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

Submission Title: [Proposal of SUN FSK LR for 802.15.4ad]
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Re: [Wireless Next Generation, Long Range extension enhancements to 802.15.4-2020]

Abstract: Propose of 802.15.4 SUN FSK Low Rate (LR)for 802.15.4ad. 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:

Proposal of SUN FSK LR for 802.15.4ad

July 31 , 2025

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802.15.4 SUN FSK LR (Low Rate)

Fundamental design policy

- 802.15.4 SUN FSK is widely used in over tens of millions of devices, mainly smart meters
- The structure of 802.15.4 SUN FSK should not be changed fundamentally
- If the data rate is reduced without changing the structure of 802.15.4 SUN FSK, data spreading is necessary because there is a need for sufficient resistance to urban noise and interference

- Even if the data rate is reduced by data spreading without changing the structure of 802.15.4 SUN FSK, and if the transmission distance does not increase or there is no resistance to interference, there is a need to add a new mode to 802.15.4 SUN
- Even with this new mode, in order to avoid interference with the existing 802.15.4 SUN FSK mode, the modification parts (e.g. SHR) should follow the assets of 802.15.4 SUN FSK as much as possible.

Current 802.15.4-2024 SUN-FSK (Japan)

Parameter	Operating mode #1	Operating mode #2	Operating mode #3	Operating mode #4	Operating mode #5	Operating mode #6	Operating mode #7	Operating mode #8	Operating mode #9	Operating mode #10	Operating mode #11	Operating mode #12
Data rate (kb/s)	50	100	200	400	400	150	300	300	400	600	600	800
Modulation	2-FSK	2-FSK	2-FSK	4-FSK	4-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	4-FSK	4-FSK
Modulation index	1.0	1.0	1.0	0.33	0.33	0.5	0.5	0.5	0.5	0.4	0.5	0.33
Channel spacing (KHz)	200	400	600	600	400	400	400	600	1000	1000	1000	1000

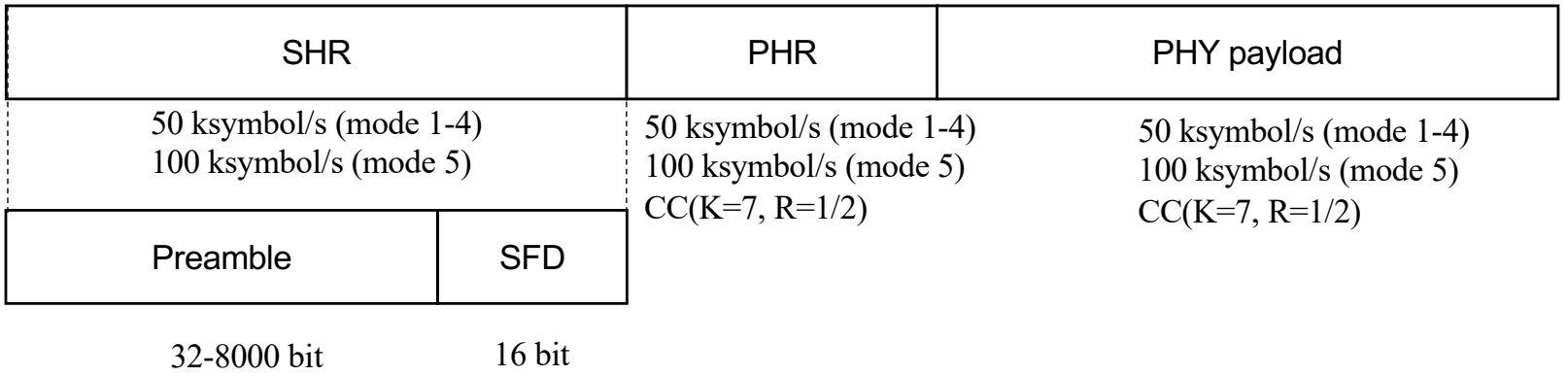
Proposed 802.15.4-2024 SUN-FSK Low Rate (LR) PHY

Parameter	Option LR1					Option LR2			
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 1	Mode #2	Mode #3	Mode #4
Data rate (kb/s)	6.25	12.5	25	50	100	0.521	1.041	2.083	4.166
Modulation	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK
Modulation index	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Channel spacing (KHz)	200	200	200	200	400	200	200	200	200
Coding Scheme and rate	Convolutional code (Constraint length: 7) Coding rate1/2								
Spreading factor	8	4	2	1	1	8	4	2	1

