Enabling Reliable and Real-Time Packet Reception in User-Defined Overlapping LoRa Channels

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LoRa today

Deployed in various scenarios e.g.,

- Production line management in the **factory**.
- Intelligent meter reading in the **city**.
- Soil moisture monitoring in the **farmland**.

FACTORY

CITY

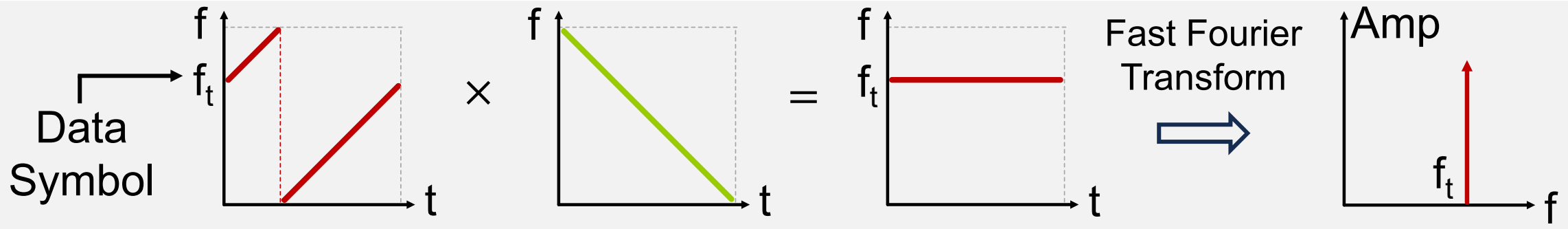
FARMLAND

LoRa primer

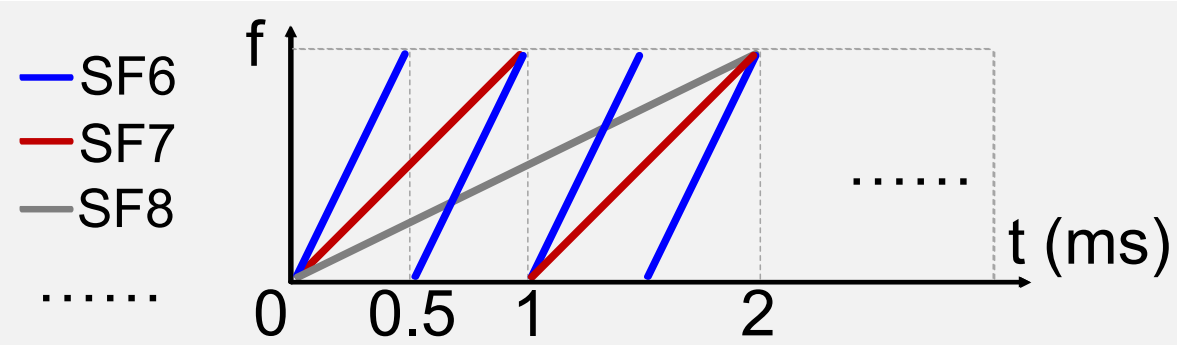
Physical layer: Chirp Spreading Spectrum (CSS)

- Linear chirp in time-frequency domain.

Modulation and Demodulation



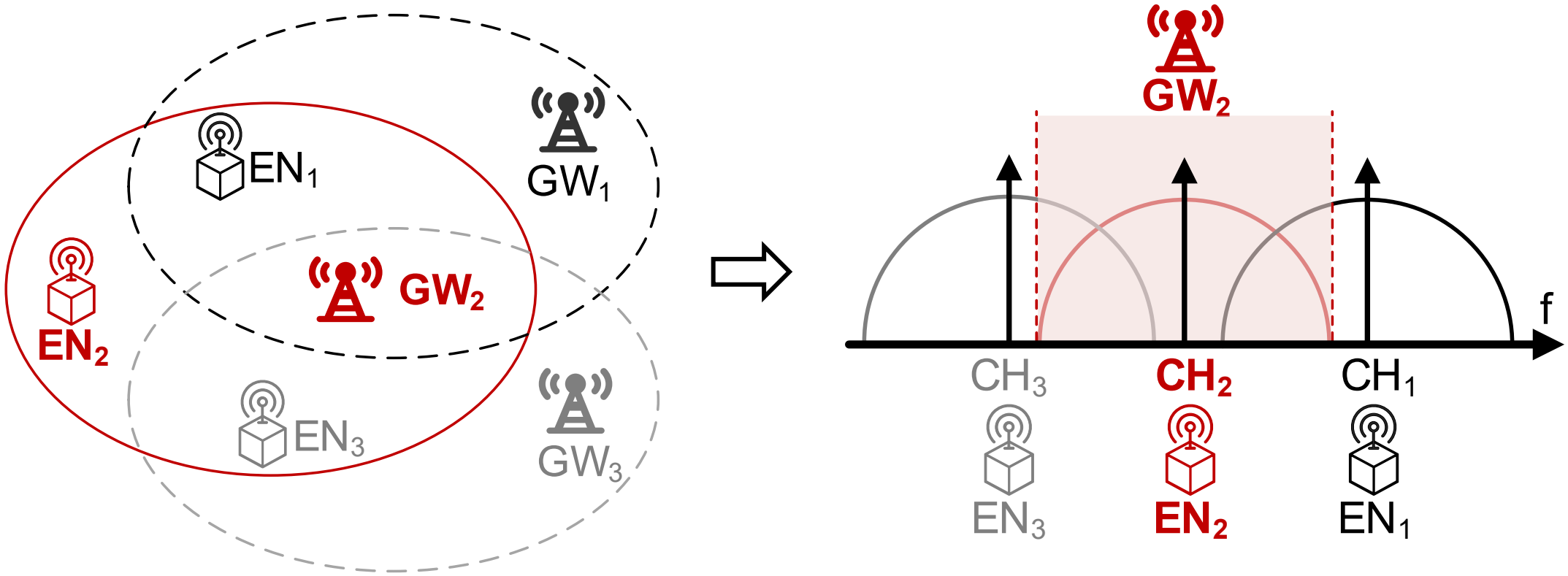
Orthogonality between different Spreading Factor (SF)



Is LoRa already sufficient to support large-scale connectivity?

Problem: overlapping channel interference

Massive LoRa devices and limited uplink spectrum inevitably leads to increased packet collisions in overlapping logical channels.



OCI: the interference among multiple overlapping logical channels.

