MAC Protocol with Interference Mitigation Using Negotiation Among Coordinators in Multiple Wireless Body Area Networks

Shunya Ogawa[1(✉)], Takahiro Goto[1], Takumi Kobayashi[1], Chika Sugimoto[1], and Ryuji Kohno[1,2]

[1] Graduate School of Engineering Science, Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama, Kanagawa 240-8501, Japan
{ogawa-shunya-md,goto-takahiro-wx,kobayashi-takumi-ch,chikas, kohno}@ynu.jp

[2] Centre for Wireless Communications, Faculty of IT and EE, University of Oulu, Linnanmaa, P.O. Box 4500, 90570 Oulu, Finland
ryuji.kohno@oulu.fi

Abstract. In this paper Cwe propose a new MAC protocol in presence of multiple wireless Body Area Network (BANs) which can for reduce inter-WBAN interference and improve overall performance of all BANs. A BAN system consists of a coordinator and some sensor nodes. When coverages of multiple BANs are overlapped, some packets transmitted from sensor nodes of different BANs cause interference. Although an international standard for wireless medical BAN, i.e. IEEE802.15.6 can reduce intra-WBAN interference within a single BAN, inter-WBAN interference caused by coexistence of multiple BANs can not reduce effectively. Therefore, this paper proposes such a new MAC protocols method that coordinators of overlapped BANs can negotiate among coordinators of BANs. In addition, to enable priority control which is a feature of the standard, we propose a method that changes parameters of the proposed method according to priority of packets. Throughput and delay time of the proposed scheme are illustrated by simulation, in which it is convinced that the proposed scheme can improve overall performance such as throughput and delay considering efficiency of priority control.

Keywords: Multiple WBAN · IEEE802.15.6 · MAC · Interference mitigation · Negotiation among coordinators

1 Introduction

Wireless Body Area Network (WBAN) is a technology for health care. WBAN is constructed with wearable or implant sensors and coordinators placed around the human body. It can monitor personal health conditions by using psysiological and biological information from sensors. WBAN is not only applied for

L. Mucchi et al. (Eds.): BODYNETS 2019, LNICST 297, pp. 384–393, 2019.
https://doi.org/10.1007/978-3-030-34833-5_29

medical applications, but also applied for non-medical application, research has progressed in recent years [3]. In WBAN, it is important to satisfy flexible quality of service (QoS) and latency, because allowable delay time is different between medical and non-medical information.and many paper discuss this problem [7,8].

IEEE802.15.6 was published as a international standard for WBAN and it standardize PHY layer and MAC layer [1]. As shown in Table 1, standard defines user priority (UP) and it can control QoS. There are two protocols in MAC layer such as contention base protocol and contention free protocol [2], and there are three access modes in standard, one of them is called superframe and it consists of beacon, contention access period such a CSMA/CA and contention free period.

In intra-WBAN, the coordinator schedules many sensor nodes so that they can send packets at the same time without interfering with each other, and can co-exist in a single BAN. Since WBAN move with people, when many people with WBAN enter into the communication range of each other, interference will occur between WBANs. Therefore, the interference of coexistent WBAN is a problem, and to solve this interference problem an appropriate MAC protocol is required [5], and many paper discuss this problem [4,6]. The standard IEEE802.15.6 only provides a basic outline and interference within a single BAN. Although intra-WBAN interference can be avoided by using an access technology such as TDMA, inter-WBAN interference caused by coexistence of many BANs can not be avoided. This is because coordination between coordinators of different WBANs is not done, and collisions occur if the transmission periods of packets is overlapped.

In order to solve this problem, in this paper, negotiation was performed among the coordinators, which was not recognized in the standard. Thereby enable to schedule among different BANs, and reduce interference. In addition to interference mitigation, we also consider different QoS requirements.

Table 1. IEEE802.15.6 Priority Mapping

User priorit	Traffic designation
0	Background (BK)
1	Best effort (BE)
2	Excellent effort (EE)
3	Video (VI)
4	Voice (VO)
5	Medicald data or network control
6	High-priority medical data or network control
7	Emergency or medical implant event report

2 Overview of IEEE802.15.6 MAC Protocol

This chapter describes the features of the conventional IEEE802.15.6 MAC protocol [1]. Specifically, it shows two access control methods and access modes.

