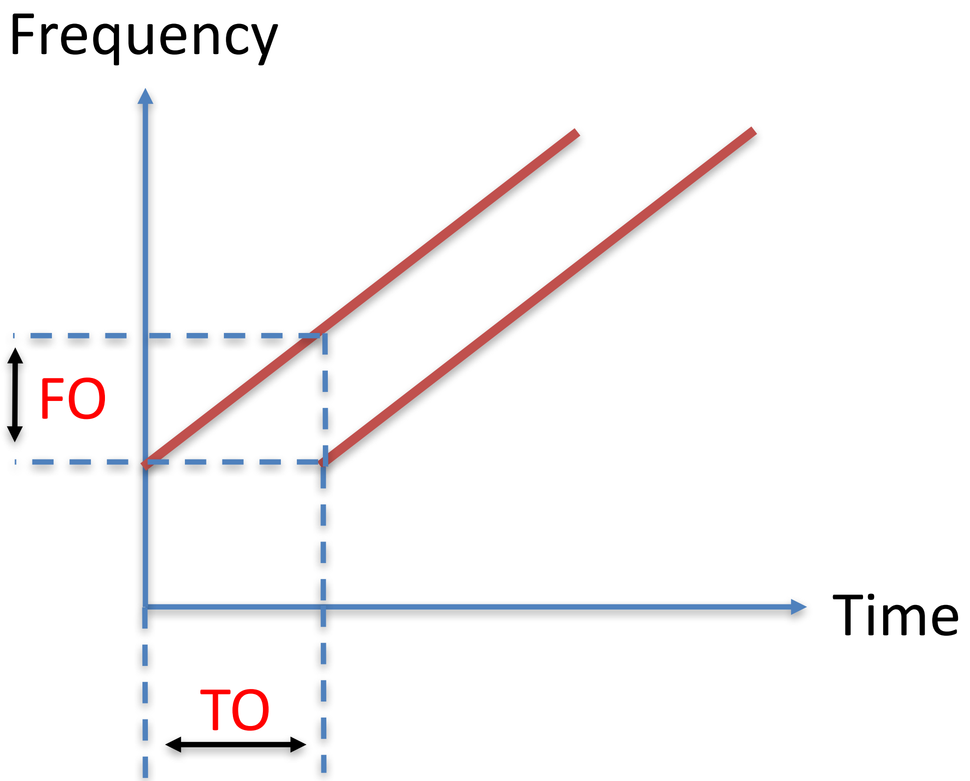
Timing offsets (TO)



Recall

Chirps are signals whose frequency increases linearly with time

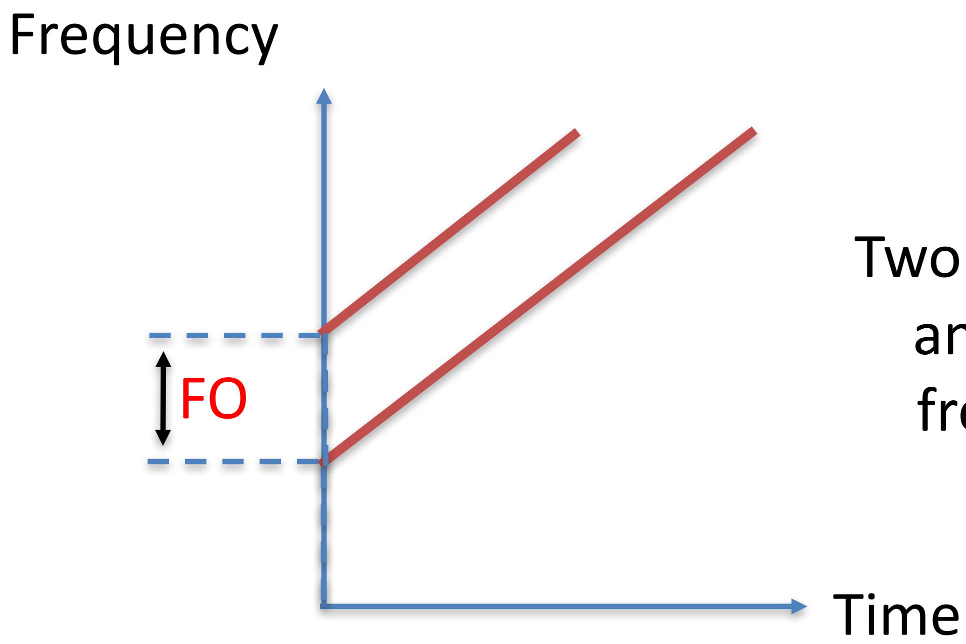
Timing offsets (TO)



Thus,

An offset in time maps to an offset in frequency!

Timing offsets (TO)

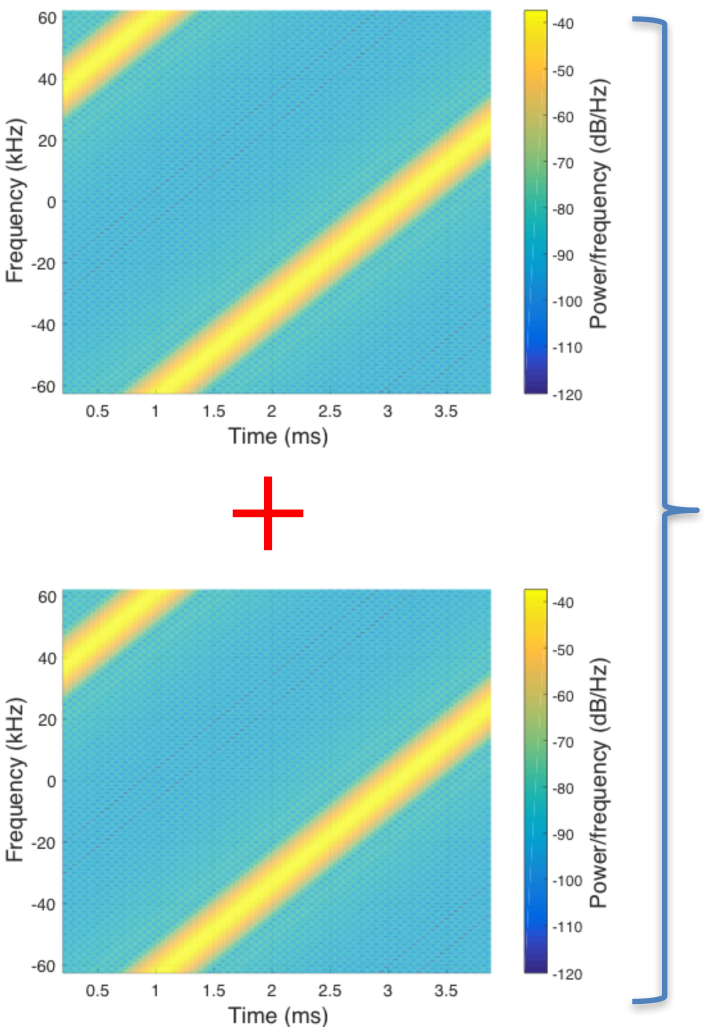


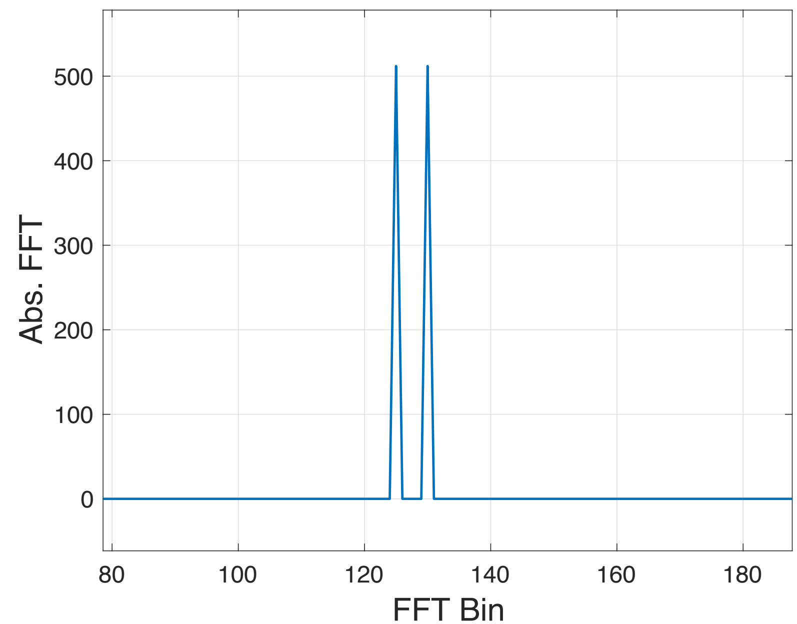
Two chirps with an offset in frequency!

