A Flexible Retransmission Scheme in IEEE 802.15.4-based WBAN

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Abstract

WBAN (Wireless Body Area Network) is a wireless communication technology which operates around the human body and requires various data rate, short-range, high data reliability and low-power consumption. Due to frequency fading, noise, and interference from devices which share the same frequency band, frame errors occur frequently in wireless communication. Because errors inside a frame result in retransmission of the whole frame, existing retransmission scheme may increase unnecessary power consumption and reduce WBAN lifetime. In this paper, we propose a flexible retransmission scheme in IEEE 802.15.4-based WBAN. The proposed scheme focuses on reduction of retransmission energy compared with existing ARQ on IEEE 802.15.4. Extensive simulations were performed and the reduction of retransmission energy was validated.

1. Introduction

WBAN is a wireless communication technology to provide both medical and CE (Consumer Electronic) services in/on/around human body [1]. WBAN consists of coordinator and variety devices which can be categorized into implant and wearable devices according to position of equipment. By this reason, WBAN should operate in long time around body area. Especially, low power consumption is the most important requirement of WBAN because replacement of battery in WBAN devices is difficult. Moreover, WBAN uses variety of frequency bands such as MICS (Medical Implant Communication System), WMTS (Wireless Medical Telemetry Service), ISM (Industrial Scientific and Medical band), and UWB (Ultra Wide Band). Various usage of frequency bands in WBAN can fatally affect communication reliability by interference and it can cause that critical user requirement may fail. Therefore, ultra-low power consumption and high reliability should be guaranteed.

Meanwhile, IEEE 802.15.4 communication technology which satisfies both low data rate and low power consumption was considered WBAN standard in early stage of WBAN studies [2]. However, other communication technologies which share ISM band (such as IEEE 802.11, IEEE 802.15.1) interrupt data communication of IEEE 802.15.4. Furthermore, CEs which generate high-frequency in ISM band can interfere to frame error on IEEE 802.15.4. For these reasons, data communication in IEEE 802.15.4 shows a high BER (Bit Error Rate) and error bits occur mainly in the forms of burst error [3, 4].

To solve above problem, IEEE 802.15.4 uses ARQ (Automatic Repeat & Request) method which retransmit previously transmitted frame [2]. However, this method consumes transmission energy due to the retransmission. Furthermore, because it retransmits the whole frame used for the failed transmission, the retransmitted frame includes error as well as error-free areas. Thus, each retransmission generates unnecessary energy consumption during retransmission process. If the frame error occurs frequently in WBAN, the accumulation of wasted transmission energy will be intense. As a result, these problems cause decreasing the network lifetime and reliability. Because the requirements of data reliability and low power consumption are important, IEEE 802.15.4 data communication in WBAN requires efficient retransmission techniques.

In this paper, we propose a scheme to efficiently handle frame error that occurs frequently in IEEE 802.15.4-based WBANs. The proposed scheme can provide low power consumption and high reliability by using split decision model and partitioned data.

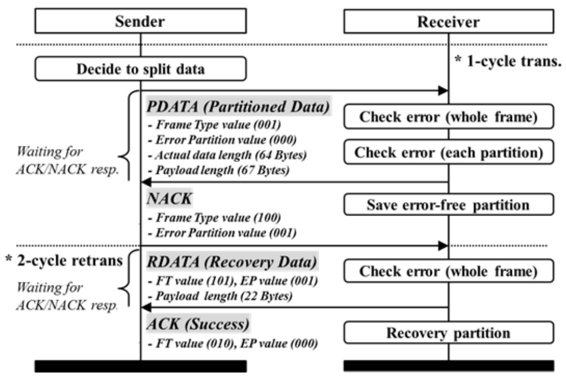

Figure 1. Operation flow of proposed scheme

2. Related works

There was a variety of control method to efficiently resolve the frame error in wireless environment.

First, adaptive ARQ and selective-repeat ARQ which improve the Go-back-N are unsuitable for applying to characteristics of WBAN which are small data and variable period.

