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

Submission Title: [NICT's PHY proposal --- Part 3: Narrowband PHY solution]
Date Submitted: [March 9, 2009]
Source: [Shinsuke Hara, Kenichi Takizawa, Takahiro Aoyagi, Ryuji Kohno] Company [NICT]
Address [3-4 Hikarino-oka, Yokosuka, Japan]
Voice:[+81 468475085], FAX: [+81 468475431], E-Mail:[takziawa@nict.go.jp]

Re: TG6 Call For Proposals, IEEE P802.15-08-0829-01-0006, 3 December 2008.

Abstract: A simple and power-efficient PHY based on GFSK is proposed as a narrowband PHY solution operable in MICS and WMTS bands.

Purpose: This document is intended as a proposal for addressing the requirements of the TG6 standard.

NICT's PHY Proposal

Part 3: Narrowband PHY solution

Shinsuke Hara, Kenichi Takizawa, Takahiro Aoyagi, Ryuji Kohno
National Institute of Information and Communications Technology (NICT)

Why do we need a narrowband PHY solution?

Wideband PHY will not be easily applied to the medical-authorized frequency bands such MICS and WMTS bands, because of

- Emission power limit
- Channel spacing
- Modulation type

Summary

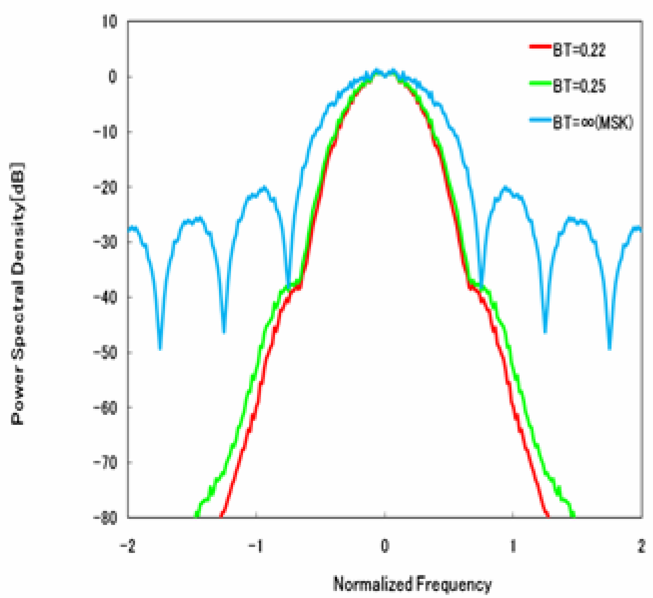
- Target data rate
  - Mandatory mode: less than 300 kbps
    - ✓ Available Frequency bands: MICS band (402-405 MHz), WMTS bands (608-614, 1395-1400, 1427-1432 MHz) and ISM bands (433 MHz, 868 MHz, 915 MHz)
  - Optional mode: 2 Mbps
    - ✓ Available Frequency bands: ISM bands (433 MHz, 600 MHz, 950 MHz)
- PHY solution
  - G(aussian-filtered) FSK modulation with an optional convolutional code with R=1/2 (133, 171) for longer payloads

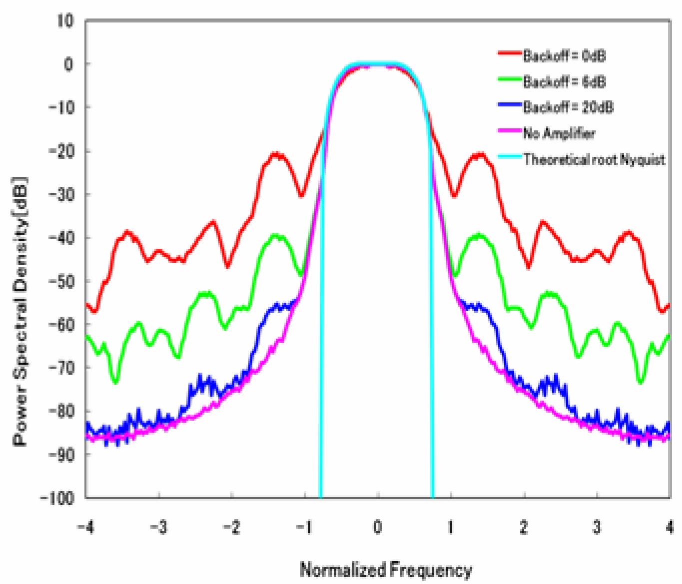
Why do we employ GFSK?

