An Emergency Handling Scheme for Superframe-structured MAC protocols in WBAN

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ABSTRACT
Wireless Body Area Networks (WBANs) provide a network communication service within the vicinity of a human body. Since WBANs must provide both medical and Consumer Electronics (CE) services at the same time, the MAC protocol in WBANs must satisfy the requirements of each service, especially hwen considering the need for immediate and reliable data transmission during an emergency situation. In this paper, we propose an emergency handling scheme for WBAN MAC protocol. The proposed scheme can be applied to superframe-structured MAC protocols such as IEEE 802.15.4 and its extended versions which support dynamic Contention-Free Period (CFP) allocations. In addition, our scheme can be incorporated with working drafts for IEEE 802.15.6 standardization.

Categories and Subject Descriptors
C.2.2 [**Network protocols**]: MAC protocols.

General Terms
WBAN MAC protocols

Keywords
Wireless body area networks, emergency handling, superframe structure.

1. INTRODUCTION
Since attention to heathcare and lifecare have increased driving forces behind wireless personal area networks (WPANs). A wireless body area networks (WBANs), which support both medical and Consumer Electronics (CE) services with sensor devices that function around, on, or in human bodies have become the next generation of wireless technology for Wireless Personal Area Networks (WPANs). WBAN, which consist of a coordinator, medical devices, and CE devices, can provide various services in medical and non-medical areas. The IEEE 802.15.6 task group established WBAN standardization organization and also published draft documents [1]. The objective of the IEEE 802.15.6 task group is to standardize the PHY and MAC protocols for WBAN, which can provide various ubiquitous services.

In general, medical applications imply periodic characteristics with low data rates and small data size. Conversely, CE applications have sporadic characteristic with burst data rates and various data sizes such as video, audio and regular files. The MAC protocol for WBAN should simultaneously provide these different service characteristics [2], [3].

Moreover, in WBAN, emergency handling is one of the most important requirements. If WBAN cannot immediately handle the emergent data, critical user issue may result. Therefore, it is necessary that the emergency handling mechanisms possess high reliability and low delay.

The Typical low power MAC protocol, IEEE 802.15.4 has a superframe-structure with a beacon [4]. Its active period is divided into 16 equally-sized slots and consists of a contention-free period (CFP) and a contention-access period (CAP). In the protocol, a guaranteed time slot (GTS) can be allocated in CFP to a devices. If many GTS slots are allocated, then the CAP is decreased. Also the GTSs of IEEE 802.15.4 are allowed to use a maximum of 7 devices, if more than 7 nodes request GTSs, IEEE 802.15.4 cannot guarantee all of requests.

In order to solve the above problem, several studies have aimed to enhance the GTS mechanism [5], [6], [7]. In general, the can additionally allocate more than 7 slots. However, this allocation results in a large and continuous CFP, in which it is difficult to deliver the emergent traffic. Specifically, a large and continuous CFP leads to significant transmission delays within the emergent traffic.

In this paper, we propose an adoptive and effective emergency handling scheme for superframe-structured WBAN MAC protocols. For effective emergency handling for a large and continuous CFP, the proposed scheme support immediate emergency handling using a Mixed Period (MP) instead of a CFP. Next, we propose an additional data transmission scheme using an Extended Period (EP), which supports GTS and which are not allocated due to emergency handling and burst traffic. This scheme can be applied to a general superframe-structured MAC protocol such as IEEE 802.15.4 and its extended version, which

ICUIMC'11, February 21–23, 2011, Seoul, Korea.

supports dynamic CFP allocations. In addition, our scheme can be incorporated with IEEE 802.15.6 standardization proposals.

The rest of the paper is organized as follows: Section 2 discusses the requirements of WBANs and related MAC protocols. In Section 3, we describe the proposed emergency handling scheme and its performance is evaluated via extensive simulations in Section 4. Finally, Section 5 highlights our conclusion and future work.

2. RELATED WORKS

WBAN consist of various devices with different characteristics (i.e., medical, CE application) that exist within the vicinity of human bodies. In order to flexibly and reliably support these different characteristics, WBAN MAC protocols must satisfy the following requirements [2], [3].

First, WBAN devices should operate via battery power in, on, and around human bodies in order to provide mobility. Due to this requirement, low power consumption of WBAN devices is one of the most important factors. For satisfying this requirement, WBAN technical requirement document (TRD) define factor of duty-cycle (i.e., <1% or 10%).

Second, scalability is an indispensable requirement in WBAN. WBAN networks should be able to accommodate 256 devices, as well as satisfy various transmission rates (10kbps ~ 100Mbps).

