Energy Efficiency Evaluation of ECC Scheme Utilizing Decomposable Codes in IEEE Std 802.15.6 Based WBANs

Kento Takabayashi
Graduate School of Engineering, Yokohama National University
79-5 Tokiwadai, Hodogaya, Yokohama, 240-8501, Japan
takabayashi-kento-xp@ynu.jp

Heikki Karvonen
Centre for Wireless Communications (CWC), University of Oulu
P.O.Box 4500, 90014 Oulu, Finland
heikki.karvonen@ee.oulu.fi

Tuomas Paso
Centre for Wireless Communications (CWC), University of Oulu
P.O.Box 4500, 90014 Oulu, Finland
tuomas.paso@ee.oulu.fi

Hirokazu Tanaka
Graduate School of Information Sciences, Hiroshima City University
3-4-1, Ozuka-Higashi, Asa-Minami-Ku, Hiroshima, 731-3194, Japan
hi.tanaka@m.ieice.org

Chika Sugimoto
Graduate School of Engineering, Yokohama National University
79-5 Tokiwadai, Hodogaya, Yokohama, 240-8501, Japan
chikas@ynu.ac.jp

Ryuji Kohno
Graduate School of Engineering, Yokohama National University
79-5 Tokiwadai, Hodogaya, Yokohama, 240-8501, Japan
kohno@ynu.ac.jp

ABSTRACT

Recently, studies on medical and health monitoring systems using wireless communications have been actively conducted. In the field of health monitoring systems, wireless body area network (WBAN) is one of the key technologies and its standardization activities have also been extensively carried out. In previous work we proposed an optimal QoS control scheme employing a decomposable error control coding scheme. Furthermore, we extended the error correction capacity of our decomposable code and evaluated its bit error ratio and throughput performance in a multiple WBAN environment. In this paper, we evaluate the energy efficiency of the proposed scheme by computer simulations and compare it with energy efficiency of error control scheme defined in the IEEE Std. 802.15.6. Based on the results it can be stated that the proposed ECC method is more energy efficient especially in poor channel conditions.

Categories and Subject Descriptors

C.2.2 [**Computer - Communication Networks**]: Network protocols—*Network Architecture and Design - Wireless Communication.*

General Terms

Performance, Design, Reliability, Theory.

Keywords

IEEE802.15.6, QoS control, Decomposable codes, Energy efficiency, UWB

1. INTRODUCTION

Recently, health monitoring systems employing wearable vital sensors and wireless communication have received significant attention [1]-[3]. It is expected that wearable sensors will pave the way for a new tele-health and tele-care era that may include continuous monitoring of physical conditions and prevention of serious consequences. In the field of health monitoring systems, the body area network (BAN) is a key technology. Its standardization activities have been carried out extensively [4]-[5].

When moving towards smaller sensor devices and longer battery life, some technical requirements should be considered. Firstly, much lower power consuming physical layer (PHY) technologies are required. Secondly, the 2.4 GHz ISM band is assigned globally for common use in local area network (LAN) and personal area network (PAN) devices. This frequency band is potentially a good candidate for the BAN. However, when using this band, interference by other systems e.g., LANs and PANs must be considered. Finally, a wearable vital sensor can connect various types of sensors, and the data rate of such sensors varies. In addition, their allowable delay depends on the application. In the IEEE Std. 802.15.6, eight levels user priorities are defined. Therefore, the optimal QoS control for input data is an important factor in transmitting sensor data.

In order to address the above requirements, we have proposed an optimal QoS control scheme that employs a multiplexing layer for priority scheduling and a decomposable error control coding scheme [6]. Our target WBAN consists of a wearable sensor device which has multiple sensors whose

BODYNETS 2015, September 28-30, Sydney, Australia

DOI 10.4108/eai.28-9-2015.2261439

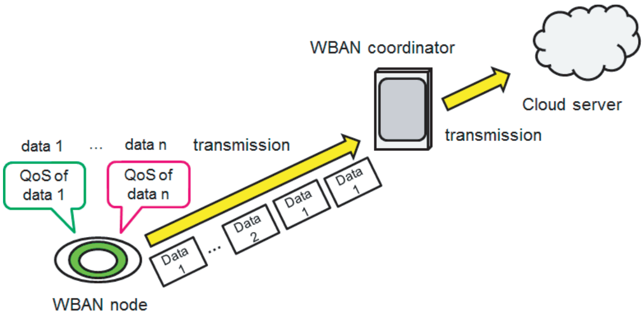


Figure 1: System concept.

