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Purpose:

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Proposal of 802.15.4 SUN PHY extension for 802.15.4ad

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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

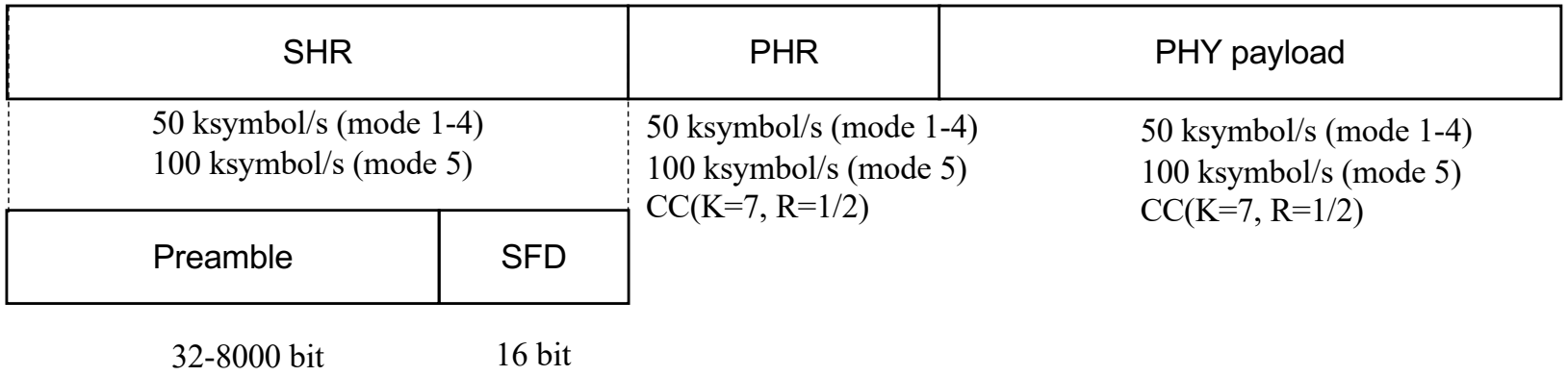
Parameter	Option LR1					Option LR2		
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 1	Mode #2	Mode #3
Data rate (kb/s)	6.25	12.5	25	50	100	0.521	1.041	2.083
Modulation	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK
Modulation index	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Channel spacing (KHz)	200	200	200	200	400	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

