17-EURE-0004

Meet-up #DIGITAL Sciences & Technologies

Innovation

Research

UNIVERSITÉ CÔTE D'AZUR

DIGITAL SYSTEMS FOR HUMANS

GRADUATE SCHOOL AND RESEARCH

MIMO-based range extension for LP-WAN

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LABORATOIRE D'ELECTRONIQUE ANTENNES ET TELECOMMUNICATIONS

Gredeg Groupe de recherche en Droit, Economie et Gestion

Outline

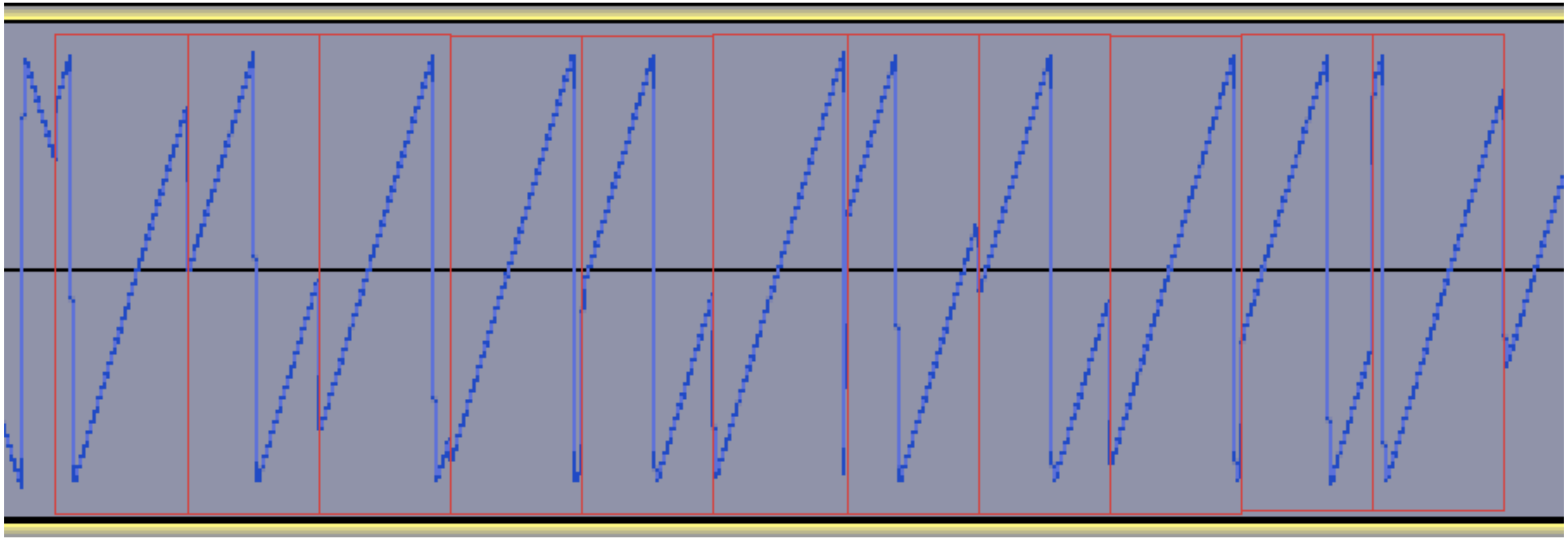
- Low Power Wide Area Networks
- LoRa physical layer and outdoor measurement campaign
- Indoor LP-WAN MIMO range extension
  - Spatial filtering
  - Coherent combining
- Robust AoA-based localization
- System Evaluation
- Conclusion

Context and Motivation

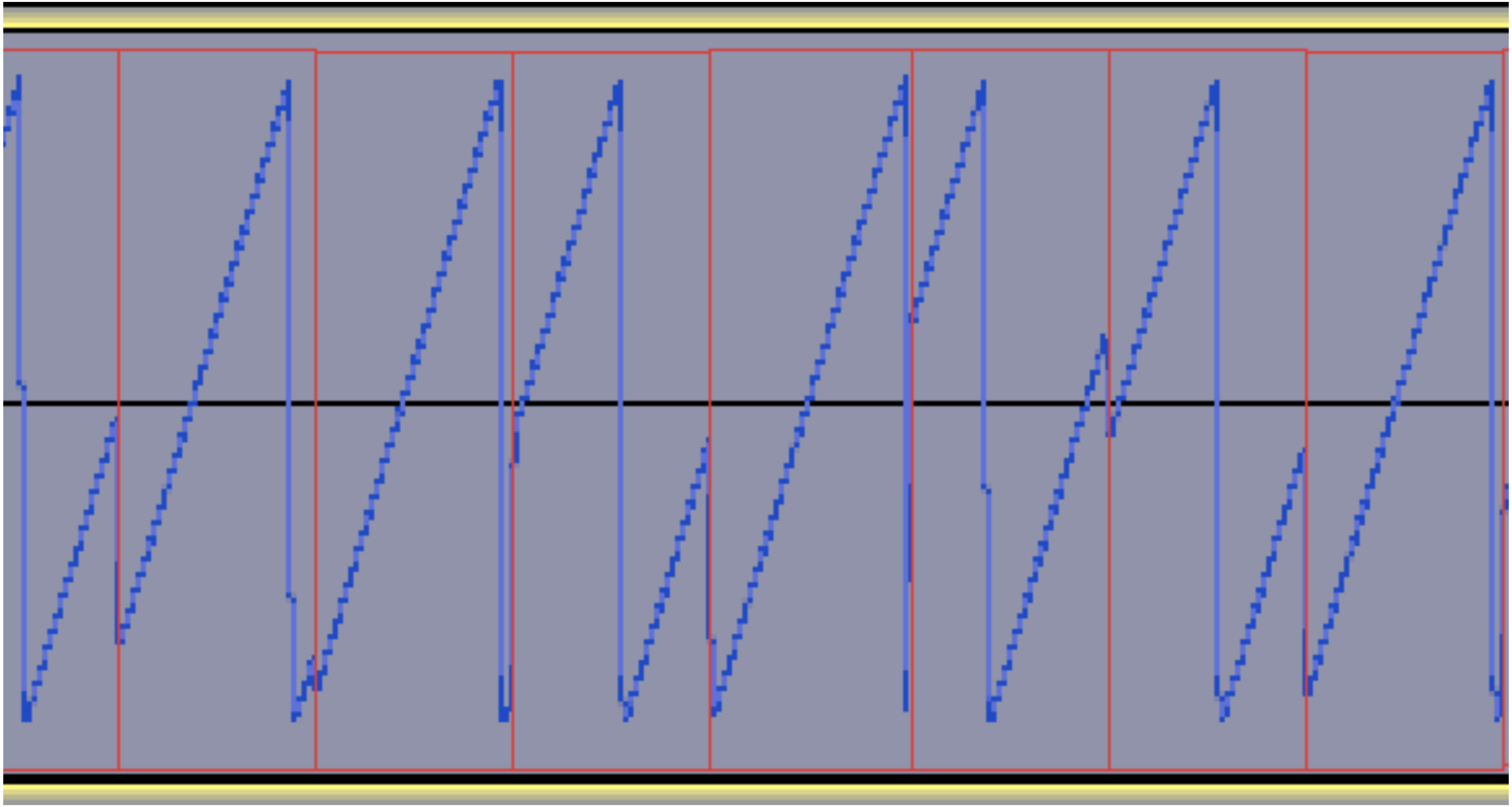
- LP-WANs for large scale IoT communication in urban areas
  - Low power consumption
  - Large coverage (few Km)
  - No costly license
- Private LoRa deployments
  - Inherent heterogeneity and poor dimensioning
- Leverage multipath to extend communication range in both directions
  - Requires an accurate and precise localization based system
- Leverage chirp spreading spectrum to provide robust localization

