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

Submission Title: [SFF PHY revised proposal in Atlanta meeting]
Date Submitted: []
Source: [Hiroshi Harada[1], Fumihide Kojima[1], Sum Chin Sean[1], Ryuhei Funada[1], Takaaki Hatauchi[2], Minoru Tanabe[3], Kentaro Sakamoto[4], Aiichiro Kashiwagi[5], Takahiro Banno[6], Hirohito Nishiyama[7]]
Company [[1]NICT, [2]Fuji Electric, [3]Panasonic, [4]Tokyo Gas, [5]Osaka Gas, [6]Toho Gas, [7]Mitsubishi Electric Corp.]
Address [[1]3-4, Hikari-no-oka,Yokosuka-shi,Kanagawa239-0847,Japan]
Voice:[[1]+81-46-847-5074]
FAX: [[1]+81-46-847-5440]
E-Mail:[f-kojima@nict.go.jp, harada@nict.go.jp]
Re: [In response to TG4g Call for Proposals]
Abstract: [Proposal of PHY and MAC for low-power consumption SUN]

Authors

This is a merged proposal from the following authors

- NICT
- Fuji Electric
- Panasonic
- Tokyo Gas
- Osaka Gas
- Toho Gas
- Mitsubishi Electric Corp.

This merged proposal is supported by:

- Silicon labs

What is revised from the previous Hawaii proposal

- Channelization summarized for allocation on both 950MHz and 400MHz band assuming 200kHz spacing with overlapping
- PHY parameter revision in symbol rate and modulation index
- FEC by systematic convolutional code that effectively realizes low rate transmission
- SFD proposal to identify PHR+PSDU
- PSDU modification for flexibility

Hawaii proposal

- FSK based SUN is considered to work well in Japanese region(400/950MHz) without suffering from multi-path degradation
  - No serious multi-paths are found in the propagation range assumed in Japanese SUN
  - Multi-hop capability for service area expansion could also provide route with less multi-path effects
- Link budget analysis and outdoor experiment results confirm that:
  - Up to 150m propagation range to achieve -60dBm received power with 10mW transmission power
    - 300m with 700mW
  - No notch attenuation more than 20dB over 300m radius area
- Computer simulation results confirm that frames are successfully relayed to the collection station where 80% of all radio links are seriously degraded over 400m x 400m area, while only 20% of frames are successfully sent without multi-hop transmission

Latest status for modulation and channel parameters

- With channelization revisions on both 950MHz and 400MHz thereby number of channels for each rate has been determined
  - Overlapping channels assumed: 400/600kHz width with 200kHz spacing
- Modulation indexes are reconsidered for 200ksymbols/s
  - Previous become (1.0, 0.33) for (200kbps, 400kbps)

