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

Submission Title: [NICT's Narrow band PHY proposal for WBAN]

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Source: [Shinsuke Hara, Kenichi Takizawa, Ryuji Kohno] Company [NICT]

Address [3-4 Hikarino-oka, Yokosuka, Japan]

Voice:[+81 468475085], FAX: [+81 468475431], E-Mail:[takziawa@nict.go.jp]

Re: [Response to CFP]

Abstract: [Narrowband PHY proposal for IEEE802.15.6.]

Purpose: [To be considered in IEEE802.15.6.]

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NICT's Narrow-Band PHY Proposal for WBAN

Shinsuke Hara, Kenichi Takizawa, Ryuji Kohno

National Institute of Information and Communications Technology (NICT)

Summary

- Narrowband solution
 - Mandatory : Data rate = 50.0 kbps (BW = 200 kHz)
 - Available frequency bands: MICS (402-405 MHz) and ISM (868 MHz (EU), 902-928 MHz (US), 950-956 MHz (Japan), etc.)
 - Option (1): Data rate = 12.5~75.0 kbps
 - Aggregation of the base BW (50kHz) up to 300 kHz
 - Option (2): Data rate = 50 kbps
 - Frequency hopping (FH) is supported.
 - Available frequency bands: WMTS (608-614 MHz (US)) and ISM
 - Optional (3): Data rate = 300 kbps and 2.0 Mbps
 - Available frequency bands: ISM bands
- Key technology
 - GFSK modulation (modulation index $h=1.0$ and $BT=0.5$)
 - Optionally, (63,55)-RS code in $GF(2^6)$ is supported.

Q1. Why do we need a narrowband PHY solution?

Wideband PHY cannot be successfully applied to the medical-authorized frequency bands

- Emission power limit
- Channel spacing
- Modulation type

Q2. Why do we employ GFSK?

- It is implementable with low cost and low power consumption with matured technology
- It is highly power-efficient
 - Can use a nonlinear amplifier at Tx
 - Can be non-coherently detected without PLL at Rx
 - Can shorten the length of preamble

Data rate

- Modulation: GFSK (modulation index $\beta = 1.0$, and $BT=0.5$)
 - No specific band plan (No channelization)
 - Frequency hopping (FH) is optionally supported.
- FEC: Optional RS code with (63, 55) in $GF(2^6)$

Data rate R	Modulation	Modulation parameters	Channel spacing B	FEC	Mandatory	Target frequency bands
12.5 kbps	GFSK	$\beta=1.0, BT=0.5$	50 kHz	Mandatory : None Optional: RS code	No	MICS, ISM, etc.
25.0 kbps			100 kHz		No	
37.5 kbps			150 kHz		No	
50.0 kbps			200 kHz		Yes	
62.5 kbps			250 kHz		No	
75.0 kbps			300 kHz		No	
50.0 kbps	FH-GFSK (6 channels)	$\beta=1.0, BT=0.5$	1.2 MHz (200 kHz)	Mandatory : None Optional: RS code	No	WMTS (608-614MHz), ISM
300.0 kbps	GFSK	$\beta=1.0, BT=0.5$	1.2 MHz	Mandatory : None Optional: RS code	No	ISM
2 Mbps	GFSK	$\beta=1.0, BT=0.5$	4.0 MHz	Mandatory : None Optional: RS code	No	ISM

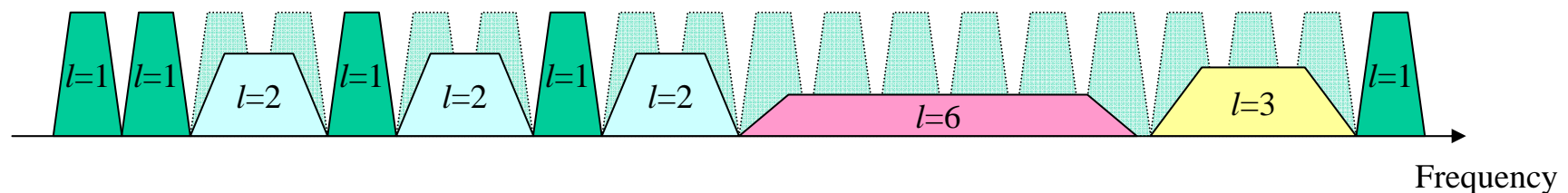
Accommodation of different data rates (channel spacings) in a given frequency band

