IEEE P802.15

Wireless Personal Area Networks

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)
Title	**NICT Narrowband PHY Proposal**
Date Submitted	[January 11, 2010]
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Re:	This is in response to the TG6 Call for Proposals (CFP), IEEE P802.15-08-0811-03-0006.
Abstract	[The NICT narrowband PHY is described and detailed in response to the wireless BAN technical requirements document.]
Purpose	Submitted as the candidate proposal for TG6-PHY-MAC.
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1 Introduction

This document contains the technical description of a physical layer (PHY) proposal to IEEE TG6, wireless body area networks (BANs), targeting wearable and implantable medical BAN applications. It is submitted in response to the TG6 Call for Proposals. The proposed PHY is based on Gaussian-filtered frequency shift keying (GFSK).

1.1 Medical BAN applications

The PHY described in this document is designed to be used in various medical applications, which may include:

- EEG (Electroencephalography)
- ECGs (Electrocardiograms)
- EMG (Electromyography)
- Blood pressure monitors
- Blood SpO_2 monitors
- Blood pH monitors
- Respiration monitors
- Posture (human position) monitors
- Vital signals monitoring
- Temperature measurement (wearable thermometers)
- Respiratory monitors
- Wearable heart rate monitors
- Wearable blood pressure monitors
- Wearable glucose sensors
- Muscle tension sensing and stimulation
- Wearable weighing scales
- Fall detection
- Sports training aids

In these applications, the required data rate is typically 100 kbps or less [1]. Many other health and medical applications may also be possible, and the PHY is not limited to health and medical applications. However, health and medical applications are the focus of this proposal.

2 Narrowband PHY

The proposed narrowband PHY solution targets both wearable and implantable wireless BANs (WBANs) in the sub-GHz band. This PHY is based on GFSK, which generates a signal waveform with a constant envelope. This digital modulation has been adopted in many wireless communication systems in order to realize low-cost transceivers that consume less power. In addition, the use of GFSK enables the deployment of highly power-efficient transceivers, because GFSK permits one to employ a nonlinear amplifier at the transmitterside and noncoherent detection at the receiver side.

2.1 Overview

Table presents an overview of the narrowband PHY based on GFSK, with a modulation index β of 1.0 and a BT product of 0.5. The proposed solution is designed to operate in the sub-GHz band, in which medical implantable communications systems (MICS) (402–405 MHz), Japanese medical telemetry systems (420–450 MHz), Japanese active RFID (950–955 MHz), and ISM bands in the sub-GHz band are included. In this proposal, no specific band plan is shown, but channel spacing for each data rate is provided. In order to accommodate different data rates (channel spacing), a channel-bonding mechanism is introduced. Optionally, a frequency hopping (FH) mechanism is supported, in order to mitigate interference from other wireless devices or industrial equipment such as microwave ovens and medical electrical surgery devices.

Table 1: System overview of this GFSK-based narrowband PHY proposal.

Parameter	Value
Modulation	GFSK (β = 1.0, BT = 0.5)
Data rate	12.5 kbps ~ 2.0 Mbps (mandatory : 50 kbps)
Channel spacing	50 kHz ~ 4.0 MHz (mandatory : 200 kHz)
FEC	Mandatory : none Optional : (63,55)-RS code over GF(2^6)
Frequency hopping	Optinally supported

2.2 Specifications

Figure shows the data rates supported by this proposal. The data rates up to 75 kbps without the FH function are designed to use MICS, ISM, and other available bands in the sub-GHz band. The mandatory data rate is 50 kbps under a channel spacing of 200 kHz. The data rate of 50 kbps is for FH, and other data rates are for the ISM band. The use of FEC is not included, but optionally, a (63, 55) Reed-Solomon code over GF (2^6) is introduced. When the RS code is used, data rates decrease according to the coding rates. The optional mode using FH utilizes a channel spacing of 1.2 MHz over 6 channels, but the channel spacing of each channel is set to 200 kHz.

Table 2: Data rates supported by this narrowband PHY.