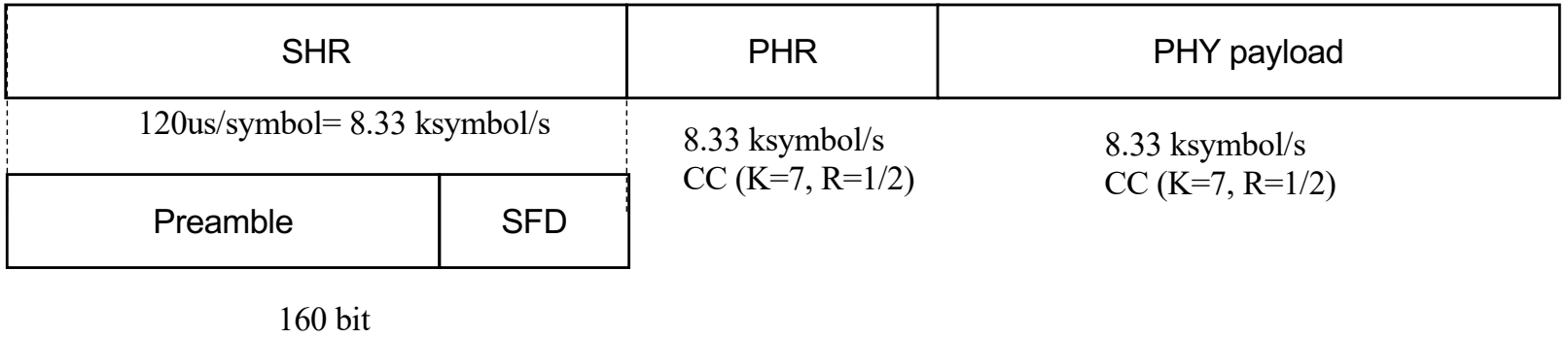
15-25/0035r0 15-25/0035r0 This document

Proposed frame format of SUN-FSK LR (15-25/0035r0)

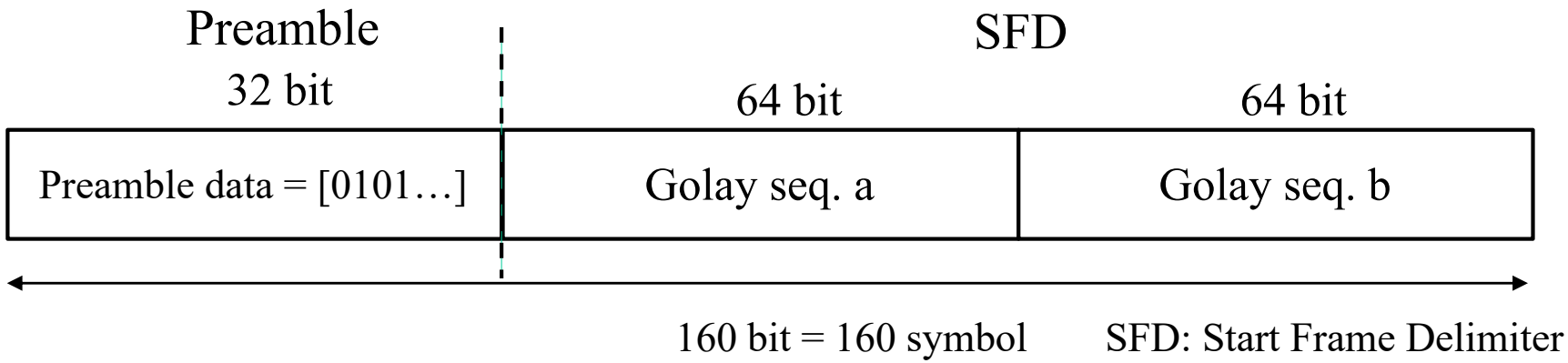
FSK LR1 (Same as SUN FSK)



FSK LR2



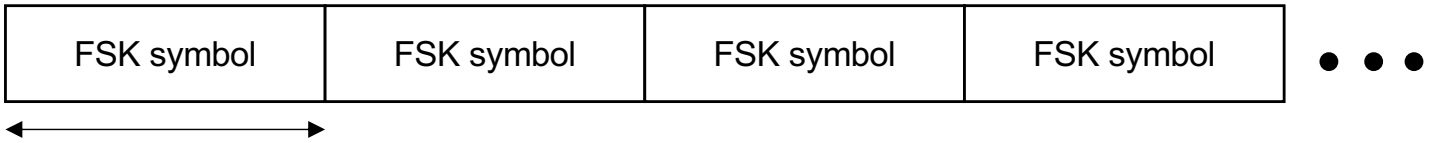
Proposed SHR of SUN-FSK LR2 (15-25/0247r1)



