

# NELoRa

## Towards Ultra-low SNR LoRa Communication with Neural-enhanced Demodulation

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MICHIGAN STATE UNIVERSITY

# Low-power Wide-area Networks

Imaging a world where every single object is connected to the Internet



# IoT Connectivity via LoRa

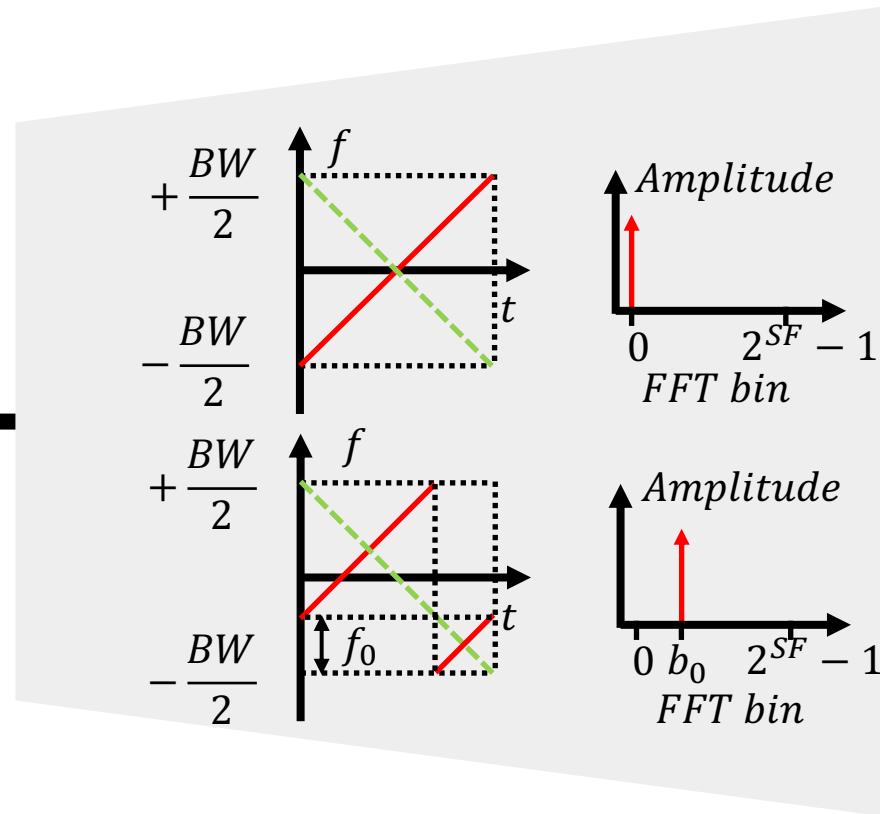
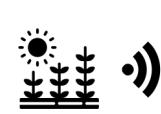


Long Range

Low Power

## PHY Layer: Chirp Spread Spectrum (CSS) Modulation

IoT  
Sensors



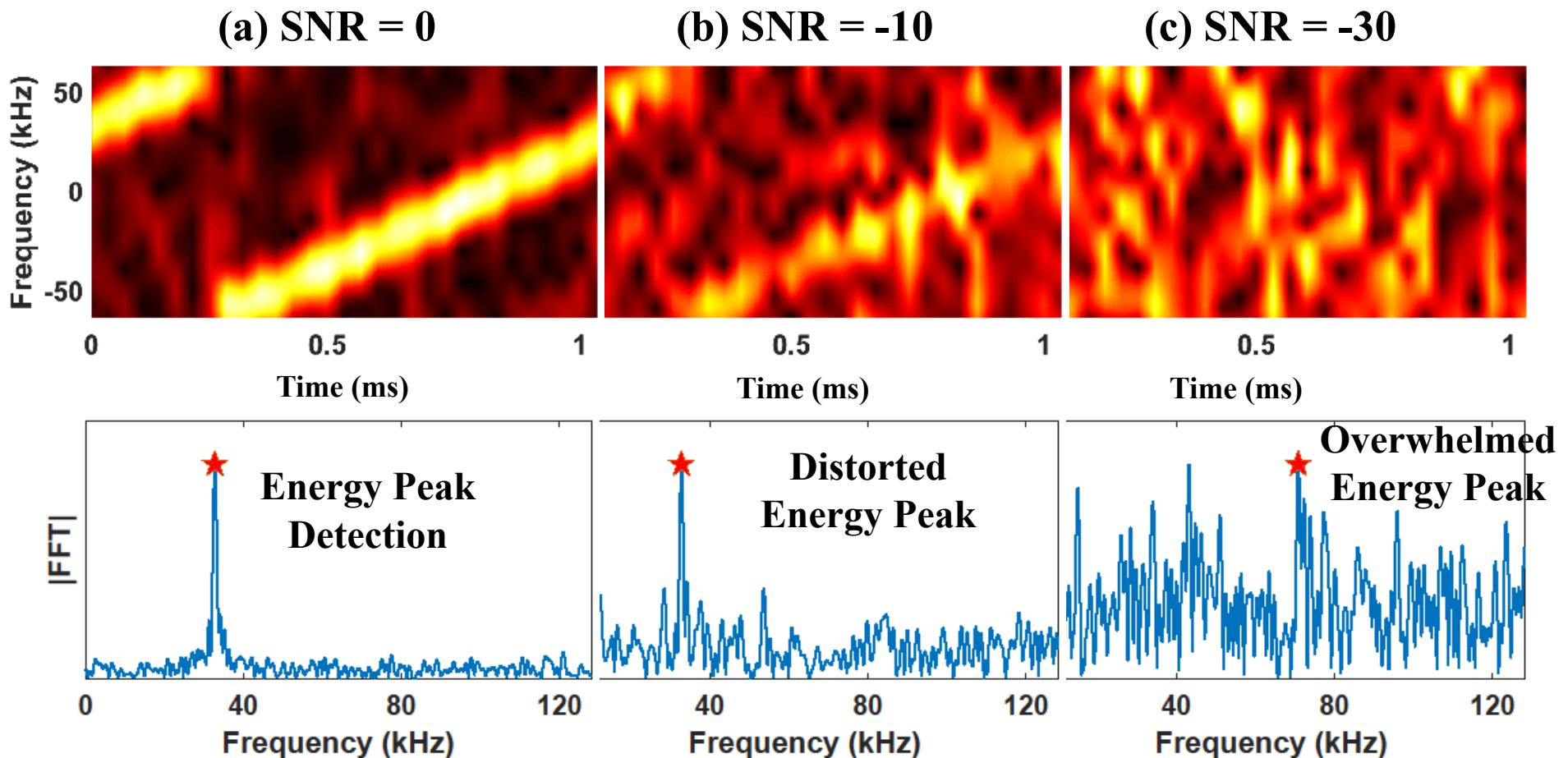
Gateway



# IoT Connectivity via LoRa

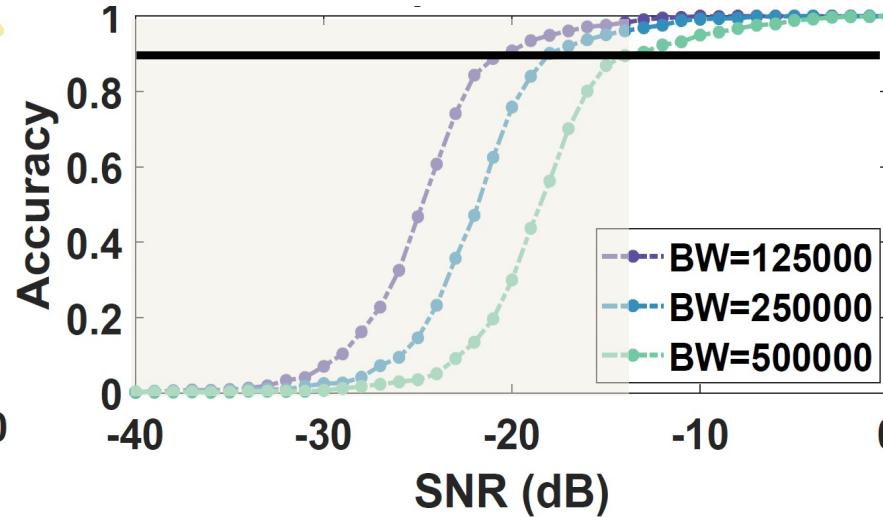
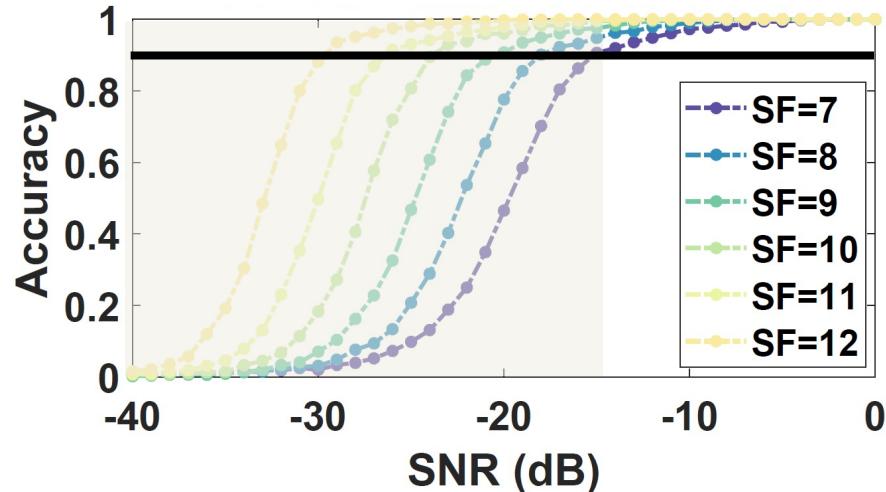
Long Range