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

The data rates among 12.5, 25.0, 37.5, 50.0, 62.5, and 75.0 kbps without FH are accommodated within a given frequency band, as shown in Figure 1. In this accommodation mechanism, the base data rate and base channel spacing are set to 12.5 kbps and 50.0 kHz, respectively. Then, multiplications of the base data rate and channel spacing are allowed up to 6. Table 3 summarizes the available data rates and channel spacing by using this accommodation mechanism.

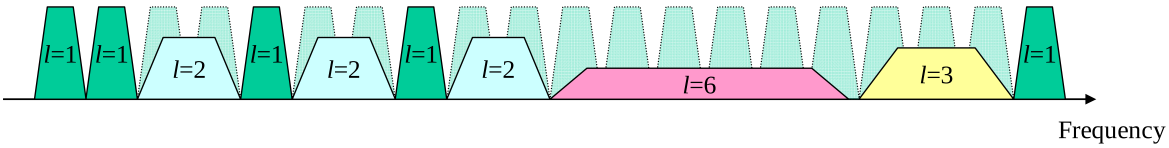


Figure 1: Conceptual image of accommodation of different data rates.

Table 3: Accommodation of different data rates (channel spacings) in given frequency band.

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

This narrowband PHY proposal includes an FH option in order to reduce the impact of radio interference. Figure 2 shows an example sketch of channel assignment for the FH option. As shown in this sketch, FH is supported among 6 sub-channels when the channel spacing between two sub-channels is 200 kHz. Table 4 displays the hopping patterns that are obtained from a set of one-coincidence codes. By introducing the set of hopping patterns, 6 WBANs are simultaneously accommodated.

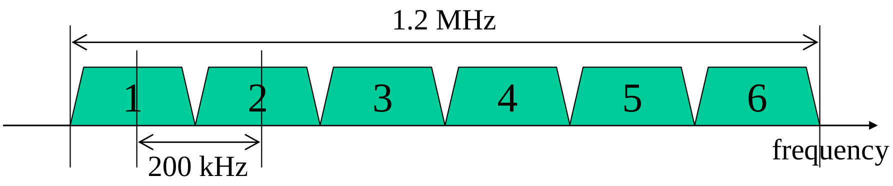


Figure 2: Frequency-hopping (FH) mechanism.

Table 4: Hopping sequences supported by this proposal.

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

Here, a short discussion on interference and coexistence is provided. The MICS and WMTS bands are the frequency bands authorized for medical uses; in principle, these bands are interference free. In addition, more than 10 channels can be accommodated in a frequency band; therefore, a BAN can be supported in a different frequency channel, in principle, with interference-free inter-BAN operation. In ISM bands, more than 10 physical channels can be accommodated, as well as MICS and WMTS bands. Therefore, the requirement of the Technical Requirements Document (requirement 15.6), which states that the standard shall support 10 BANs as simultaneously operating networks, is satisfied.

Figure 4 gives a basic packet format supported by this PHY proposal. A short header (SHR) has a 4-octet preamble and a 1-octet start frame delimiter (SFD) given by 0xAA. The PHY header (PHR) consists of 2 octets, in which the PHR contains 3 bits to indicate the selected FH sequence (FH_SEQ), 1 bit to send the ON/OFF status of the FEC coding (FEC), 7 bits for the length of the following payload, 2 bits to notify the application type (medical or nonmedical, continuous packet or not, etc.), and 3 bits as reserved bits. The maximum length of the PHY payload is 127 octets.

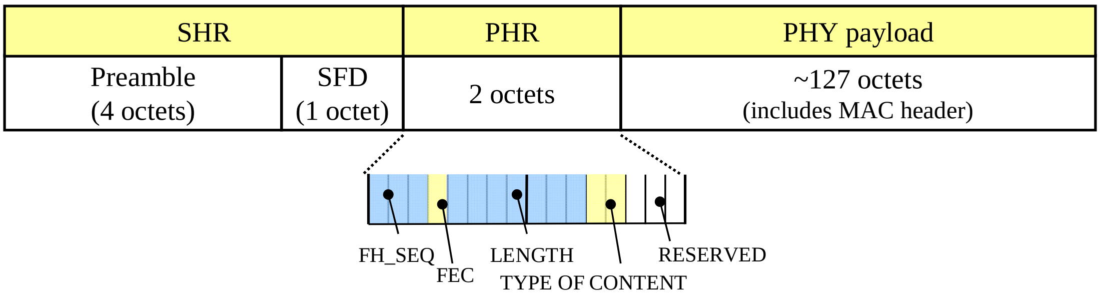


Figure 4: Packet format in a PHY layer.