Conventional 802.15.4 SUN FSK-based

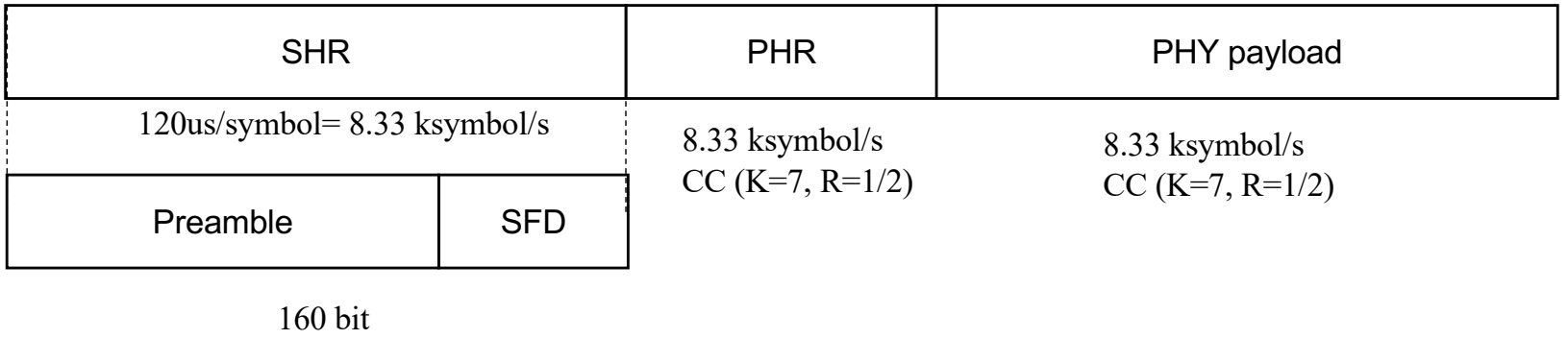
New mode

Proposed frame format of SUN-FSK LR

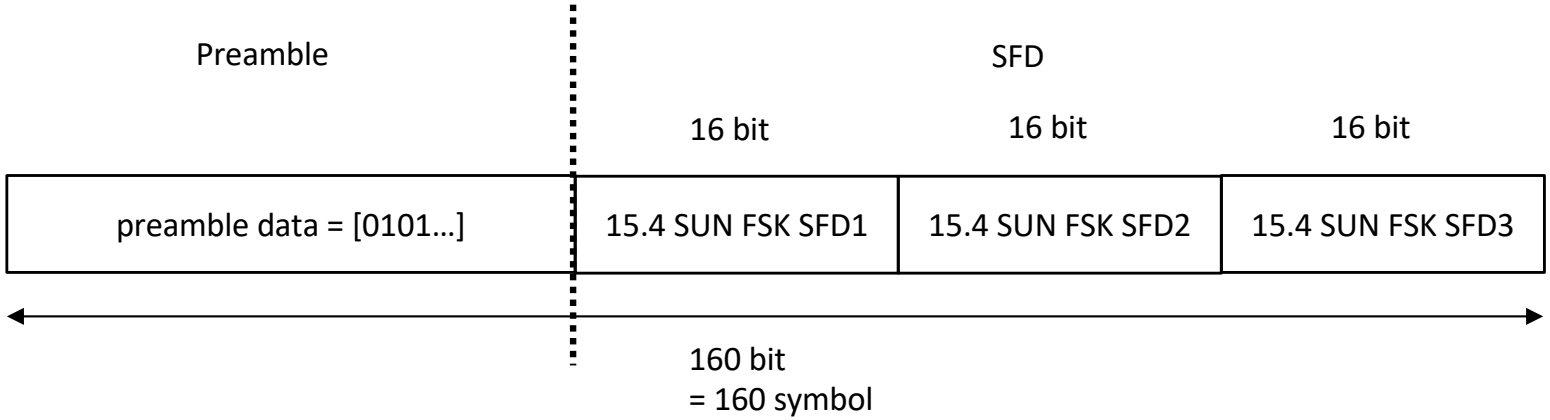
FSK LR1 (Same as SUN FSK)



FSK LR2



Proposed SHR of SUN-FSK LR2



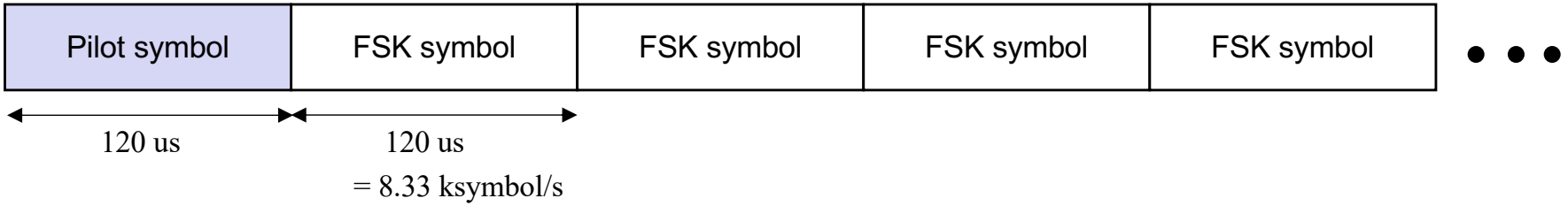
Preamble

- Preamble is 112 bits
- Repetition of 01 used in 15.4-2024 SUN FSK or other series