Hardware offsets := { CFO + TO}

Collision of chirps

Same data



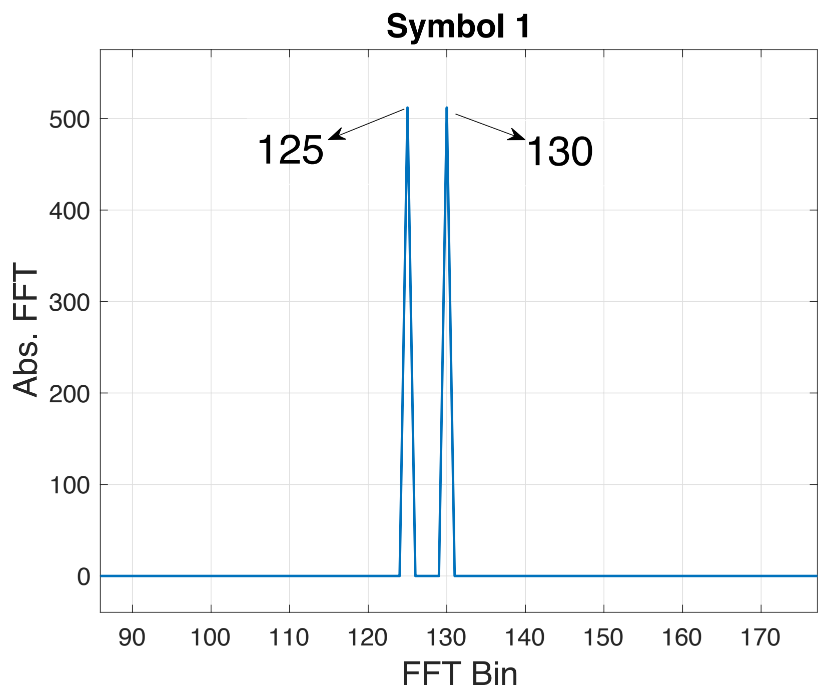


Hardware offsets!

idea

Exploit hardware imperfections to resolve collisions!

Decoding data



U1 data: ✓ U2 data: ✓

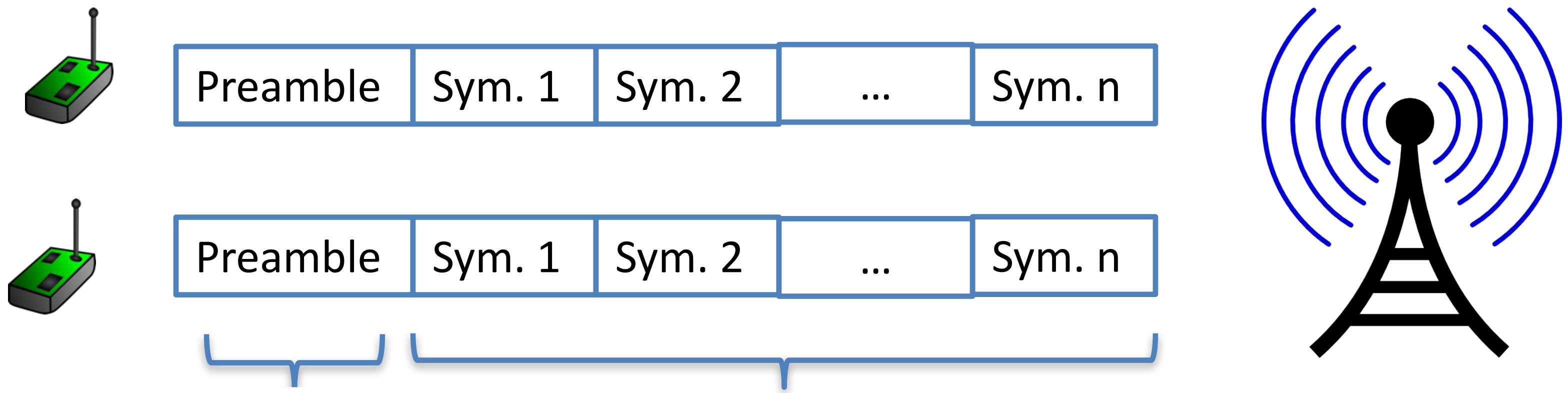
U1 data + U1 hardware offsets = 125

U2 data + U2 hardware offsets = 130

!

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

Decoding data



Peak locations are used to estimate hardware offsets

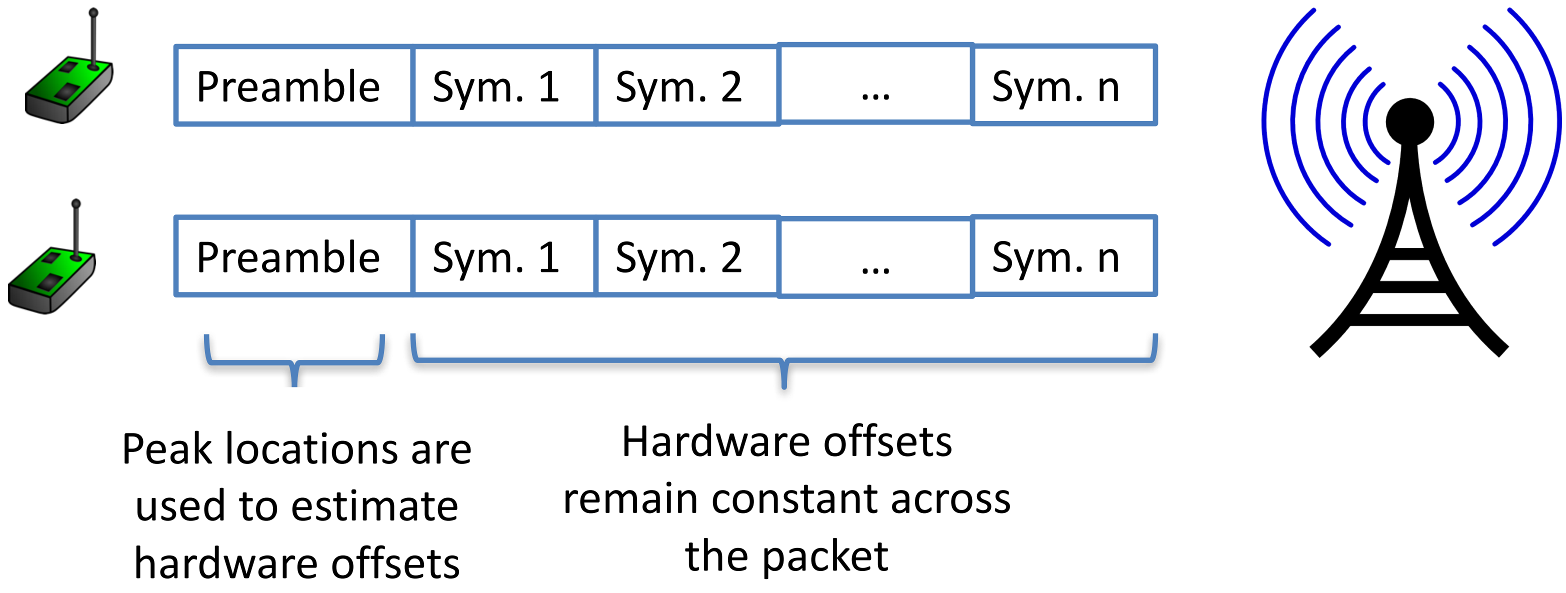
Hardware offsets remain constant across the packet

Symbol 1:

U1 data + U1 hardware offsets = 125 ✓

U2 data + U2 hardware offsets = 130

Decoding data



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

Details in the paper…

Which peak corresponds to which user?