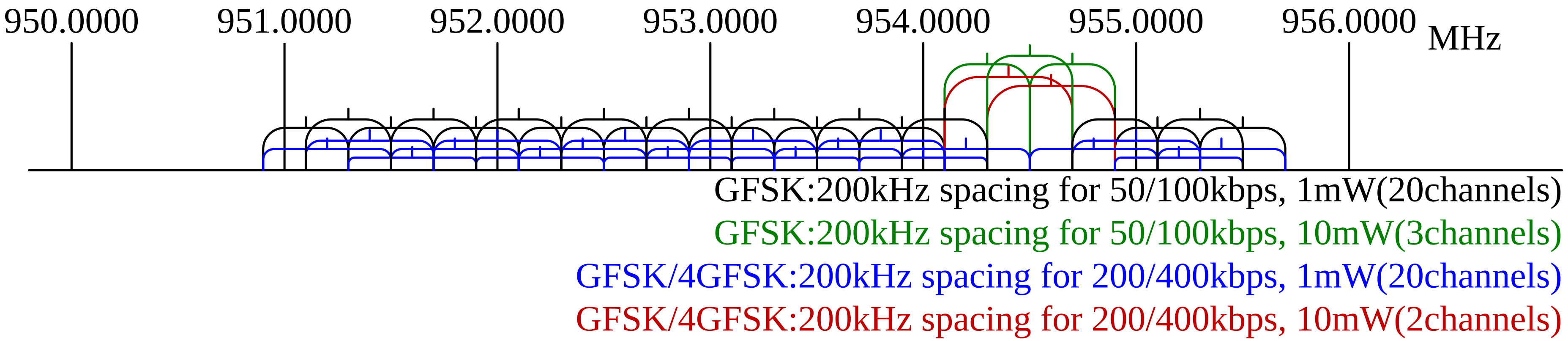
For Japanese bands

Frequency band (MHz)	Parameter	Low rate 50 kbps	Medium rate 100 kbps*	High rate 200/400 kbps
950.9-955.7 (Japan, 23/22 Ch.)	Channel spacing (kHz)	**200**	**200**	**200**
	Modulation	GFSK	GFSK	GFSK/4GFSK
	Modulation Index	1.0	1.0	**(1.0, 0.33) for** (2, 4GFSK)
	# of channels within band	**23**	**23**	**22**
	Channel overlap	**Y**	**Y**	**Y**
400-430 (**1.0**MHz BW) (Japan, 4/5 Ch.)	Channel spacing (kHz)	**200**	**200**	**200**
	Modulation	GFSK	GFSK	GFSK/4GFSK
	Modulation Index	1.0	1.0	**(1.0, 0.33) for** (2, 4GFSK)
	# of channels within band	**4** (TBD)	**4** (TBD)	**3**(TBD)
	Channel overlap	**Y**	**Y**	**Y**

Note: BT of 0.5 used with GFSK ***baseline rate**

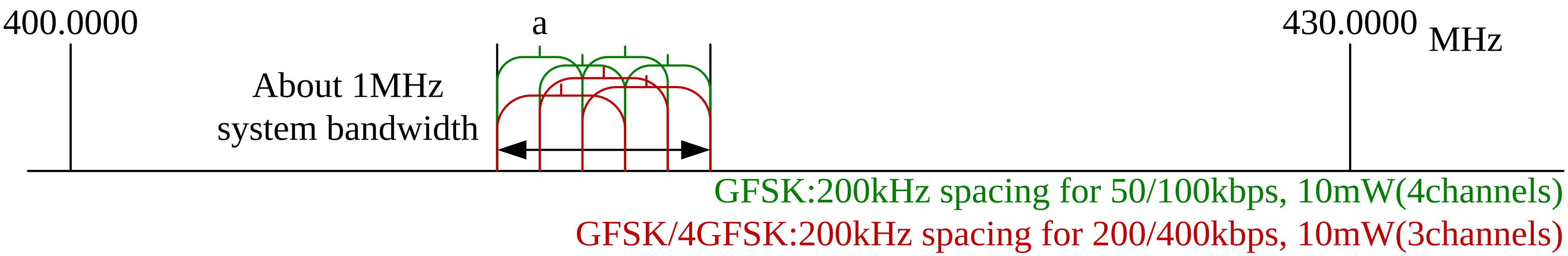
Allocation on 950MHz band

- Channel BW: 400kHz for 50/100kbps, 600kHz for 200/400kbps
  - 2 or 3 bundling of 200kHz BW channels
- Channel spacing: 200kHz
  - Channel overlap is necessary to accommodate with Japanese regulatory requirements



Allocation on 400MHz band

- About 1MHz system bandwidth are under consideration out of 400-430MHz band
- Channel allocation is similarly done to 950MHz case



Allocation Table

Channel page (decimal)	Channel page (binary) (b31, b30, b29, b28, b27,)	Channel number (decimal)	Channel number description
6	0 0 1 1 0		
7	0 0 1 1 1	0 - 10	(additional) Channels 0 to 10 in 950 MHz band using GFSK at 100 kbps
		11 – 26	Reserved
8	0 1 0 0 0	0 - 22	Channels 0 to 22 in 950 MHz band using GFSK at 50 kbps
		23 - 26	Reserved
9	0 1 0 0 1	0 - 21	Channels 0 to 21 in 950 MHz band using GFSK at 200 kbps
		22 - 26	Reserved
10	0 1 0 1 0	0 - 21	Channels 0 to 21 in 950 MHz band using 4GFSK at 400 kbps
		22 - 26	Reserved
11	0 1 0 1 1	0 - 3	Channels 0 to 3 in 400 MHz band using GFSK at 100 kbps
		4- 7	Channels 4 to 7 in 400 MHz band using GFSK at 50 kbps
		8 - 10	Channels 8 to 10 in 400 MHz band using GFSK at 200 kbps
		11 - 13	Channels 11 to 13 in 400 MHz band using 4GFSK at 400 kbps
		14-26	Reserved
~~6~~ 12-31	0 1 1 0 0 - 1 1 1 1 1	Reserved	