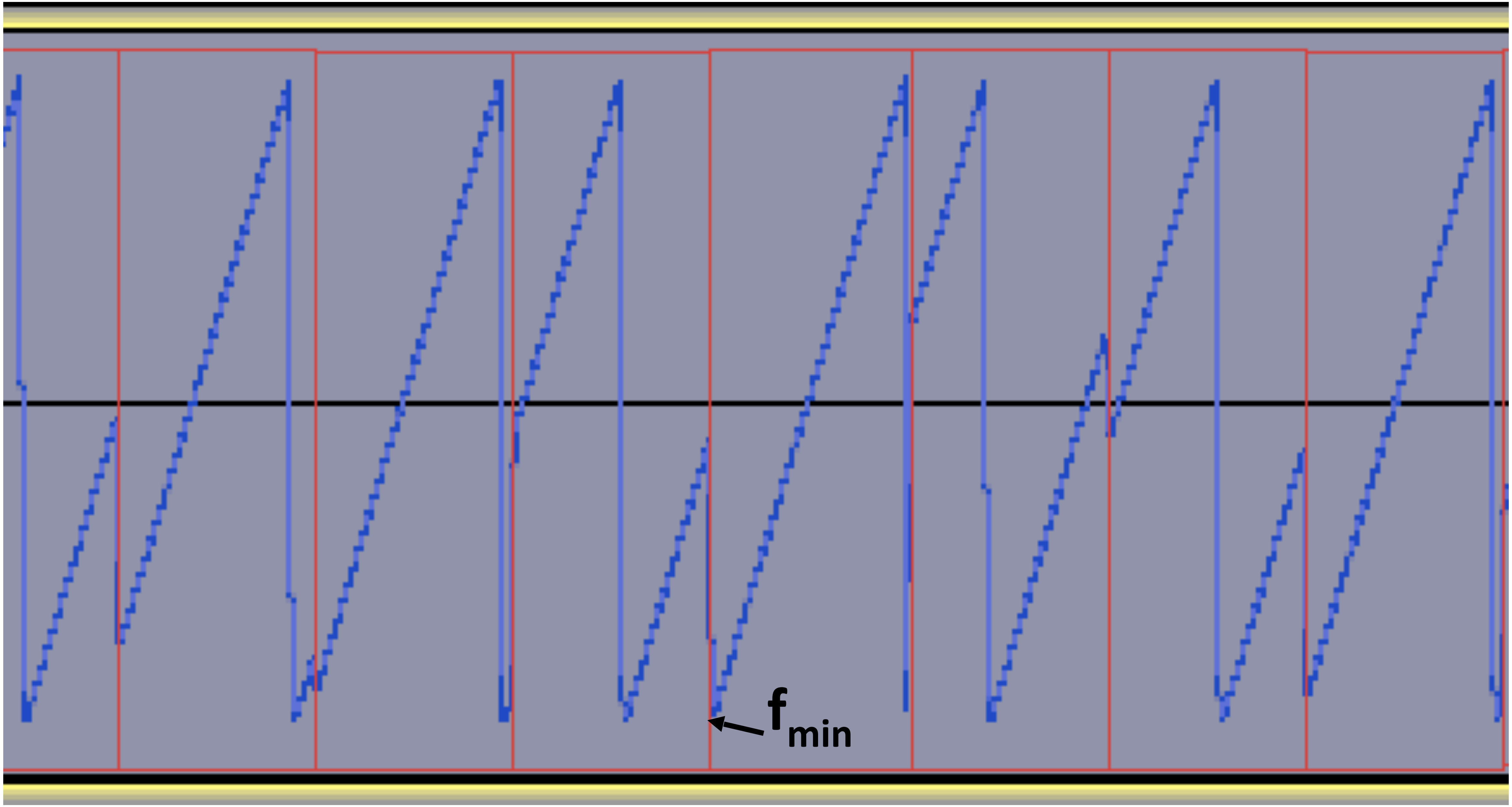
LoRa Physical Layer

- Chirp spread spectrum

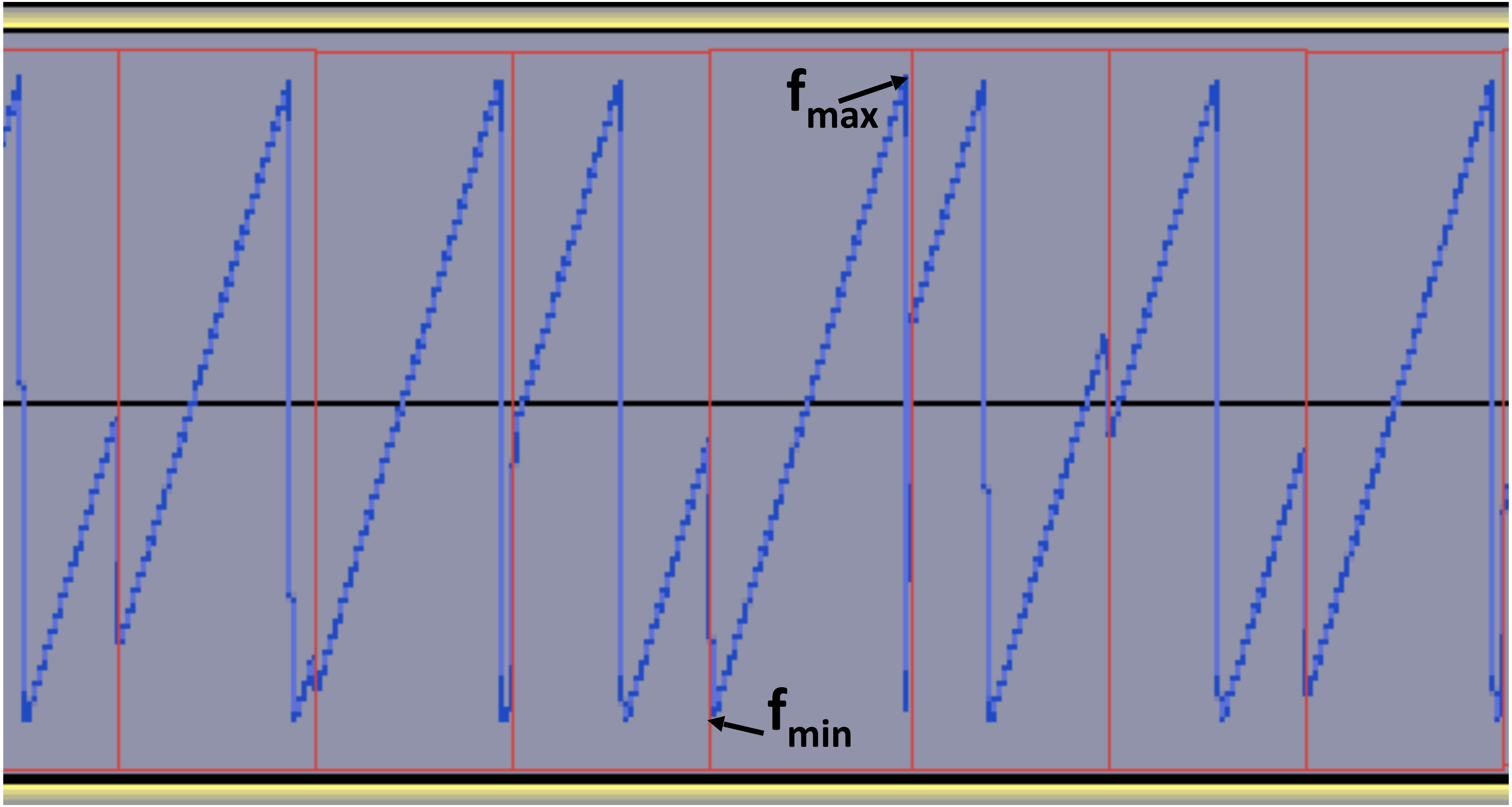


https://electronics.stackexchange.com/questions/278192/understanding-the-relationship-between-lora-chips-chirps-symbols-and-bits

