OCDP : A WBAN MAC Protocol for Contention-based Medical and CE applications

Young-Sun Seo, Dae-Young Kim, and Jinsung Cho
Department of Computer Engineering
Kyung Hee University, Korea
{lamooss,kimdy,chojs}@khu.ac.kr

Ben Lee
School of Electrical Engineering and Computer Science
Oregon State University, Oregon
benl@eecs.oregonstate.edu

ABSTRACT

Wireless body area networks (WBANs) provide communication services in the vicinity of the human body. Since the WBAN services consists of both medical and consumer electronics (CE) applications, MAC protocols in the WBAN should be designed considering flexibility and different characteristics between medical and CE applications.

In this paper, we propose a WBAN MAC protocol for contention-based medical and CE applications. To support bursty CE data and emergency medical data, the proposed WBAN MAC protocol provides a temporary switching method between the Inactive period and the Opportunity period through OCDP (opportunistic contention decision period), and 4-mode opportunity period. Through the extensive simulations, we show the proposed protocol achieves improved latency in the WBAN environment compared with the IEEE 802.15.4.

Categories and Subject Descriptors

C.2.2 [**Network Protocols**]: MAC protocols.

General Terms

MAC, Design.

Keywords

wireless body area networks, hybrid MAC, contention-based protocol.

1. INTRODUCTION

Recent advances in the healthcare studies that are based on the state-of-the-art wireless communications and the advanced medical sensor technologies have provided driving forces on wireless personal area network (WPAN) studies. A wireless body area network (WBAN), which focuses on medical applications and supports consumer electronics (CE) applications simultaneously, functions in the vicinity of the human body within 3m. The WBAN becomes the next generation of wireless technology for the WPAN [1]. IEEE 802.15.6 task group started a standardization for the WBAN on November, 2007 [1, 2]. The WBAN allows wireless communications for both medical and CE applications.

Typically, medical applications continuously maintain network connection of the WBAN and perform communication periodically with low data rate. They work monitoring, diagnosis, healing, communications, etc. WBAN requires battery-operated medical application to ultra low power consumption, and so demands low duty cycle(e.g.,$<$1% or $<$10%) [3, 4].

On the other hand, CE applications connect the network occasionally and transmit packets, which are generally generated with sporadic and bursty traffic, such as video clip and audio streaming, entertainment, or remote control with high data rate. CE applications have the characteristic which is independent in duty cycle (e.g., low, medium or high) [3].

From the Technical Requirement Document(TRD), moreover, latency is demanded that medical applications should be less than 125ms for QoS packet and CE application should be less than 250ms [4].

Because the WBAN focuses on medical communications, previous WBAN researches were generally studied in MAC protocols for medical sensor devices (i.e., ultra low power consumption, low duty cycle, etc.). Therefore existing MAC protocols for the wireless sensor network (i.e.,TDMA or IEEE 802.15.4 MAC) are generally used in the WBAN studies.

In order to meet the requirements of the WBAN, however, WBAN MAC protocol considers that the various characteristics of not only medical applications but also CE applications. Therefore we propose a WBAN MAC protocol for both medical and CE applications which are using contention mechanism. The proposed MAC protocol exploits OCDP (opportunistic contention decision period) and 4-mode Opportunity period to support bursty CE data and emergency medical data and to provide mesh topology communications simultaneously. The OCDP provides a temporary switching method between the Inactive period and the Opportunity period. The Opportunity period is selected by the coordinator based on the 4-mode Opportunity period according to the characteristics of the WBAN device.

The remainder of this paper is organized as follows: In Section 2, the existing sensor MAC protocol for the WBAN as related work. Section 3 describes the proposed WBAN MAC protocol. Next, we evaluate its performance through extensive simulations in Section 4 and conclude the paper in Section 5.