Problem: overlapping channel interference

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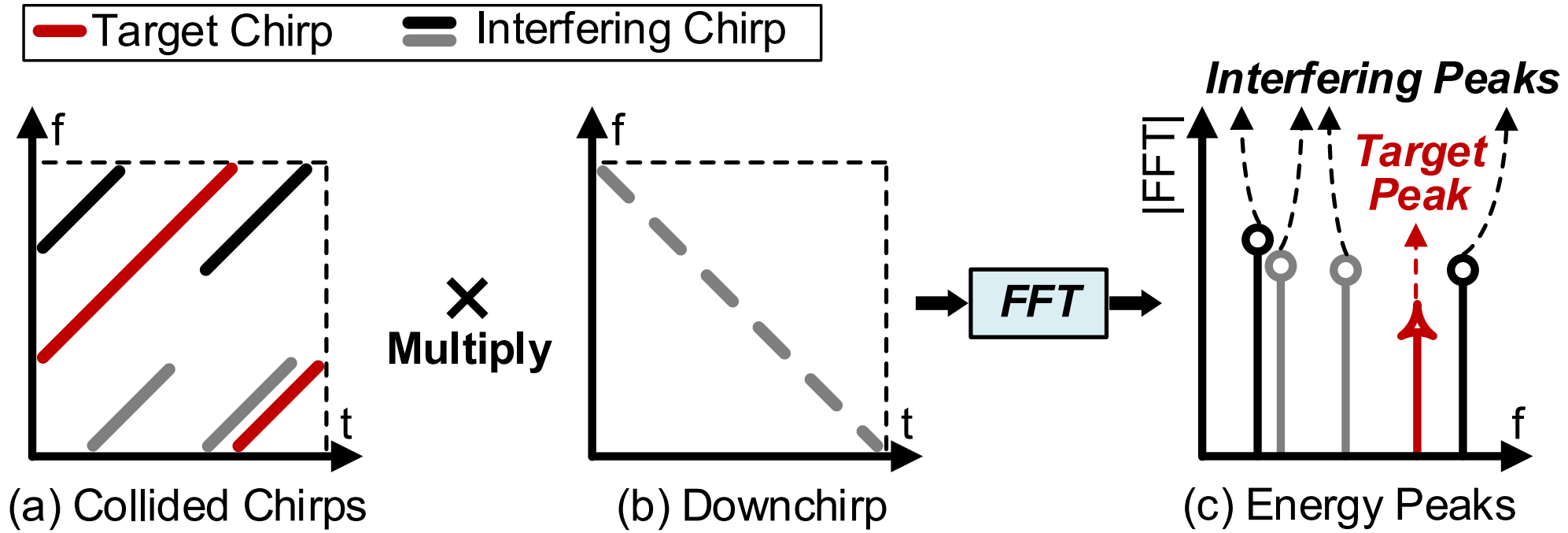
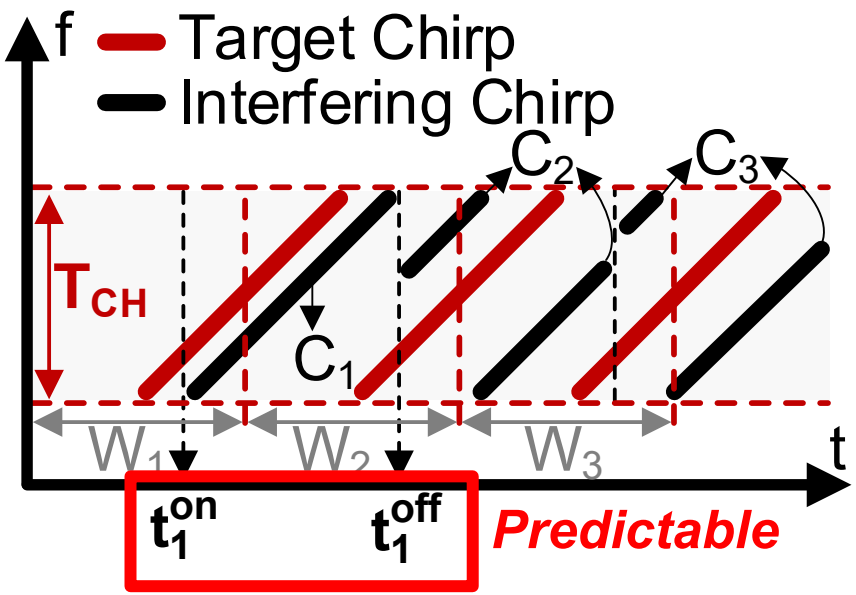


Goal: achieve reliable LoRa transmission under OCI

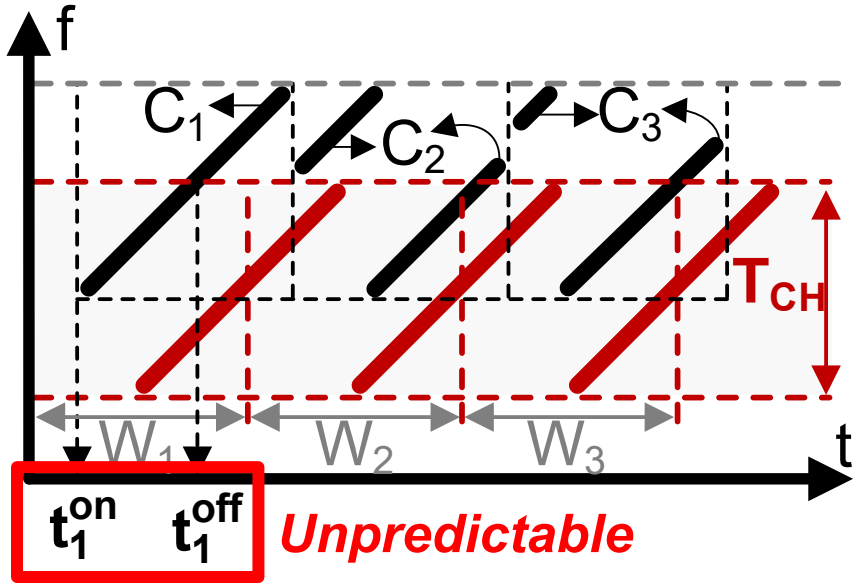
Weakness of existing methods

Category	Key Idea	Failure Cause
Concurrency Demodulation	Leveraging the arrival time of chirps to decouple	Unpredictable onset and offset times for incomplete chirp
Collision Avoidance	Schedule nodes to use single channel in different time	Cannot assign channels for different networks