input data is transmitted through a common medium access control (MAC) and PHY layer [6]. We have conducted simulations to evaluate the performance of the proposed system by comparing it with the performance of system based on IEEE Std. 802.15.6. In addition, we have evaluated residual bit error ratio (RBER) and throughput performances of the proposed scheme in a multiple WBAN environment [7]. In this paper, energy efficiency of the proposed scheme is evaluated by computer simulations. Energy efficiency is an important factor for WBAN because WBAN node is small and the battery capacity is not large. Therefore, it is crucial to evaluate the energy efficiency performance of the proposed decomposable error control codes.

The rest of this paper is organized as follows. In the next section, we introduce the system model of our scheme. Section III explains an energy efficiency model. The performance evaluations by simulations are shown in Section IV. Finally, we conclude this paper in Section V.

2. SYSTEM MODEL

2.1 System concept

It is assumed that a sensor node includes multiple sensors which produce different types of data to be transmitted to the hub as illustrated in Figure 1. In this study, two data (Data A and Data B) with different types of QoS are considered. Low RBER is desired for Data A, while high throughput and low latency are important for Data B. It is assumed that Data A is a physiologic parameter with low data rate (e.g. blood pressure, SpO2 or temperature) and Data B is a waveform such as ECG. Transmission order and error control process of different types of data packets depends on their QoS requirements. Table 1 summarizes characteristics of different data types.

Table 1: Characteristics of different data types.

Data Types	Data A	Data B
User priority	5	6
Error	restricted	allowable
Latency	allowable	restricted
The maximum number of retransmissions, q	10	4
Required data rate [13]	160 bps	2.4 kbps

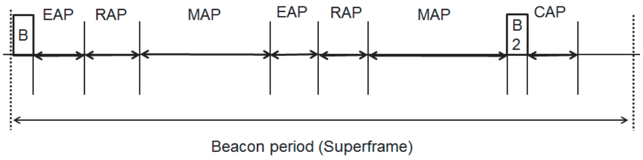


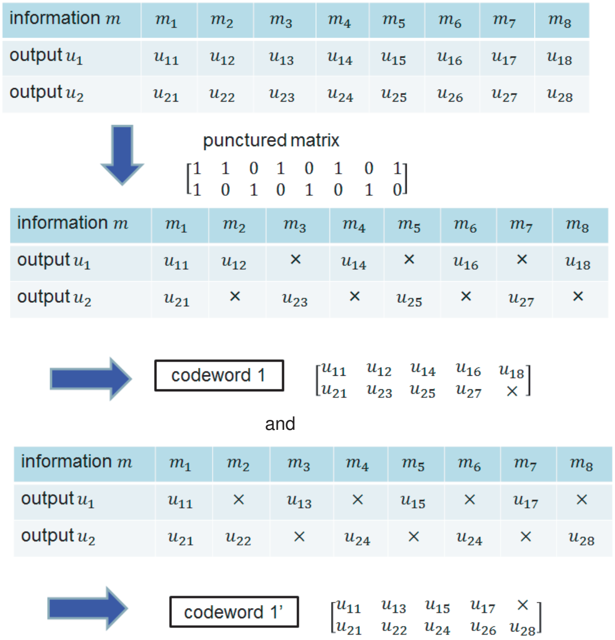
Figure 2: Beacon mode with superframes (mode I).

In the PHY layer, data can be modulated by either: on-off keying (OOK) in the default mode and optionally in the high QoS mode; differentially encoded binary phase-shift keying (DBPSK) in the high QoS mode and optionally in the default mode [4]. In this paper, we assume DBPSK is used. To increase robustness against multipath fading and multi-user interference, direct spread spectrum (DSSS) technique can be utilized for the DBPSK modulated data.

In the MAC layer, beacon mode with super frames is assumed in this study [4]. In this mode, a hub shall place the access phases such as exclusive access phase (EAP), random access phase (RAP), managed access phase (MAP), and contention access phase (CAP) as illustrated in Figure 2. A hub may set to zero the length of any of these access phases. In this paper, only MAP is used. A hub and nodes may send data by utilizing scheduled allocations. Hence, collision does basically not occur in the same WBAN.