ICUIMC 2010, Jan 14-15, 2010, Suwon, Korea

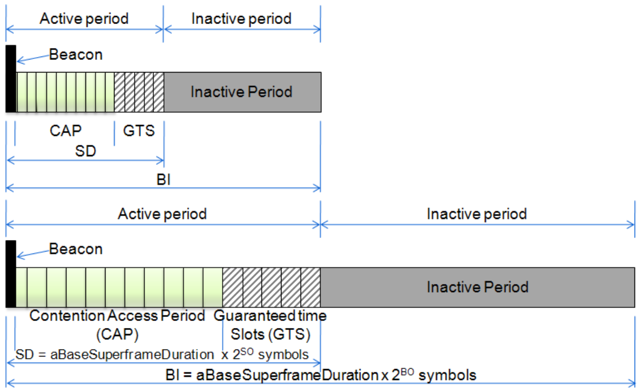


Figure 1: Superframe structure in IEEE 802.15.4

2. RELATED WORK

Since medical applications are the major issues of the WBAN, existing WBAN MAC protocol (i.e., TDMA and IEEE 802.15.4) have been proposed for medical applications.

TDMA was studied in early stage of WBAN researches which consist of the medical sensor devices [5, 6]. When a WBAN consists of various devices with different characteristics (e.g., medical or entertainment characteristics), TDMA may not be adequate.

IEEE 802.15.4 MAC [7] protocol, which is standard for wireless sensor networks, is considered for the WBAN [8, 9]. IEEE 802.15.4 MAC uses a superframe structure in a beacon-enabled mode as shown in Figure 1. The superframe duration (SD) as an active period is divided into 16 equal-sized time slots. A guaranteed time slot (GTS) is allocated in one or more slots to a device. If lots of GTS slots are allocated, a contention access period (CAP) is decreased. In addition, the GTS of IEEE 802.15.4 allows at most 7 devices. In general, IEEE 802.15.4 needs more CAP slots so that a coordinator may increase a value of SO for the extension of the CAP duration. By increasing superframe order (SO), however, the GTS slots also increases together. Thus, unnecessary increase of the size of GTS slots exponentially.

Since the medical application is the focus of the WBAN, as we identified in Section 1, existing MAC protocols are generally used in the WBAN. In WBAN environments, however, CE devices may generate bursty data with event-driven methods and connect with the WBAN occasionally. Thus, existing MAC protocols using periodic sleep method for low power consumption have the latency due to the periodic sleep. That is, since existing MAC protocols are designed for sensor devices required low power consumption, the WBAN MAC protocol should be designed for both medical and CE applications flexibly.

3. PROPOSED WBAN MAC PROTOCOL

As mentioned earlier, since providing the flexibility for various applications is the main goal, we propose a hybrid superframe structure MAC protocol for the WBAN. As shown in Figure 2, the proposed WBAN MAC protocol focuses on the following ideas:

First, we exploit the **OCDP** for the flexible ranges of the latency. In IEEE 802.15.4, the Inactive period is determined by beacon order (BO) and SO in a beacon and all devices

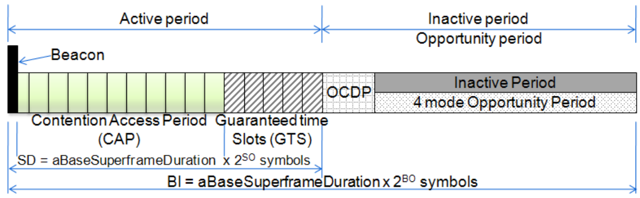


Figure 2: The proposed WBAN MAC protocol

sleep in the Inactive period. If CAP is insufficient due to increased temporary traffics, IEEE 802.15.4 expands CAP by increasing SO in a beacon. However, if SO increases, the size of GTS slots also exponentially increases as shown in Figure. 1. To support the WBAN devices required latency and the sporadic traffics of CE applications flexibly, the OCDP is proposed.

Second, we exploit the **4-mode Opportunity period**. The 4-mode Opportunity period has 4 kinds of design patterns for the Opportunity period. WBAN devices request the Opportunity period through transmitting the **OCM (opportunity contention message)** frame in the subperiod of **RO (request or opportunity)** in the OCDP. The coordinator selectively decides the Opportunity period among the 4-mode Opportunity period, and then the coordinator broadcasts a **OCM ACK (acknowledgement)** frame in the **AO (acknowledgement of Opportunity)** subperiod in the OCDP as shown in Figure 3.

