PRONTO: Preamble Overhead Reduction with Neural Networks for Coarse Synchronization

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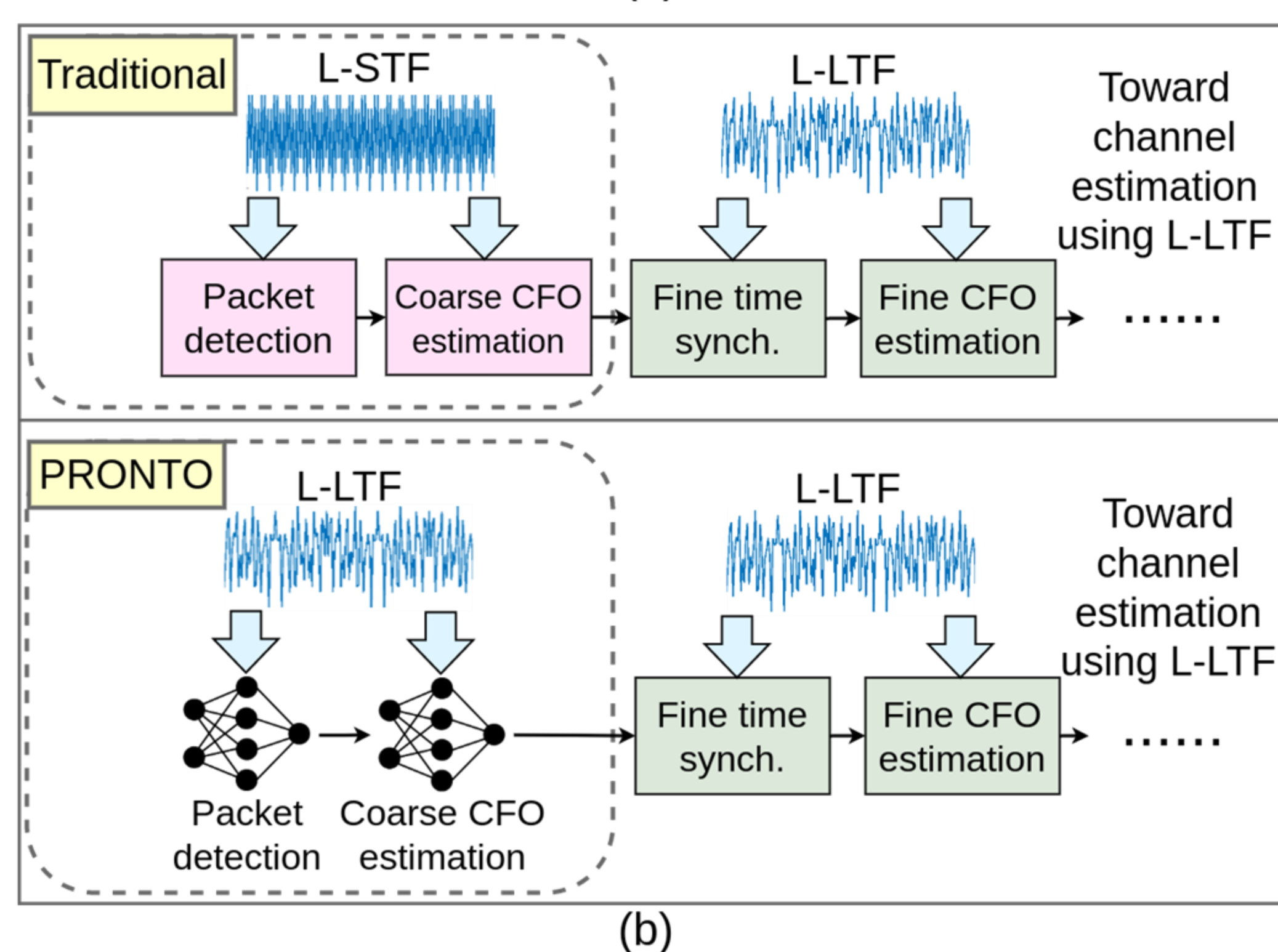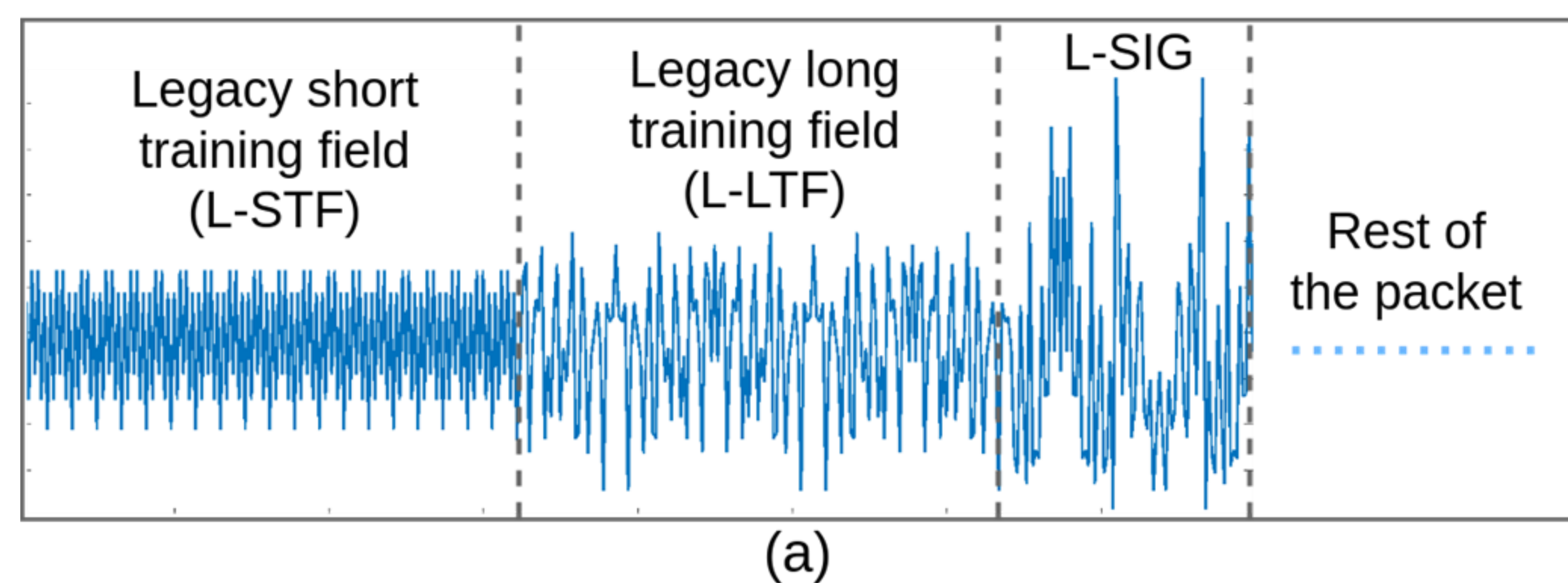
ID23 WIoT Industry Day