Second, ARQ combined with FEC (Forward Error Correction) advantages the error detection and correction [5]. However, it has complex decoding overhead and has variable recovery rate depending on the additional parity length.

Finally, stop-and-wait ARQ used in IEEE 802.15.4 performs with simple logic. However, this method wastes the unnecessary energy because of the problem which retransmits error-free data.

3. Proposed scheme

We focus on extending network lifetime and increasing reliability in IEEE 802.15.4 based WBAN where occurs frequently frame error. From this perspective, the proposed scheme can satisfy the minimum requirements of WBAN and performs the effective retransmission process according to the split decision model. In addition, the proposed scheme has the advantage which can be incorporated into both beacon enabled superframe and beacon enabled non-superframe mode supported by IEEE 802.15.4.

The overall operation of data transmission begins with the split decision model. This model calculates error rate by checking the status of transmission through the frequency channel. Then, the result of the decision model is compared with the allowed pre-defined maximum PER (Packet Error Rate) value in IEEE 802.15.4. If the condition is not satisfied, the proposed scheme splits the payload data into 3 partitions and inserts the proposed one byte error check code of which the name is CRC-8 at the end of each partition.

Figure 1 illustrates an example of proposed scheme when pre-mentioned condition is not satisfied. In the first transmission cycle, sender transmits PDATA (Partitioned Data) frame which is divided into 3 partitions by the decision model. After receiver receives a PDATA, it checks error of whole payload in the frame by CRC-16. If error is detected, receiver checks error in each partition and replies NACK (Negative Acknowledgement) frame with information of error partition. In the next cycle, sender sends RDATA (Recovery Data) frame which includes recovery partition based on information about the error partitions in received NACK. First, the receiver which received RDATA from sender checks the frame error though the CRC-16 in IEEE 802.15.4. If error is not detected, receiver performs partial recovery without CRC-8 after ACK transmission. From the result of this example, the proposed scheme used 22-bytes of data from the retransmission process and it can reduce the length of total transmitted data (45-bytes) compared with existing ARQ in IEEE 802.15.4.

In another case which satisfies conditions, sender does not split data in payload, and also does not include the individual CRC-8 into the end of data. At the receiver side, the frame is checked by CRC-16 defined IEEE 802.15.4 without CRC-8 which detects each partition error. The reasons for these operations are to eliminate the additional overhead (such as additional bits of CRC-8 and processing overhead for error detection) in low PER. As a result, the proposed scheme operates in the same way as ARQ in IEEE 802.15.4 when pre-mentioned condition is satisfied.

Details of operation which are partial error check, split decision model, and re-defined frame type based on IEEE 802.15.4 are as follows.

3.1 Partial error check

Most of transmission errors in wireless environments occur in the form of continuous burst [3, 4]. CRC

MSB		LSB	
00100000	00000011	10100011	= Data String (20 03 A3h)
100000111			= XOR polynomial
00100000	00000011	10100011	= Shift in 1^{st} 8 bits
00100000			= XOR and result as an pointer to lookup table (20h)
11100000			= Returned value from table (E0h)
	00000011	10100011	= Shift in 2^{st} 8 bits
	11100011		= XOR and result as a pointer (E3h)
	10100111		= Returned value from table (A7h)
		10100011	= Shift in 3^{st} 8 bits
		00000100	= XOR and result as a pointer (04h)
		00011100	**= Complete CRC-8 value (1Ch)**

Figure 2. CRC-8 using lookup table

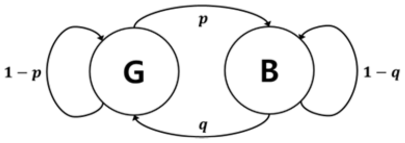

Figure 3. Gilbert model

checksum method is one of methods checking errors and takes a checking code generation method by polynomial computation [6]. Especially, it has a very strong ability against burst errors in wireless data communication.

If basic CRC method is implemented in software, however, it generates overheads from the bit shifting and exclusive calculation depending on the length of data, and it causes increase of network delay.