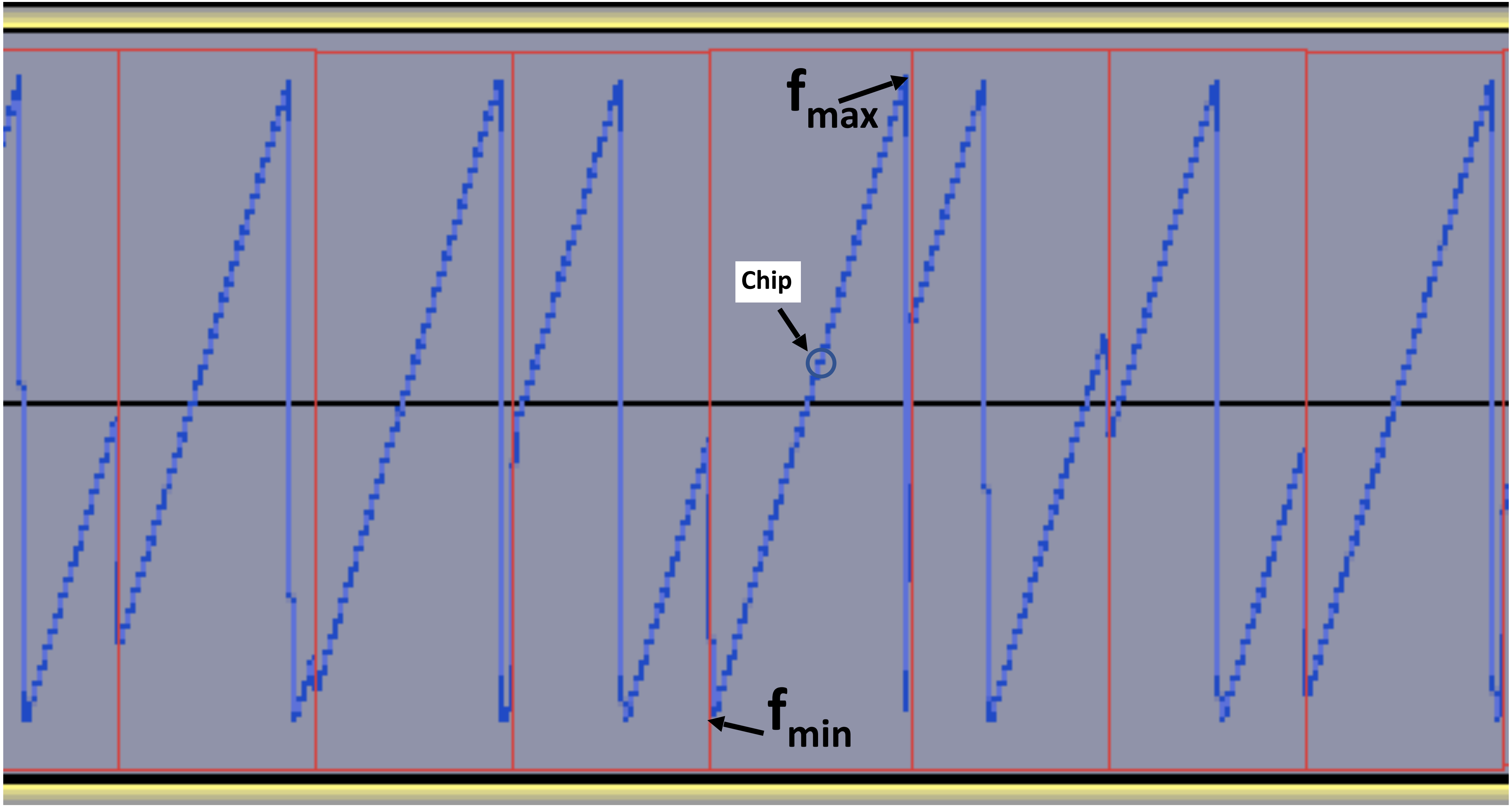




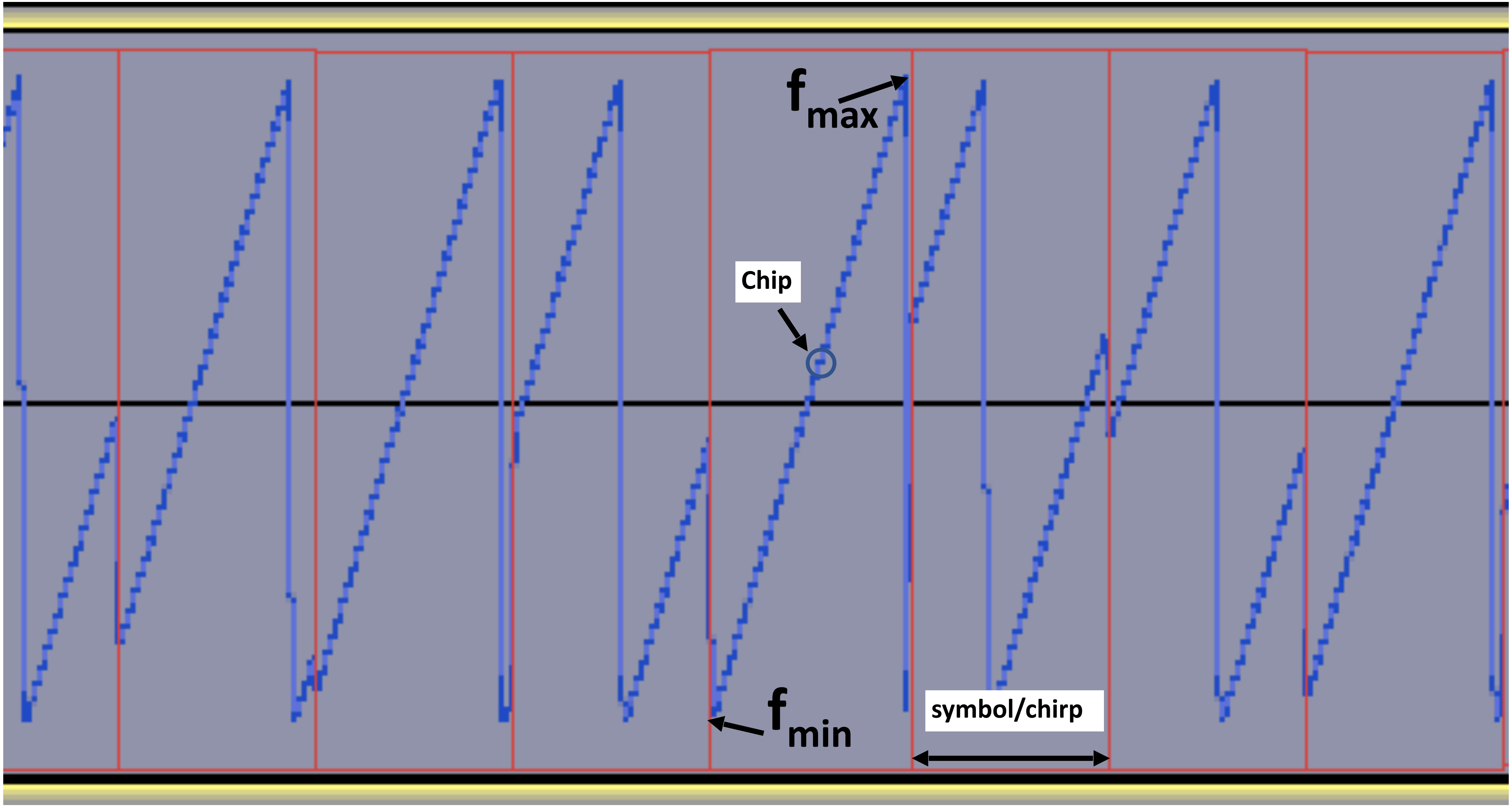
f_{min}



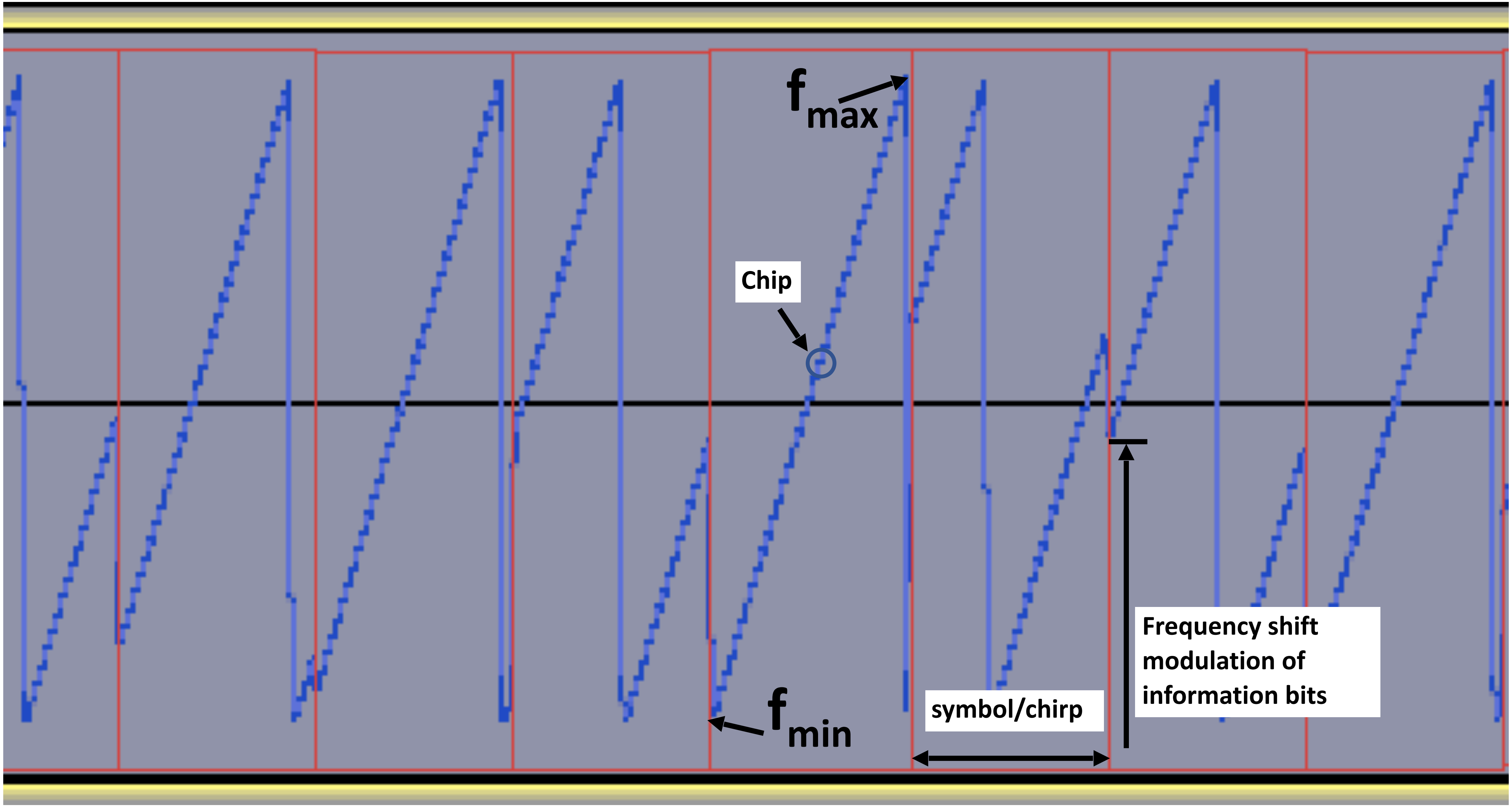
f_{max}
f_{min}



f_{max}
Chip
f_{min}



f_{max}
Chip
f_{min}
symbol/chirp

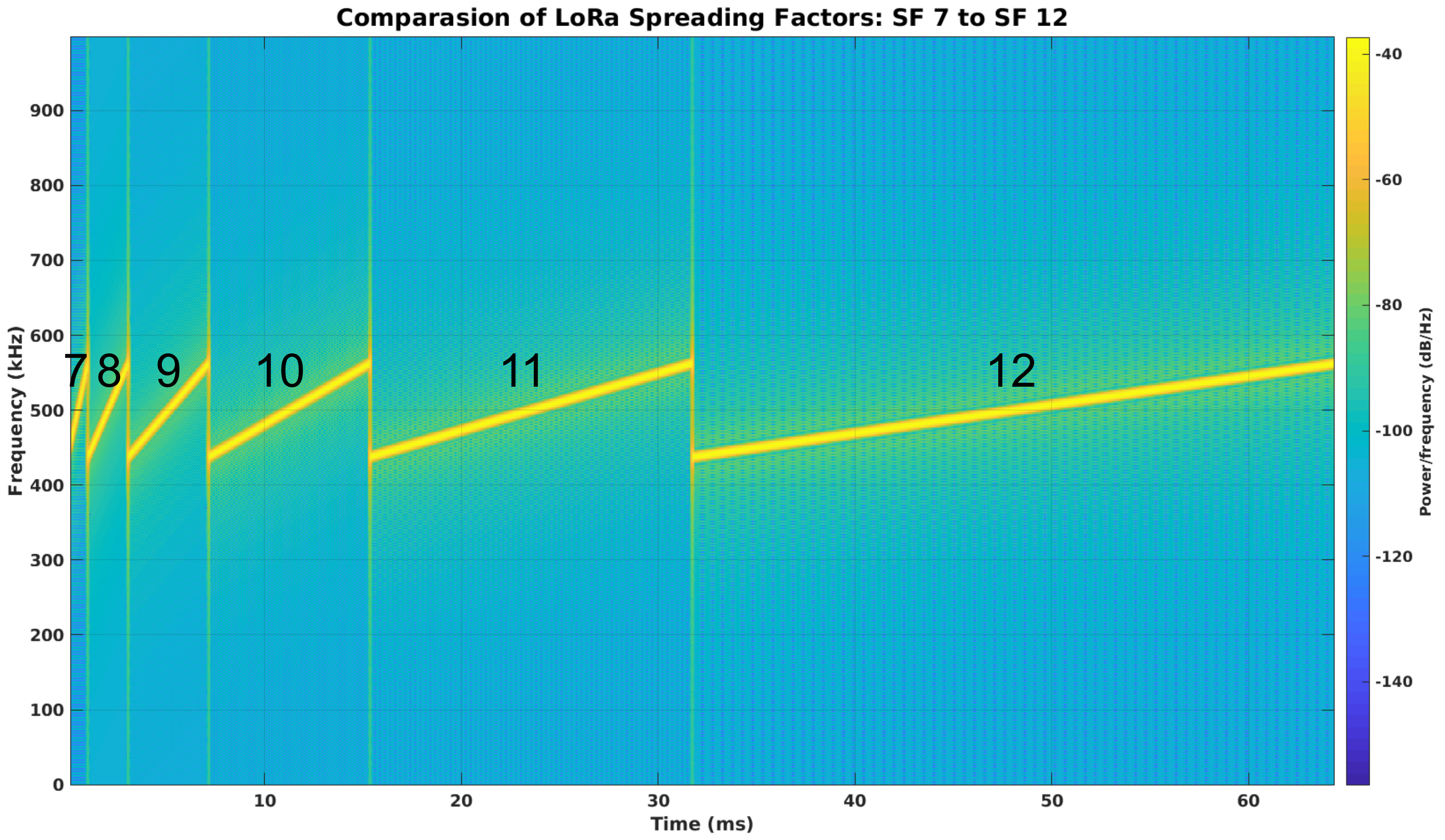


f_{max}
Chip
f_{min}
symbol/chirp
Frequency shift modulation of information bits

Spreading Factor (SF)

- BW = $f_{max} - f_{min}$
- 2^{SF} chips per symbol
- Chip duration = 1/BW fixed for a given BW
- Symbol rate = Chip rate / 2^{SF}, Symbol duration = 2^{SF} / BW
- Unmodulated chirp: 2^{SF} chips with frequency increasing from f_{min} to f_{max} in steps of BW/ 2^{SF}
- Modulated chirp: 2^{SF} chips, but frequency increases from $f_{min} + \triangle f$ to f_{max} then recycles from f_{min} up
- Frequency shift $\triangle f$ = the value of SF raw information bits
- SF: number of raw information bits per symbol

Spreading Factor and Range



For a given bandwidth : Higher SF = Higher time on air, Lower Packet Error Rate, Longer Coverage (but Lower Symbol rate)

LoRa Range Measurement: Scenario

LoRa

4G

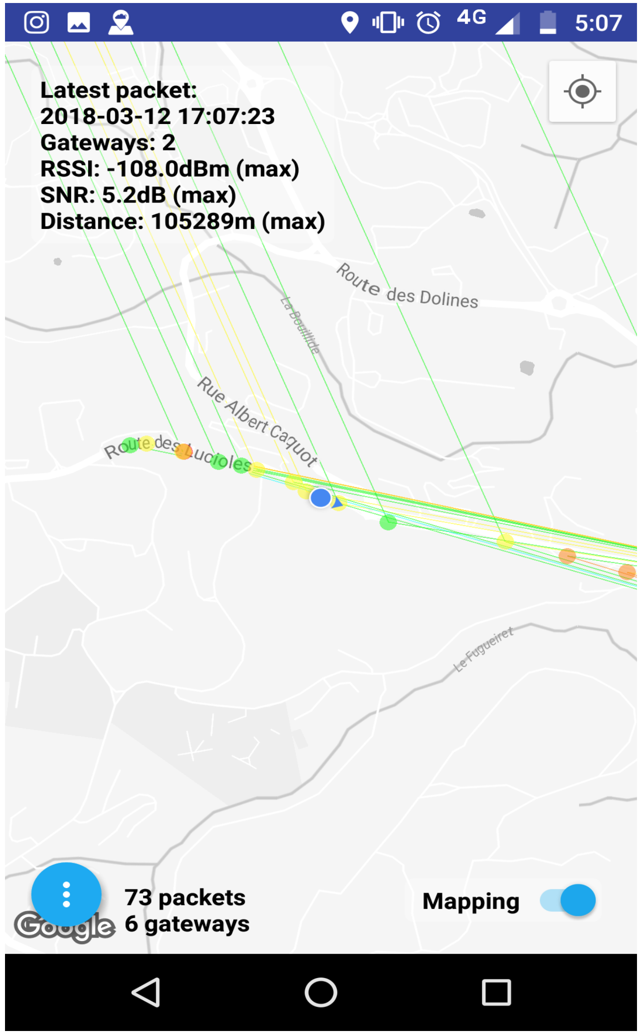
THE THINGS NETWORK

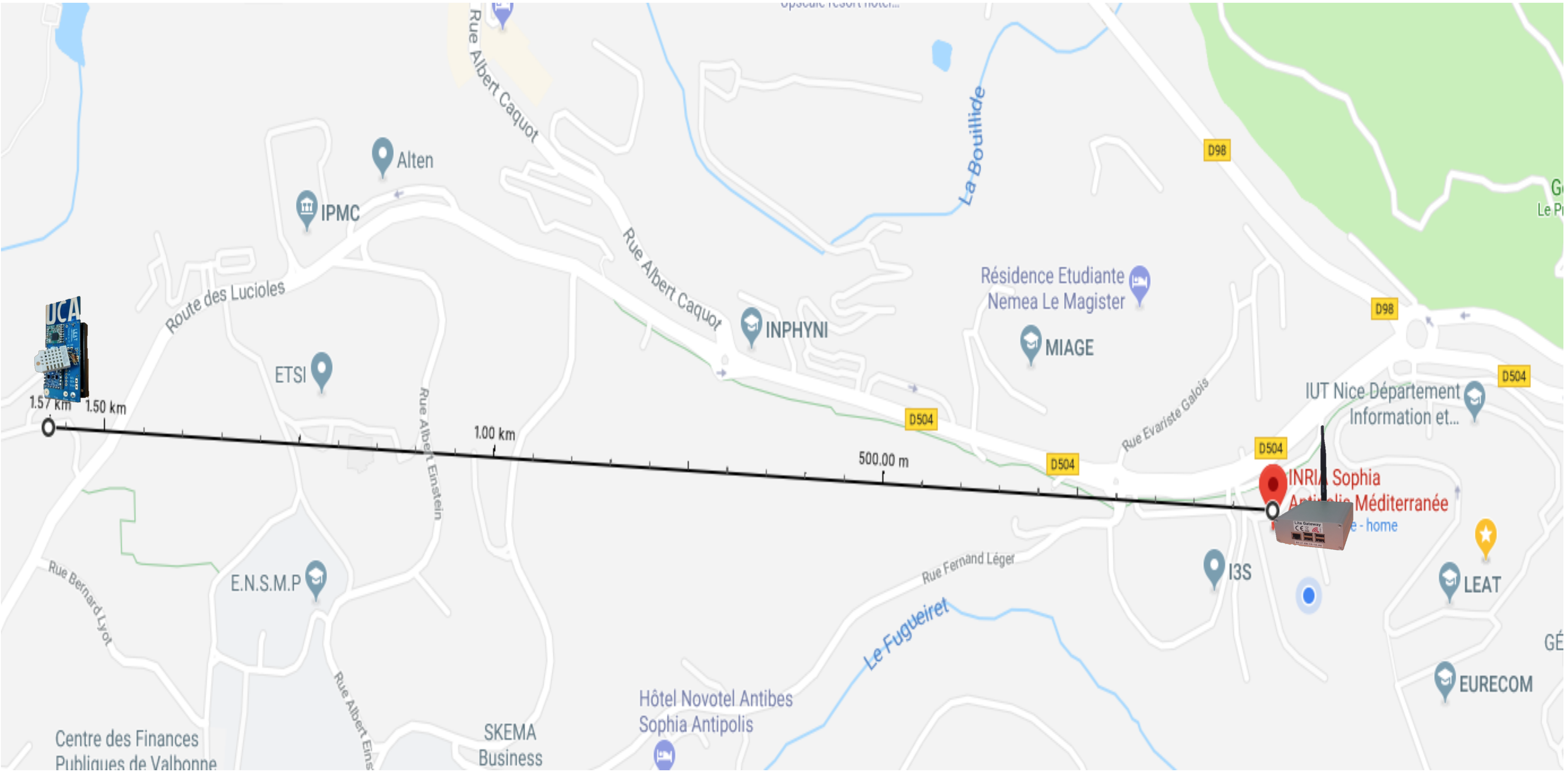
End device:
(LEAT board)