Overview

Legacy WiFi preamble has 3 fields:
- L-STF
- L-LTF
- L-SIG

(a)

(b)

L-STF is used for coarse time and frequency synchronization in the traditional receiver, however, in the PRONTO-aided receiver **L-LTF** is used for coarse synchronization, and **L-STF can be removed**.

Motivation

L-STF occupies upto 40% of the preamble in different WiFi versions. Removing it contributes to **increased communication throughput**.

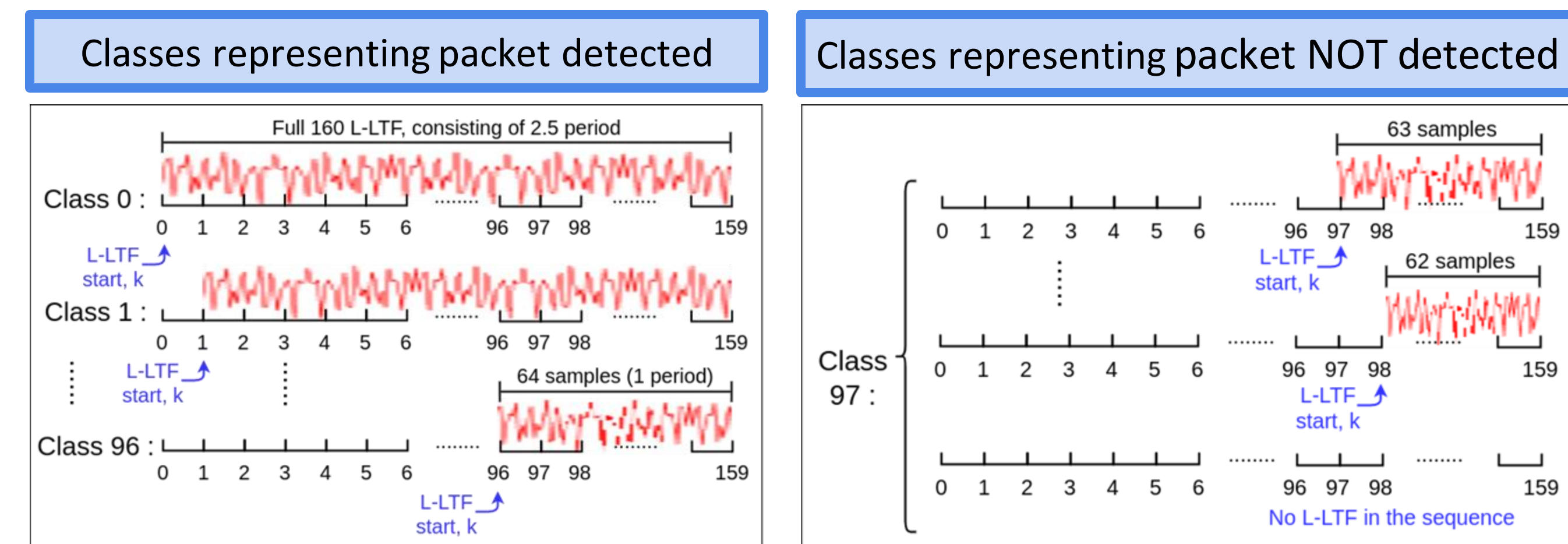| Non-HT format | 40% | L-STF | L-LTF | L-SIG | | | | | | | |
HT format	~16%	L-STF	L-LTF	L-SIG	HT-SIG	HT-STF	HT-LTF	...	HT-LTF	HT-LTF	HT-LTF
VHT format	~15%	L-STF	L-LTF	L-SIG	VHT-SIG-A	VHT-STF	VHT-LTF	VHT-SIG-B			
HE SU format	~18%	L-STF	L-LTF	L-SIG	RL-SIG	HE-SIG-A	HE-STF	HE-LTF	...	HE-LTF		
HE ex ra. SU format	~15%	L-STF	L-LTF	L-SIG	RL-SIG	HE-SIG-A	HE-STF	HE-LTF	HE-LTF			
HE TB format	~16%	L-STF	L-LTF	L-SIG	RL-SIG	HE-SIG-A	HE-STF	HE-LTF	HE-LTF			
HE MU format	~15%	L-STF	L-LTF	L-SIG	RL-SIG	HE-SIG-A	HE-SIG-B	HE-STF	HE-LTF	...	HE-LTF	