- Base data rate (R) / channel spacing (B) :

$$R/B = 12.5\text{kbps}/50\text{kHz}$$
- Accommodatable data rate/channel spacing :

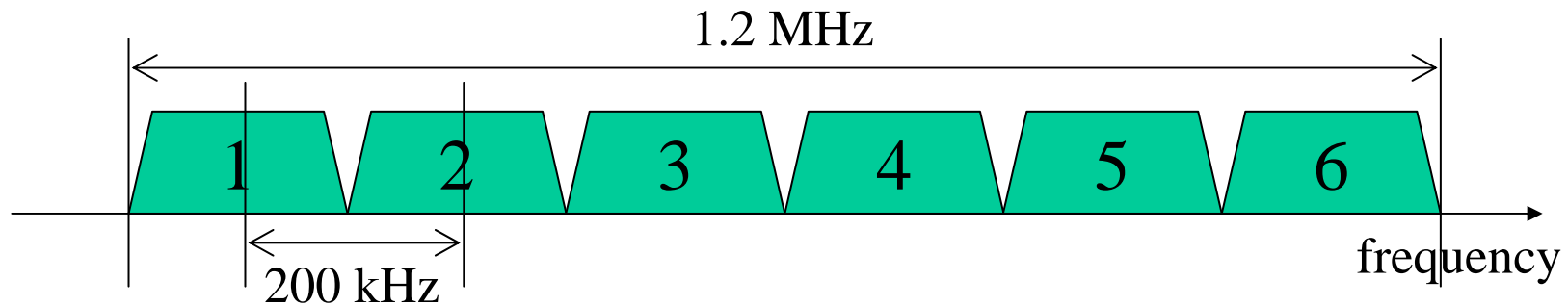
$$(R/B) \cdot l \quad (l=1,\dots,6)$$

l	1	2	3	4	5	6
R [kbps]	12.5	25	37.5	50	62.5	75
B [kHz]	50	100	150	200	250	300



Hopping Pattern in FH-GFSK

- 6 sub-channels in a BW=1.2 MHz channel



- 6 hopping sequences based on one coincident code (OCC) are defined.
 - 6 WBANs are simultaneously accommodated.