Gateway:
(LoRa Lite Gateway)

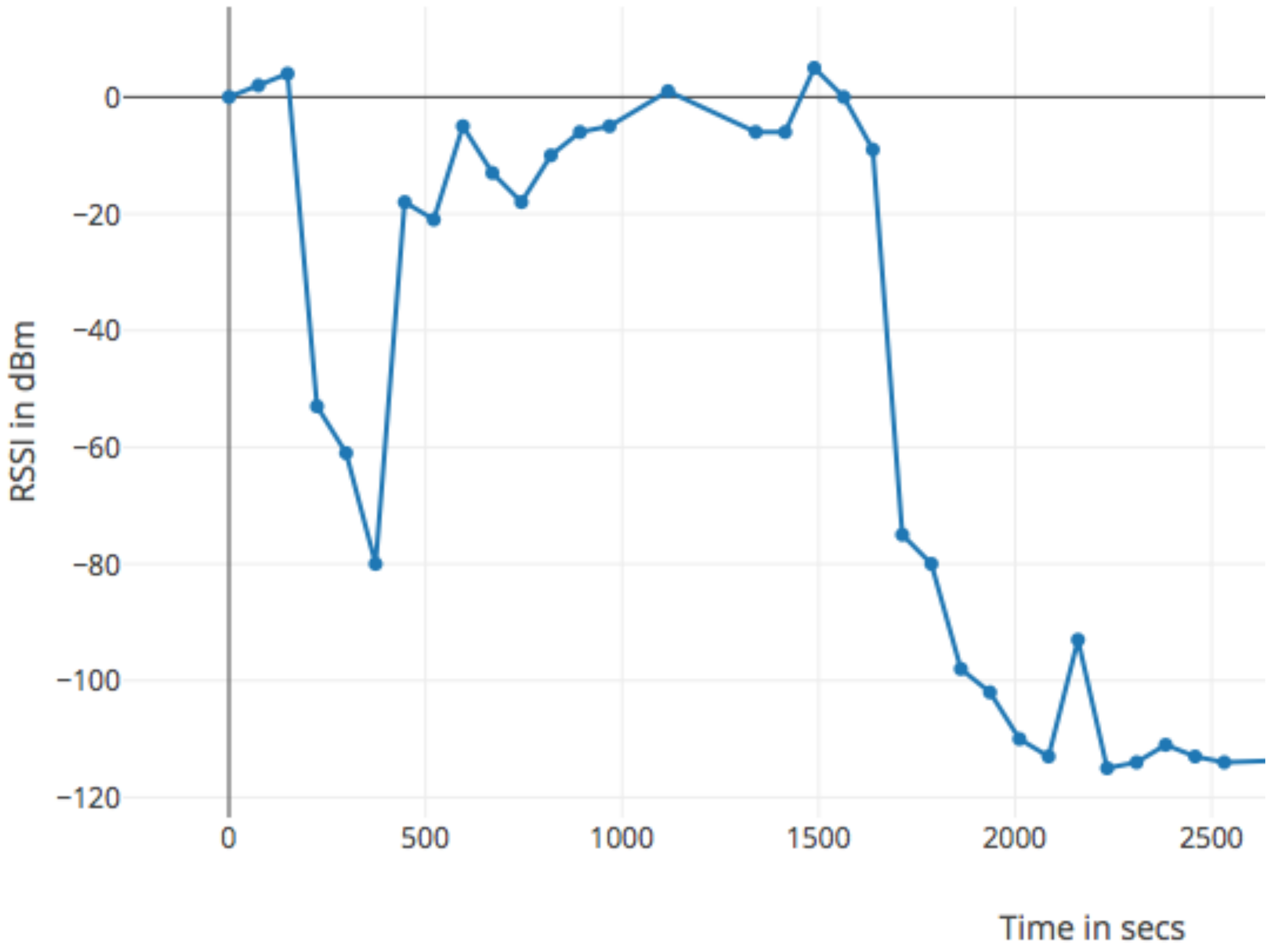
Net & App Server:
The Things Network
(TTN)