Low Power



# IoT Connectivity via LoRa

IoT  
Sensors



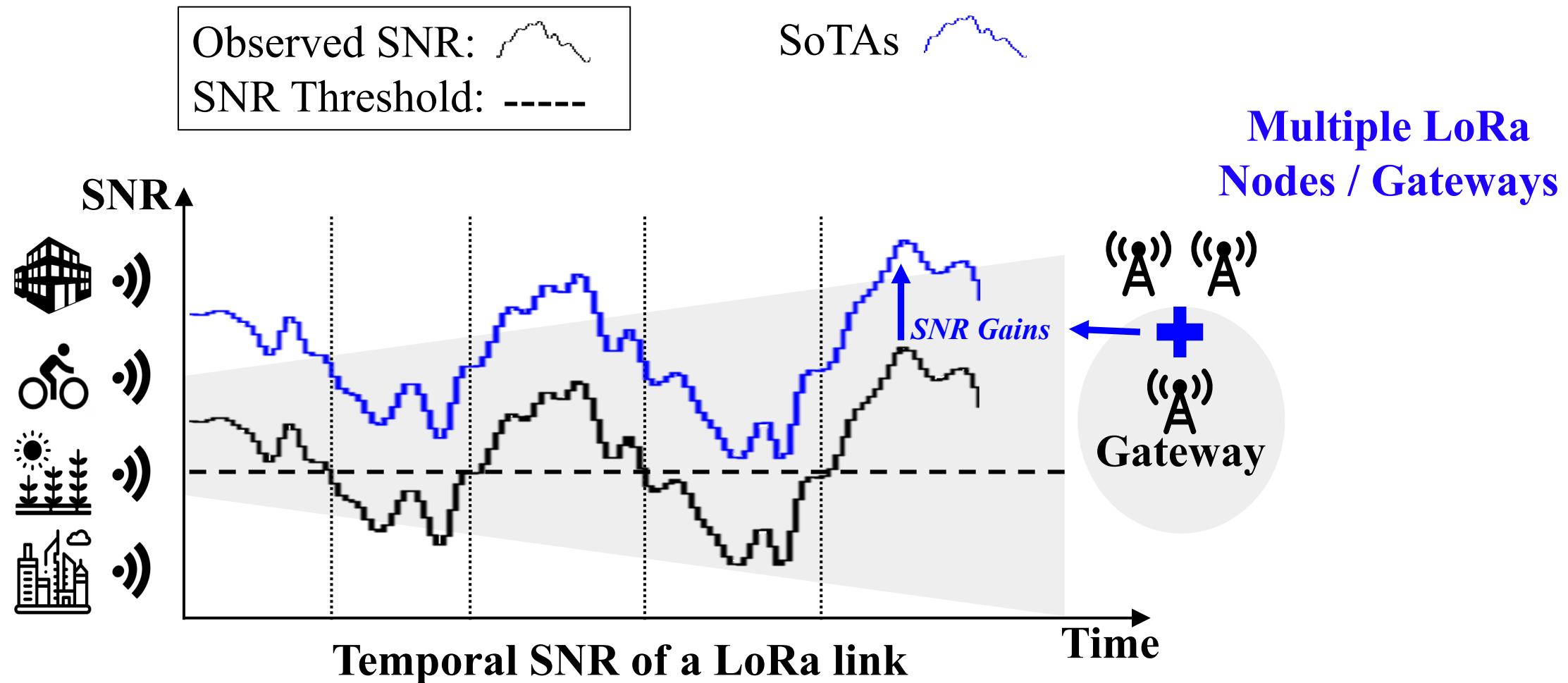
Gateway



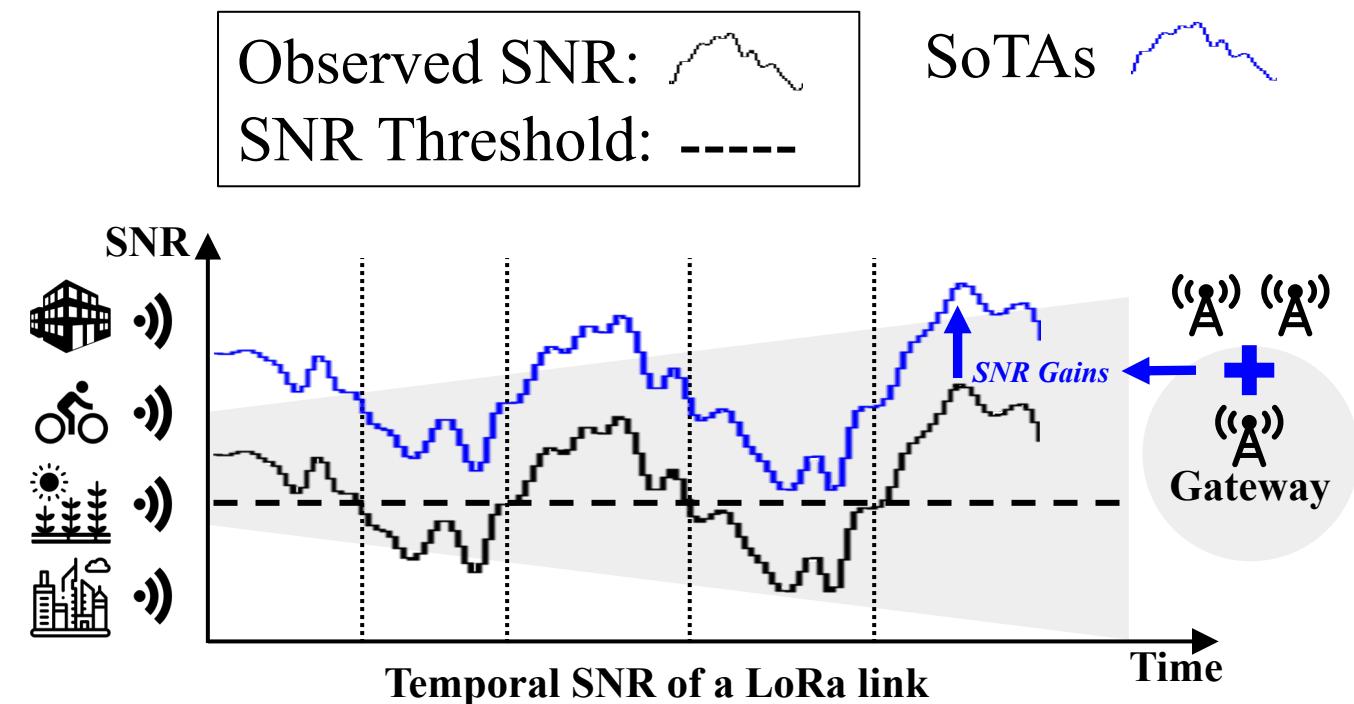
Weak Signal Decoding

- SNR Threshold of the standard Dechirp processing
- Communication Range & Battey Life