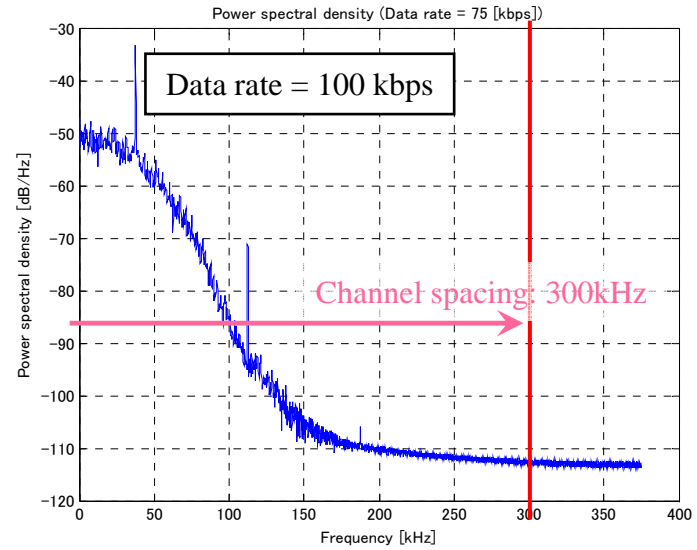
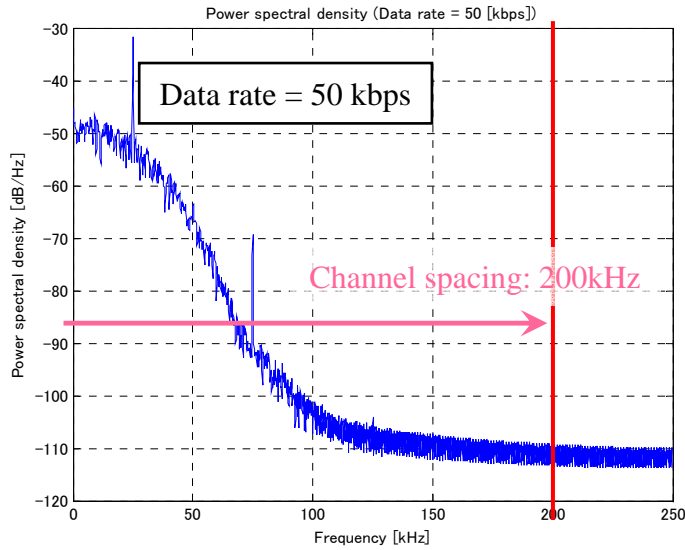
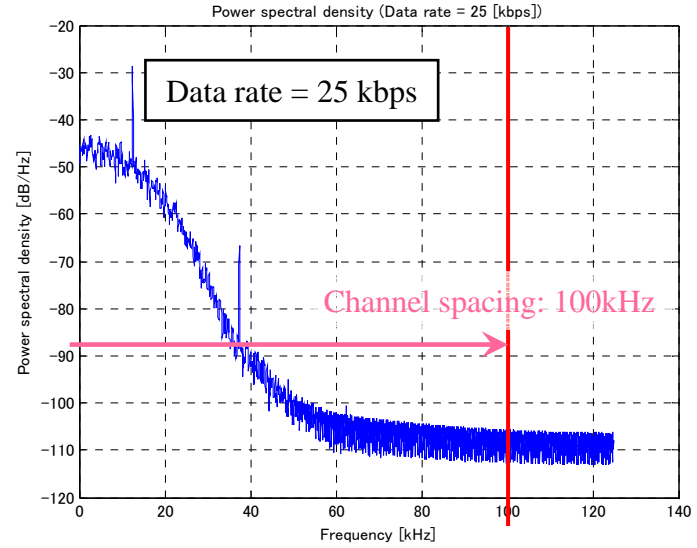
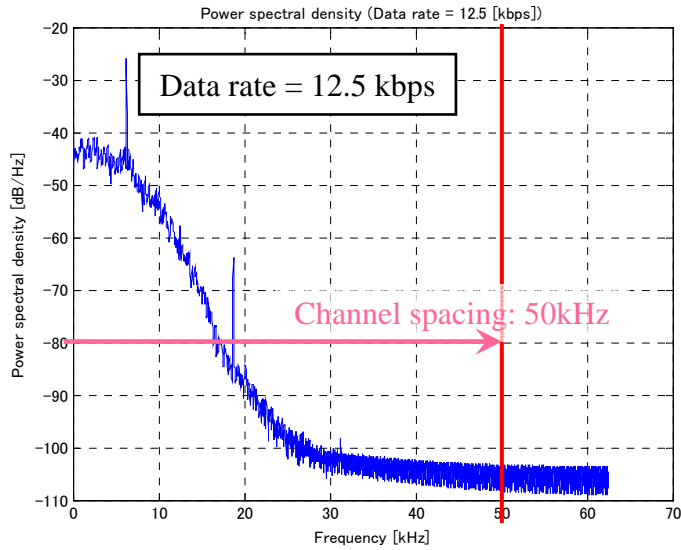
FH_SEQ(0)	1	2	3	4	5	6
FH_SEQ(1)	5	3	1	6	4	2
FH_SEQ(2)	4	1	5	2	6	3
FH_SEQ(3)	6	5	4	3	2	1
FH_SEQ(4)	2	4	6	1	3	5
FH_SEQ(5)	3	6	2	5	1	4