- 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

Systematic comparison between FSK and PSK

	FSK	PSK
Nonlinear amplification	OK	NG (larger out-band radiation)
Detection	Non-coherent (w/o PLL)	Coherent (w/ PLL)
Preamble length	Short	Long





ETSI BRAN's AM/AM conversion and AM/PM conversion models for class-AB nonlinear amplifiers

Why is FSK suitable for medical applications ?

FSK is a robust modulation scheme against harsh channel conditions encountered in medical scenes

- Erroneous channels
- Fading and shadowing
- Sudden blocking

Supportable applications

Low data rate applications in 08-0407-05 can be supported by the narrowband PHY mainly in hospitals, such as

Class A: Medical applications

A1-1: Wearable BAN

Electroencephalogram EEG, Electrocardiogram ECG, Electromyography EMG, Vital signals monitoring, Temperature (wearable), Respiration monitor (wearable), Heart rate monitor (wearable), Pulse oximeter SpO2 wearable, Blood pressure monitor (wearable), pH monitor (wearable), Glucose sensor (wearable), Hearing aid (ear to ear communication)

A1-1a: Disability assistance

Muscle tension monitor, Muscle tension stimulation, Weighing scale (wearable), Fall detection (wearable)

A1-1b: Human performance management

Aiding professional and amature sport training, Assessing emergency service personnel performance, Assessing soldier fatigue and battle readiness, Non Human (Animal)

A1-2a: Implant BAN

Glucose sensor (implant), Cardiac arrhythmia monitor/recorder (implant), Brain liquid pressure sensor (implant) Endoscope capsule (gastrointestinal), Drug delivery capsule, Deep brain stimulator (eg, Epilepsy, Parkinson's therrepy), Cortical stimulator, Visual neuro-stimulator, Audio neuro stimulator, Brain-computer interface

A1-2b: Remote control of medical devices

Pacemaker, Implantable cardioverter defibrallitor ICD, Implanted actuator, Insulin pump, Hearing aid (wearable and implanted), Retina implants

Radio regulations

- MICS
  - 402 - 405 MHz, BW is less than 300 kHz (@-20 dB).
  - Transmission power is less than 25 uW (EIRP)
  - Listen-before-talk (LBT) is necessary: within 5 sec prior to initiating a session, outside device must monitor channels for at least 10 ms.
  - Outside device initiates every communication except “medical implant event”.
- WMTS
  - No restriction on PHY format in 1395-1400 and 1427-1432 MHz bands
  - 1.5 MHz channel spacing with spread spectrum in 608-614 MHz band
  - BW is less than 1.7 MHz for transmission power of less than 1 mW (erp)
  - 50 kHz channel spacing preferable for Japan and Europe

Data rate and modulation

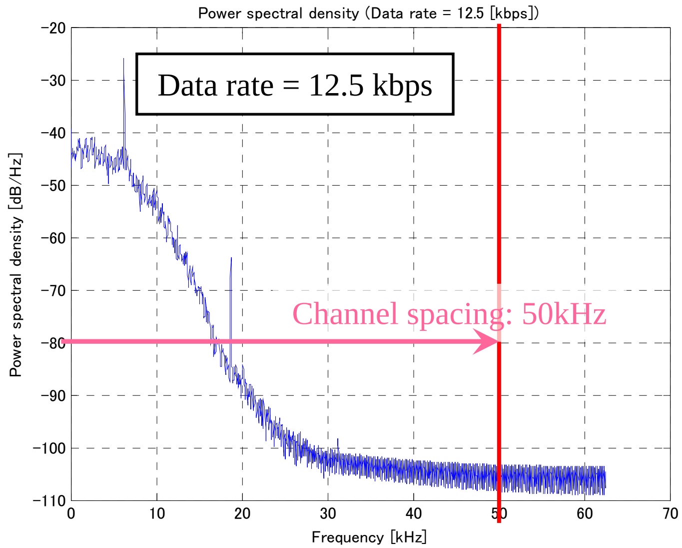
- GFSK (modulation index β =1.0, and *BT*=0.5)
- Multiple sets of channel spacing/data rate
- No specific band plan
- Optional convolutional code with R=1/2 (133, 171)