	Golay seq. a	Golay seq. b
Value	0x63AF05C963500536	0x6CA00AC66C5F0A39

The sequence is based on [1]

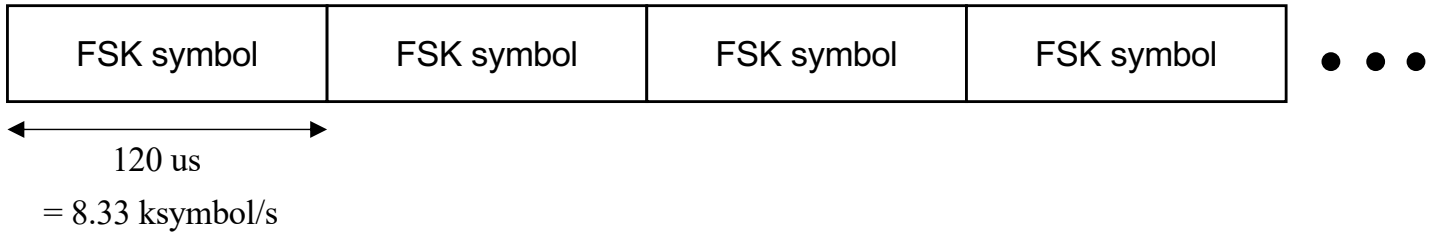
PHR & PHY payload of SUN-FSK LR1



10 us (Mode 5)

20 us (Mode 1-4)

PHR & PHY payload of SUN-FSK LR2



- The PHR and PHY payloads are transmitted in blocks of several symbols each.
- The transmission time for one symbol is 120 us.

Transmission Performance of 802.15.4 SUN FSK LR (Low Rate)2

Proposed 802.15.4-2024 SUN-FSK Low Rate (LR) PHY

Parameter	Option LR1					Option LR2			
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 1	Mode #2	Mode #3	Mode #4
Data rate (kb/s)	6.25	12.5	25	50	100	0.521	1.041	2.083	4.083
Modulation	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK
Modulation index	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Channel spacing (KHz)	200	200	200	200	400	200	200	200	200
Coding Scheme and rate	Convolutional code (Constraint length: 7) Coding rate1/2								
Spreading factor	8	4	2	1	1	8	4	2	1

15-25/0035r0 15-25/0035r0 This document

Simulation parameters

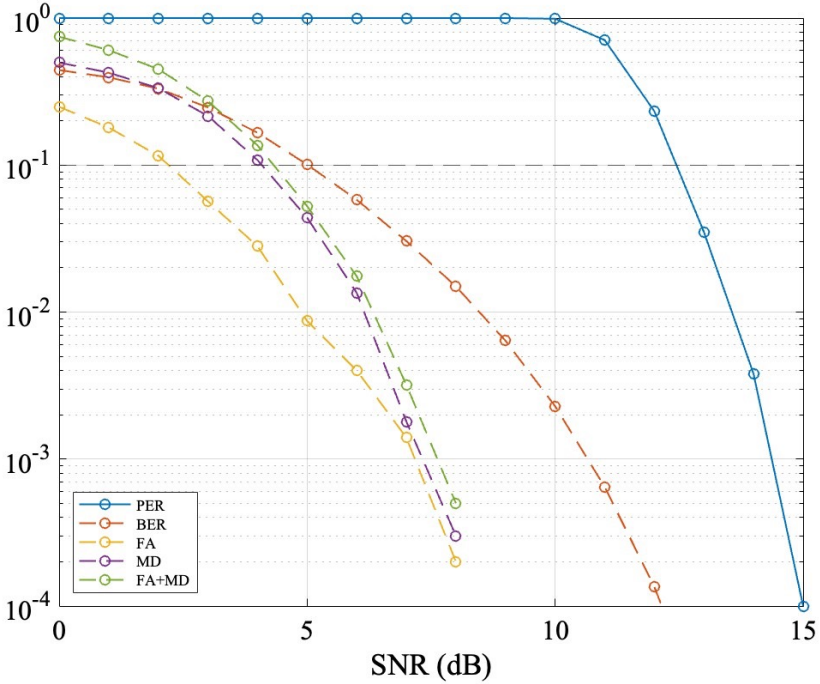
- LR1
  - Packet length: 250 octet
  - Symbol rate: 100 ksymbol/s
- LR2
  - Packet length: 20 octet
  - Symbol rate: 8.33 ksymbol/s

