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An Emergency Handling Scheme for Superframe-Structured MAC Protocols in WBANs*

BeomSeok KIM†, *Nonmember*, Jinsung CHO†a), *Member*, *and* Dae-Young KIM††, *Nonmember*

SUMMARY Wireless body area networks (WBANs) provide medical and/or consumer electronics (CE) services within the vicinity of a human body. In a WBAN environment, immediate and reliable data transmissions during an emergency situation should be supported for medical services. In this letter, we propose a flexible emergency handling scheme for WBAN MAC protocols. The proposed scheme can be applied to superframe-structured MAC protocols such as IEEE 802.15.4 and its extended versions. In addition, our scheme can be incorporated into the current working draft for IEEE 802.15.6 standards. Extensive simulations were performed and the low latency of emergent traffics was validated.
key words: *wireless body area network, emergency handling, superframe structure*

1. Introduction

Ubiquitous healthcare and/or lifecare services have attracted a great deal of attention in recent years. As a result, wireless body area networks (WBANs) have become the next generation of wireless personal area networks (WPANs). A WBAN consists of a coordinator, medical devices, and consumer electronics (CE) devices that function around, on, or in a human body and provides both medical and CE services. For the standardization of WBANs, the IEEE 802.15.6 Task Group was established and in May, 2010, the group published a working draft document [1]. The goal of the IEEE 802.15.6 Task Group is to standardize the PHY and MAC protocols for WBANs that can provide various ubiquitous services.

In general, WBANs support a variety of devices with different characteristics. Devices for medical services possess periodic characteristics with low data rates and small data sizes. In contrast, CE services have sporadic characteristics with burst data rates and video, audio, and regular files with various data sizes. Therefore, the MAC protocol for a WBAN should support different service characteristics simultaneously [2], [3]. Furthermore, emergency handling for WBAN services is an important requirement. If a WBAN cannot handle emergent data immediately, critical user requests may fail. Thus, the emergency handling mechanism in a WBAN should provide high reliability and low delay.

In the early stage of WBAN development, the IEEE 802.15.4 protocol, a typical low-power protocol for WPANs, was considered for WBAN services. The MAC protocol of IEEE 802.15.4 employs a frame structure of superframe type with a beacon [4]. Its active period is divided into 16 equal-sized slots and consists of a contention-free period (CFP) and a contention-access period (CAP). In the protocol, guaranteed time slots (GTSs) can be allocated in the CFP to a maximum of 7 devices. However, if more than 7 medical devices request GTSs, the periodic characteristics of medical services cannot be satisfied.

In order to solve the above problem of IEEE 802.15.4, several researchers focused on enhancing the GTS mechanism [5]–[7]. In general, the goal was to allocate more than 7 slots. However, this additional allocation results in a large and continuous CFP, which leads to significant transmission delays in emergent traffic.

For emergency handling, Yoon et al. proposed special slots within the intervals of GTSs; the scheme is known as ‘PNP-MAC’ [8]. PNP-MAC consists of CAP, data transmission slot (DTS) which is similar to the GTS of IEEE 802.15.4, and a special slot. Special slot is called a non-preemptive emergency transmission slot (ETS). The number of ETSs is configurable and the ETSs are used for handling medical and emergent traffic. However, since a large delay may occur until the next ETS is available, PNP-MAC cannot guarantee the immediate transmission of emergent data.

In addition, there are several works that have replaced inactive periods with CAP for retransmission or burst traffic [7], [8]. Such schemes can handle additional traffic, but do not guarantee periodic data transmission because the CAP is based on contention.

In this letter, we propose a flexible emergency handling scheme for superframe-structured WBAN MAC protocols. For flexible emergency handling against a large and continuous CFP, a mixed period (MP) rather than CFP is proposed. We then suggest an additional data transmission scheme using an extended period (EP) that allows for GTS re-allocation and additional CAP. The proposed scheme can be applied to a general superframe-structured MAC protocol such as the IEEE 802.15.4 standard and IEEE 802.15.6 WBAN standard proposals.

