Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [**Performance of CFO compensation for FSK and LR-OFDM**]
Date Submitted: 18 Sept 2025

Source: Hiroshi Harada, Jaeseok Lim, and Goro Kawabuchi (Kyoto University)
Address Yoshidahonmachi. Sakyo, Kyoto, 606-8501, Japan
Voice: +81-75-753-5317 , E-Mail: hiroshi.harada@i.kyoto-u.ac.jp

Re: [Wireless Next Generation, Long Range extension enhancements to 802.15.4-2020]

Abstract: We have submitted technical proposals to 802.15.4ad regarding FSK and LR-OFDM. Regarding these proposals, we will discuss the possibility of compensating for carrier frequency offset (CFO) of approximately 20 ppm. A part of this contribution supported from the commissioned research (No. JPJ012368C05101) by National Institute of Information and Communications Technology (NICT) , Japan is included.

Purpose:

Performance of CFO compensation for FSK and LR-OFDM

September 18 , 2025

Kyoto University

Hiroshi Harada, Lim Jaeseok, Goro Kawabuchi

Summary

- We have submitted technical proposals to 802.15.4ad regarding FSK and LR-OFDM.
- Regarding these proposals, we will discuss the possibility of compensating for carrier frequency offset (CFO) of approximately 20 ppm.

Performance of CFO compensation for FSK

Sep. 18 , 2025

Hiroshi Harada and Lim Jaeseok

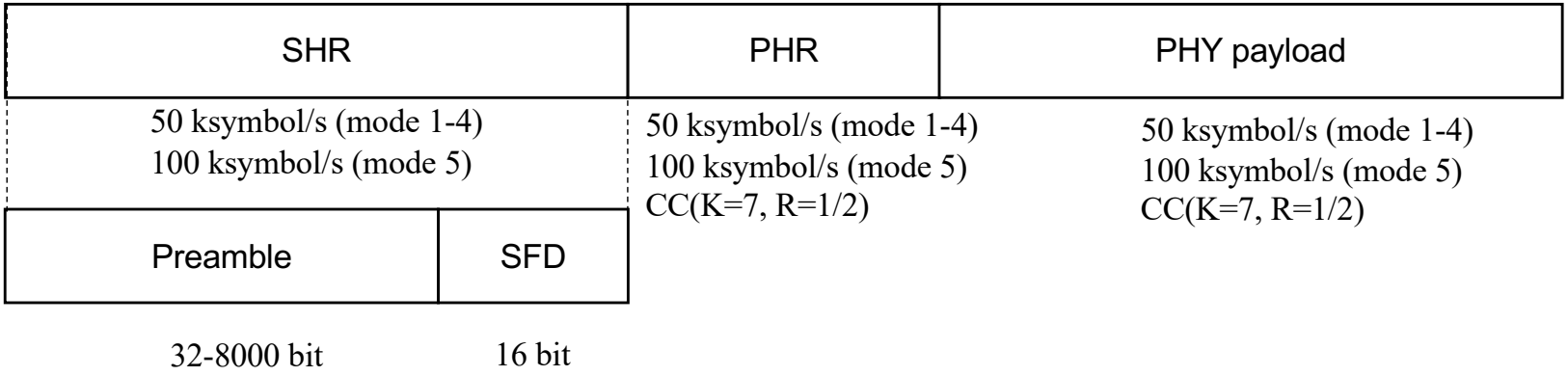
Proposed 802.15.4-2024 SUN-FSK Low Rate (LR) PHY (15-25/0391r0)

Parameter	Option LR1				
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Data rate (kb/s)	6.25	12.5	25	50	100
Modulation	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK
Modulation index	0.5	0.5	0.5	0.5	0.5
Channel spacing (KHz)	200	200	200	200	400
Coding Scheme and rate	Convolutional code (Constraint length: 7) Coding rate1/2				
Spreading factor	8	4	2	1	1

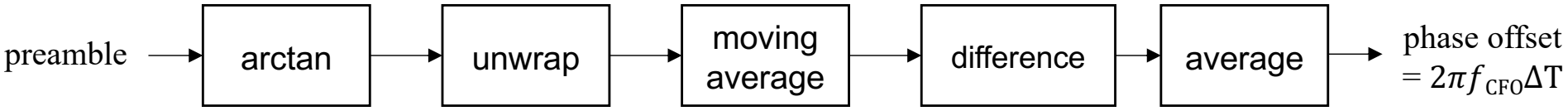
15-25/0035r0

Proposed frame format of SUN-FSK LR (15-25/35r0 and 15-25/391r0)