# SoTAs: Weak Signal Decoding

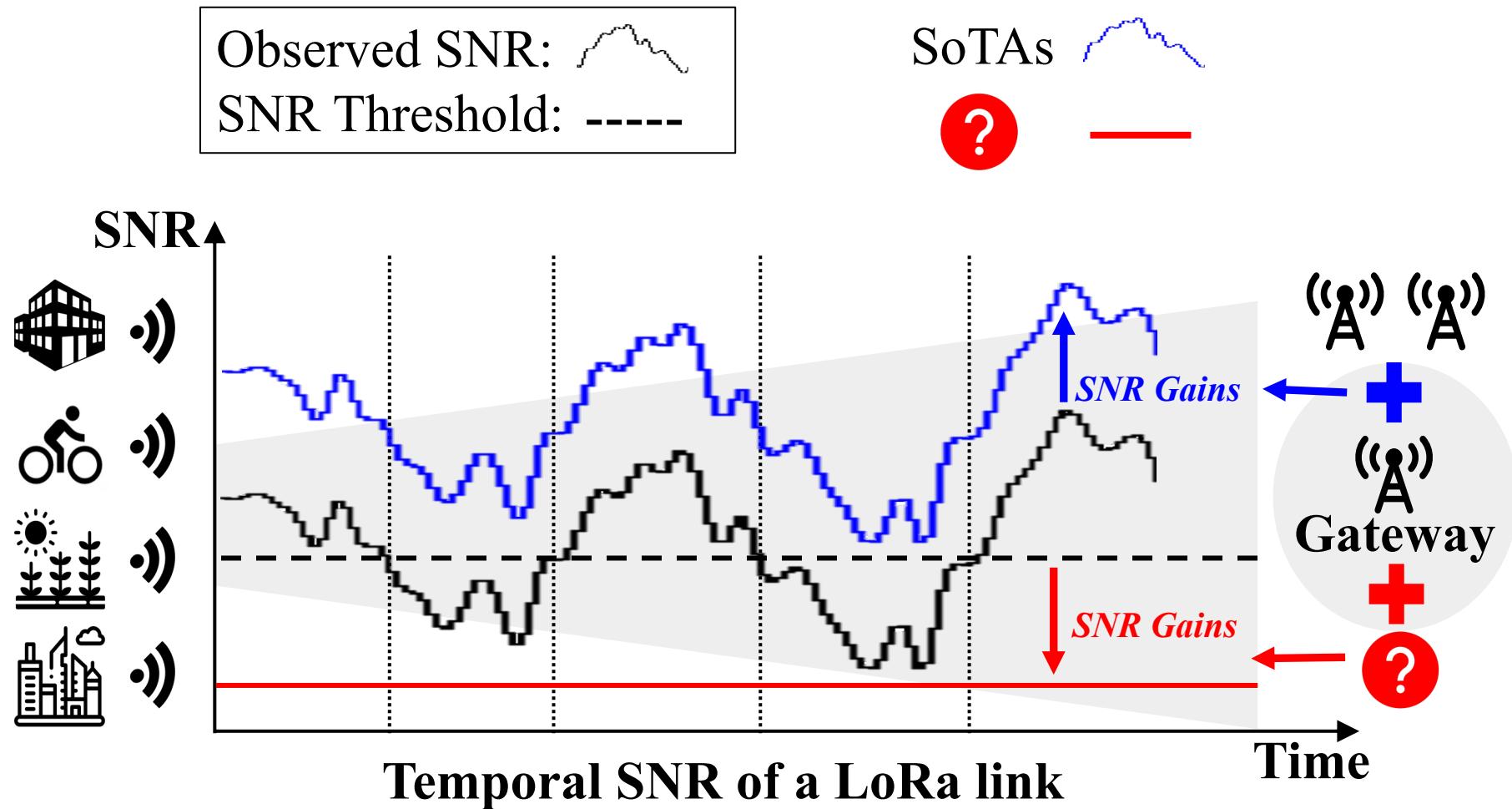


# SoTAs: Multi-pair Transceivers

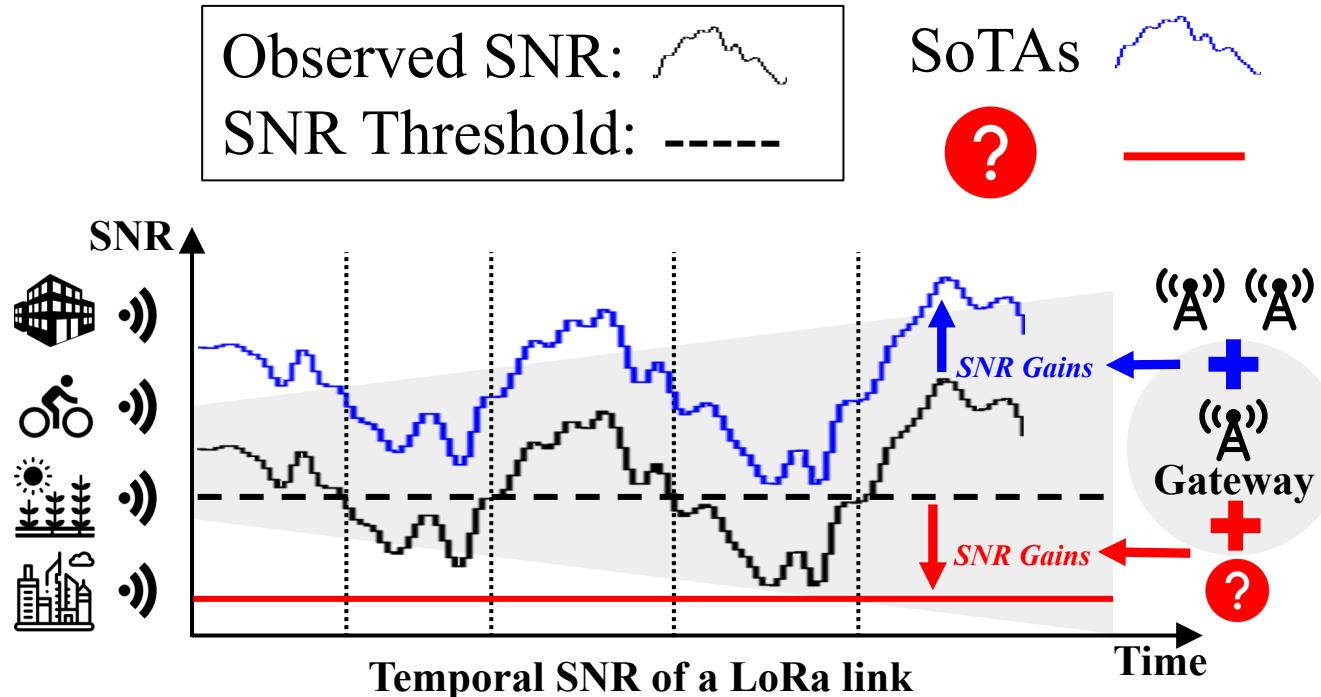


	IoT Sensors	Gateway	SNR Gains
<b>Choir</b> SIGCOMM'17	36	1	N/A
<b>Charm</b> IPSN '18	1	2-8	1-3dB
<b>OPR</b> MobiSys '20	1	2-6	1.5-2.5dB
<b>Chime</b> NSDI '20	1	4-6	2.4-3.4dB

# Problem: Weak Signal Decoding



# Motivation: Weak Signal Decoding



Observations

System  
Design

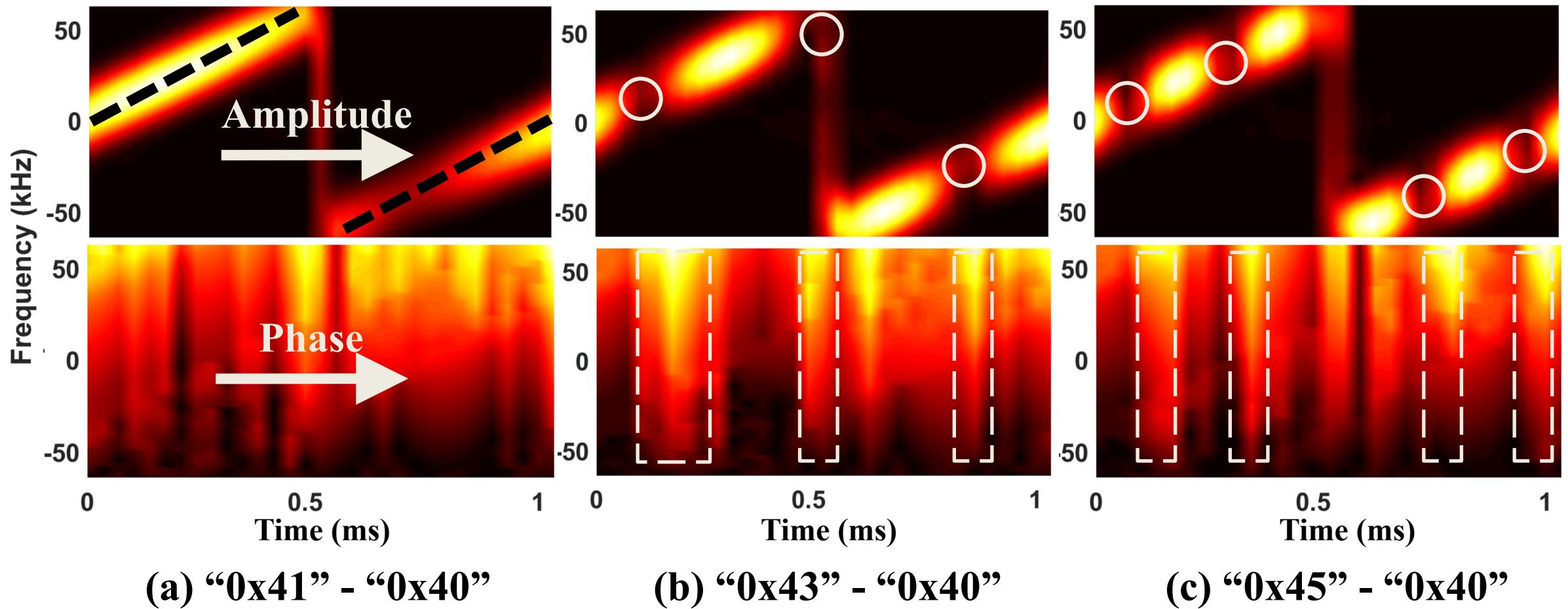
Challenges

?