Third, most medical devices have a periodic characteristic. Conversely, CE devices have sporadic characteristics including burst data transmission in an event-driven manner. WBAN should be able to satisfy both of these characteristics with the ability to function both periodically and sporadically.

Finally, WBAN must be able to guarantee highly reliable and prompt transmission during an emergency situation. Medical services on WBAN may directly affect the life or death of a user. When devices sense an irregular data by monitoring vital signal, the service provider should immediately handle the situation. The ability to immediately respond to sporadic emergency data is one of the important requirements of WBAN.

For these reasons, the WBAN MAC protocol should be designed to satisfy all of these different requirements. In particular, emergent data handling with high reliability and low latency as well as supporting both periodic and non-periodic traffic is mandatory in WBAN environments. Additionally, MAC protocols should be flexible and adaptive in order to satisfy various WBAN requirements.

The existing IEEE 802.15.4 MAC protocol, which has low power consumption and low data rate characteristics, satisfies requirements of power consumption and scalability. But it does not satisfy the above-mentioned requirements of WBAN [4]. Since the GTS slots of IEEE 802.15.4 can only be allocated to a maximum of 7 devices, cannot guarantee periodic traffic when more than 7 nodes request GTS slots. Moreover, when IEEE 802.15.4 requires additional CAP slots, a coordinator may increase the superframe order (SO) to extend the CAP duration. In this case, the GTS duration also increases, resulting in low utilization due to an unnecessary increase in GTS slots.

To solve the issue of IEEE 802.15.4, several studies have been conducted to enhance the GTS mechanisms [5], [6], [7]. However, since they have proposed additional GTS allocation schemes on CFP, the continuous GTS allocations in these proposals increase the CFP. When an emergency condition occurs under CFP, the immediately delivery of emergent data cannot be achieved. This protocol is, therefore, not suitable for WBAN environments because the emergent data requires a low latency. Moreover because these mechanisms do not provide re-allocation for the GTS manner, the allocated GTS is not guaranteed when link loss problems occur resulting in low reliability.

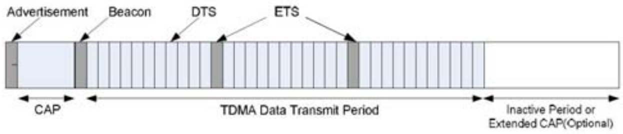

Figure 1. PNP-MAC

As for emergency handling, the authors in [8] proposed special slots within the intervals of GTSs which are called 'Preemptive slots allocation and Non-preemptive transmission for Providing QoS MAC Protocol (PNP-MAC)'. Figure 1 shows the structure of a PNP-MAC, which provide fast and preemptive data transmission slot (DTS) allocation, non-preemptive emergency transmission slot (ETS) transmission, and prioritized CCA and random backoff. CAP is used for DTS allocation requests, CE data, and network configuration packet transmission. A late beacon message provides the information of the DTS allocation result as well as the number of ETS slots. The number of ETS slot is configurable, and ETSs are specialized for handling medical and emergency traffic. However, this proposal may not guarantee immediate transmission of the emergent data because a large delay will exist until the next special slot is available.

Meanwhile, there have been several studies that have replaces inactive methods with CAP for retransmission or burst traffic [7], [8]. The schemes for changing from inactive to CAP can retransmit failed GTSs but do not guarantee periodic data transmission because CAP operates based on contention.

3. THE PROPOSED SCHEME

As previous mentioned, emergency data transmission with low delay and high reliability in the WBAN environment is one of the most important requirements. In this section, we propose a poll-based adaptive and effective emergency handling scheme which can be applied to superframe-structured MAC protocol. The reasons for using a polling mechanism are to provide adaptability to a superframe-structured MAC protocol including IEEE 802.15.6 baseline MAC protocol [1] and to more efficiently handle the emergent data. For Emergency handling on CFP, we consider the concept of a Mixed Period (MP), which consist of both GTS and CAP slots. In addition, we propose the Extended Period (EP) for re-allocating failed GTSs or for handling burst data.