SNR and received signal power conversion

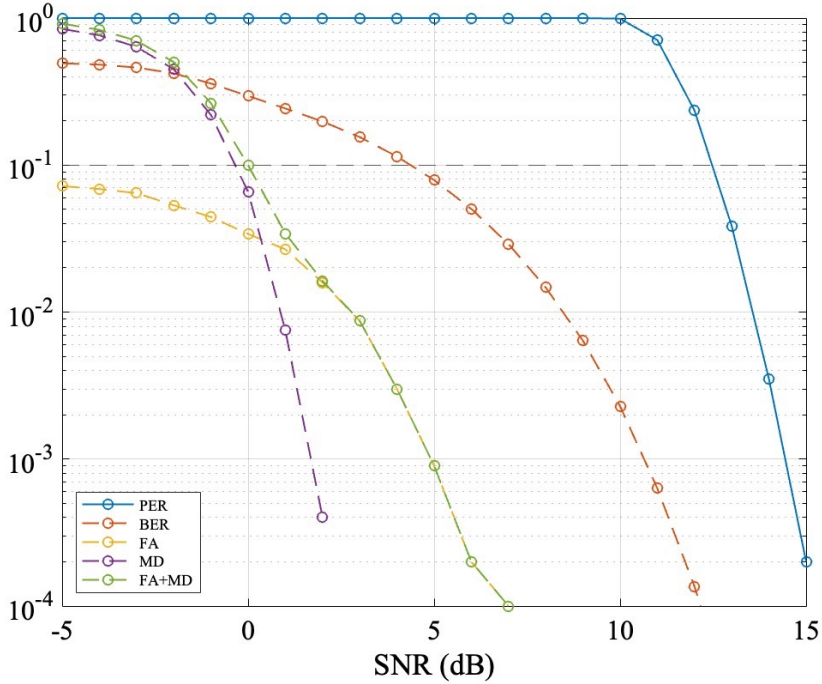
- In the case of Noise Figure (NF) =0dB and bandwidth =31.25/3 kHz, noise power should be -133.8 dB
- The conversion between SNR and received signal power is shown as follows

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

FA, MD Characteristics (2GFSK, w/o FEC, AWGN, 15-25/0247r1)