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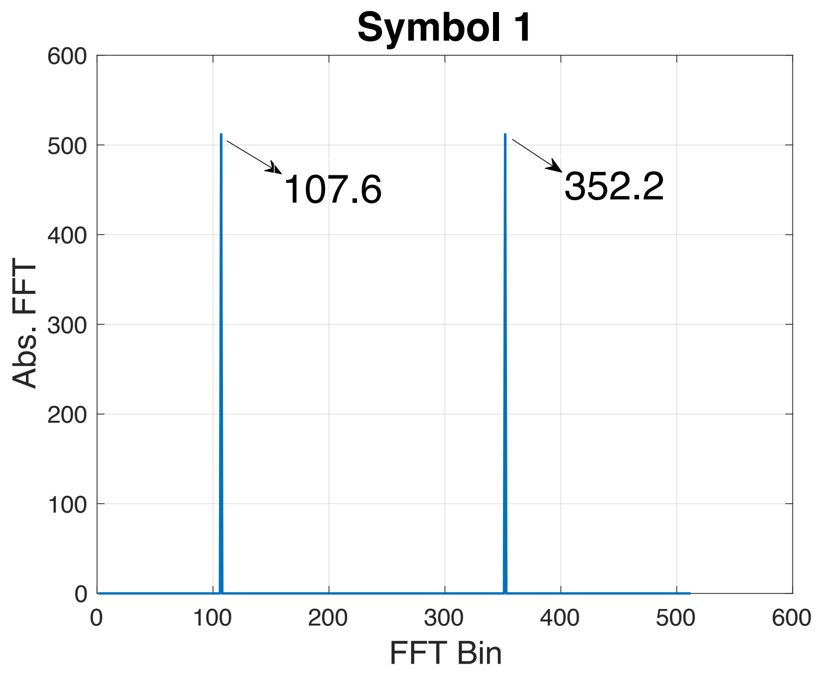
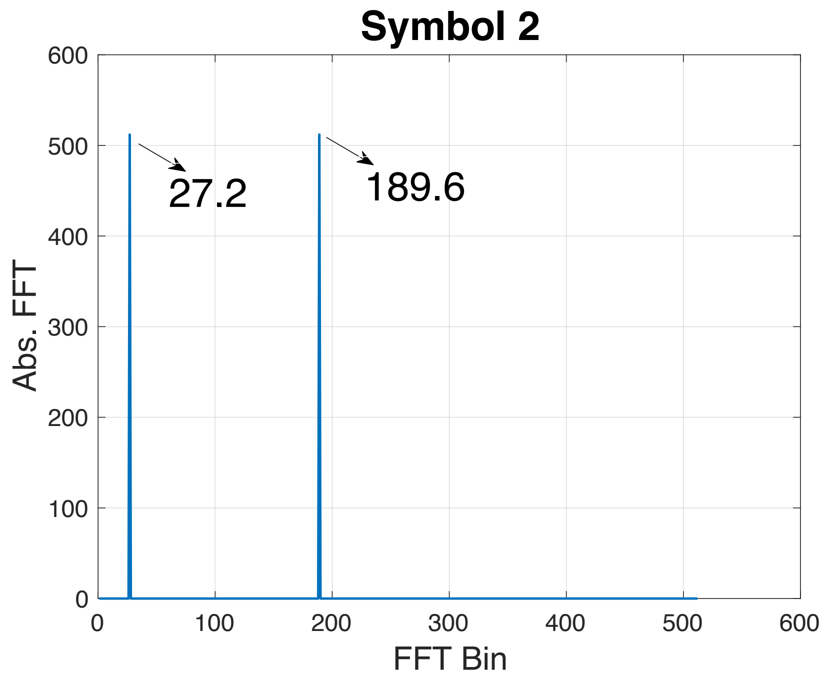
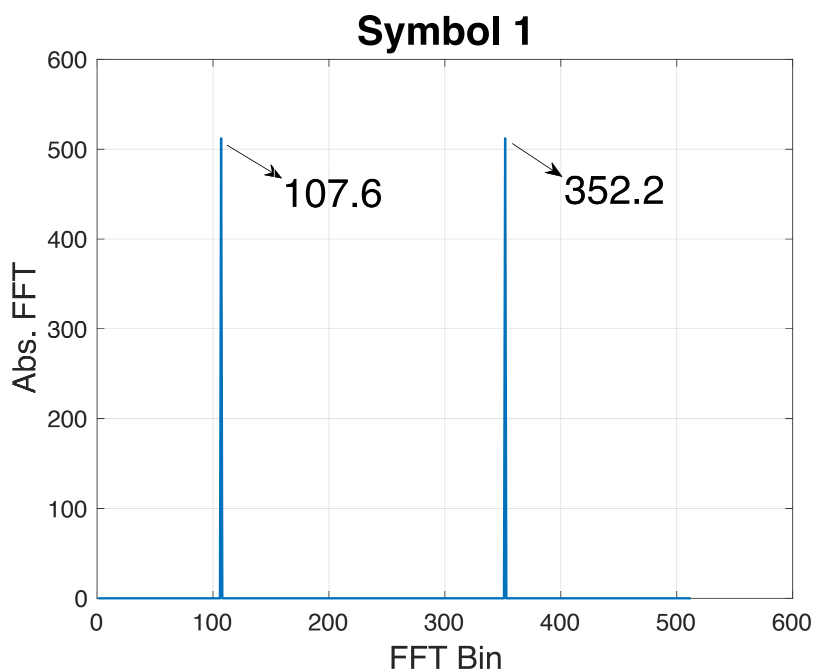
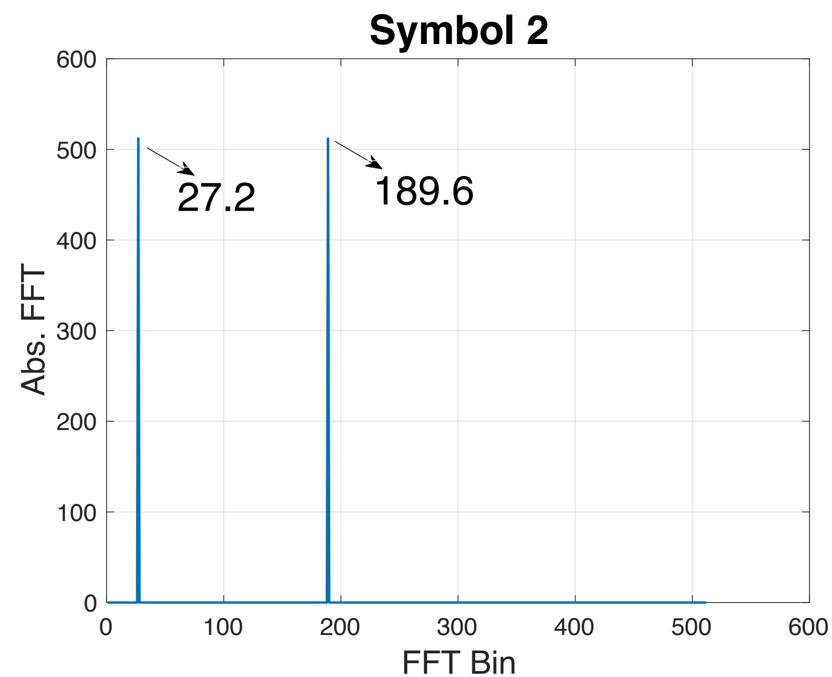




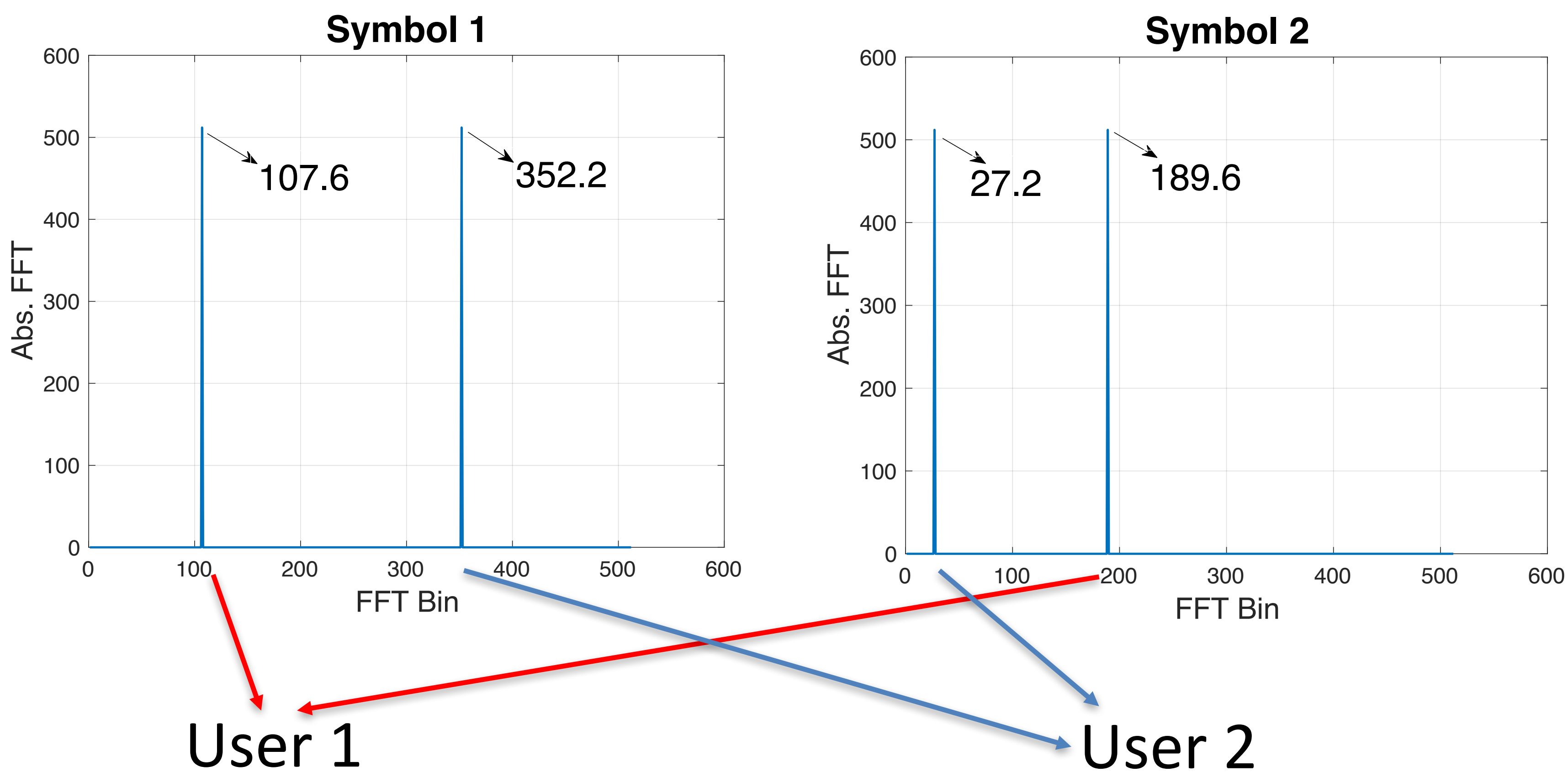
Which peak corresponds to which user?