2.3 **Radio performance**

In this section, which describes the system performance, the link budget corresponding to a couple of frequency bands are shown. Each required Eb/N0 in the link budget is obtained from a MATLAB simulation, in which a statistical channel model provided by requirement 15.6 [2] is used.

First, a link budget for a wearable WBAN is shown. In this evaluation, the use of no FEC and a frequency discriminator at the Rx side is assumed, as shown in Figure 5. The evaluated frequency bands include 400 MHz, 600 MHz, and 900 MHz. The channel model used in the simulation is CM3-A. The length of payload is set to 127 octets. Figure 6 shows the packet error rate (PER) vs. Eb/N0, as well as the required Eb/N0 for PER of 10% for each frequency band. By using the required Eb/N0, the link budget for each frequency band is calculated, as listed in Table 5. As can be observed, this PHY creates sufficient link margins for every data rate and frequency band. In this evaluation, both an implementation loss (IL) of 10 dB and a noise figure (NF) of 10 dB are included.

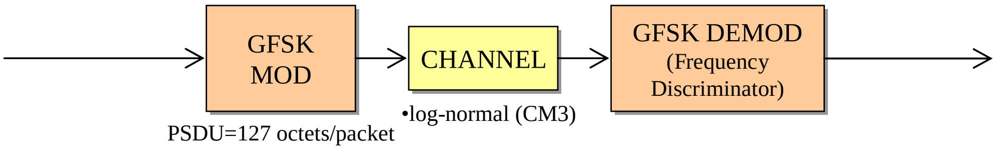
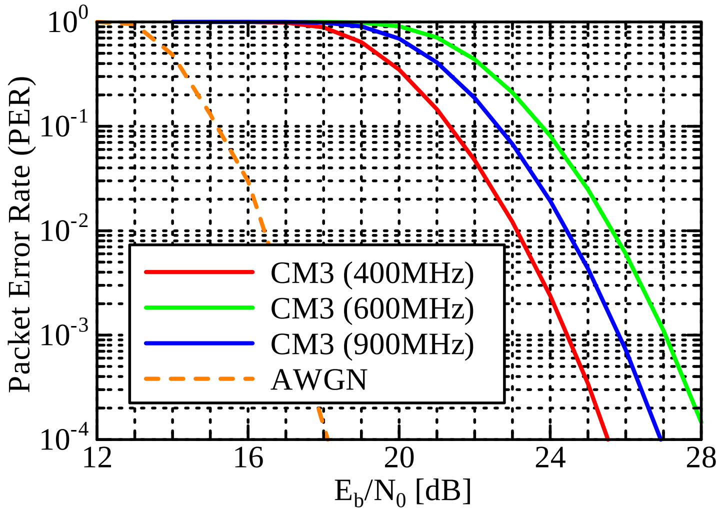


Figure 5: Block diagram of performance evaluation of wearable WBAN.



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

Figure 6: Simulation result of packet error rate (PER) vs. Eb/N0 for wearable WBAN.

Table 5: Link budget for wearable WBAN.

(a) Wearable WBAN at 400 MHz

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

(b) Wearable WBAN at 600 MHz

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

(c) Wearable WBAN at 900 MHz

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

Next, a link budget for an implantable WBAN is calculated. In implantable WBANs, the signal level is probably attenuated by the transmission media. In order to increase the link margin, the use of optional FEC is also considered. A block diagram of the evaluation model is shown in Figure 7. The FEC employed is a (63, 55) RS code over GF (2^6). At the receiver side, a hard decision on each codeword bit is sent to the RS decoder. The results are shown in Figure 8. In the no-FEC case, the length of a payload is set to 127 octets. On the other hand, the length of the payload in the FEC case is set to 2 code words, which is equivalent to 96 octets. Table 6 displays a link budget, in which both an IL of 10 dB and an NF of 10 dB are taken into account. The path loss of the in-body in every data rate except 2 Mbps is obtained from [3]. In the 2 Mbps case, a typical figure of CM2, which is given by the channel model document, is introduced. The link budget shows that this PHY proposal provides a link margin for every data rate. By introducing FEC coding, the link margin increases. For every data rate except 2 Mbps, the use of a MICS band is assumed. At the data rate of 2 Mbps, we assume that there is an available frequency band in which a Tx power of 0 dBm is acceptable over a frequency band of 4 MHz.