FSK LR1 (Same as SUN FSK)

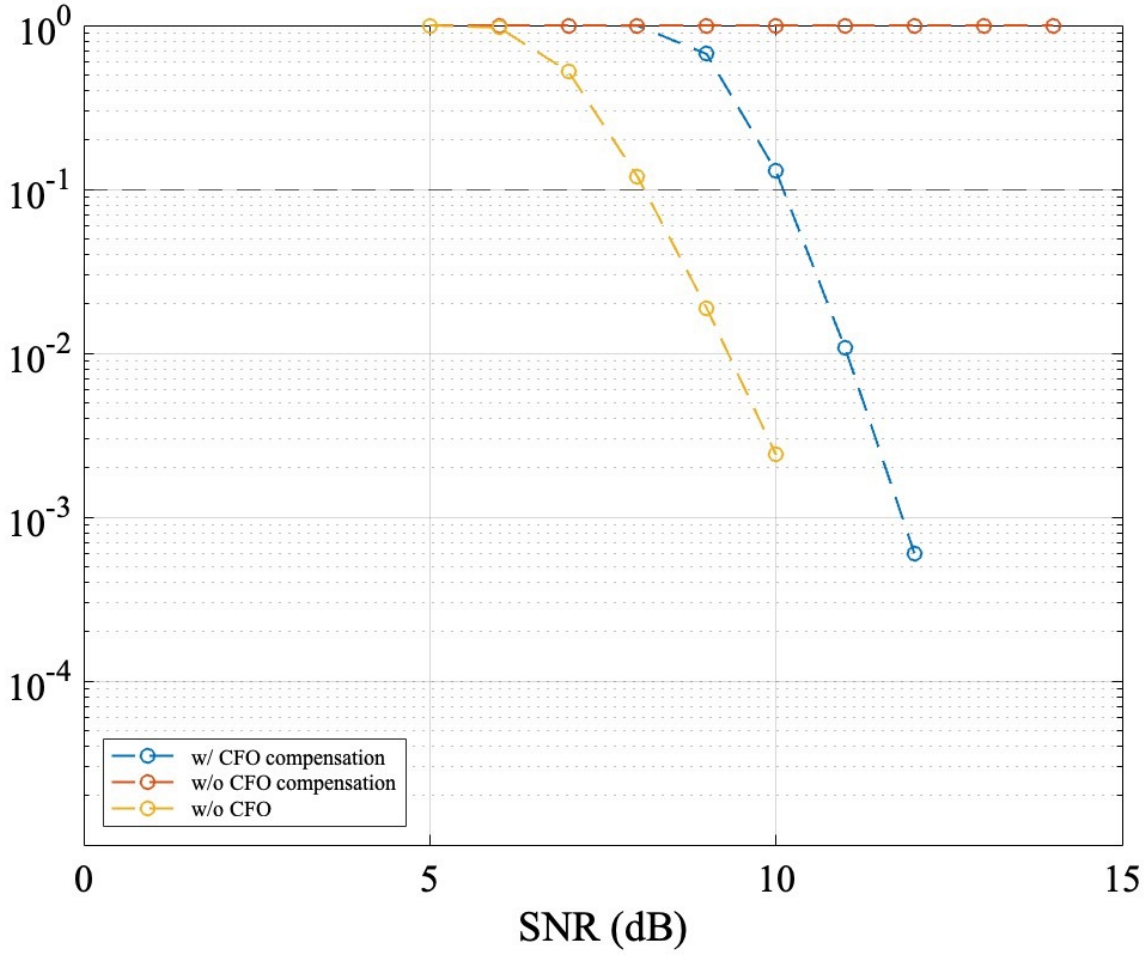


Block diagram of CFO compensation



Performance of CFO compensation (FSK LR1)