LoRa Range Measurement: Position Labelling

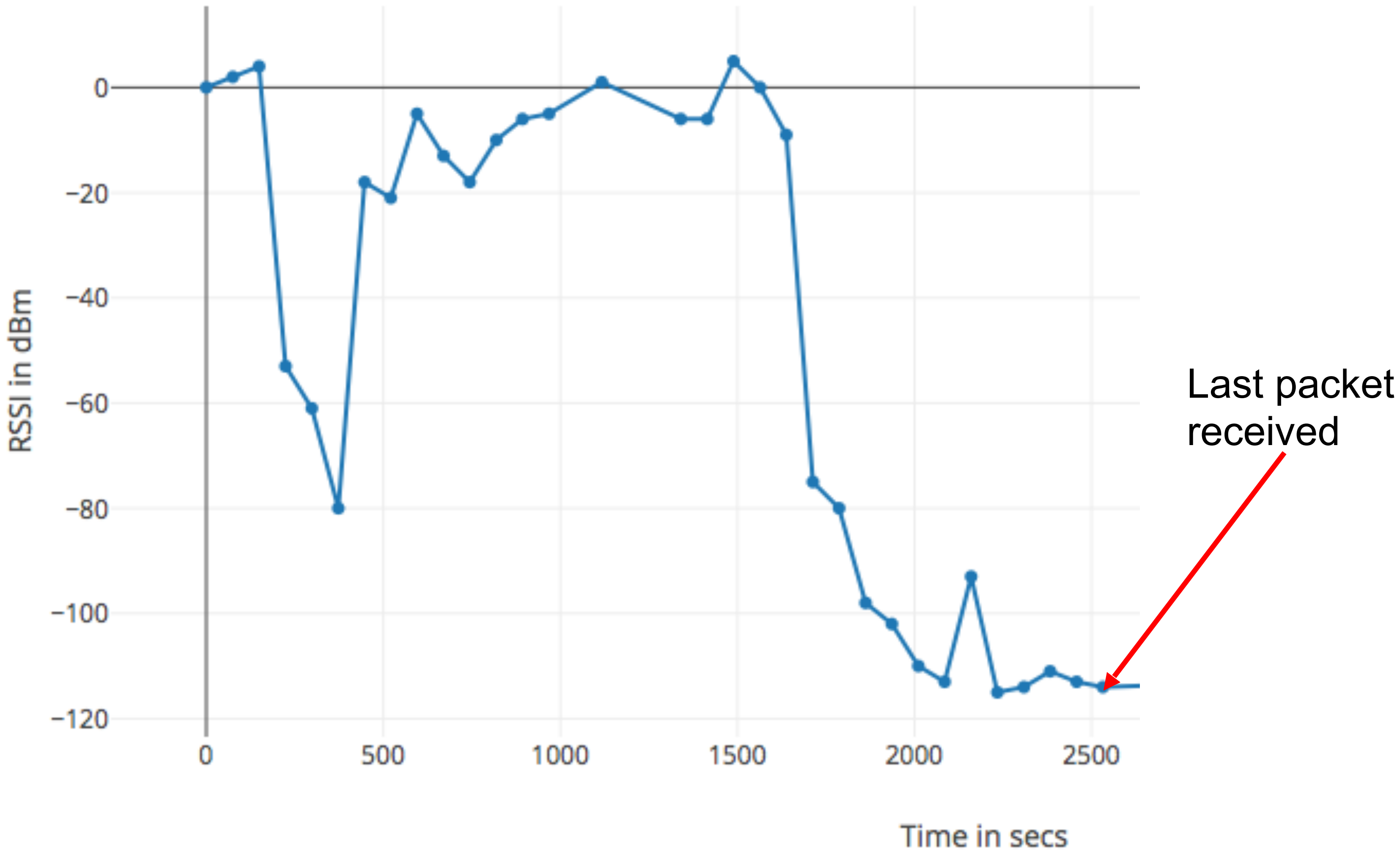




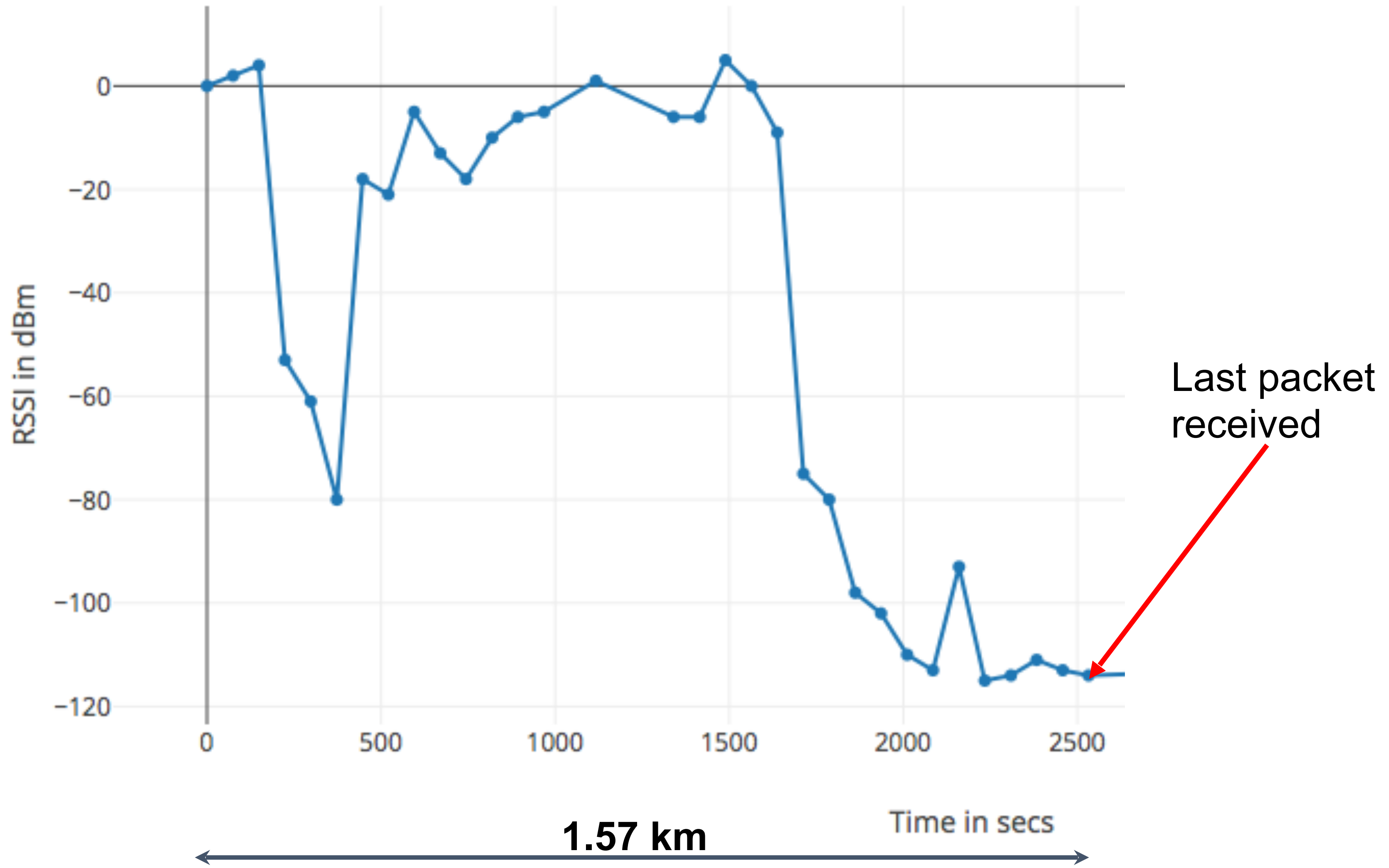
RSSI Measurement



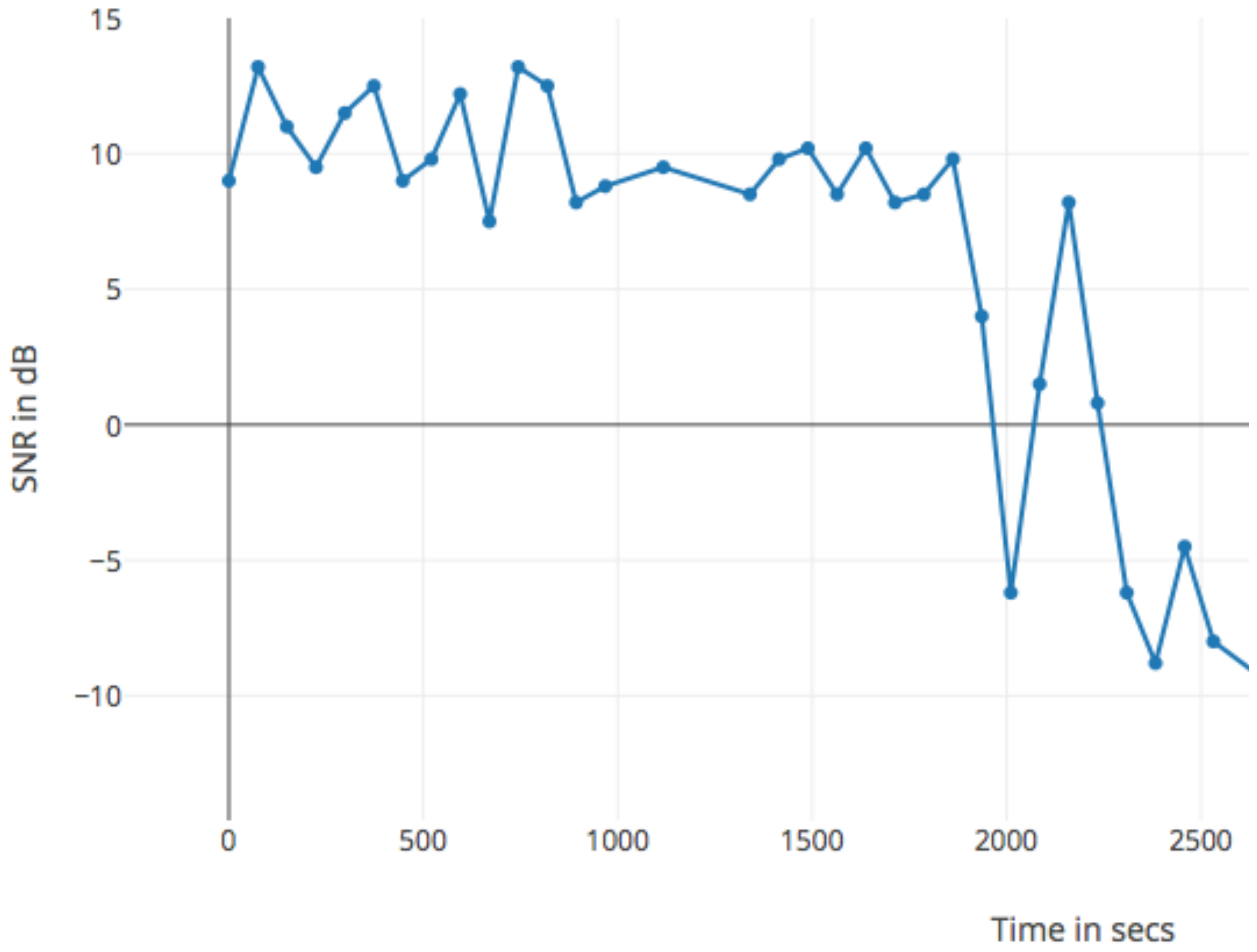
RSSI Measurement



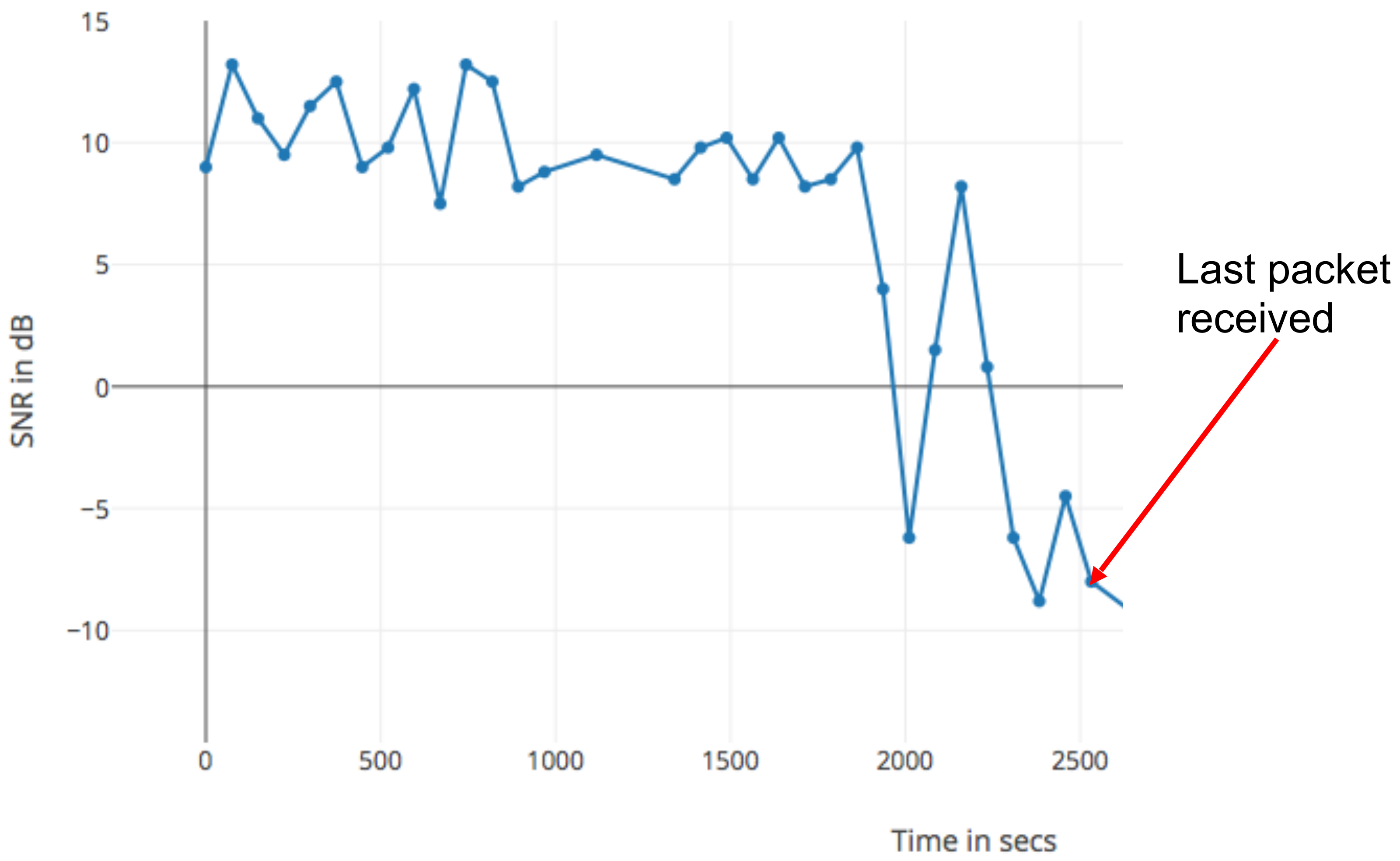
RSSI Measurement



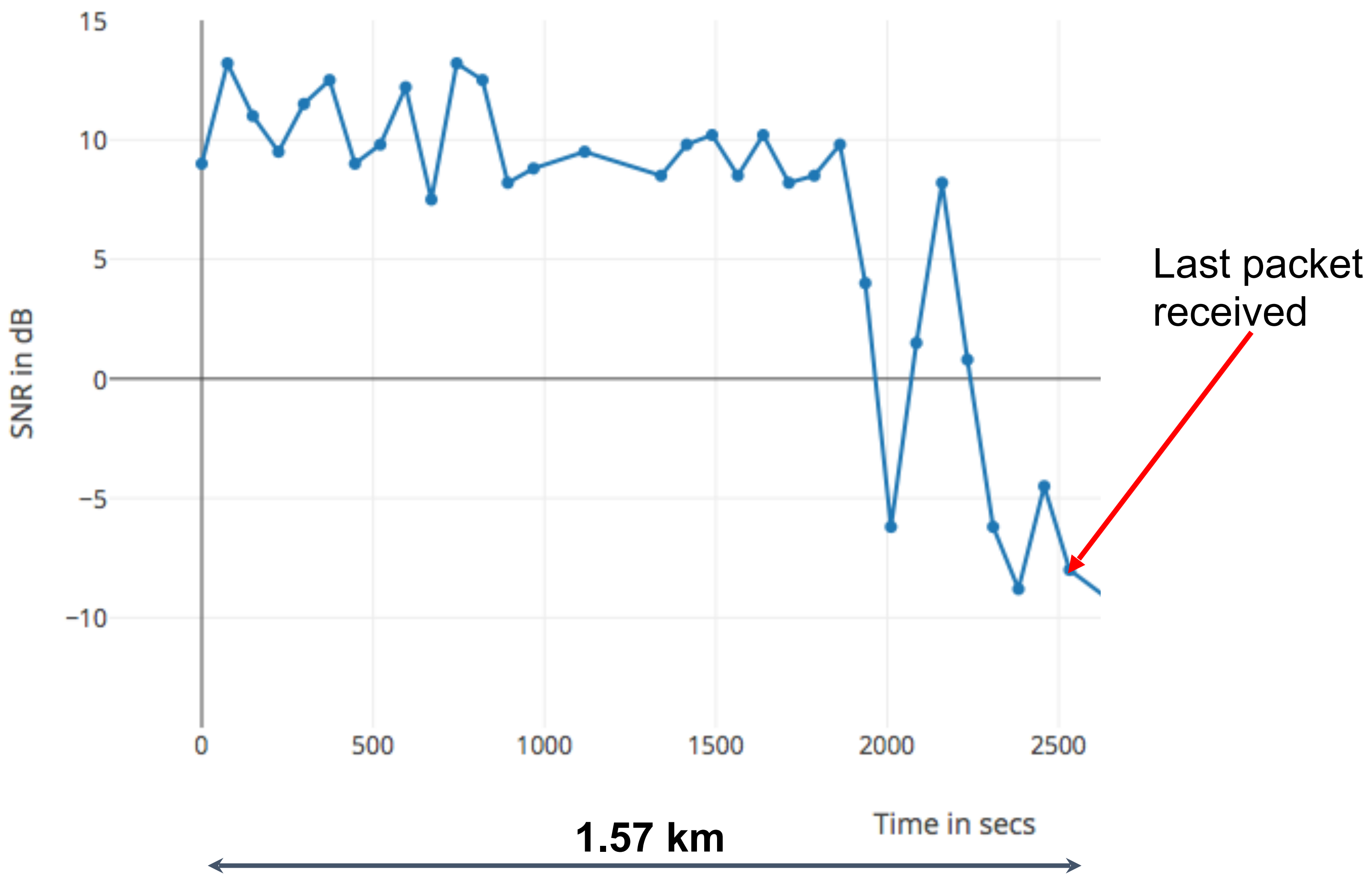
SNR Measurement



SNR Measurement



SNR Measurement



LoRa Range Extension

- Charm[1] enhances coverage of LPWANs by coherently combining signals coming from multiple gateways in a cloud infrastructure.
- We propose to use a single MIMO gateway to extend the range of LPWANs for both the uplink and the downlink:
  - Uplink is enhanced by coherently combining signals coming from multiple antennas of the same gateway.
  - Downlink is improved by focusing the radiation pattern of the Tx towards the end device using the direction of arrival information.