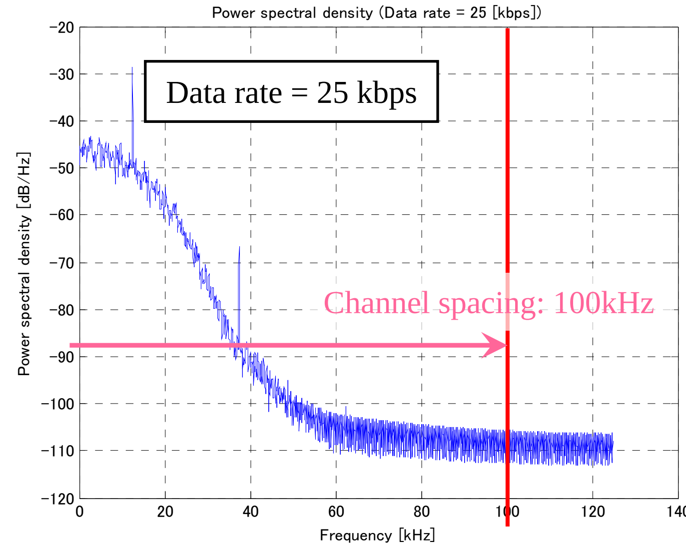
Data rate	Modulation	Parameters	Channel spacing	FEC	Mandatory	Target frequency bands
12.5 kbps	GFSK	β=1.0, *BT*=0.5	50 kHz	Mandatory: None Optional: Convolutional code (R=1/2, 133,171)	No (A single channel spacing allowed in a frequency band)	MICS, WMTS (except for 608-614MHz), ISM
25.0 kbps			100 kHz			
50.0 kbps			200 kHz			
75.0 kbps			300 kHz			
300.0 kbps			1.2 MHz			
50.0 kbps	FH-GFSK	β=1.0, *BT*=0.5	1.2 MHz	None	Yes	WMTS (608-614MHz)
2 Mbps	GFSK	β=1.0, *BT*=0.5	4 MHz	None	No	ISM

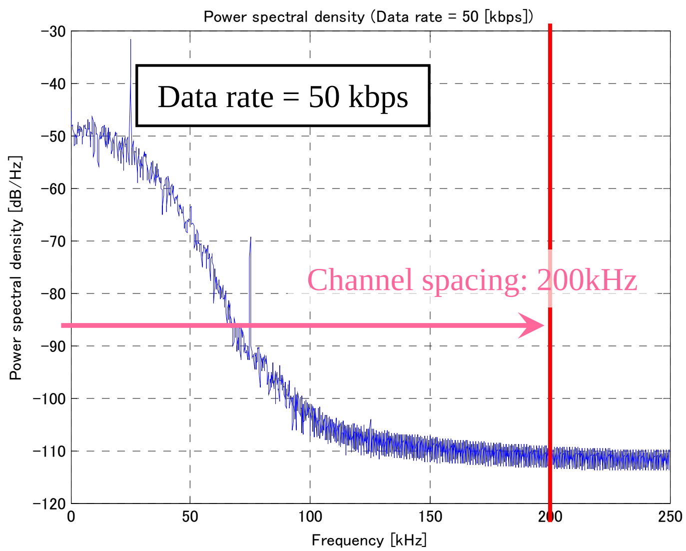
Interference and coexistence

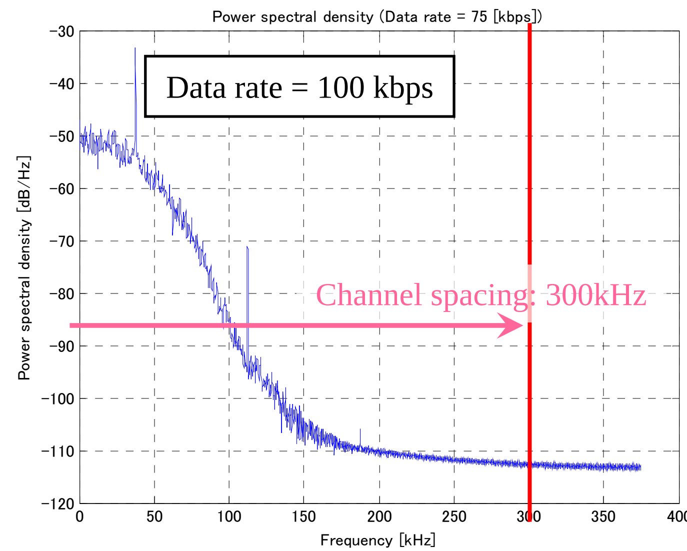
- MICS and WMTS
  - These are the frequency bands authorized for medical uses, in principle, with interference free
  - More than ten channels can be accommodated in a frequency band, so a BAN can be supported in a different frequency channel, in principle, with inter-BAN interference free
- ISM
  -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