Proposed Method

Reduce Preamble Length
We propose to remove L-STF and do **Packet Detection** and **Coarse CFO Estimation** using L-LTF with CNNs.
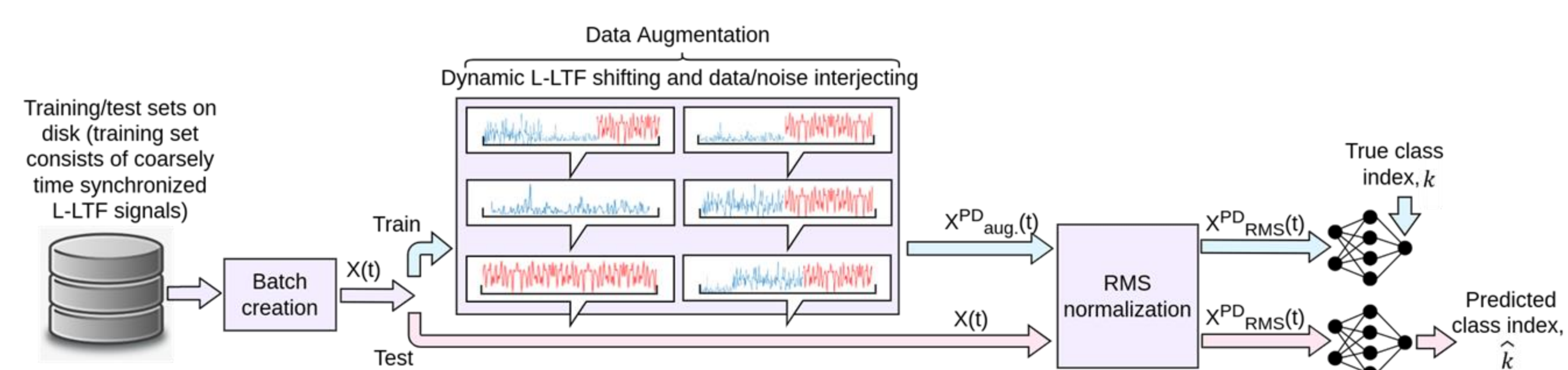
Packet Detection
Formulated as a classification problem.
Classes are packet start index.

Classes representing packet detected

Classes representing packet NOT detected

Full 160 L-LTF, consisting of 2.5 period

Class 0 : 0 1 2 3 4 5 6 ... 96 97 98 159 L-LTF start, k
Class 1 : 0 1 2 3 4 5 6 ... 96 97 98 159 L-LTF start, k 64 samples (1 period)
Class 96 : 0 1 2 3 4 5 6 ... 96 97 98 159 L-LTF start, k

63 samples
62 samples
Class 97 : 0 1 2 3 4 5 6 ... 96 97 98 159 L-LTF start, k
0 1 2 3 4 5 6 ... 96 97 98 159 No L-LTF in the sequence

Classes where one period of L-LTF is in the frame, therefore the packet is detected.

The Class where less than one period of L-LTF is in the frame, therefore the packet is NOT detected.

Data Augmentation
Dynamic L-LTF shifting and data/noise interjecting
Training/test sets on disk (training set consists of coarsely time synchronized L-LTF signals)
Batch creation — Train — $X^{PD}_{aug.}(t)$ — RMS normalization — $X^{PD}_{RMS}(t)$ — True class index, k — Predicted class index, $\hat{k}$
$X(t)$ — Test

Training PRONTO packet detection CNN with data augmentation block, to expose the CNN to different varieties of packet placement.