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†The authors are with the Dept. of Computer Engineering, Kyung Hee University, Korea.
††The author is with the Communication R&D Lab., LIG Nex1 Co., Ltd., Korea.
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a) E-mail: chojs@khu.ac.kr
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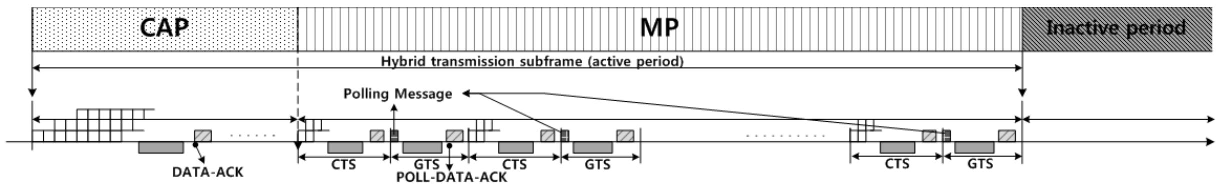

Fig. 1 Mixed Period (MP): A CAP slot (CTS) is inserted in front of each GTS for immediate transmission of emergent data.

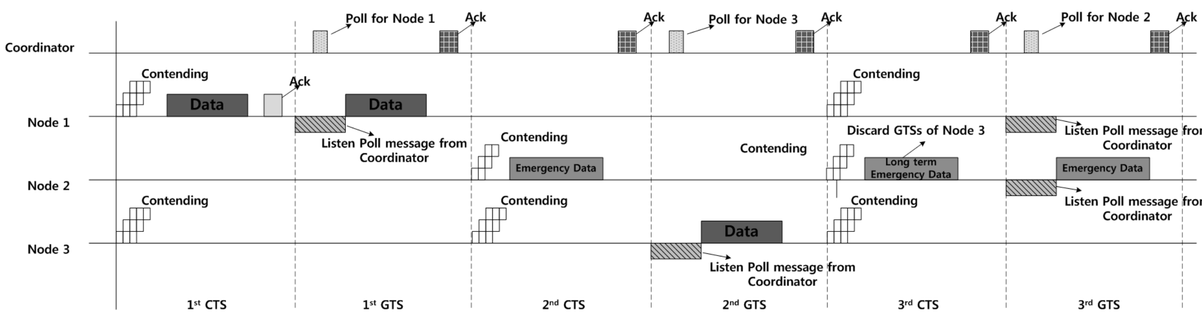

Fig. 2 An example of emergency handling mechanism on MP.

2. Mixed Period (MP)

As mentioned in Sect. 1, the delay of emergent data is quite large on IEEE 802.15.4 MAC or its extended version. For example, if an emergency situation occurs at the beginning of the CFP, the transmission of emergent data should be delayed until the beginning of the CAP on the next superframe. When beacon order (BO) and superframe order (SO) values are 4 and 3, respectively, the maximum length of the CFP is 53.76 ms and the inactive period is 122.88 ms. The total delay is 176.64 ms, which does not satisfy the 125 ms or less delay requirement of medical services [2].

The basic idea behind the use of MP instead of CFP is shown in Fig. 1. In order to provide immediate transmission of emergent data in the proposed MP, a CAP slot is inserted in front of each CFP slot (i.e., GTS). This inserted CAP slot is called the contention time slot (CTS). While the periodic data of medical devices are delivered on GTSs, a low latency in both the emergent data of medical devices and sporadic data of CE devices can be obtained through CTSs. The guarantee of access on CTS for emergent data is accomplished through priority-based contention window (CW) and contention probability (CP) values that are defined in the IEEE 802.15.6 baseline draft [1]. In other words, the CW and CP values enable priority-based channel access on the CTS for emergent, medical, video, and audio data. If the emergent node needs more slots, it sends a long-term transmission request that is piggybacked with emergent data to the coordinator on the CTS. The coordinator then allocates the next GTS to the emergent node and inserts a node that reserved the GTS but failed into the waiting list, in which nodes would be serviced later. Next, the coordinator broadcasts a polling message that indicates the change of the node to use the GTS (i.e., the failed node to the emergent node). This polling message is proposed in the IEEE 802.15.6 baseline draft so as to provide flexible usage of GTSs. Due to the polling mechanism, we can easily change the use of the GTS from the failed node to the emergent node.