- Symbol rate = 50 kHz
- CFO = 18.4 kHz (20 ppm @ 920 MHz)
- AWGN



Performance of CFO compensation for LR-OFDM

September 18 , 2025

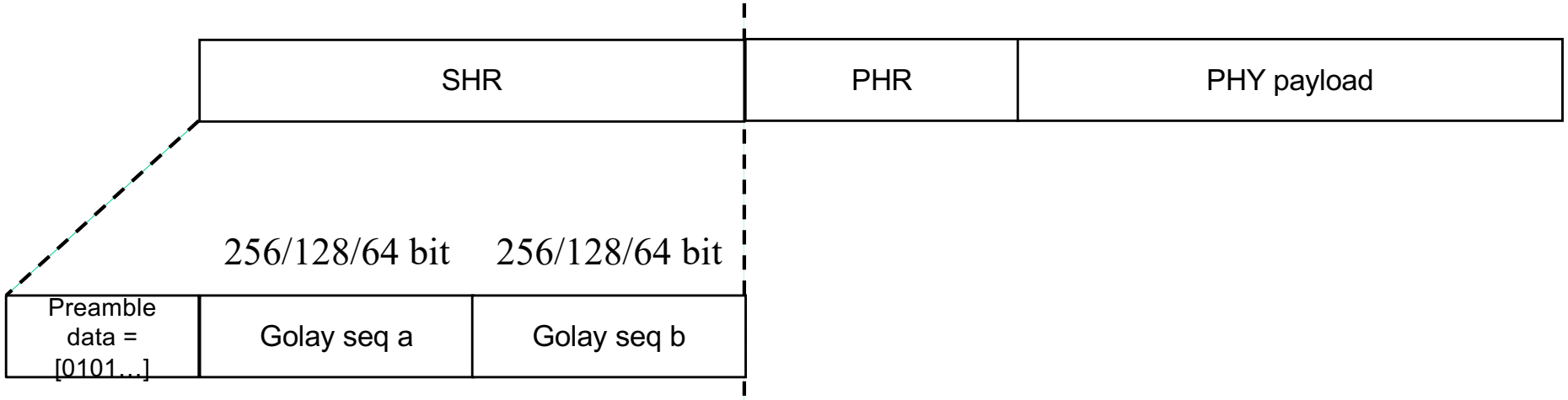
Hiroshi Harada and Goro Kawabuchi

Proposed 802.15.4 SUN-OFDM LR (15-25/0035r0, 15-25/0262r0)

		Option LR1	Option LR2	Option LR3	Option LR4*
Channel spacing		200 kHz			800 kHz
Subcarrier spacing		31.25/3 kHz			
DFT size		16	16	16	64
Number of subcarriers used		14	14	14	52
Num. of data-subcarriers		12	6	1	1
OFDM symbol duration		120 us			
Guard interval		24 us			
Primary modulation scheme		BPSK			
Coding Scheme and rate		Convolutional code (Constraint length: 7) Coding rate1/2			
Spreading factor		8 (MCS 0), 4 (MCS1), 2(MCS 2)			
Data rate for PSDU (kb/s)	MCS 0	6.25		0.260	0.260
	MCS 1		6.25	0.694	0.694
	MCS 2			1.667	1.667
	MCS 3			3.704	3.704

LR4: for FCC 15.247

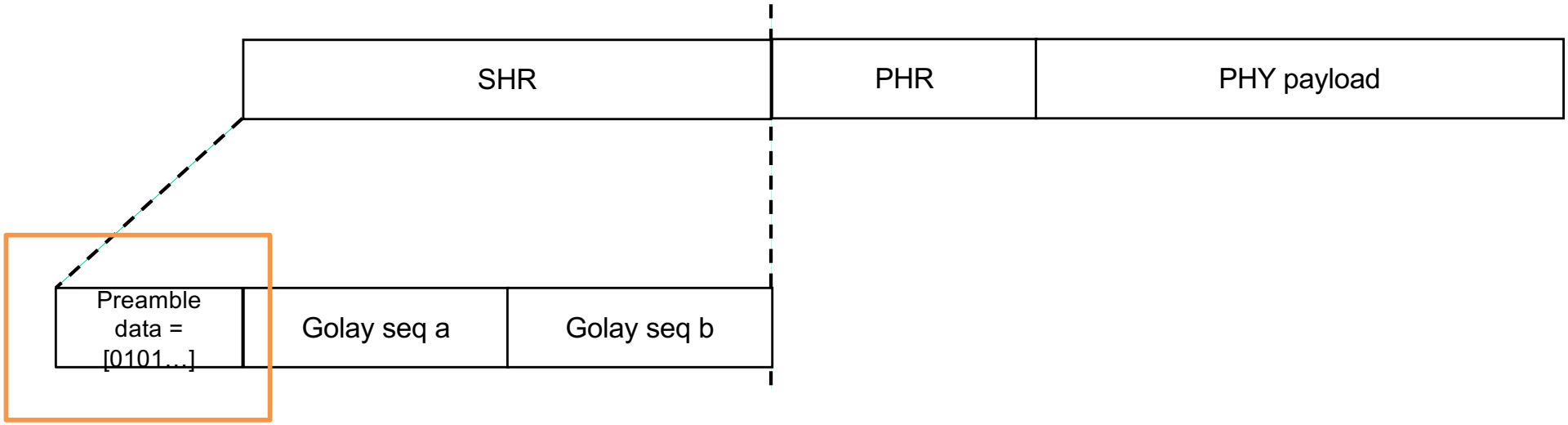
Current proposal of SHR for SUN-OFDM LR 3 (15-25/0348r3)