2.2 Decomposable error control coding

In our previous work, a decomposable error control code is applied to optimize QoS of each data [7]. As an example of the decomposable code, a punctured convolutional code is used whose constraint length K is 3 and coding rates are 8/9∼1/16 [7].



information m	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8
output u_1	u_{11}	u_{12}	u_{13}	u_{14}	u_{15}	u_{16}	u_{17}	u_{18}
output u_2	u_{21}	u_{22}	u_{23}	u_{24}	u_{25}	u_{26}	u_{27}	u_{28}

punctured matrix

$$\begin{bmatrix} 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \end{bmatrix}$$

information m	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8
output u_1	u_{11}	u_{12}	×	u_{14}	×	u_{16}	×	u_{18}
output u_2	u_{21}	×	u_{23}	×	u_{25}	×	u_{27}	×

codeword 1

$$\begin{bmatrix} u_{11} & u_{12} & u_{14} & u_{16} & u_{18} \\ u_{21} & u_{23} & u_{25} & u_{27} & \times \end{bmatrix}$$

and

information m	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8
output u_1	u_{11}	×	u_{13}	×	u_{15}	×	u_{17}	×
output u_2	u_{21}	u_{22}	×	u_{24}	×	u_{24}	×	u_{28}

codeword 1'

$$\begin{bmatrix} u_{11} & u_{13} & u_{15} & u_{17} & \times \\ u_{21} & u_{22} & u_{24} & u_{26} & u_{28} \end{bmatrix}$$

Figure 3: Punctured convolutional code $R = 8/9$.

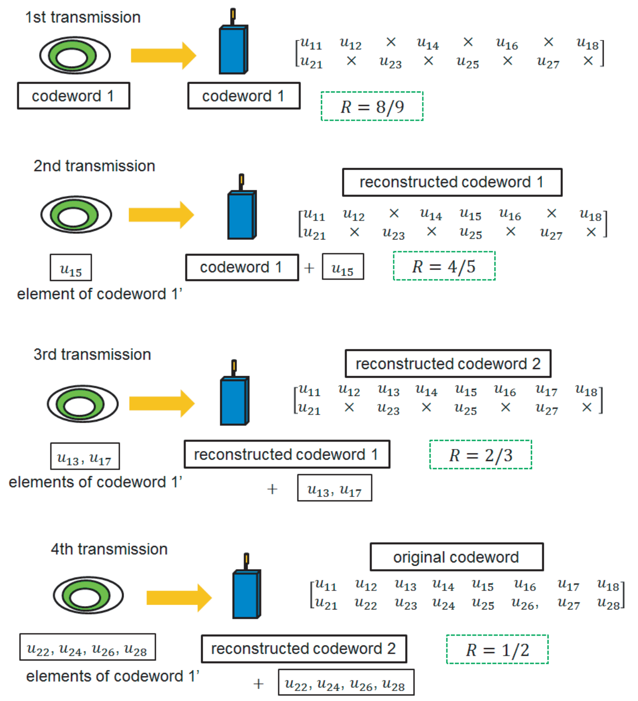


Figure 4: Method of reconstructing decomposable codes $R = 8/9 \sim 1/2$.

The punctured convolutional code is generated based on the convolutional code whose generator polynomial is [7,5] and code rate is $r = 1/2$. The punctured matrix of $r = 8/9$ is shown in Figure 3.

The two patterns of the $r = 8/9$ punctured codes (code word 1 and code word 1') can be generated using this punctured matrix. At the first transmission, the code word 1 is sent. Then in order to increment the code rate of the punctured code, elements of the code word 1' are sent after the first transmission as illustrated in Figure 4. After sending all elements to reconstruct the original convolutional code, code word 1 and code word 1' are transmitted alternately. The example is illustrated in Figure 5. Then, a receiver reconstructs and decodes any low-rate decomposable code by changing the number of data copies in Weldon's ARQ protocol [8].

In this paper, parameters of Weldon's ARQ protocol are set as shown in Table 2. At that time, a buffered old code word is updated to a transmitted new code word. The error correction ability becomes higher as the coding rate decreases in the order of 8/9∼1/16.