Intra-channel interference

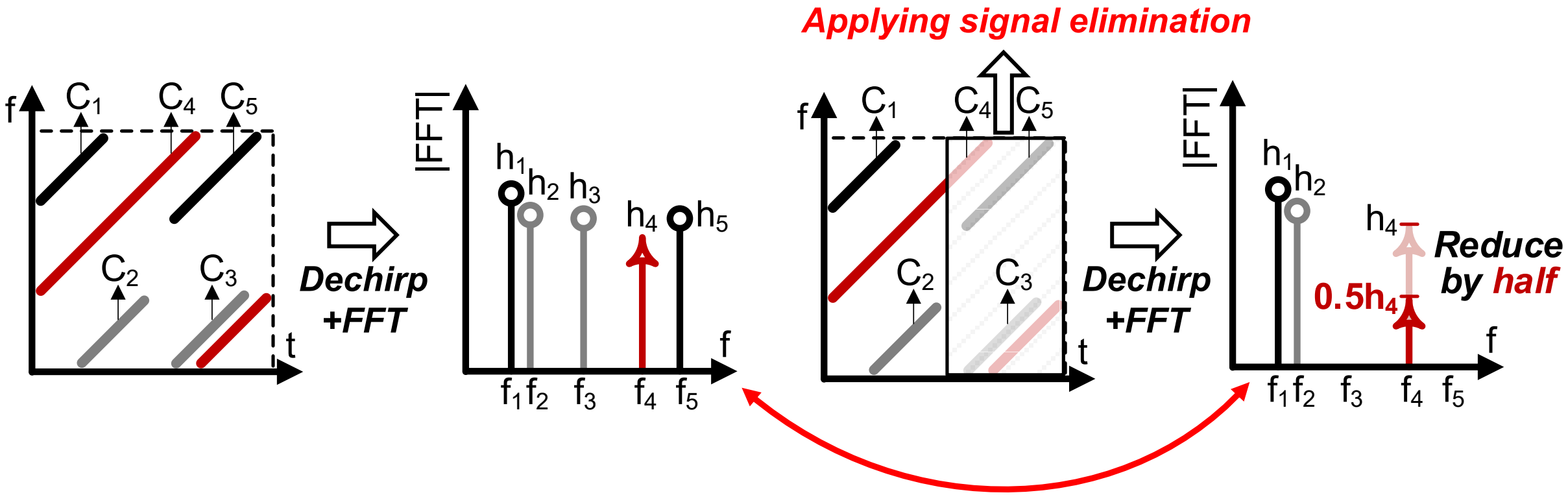


Overlapping channel interference



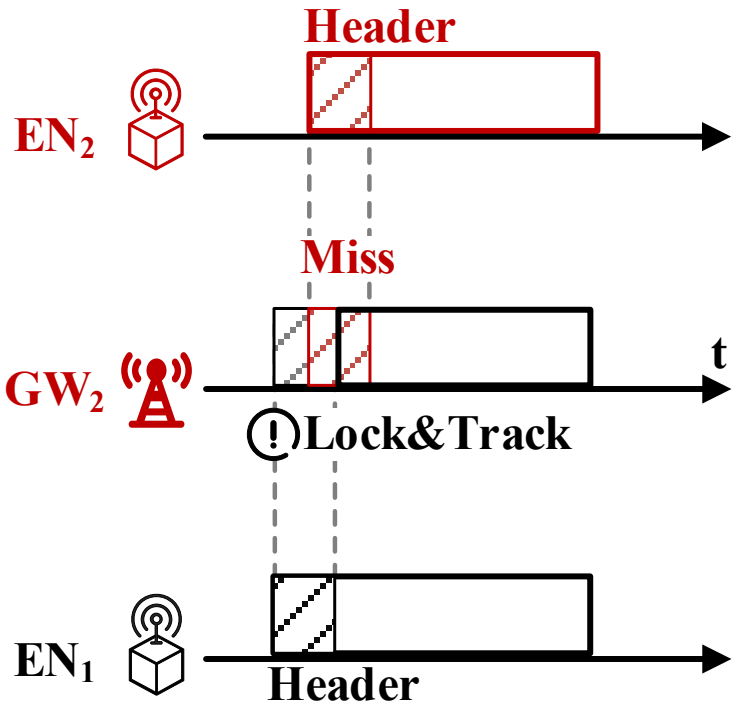
Insight: different onset and offset times

Target chirp always have stable time-domain distribution but interfering chirps in partially overlapping channel are not.

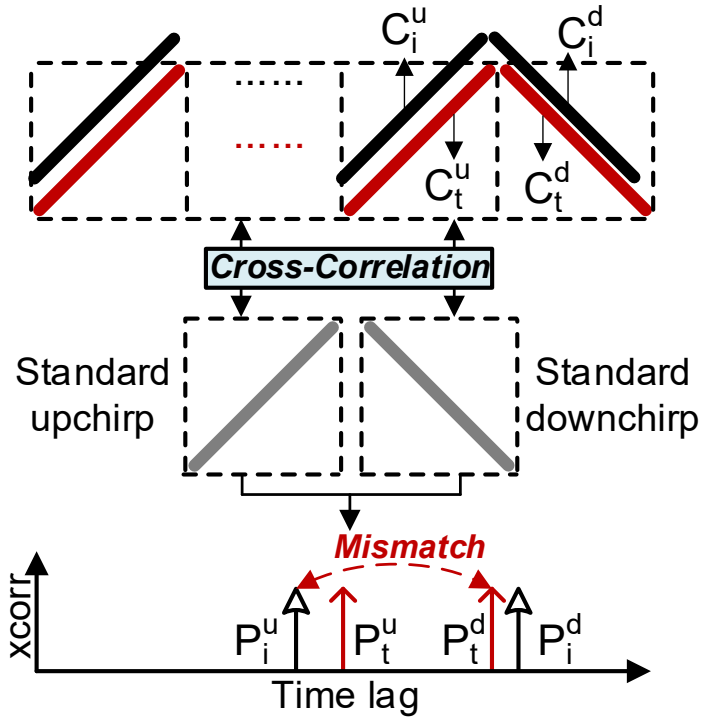


Challenge 1: how to capture target packet?