SFD

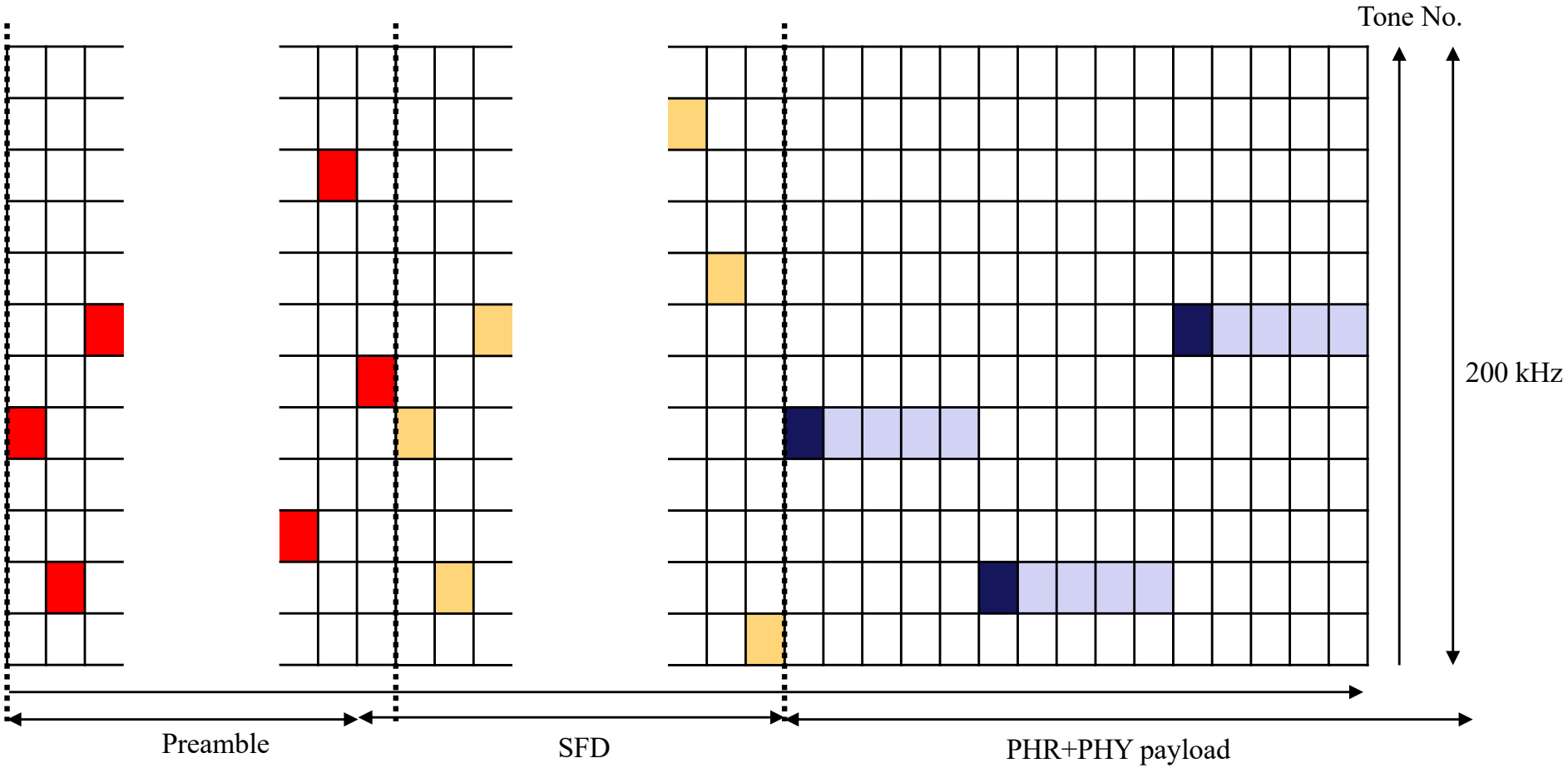
- It has been shown in discussions at 15.4k that long-distance transmission is possible with three or more SFDs. (Doc:15-12-0030r0)
- SFD1, SFD2, and SFD3 are the same as those used in 15.4-2024 SUN FSK
- Basically, different ones should be used, but some of the same ones may be used
- The characteristics of each SFD have already been evaluated in discussions at 15.4g, and their characteristics are well known

PHR & PHY payload of SUN-FSK LR2



- The PHR and PHY payloads are transmitted in blocks of several symbols each.
- For example, if the PHY header (2 octets) is taken into account, one pilot data is inserted every 64 bits.
- The transmission time for one symbol is 120 us.
- A pilot symbol is added to the beginning of each block.