Interference and coexistence

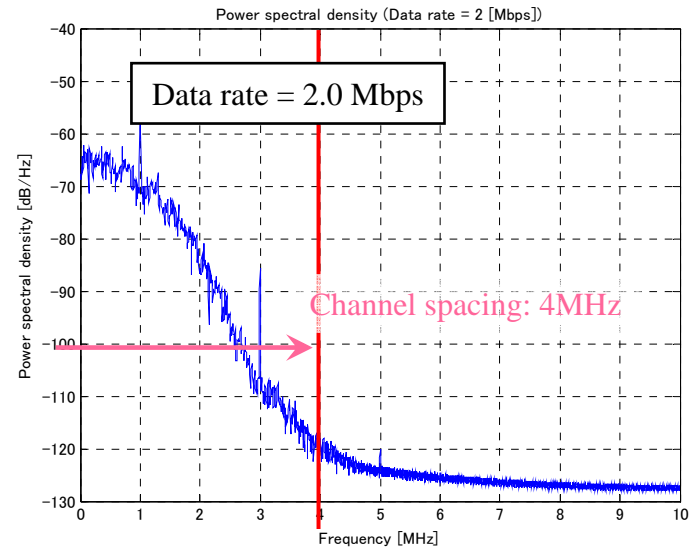
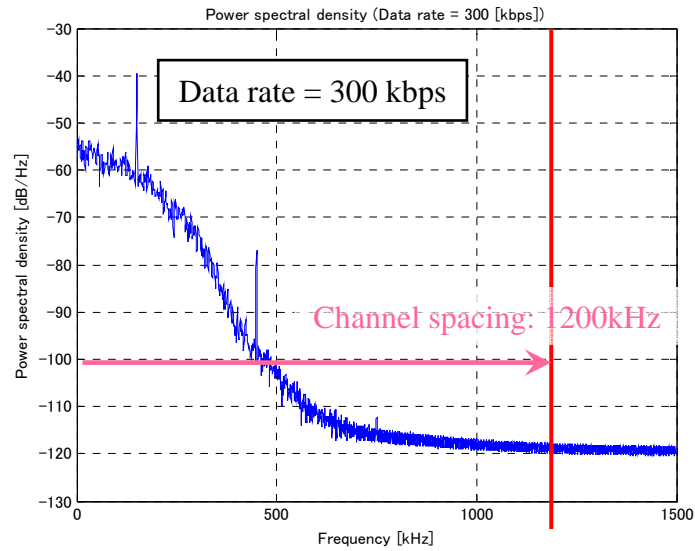
- MICS and WMTS
 - These are the frequency bands authorized for medical uses, in principle, with interference free
 - More than ten channels can be accommodated in a frequency band, so a BAN can be supported in a different frequency channel, in principle, with inter-BAN interference free

- ISM
 - More than ten physical channels can be accommodated in a frequency band, so a BAN can be supported in a different frequency channel, in principle, with inter-BAN interference free

Tx Spectrum (1)

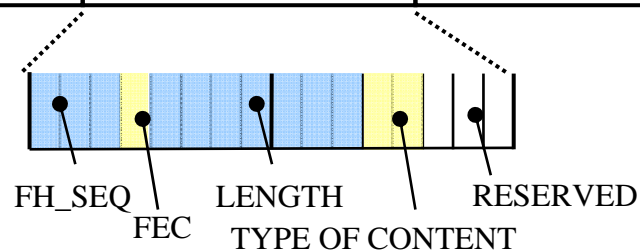
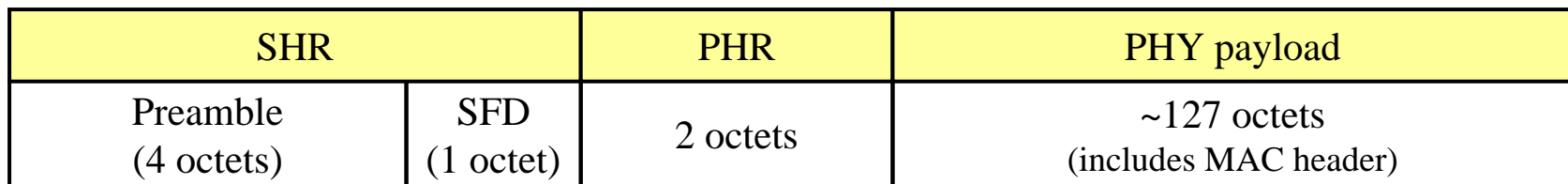