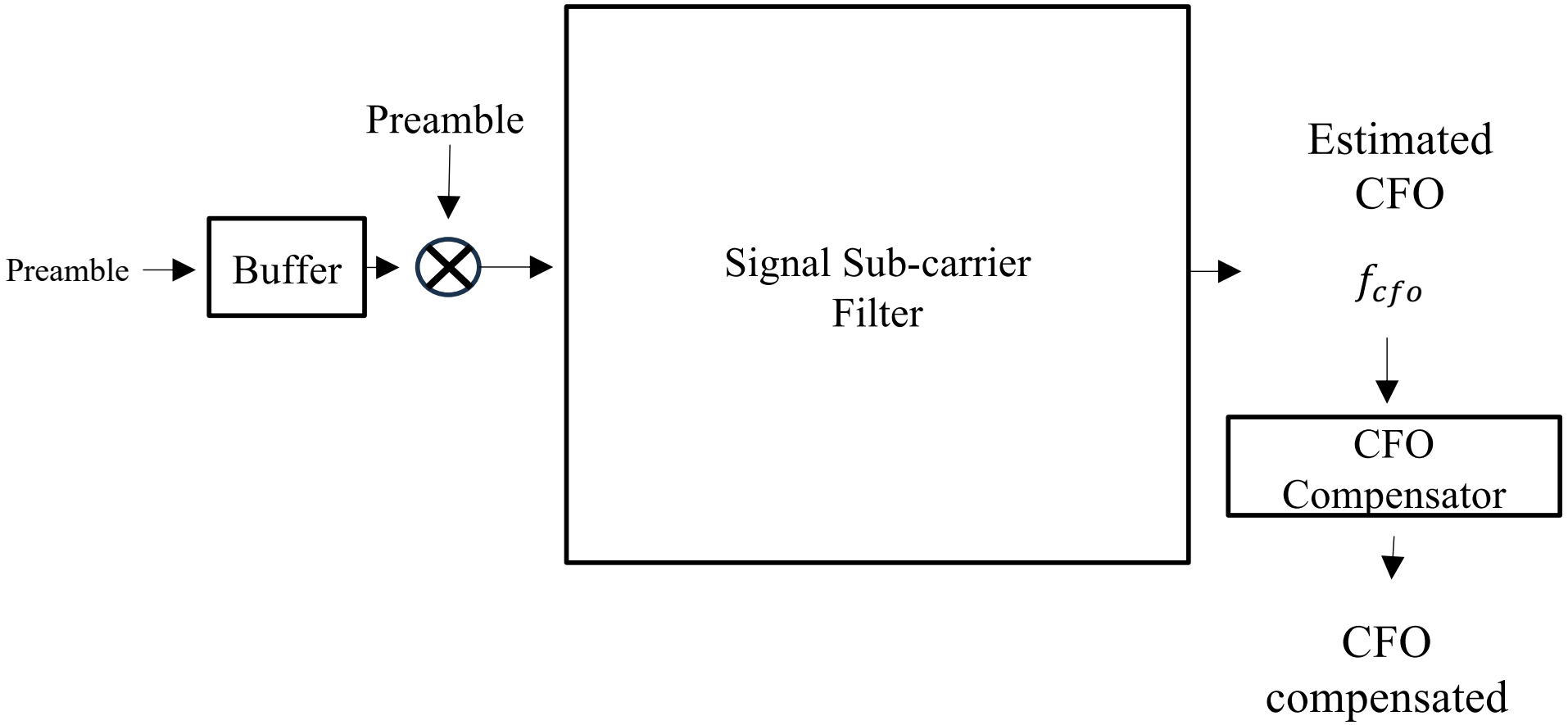
- In this SC-OFDM, SHR consists of two Golay sequences a and b of equal length.
- This is because the PHR and PHY payload parts are transmitted in blocks, and pilot data is stored in each block.
- Good auto correlation function and good cross correlation function with existing 802.15.4g SFD
- The length of Golay code can be changed (64/128/256 bit…)
- The length of preamble data should be discussed from the viewpoint of CFO compemsation