Coarse CFO Estimation
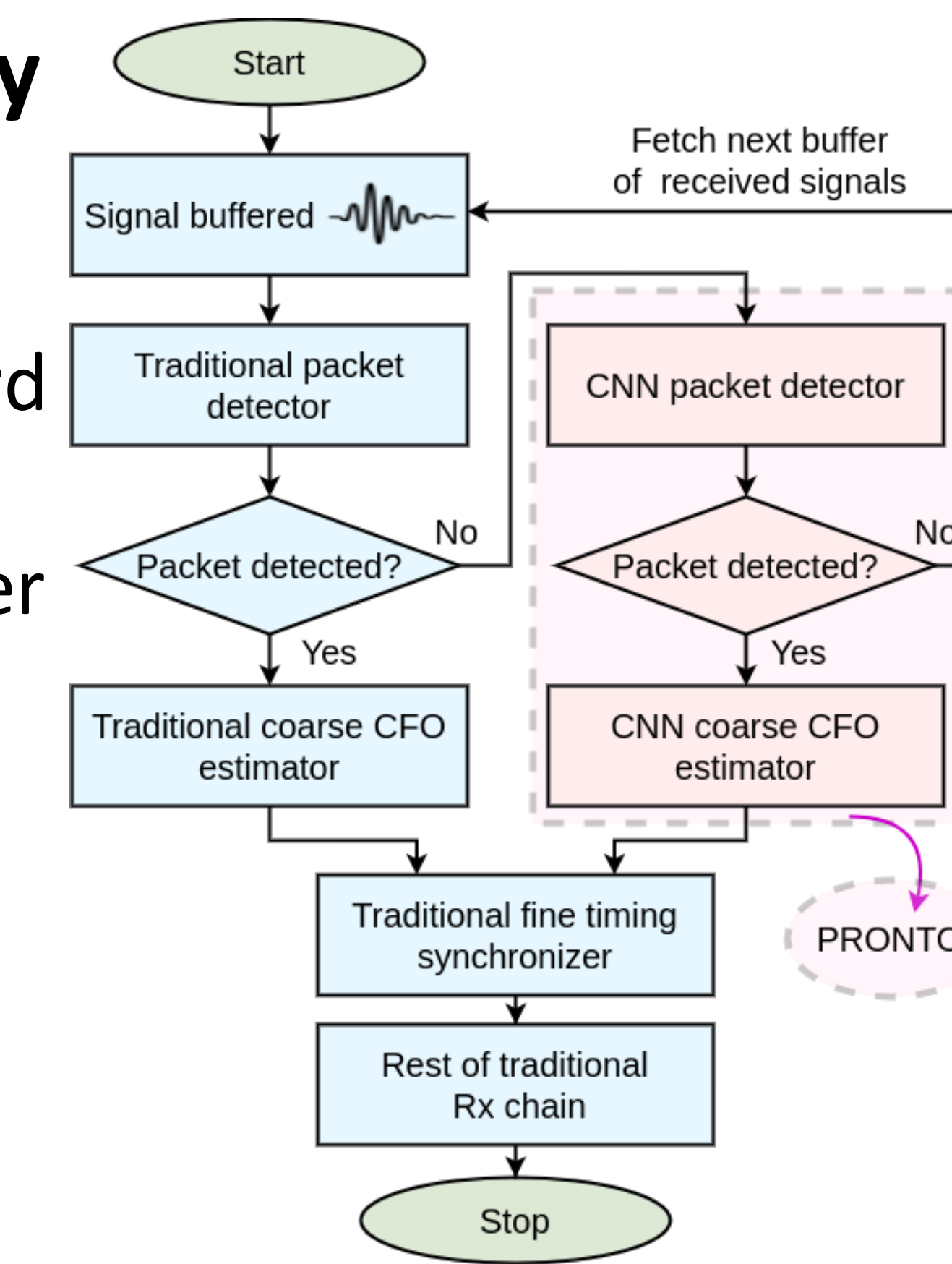Formulated as a regression problem.