2.1 CSMA/CA

CSMA/CA is a contention based protocol. If the node has a packet, it checks whether the channel is idle. If it is idle it decrements the backoff counter that set based on contention window (CW) by 1. When the backoff counter becomes 0. The backoff counter takes different values depending on UP. Specifically, high UP makes it easy to take a low value, and it enables priority control.

2.2 Polling

Polling is a contention free protocol, in which the coordinator assigns slots for packets to specific noeds. Therefore, in polling, packet collisions do not occur, so reliable communication can be performed.

2.3 Access Mode

There are three access mode in standard and one is beacon mode with superframes. Figure 1 shows the structure of Superframe. B shown in Fig. 1 is a beacon, which is transmitted from the coordinator to all sensor nodes in the communication range, and has the role of informing the start of Superframe and the configuration of Superframe. Also, the structure of Superframe can be roughly divided into two: CAP (Contension Access Period) and CFP (Contention Free Period). EAP (Exclusive Access Phase), RAP (Random Access Phase), and CAP (Contention Access Phase) shown in Fig. 1 are CAP, and MAP (Managed Access Phase) is CFP. EAP is a section that handles only User Priority 7 packets, which are emergency and implant information. RAP is an interval that handles all packets. CAP is an interval when B2 is in Superframe, and CAP is an interval that handles all packets. MAP is a section in which the coordinator gives each sensor node the right to transmit packets and can communicate without collisions. In addition, the coordinator is designed to be able to change the length, ratio between CAP and CFP and the length of Superframe itself.

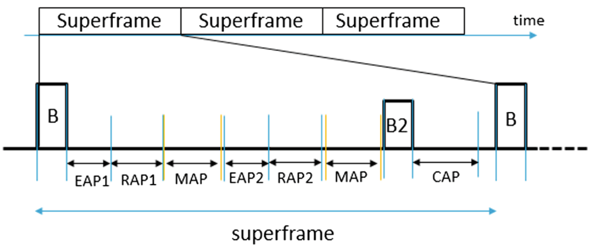

Fig. 1. Beacon mode with superframe in IEEE802.15.6

3 MAC Protocol with Interference Mitigation Using Negotiation Among Coordinators

IEEE802.15.6 has the problem that it can not avoid inter-WBAN interference. This is because coordination between coordinators of different WBANs is not done, and collisions occur if the transmission periods of packets is overlapped. In order to solve this problem, in this paper, negotiation was performed among the coordinators, which was not recognized in the standard, Thereby enable to schedule among different BANs, and reduce interference.

3.1 Negotiatiom Among Coordinators

Information obtained by negotiation between coordinators is sharing of overlap situation of each BAN. When an overlapping sensor node and the sensor node under its control transmits a packet simultaneously, contention will occur and packets will be destroyed. Therefore, if there are overlap nodes, they do not send packets simultaneously.

We assume that overlap situations are shared among coordinators. So, we show the procedure of how to identify overlap situations.

1. Since BAN uses UWB communication, they can share the distance (between coordinators, between coordinators and sensor nodes, etc.).
   By sharing the distance between a sensor node and the coordinator, it is possible to identify whether the node is within its communication range or not. However, just by distance, they does not know that sensor nodes belongs to which WBAN system.
2. Use the address of the sensor node given for each BAN.
   The MAC layer has the role of defining the MAC address for identifying the wireless device in the preamble part of the frame, so the address differs for each sensor node. By sharing this address among the coordinators, it is possible to identify whether a sensor node belong to own BAN or another BAN.

For example, in the case of Fig. 2, by identifying the distance and address between nodes, it is possible to identify which node causes interference.

3.2 Interference Mitigation MAC Protocol

The basic concept of this proposed method is sharing the overlap situation to identify the nodes that cause interference. Therefore, by sharing the overlap situation, coordinator with each BAN configure superframe in order not to send packets at the same time.