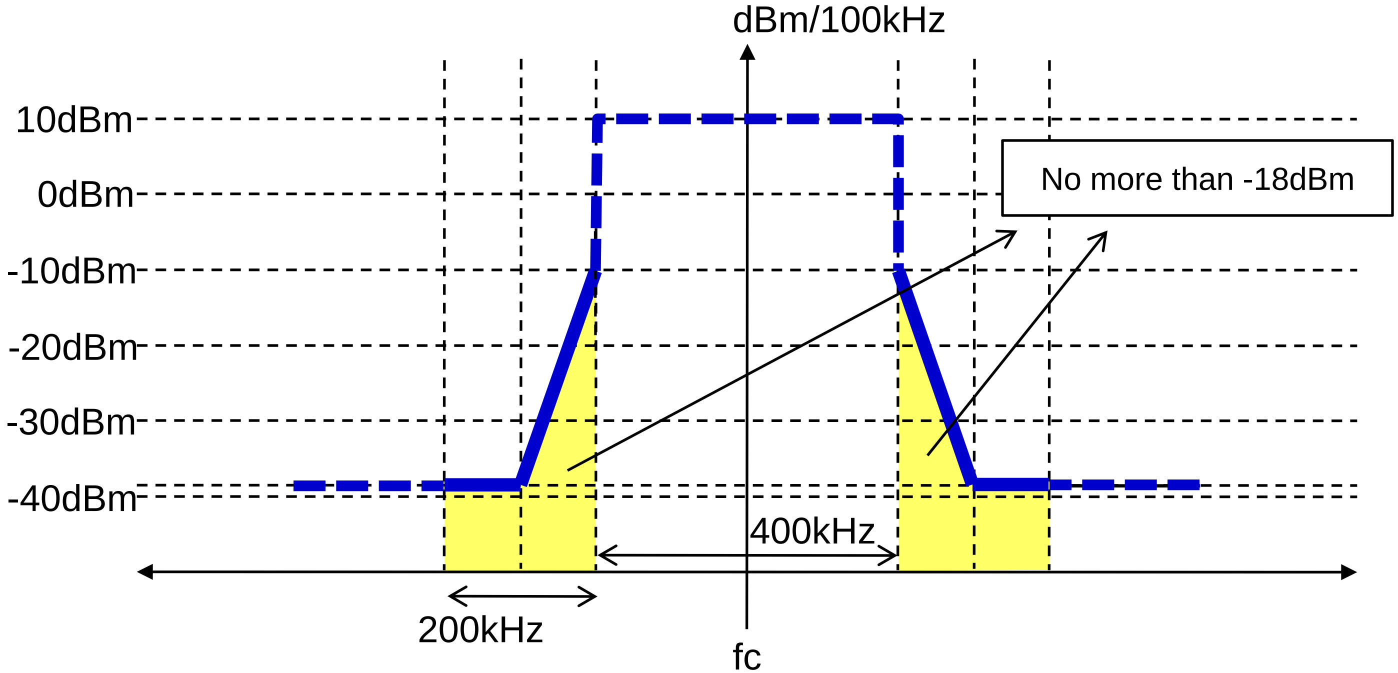
Backup: MCS determination for Japan band

950MHz band

Data rate	Parameter candidate				T-96 compliance	Note; "Why it must be eliminated?" (Need to be validated)
	Mod. scheme	Symbol rate	Modulation index	Channel bundling		
Low and Medium rate (50 and 100kbps)	2GFSK	100ksps	1.0	3	Y	Excess bandwidth
				2	Y	Tentatively employed (same as 802.15.4d)
				1	N	-
			0.5	3	Y	Excess bandwidth
				2	Y	Worse sensitivity than MI:1.0
				1	???	???
			0.3	3	Y	Excess bandwidth
				2	Y	Worse sensitivity than MI:1.0
				1	???	???
High rate (200/400kbps)	2GFSK	200ksps	1.0	3	Y	May better accommodate with 400kbps
				2	N	
				1	N	
			0.5	3	Y	Better accommodate with 400kbps
				2	Y	Best choice for performance and spectrum efficiency
				1	N	
			0.3	3	Y	Worse sensitivity than MI:0.5
				2	Y	Worse sensitivity than MI:0.5
				1	N	-
	4GFSK		1.0	3	N	-
				2	N	-
				1	N	-
			0.5	3	Y	Best choice for performance and spectrum efficiency
				2	N	-
				1	N	-
			0.33	3	Y	Better accommodate with 200kbps
				2	Y	Possible NG for practical design (little margin)
				1	N	- (anticipated from 2 ch bundling simulation)