3.1 OCDP (Opportunistic Contention Decision Period)

Figure 3 depicts the proposed OCDP. Unlike the IEEE 802.15.4 MAC protocol, the proposed MAC protocol has the OCDP. The coordinator could decide whether the Inactive period or the Opportunity period in the OCDP. When bursty data increase temporarily, the latency is inevitable in periodic sleep mechanisms such as the IEEE 802.15.4 MAC. In the proposed MAC protocol, the OCDP provides the opportunities for switching from the Inactive period to the Opportunity period.

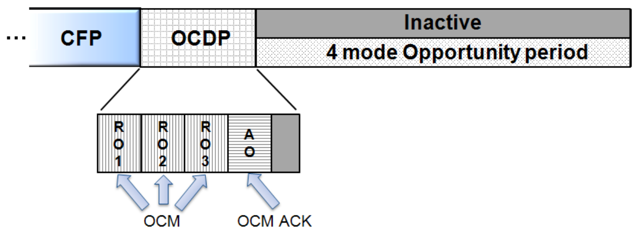


Figure 3: The detailed OCDP

The OCDP consists of both the **RO** subperiod and the **AO** subperiod. To use those of subperiods, the proposed WBAN MAC protocol provides two request frames named OCM and OCM ACK. The WBAN devices may request the Opportunity period through transmitting the OCM frame to the coordinator. On the other hand, the coordinator broadcasts the OCM ACK frame including the selected Opportunity period among the 4-mode Opportunity period.

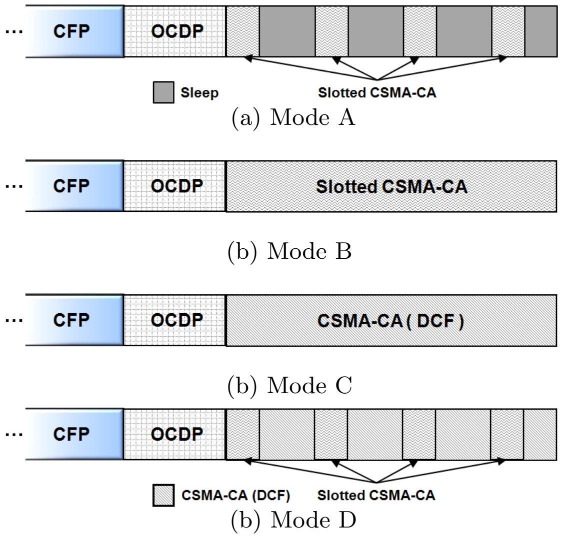
The RO subperiod is designed for transmitting the OCM

Table 1: Table of RO

Number of RO	WBAN devices
RO 1	Medical devices, sensor, etc
RO 2	CE with slotted CSMA-CA
RO 3	CE with CSMA-CA (DCF)

Table 2: Decision Table of Opportunity period

Received OCM (RO_1, RO_2, RO_3)	select mode of 4-mode Opportunity period
0, 0, 0	Inactive period
0, 0, 1	Mode C
0, 1, 0	Mode B
0, 1, 1	Mode D
1, 0, 0	Mode A
1, 0, 1	Mode D
1, 1, 0	Mode B
1, 1, 1	Mode D



(a) Mode A

(b) Mode B

(b) Mode C

(b) Mode D

Figure 4: 4-mode Opportunity period.

frame. As shown in Figure 3, the RO subperiod has three kinds of subperiods from the **RO 1** subperiod to the **RO 3** subperiod in OCDP. As shown in **Table 1**, these subperiods are mapped to the WBAN devices according to its characteristics. As shown in Table 1, since the RO subperiod is distinguished into 3 groups, each WBAN device issues and transmits the OCM frame to the coordinator for requesting the Opportunity period.