Data bits are discrete, hardware offsets are continuous!

Which peak corresponds to which user?



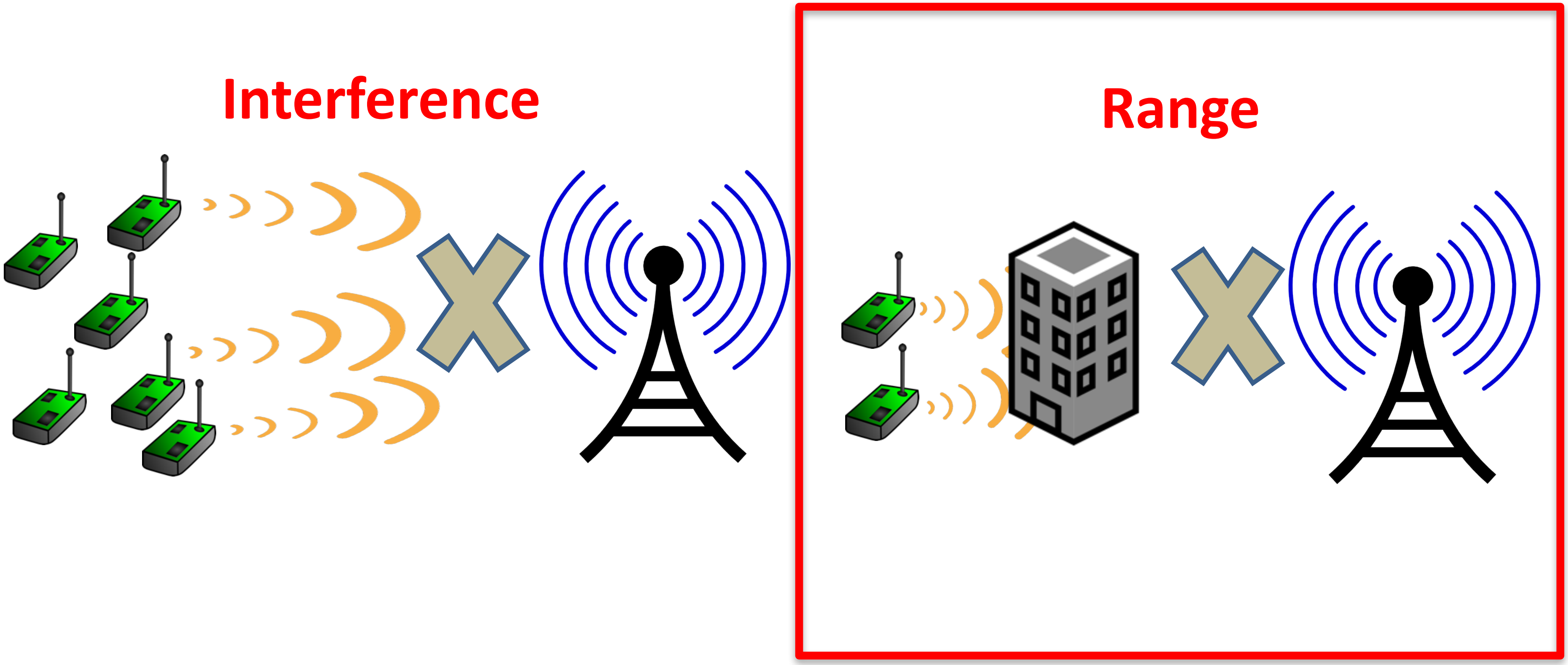
Integer part depends on both data and hardware offsets

Fractional part depends only on hardware offsets

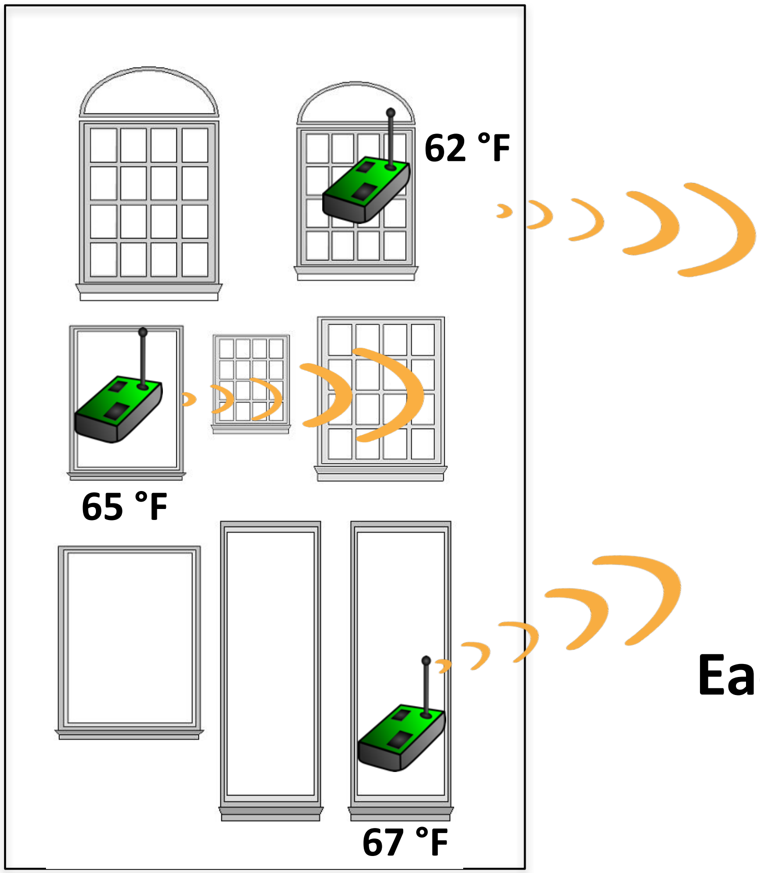
We generalize this solution to account for…

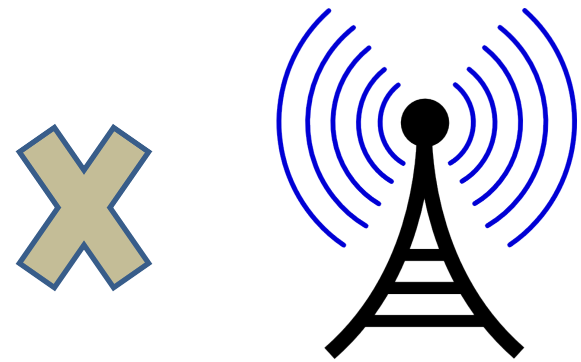
1. Near-far effect
2. Inter-symbol interference
3. Handling a general number of collisions

Choir in action



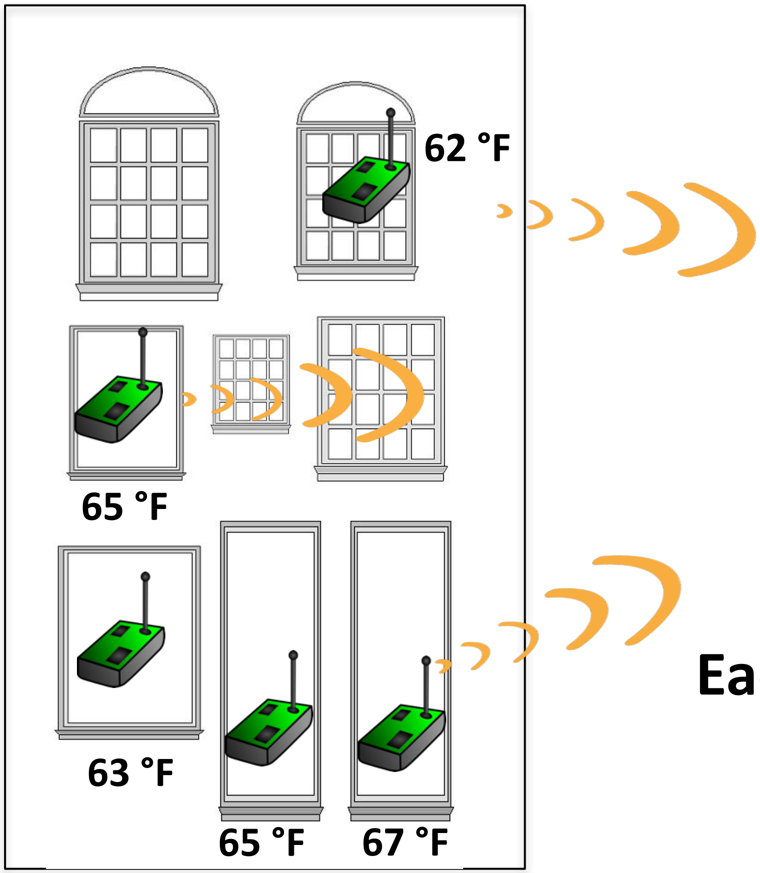
Range Extension

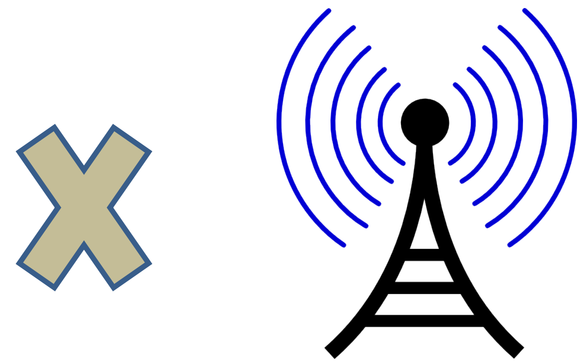




Each node is out-of-range!