CFO compensation

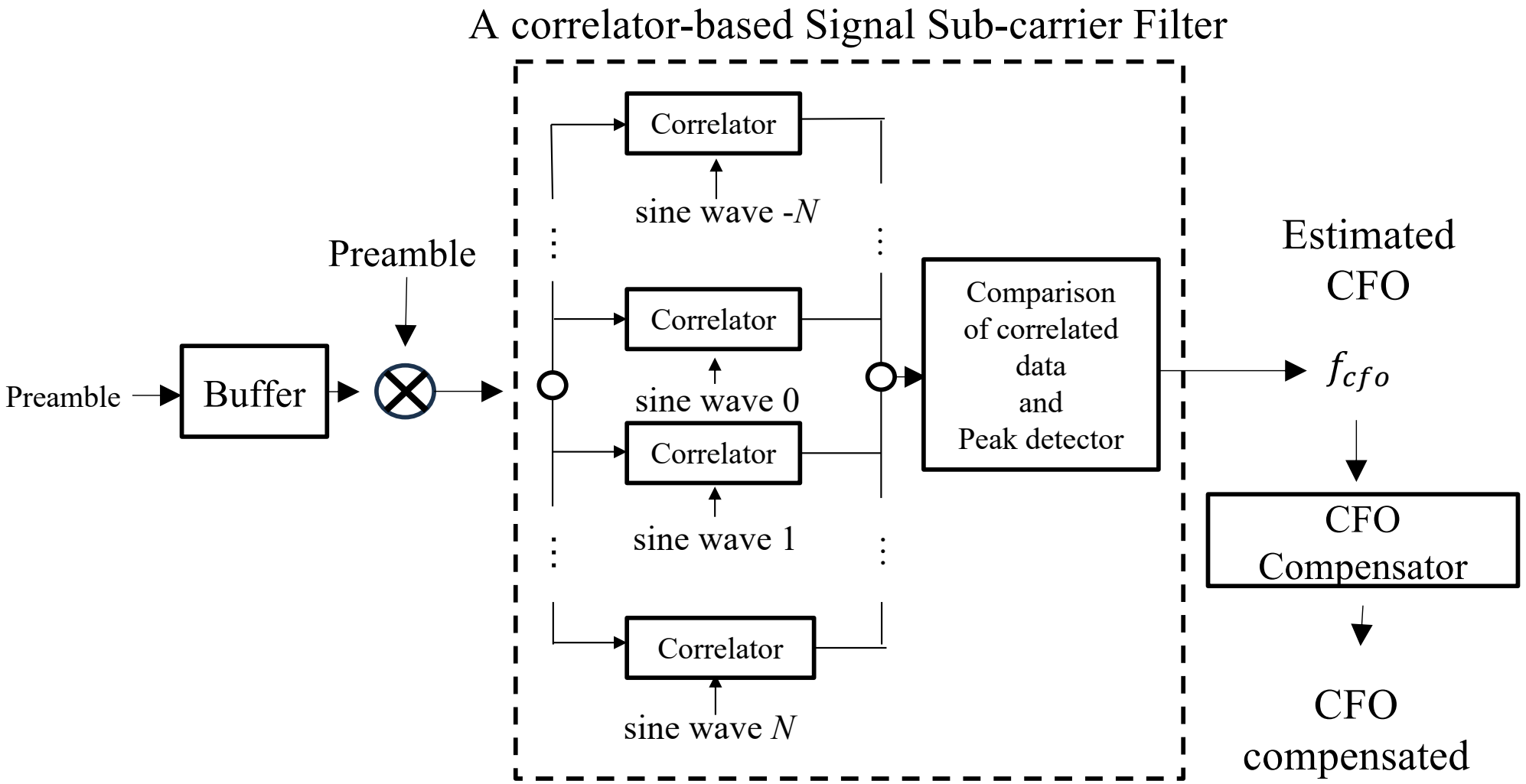
- Use preamble part



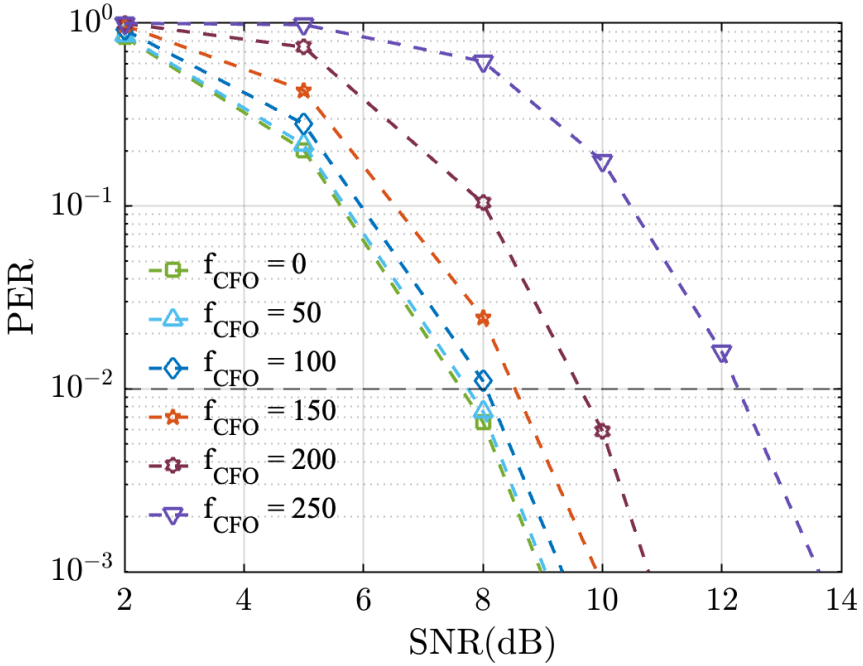