**NELoRa: neural-enhanced Demodulator**

- Neural-enhanced Decoder
- Extra SNR Gains
- Single Pair of LoRa Transceiver
- Orthogonal to existing works

# Observation-1: Unique Pattern



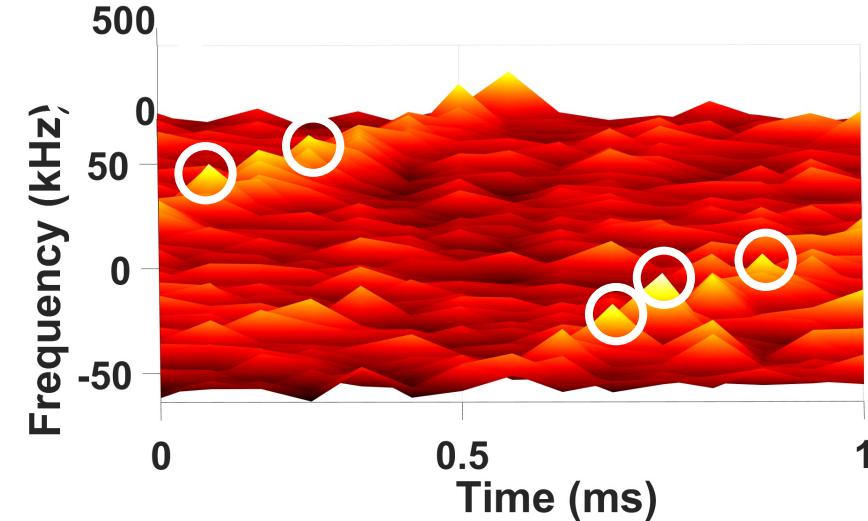
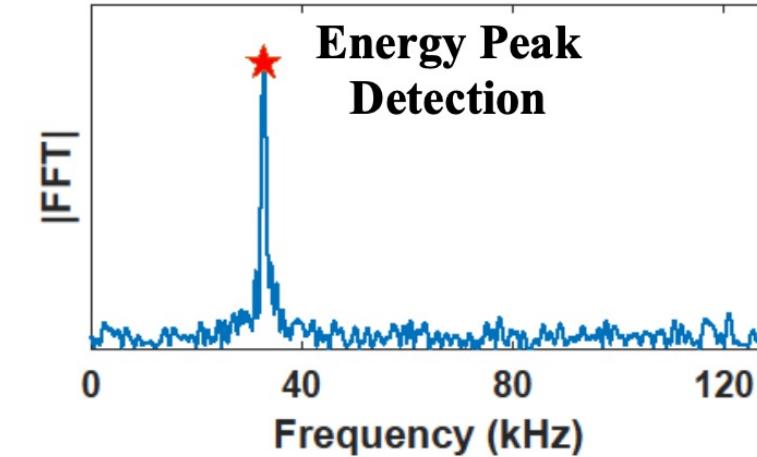
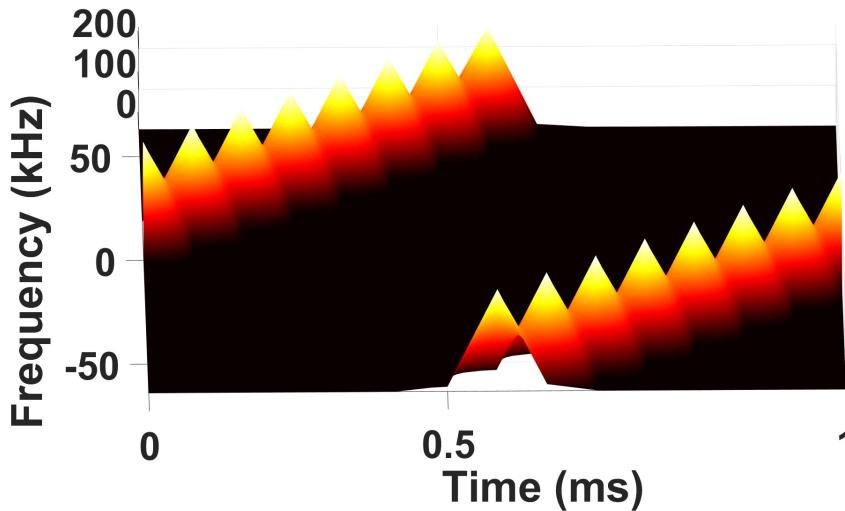
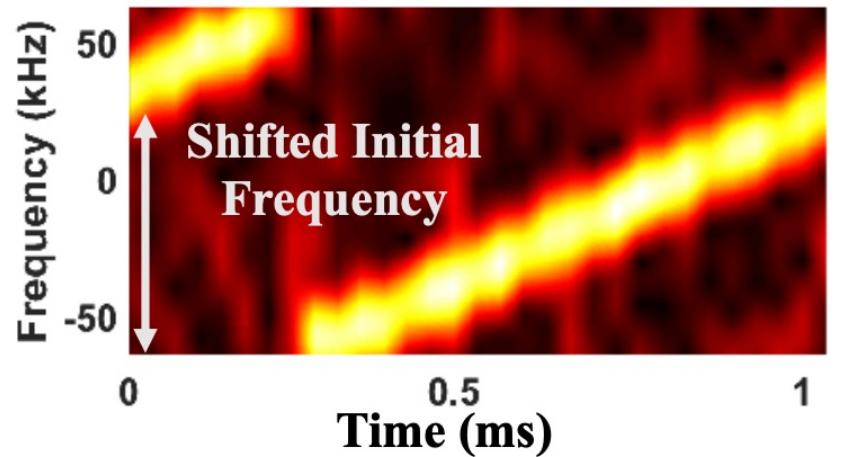
Takeaway-1: the spectrogram pattern makes it a unique feature

# Observation-2: 2D Robust Pattern

Standard  
Dechirp

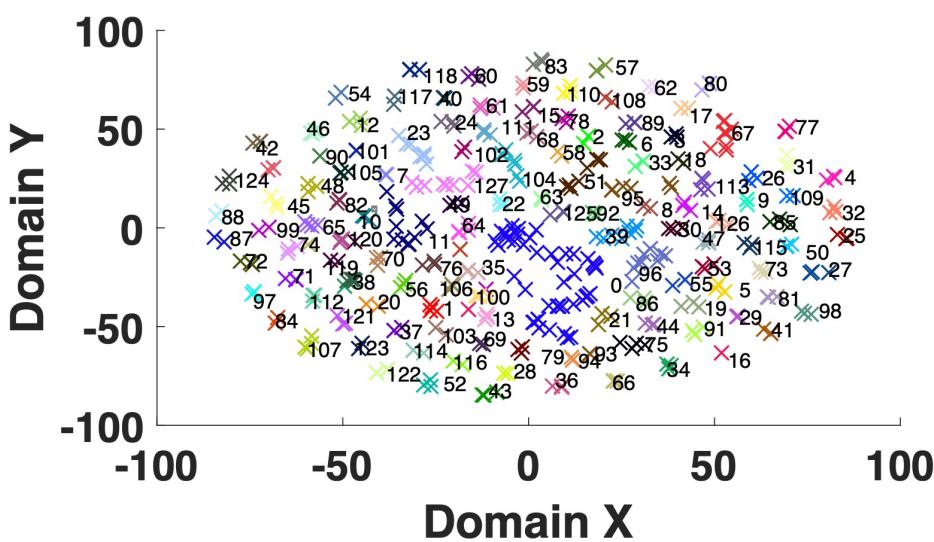
VS.