Table 2: The number of data copies in Weldon's ARQ n_i.

i	0	1	2	3	4	5	6	7	8	9	10
Data A, n_i	1	4	4	5	5	6	6	8	8	8	8
Data B, n_i	1	1	2	3	4	-	-	-	-	-	-

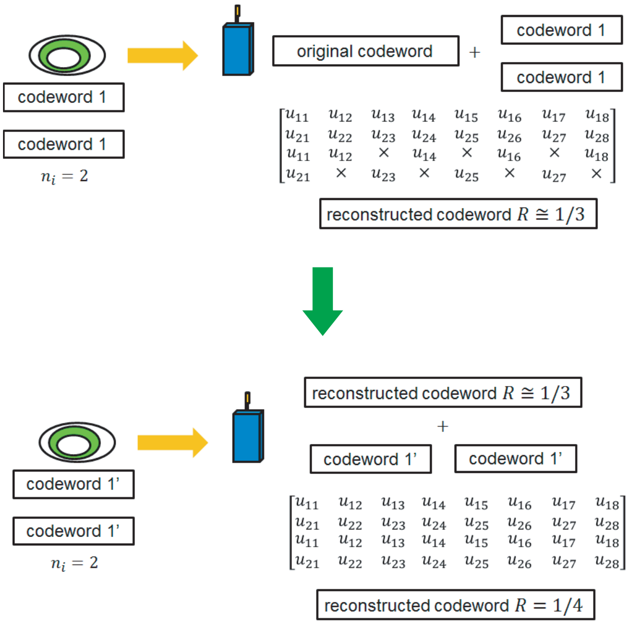


Figure 5: Example of method of reconstructing decomposable codes $R = 1/2 \sim$.

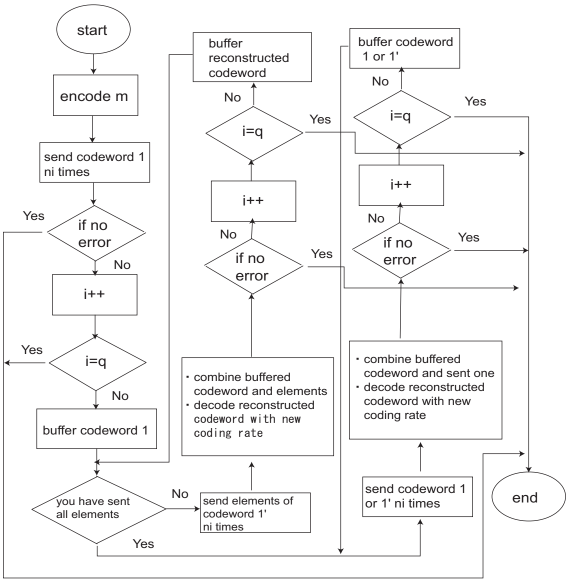


Figure 6: Flowchart of the proposed ARQ protocol.

Figure 6 shows the flowchart of the protocol of the proposed scheme. The operation is continued until no errors are detected or the maximum number of retransmissions q is achieved.

3. ENERGY EFFICIENCY MODEL

The energy consumption modeling of our proposed scheme is based on [9] and is calculated as

$$
\begin{aligned}
E_{link} &= (T_{TOT} + N_{tx}T_{ACK}) \\
&\quad \times (P_{tx,RF} + P_{tx,circ} + P_{rx}) \\
&\quad + N_{tx}(\epsilon_{enc} + \epsilon_{dec}) && (1) \\
T_{TOT} &= \sum_{i=1}^{N_{tx}} \frac{L_{packet,i}}{R} && (2) \\
L_{packet,i} &= L_{PHR} + L_{SHR} + L_{PSDU,i} && (3) \\
L_{PSDU,i} &= n_{block,i} m_{tbit,i} && (4) \\
T_{ACK} &= \frac{L_{ACK}}{R}, && (5)
\end{aligned}
$$

where L_{ACK} is acknowledgement (ACK) packet length, R is data rate, L_{PHR} is length of physical layer header (PHR), L_{SHR} is length of synchronization header (SHR), $L_{PSDU,i}$ is length of physical layer service data unit (PSDU) for i_{th} transmission, $L_{packet,i}$ is length of i_{th} transmission, N_{tx} is the number of transmissions, T_{TOT} is duration of N_{tx} transmissions, $P_{tx,RF}$ is transmitter RF power consumption, $P_{tx,circ}$ is transmitter circuitry power consumption, P_{rx} is receiver power consumption, ϵ_{enc} and ϵ_{dec} are the encoding and decoding energies, $m_{tbit,i}$ is the number of transmitted bits and $n_{block,i}$ is the number of copy blocks of Weldon's ARQ at the i_{th} transmission. PSDU length is changed in every retransmission according to the used decomposable ECC method.