Frequency Hopping for SUN-FSK LR2



- The hopping pattern should be set considering the coherent bandwidth of the assumed radio propagation channel.
- For the PHR and PHY payload, in addition to block-by-block hops, it is also possible to perform small symbol-by-symbol hops within adjacent subcarrier channels.

802.15.4 SUN OFDM LR

Fundamental design policy

- 802.15.4 SUN OFDM is being promoted for use in smart meters
- The structure of 802.15.4 SUN OFDM should not be changed fundamentally
- If the data rate is to be reduced without changing the structure of 802.15.4 SUN OFDM, data spreading is necessary because there is a need for sufficient resistance to urban noise and interference
- One way to reduce the data rate without changing the structure of 802.15.4 SUN OFDM is to change the number of subcarriers
- Even if the data rate is reduced by changing the data spread or the number of subcarriers without changing the structure of 802.15.4 SUN OFDM and if the transmission distance does not increase or there is no resistance to interference, it is necessary to add a new mode, 802.15.4 SUN OFDM LR, to 802.15.4 SUN OFDM
- This new mode 802.15.4 SUN OFDM LR is required to be highly compatible with the new mode 802.15.4 SUN FSK LR.

802.15.4-2024 SUN-OFDM

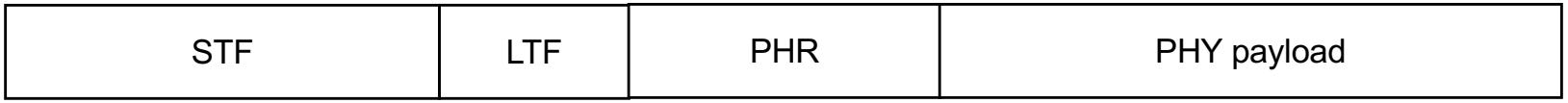
		Option1	Option2	Option3	Option4
Nominal Bandwidth		1094 kHz	552 kHz	281 kHz	156 kHz
Channel spacing		1200 kHz	800 kHz	400 kHz	200 kHz
Subcarrier spacing		31.25/3 kHz			
DFT size		128	64	32	16
Number of subcarriers		104	52	26	14
Num. of data-subcarriers		96	48	24	12
Primary modulation scheme		BPSK(MCS 0-1), QPSK(MCS 2-4), 16QAM(MCS5-6)			
Coding Scheme and rate		Convolutional code (Constraint length: 7) Coding rate1/2 (MCS 0-3, 5), 3/4 (MCS 4,6)			
Spreading factor		4 (MCS 0), 2 (MCS1-2), 1(MCS 3-6)			
Data rate for PSDU (kb/s)	MCS 0	100	50	25	12.5
	MCS 1	200	100	50	25
	MCS 2	400	200	100	50
	MCS 3	800	400	200	100
	MCS 4	1200	600	300	150
	MCS 5	1600	800	400	200

802.15.4-2024 SUN-OFDM LR

		Option LR1	Option LR2	Option LR3
Channel spacing		200 kHz		
Subcarrier spacing		31.25/3 kHz		
DFT size		16	16	16
Number of subcarriers used		14	14	14
Num. of data-subcarriers		12	6	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		0.521
	MCS 1		6.25	1.041
	MCS 2			2.083

Frame format SUN-OFDM LR

OFDM LR1 and LR2 (Same as SUN-OFDM option 4)