Neural-  
enhanced  
Decoder

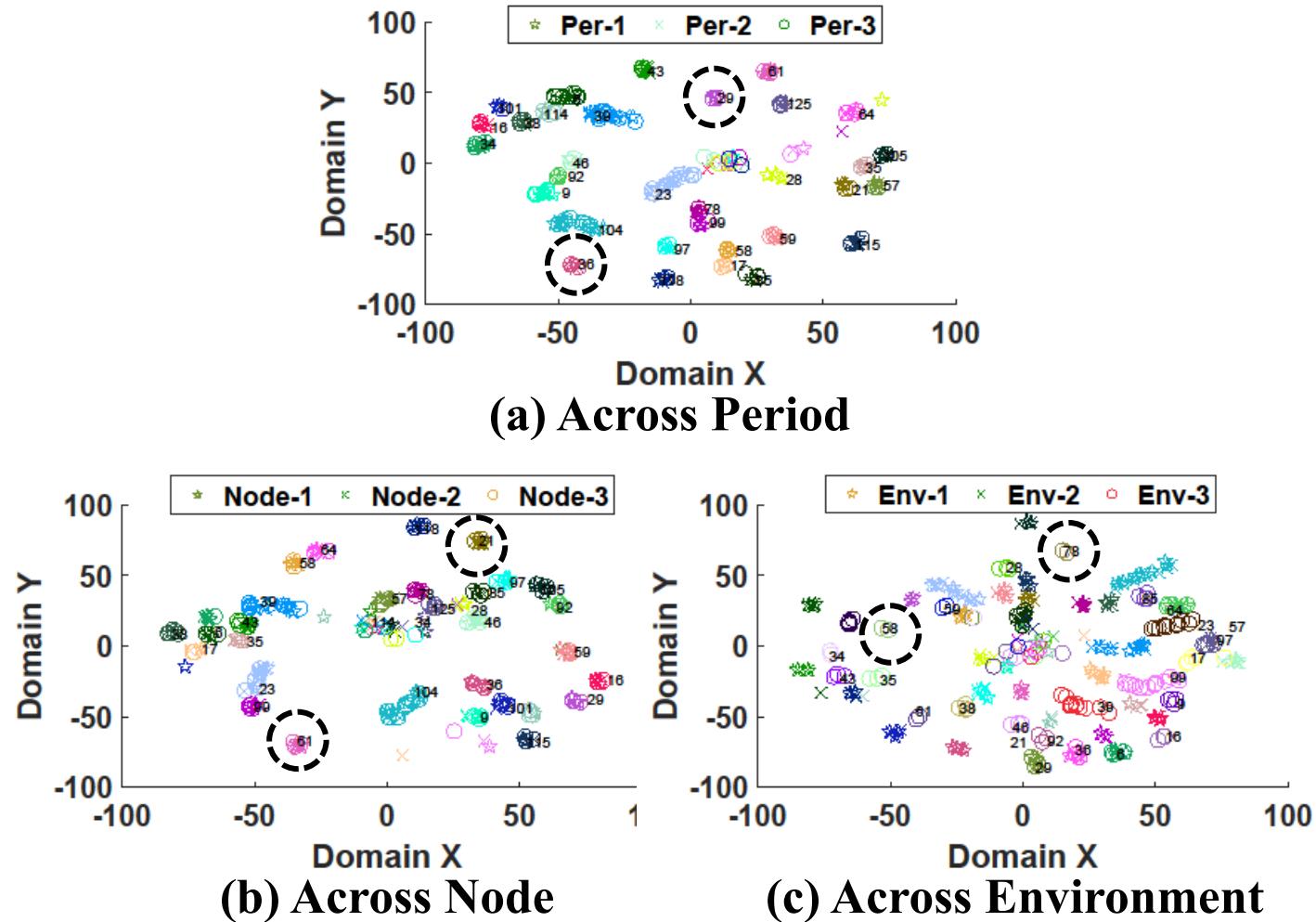


Takeaway-2: NELoRa can still recognize it even with partial energy peaks

# Observation-3: Finite Feature Space

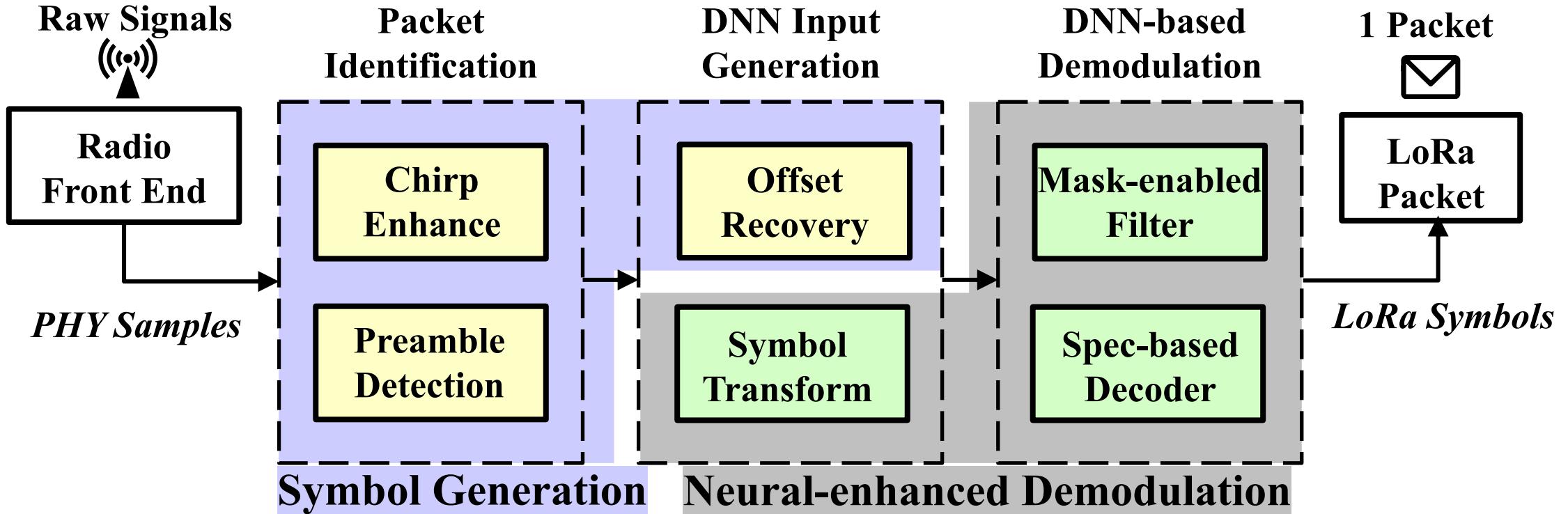


SF=7: 128 Different Codes

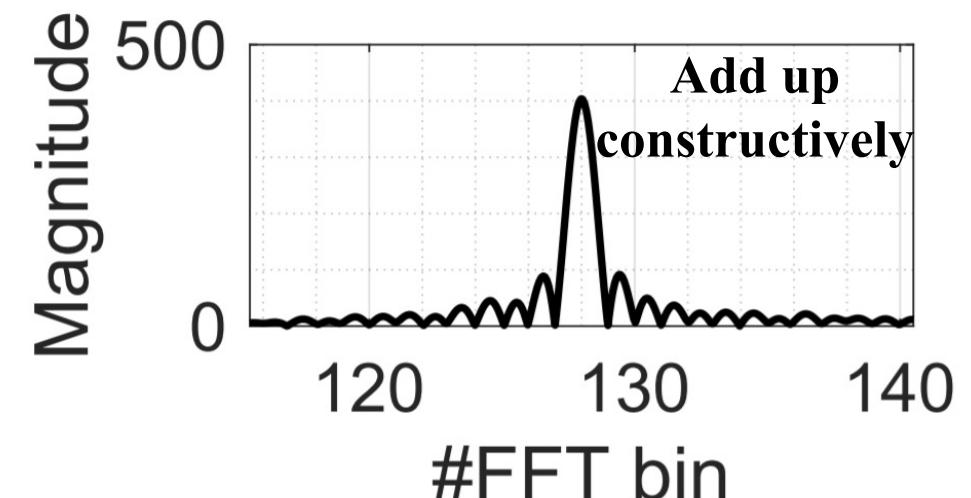
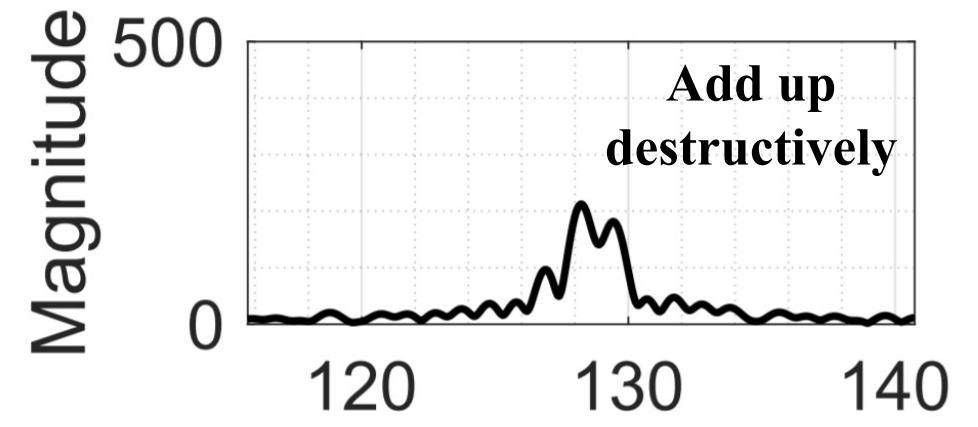
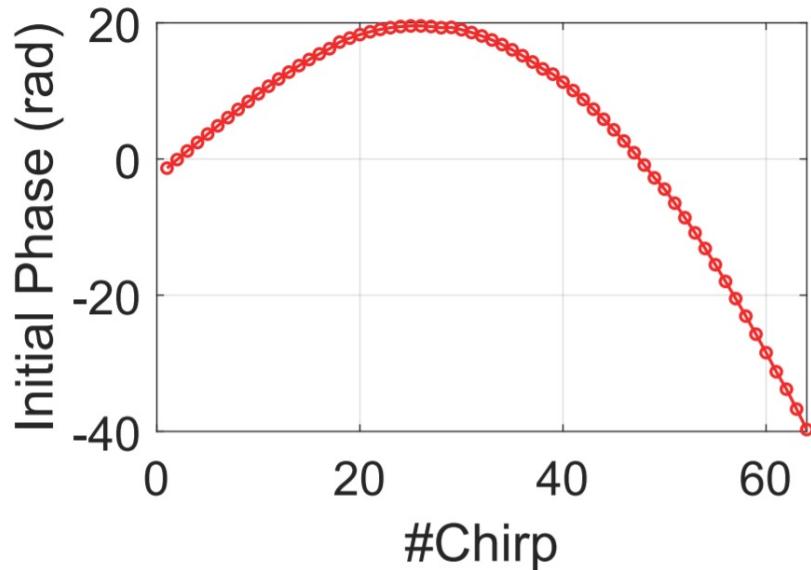
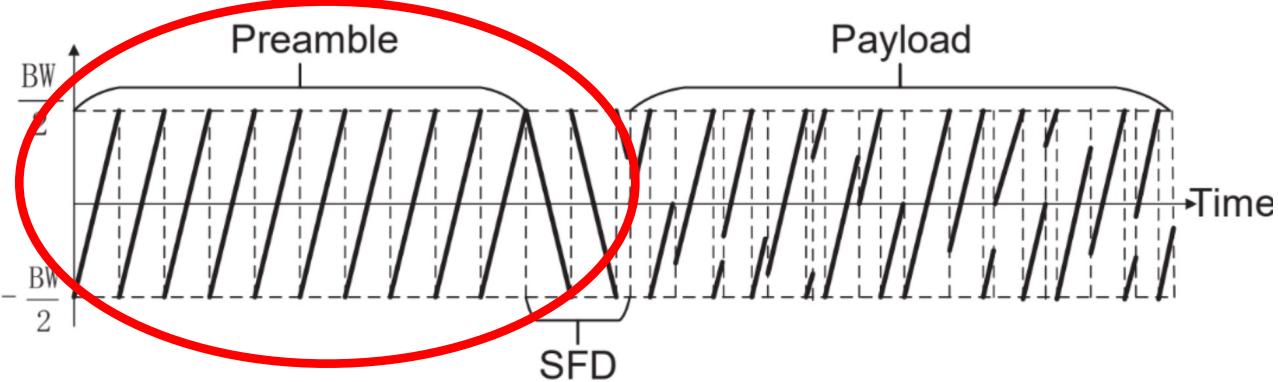