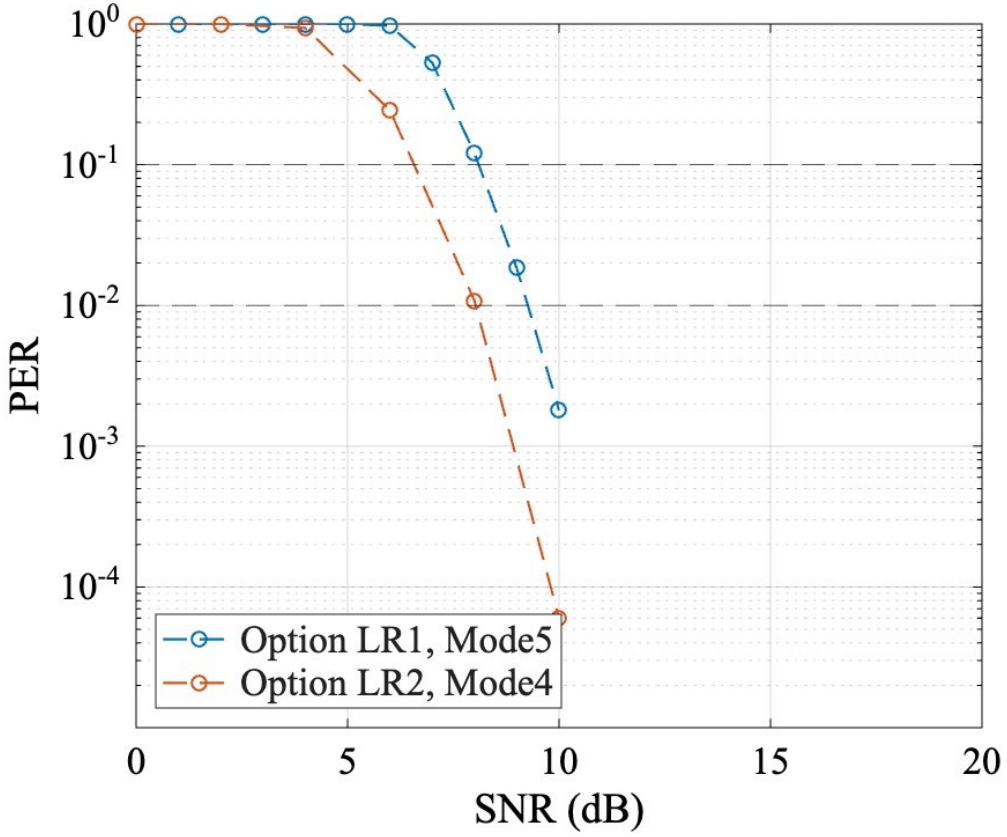
15.4g SFD for 2GFSK LR1



Proposed Golay-based SFD for 2GFSK LR2

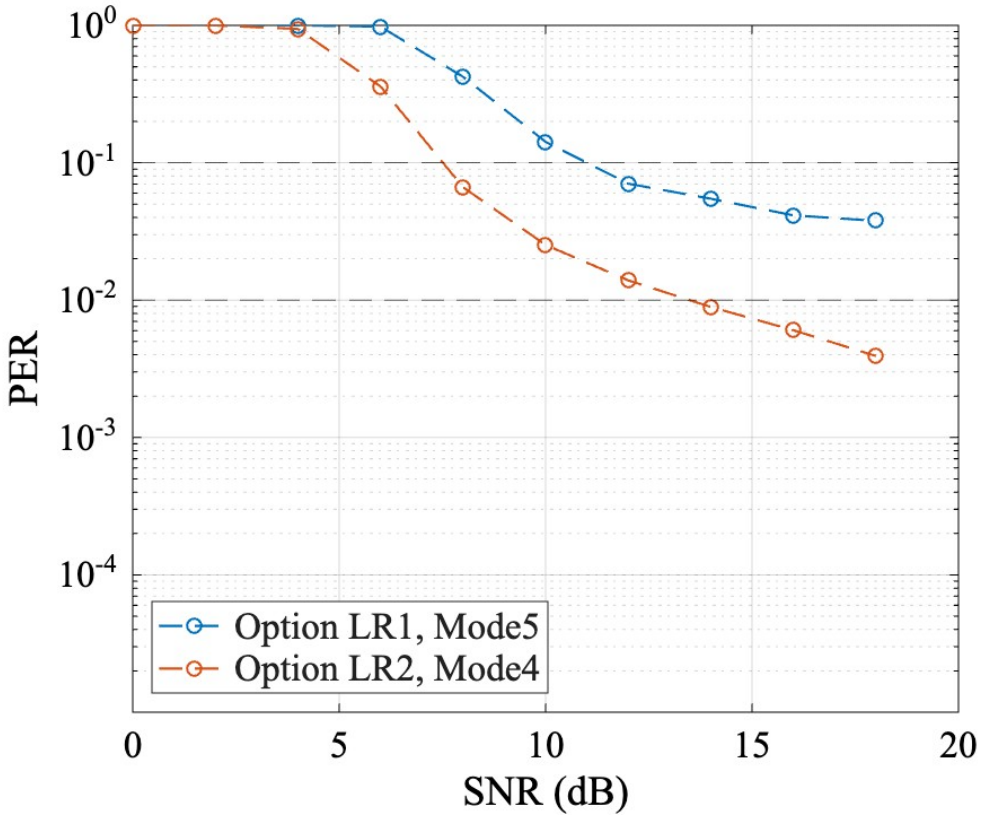
- The required SNR is 4dB (received power -133.8 dBm) to achieve error rate of 10^{-1} by using 15.4g SFD for 2GFSK LR1.
- The required SNR is 3dB (received power -133.8 dBm) to achieve error rate of 10^{-2} by using proposed Golay-based SFD for 2GFSK LR2

PER performance
(2GFSK, LR1 mode 5 and LR2 mode 4, AWGN)



Parameter	Option LR1	Option LR2
	Mode 5	Mode #4
Data rate (kb/s)	100	4.083
Modulation	2-FSK	2-FSK
Modulation index	0.5	0.5
Channel spacing (KHz)	400	200
Coding Scheme and rate	Convolutional code (Constraint length: 7, Coding rate1/2)	
Spreading factor	1	1
Payload length (Byte)	250	20
Required PER	10^{-1}	10^{-2}
Required SNR to achieve Required PER (dB)	8	8

