A Study on SmartBAN Physical Layer Applying Multi-Level PSK Modulation

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Abstract

An Internet of Medical Things (IoMT) system has attracted attention. This research provides a study on an ETSI Smart Body Area Networks (SmartBAN), as one of the IoMT systems, physical layer (PHY) applying multi-level modulation. Specifically, comparative evaluation is performed to see how much packet error rate (PER) changes by changing the modulation scheme of the SmartBAN PHY from GFSK to several multi-level PSKs. Computer simulation shows that the multi-level PSK modulation is also useful in the wearable wireless body area networks (WBAN) channel model. In addition, it is shown how much the symbol rate can be improved with respect to the available frequency band. From these results, it is examined whether multi-level PSKs can be used for SmartBAN PHY by calculating the link budget and the receiver sensitivity.

1 Introduction

Recently, an Internet of Medical Things (IoMT) system has attracted attention to support a remote medical and health care [1, 2]. The system involves wearable wireless vital sign sensors or medical robots. Then, wireless body area networks (WBAN) are well-known IoMT systems [3-7]. WBAN consist of a collection of low power, miniaturized, invasive or non-invasive lightweight sensors with wireless communication capabilities that operate near the human body. By the way, system specifications for a physical layer (PHY) and a media access control layer (MAC) in smart body area networks (SmartBAN) were issued in April 2015. These specifications represent a standard for medical and other health care advanced by the European Telecommunications Standards Institute (ETSI) [6, 7]. Our previous research provided an integrated performance evaluation of the ETSI SmartBAN PHY while considering the preamble detection [8]. This study examines the applicability of multi-level phase shift keying (PSK) modulation to SmartBAN PHY.

2 SmartBAN PHY [7]

2.1 Frequency Spectrum

The SmartBAN uses a frequency band within 2401 MHz to 2481 MHz. Each channel has a bandwidth of 2 MHz. In addition, each center frequency is defined as the following equation:

$$f_c = 2402 + 2n \text{ MHz, for } n = 0 \text{ to } 39. \quad (1)$$

Here, n is the channel number.

2.2 Physical-Layer Protocol Data Unit

The physical-layer protocol data unit (PPDU) has a sixteen-bit preamble “1010101010101010” used for frequency synchronization, timing synchronization, and automatic gain control. The physical layer convergence protocol (PLCP) header consists of the packet length, PHY scheme and so on. The Physical-Layer Service Data Unit (PSDU) is either an encoded or uncoded MAC Protocol Data Unit (MPDU). The MPDU shall be encoded by CRC-8(-CCITT) and CRC-16(-CCITT) as an error detecting code.

2.3 Modulation and Error Controlling

The SmartBAN PHY uses Gaussian Frequency Shift Keying (GSFK) with a bandwidth-bit period product BT = 0.5 and modulation index h = 0.5 as a modulation scheme. Then, a scheme of repeatedly transmitting PPDUs and a scheme encoding the MPDU by using the (127, 113) BCH code as an error correcting code (ECC) can be used as an error controlling scheme.

3 PSDU Error Ratio Evaluation

PSDU error ratio (PSDUER) of the SmartBAN and several multi-level PSK modulation schemes is evaluated under the additive white Gaussian noise (AWGN) and a wearable WBAN channel model such as IEEE model CM3 [9] by a computer simulation. As a multi-level PSK modulation, quadrature phase shift keying (QPSK), offset QPSK (OQPSK), $\pi/4$ shift differential QPSK (DQPSK), and D8PSK are selected. In addition, (127.85) and (127.63) BCH codes are examined as an optional ECC. The PSDU length (L_{PSDU}) is 127 bytes.

Figures 1 and 2 show PSDUER performances under the AWGN channel and IEEE model CM3 as a function of energy per bit to noise power spectral density ratio (E_b/N_0). Table 1 summarizes E_b/N_0 [dB] satisfying PSDUER $\leq 10^{-2}$ without ECC case. As shown in those figures, QPSK and OQPSK modulation are the best performance. On the other hand, $\pi/4$ shift DQPSK can obtain a PSDUER almost the same as that of GFSK, QPSK, and OQPSK without ECC by using the (127, 113) BCH code. Although the performance of D8PSK is inferior to other modulation schemes, it can be used if E_b/N_0 is enough. Then, (127, 64) BCH code and (127,

85) BCH code have no significant difference in the performance with those modulation schemes.