Packets in same BW confuse the detection of target packet

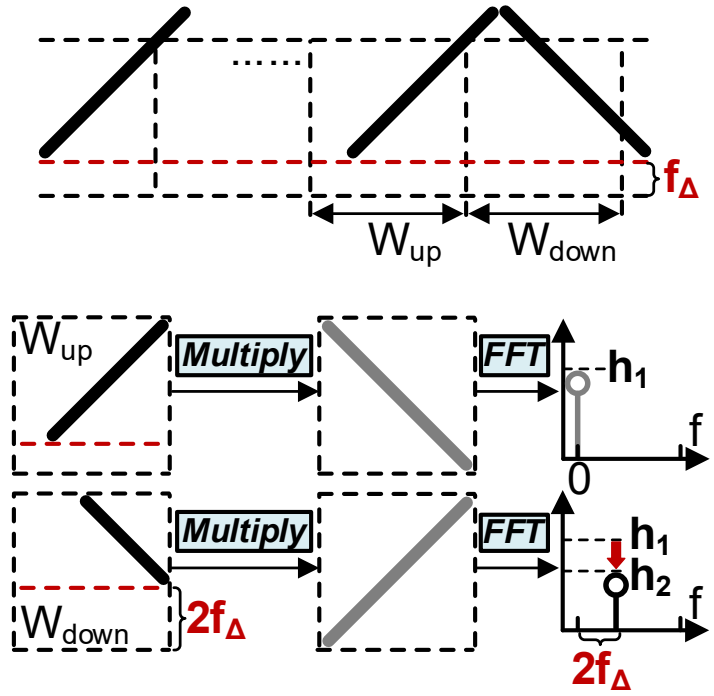


Correlation based method



Cannot match upchirp and downchirp for one packet

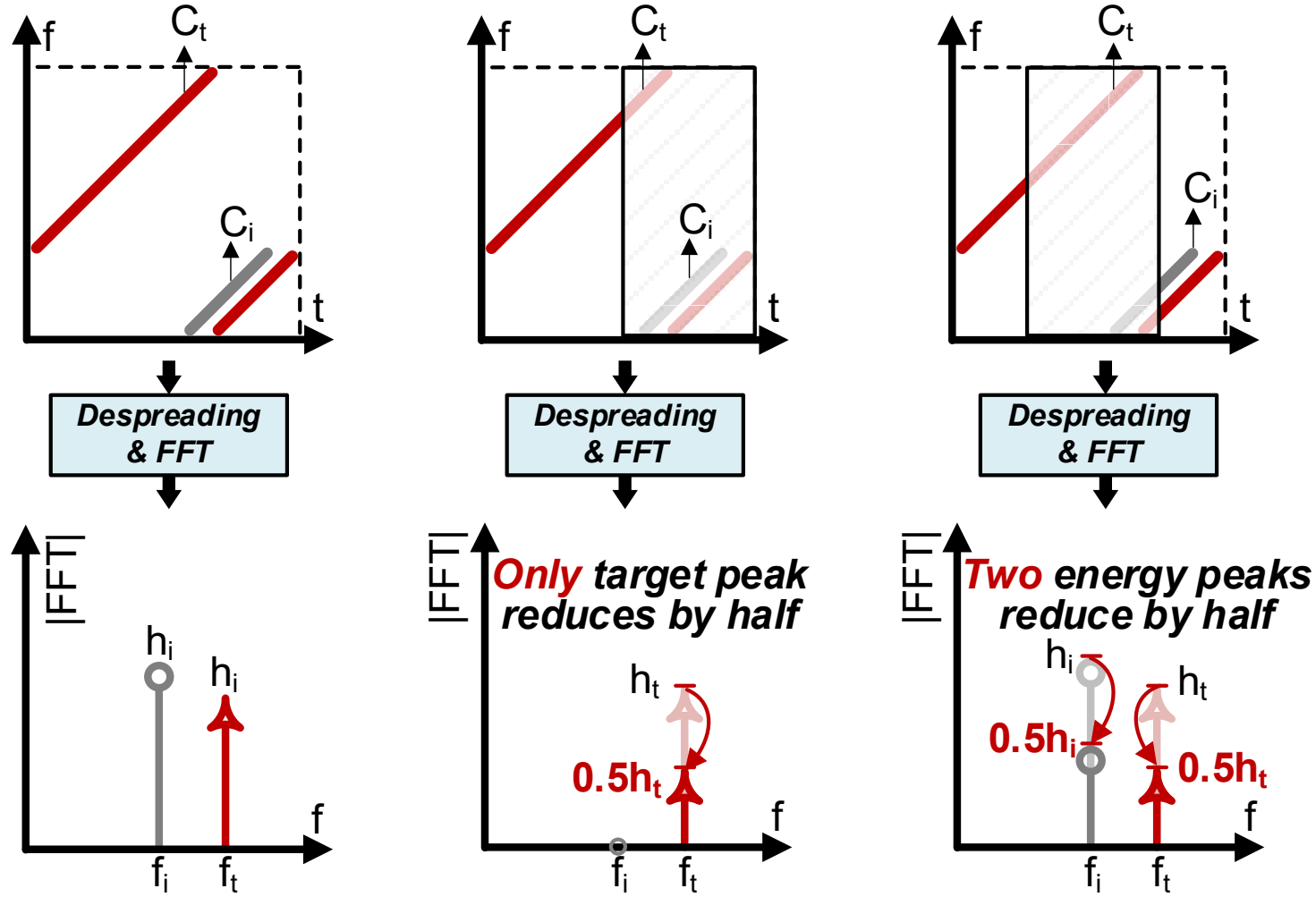
Frequency shift based method (Our solution)