CFO augmentation
random $f_{off.}$ from uniform $(-\Delta f/2, \Delta f/2)$
Training/test sets on disk (Coarsely time synchronized L-LTF signals)
$X(t)$ — Batch creation and RMS normalization — $X^{CFO}_{RMS}(t)$ — Train — $e^{-j2\pi ft}$ — $X_{compen.}(t)$ — $e^{j2\pi f_{off.}t}$ — $X^{CFO}_{aug.}(t)$ — True CFO value ($f_{off.} / (\Delta f/2)$) — Predicted CFO
Compensate CFO — Dynamic CFO imposing
Test
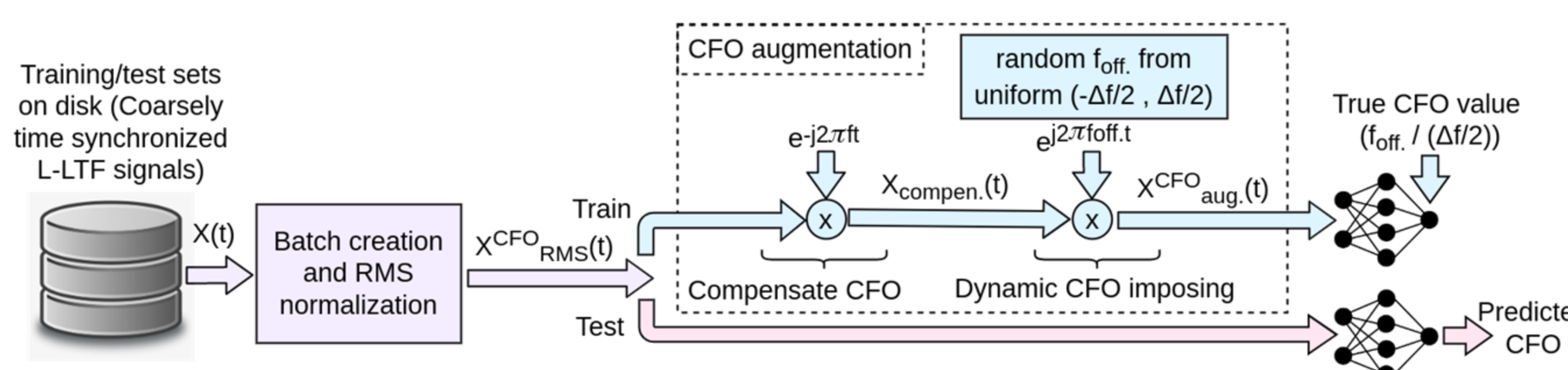
Training PRONTO coarse CFO estimation CNN with CFO augmentation block, to expose the CNN to a wide range of CFOs.

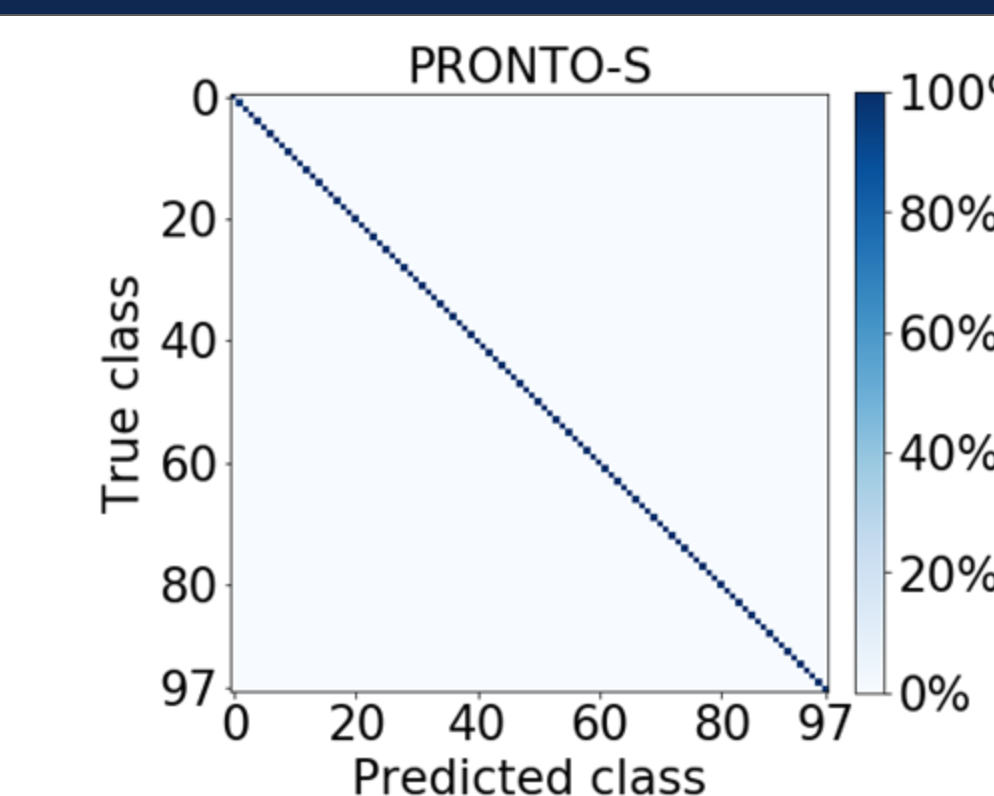## System Integration

Backward Compatibility

We propose a scheme to receive and decode standard WiFi waveform (with L-STF) using the traditional receiver chain, as well as shortened preamble WiFi waveforms (without L-STF) using PRONTO-aided receiver chain.