4 OFDM symbols
(480 us)

2.5 OFDM symbols
(300 us)

120us/ OFDM symbol

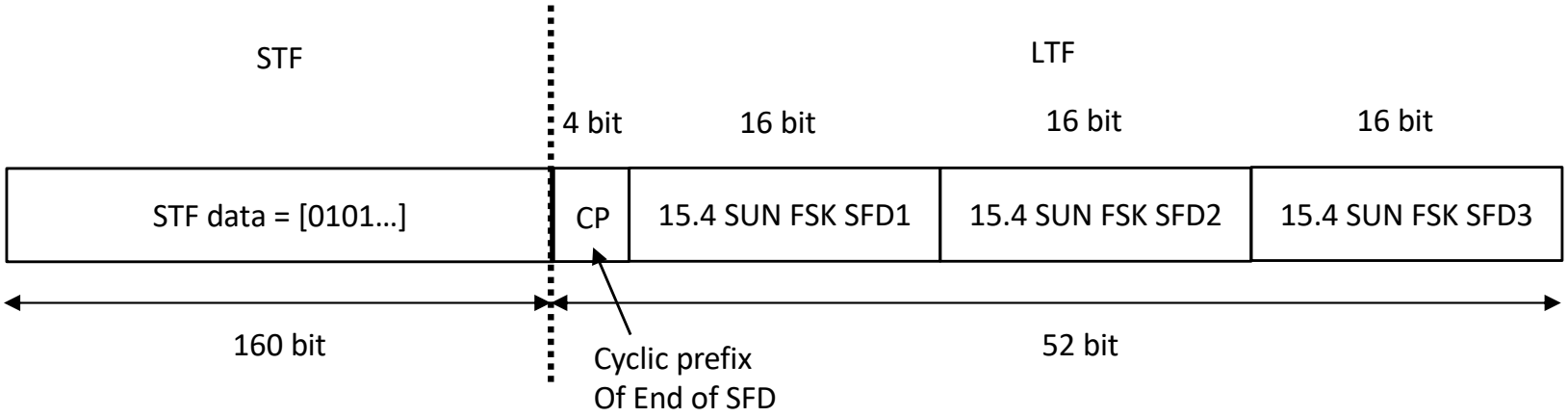
OFDM LR3

160 bit

52 bit

120us/symbol= 8.33 ksymbol/s

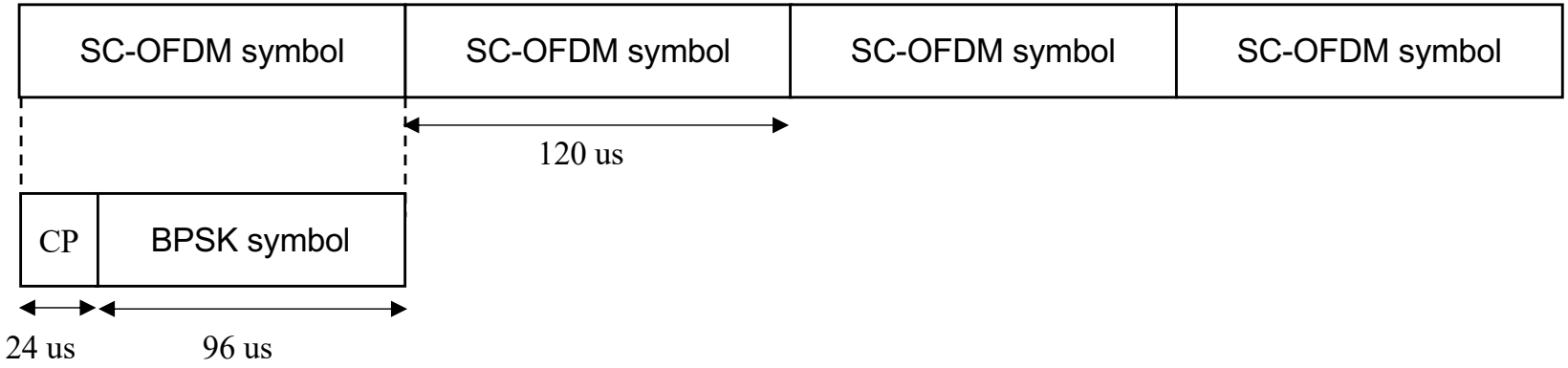
Proposed SHR of SUN-OFDM LR3



STF
- Preamble is 160 bits
- Repetitive data of 01 or other sequences are used in 15.4-2024 SUN FSK