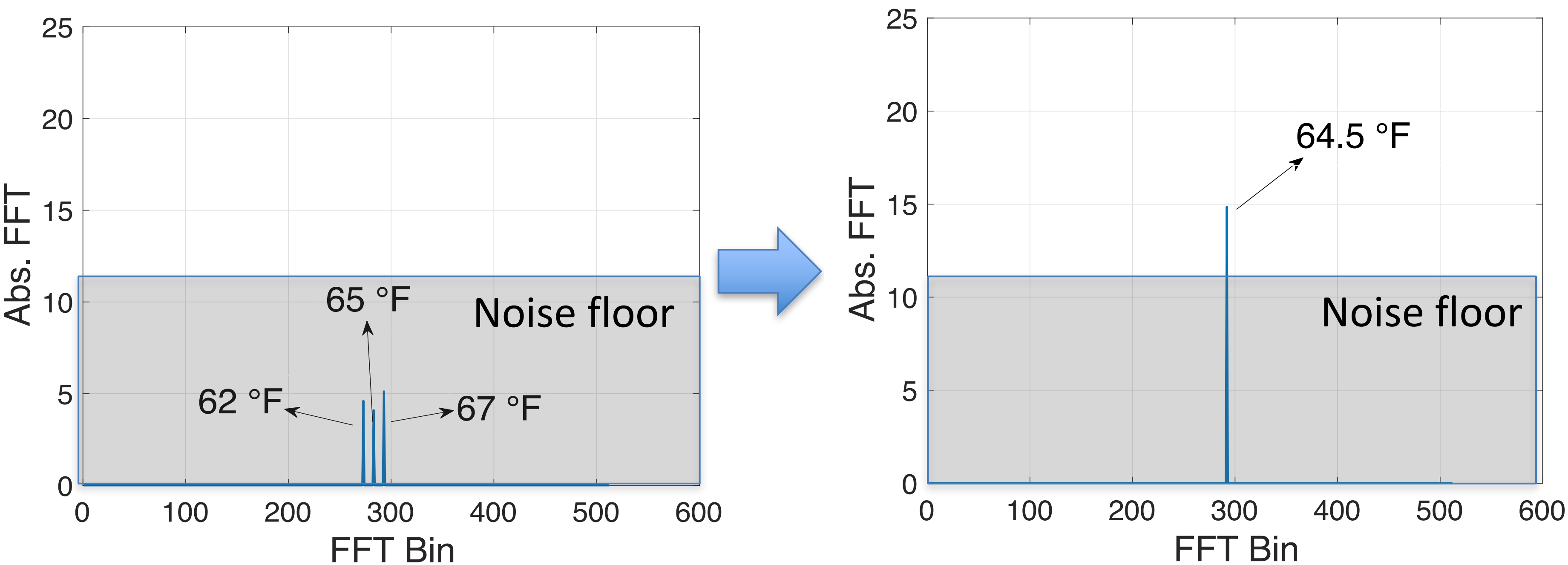
Range Extension





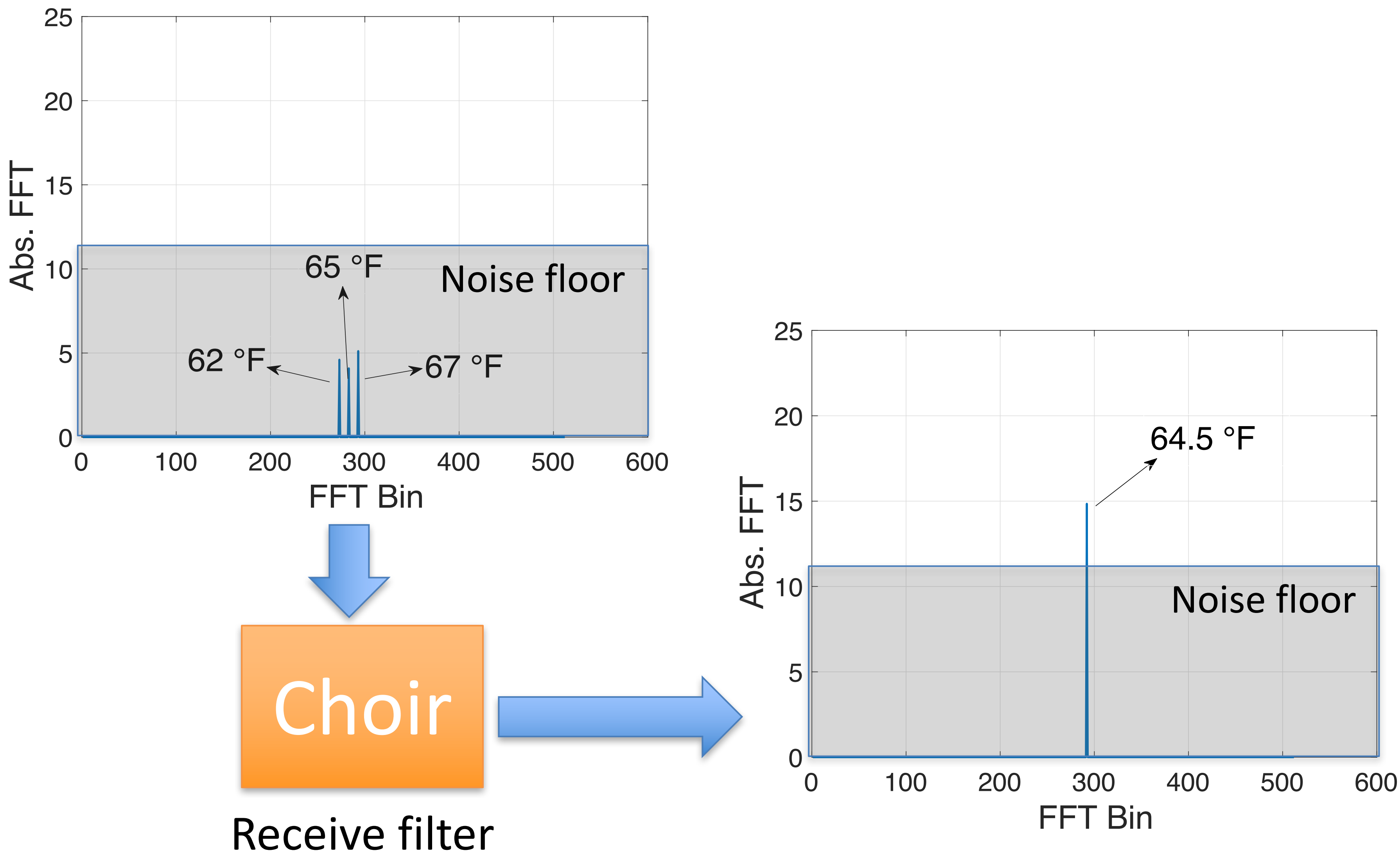
Each node is out-of-range!