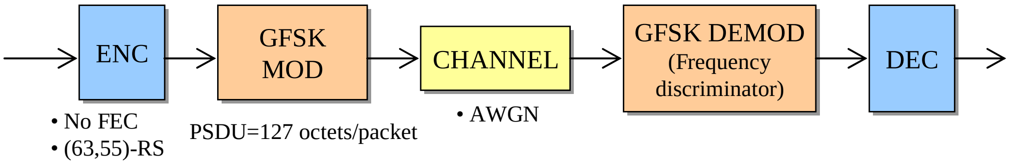
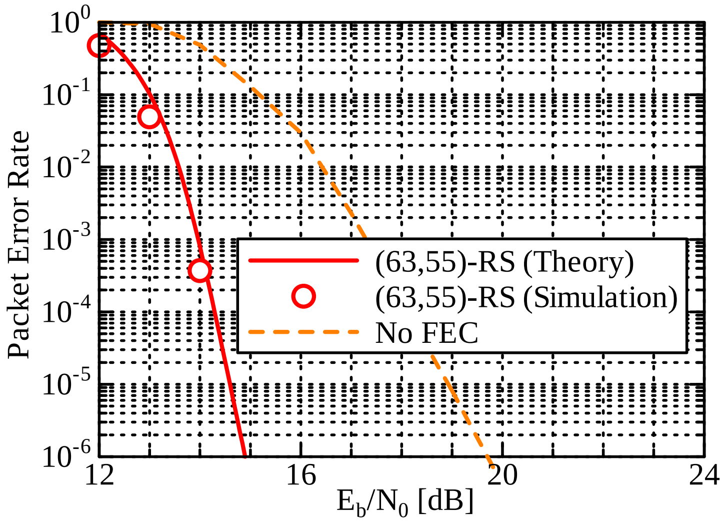


Figure 7: Block diagram of performance evaluation of implantable WBAN.



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)

Figure 8: Simulation result of packet error rate (PER) vs. Eb/N0 for implantable WBAN.

Table 6: Link budget for wearable WBAN.

(a) Implantable WBAN without FEC

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 (CM2)	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 (CM2)	33.6 dB (free-space)	10dB	10dB	15.3 dB
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

(b) Implantable WBAN with FEC

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** (CM2)	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** (CM2)	33.6 dB (free-space)	10dB	10dB	17.5 dB
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

3 Summary and concluding remarks

A narrowband PHY solution for wearable and implantable medical WBAN applications is described in this document. This solution satisfies the technical requirement 15.6 [4] and meets or exceeds the targets identified in the 15.6 proposal comparison criteria [5]. This GFSK-based narrow band PHY is proposed for standardization in response to the IEEE802.15.6 Call for Proposals.

4 References

[1] IEEE Task Group 6 (TG6), Application Matrix, 15-08-0406-00-006-tg6.

[2] K. Y. Yazdandoost, K. Sayrafian-Pour, “Channel Model for Body Area Network (BAN),” IEEE 802.15-08-0780-05-0006, February 2009.

[3] T. Aoyagi, J. Takada, K. Takizawa, H. Sawada, N. Katayama, K. Y. Yazdandoost, T. Kobayashi, H.-B. Li, and R. Kohno, “Channel Models for WBANs - NICT,” IEEE802.15-08-0416-04-0006, November 2008.

[4] IEEE 802.15.6, Technical Requirements Document (TRD), 15-08-0037-04-0006-ieee-802-15-6.

[5] IEEE 802.15.6, TG6 Proposal Comparison Criteria, 23 March 2009, IEEE P802.15-08-831-05-006.