Power spectra



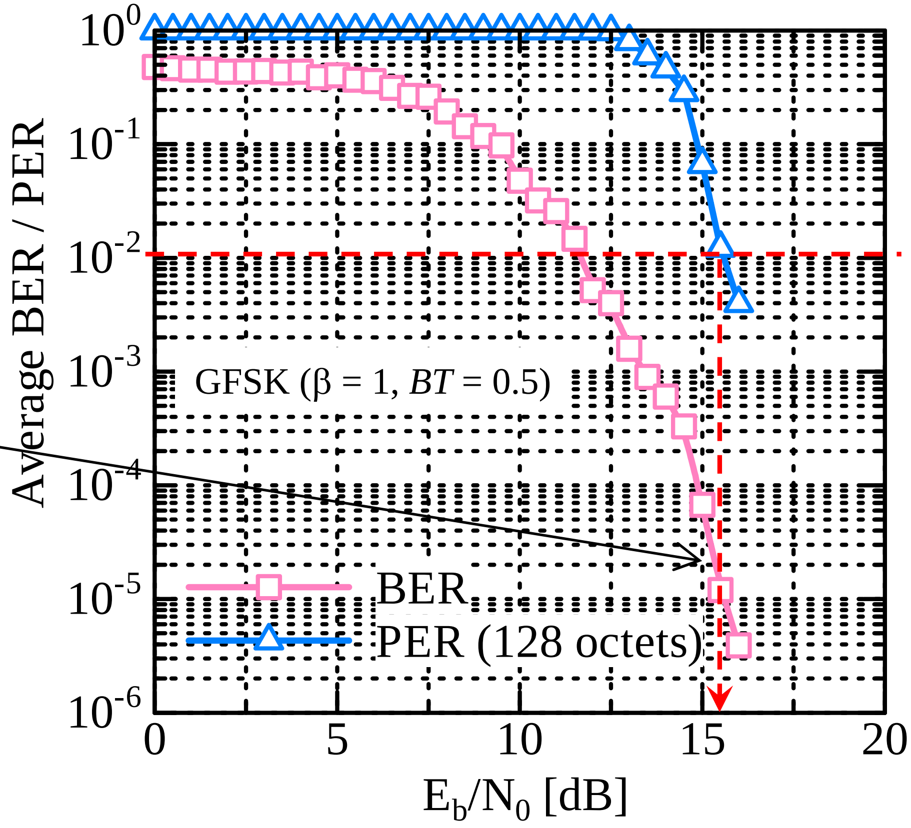






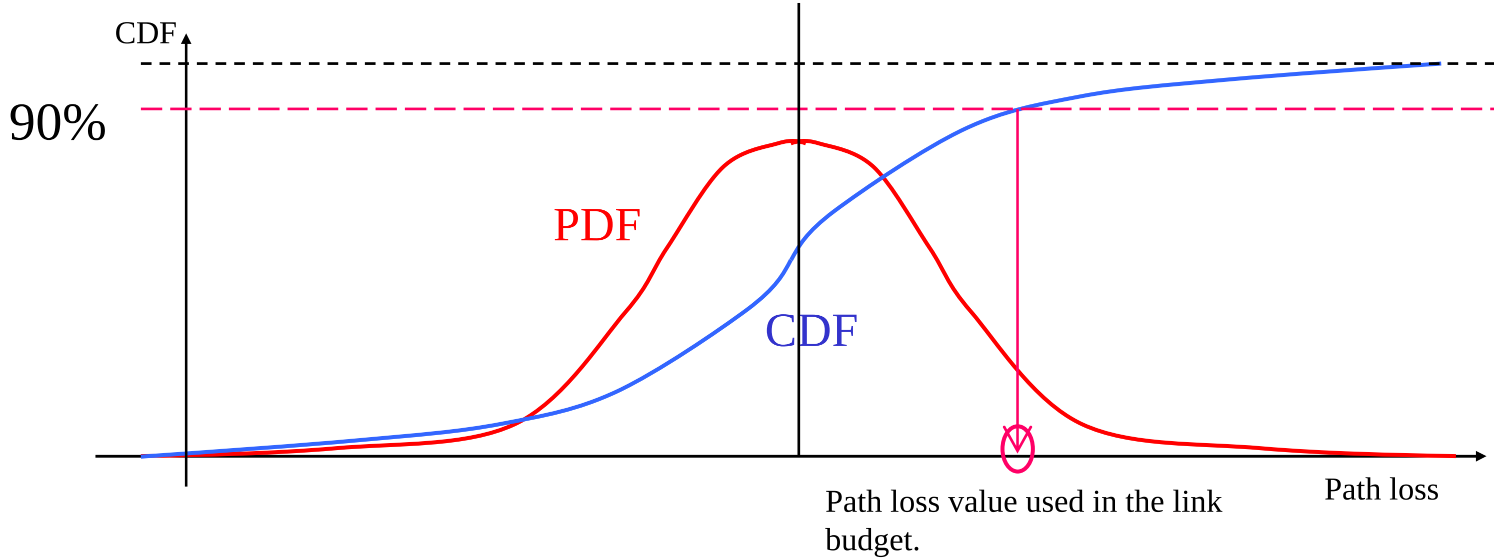
Performance evaluation (1/4)