Takeaway-3: the finite coding space of LoRa for data-driven NELoRa

# System Design

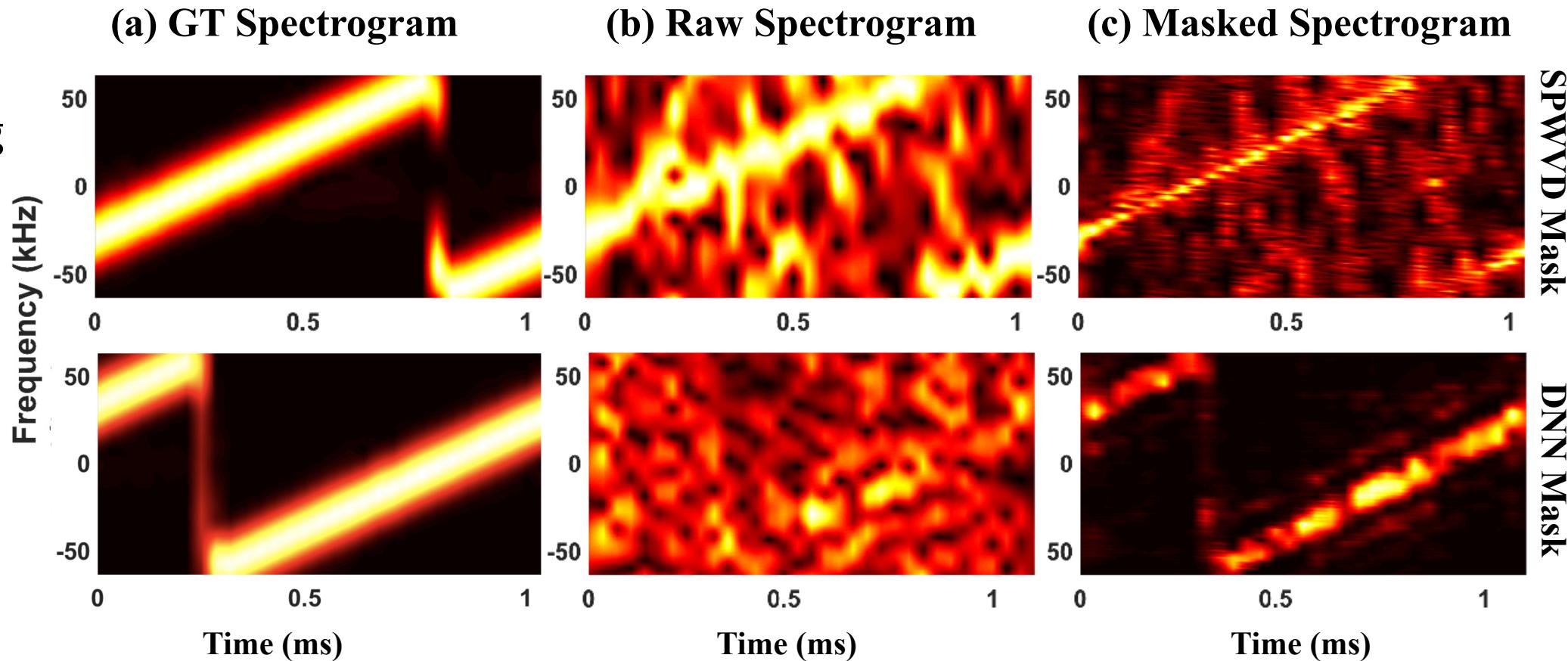


# Challenge-1: Symbol Generation

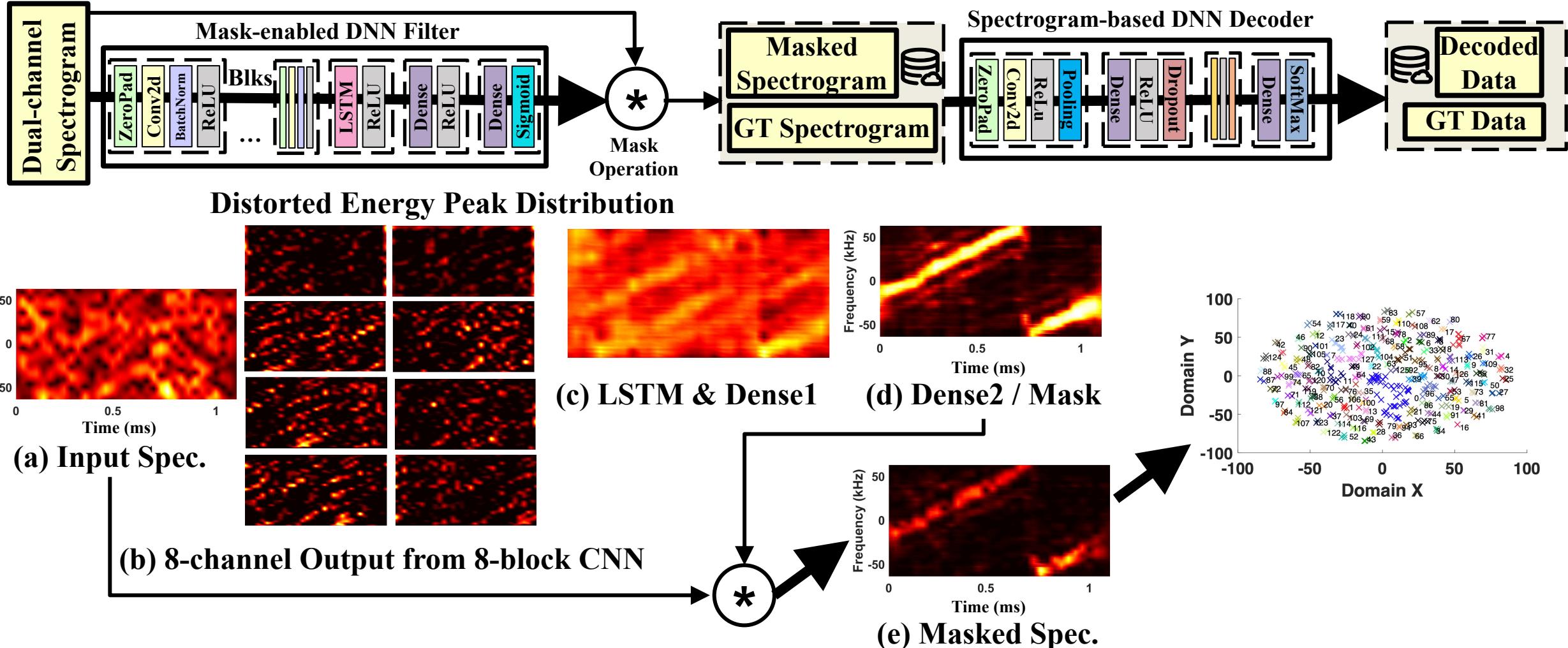


# Challenge-2: Noise & Interference

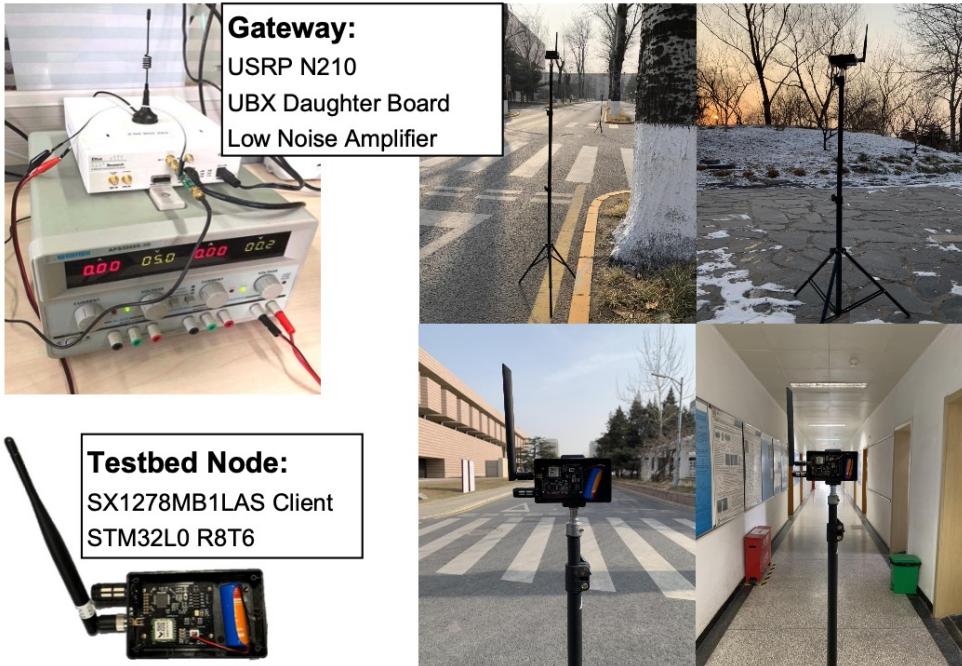
Signal  
Processing  
Filter  
**VS.**  
Neural-  
enhanced  
Filter