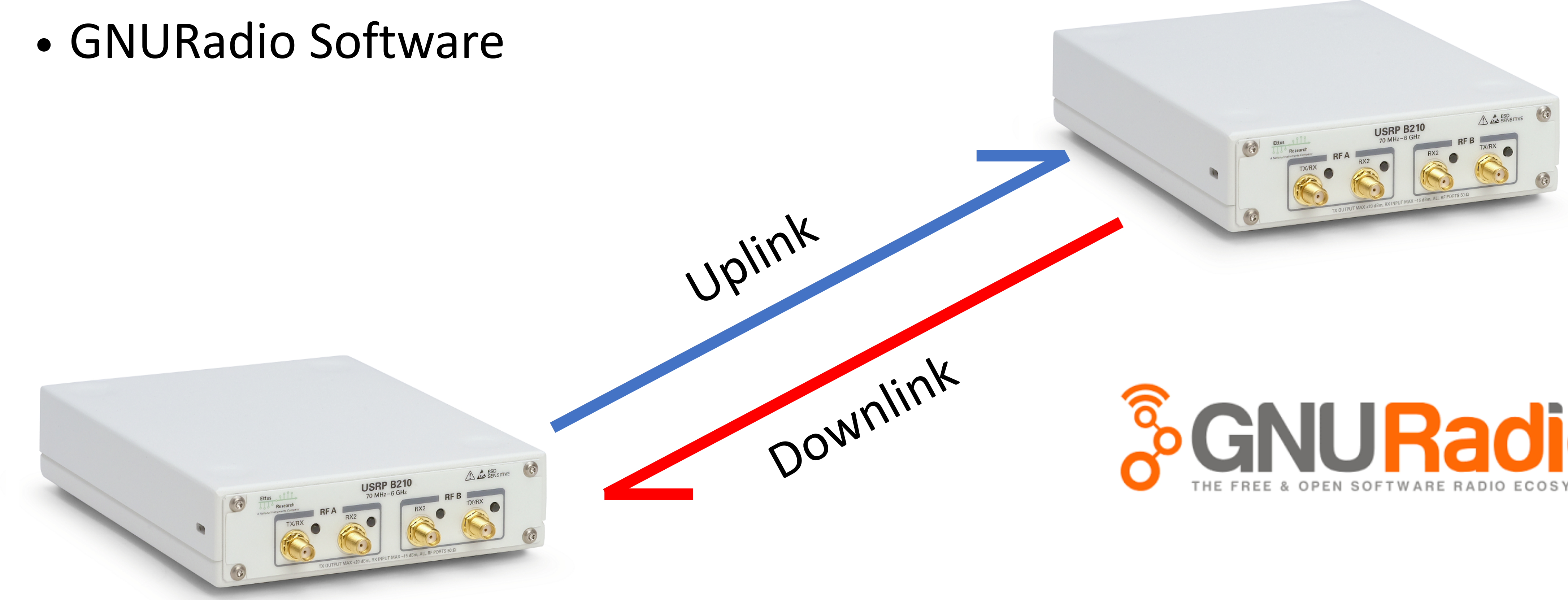
[1] Eletreby Rashad, Zhang Diana, Kumar Swarun, Yağan Osman. Empowering Low-Power Wide Area Networks in Urban Settings, pp. 309–321. SIGCOMM ’17, New York, NY, USA, ACM 2017.

LoRa Range Extension and Localization

- TDoA techniques have relatively large error
- Indoor environment
  - No GPS
  - Rich multipath
- LoRa Chirp modulated signals provide time-frequency diversity
- Take advantage of this diversity to perform opportunistic angle of arrival based localization
  - with no dedicated modules (GPS)
- Combine localization with spatial filtering techniques to enhance extend the communication range

LoRa Range Extension: Implementation

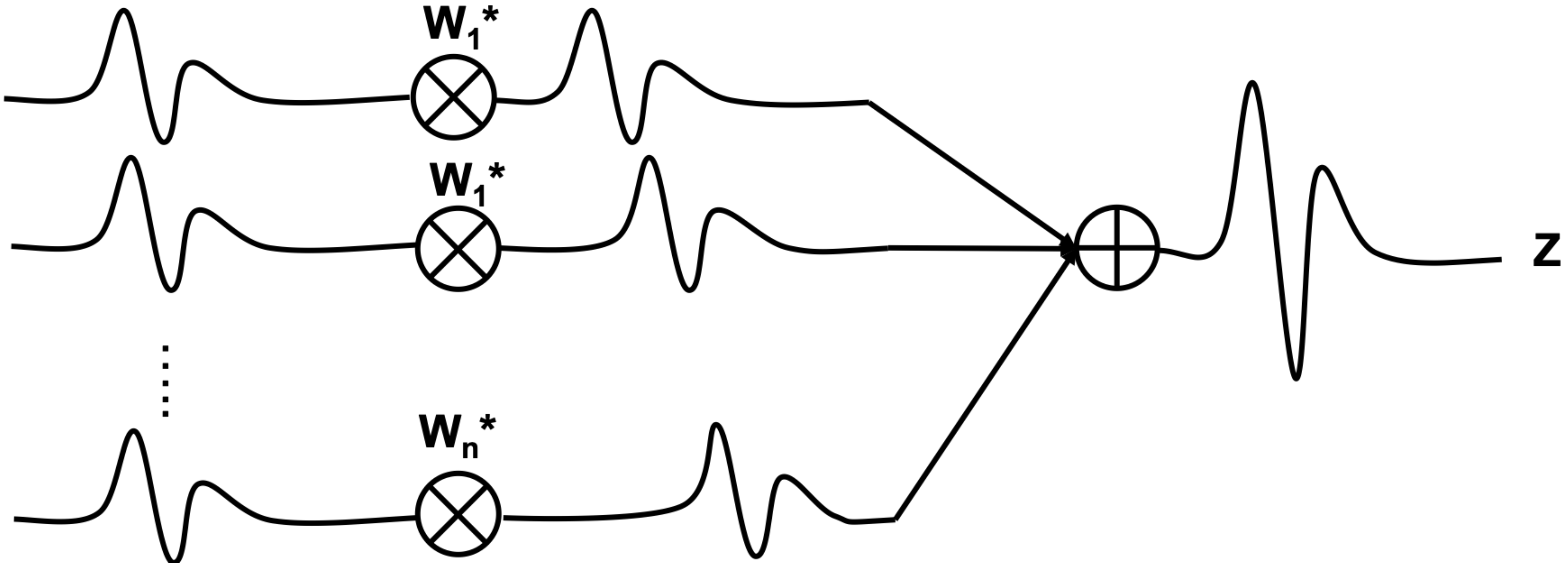
- Use of two SDR 2-antenna gateway (2Tx/ 2Rx)
- GNURadio Software



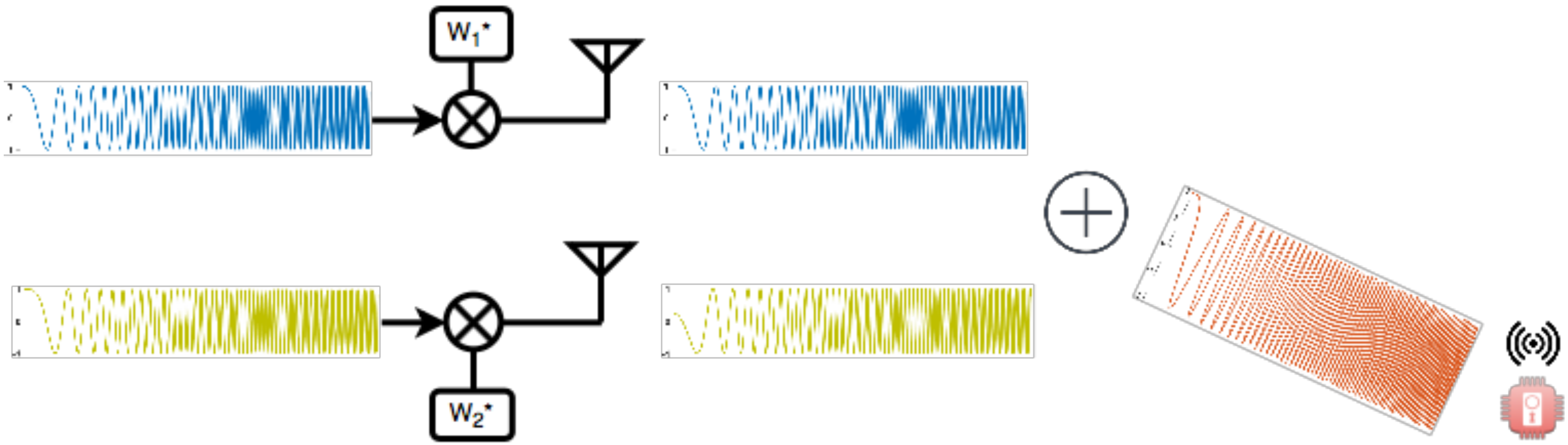
Beamforming for DL Range Extension

- With beamforming omnidirectional radiated signals are combined to form a higher gain beam to a certain direction
- To control the direction of the beam, complex weights need to be adequately chosen on each one of the RF chains
- Weights values are related to the position of the target
  - Need to estimate accurately the AOA of the signal radiated from the end devices in order to steer the Tx beam to the target's direction
- Beamforming can be performed by the LoRa gateway