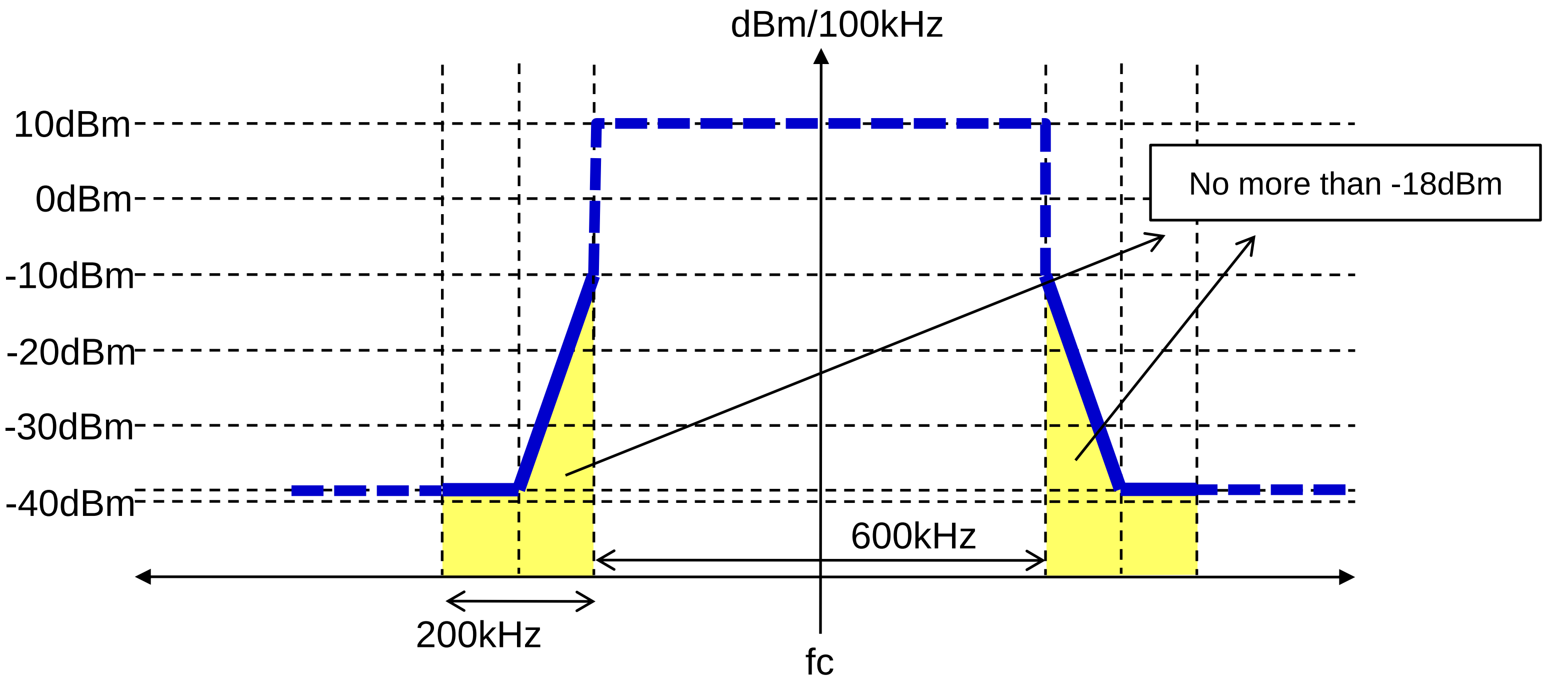
Appendix1: PSD on 950MHz for 400kHz-bandwidth

Frequency band	Frequency	Relative limit	Absolute limit
950 MHz band (for 10mW GFSK channels)	|f-fc| > 0.4MHz	-	-39dBm
	0.4MHz>|f-fc|>0.2MHz	-	-18dBm (within 200kHz width)