# Challenge-3: Network Design

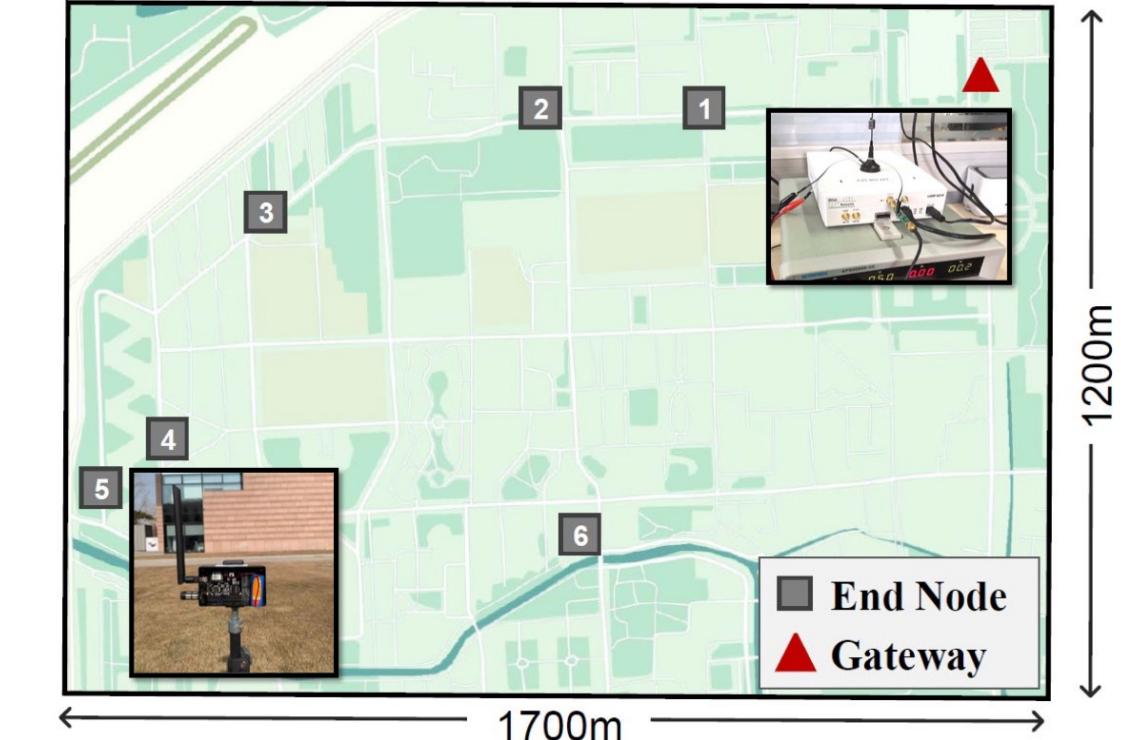


# Implementation



## Metric:

- Symbol Error Rate (SER)
- SNR Gains (SER=10%)
- Battery Life Gain (BLG)

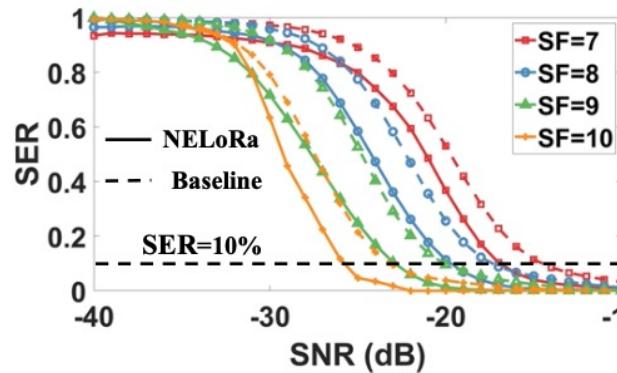


## Baseline:

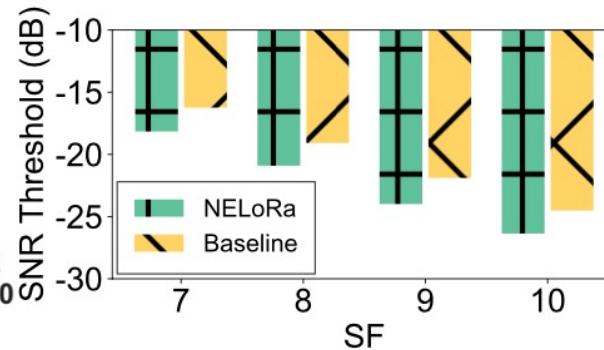
- Standard Dechirp Processing

# Evaluation: Indoor Performance

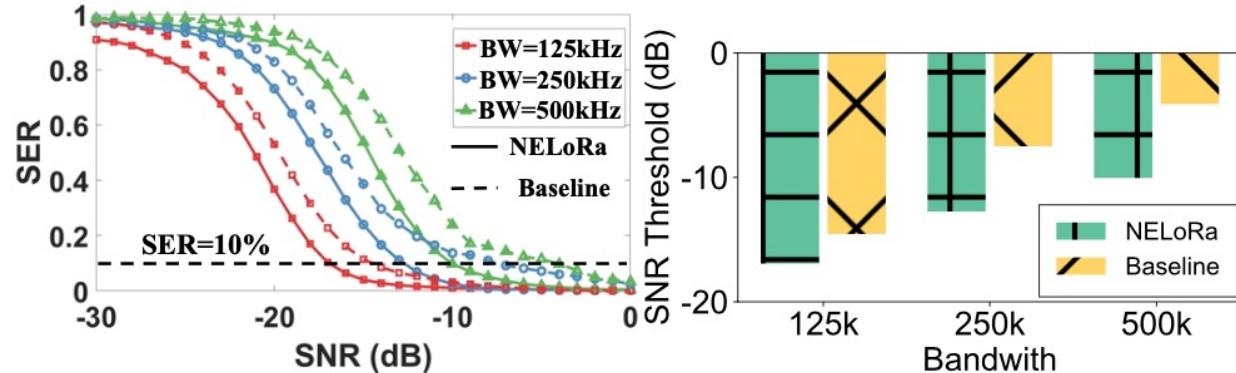
Q1 - How much does NELoRa improve the demodulation performance than Dechirp under various LoRa configurations?