Beamforming: Delay and Sum



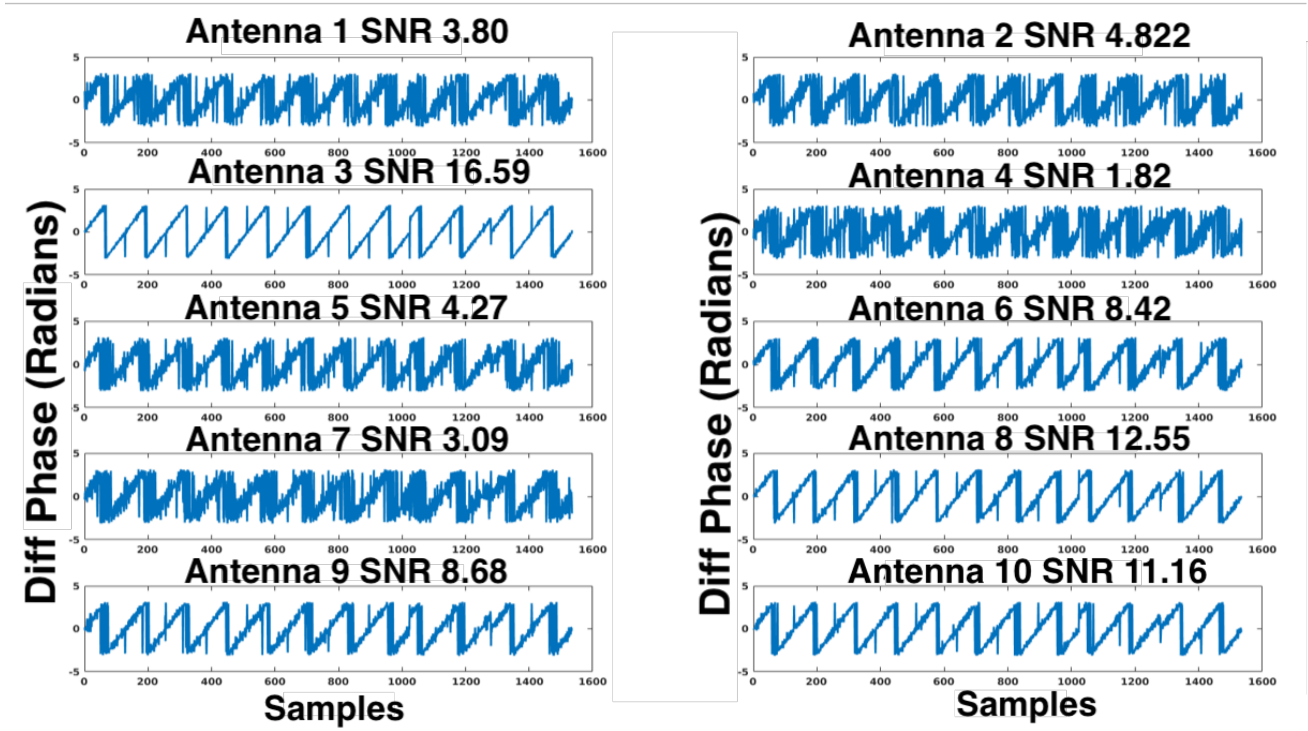
Beamforming: Two RF Chains

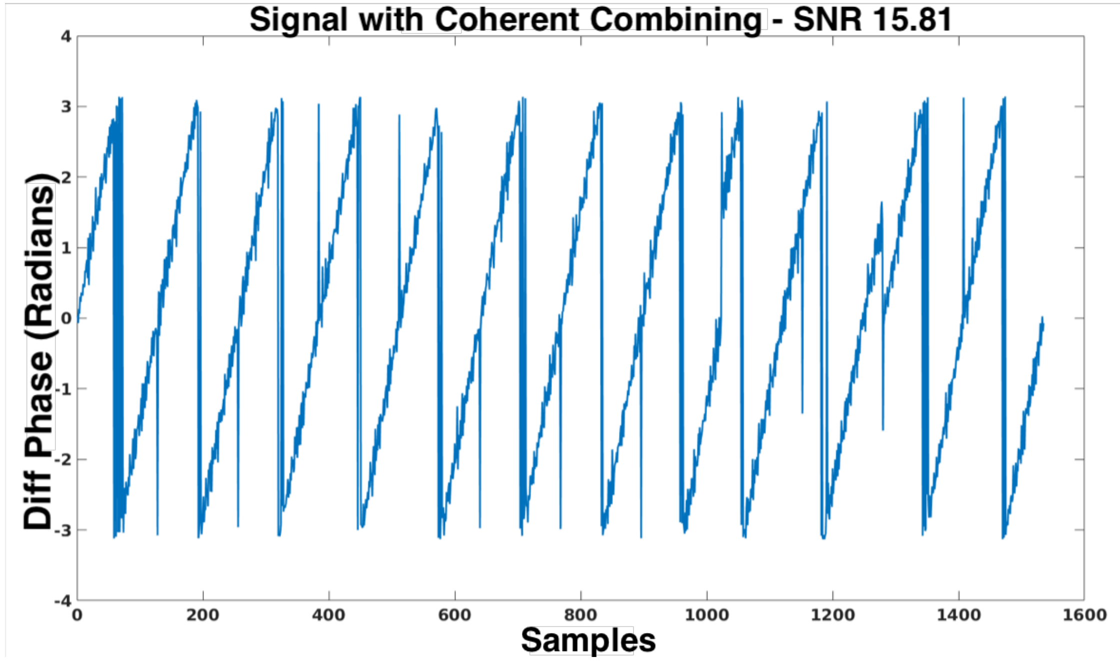


Coherent Combining for UL Range Extension

- Several RF chains and antennas are present at the MIMO gateway
- Signal coming from the end-device suffers from multipath fading
- Benefit from spatial diversity of antennas
- Combine coherently different copies to obtain a better representation of the signal
- The chosen approach: add delay to align the different copies
  - receiver beamforming
- Same process as DL

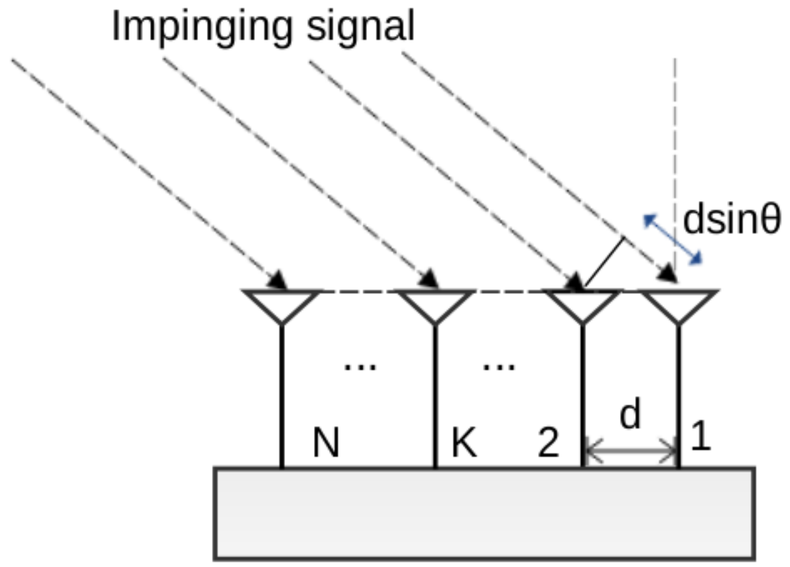
Coherent Combining: Simulation





AoA Based Localization

- Gateways need to track end devices and update the steering angle
  - For DL beamforming
- AoA estimation can be done at the MIMO gateway
- Based on the relative phase between the signals received at the antenna array (N = 2 in our case)

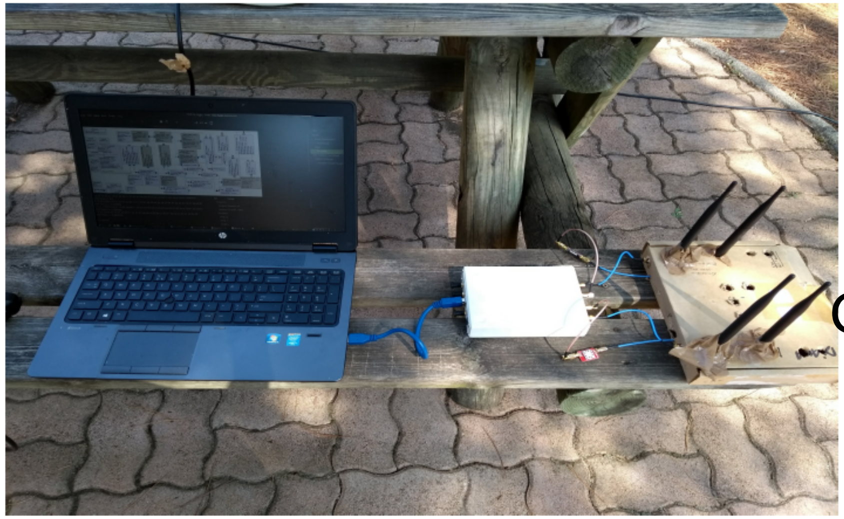


AoA Based Localization

- Compute the covariance matrix from the received signal IQ samples corresponding to K (very few) time samples
- Taking advantage of the intrinsic diversity of chirp modulated signals
- Eigen decomposition, signal and noise uncorrelation assumption
- Eigen vectors corresponding to higher eigenvalues designate signal
- MUSIC algorithm gives steering vectors related to signal
- The estimated signal AoA correspond to peaks in the so-called pseudospectrum function

System Evaluation

- Experimental set-up
  - MIMO gateway and an end node: custom SDR testbed based on GnuRadio
  - Two Ettus Research USRP B210 equipped with 2-element Uniform linear arrays (VERT 900MHz antennas)

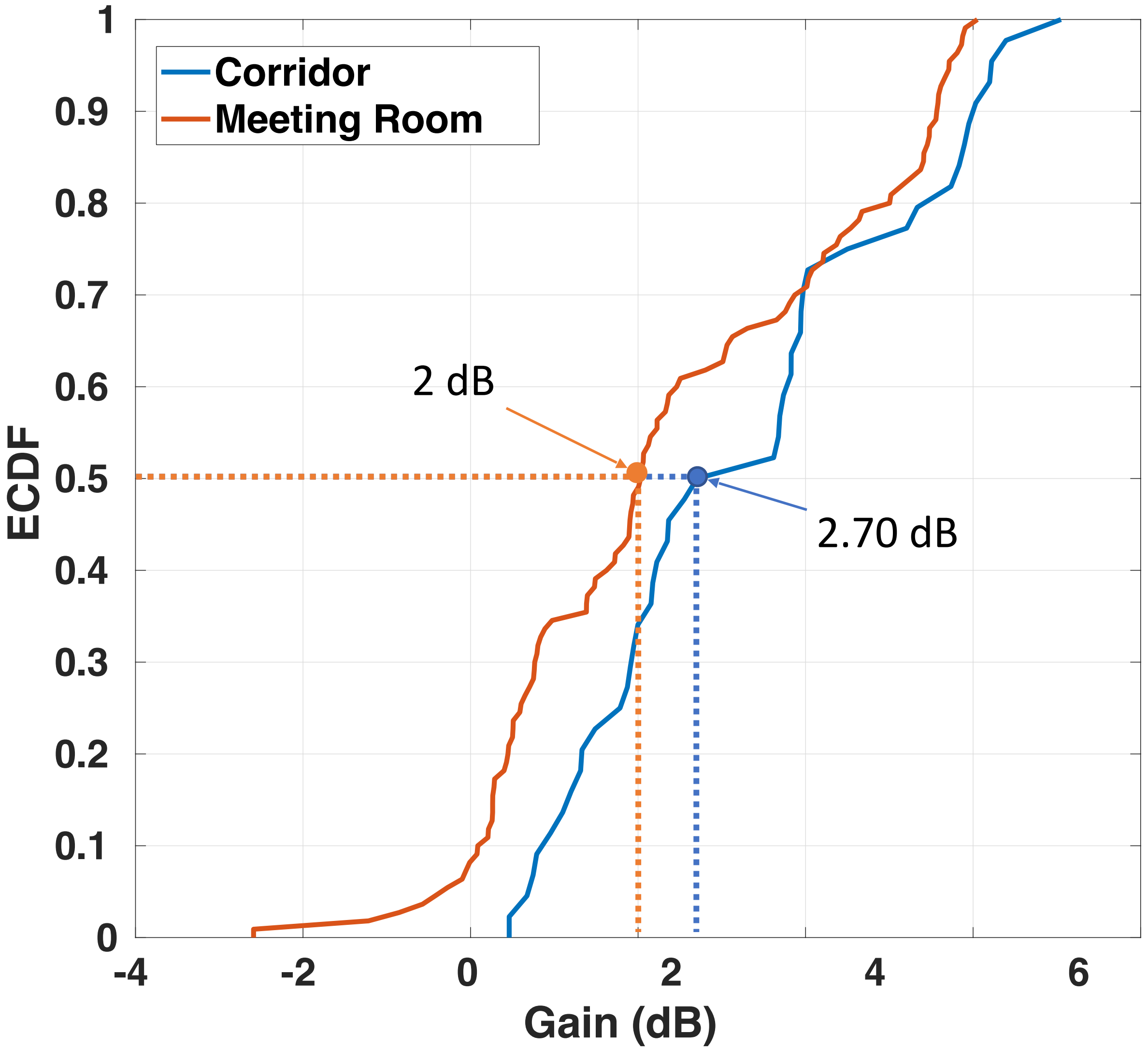


Gateway

node

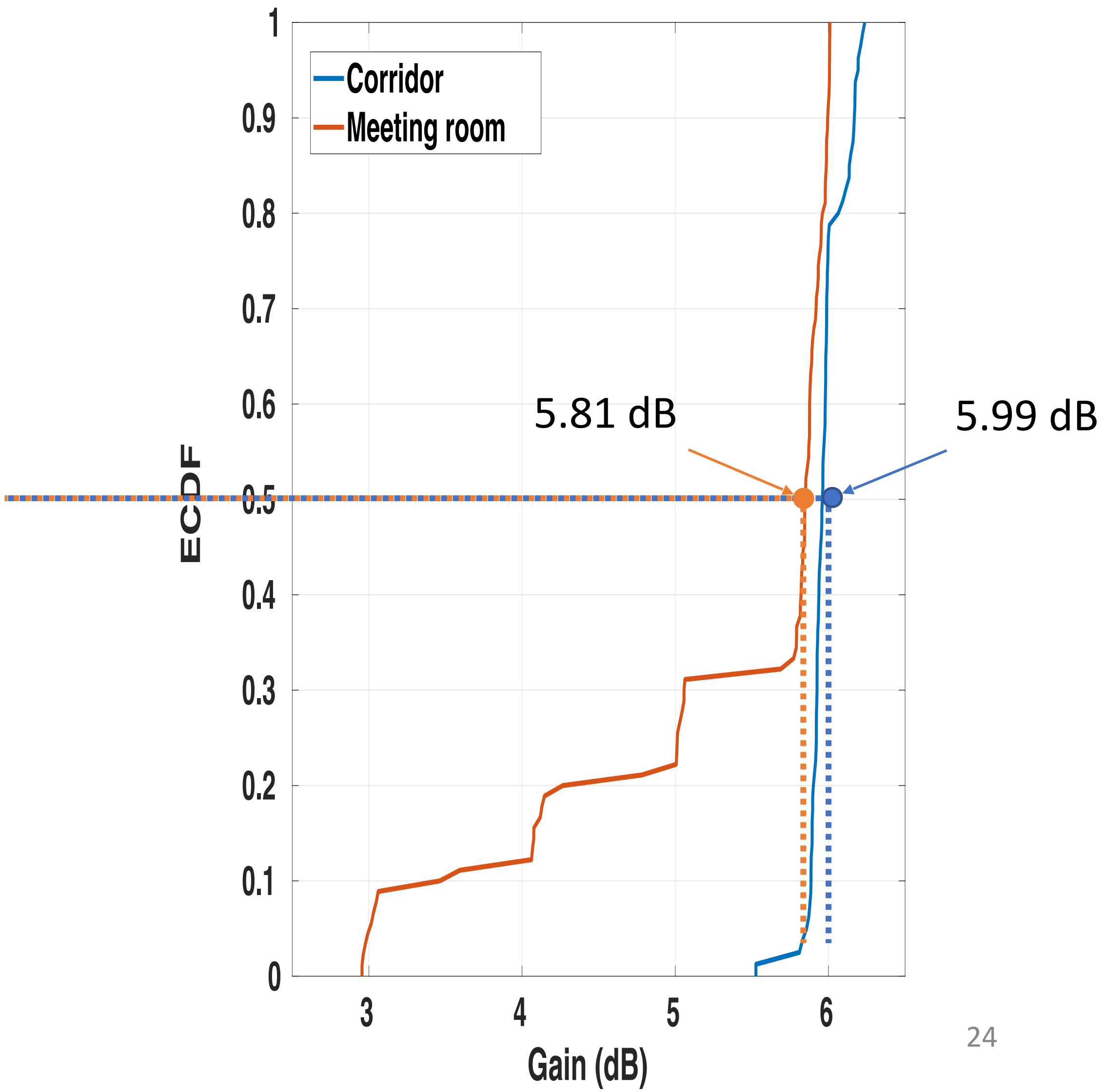
Beamforming Gain

- Corridor and meeting room environment
- Avg power gain
  - corridor: 2 dB
  - meeting room: 2.70 dB
- Impact of "through-the-wall" transmission