An example of our emergency handling scheme in the MP is shown in Fig. 2. In this figure, node 1 and node 3 attempt to access the 1st CTS with their own CW and CP values. Node 1 wins the contention and accesses the 1st CTS although data of node 1 are not emergent. The 1st GTS is used by reserved node 1. On the 2nd CTS, node 2 and node 3 attempt to access the CTS. The data of node 2 are emergent and have a higher priority than the data of node 3. Therefore, node 2 takes the 2nd CTS. The emergent data of node 2 are delivered on the slot and reserved node 3 uses the 2nd GTS. On the 3rd CTS, node 1, node 2, and node 3 try to access the slot. Due to the CW and CP values that correspond to the emergency priority, node 2 takes the 3rd CTS and sends emergent data piggybacked with a long-term transmission request. Node 2 continues to use the 3rd GTS, which was reserved by node 1, and the coordinator inserts node 1 into the waiting list.

3. Extended Period (EP)

In the example shown in Fig. 2, node 3, which reserved the 3rd GTS, could not use the slot and was inserted into the waiting list because of the emergent traffic of node 2. In order to handle this traffic and additional sporadic traffic, we propose to switch the inactive period and the EP. As shown in Fig. 3, the EP consists of an extending request period (ERP), a re-allocated CFP, and an additional CAP. In the ERP, nodes that need additional CTSs can send requests

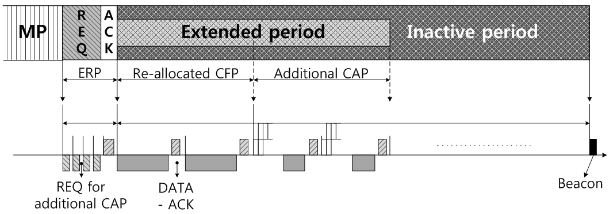

Fig. 3 Extended Period (EP): Re-allocated CFP and additional CAP can be used in inactive period, if needed.

and the coordinator broadcasts an ACK message with timing information regarding the beginning of additional CAP. The ACK message also contains the slot allocation information in the re-allocated CFP for nodes in the waiting list.

A CTS is not inserted in front of the GTS in the re-allocated CFP because the length of the re-allocated CFP is generally one or two slots. Even in the worst case, the length is 7-slots long (i.e., 53.76 ms when BO=4, SO=3), which is much less than the delay requirement of 125 ms for medical services. The emergent traffic that may occur in the re-allocated CFP can be delivered in the following additional CAP. If additional CAP requests exist in the ERP, the additional CAP of the EP is enabled and emergency and burst traffic can be handled in the period. The coordinator maintains the count of additional CAP requests and decreases the count when nodes complete their transmission.

4. Performance Evaluation

In this section, we first describe our simulation model that was used to evaluate the performance of the proposed emergency handling scheme. The performance of the proposed scheme is then compared with those of IEEE 802.15.4 MAC [4] and PNP-MAC [8]. For the PHY model, we assume the ISM band, O-QPSK modulation, 2,000 kcps chip rate, and 250 kbps data rate. Such conditions are identical to those of IEEE 802.15.4 [4]. Both of the protocols used for comparison are based on the superframe structure, and BO and SO values determine the superframe length and the active period length, respectively. In order to satisfy the delay requirement of WBAN services (as mentioned in Sect. 1), we set BO=4 and SO=3. In the case of BO=4 and SO=2, the length of the inactive period is 184.32 ms and thus, it cannot satisfy the delay requirement of medical services. We also performed additional simulations in which there is no inactive period (BO=SO=3) but it should be mentioned that such a scenario is not common.