Appendix2: PSD on 950MHz for 600kHz-bandwidth

Frequency band	Frequency	Relative limit	Absolute limit
950 MHz band (for 10mW GFSK channels)	|f-fc| > 0.5MHz	-	-39dBm
	0.5MHz>|f-fc|>0.3MHz	-	-18dBm (within 200kHz width)



PHR coding and whitening

- SFF proposes data whitening on whole PHR + PSDU input, as in 15.4 and 15.4d
- Since SFF employs single sequence for scrambling, the received PHR part can be read after descrambling without scrambler seed information
- Then, the following PSDU with variable length can be successfully received based on the PSDU length information in the descrambled PHR

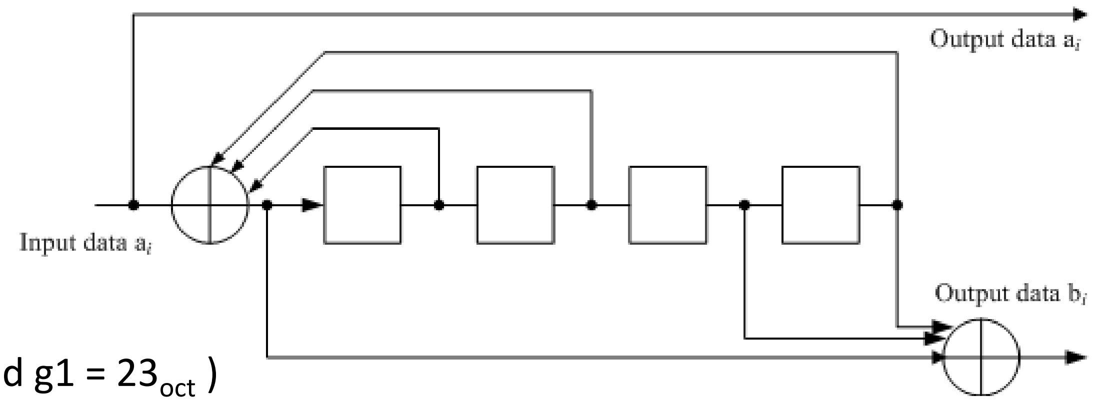
Modulation and coding for each field

- First cut of PPDU design

	SHR		PHR	PSDU
	Preamble	SFD		
50kbps	100ksymbols/s (Spreading factor:2 , no FEC, 2GFSK)	100ksymbols/s (no spreading, no FEC, 2GFSK)	100ksymbols/s (no spreading, FEC, 2GFSK)	
100kbps	100ksymbols/s (no spreading, no FEC, 2GFSK)			
200kbps	200ksymbols/s (no spreading, no FEC, 2GFSK)			
400kbps	200ksymbols/s (no spreading, no FEC, 2GFSK)			200ksymbols/s (no spreading, no FEC, 4GFSK)