3.1 Mixed Period (MP)

As mentioned above, in order to solve the limited GTS allocation problems of IEEE 802.15.4, general MAC structures are used to allocate additional GTSs. However, this mechanism requires continuous GTS which increases the CFP length. If an emergency occurs on a long CFP, emergent data cannot be delivered using the existing scheme. Via the CFP and the Inactive

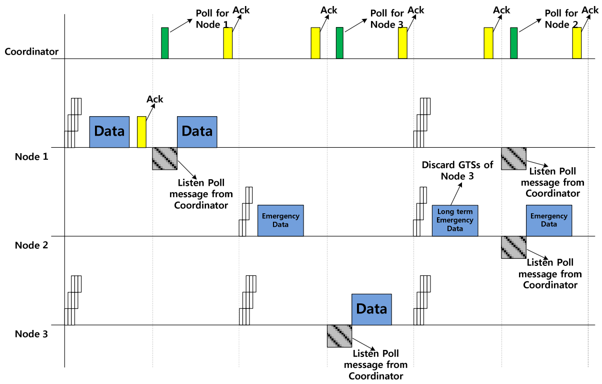

Figure 3. Emergency handling mechanism on MP.

period, the minimum delay of this emergent data is 'superframe duration (SD) – generated time of emergent data + winning time on contention'. For example, when the SO and BO values are 3 and 4, (these are the maximum values used to satisfy the delay of the WBAN requirement [1]), and the emergent data are generated at the start of CFP and the number of GTS slots is 7, the minimum latency is 176.64 ms. In this situation, during the CAP within the next superframe interval, the emergent data handling cannot be guaranteed and a higher latency greater than 176.64 ms is produced.

As show in Fig. 2, we introduce the concept of MP for use in place of CFP. The MP is two time longer than CFP because it consist of both CAP and GTS slots, which are placed on the exchange. CAP slots on MP are used for several reasons. First, the burst and sporadic data of the CE devices are handled with low latency on the CAP slots, reducing the delay caused by continuous GTS allocation. Second, the emergent data can be handled immediately with CAP slots. The guarantee of channel access for the emergent data on the CAP slot in accomplished through the use of a priority-based contention window (CW) and a contention probability (CP) value, as defined in the IEEE 802.15.6 baseline draft which defines both the minimum and maximum values of CW on CSMA/CA and CP on the slotted ALOHA [1]. This makes it possible for the CAP period. If an emergent node accesses the CAP slot with the highest priority, the coordinator decides whether or not the node will use the next GTS slot for emergency handling. If the coordinator can handle the emergent data on a CAP slot, the user of the next GTS slot is not changed. Otherwise, the coordinator uses the GTS for emergent handling, and inserts the information of the reserved node into the re-allocation list for retransmission on the EP. Then, the coordinator sends poll messages to both the reserved node and the emergent node to provide the information that the emergent node has to use the GTS slot. When they receive polling messages with the destination address of the emergent node, the reserved node goes to sleep and the emergent node is able to use the GTS slot.

Figure 3 is an example of emergency handling on MP. In Figure 3, node 1 and node 3 attempt to access the first CAP slot with their own CW or CP value [3]. Node 1 wins the contention and accesses the first CAP slot. The data from node 1 are not emergent and the next CFP is used by a reserved node. At the second CAP slot, node 2 and node 3 attempt to access the CAP. The data from node 2 has high priority emergency information that corresponds to both the CW and CP values. Therefore, node 2 uses the second CAP slot. The emergent data of node 2 is able to function with a single slot, and the reserved node 3 can then use the next CFP slot. On the third CAP slot, node 1, node 2, and node 3 want to access the CAP slot. Node 1 and node 3 do not have emergency data, but node 3 has emergent data with a request for a long-term transmission. Due to its priority, the CW and CP values, and the request for long-term transmission, node 3 takes the CAP slot and reserves the CFP for node 1, which is discarded by the coordinator.

3.2 Extended Period (EP)

Within WBAN environment, failed GTSs may occur due to link loss or position of the human body. Additionally, in a relatively short CAP with continuously allocated CFP, burst traffic cannot be satisfied with QoS requirements. In order to solve these problems, we propose switching the inactive period and the EP. As Depicted in Fig.4 the first part of EP is an Extending Request sub-Period (ERP) through which the coordinator can receive request messages and transmit ACK messages. In ERP, nodes which want to use CAP can request an EP from the coordinator, and the coordinator will transmit an ACK message with time information of start of additional CAP slots.