In the traffic model, there exist 4 types of medical devices for 12-channel electrocardiography (ECG) (250 Hz), breathing rate (50 Hz), arterial pressure (120 Hz), and respiration rate (20 Hz) [3]. These devices send a packet of 40 bytes periodically. Emergent packets occur randomly and their packet size is uniformly distributed between 40 bytes and 400 bytes. In contrast, a CE device sends a message of 2500 bytes sporadically. The message is divided into MAC-layer packets of 127 bytes which is the maximum size in IEEE 802.15.4 [4].

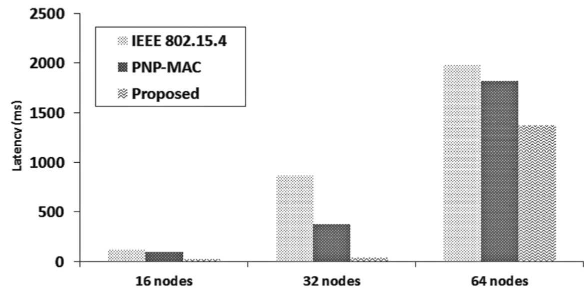

Fig. 4 Medical traffic (BO=4/SO=3): Due to priority-based CTS and re-allocated CFP in EP, the proposed scheme provides the lowest latency for medical traffics.

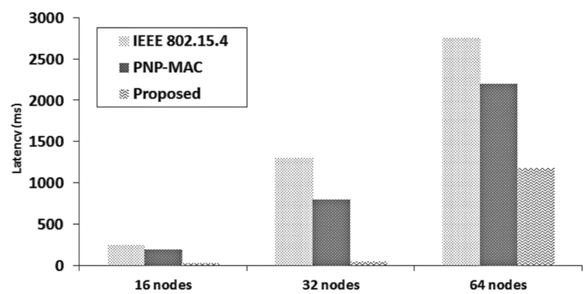

Fig. 5 Emergent traffic (BO=4/SO=3): Due to both MP and EP, the proposed scheme outperforms IEEE 802.15.4 and PNP-MAC in terms of emergency handling.

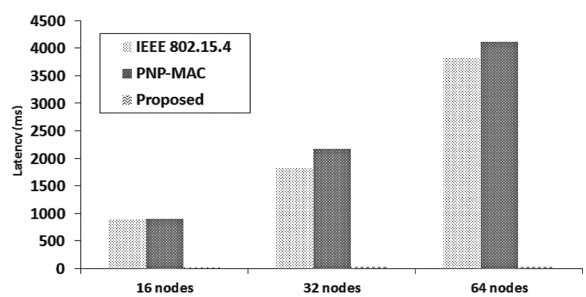

Fig. 6 CE traffics (BO=4/SO=3): Due to the additional CAP in EP, the proposed scheme lowers the latency of CE traffics dramatically.

Random backoff and CW values are not prioritized in IEEE 802.15.4. However, PNP-MAC applies both its policy of prioritized CW in the ETS and random backoff in the CAP [8]. Our scheme also exploits the priority-based CW value defined in the IEEE 802.15.6 draft [1]. The simulator is implemented in OMNeT++ [11].

The latency of medical, emergency, and CE data when the superframe parameters are set at BO=4 and SO=3 is shown in Figs. 4, 5, and 6, respectively. In general, IEEE 802.15.4 exhibits a high latency for medical and emergent traffic. On the other hand, the latency of medical and emergent traffic for PNP-MAC is lower than that for IEEE 802.15.4 because of prioritized clear channel assessment (CCA), random backoff, and special slot for emergency handling. However, PNP-MAC cannot handle emergent data immediately because the interval of the ETS is quite long.