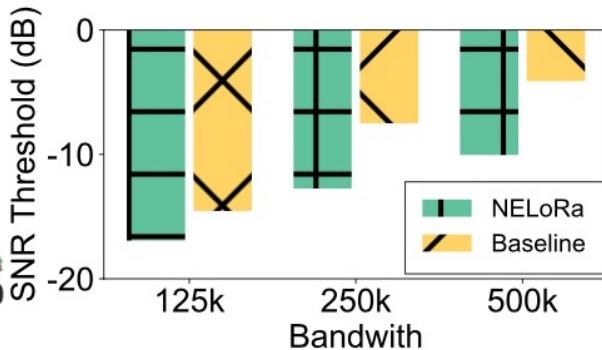
(a) SER-SNR Curves of Different SFs



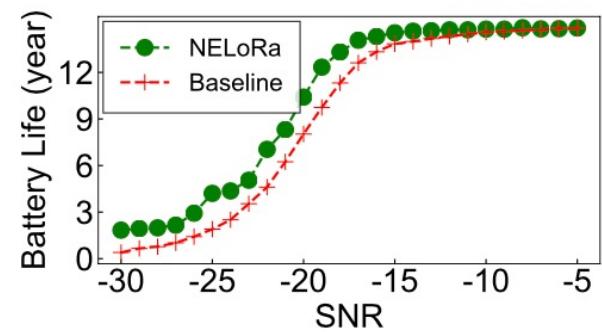
(b) SNR Gains of Different SFs



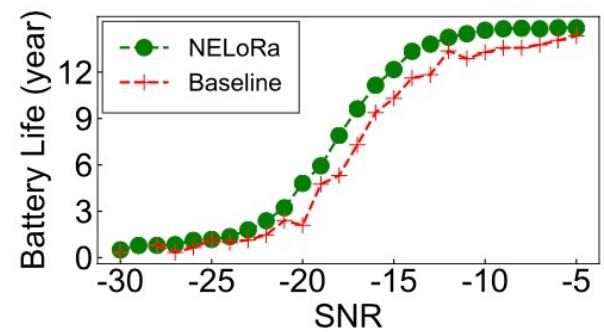
(c) SER-SNR Curves of Different BWs



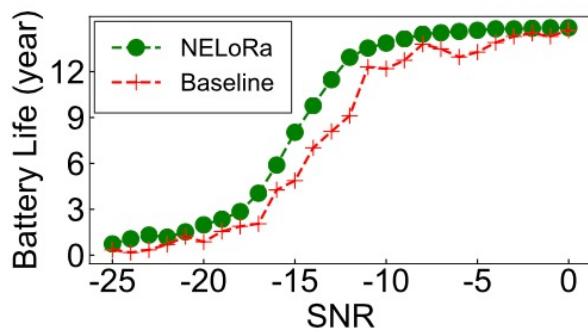
(d) SNR Gains of Different BWs



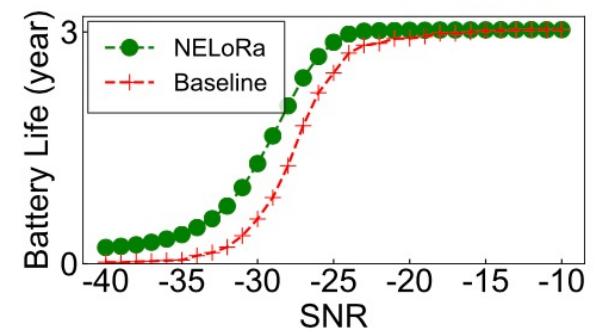
(e) BLG under SF=7, BW=125K



(f) BLG under SF=7, BW=250K



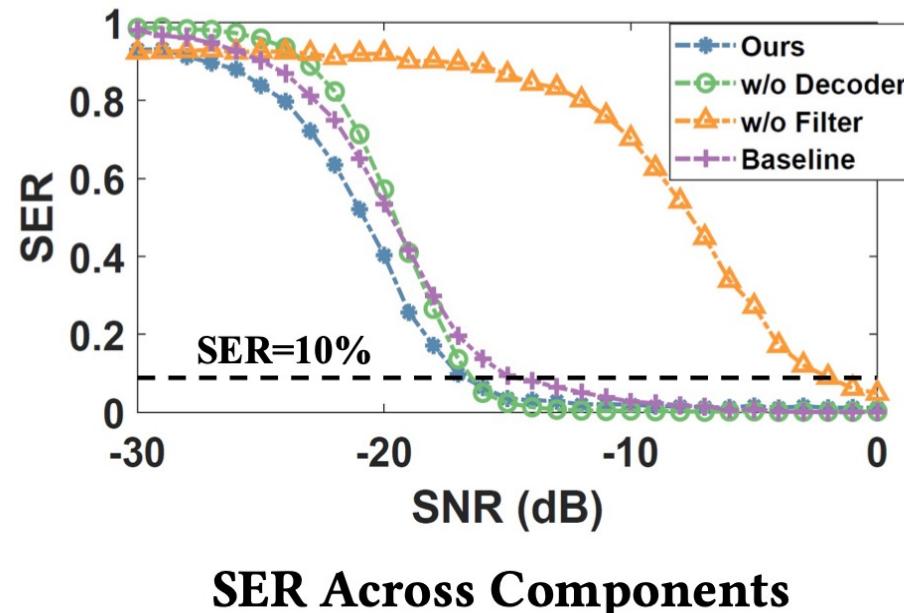
(g) BLG under SF=7, BW=500K



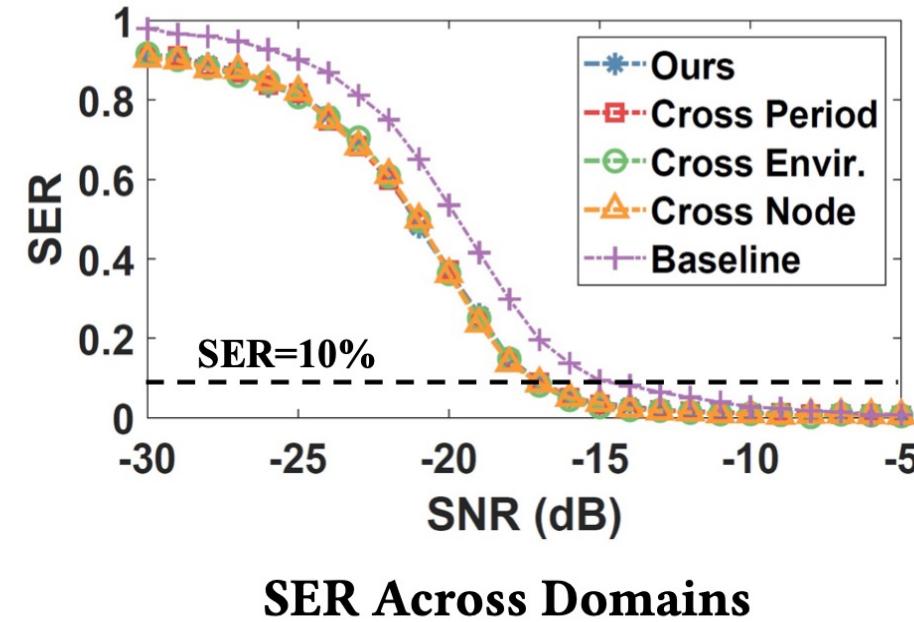
(h) BLG under SF=10, BW=125K

# Evaluation: Robustness Analysis

Q2 - How effective is each key technique incorporated in the design of NELoRa?



Q3 - Is NELoRa robust to different environments for low-cost deployment?



# Evaluation: Outdoor Performance

Q4. What is the performance of NELoRa in outdoor environment?

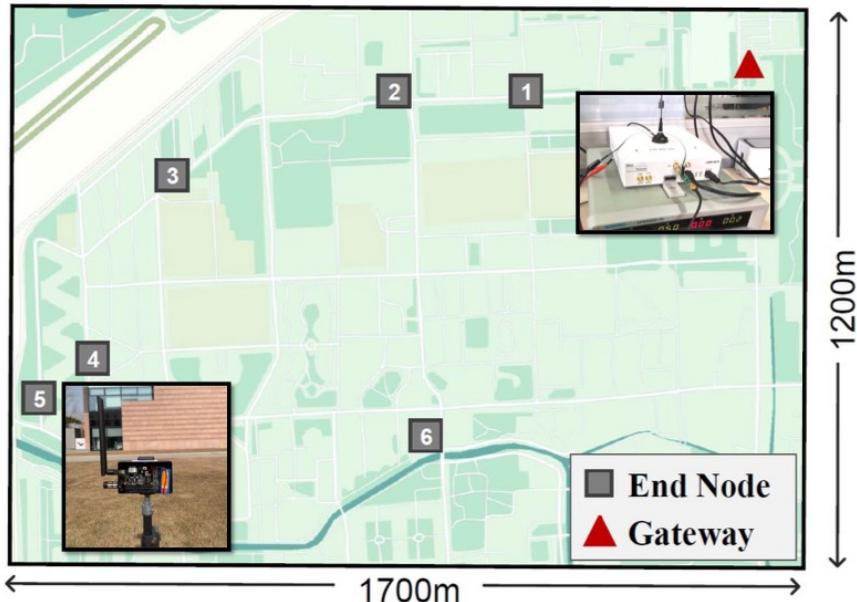
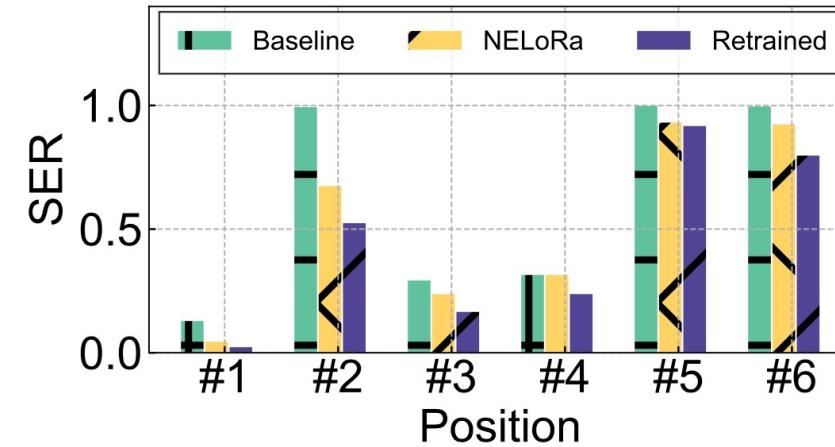
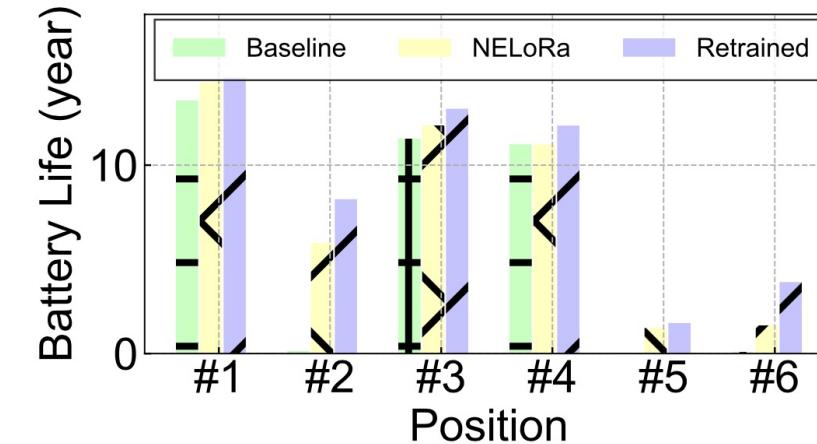


Figure 16: The illustration of our outdoor testbed and the topology of the LoRa nodes and NELoRa gateway.



(a) SER at different locations



(b) BLG at different locations

# Conclusions

- To the best of our knowledge, NELoRa represents the first neural-enhanced LoRa demodulation method with the minimum deployment cost.



The datasets and source codes are available at  
<https://github.com/hanqingguo/NELoRa-Sensys>



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