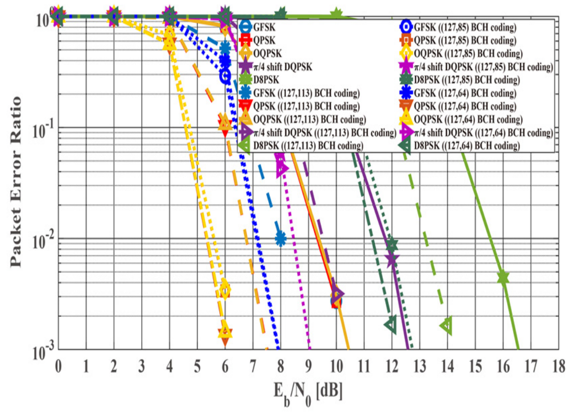

Figure 1. PSDUER under the AWGN channel.

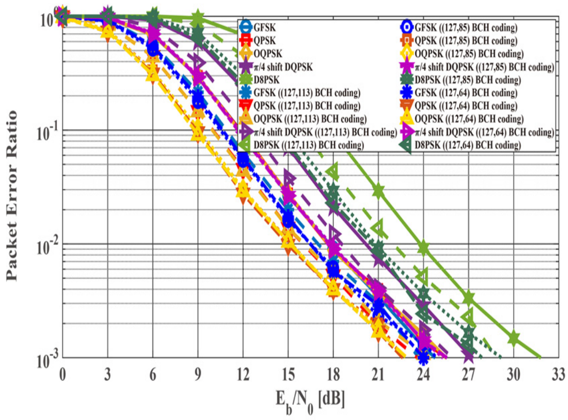

Figure 2. PSDUER under the IEEE model CM3.

Table 1. E_b/N_0 [dB] satisfying PSDUER $\leq 10^{-2}$ without ECC case.

	GFSK	QPSK OQPSK	$\pi/4$ shift DQPSK	D8PSK
AWGN	9.4	9.4	11.8	15.6
CM3	18	18	20.5	24

4 Power Spectral Density

The symbol rate of SmartBAN is 1.0 (mega-symbol per second (Msps). On the other hand, each channel bandwidth is 2 MHz. Hence, the symbol rate may be increased. Figures 3 and 4 illustrate normalized power spectral density (PSD) of GFSK and PSK in the constant symbol rate case [10]. As shown in those figures, it is possible to suppress inter-symbol interference with adjacent channels by applying a raised-cosine filter having a roll-off rate of 0.33 to PSK modulation in the case that the symbol rate is 1.5 Msps. On the other hand, inter-symbol interference to adjacent channels due to out-of-band radiation cannot be avoided in the case that the symbol rate is 2.0 Msps. Hence, this case needs to monitor the use status of the adjacent channel.

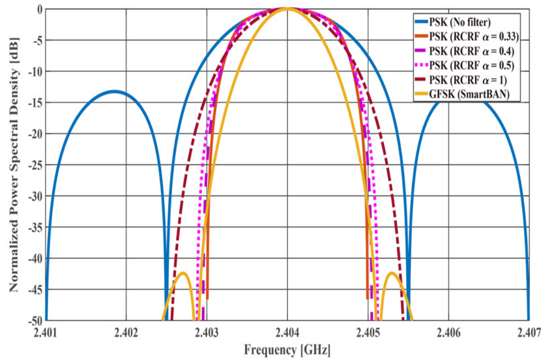

Figure 3. Normalized PSD in the constant symbol rate = 1.5 Msps.