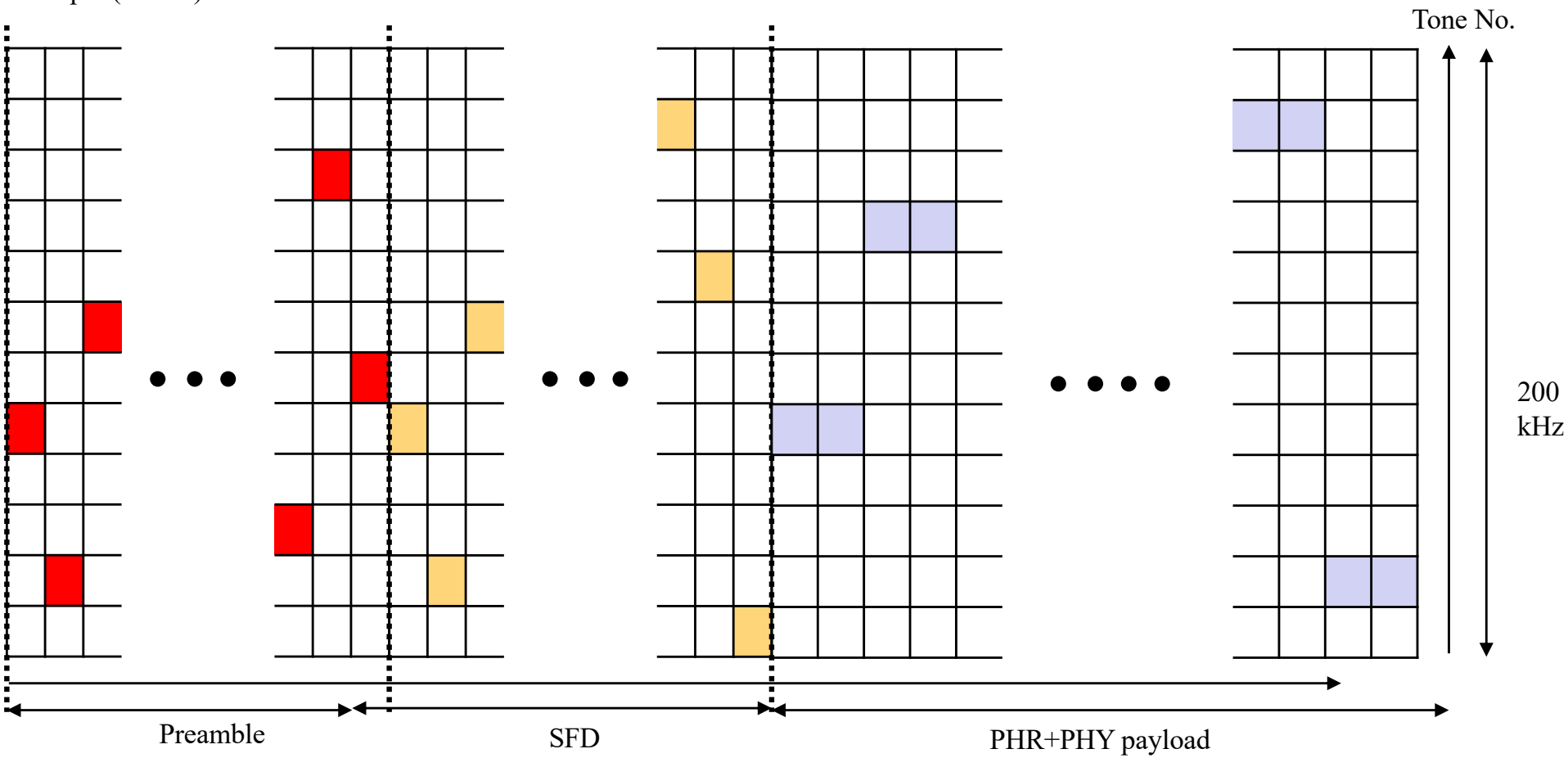
LTF
- SFD1, SFD2, and SFD3 are the same as those used in 15.4-2024 SUN FSK
- Basically, different ones are used, but some of them may be the same
- Each SFD has already been commercialized and its characteristics are well known
- The last 4 bits of the SFD are added as CP at the beginning