The AO subperiod is provided for transmitting the OCM ACK which is a decision message of switching between the Inactive period and the Opportunity period. Table 2 shows the decision table of the Opportunity period. If a WBAN device transmits the OCM frame, the coordinator receives the OCM frame and sets the RO_n (e.g., RO_1, RO_2, or RO_3) to 1. In case that the value of the RO_1 sets to 1, it means that either medical devices or sensor devices transmits the OCM frame. When a CE device generates bursty data, the OCM frame transmitted by the CE device. Thus, the value of RO_2 sets to 1. Since the IEEE 802.15.4 MAC uses the slotted CSMA-CA mechanism for sensor devices with low power consumption and low data rate, the data transmits to the coordinator without RTS (request to send), CTS (clear to send), and NAV(network allocation vector). For providing peer to peer communications without relaying to the coordinator, the proposed MAC protocol provides DCF mechanism to the CE devices optionally. These CE devices request the Opportunity period in the RO 3 subperiod. A coordinator used in the Table 2 decides the one of opportunity period among 4-mode opportunity period through compounding each OCM frame of RO_n.

The proposed OCDP has additional overhead in comparison with the IEEE 802.15.4 MAC. Since the medical applications generally use the Active period, however, they use the OCDP and the Opportunity period in the emergency situation or the medical device requiring the latency. Both CE applications and event-driven medical applications (e.g., motion detection and fall detection for the elderly or disabled people) use the Opportunity period for the low latency to resolve bursty data traffic occasionally. Therefore, the coordinator usually spends energy to wake-up the system in the OCDP.

3.2 4-Mode Opportunity Period

In OCDP, if there is any WBAN device which wants to use the Opportunity period, they request the Opportunity period through transmitting the OCM frame in the subperiod of RO in the OCDP. When all of the subperiods of RO end, the coordinator decides and selects the Opportunity period among four kinds of Opportunity period as shown in Figure 4. Since each RO is mapped to WBAN device characteristics, as shown in Table 1, the coordinator calculates and decides the Opportunity period through Table 2.

As shown in Figure 3, the Mode A provides the slotted CSMA-CA with periodic sleep alternately for low power consumption. Since Mode A means that the medical device only requests the Opportunity period, the all of CE devices sleep during Mode A. Mode B provides the slotted CSMA-CA during the Mode B. Mode C provides only DCF mechanism during the Mode C. Mode D provides both the slotted CSMA-CA and the DCF mechanism alternately.

4. PERFORMANCE EVALUATION

We first describe our simulation model to compare the performance of the proposed WBAN MAC protocol with the IEEE 802.15.4. We assume following PHY model as wireless channel: ISM band, O-QPSK modulation, 2,000kcps chip rate, and 250kbps data rate [5]. In addition, both the proposed and IEEE 802.15.4 MAC protocols use the superframe structure. In order to satisfy the latency requirement in Section 1, we set BO=4 (245.76ms of superframe) and SO=3 (122.88ms of active period).

Next, the traffic model is as follow: There exists medical devices of which the sampling rate is 12 channel electrocardiography (ECG) (250Hz), Temperature (2Hz), Oximetry (60Hz), Breathing rate (50Hz), Skin resistance (50Hz), Arterial pressure (120Hz), Respiration rate (20Hz), Cardiac rate (10hz). The period of packet generation are between

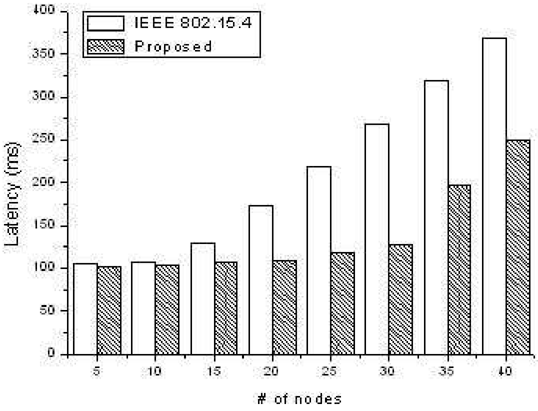


Figure 5: Latency comparison (medical devices)

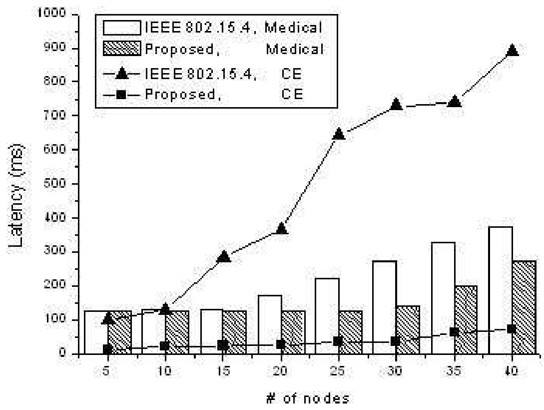


Figure 6: Latency comparison (with CE device)

300ms and 550ms. They send a packet of 40 bytes periodically [8, 9]. On the other hand, one CE device sends a message of 2000 bytes sporadically. The message is split into MAC-layer packets of 127 bytes which is the maximum size of IEEE 802.15.4 [5]. The inter-packet interval is 20ms with CBR (constant bit rate) packet generator [10].