- BER and PER performance
  - Receiver: frequency discriminator
  - FEC: none
  - Channel: AWGN
- If the target PER is 10^{-2}, its required Eb/N0 is 15.6 dB.



Performance evaluation (2/4)

- Link budget
  - The path loss in the budget is based on 15.6 channel model document. (Doc. IEEE P802.15-08-0780-05-0006)
  - Each path loss model in the 15.6 document has a normal distribution. So, we use the 90-% path loss value in its CDF at the distance of 3 m.
    - for the path loss model which is given by $PL(d) = a*\log_{10}(d)+b+S$, where S has normal distribution with standard deviation of σ, the 90-% path loss in the CDF is $PL(d) = a*\log_{10}(d)+b+1.28*\sigma$.



Performance evaluation (3/4)

- Implantable WBAN (NIST-NICT model)

Data rate	Modulation	Rx BW	NF*	Duty ratio	FEC	Required Eb/N0 (PER = 10^{-2})	Path loss In-body (150 mm)	Path loss Outside (2.85m)	Tx power	Margin
12.5 kbps	GFSK	50 kHz	10 dB	10 %	None	15.6 dB	64.7 dB (CM2, deep tissue)	33.6 dB (free-space)	-16 dBm (MICS)	17.2 dB
25 kbps		100 kHz								14.1 dB
50 kbps		200 kHz								11.1 dB
75 kbps		300 kHz								9.3 dB
300 kbps	GFSK	1.2 MHz	10 dB	100 %	None	15.6 dB	64.7 dB (CM2, deep tissue)	0 dB (body surface)	-10 dBm (eg. ISM)	22.9 dB

Data rate	Modulation	Rx BW	NF*	Duty ratio	FEC	Required Eb/N0 (PER = 10^{-2})	Path loss In-body (150 mm)	Path loss Outside (0 m)	Tx power	Margin
2 Mbps	GFSK	4 MHz	10 dB	100 %	None	15.6 dB	64.7 dB (CM2, deep tissue)	0 dB (body surface)	-10 dBm (eg. ISM)	27.7 dB

*: NF of 10 dB is tentative value.

Performance evaluation (4/4)

- Wearable WBAN (NICTA model)
  - 900 MHz

Data rate	Modulation	Rx BW	NF*	FEC	Required Eb/N0 (PER = 10^{-2})	Path loss (3m)	Tx power	Margin
12.5 kbps	GFSK	50 kHz	10 dB	None	15.6 dB	66.12 dB CM3	0 dBm	34.2 dB
25 kbps		100 kHz						31.2 dB
50 kbps		200 kHz						28.2 dB
75 kbps		300 kHz						26.5 dB
300 kbps		1.2 MHz						20.4 dB

*: NF of 10 dB is tentative value.

Conclusions

NICT's GFSK-based narrowband PHY

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

NICT’s PHY (with a common MAC)

- UWB PHY in UWB band
- Narrowband PHY in MICS and WMTS bands

is a systematic solution for efficiently providing medical and non-medical applications