PHR & PHY payload of SUN-OFDM LR3



Frequency Hopping for SUN-OFDM LR3

Example (MCS2)

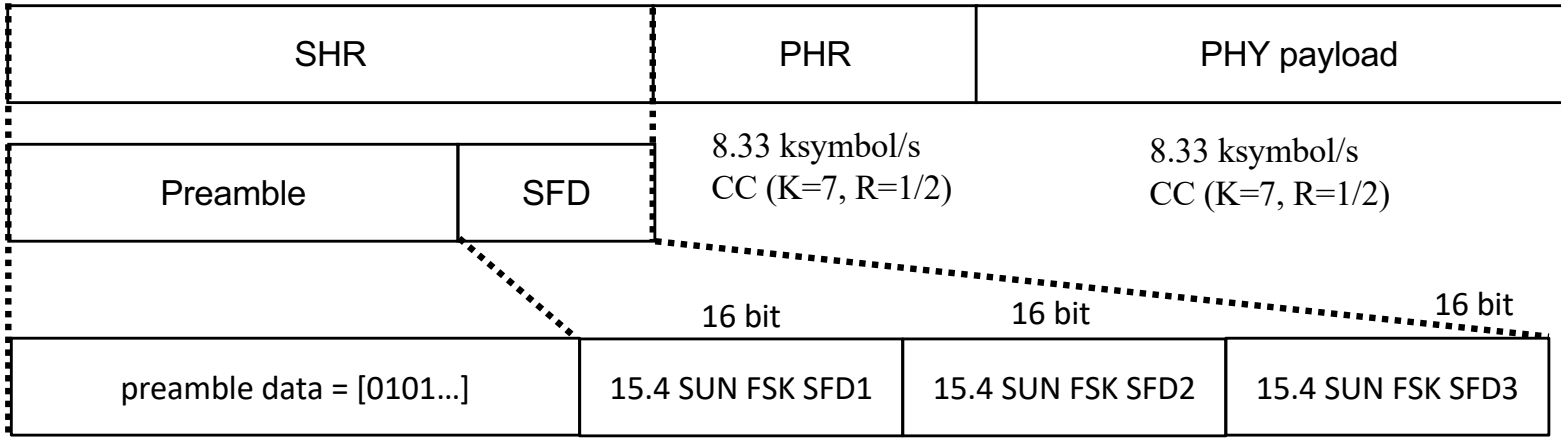


- The hopping pattern should be set considering the coherent bandwidth of the assumed radio propagation channel.
- If each symbol is spread, perform a hop for each symbol that is spread.

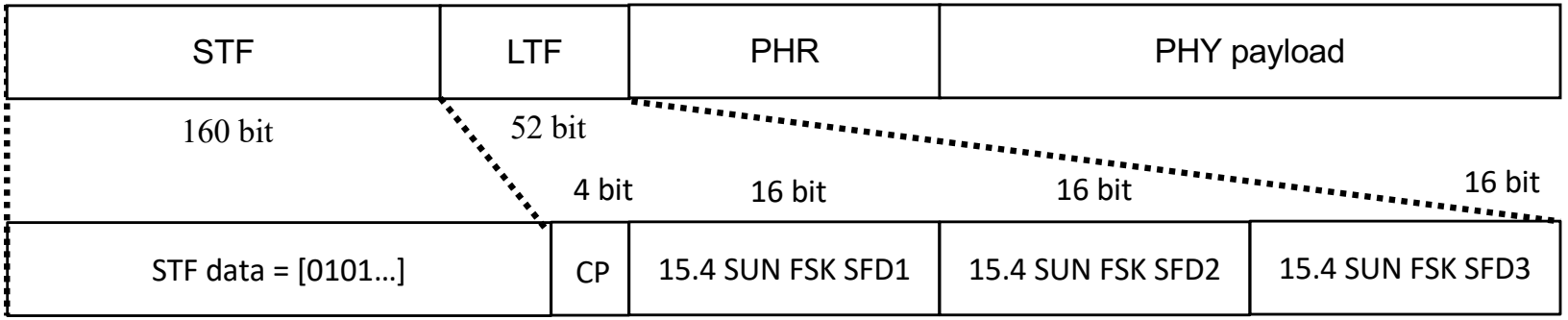
Features of the proposal system

FSK LR2 and OFDM LR2 have very similar structures and are highly compatible.