GTS re-allocation and additional CAP, instead of an inactive period, are explained in Fig. 4. GTS re allocation supports the guarantee of discarded GTS slots which register on the previous MP. Re-allocation GTS slots are sequentially scheduled and are no longer than the length of the inactive period because they can be requested via the failed GTSs on the CFP of the previous active period. On pre-scheduled re-allocated GTS slots, emergency handling is not possible; however, emergencies can be handled through the use of additional CAP slots which can be used by the emergent node and the CE node after the re-allocation period of the GTSs. The coordinator maintains a count of additional CAP requests and decreases the count when nodes complete a transmission on each additional CAP slot. If the count is 0 and there exists an idle time until the end of the Beacon Interval (BI), EP is switched to an inactive state for low power consumption. Conversely, if the count of additional CAP requests is not 0, but the coordinator meets at the end of BI, a count of 0 is

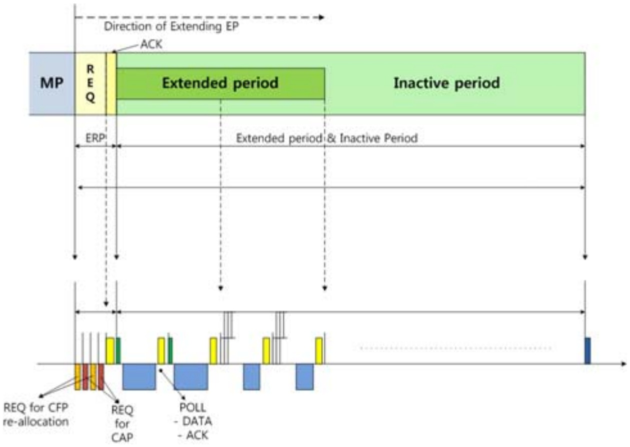

Figure 4. Extended period(EP).