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

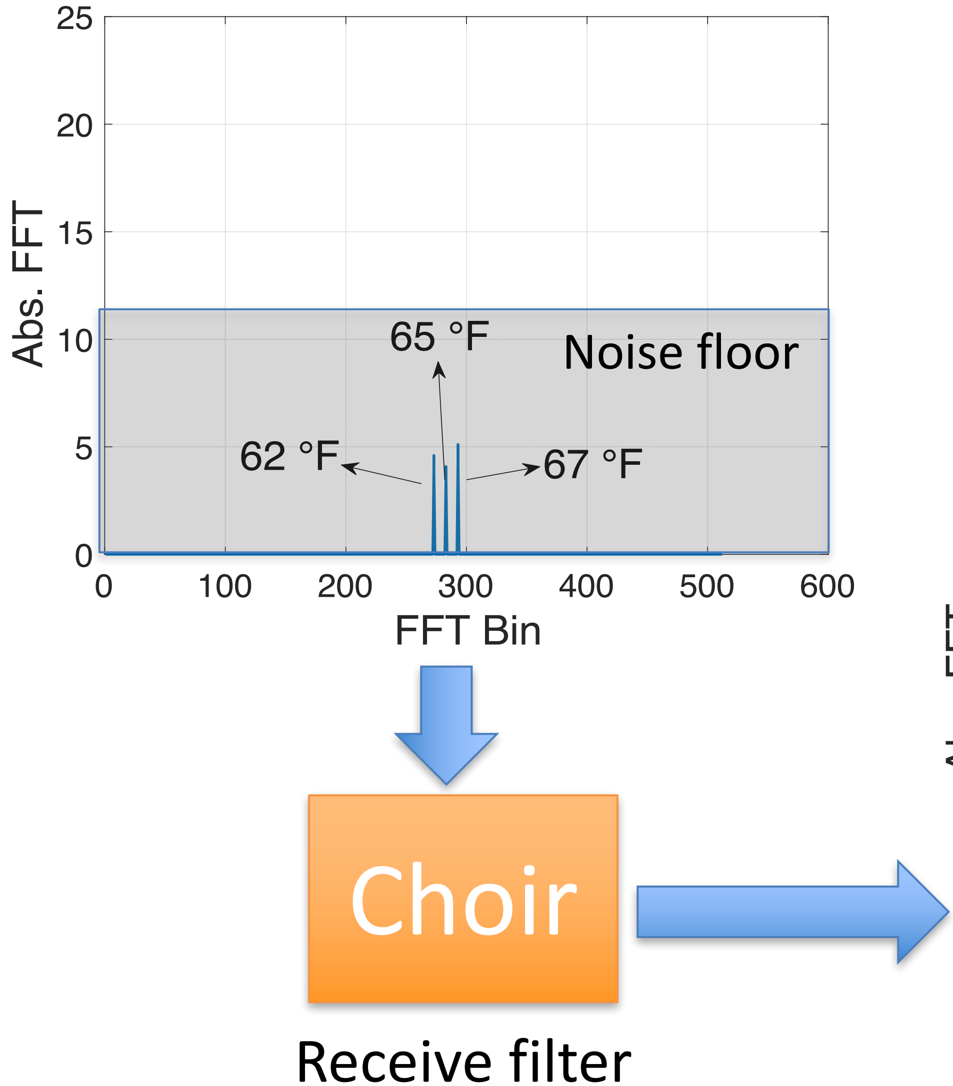


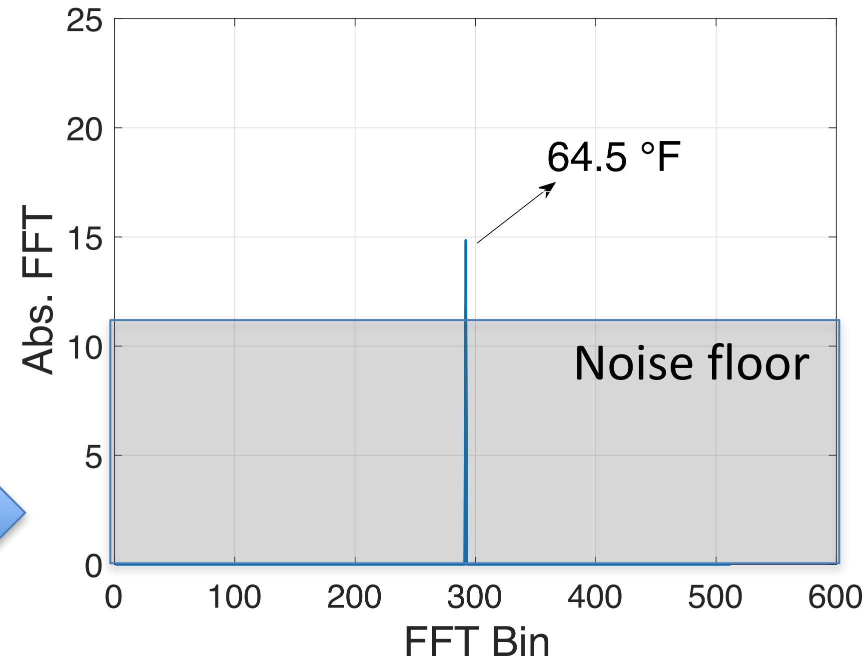
Objective

Coalesce these peaks around an aggregate value



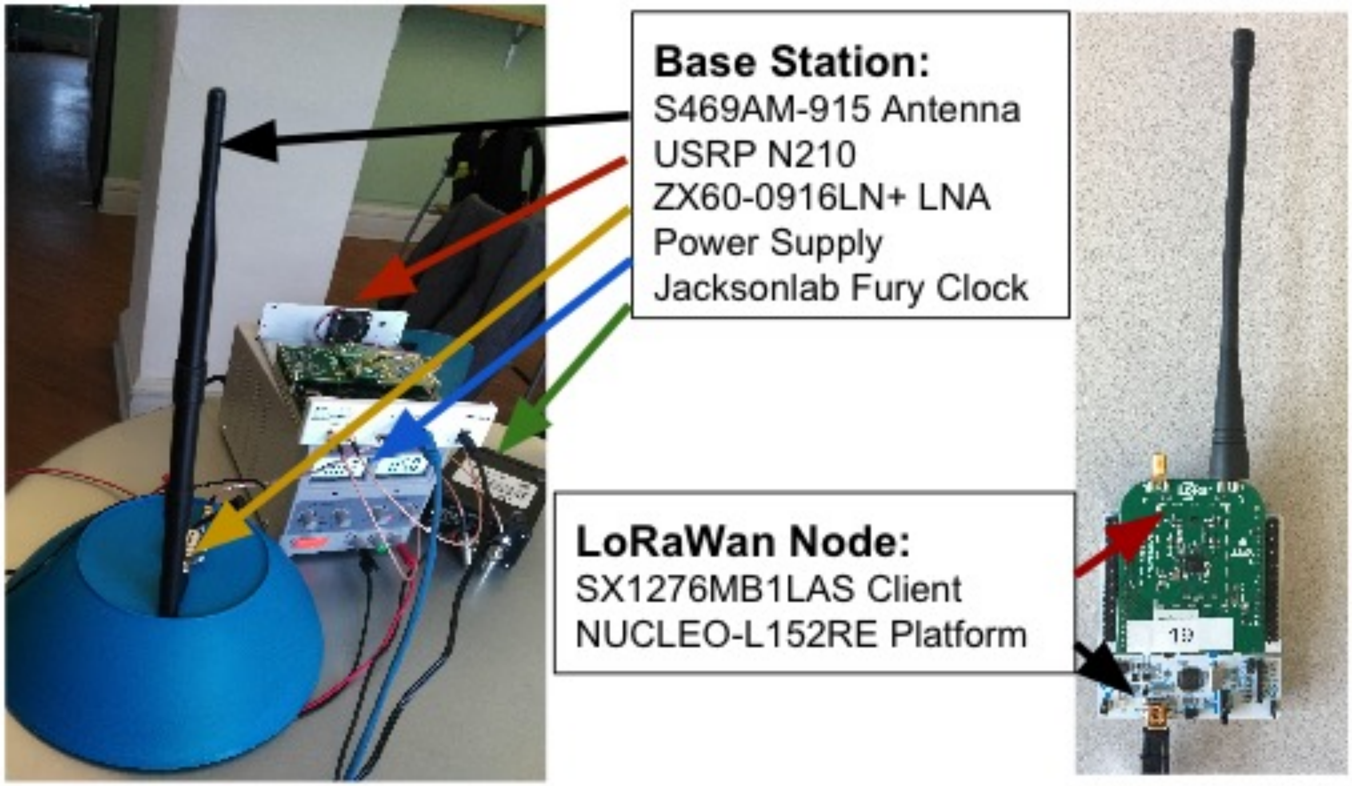
Approach Signal processing based on exploiting frequency offsets to coalesce transmissions