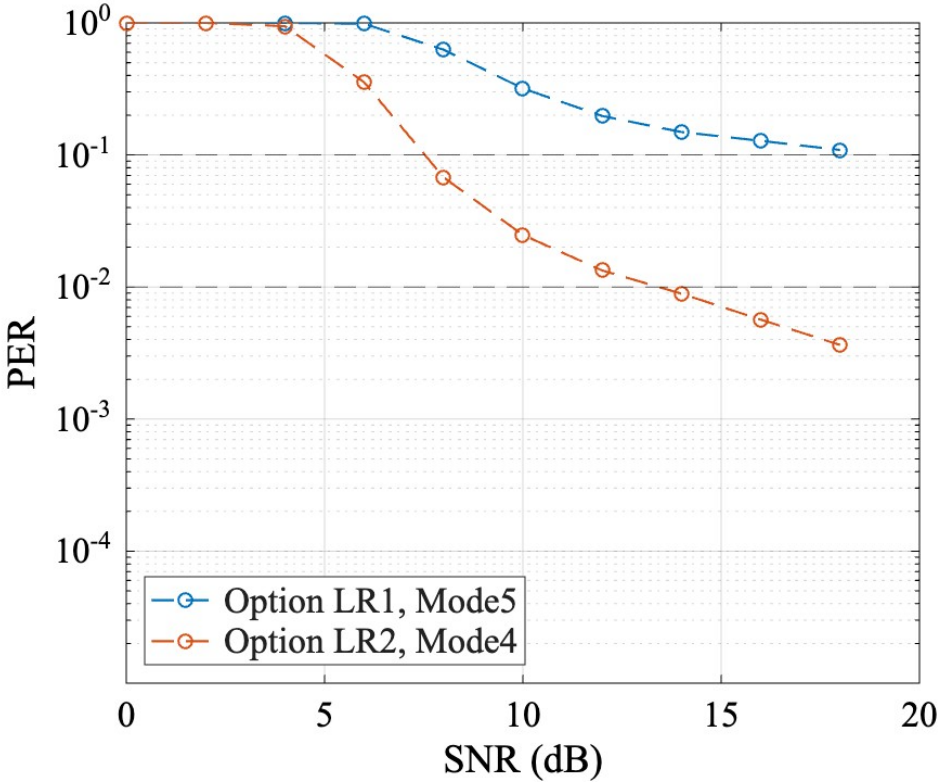
PER performance
(2GFSK, LR1 mode 5 and LR2 mode 4, COST207)



Parameter	Option LR1	Option LR2
	Mode 5	Mode #4
Data rate (kb/s)	100	4.083
Modulation	2-FSK	2-FSK
Modulation index	0.5	0.5
Channel spacing (KHz)	400	200
Coding Scheme and rate	Convolutional code (Constraint length: 7, Coding rate1/2)	
Spreading factor	1	1
Payload length (Byte)	250	20
Required PER	10^{-1}	10^{-2}
Required SNR to achieve Required PER (dB)	11	13

PER performance

(2GFSK, LR1 mode 5 and LR2 mode 4, 802.22 Profile A)



Parameter	Option LR1	Option LR2
	Mode 5	Mode #4
Data rate (kb/s)	100	4.083
Modulation	2-FSK	2-FSK
Modulation index	0.5	0.5
Channel spacing (KHz)	400	200
Coding Scheme and rate	Convolutional code (Constraint length: 7, Coding rate1/2)	
Spreading factor	1	1
Payload length (Byte)	250	20
Required PER	10^{-1}	10^{-2}
Required SNR to achieve Required PER (dB)	13	18

Required SNR and power (SUN FSK LR1 mode 5, 250 Octet)

	Required error rate		SHR		Payload	
			Required SNR(dB)	Required power(dBm)	Required SNR(dB)	Required power(dBm)
LR1 Mode 5	10^{-1}	AWGN	4	-129.8	8	-125.8
	10^{-1}	COST 207			11	-122.8
	10^{-1}	802.22 Rural			13	-120.8

Required SNR and power (SUN FSK LR2 mode 4, 20 Octet)

	Required error rate		SHR		Payload	
			Required SNR(dB)	Required power(dBm)	Required SNR(dB)	Required power(dBm)
LR2 Mode 4	10^{-2}	AWGN	3	-128.8	8	-125.8
	10^{-2}	COST 207			13	−120.8
	10^{-2}	802.22 Rural			18	-115.8