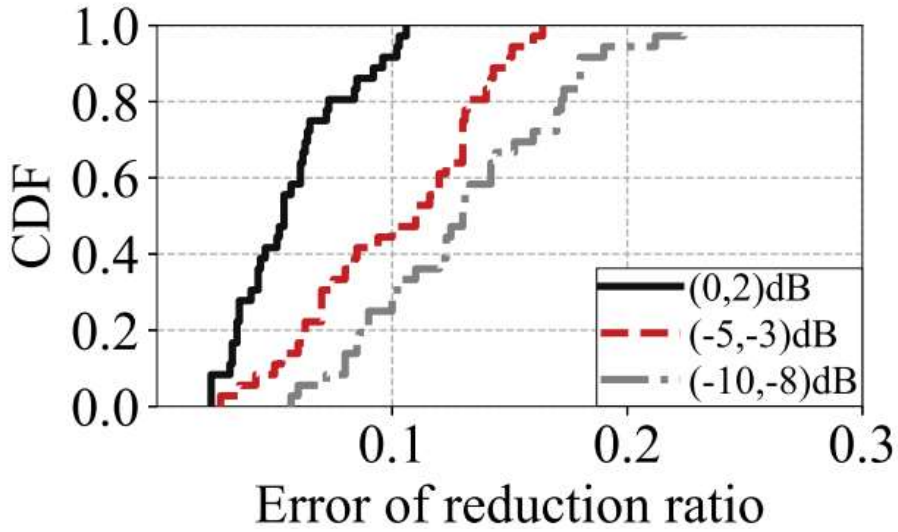


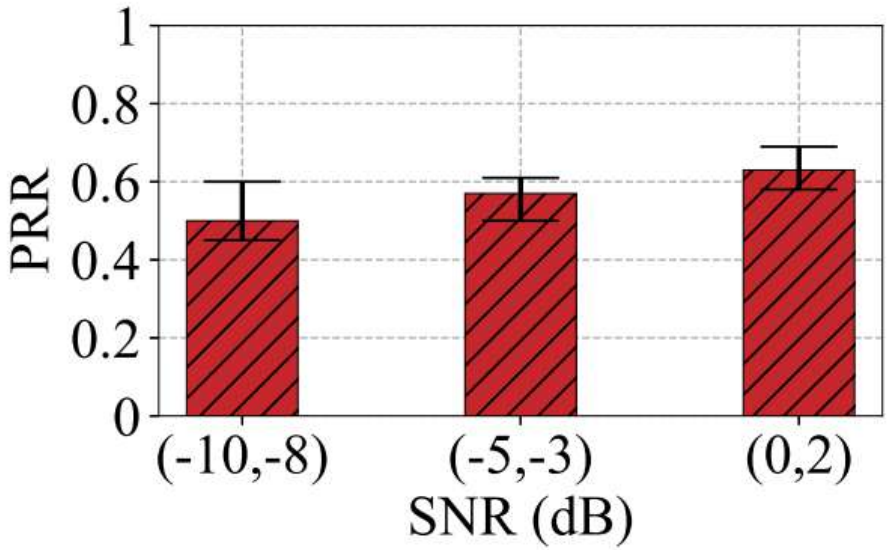
Construct frequency shift to match upchirp and downchirp

Challenge 2: which elimination is valid?

Invalid signal elimination cause demodulation failure under noise

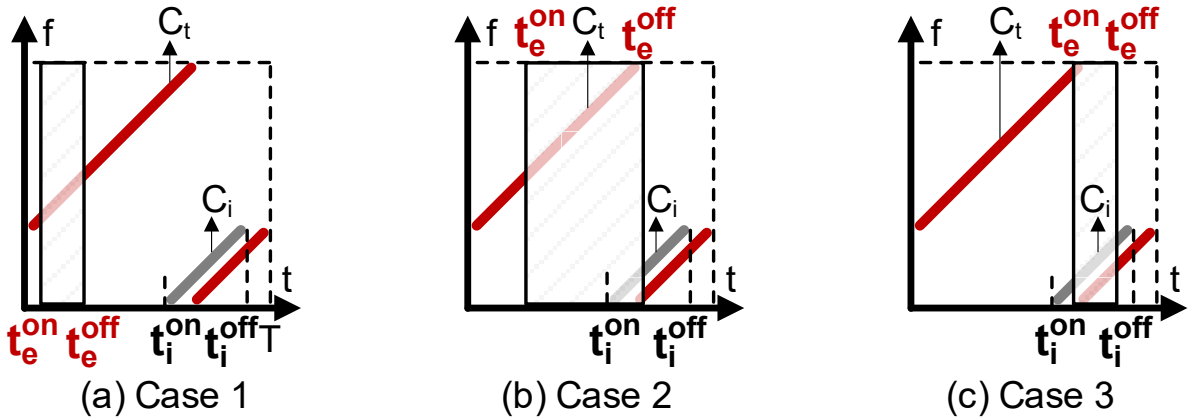






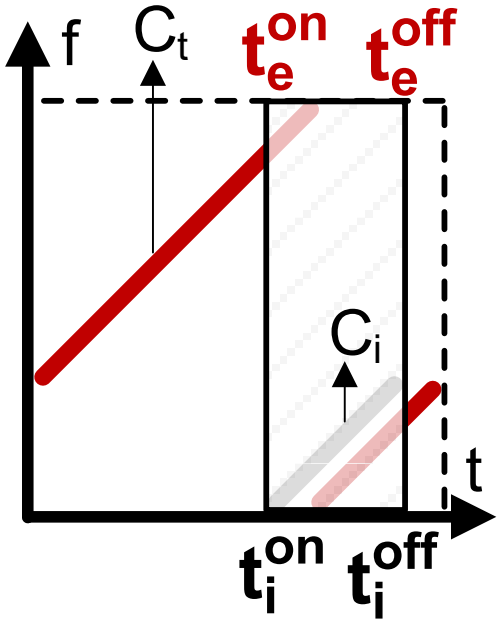
Challenge 2: which elimination is valid?

Solution: signal elimination modeling



(a) Case 1 (b) Case 2 (c) Case 3

(d) Case 4 (e) Case 5



$t_e^{on}=t_i^{on}$

$t_e^{off}=t_i^{off}$

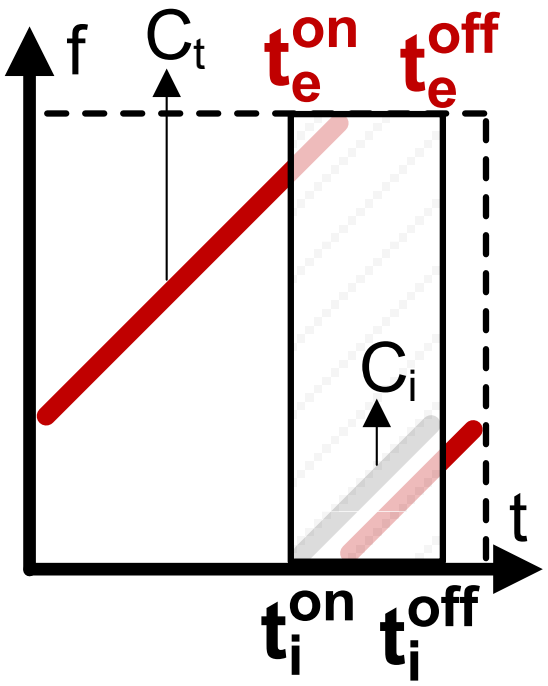
Optimal: Signal elimination completely overlaps with the interfering chirp

t_e^{on}&t_e^{off}:onset and offset time of elimination

t_i^{on}&t_i^{off}:onset and offset time of interfering chirp

Challenge 3: how to efficiently achieve valid elimination?

The optimal elimination position cannot be directly obtained



The onset and offset time of interfering chirp is unknown.

Noise estimation

Measures the SNR of target packet by using 8 upchirps in preamble.