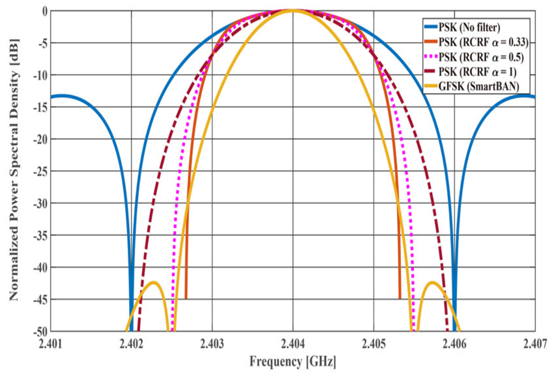

Figure 4. Normalized PSD in the constant symbol rate = 2.0 Msps.

5 Link Budget and Receiver Sensitivity

The link budget is calculated as follows:

$$P_{\mathrm{rx}} = P_{\mathrm{tx}} + G_{\mathrm{tx}} - L_{\mathrm{tx}} - L_{\mathrm{path}} + G_{\mathrm{rx}} - L_{\mathrm{rx}}$$
$$L_{\mathrm{path}} = L_{\mathrm{fs}} + L_{\mathrm{m}} \quad (2)$$

Here, P_{rx} and P_{tx} are receiver and transmitter power, G_{tx} and G_{rx} are antenna gain at a transmitter and a receiver, L_{tx} and L_{rx} are transmitter and receiver losses, L_{path} is a path loss, L_{fs} is a free space loss, and L_{m} is miscellaneous losses such as fading loss, body loss and so on. When P_{tx} = 4 dBm, G_{tx} and G_{rx} = 3 dBi, L_{tx} and L_{rx} = 3dB, L_{path} = 53.9 dB (calculated with reference to [9]), the calculation example of the link budget is as follows:

$$P_{\mathrm{rx}} = 4 + 3 - 3 - 53.9 + 3 - 3 = -49.9 \text{ dBm} \quad (3)$$

Then, the receiver sensitivity (S_{dBm}) and the fade margin are also calculated as follows:

$$S_{\mathrm{dBm}} = -174\ (\mathrm{dBm}) + NF_{\mathrm{dB}} + \frac{E_b}{N_0}\ (\mathrm{dB}) + 10\log_{10} R + I_{\mathrm{dB}} \quad (3)$$

$$\text{Fade margin} = P_{\mathrm{rx}} - S_{\mathrm{dBm}} \quad (4)$$

Here, NF_{dB} is a noise figure, R is a symbol rate and I_{dB} is an implemental loss. Table 2 summarizes examples of S_{dBm} without ECC case under the AWGN channel. Then, Table 3 summarizes examples of each fade margin. As shown in Table 1 again, the difference of E_b/N_0 satisfying PSDUER $\leq 10^{-2}$ between the AWGN channel and the IEEE model CM3 is about 8.5 dB. Hence, it can be said that the fade margin is sufficiently obtained.

Table 2. Examples of S_{dBm} [dBm]. PSDUER $\leq 10^{-2}$, L_{PSDU} = 127 bytes, NF_{dB} = 113 dB, and I_{dB} = 6 dB [5].

R [Msps]	GFSK	QPSK OQPSK	$\pi/4$ shift DQPSK	D8PSK
1.0	-85.6	-82.6	-80.2	-74.6
1.5	-83.8	-80.8	-78.4	-72.9
2.0	-82.6	-79.6	-77.2	-71.6

Table 3. Examples of fade margin [dB].

R [Msps]	GFSK	QPSK OQPSK	$\pi/4$ shift DQPSK	D8PSK
1.0	35.7	32.7	30.3	24.7
1.5	33.9	30.9	29.5	23.0
2.0	32.7	29.7	27.3	21.7

6 Conclusion

This research has presented the applicability of multi-level PSK modulation to SmartBAN PHY. Specifically, computer simulation has shown PSDUER performance and E_b/N_0 satisfying PSDUER $\leq 10^{-2}$ in each modulation scheme. In addition, it has been shown that the symbol rate of PSK modulation can be increased by applying a raised cosine filter with an appropriate roll-off rate. It has been also confirmed that sufficient fade margin is obtained by calculating the link budget and the receiver sensitivity. Hence, it is concluded that the application of multi-level PSK modulation to SmartBAN PHY is sufficiently possible and useful.

As for future work, it is necessary to perform cross-layer evaluation with the MAC layer and the PHY studied this time.

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