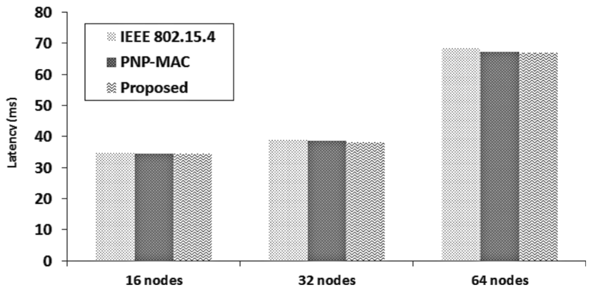

Fig. 7 Medical traffic (BO=SO=3): Due to priority-based CTS, the proposed scheme and PNP-MAC shows a little lower latency than IEEE 802.15.4.

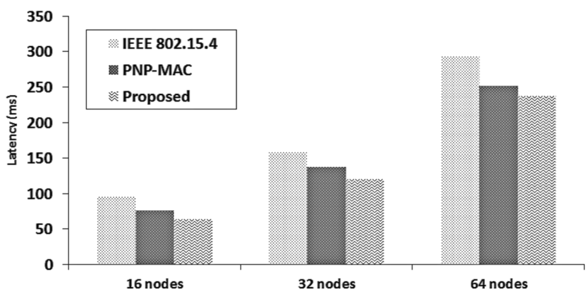

Fig. 8 Emergent traffic (BO=SO=3): With the helpful of MP, the proposed scheme provides the lowest latency even in case of BO=SO=3.

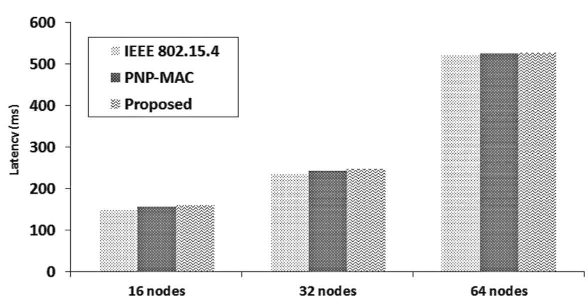

Fig. 9 CE traffic (BO=SO=3): The highest priority to emergent traffics in the proposed scheme results in the highest latency of the proposed scheme.

Furthermore, PNP-MAC exhibits the high latency for CE data due to the limited number of DTS allocations. In contrast, our proposed scheme exhibits the lowest latency due to both the MP and EP. The latency of medical and emergent data is especially low because they can be handled in the CAP, MP, and EP.

We also performed a simulation with BO=4 and SO=2, even though the length of the inactive period is 184.32 ms which is larger than 125 ms delay requirement of medical service. Since the inactive period is enlarged when compared to that in the simulation with BO=4 and SO=3, the gap of the latency is also enlarged. We omitted the graphs due to page limitations.

The simulation results of simulation with BO=SO=3 are shown in Figs. 7–9. Since there is neither the inactive period nor the EP, i.e., IEEE 802.15.4, PNP-MAC, and the proposed scheme have the same number of slots to transmit traffic, we can see from Fig. 6 that the results are slightly different. Due to the proposed MP, which focuses on emergent traffic, the latency of emergent traffic is the lowest, while that of CE traffic is the highest. This indicates the superiority of the proposed MP.

5. Conclusion

In this letter, we proposed an emergency handling scheme for WBANs using two mechanisms: MP and EP. A CTS in front of each GTS in the MP enables the immediate transmissions of emergent data. In addition, the EP guarantees transmissions of reserved but failed slot in MP at reallocated CFP, and handles the burst or sporadic traffic of CE services at additional CAP. Since our proposed scheme has both an MP and EP, it can handle emergent data with low latency. The proposed scheme can be applied to general superframe-structured MAC protocols and its efficiency has been validated through extensive simulations. Although our scheme may require more power consumption than IEEE 802.15.4 MAC and PNP-MAC due to polling messages and request messages for additional CAP in the EP, the latency of emergent traffics can be reduced dramatically.

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