Interference Mitigation MAC Protocol in CFP
In CFP, inter-WBAN interference occurs when transmission rights are assigned to a overlapped of each BANs sensor node. In order to solve this problem, the

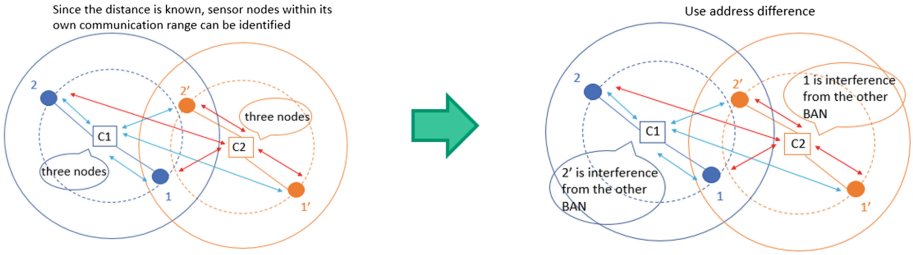

Fig. 2. How to identify overlap situations

structure of MAP of Superframe is divided into MAP1 and MAP2 The role of MAP1 and MAP2 is shown as follows.

– MAP1 assigns transmission rights to nodes not subject to interference. Even if they try to transmit at the same time, packet collision does not occur.
– MAP2 assigns transmission rights to nodes giving interference. This is because nodes giving interference will cause contention on their own BAN and other BANs if they are sent at the same time, so if one BAN is transmitting in MAP2, Other BANs are put on standby.

Figure 3 illustrates this protocol. C1 and C2 mean coordinator.Coordinator1 non-overlapped node (number 2, 3, 4) and coordinator2 non-overlapped node (number 1', 2', 3') are assigned MAP1 and send at the same slot. Since they do not overlap, they can be transmitted in the same slot without interference. On the other hand, coordinator1 overlapped node (number 1) and coordinator2 overlapped node (number 4') are assigned MAP2 and send different slot. Although they overlap, Interference does not occur because only one side transmits in a slot.

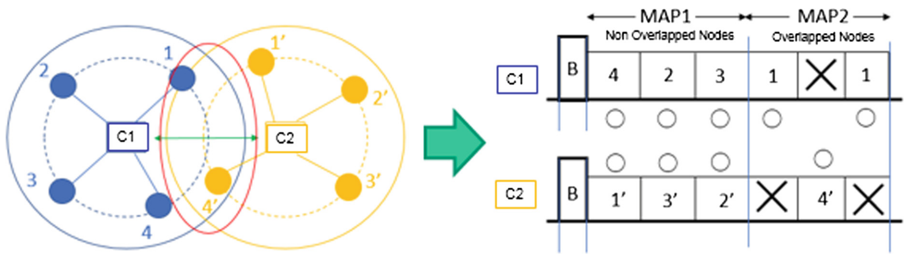

Fig. 3. MAC protocol of MAP

Interference Mitigation MAC Protocol in CAP
Although CAP adopts CSMA/CA, in CSMA/CA, inter-BAN interference occur when overlapped nodes get transmission rights at the same time. Especially, if the user priority of the overlap node is high, the frequency of contention will

increase considerably. In order to solve this problem, the protocol of Superframe RAP is as follows.

– If the overlapped node is a non-medical node (UP4 or less), it will not be put in the competition for transmission right
– If the overlapped node is a medical node (UP5 or higher), compete the transmission right as usual

As a point of caution, nodes that are lower than UP of overlapped node did not give transmission right either, in order to guarantee in the order of high UP. Although overlapped nodes may also have transmission rights, and cause inter-BAN interference, if you do not give the right to transmit to the medical node (UP5 or higher), you can not guarantee UP in the order of high UP.

Figure 4 illustrates this protocol. Non-medical interfering nodes do not acquire transmission rights. By doing so, priority control is possible.

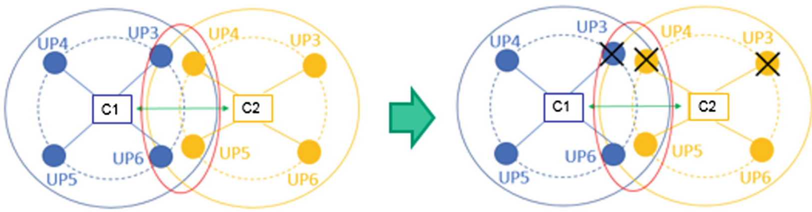

Fig. 4. MAC protocol of RAP

3.3 MAC Protocol to Enable Priority Control

The protocol described so far is a method in which improves average performance of whole UP, but there is no purposeful control such as guaranteeing high UP and sacrificing low UP. Therefore, we propose a MAC protocol that makes a gap between high UP and low UP.