Figure 5 shows the latency when there exists only medical devices. In proposed MAC protocol, the medical devices required the low latency are able to use Mode A. Since the proposed MAC protocol provides the Opportunity period, the proposed MAC protocol increases the latency when there are more than 35 devices. However, IEEE 802.15.4 using periodic sleep increases the latency when there are more than 20 devices.

Figure 6 shows the latency when a CE device is added. The CE device should contend medical devices in CAP in the Active period. When the CE device generates the bursty data and goes to sleep in the Inactive period, the latency is inevitable. However, the CE device can use the Opportunity period (i.e., Mode B) in the proposed MAC protocol, so that the latency can be reduced dramatically. The proposed protocol can be used flexibly in a variety of WBAN applications as mentioned in Section 1.

5. CONCLUSION

In this paper, we have proposed a WBAN MAC protocol for WBAN applications using the contention mechanism. Since our proposed protocol has the OCDP and 4 mode Opportunity period, it can be used flexibly in various WBAN devices and applications which require low latency. We have validated the flexibility through extensive simulations.

6. ACKNOWLEDGMENTS

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MEST) (No. R01-2008-000-20029-0) and by the MKE (Ministry of Knowledge Economy), Korea, under the ITRC (Information Technology Research Center) support program supervised by the NIPA (National IT Industry Promotion Agency) (NIPA-2009-(C1090-0902-0002)).

7. REFERENCES

[1] H. B. Li, R. Kohno. Introduction of SG-BAN in IEEE 802.15 with related discussion. *Proc. IEEE International Conference on Ultra Wideband*, pp. 134–139, September 2007.

[2] IEEE 802.15 WPAN Task Group 6 BAN: `http://www.ieee802.org/15/pub/TG6.html.`

[3] 802.15.6 Call for Applications - Response Summary, IEEE 802.15-08-0407-05-0006.

[4] TG6 Technical Requirements Document (TRD), IEEE 802.15-08-0664-09-0006.

[5] Omeni. O, Wong. A, Burdett. A. J, and Toumazou. C. Energy Efficient Medium Access Protocol for Wireless Medical Body Area Sensor Networks. *Biomedical Circuits and Systems, IEEE Transactions on*, vol. 2, Issue. 4, pp. 251–259, December 2008.

[6] C. Min, P. Chenglin, G. Xingming, L. Jianmei. A Novel MAC Protocol for Wireless Physiological Information Sensor Network. *Medical Devices and Biosensors, 2007. 4th IEEE/EMBS International Summer School and Symposium on*, pp. 79–81, August 2007.

[7] IEEE 802.15.4 Standard-2003, "Part 15.4: Wireless Medium Access Control(MAC) and Physical Layer(PHY) Specifications for Low-Rate Wireless Personal Area Networks(LR-WPANs)," 2003

[8] Haifeng. C, Wanqing. W, Jungtae. L. A WBAN-based Real-time Electroencephalogram Monitoring System: Design and Implementation. *Journal of Medical Systems*, March 2009.

[9] G. Oscar, C. Paulo, Afonso, J. A, Mendes. P. M. Quality of Service Support in Wireless Sensor Networks for Emergency Healthcare Services. *Engineering in Medicine and Biology Society, 2008. 30th Annual International Conference of the IEEE*, pp. 1296–1299, August 2008.

[10] Romdhani. L, Qiang. Ni, Turletti. T. Adaptive EDCF: enhanced service differentiation for IEEE 802.11. *Wireless Communications and Networking, 2003. WCNC 2003.*, vol. 2, pp. 1373–1378, March 2003.