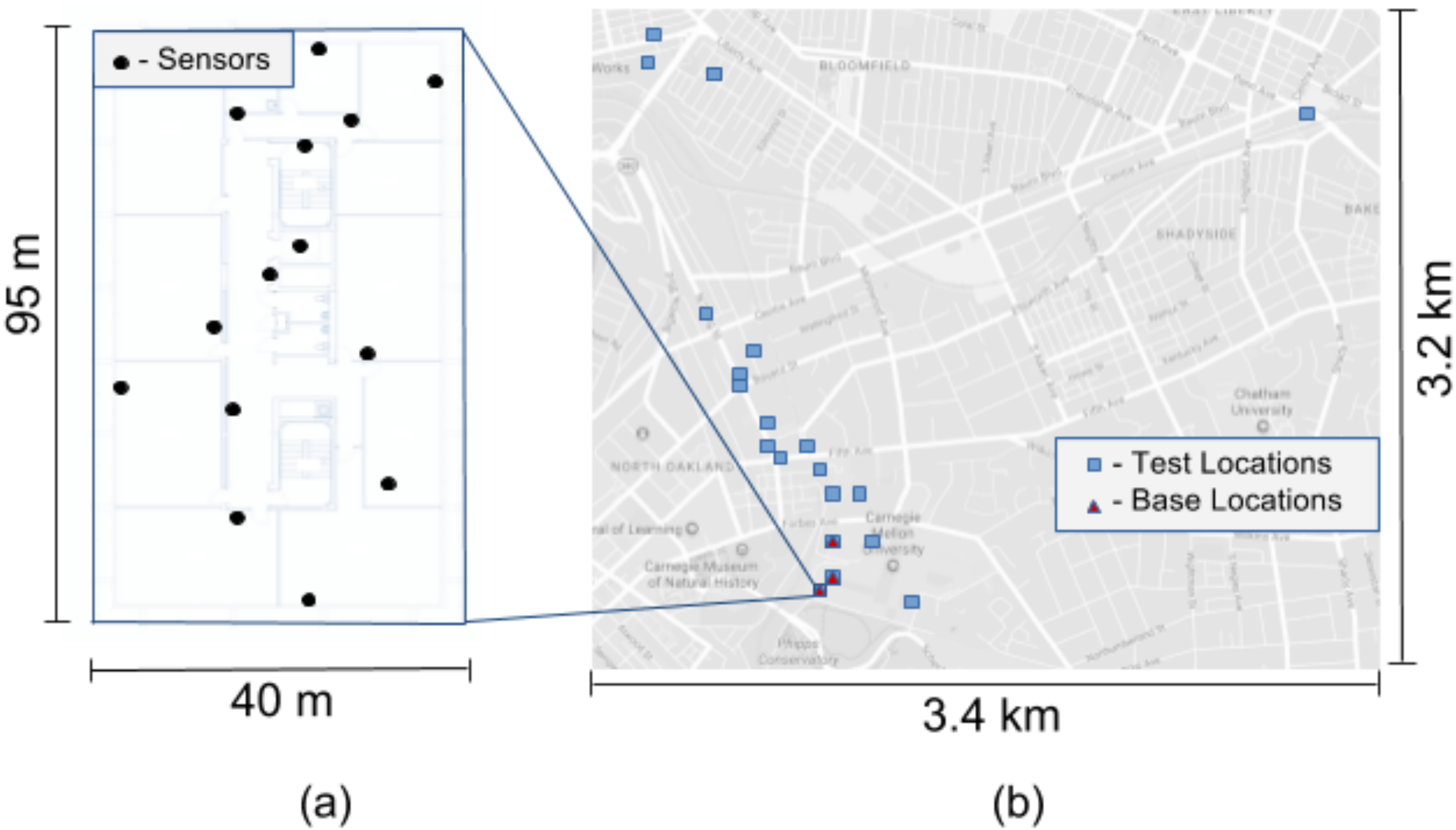


Details in the paper…

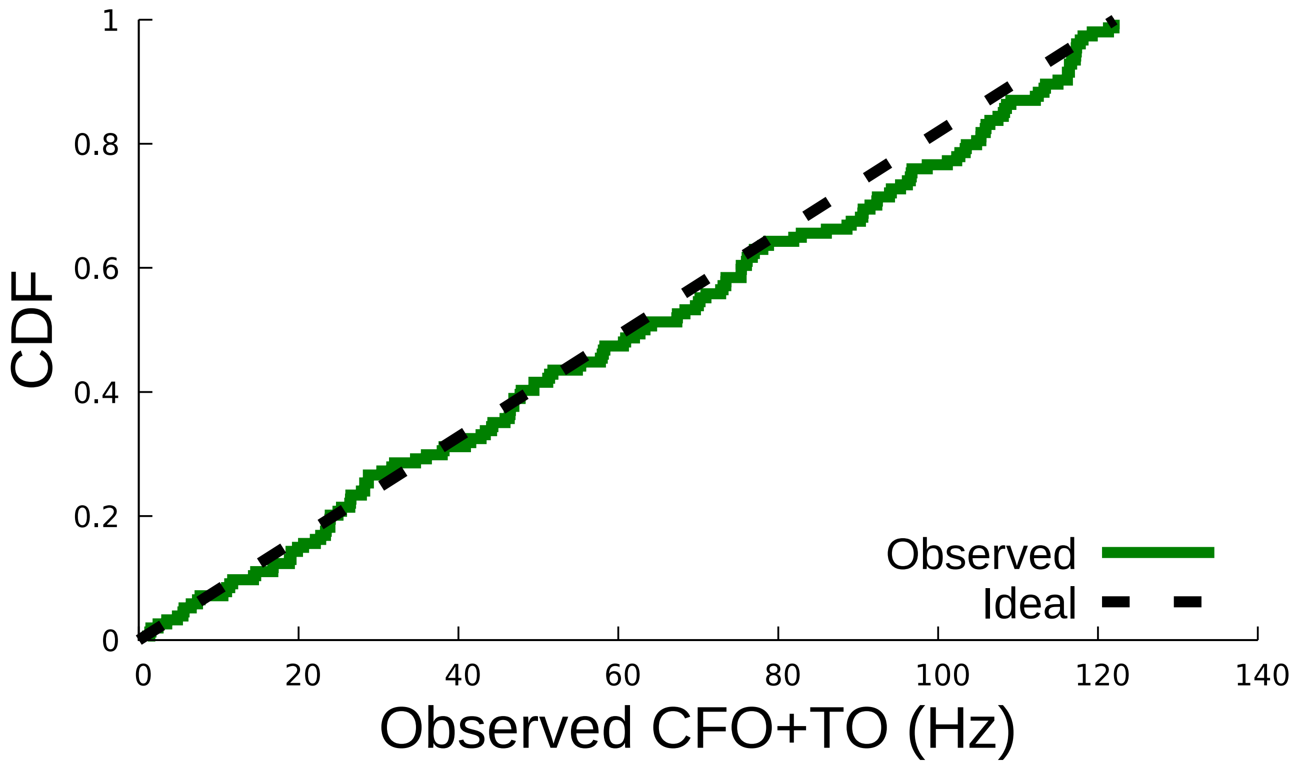
Implementation



Evaluation

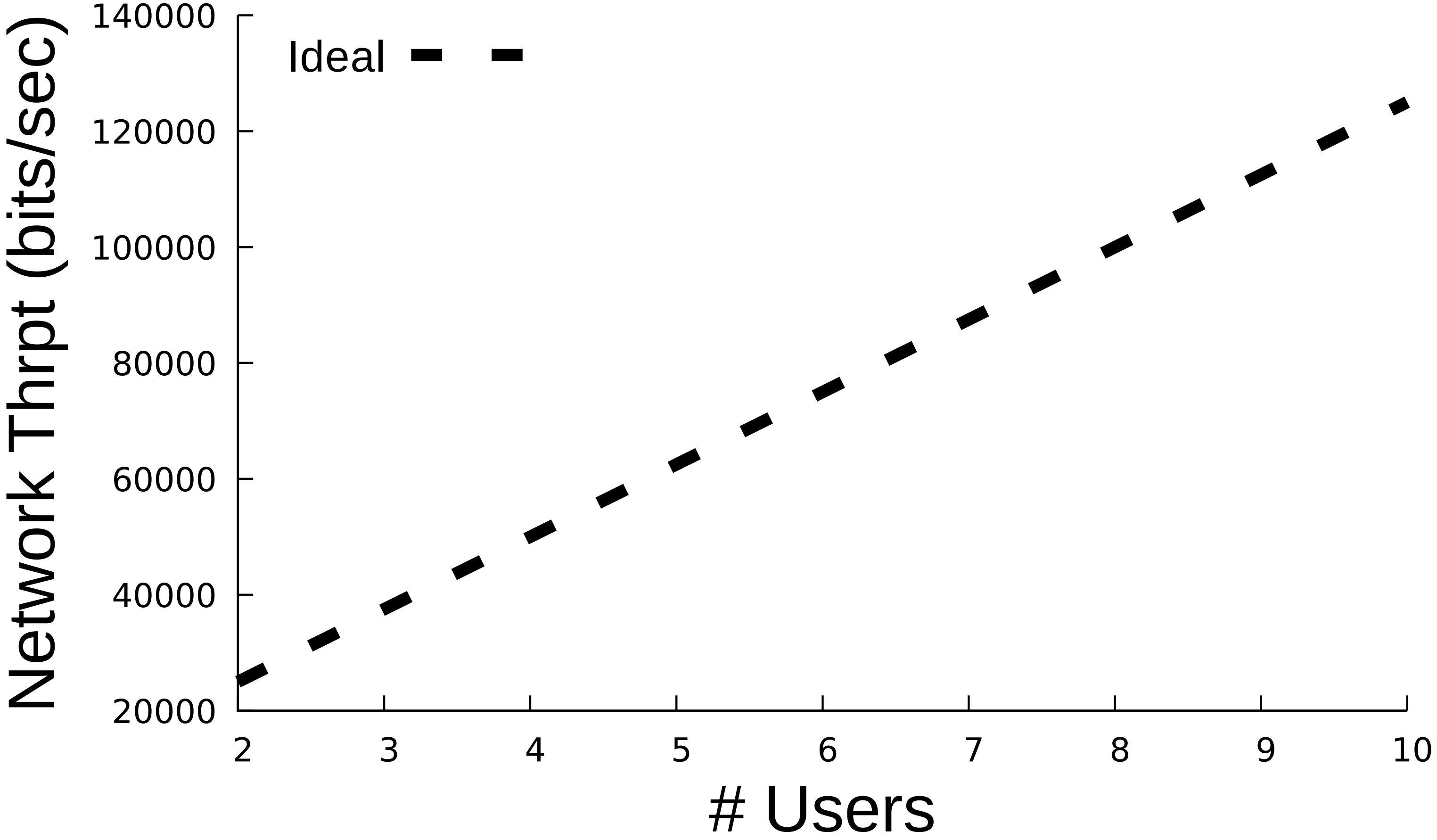


Hardware offsets

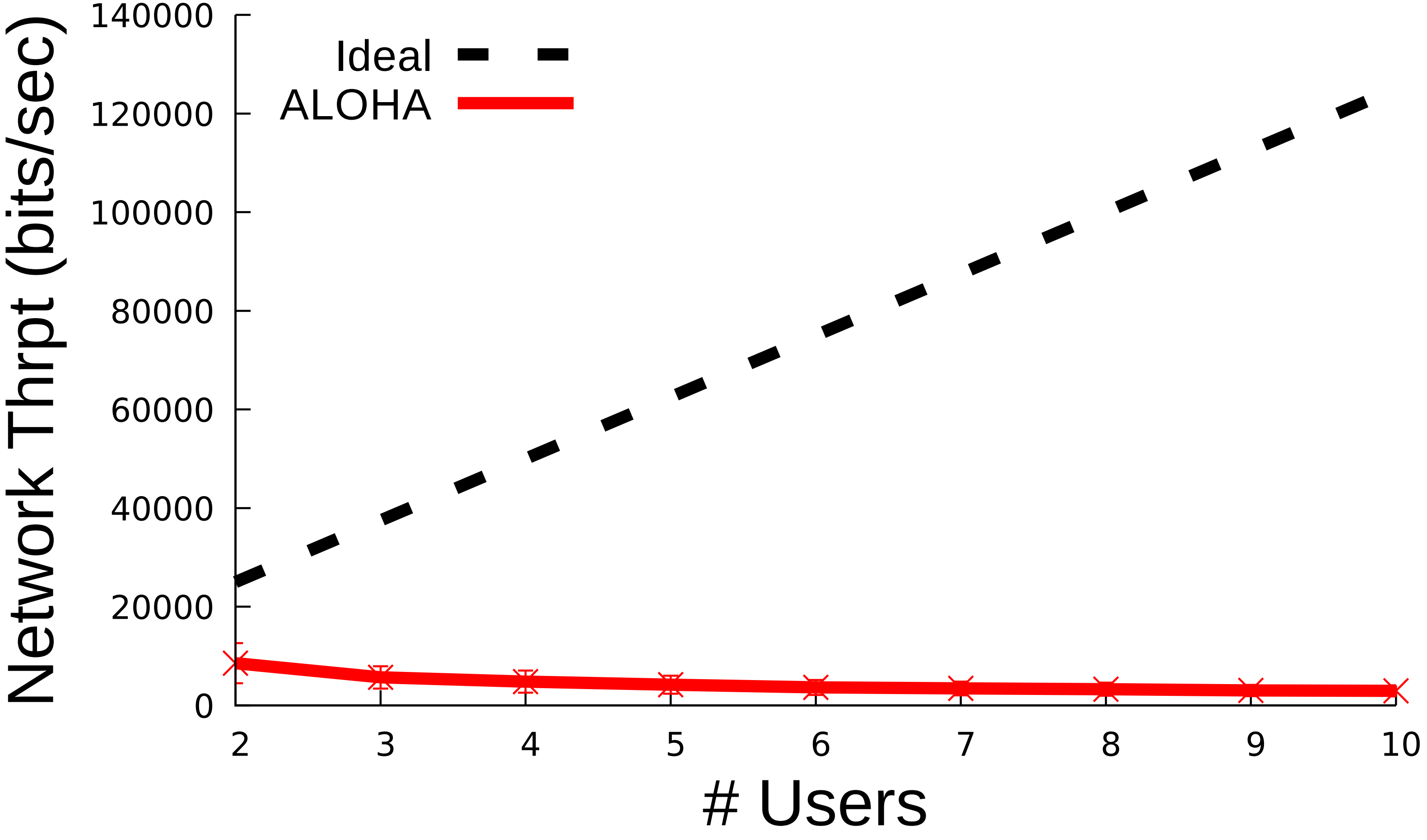