Tx spectrum (2)



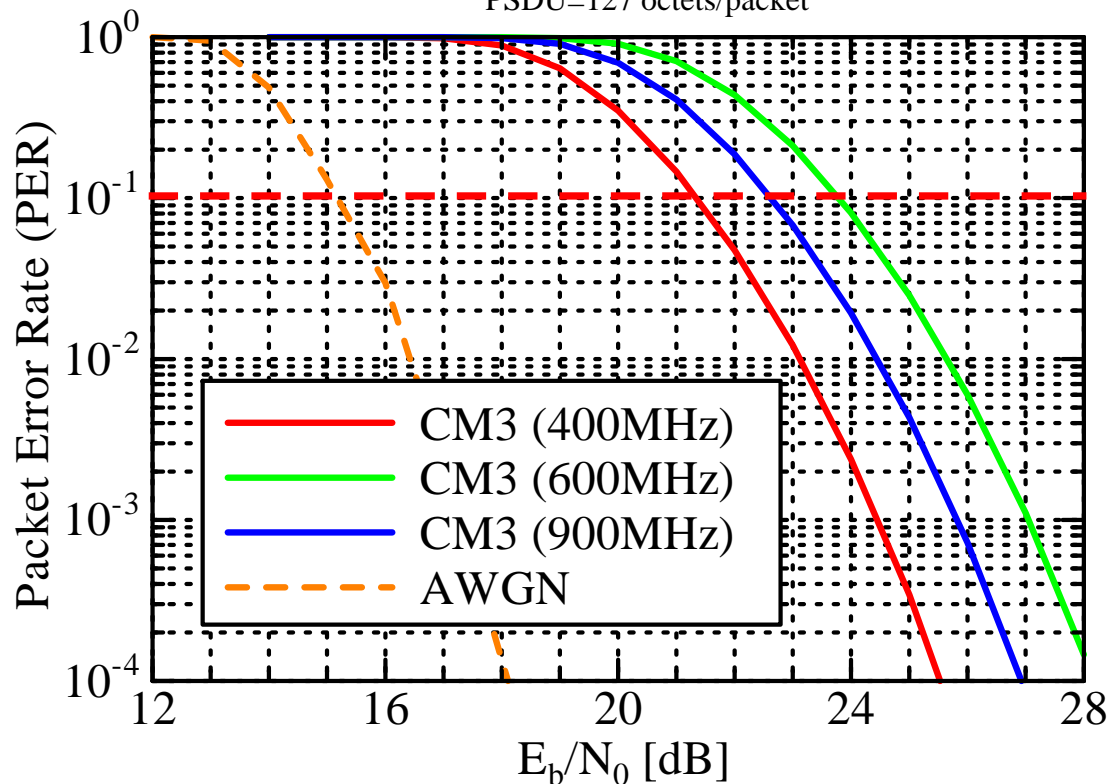
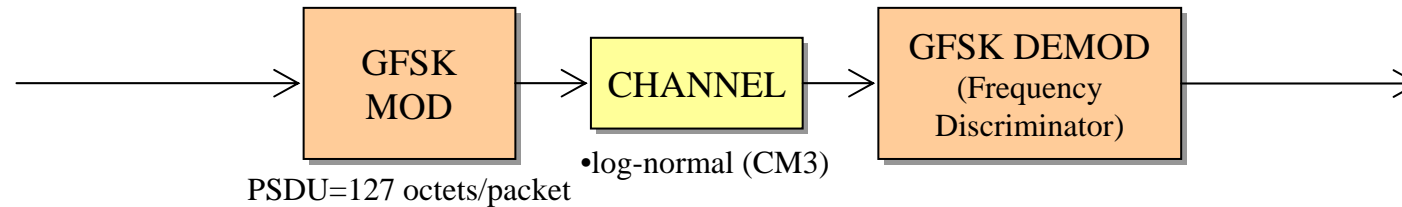
Packet format

- SHR
 - Preamble: 4 octets (0xAA)
 - SFD (start frame delimiter): 1 octet
- PHR
 - Length: 2 octets
 - FH_SEQ: 0~5 (000~101), FEC: ON/OFF (0/1), LENGTH: ~127 (~1111111)
 - TYPE OF CONTENT: medical or non-medical, continuous packets or not, etc.
- PHY payload: ~127 octets