Start
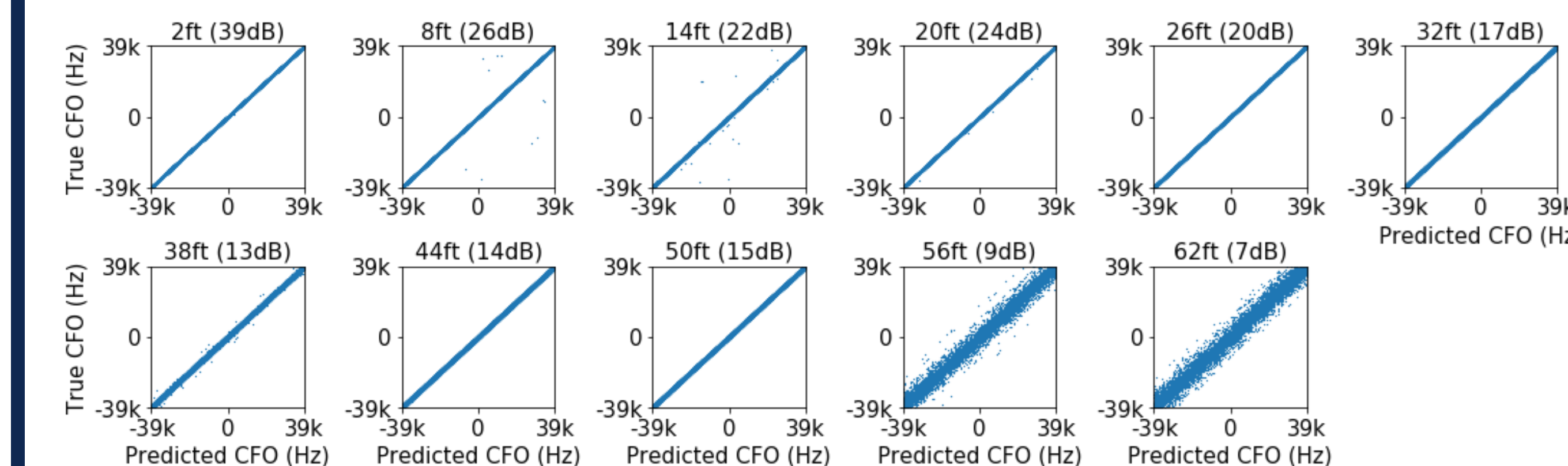Signal buffered
Fetch next buffer of received signals
Traditional packet detector
CNN packet detector
Packet detected? No
Packet detected? No
Yes
Yes
Traditional coarse CFO estimator
CNN coarse CFO estimator
PRONTO
Traditional fine timing synchronizer
Rest of traditional Rx chain
Stop

Evaluations

Packet Detection
PRONTO packet detection CNN performs same as the traditional packet detector and gives **100% detection accuracy**.

PRONTO-S

Coarse CFO Estimation
PRONTO coarse CFO estimation CNN gives **errors as small as 3%**.

2ft (39dB) 8ft (26dB) 14ft (22dB) 20ft (24dB) 26ft (20dB) 32ft (17dB)
38ft (13dB) 44ft (14dB) 50ft (15dB) 56ft (9dB) 62ft (7dB)

PRONTO is robust to indoor environment change, and generalizes without performance drop.

Test on Oracle
Test on Arena

Nasim Soltani, Debashri Roy, and Kaushik Chowdhury, "PRONTO: Preamble Overhead Reduction with Neural Networks for Coarse Synchronization," in IEEE Transactions on Wireless Communications. 2023 Mar 20.