Systematic convolutional coding for FEC

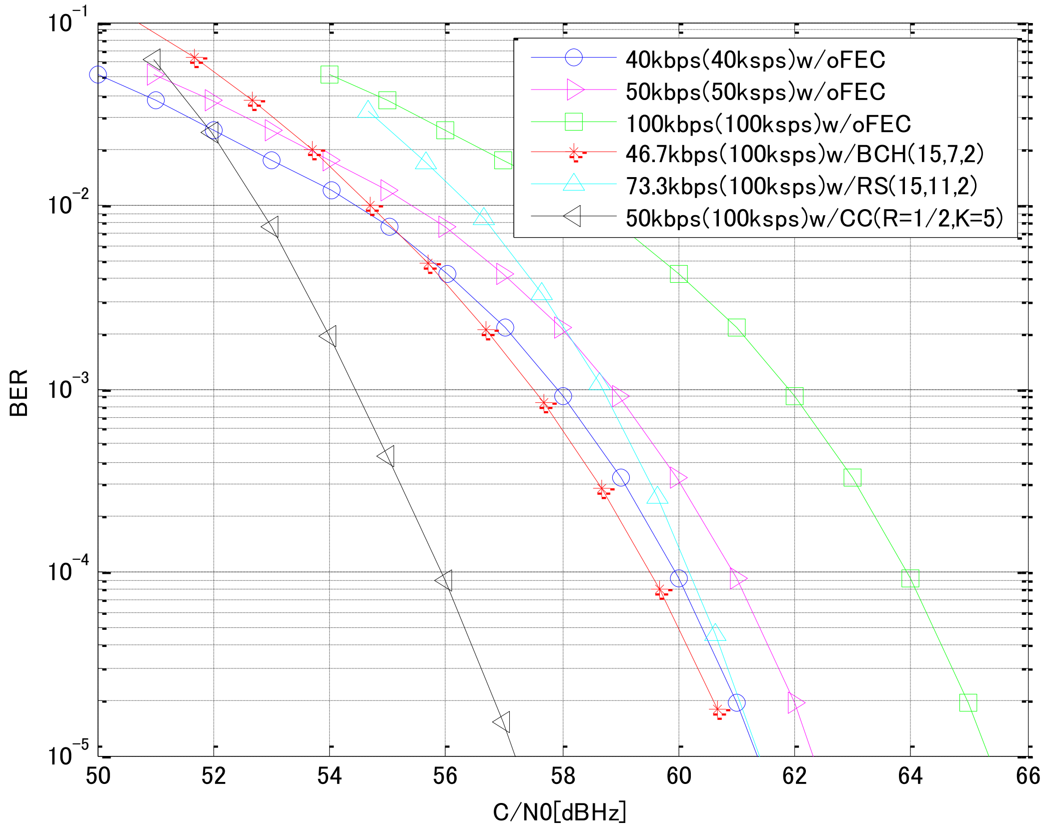
- Better coding gain with moderate gate count (10k@R=1/2, K=5,3 soft bit) is achieved.
- Same as other systematic coders, a systematic convolutional encoder **outputs original input data** (see the following figure), which means the receiver can **demodulate the received encoded data without Viterbi decoding**.
  - The receiver can choose decoding method (Viterbi decoding or withtout-decoding) according to link performance or power consumption he want to achieve.
  - Manufacturer also can decide to implement the Viterbi decoder in the receiver according system they use.
- Smaller K is possible to use for lower burden with moderate coding gain.



The proposed encoder
(generator polynomials: g0 = 35_{oct} and g1 = 23_{oct})

Bit rate characteristics on 100ksymbols/s

- In order to support interoperability among 50kbps and 100kbps modes with single filter, SFF employs 50kbps low data rate by ½ systematic convolutional coding
- When decoded by the receiver, it can achieve 50kbps rate transmission performance with 5.1dB coding gain compared with 50kbps based on 50ksymbol/s



FEC candidates evaluated

- FEC candidates listed in the following table were evaluated in NICT for the lowest data-rate mode using 2GFSK with 100 ksymbol/s
- We concluded that **plan A** is the best in the all

Plan	PHR/PSDU FEC	Information bit rate	Coding gain (@BER =10^{-5} in AWGN)	Required CNR (@BER =10^{-5} in AWGN)
A	Systematic convolutional code with Viterbi dec. (R=1/2,K=5)	50 kbps	**5.1 dB**	7.2dB
B	RS(15,11,2)	73.3 kbps (=11/15*100 ksymbol/s)	2.5 dB	11.2dB
C	BCH (15,7,2)	46.7 kbps (=7/15*100 ksymbol/s)	0.9 dB	11.1dB

Proposed SFD patterns

- Four types of SFD pattern proposed to identify other FSK camps and No-FEC mode:

SHR (repetitions of [-1 1]	SFD	PHR

	SFD1	SFD2
SFD#1	SFD1(8btis): Golay seq *a*	SFD2(8btis): Golay seq -*b*
SFD#2	SFD1(8btis): Golay seq *b*	SFD2(8btis): Golay seq *a*
SFD#3	SFD1(8btis): Golay seq *b*	SFD2(8btis): Golay seq -*a*
SFD#4	SFD1(8btis): Golay seq *a*	SFD2(8btis): Golay seq *b*