Performance evaluation

- For wearable WBAN (No FEC)



Channel model	Required Eb/N0 for PER of 10 % (PSDU=127 octets)
AWGN	15.1 dB
CM3 (400 MHz) log-normal ($\sigma=4.63$)	21.3 dB
CM3 (600 MHz) log-normal ($\sigma=5.99$)	23.7 dB
CM3-A (900 MHz) log-normal ($\sigma=5.35$)	22.5 dB

Performance evaluation

- Wearable WBAN in 400 MHz
 - Channel model: CM3 (Average path loss @ 3m: 45.0 dB, 3σ : 13.9 dB)

Data rate	Modulation	Rx BW	FEC	Tx power	Required Eb/N0 (PER=10%)	Average path loss (3m)	IL*	NF*	Link margin
12.5 kbps	GFSK	50 kHz	None	0 dBm	21.3 dB	45.0 dB (CM3)	10dB	10dB	40.7 dB
25.0 kbps		100 kHz							37.7 dB
37.5 kbps		150 kHz							36.0 dB
50.0 kbps		200 kHz							34.7 dB
62.5 kbps		250 kHz							33.7 dB
75.0 kbps		300 kHz							32.9 dB
50.0 kbps	FH-GFSK	1.2 MHz (200kHz x 6)	None	0 dBm	21.3 dB	45.0 dB (CM3)	10dB	10dB	34.7 dB
300 kbps	GFSK	1.2 MHz	None	0 dBm	21.3 dB	45.0 dB (CM3)	10dB	10dB	26.8 dB

*: IL (implementation loss), NF (noise figure)

Performance evaluation

- Wearable WBAN in 600 MHz
 - Channel model: CM3 (Average path loss @ 3m: 57.6 dB, 3σ : 17.9 dB)

Data rate	Modulation	Rx BW	FEC	Tx power	Required Eb/N0 (PER=10%)	Average path loss (3m)	IL*	NF*	Link margin
12.5 kbps	GFSK	50 kHz	None	0 dBm	23.7 dB	57.6 dB (CM3)	10dB	10dB	25.7 dB
25.0 kbps		100 kHz							22.7 dB
37.5 kbps		150 kHz							20.9 dB
50.0 kbps		200 kHz							19.7 dB
62.5 kbps		250 kHz							18.7 dB
75.0 kbps		300 kHz							17.9 dB
50.0 kbps	FH-GFSK	1.2 MHz (200kHz x 6)	None	0 dBm	23.7 dB	57.6 dB (CM3)	10dB	10dB	19.7 dB
300 kbps	GFSK	1.2 MHz	None	0 dBm	23.7 dB	57.6 dB (CM3)	10dB	10dB	11.9 dB

*: IL (implementation loss), NF (noise figure)