Step size setting

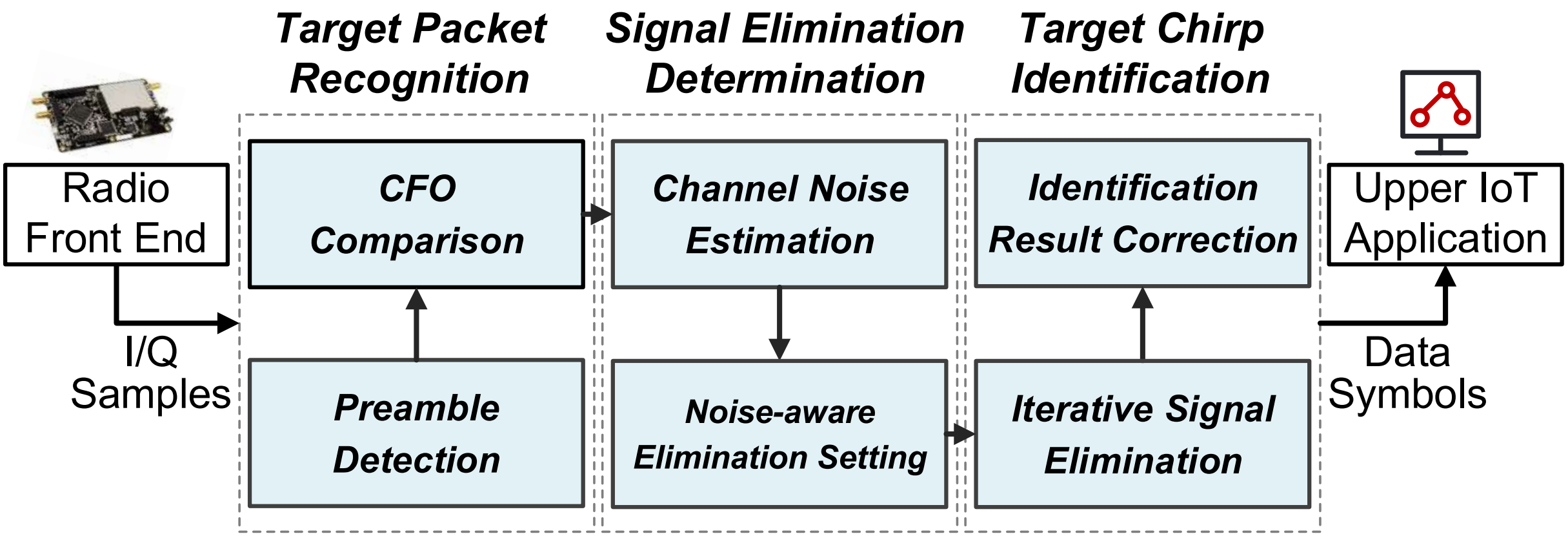
Select suitable step size and interval according to the channel noise.

Candidate position searching

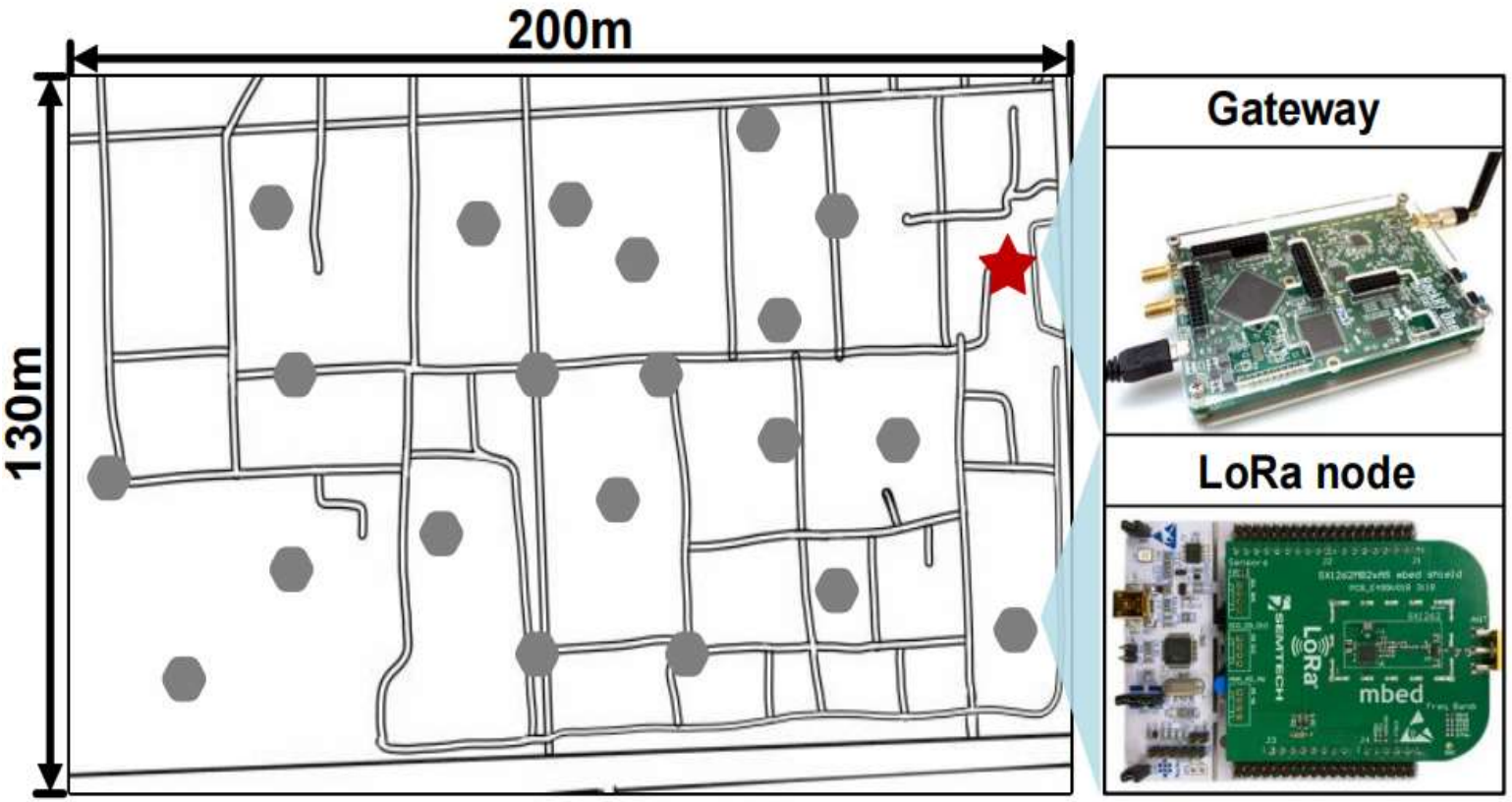
Search the positions used in multiple rounds of elimination.