Block diagram of CFO compensation



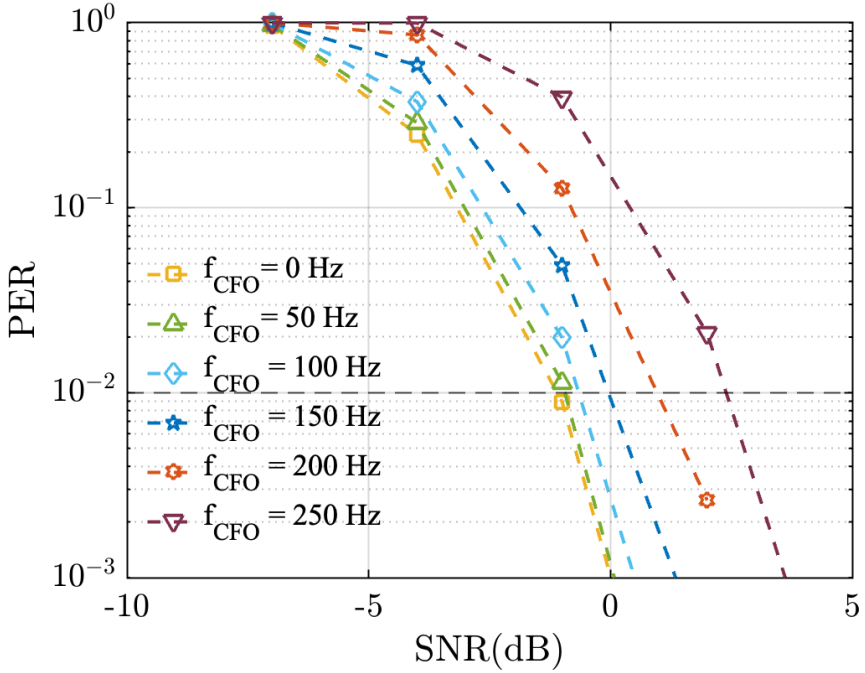
Block diagram of CFO compensation



Impact of CFO for PER