Performance evaluation

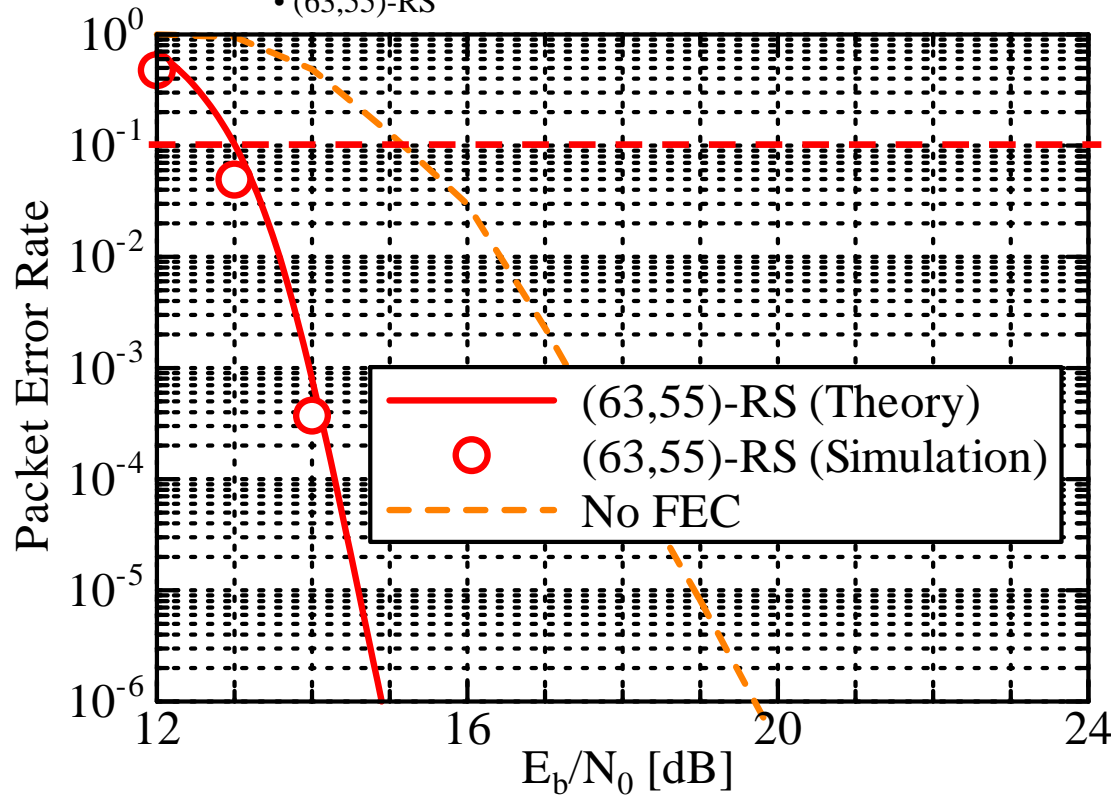
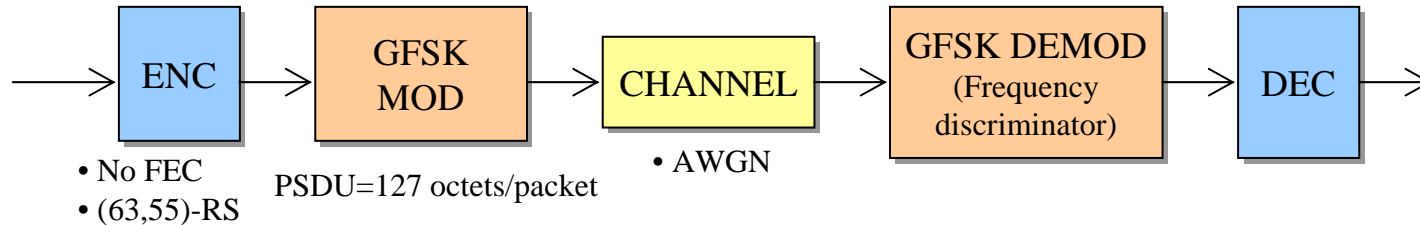
- Wearable WBAN in 900 MHz
 - Channel model: CM3-A (Average path loss @ 3m: 59.2 dB, 3σ : 16.0 dB)

Data rate	Modulation	Rx BW	FEC	Tx power	Required Eb/N0 (PER=10%)	Average path loss (3m)	IL*	NF*	Link margin
12.5 kbps	GFSK	50 kHz	None	0 dBm	22.5 dB	59.2 dB (CM3)	10dB	10dB	22.3 dB
25.0 kbps		100 kHz							19.3 dB
37.5 kbps		150 kHz							17.5 dB
50.0 kbps		200 kHz							16.3 dB
62.5 kbps		250 kHz							15.3 dB
75.0 kbps		300 kHz							14.5 dB
50.0 kbps	FH-GFSK	1.2 MHz (200kHz x 6)	None	0 dBm	22.5 dB	59.2 dB (CM3)	10dB	10dB	16.3 dB
300 kbps	GFSK	1.2 MHz	None	0 dBm	22.5 dB	59.2 dB (CM3)	10dB	10dB	8.5 dB

*: IL (implementation loss), NF (noise figure)