FSK LR2 120us/symbol= 8.33 ksymbol/s



OFDM LR3 120us/symbol= 8.33 ksymbol/s



52 bit

802.15.4 SUN OFDM HR(High Rate)

Fundamental design policy

- 802.15.4 SUN OFDM is being promoted for use in smart meters and other applications
- The structure of 802.15.4 SUN OFDM should not be changed
- If the transmission rate is to be increased without changing the structure of 802.15.4 SUN OFDM, the most direct approach is to reduce the symbol duration
- If the symbol duration is reduced, the guard interval will also be reduced. But the current 802.15.4 SUN OFDM guard interval is 24 μs, and even if the symbol transmission time is reduced to 1/3, the guard interval will still be 8 μs, which is sufficient for use within urban structures. Also, even when transmitting over long distances, it is possible to reduce long-delay multipath by using directional antennas, so there is a high possibility that it will be of sufficient use
- Considering coexistence with 11ah, it is desirable that the channel spacing be the same.

802.15.4-2024 SUN-OFDM

		Option1	Option2	Option3	Option4
Channel spacing		1200 kHz	800 kHz	400 kHz	200 kHz
OFDM symbol duration		120 μs			
Subcarrier spacing		31.25/3 kHz			
DFT size		128	64	32	16
Number of subcarriers		104	52	26	14
Num. of data-subcarriers		96	48	24	12
Primary modulation scheme		BPSK(MCS 0-1), QPSK(MCS 2-4), 16QAM(MCS5-6)			
Coding Scheme and rate		Convolutional code (Constraint length: 7) Coding rate1/2 (MCS 0-3, 5), 3/4 (MCS 4,6)			
Spreading factor		4 (MCS 0), 2 (MCS1-2), 1(MCS 3-6)			
Data rate for PSDU (kb/s)	MCS 0	100	50	25	12.5
	MCS 1	200	100	50	25
	MCS 2	400	200	100	50
	MCS 3	800	400	200	100
	MCS 4	1200	600	300	150
	MCS 5	1600	800	400	200
	MCS 6	2400	1200	600	300

Proposed 802.15.4-2024 SUN-OFDM High Rate (HR) PHY

		Option1	Option2	Option3
Channel spacing		4000 kHz	2000 kHz	1000 kHz
OFDM symbol duration		40 μs		
Subcarrier spacing		31.25 kHz		
DFT size		128	64	32
Number of subcarriers		104	52	26
Num. of data-subcarriers		96	48	24
Primary modulation scheme		BPSK(MCS 0-1), QPSK(MCS 2-4), 16QAM(MCS5-6)		
Coding Scheme and rate		Convolutional code (Constraint length: 7) Coding rate1/2 (MCS 0-3, 5), 3/4 (MCS 4,6)		
Spreading factor		4 (MCS 0), 2 (MCS1-2), 1(MCS 3-6)		
Data rate for PSDU (kb/s)	MCS 0	300	50	75
	MCS 1	600	100	150
	MCS 2	1200	200	300
	MCS 3	2400	400	600
	MCS 4	3600	600	900
	MCS 5	4800	800	1200
	MCS 6	7200	1200	1800

802.15.4-2024 SUN-OFDM HR

- Basically, it is based on 802.15.4-2024 SUN OFDM, and the only change is to reduce the length of the OFDM symbol to 1/3
- The basic transmitter configuration is the same as 802.15.4-2024 SUN OFDM
- Time-axis window-based filter standardized in 802.15.4m is required to fit the occupied bandwidth within the channel spacing range to fit into the spectrum

- Regarding FEC, we firstly consider using the convolution code standardized in 802.15.4-2024 SUN OFDM, but we may need to consider introducing LDPC as an option for better transmission characteristics. Just to do business simply, at first, only convolution codes may be used

- When introducing LDPC, the changes to the 802.15.4-2024 SUN OFDM radio parameters such as the number of subcarriers should be kept to a minimum.