SF=1

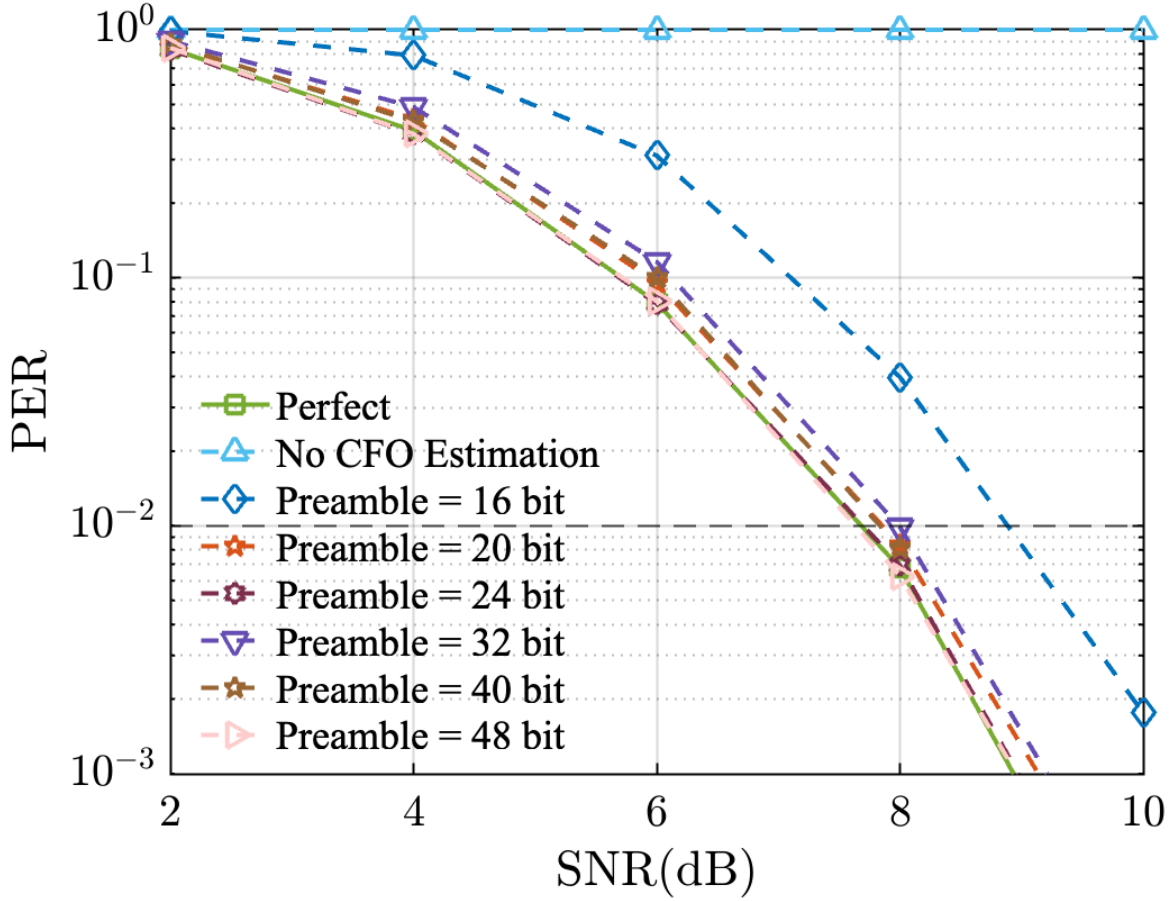


SF=8

Aim to achieve a CFO estimation accuracy of ±200 to 250 Hz.