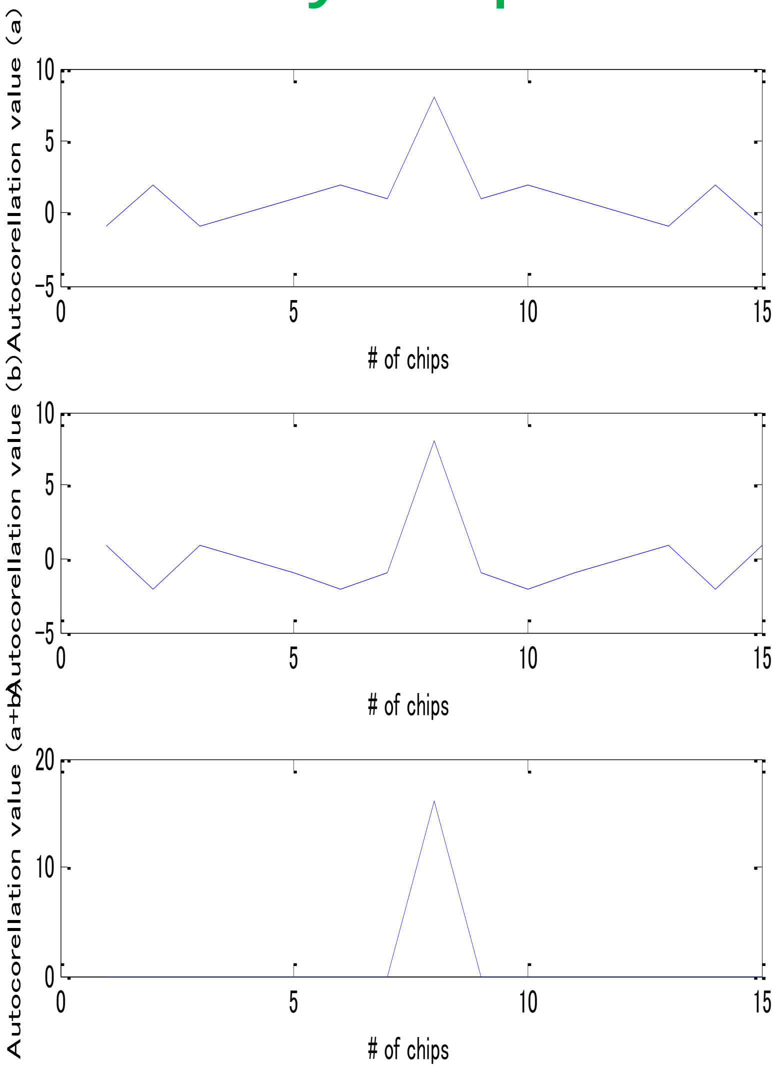
- All SFD patterns composed of 8-bit complementary Golay sequences *a* and *b*:

a=[-1 1 -1 -1 -1 -1 -1 1]

b=[1 -1 1 1 -1 -1 -1 1]

Appendix3: Features of Golay sequences

- Golay sequences consist of a pair of binary sequences ***a*** and ***b*** with length of 2^N chips, where *N* is a positive integer.
- Sum of the autocorrelations results in unique main peak without side-lobe.
- Golay sequences can carry 2-bit (4-state) information by using +***a***, -***a***, +***b*** and –***b.***



SFF PPDU

- Different SFD to distinguish between 802.15.4d and 802.15.4g in 950MHz band in Japan
  - One octet (802.15.4d) vs. two octets
- Support for short frame (with CRC-16) for efficiency
- Frame control field to define
  - CRC option (16 or 32)
  - Others (TBD)
    - FEC option
    - Data rate (modulation order, 2/4GFSK for high data rate)
- 2bit scrambler seed field is eliminated in the latest proposal

Proposed PPDU format

<table>
<tr><td>Octet: variable</td><td>2</td><td colspan="3">2</td><td>variable</td><td>2/4</td></tr>
<tr><td>Bit: variable</td><td>16</td><td>4</td><td>1</td><td>11</td><td>variable</td><td>16/32</td></tr>
<tr><td colspan="2">SHR</td><td colspan="3">PHR</td><td colspan="2">PSDU</td></tr>
<tr><td rowspan="2">Preamble</td><td rowspan="2">SFD</td><td colspan="2">Frame control</td><td rowspan="2">Frame length
(MSB first)</td><td rowspan="2">PHY payload excluding FCS</td><td rowspan="2">FCS</td></tr>
<tr><td>Reserved</td><td>CRC option</td></tr>
</table>

Reserved:
* FEC option
* Data rate (2/4 GFSK)
  -> no change in symbol rate
* Others …

CRC option:
1: CRC-16
0: CRC-32