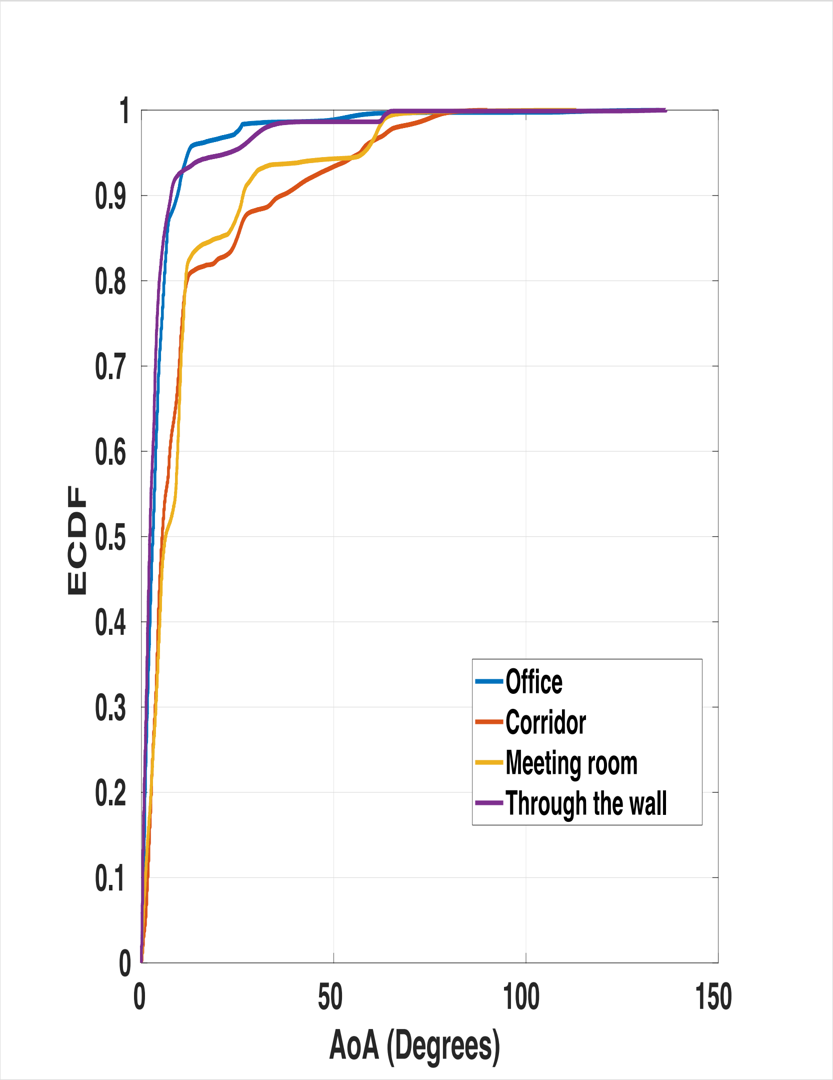
Coherent Combining Gain

- Signals impinging of the 2-element antenna array
- Avg power gain
  - corridor: 5.99 dB
  - meeting room: 5.81 dB
- Factor 4 w.r.t. baseline
- Same power gain across environments and conditions (LoS and NLoS)



AoA Estimation Precision

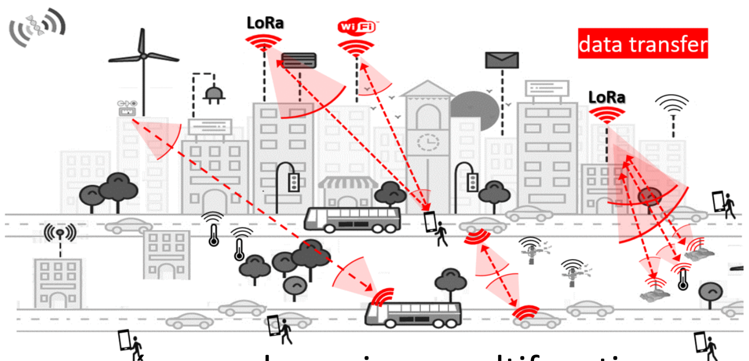
- Mean error:
  - office: 4.8°
  - corridor: 12.1°
  - meeting room: 11.2°
- Longer distance :
  - Higher number of reflected signals
  - Higher estimation error
- Error still relatively small
  - time-frequency diversity



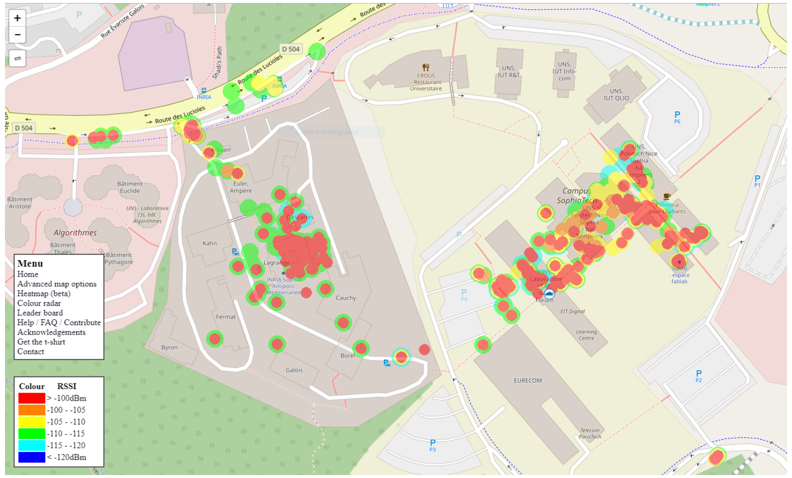
Conclusion

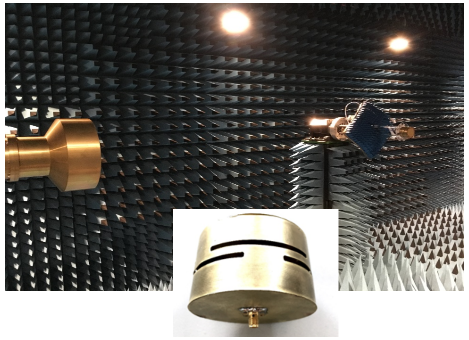
- Possible to leverage the time-frequency distribution of the LoRa signal to reduce AoA estimation error
  - without additional module
- AoA estimation is done at the gateway
  - requires more antennas
  - preserves node battery
  - avoid Cloud based solutions
- Beamforming and Coherent combining enhance DL and UL transmission range respectively

Improved Localization in Wireless IoT Networks



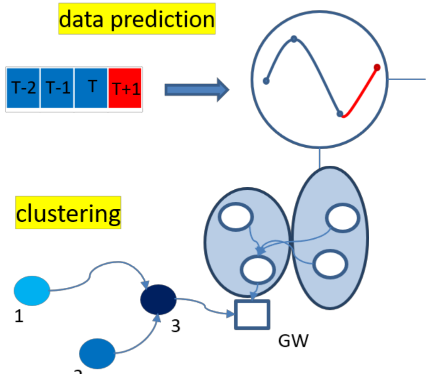
réseaux dynamique multifonctions





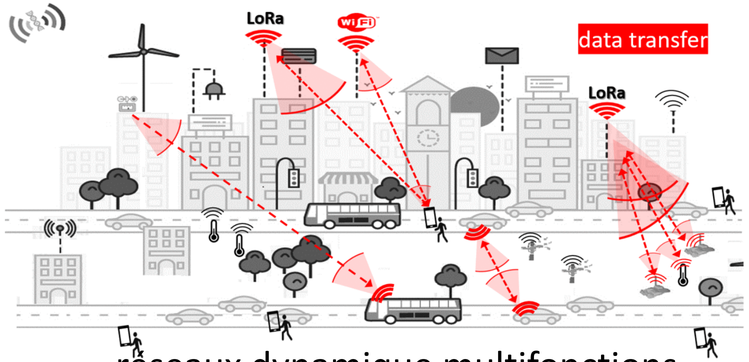
physical layer

network layer

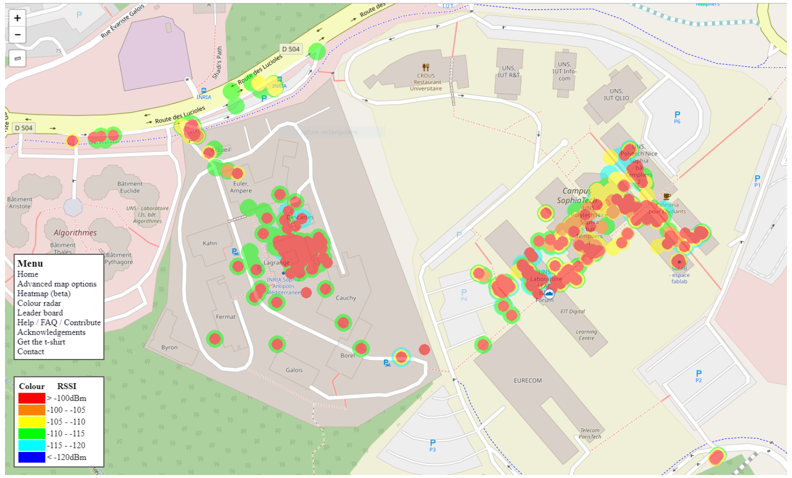


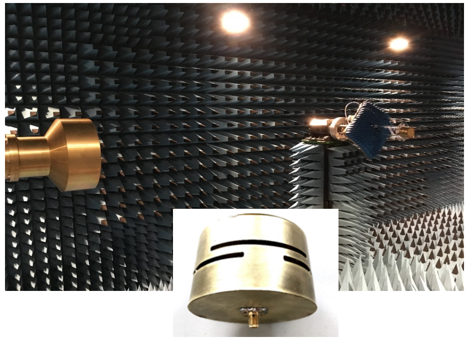
application layer

Improved Localization in Wireless IoT Networks

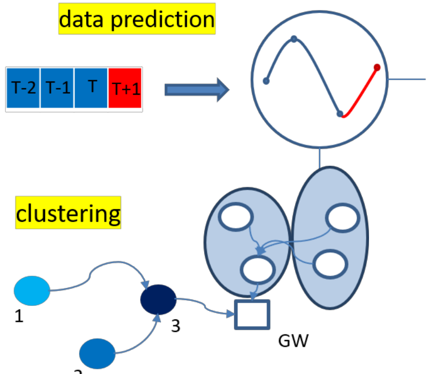


réseaux dynamique multifonctions




physical layer

network layer



application layer

I’LL WIN Project objectives

- Localization system in LPWAN IoT networks
  - Development of a miniature device adapted to be integrated into the target (LEAT)
  - Optimization of the network configuration to enhance estimation of the position (DIANA)
    - Develop reconfigurable LoRa nodes
    - Operating in either “node” or “gateway” mode
  - Development of a machine learning algorithm to improve the estimation (FBK Trento)