Then, ϵ_{enc} and ϵ_{dec} for the decomposable coding are calculated as [10]

$$
\begin{aligned}
\epsilon_{enc} &= \frac{P_{convenc}}{R} L_{info}^{2} && (6) \\
\epsilon_{dec} &= \frac{P_{vitdec}}{R} L_{info}^{2}, && (7)
\end{aligned}
$$

where $P_{convenc}$ [nW/bit] is the encoding power of a convolutional code, P_{vitdec} [nW/bit] is the decoding power of viterbi decoding and L_{info} is the number of information bits in a code word. Values of $P_{convenc}$ and P_{vitdec} are referred from [10]. Finally, energy efficiency is defined as

$$
\eta \triangleq \frac{\lambda}{E_{link}}, \qquad (8)
$$

where λ is the number of successfully received information bits.

4. PERFORMANCE EVALUATION

In this section, the proposed scheme is evaluated by computer simulations. It is assumed that there are five other WBANs following uniform distribution within three meters from an objective WBAN. A path loss of transmit power from other WBANs is regarded as the free space propagation loss. The main simulation parameters are listed in Table 3. In addition, the power consumption parameters for the transceivers are evaluated based on [9]-[12]. In the simulations we use both modes, default mode and high QoS mode, defined in the IR-UWB PHY specifications of IEEE Std. 802.15.6 [4]. Data A is transmitted using the default mode, whereas Data B is transmitted using high QoS mode utilizing hybrid ARQ.

Table 3: Simulation parameters

Channel model	AWGN
Bandwidth	499.2MHz
Central frequency	3.99GHz
Modulation	DBPSK
FEC	r=8/9 ∼ 1/16, K=3 convolutional codes
Decoding	Soft decision viterbi decoding
ARQ protocol	Weldon's ARQ
Spreading sequence	Gold sequence
Spreading Factor	7
The number of other WBAN	5
Max distance from other WBAN	3m
L_{info}	306 bits
L_{ACK}	7 bytes
R	0.557 Mbps
Time slot length	1.5ms
Superframe length	115.5ms

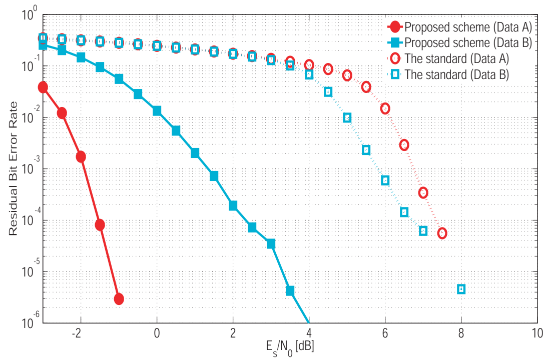


Figure 7: RBER as a function of E_s/N_0.

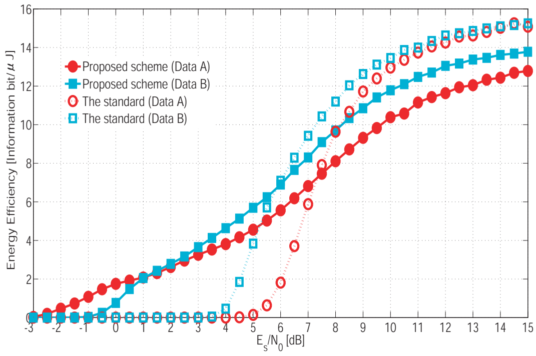


Figure 8: Energy efficiency as a function of E_s/N_0.

Figures 7 and 8 show average RBER and energy efficiency as a function of E_s/N_0. The RBER performance of our proposed scheme is clearly better in comparison to the standard scheme. Especially, in case of Data A, the difference between the proposed scheme and the standard scheme is about 9dB.