Hardware offsets are truly diverse across LPWAN radios

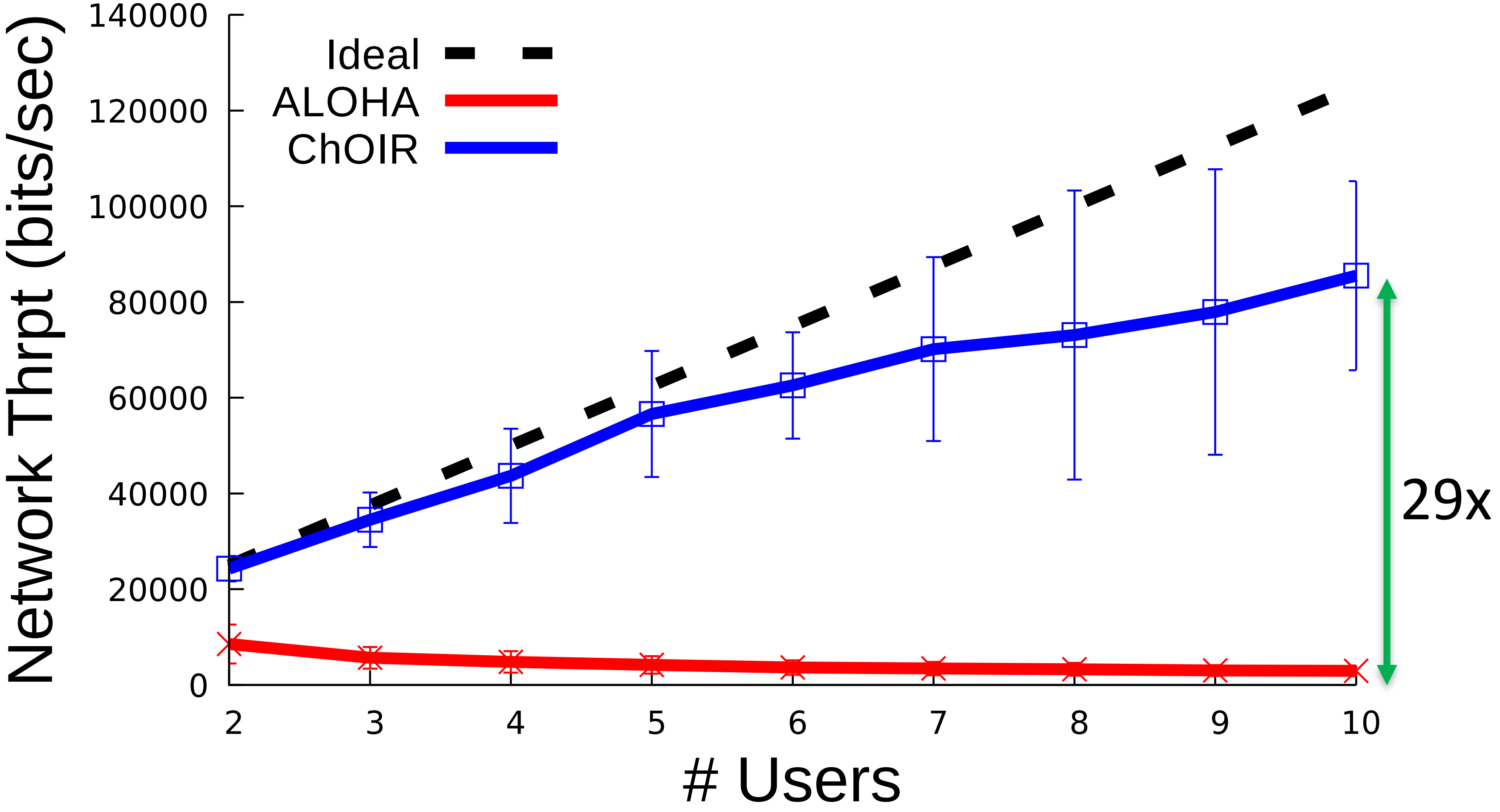
Resolving interference



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**

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