To solve these problems, the proposed scheme uses CRC-8 checksum based on pre-computed lookup table as shown in Figure 2. Lookup table is pre-computed table which collects results calculated by the XOR operation with the number of all remaining cases of CRC polynomial. It can greatly improve the CRC checking performance by calculating the byte unit compared with the basic operation.

3.2 Split decision model

In order to check the continuous PER and determine whether or not the data split, we uses Gilbert process model which operates as shown in Figure 3 [7].

Gilbert process is a two-state Markov model which consists of $State_{(G)}$, $State_{(B)}$, and transition probability of p and q. $State_{(G)}$ and $State_{(B)}$mean the channel condition and, p is defined as transition probability from $State_{(G)}$ to $State_{(B)}$ that *(N + 1)* th packet has error when Nth packet was successfully received. Next, q is defined as transition probability from $State_{(B)}$ to $State_{(G)}$ that *(N + 1)* th packet is received successfully when N th packet was not. Along with the same lines, the probability of q and *1 - q* is defined as transition probability that either *(N + 1)* th packet is successfully received or not when N th packet was failed.

Eg.(1) is defined as the number of success and failure in each of transmission, where a is the number of ACK received for the initial PDATA and b means the number of ACK received for the RDATA. c and d refer to the number of failures in current state when previous state was success or fail. Transition probability p and q can be obtained by results of Eg.(1). According to Geometric stochastic process, the stationary probability of $State_{(G)}$ and $State_{(B)}$ can be calculated as *p/(p+q) and q/(p+q)* in Eg.(3).

$$\begin{aligned} a &= The\ number\ of\ MSG_{(ACK)} \\ &\quad for\ \ MSG_{(PDATA)} \\ b &= The\ number\ of\ MSG_{(ACK)} \\ &\quad for\ \ MSG_{(RDATA)} \\ c &= If\ TX_{t-1}\ is\ successful, \\ &\quad the\ number\ of\ times\ TX_t\ failed \\ d &= \ If\ TX_{t-1}\ fails, \\ &\quad the\ number\ of\ times\ TX_t\ failed \end{aligned} \tag{1}$$

$$p = Pr[X_{n+1} = B|X_n = G] = \frac{c}{c+a} \tag{2}$$
$$q = Pr[X_{n+1} = G|X_n = B] = \frac{b}{b+d}$$

$$Pr[X_n = B] = \frac{p}{p+q}, Pr[X_n = G] = \frac{q}{p+q} \tag{3}$$

The consecutive frame error probability as shown in Eg.(4) can be calculated by state transition probabilities. In other words, if the results of $N + 1$ is satistied with the allowed reqirement of PER in IEEE 802.15.4, this model decides whether to partition data or not.

$$\begin{aligned} &Pr[X_n = B, X_{n+1} = \mathrm{B}\,] \\ &= \Pr[X_{n+1} = B|X_n = B] \cdot Pr[X_n = B] \\ &= \ (1-q) \cdot \frac{p}{p+q} > 0.01\ (\mathrm{PER}) \end{aligned} \tag{4}$$

3.3 Frame type definition

The messages of proposed scheme consists of four type based on the IEEE 802.15.4 frame format.

PDATA and RDATA message uses the general structure type and NACK and ACK similarly are configured as the same format as shown in Figure 4. These message types are not required to modify frame formats of IEEE 802.15.4 because empty bits in frame control field can be used to recover or announce error partitions for RDATA and NACK.

*** PDATA and RDATA frame format**

<table>
<tr><td>Octets:2</td><td>1</td><td>2</td><td>2</td><td>2</td><td colspan="6">Variable (Frame payload)</td><td>2</td></tr>
<tr><td rowspan="4">Frame Control</td><td rowspan="4">Seq</td><td rowspan="4">PAN ID</td><td rowspan="4">Dest Addr</td><td rowspan="4">Src Addr</td><td colspan="6">If the condition by the decision model it satisfied</td><td rowspan="4">FCS</td></tr>
<tr><td>Partition</td><td>CRC</td><td>Partition</td><td>CRC</td><td>Partition</td><td>CRC</td></tr>
<tr><td colspan="6">If the condition by the decision model is not satisfied</td></tr>
<tr><td colspan="6">Partition</td></tr>
</table>