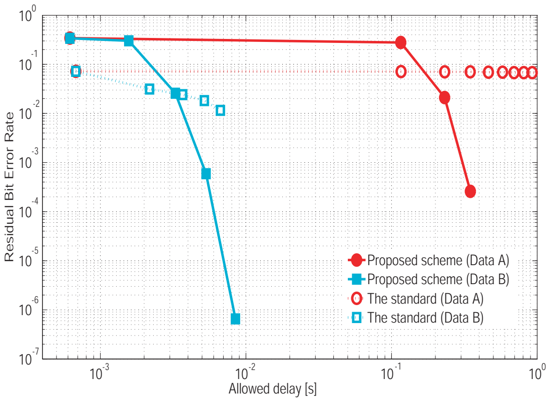


Figure 9: RBER as a function of an allowed delay (E_s/N_0=5dB).

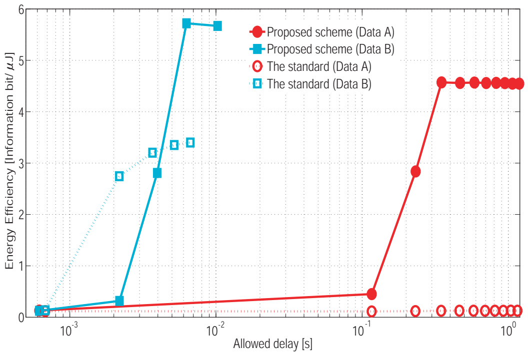


Figure 10: Energy efficiency as a function of an allowed delay (E_s/N_0=5dB).

Related to energy efficiency, in poor channel conditions the proposed scheme has better performances than the standard. In good channel conditions, energy efficiency of the standard is better in comparison to our proposed method. The reason is that in good channel conditions, the error correction capability of the standard method is sufficient and consequently lower number of retransmissions are required. However, the difference is 2.5[information bit/μJ] at most.

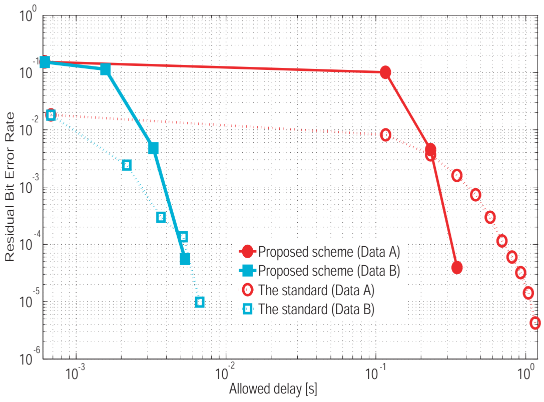


Figure 11: RBER as a function of an allowed delay (E_s/N_0=8dB).

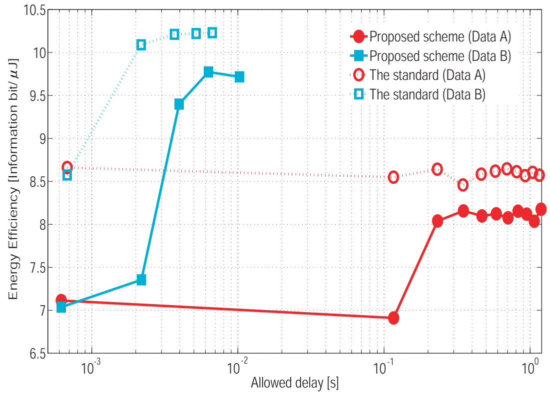


Figure 12: Energy efficiency as a function of an allowed delay (E_s/N_0=8dB).

Figures 9 and 10 show average RBER and energy efficiency performances as a function of allowed delay with E_s/N_0=5dB. Then, Figures 11 and 12 show them in the case of E_s/N_0=8dB. Allowed delay affects to the number of retransmission that can be performed within the latency requirement of the particular data type. It can be observed that when the allowed delay is larger, the RBER and energy efficiency performance of the proposed scheme is improved especially in poor channel conditions, because the error correcting capability is increased for each retransmission. However, the delay is still acceptable for the target applications. Then, in low SNR conditions, the maximum energy efficiency of our proposed scheme is 2.5[Information bit/μJ] higher in comparison to the standard scheme in case of Data B. In case of Data A, it is 4.5[Information bit/μJ] larger than the standard. Meanwhile, the RBER performance of the standard method does not improve even when the allowed delay increases, since in that case the error correction capability does not increase with retransmissions. In addition, it can be observed that in standard method case, energy efficiency increases with allowed delay in poor channel conditions, while in good channel conditions energy efficiency does not change much with allowed delay, especially that of Data A. The reason is that the error correction capability of the standard scheme is not sufficient in low SNR conditions. Therefore, more retransmission are required in comparison to high SNR conditions where the RBER is enough low already at the first transmission. Then, the maximum energy efficiency of the standard is 0.5[Information bit/μJ] larger than that of the proposed scheme about both Data A and Data B. However, the difference is small.