Our solution: use multiple rounds of elimination to approximate optimal elimination

Overview of Hole



Evaluation: experimental setup

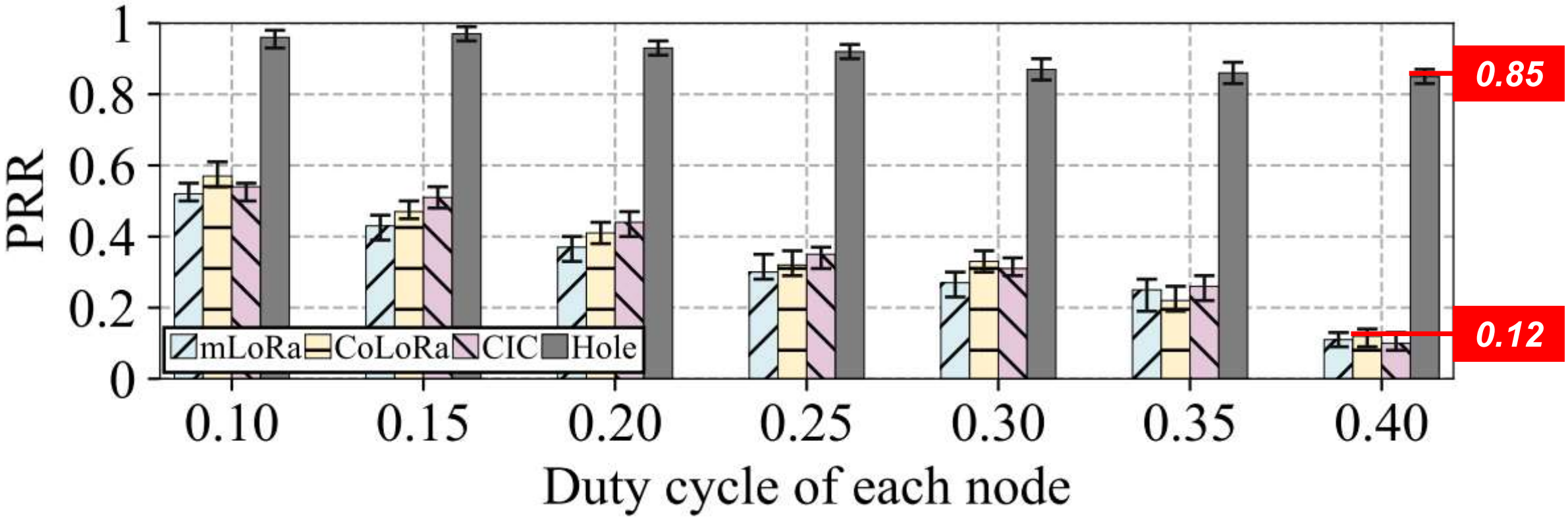


SDR based gateway:
- Hardware: USRP B210+PC
- Software: GnuRadio.

Commercial LoRa node:
- MCU: STM32L073RZ
- Transceiver: SX1262.

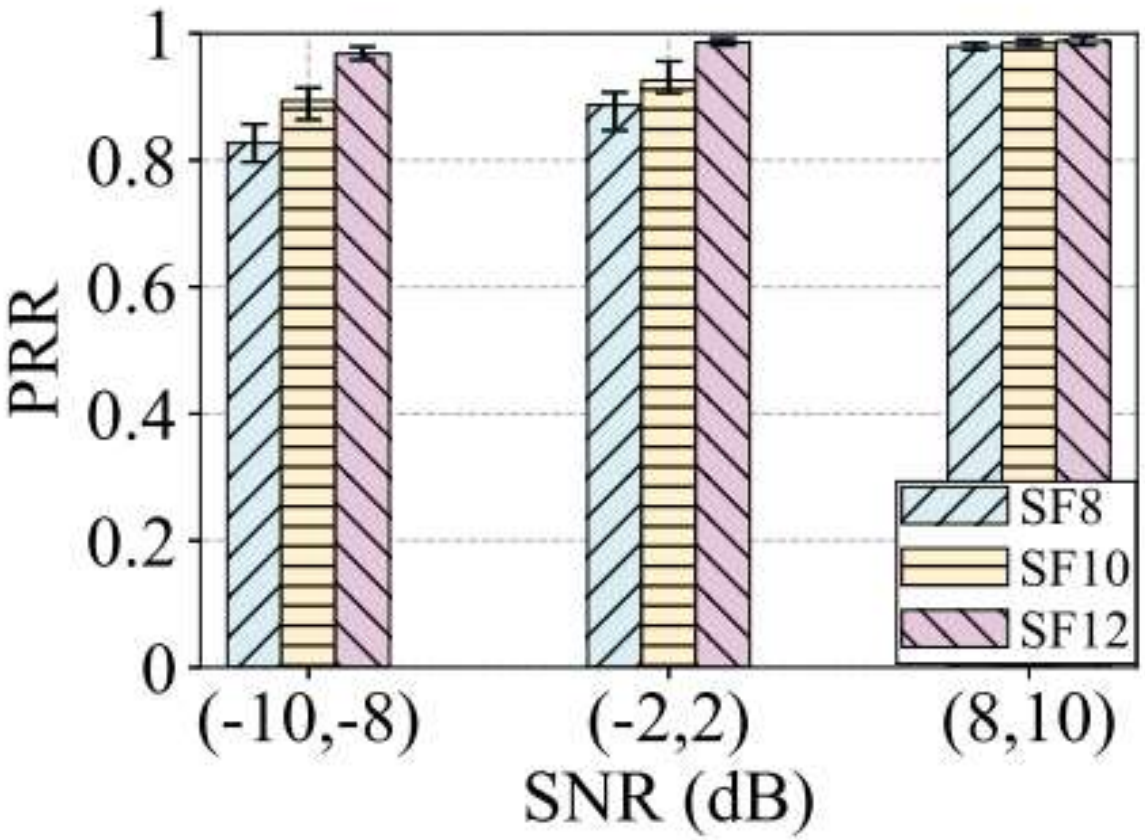
Baselines for comparison:
- CoLoRa (INFOCOM 2020)
- CIC (SIGCOMM 2022)
- MLoRa (ICNP 2019)