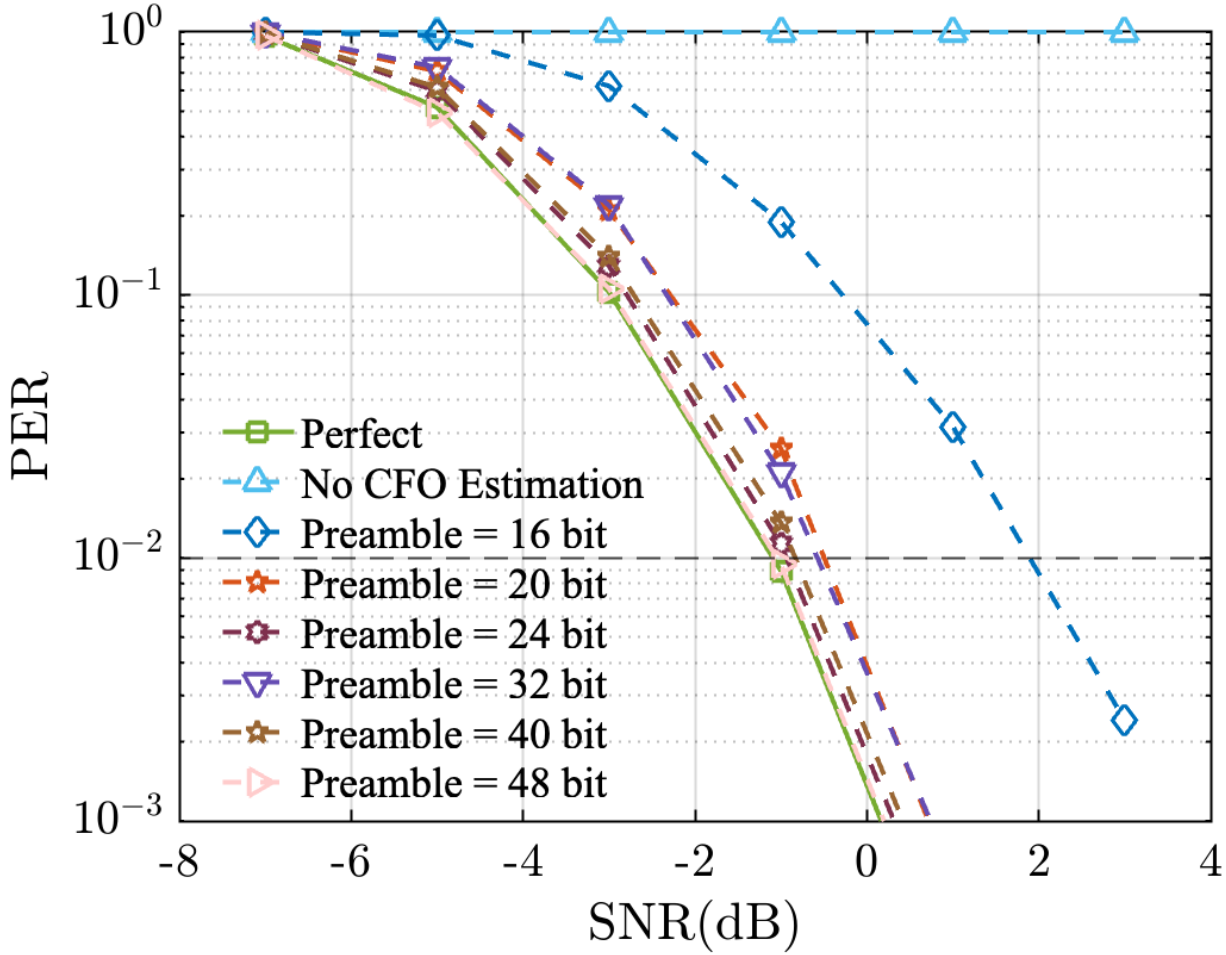
Performance of CFO compensation (Preamble length changed)

- AWGN+CFO (18.4 kHz :20 ppm @ 920 MHz)
- SF = 1
- 2, 2.5, 3, 4, 5, 6 Octet



Performance of CFO compensation (Preamble length changed)

- AWGN+CFO (18.4 kHz :20 ppm @ 920 MHz)
- SF = 8
- 2, 2.5, 3, 4, 5, 6 Octet



Num. of correlators

Preamble Size (Octet)	SF=1		SF=8	
	Required SNR (dB)	Required Received power	Required SNR (dB)	Required Received power(dBm)
2	8.9	-124.9	1.9	-131.9
2.5	7.9	-125.9	-0.5	-134.3
3	7.7	-126.1	-0.9	-134.7
4	8.0	-125.8	-0.6	-134.4
5	7.8	-126	-0.8	-134.6
6	7.6	-126.2	-1.1	-134.9

With 20 bits or more, even 20 ppm provides sufficient reception sensitivity.

SNR and received signal power conversion

- In the case of Noise Figure (NF) =0dB and bandwidth =31.25/3 kHz, noise power should be -133.8 dB
- For SNR, each active tone in the symbol is treated as the signal (S).

SNR(dB)	Received power (dBm)
-10	-143.8 dBm
-5	-138.8 dBm
0	-133.8 dBm
5	-128.8 dBm
10	-123.3 dBm