5. CONCLUSION

In this paper, energy efficiency of ECC scheme utilizing decomposable codes is evaluated in a multiple WBAN environment. It can be concluded that the proposed scheme has better performance in terms of RBER and energy efficiency especially in poor channel conditions, when compared to the method defined in IEEE Std. 802.15.6. Therefore, our error control coding scheme enables the usage of QoS control while remaining high energy efficiency. In the future work, a cross-layer optimization for our error control scheme using random access MAC protocols will be considered.

6. REFERENCES

[1] H. Cao, V. Leung, C. Chow, and H. Chan. Enabling technologies for wireless body area networks: A survey and outlook. *IEEE Commun. Mag.*, 47(12):84–93, December 2009.

[2] H. Viswanathan, B. Chen, and D. Pompili. Research challenges in computation, communication, and context awareness for ubiquitous healthcare. *IEEE Commun. Mag.*, 50(5):92–99, May 2012.

[3] T. Suzuki, H. Tanaka, S. Minami, H. Yamada, and Takashi Miyata. Wearable Wireless Vital Monitoring Technology for Smart Health Care. In *7th Int. Symp. Medical Information and Communication Technology (ISMICT)*, IEEE, March 2013.

[4] IEEE Standard for Local and Metropolitan Area Networks. Part 15.6: Wireless Body Area Network. *IEEE Computer Society*, IEEE Std. 802.15.6, 2012.

[5] M. Hämäläinen, T. Paso, L. Mucchi, M. Girod-Genet, J. Farserotu, H. Tanaka, W.H. Chin, and L.N. Ismail. ETSI TC SmartBAN - Overview of the Wireless Body Area Network Standard. In *9th Int. Symp. Medical Information and Communication Technology (ISMICT 2015)*, IEEE, March 2015.

[6] K. Takabayashi, H. Tanaka, C. Sugimoto, and R. Kohno. Multiplexing and Error Control Scheme for Body Area Network employing IEEE 802.15.6. *IEICE Trans. Communications*, E97-B(3):564–570, March 2014.

[7] K. Takabayashi, H. Tanaka, C. Sugimoto, and R. Kohno. Error Control Scheme Using Decomposable Codes for Various QoS in Multiple WBAN Environment. In *9th Int. Symp. Medical Information and Communication Technology (ISMICT 2015)*, March 2015.

[8] E. J. Weldon, Jr. An Improved Selective-Repeat ARQ Strategy. *IEEE Trans. Commun.*, 30(3):480–486, March 1982.

[9] H. Karvonen, J. Iinatti, M. Hämäläinen. A cross-layer energy efficiency optimization model for WBAN using IR-UWB transceivers. *Springer Telecommunication Systems*, 58(2):165–177, February 2015.

[10] N. Abughalieh, K. Steenhaut, A. Nowé, and A. Anpalagan. Turbo codes for multi-hop wireless sensor networks with decode-and-forward mechanism. *Eurasip J. Wireless Communications and Networking*, 204(1), November 2014.

[11] J. Ryckaert, C. Desset, A. Fort, M. Badaroglu et al. Ultra-Wide-Band Transmitter for Low-Power Wireless Body Area Networks: Design and Evaluation. *IEEE Trans. Circuits Syst. I, Reg. Papers*, 52(12):2515–2525, December 2005.

[12] Z. Zou, D. Sarmiento Mendoza, P. Wang, Q. Zhou et al. A Low-Power and Flexible Energy Detection IR-UWB Receiver for RFID and Wireless Sensor Networks. *IEEE Trans. Circuits Syst. I, Reg. Papers*, 58(7):1470–1482, May 2011.

[13] P11073-00101/D02J. Health informatics - Point-of-care medical device communication - Technical report - Guidelines for the use of RF wireless technology, *IEEE*, 2007.