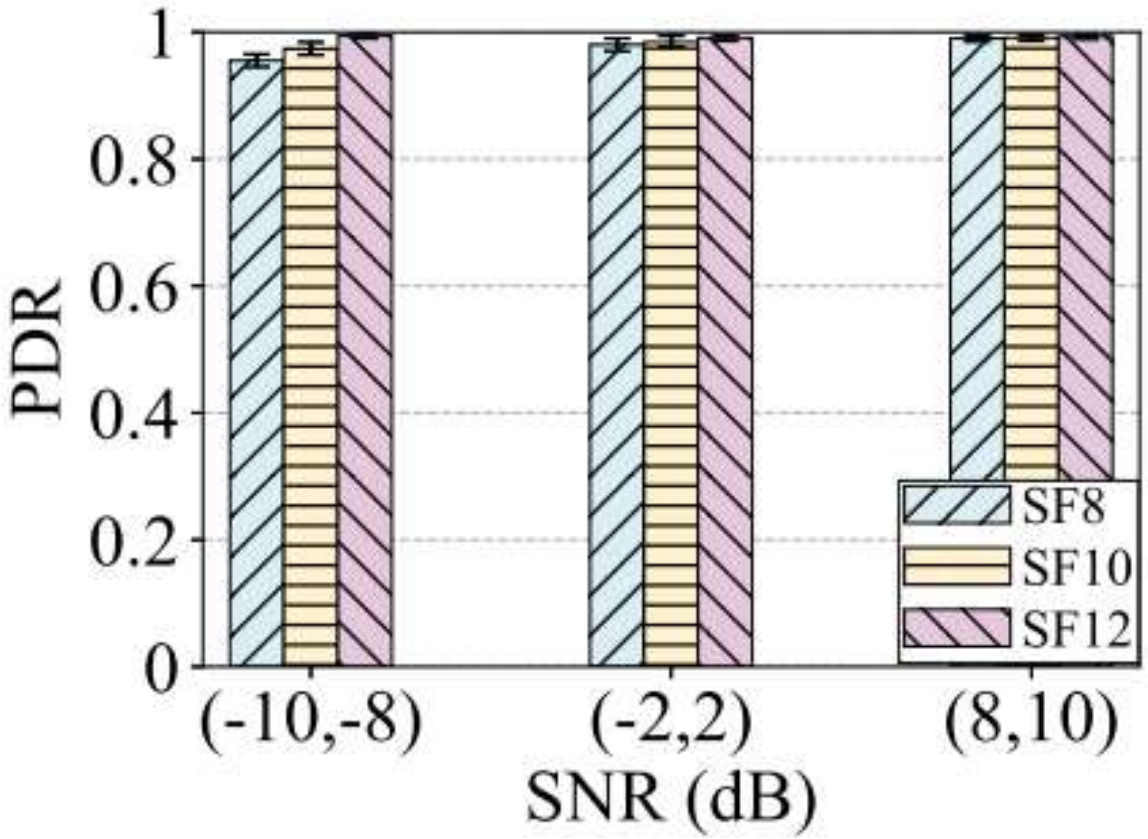
Evaluation: different duty cycle



Hole can significantly improve the transmission reliability.

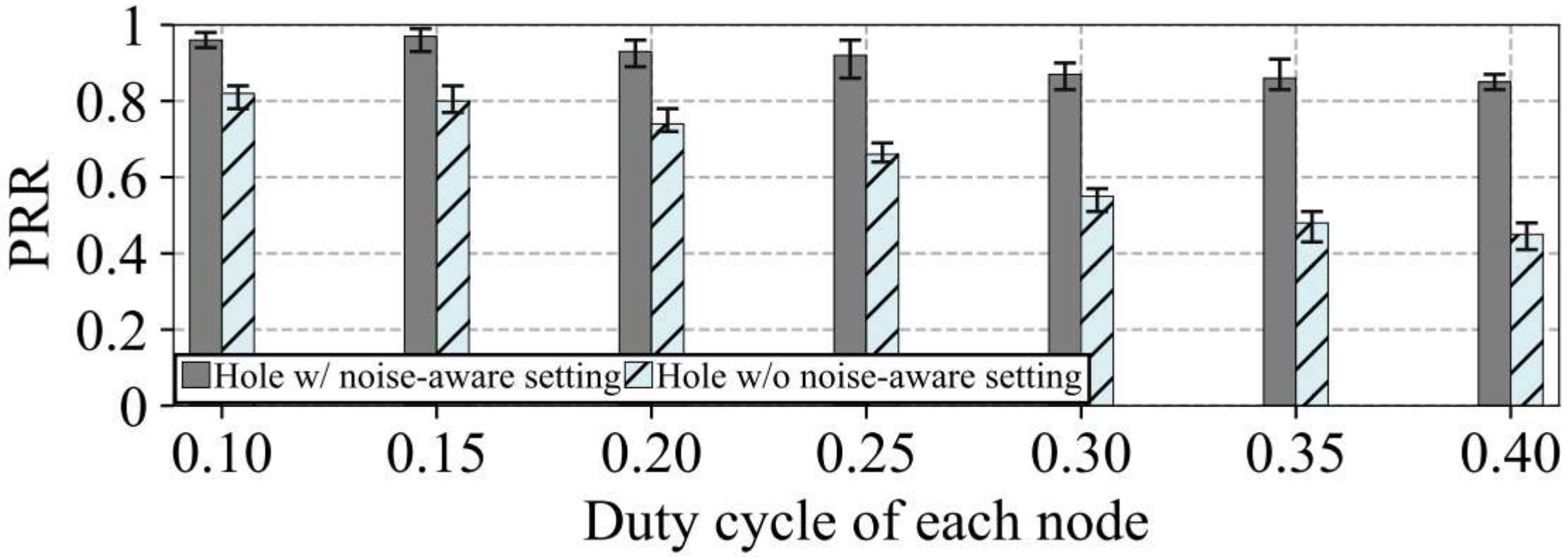
Evaluation: different SNR





Hole can achieve stable performance under different SNR.

Evaluation: ablation study



The noise-aware elimination searching is efficient.

Conclusion

The contribution of this paper is summarized as follow:

- **We reveal overlapping channel interference (OCI) in LoRa.**

- **We propose Hole, which constructs the feature for decoding by the novel operation named signal elimination that can extract the differences in chirps' time-domain distributions.**

- **Compared to state-of-the-art methods, Hole improves PRR by up to 7.5× under the impact of OCI.**

Thanks for listening!
Q&A

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