*** ACK and NACK frame format**

Octets: 2	1	2
Frame control	Seq	FCS

*** Frame control field used in all frame**

<table>
<tr><td>Bits:0-2</td><td>3</td><td>4</td><td>5</td><td>6</td><td colspan="3">7-9</td><td>10-11</td><td>12-13</td><td>14-15</td></tr>
<tr><td rowspan="2">Frame Type</td><td rowspan="2">Security</td><td rowspan="2">Frame Pending</td><td rowspan="2">AR</td><td rowspan="2">Intra PAN</td><td colspan="3">Error Partition</td><td rowspan="2">Dest Ad. Mode</td><td rowspan="2">Frame Version</td><td rowspan="2">Src Ad. Mode</td></tr>
<tr><td>0/1</td><td>0/1</td><td>0/1</td></tr>
</table>

*** Definition on Frame type**

Frame Type Value	Description	Frame Type Value	Description
000	Beacon	011	MAC command
001	PDATA	100	NACK
010	ACK	101	RDATA

Figure 4. Proposed frames based on IEEE 802.15.4

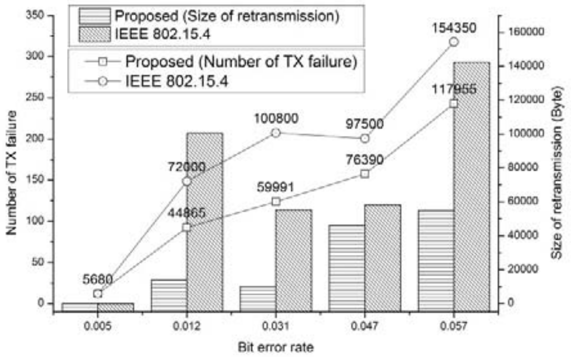

Figure 5. Comparison of the number of transmission failure and overall size of retransmission

4. Performance evaluation

In this section, we discuss the simulation environment and evaluate the performance of the proposed scheme. The performance of the proposed scheme is then compared with that of IEEE 802.15.4.

In order to verify performance of the proposed retransmission scheme, we use extracted trace data based on the actual experiments as error model. The periodic interference is generated by IEEE 802.11g and pair of IEEE 802.15.4 devices called ZigbeX-II are deployed around 802.11g networks. We extracted approximately 60,000 trace data for error samples and applied to our simulation. Furthermore, we assume that anthropometric devices which transmit 64 bytes of payload data per 1 second in accordance with personal health device standards [8].

Figure 5 shows the overall size of retransmission frame and the number of transmission failure when 3,600 transmissions with BER values which are set at 0.005, 0.012, 0.031, 0.047, and 0.057. If the BER is 0.005, the results show the same performance as the existing ARQ because it does not divide data by the split decision model. However, the proposed scheme outperforms existing ARQ in term of reliability and size of retransmission frame when BER continuously increases. The simulation results of energy consumption are shown in Figure 6. Because the proposed scheme minimizes the size of retransmission frame in burst error environment, it can reduce additional energy consumption by preserving the error-free partitions.

5. Conclusion

The burst errors which frequently occur in WBAN reduce data reliability and waste transmission energy. To solve this problem, we proposed a flexible retransmission scheme against frame error. The proposed scheme consists of the split decision model

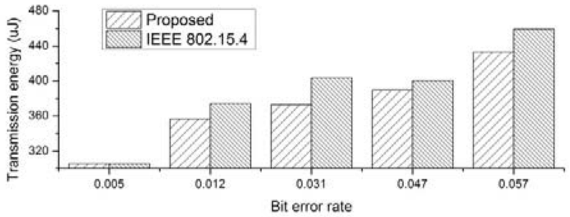

Figure 6. Comparison of the transmission energy consumption between proposed scheme and 802.15.4

and partial recovery. The performance of proposed scheme was evaluated by extensive simulations compared with existing ARQ in IEEE 802.15.4 and the proposed scheme can increase reliability and reduce power consumption dramatically.

6. Acknowledgement

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7. References

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