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Algorithm of extended period processing on coordinator
Start of Inactive period
Additional_CAP_Count = 0
while(EP REQ Time != 0)
  if(receive CAP REQ)
    Insert CAP REQ information to CAP REQ List
  end of if
end of while
if(RE-ALLOC CFP List != NULL || CAP REQ List != NULL)
  Switch to Extended period (EP)
  Broadcast ACK message
  while(RE-ALLOC CFP List != NULL)
    Dequeue from RE-ALLOC CFP List
    DATA Transmits
  end of while
  while(CAP REQ List != NULL)
    if(Inactive period time == 0 || Additional_CAP_Count == 0)
      go to sleep mode
      Additional_CAP_Count = 0
    else
       slotted-CSMA/CA operate
    end of if
  end of while
else
  Maintain Inactive period
end of if
```

Figure 5. Algorithm of extended period

initialized and a new superframe is started.

4. PERFORMANCE EVALUATION

We first describe our simulation model in other to evaluate the performance of the proposed emergency handling scheme compared to those of IEEE 802.15.4 and PNP-MAC [8]. As for the PHY model, we assume the ISM band, O-QPSK modulation, a 2,000 kcps chip rate, and a 250 kbps data rate [4]. In addition, both the proposed scheme and the IEEE 802.15.4 MAC protocols are based on a superframe structure, and BO and SO determine the superframe length and the active period, respectively. In order to satisfy the latency requirement described in Section 1, we set BO=4 (245.76ms of superframe) and SO=3 (122.88ms of active period).

Next, the traffic model is following: there exist medical devices such as 12 channel elertrocardiograpghy (ECG) (250Hz), temperature (2Hz), oximetry (60Hz), breathing rate (50Hz), skin resistance (50Hz), arterial pressure (120Hz), and respiration rate (20Hz) [3]. They periodically send a packet of 40 bytes. Emergent packets occur randomly and the packet size is between 40 bytes and 400 bytes. Conversely, a CE device sporadically sends a message of 2500 byte message that is divided into MAC-layer packets of 127 bytes, which is the maximum size in IEEE 802.15.4 [4].

Finally, the random backoff and CW values are not prioritized in IEEE 802.15.4 but PNP-MAC has a policy of prioritized CCA within ETS and random backoff in CAP [8]. Our proposal also exploits the priority-based CW value defined in the IEEE 802.15.6 draft [1]. The simulator is implemented in OMNet++ [11].

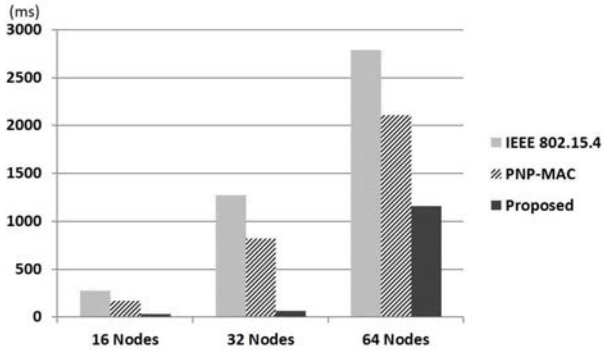

Figure 7. Latency of emergent traffic

Figure 6 shows the traffic latency for medical services. Since the IEEE 802.15.4 does not have a specific handling scheme or medical data such as a special slot on CFP or priority of data type, it shows a high latency. The PNP-MAC has medical data-specific schemes such as DTS, which has a higher number of slots in comparison to those of IEEE 802.15.4, prioritized CCA, and a random backoff scheme. Therefore, PNP-MAC exhibits a low latency in comparison to IEEE 802.15.4. However, when 64 nodes exist within the network, PNP-MAC shows a high latency due to the limited number of DTS slot allocations. Conversely, our proposed scheme shows the lowest latency because it is able to allocate the CAP slot additionally and exploit the priority-

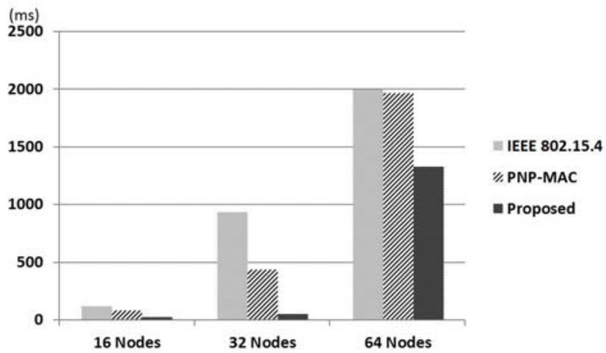

Figure 6. Latency of medical traffic

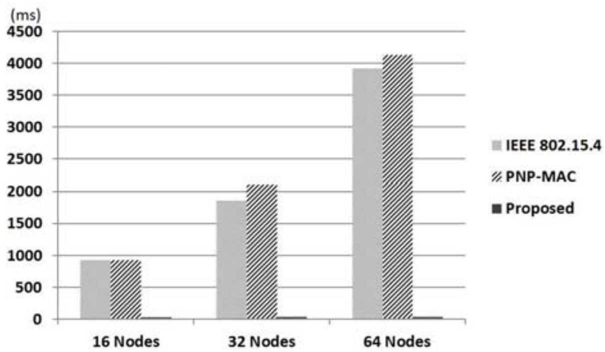

Figure 8. Latency of CE traffic

based CW value defined in the IEEE 802.15.6 draft. However, the latency on 64 nodes is relatively high because the enable slot on the superframe is empty.

Figure 7 shows the latency of emergent traffic. Inherently, IEEE 802.15.4 does not contain an emergency handling method, so it shows high latency. Specifically, when compared with the data in Figure 6, the latency is large because it cannot handle the emergent traffic on CFP. The latency of the PNP-MAC is less than that of IEEE 802.15.4 because PNP-MAC has ETS on a TDMA data transmission period. However, it cannot immediately handle emergent data because the interval of the ETS is quite long. Conversely, since our proposed scheme can immediately handle emergent data on the MP, it shows a lowest latency of less than 100 ms when there are 16 or 32 nodes within the network. However, it shows a similar result to that of the medical traffic latency on 64 nodes because the enable slot on the superframe is empty and the emergent and medical data share a queue.

Figure 8 exhibits the latency of the CE traffic and both the IEEE 802.15.4 and the PNP-MAC show high latency. Specifically, the PNP-MAC shows high latency because it has a short CAP compared to that of IEEE 802.15.4. The proposed scheme supports additional CAP slot allocations on EP and has low latency. CE traffic is sporadically generated and the ratio of CE devices among all devices is 20%; thus, the rate of CE traffic is quite low, resulting in. This is the reason of low latency of CE traffics on proposal.

5. CONCLUSION

In this paper, we have proposed an emergency handling scheme for WBAN applications using two mechanisms MP and EP. Since our proposed scheme has both MP and EP, it can handle emergent data and additional data transmission with low latency. Furthermore, it can be applied to general superframe-structured MAC protocols. We have validated the efficiency of this proposed scheme via extensive simulations. Our proposal has some overhead from additional slot use in EP. Our future works include the designof a stochastic slot allocation scheme for efficient slot utilization.

6. ACKNOWLEDGMENTS

This work was supported by the MKE(The Ministry of Knowledge Economy), Korea, under the ITRC(Information Technology Research Center) support program supervised by the NIPA(National IT Industry Promotion Agency) (NIPA-2010-(C1090-1021-0003)) and by Mid-career Researcher Program through NRF grant funded by the MEST (No. 2008-0061488).

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