Performance evaluation

- For implantable WBAN



FEC	Required Eb/N0 for PER of 10 %
No FEC	15.1 dB (PSDU=127octets)
(63,55)-RS	12.9 dB (PSDU=2RS codeword=96octets)

Performance evaluation

- Implantable WBAN (without FEC case)

Data rate	Modulation	Rx BW	Duty ratio	FEC	Tx power	Required Eb/N0 (PER=10%)	Path loss		IL*	NF*	Link margin
							In-body (150 mm)	Outside (2.85m)			
12.5 kbps	GFSK	50 kHz	5 %	None	-16dBm (MICS)	15.1 dB (127-octet PSDU)	34 dB** (CM4)	33.6 dB (free-space)	10dB	10dB	21.3dB
25.0 kbps		100 kHz									18.3dB
36.5 kbps		150 kHz									16.5dB
50.0 kbps		200 kHz									15.3dB
62.5 kbps		250 kHz									14.3dB
75.0 kbps		300 kHz									13.5dB
50.0 kbps	FH-GFSK	1.2 MHz (200kHz x 6)	5 %	None	-16 dBm (MICS)	15.1 dB (127-octet PSDU)	34 dB** (CM4)	33.6 dB (free-space)	10dB	10dB	15.3 dB

*: IL (implementation loss), NF (noise figure)

** : Reference [21] in doc. IEEE802.15-08-0780-09-0006

2 Mbps	GFSK	4 MHz	100 %	None	0 dBm	15.1 dB (127-octet PSDU)	64.7dB (CM2, deep tissue)	0 dB (body surface)	10dB	10dB	5.3dB
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Performance evaluation

- Implantable WBAN (with FEC case)

Data rate	Modulation	Rx BW	Duty ratio	FEC	Tx power	Required Eb/N0 (PER=10%)	Path loss		IL*	NF*	Link margin
							In-body (150 mm)	Outside (2.85m)			
12.5 kbps	GFSK	50 kHz	5 %	RS	-16dBm (MICS)	12.9 dB	34 dB** (CM4)	33.6 dB (free-space)	10dB	10dB	23.5dB
25.0 kbps		100 kHz									20.5dB
36.5 kbps		150 kHz									18.7dB
50.0 kbps		200 kHz									17.5dB
62.5 kbps		250 kHz									16.5dB
75.0 kbps		300 kHz									15.7dB
50.0 kbps	FH-GFSK	1.2 MHz (200kHz x 6)	5 %	RS	-16 dBm (MICS)	12.9 dB	34 dB** (CM4)	33.6 dB (free-space)	10dB	10dB	17.5 dB

*: IL (implementation loss), NF (noise figure)

**: Reference [21] in doc. IEEE802.15-08-0780-09-0006

2 Mbps	GFSK	4 MHz	100 %	RS	0 dBm	12.9 dB	64.7dB (CM2, deep tissue)	0 dB (body surface)	10dB	10dB	7.4dB
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Comparison Criteria

Criteria	Proposed capability
1. Regulatory	Compliant with TG6 regulatory document in multiple frequency bands
2. Raw PHY data rate	Mandatory data rate is 50 kbps. Optionally, 12.5 kbps~2 Mbps supported
3. Transmission distance	PER and link budget shown to support 10 % PER for 127 octets at 3 meters at the mandatory mode.
4. Packet error rate	
5. Link budget	
6. Power emission level	0 dBm / -16 dBm maximum EIRP
7. Interference and coexistence	NB PHY allows to take 10 or more physical channels. The use of FH sequence enables to accommodate 6 WBAN. FH-GFSK provides robustness to interferences.
8. Security	(MAC issue)
9. Reliability	Link margin is sufficient for the expected path loss shown in 15.6 channel model.
10. Quality of service	(MAC issue)
11. Scalability	Scalable Rx implementation is supported to provide a tradeoff between performance and power consumption.
12. MAC transparency	(MAC issue)
13. Power efficiency	Power efficient implementation is available.
14. Topology	(MAC issue)
15. Bonus point	

Conclusions

NICT's GFSK-based narrowband PHY

- A straightforward, simple and efficient solution for satisfying the requirements in medical scenes
- Supported by matured technology