To Make a Gap Between High UP and Low UP in CFP
In order to make a gap between high UP and low UP in MAP, we apply the concept of UP to how to assign packet transmission rights. As a result, high UP will be allocated more and low UP will be allocated less.

To Make a Gap Between High UP and Low UP in CAP
In order to make a gap between high UP and low UP in RAP, the protocol of Superframe RAP is as follows.

– If it is low UP (4 or less) irrespective of interference or non-interference, do not compete transmission right
– If it is high UP (5 or more) irrespective of interference or non-interference, compete transmission right as usual

The difference from the case of average performance is that the distinction between overlapped nodes and non-overlapped nodes is eliminated, which is considered to result in a gap between low UP and high UP as in MAP.

4 Performance Evaluation

4.1 Simulation Model and Parameters

Simulation parameters are based on IEEE802.15.6, as shown Table 2 and simulation model is like Fig. 5. We modeled each BAN by two circles. Solid line circle is communication range. On the other hand, dotted line circle is sensing range. We adopted star topology and there are four nodes each.One node has one priority packet. In order to see the characteristics depending on the traffic volume, we evaluated when the offeredload was varied. Evaluation was performed by simulation under the above settings unsing Matlab as shown Figs. 6, 7 and 8. The contents of the evaluation are as follows.

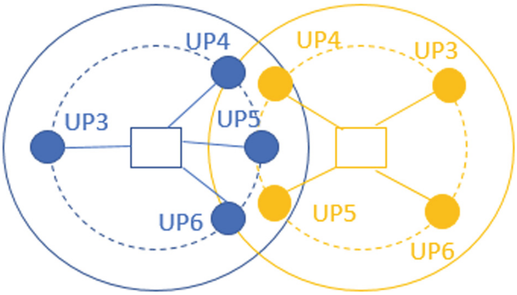

Fig. 5. Simulation model

Table 2. Simulation parameters

Number of nodes	4 (high UP 2, low UP 2)
Data rate	242.9 [kbps]
Payload length	128 [octets]
Number of BANs	2
Superframe length	115 [ms]
Beacon length	1 [ms]
Number of slots	RAP = 5, MAP = 12
Simulation time	30 [s]
Number of trials	100 [times]

- Network overall throughput characteristic
- Throughput characteristic per UP
- Delay characteristic per UP

Each of these was evaluated in two ways, one is average performance for each UP and the other is making a gap between high UP and low UP.

The definition of throughput is as follows.

$$throughput(bit/s) = \frac{Number\ of\ successfully\ transmitted\ packets \times 1024\ [bit]}{Total\ trial\ time\ [s]} \quad (1)$$

Also, the definition of delay is defined as the time from the occurrence of a packet to the successful transmission of that packet. The conditions for discarding the packet are when the number of attempts for retransmission is 4 or more due to a collision of packets and when the number of packet accumulations is 3 or more.

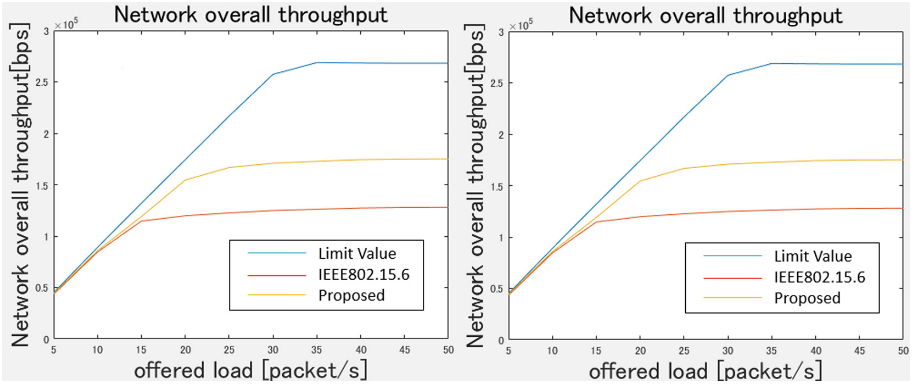

Fig. 6. Network overall throughput (left is average performance and right is making a gap between high UP and low UP)

4.2 Simulation Results

Figure 6 shows overall network throughput comparing IEEE802.15.6 and the proposed method. Left is average performance and right is making a gap between high UP and low UP. The limit value is the throughput of the entire network in the absence of interference. Compared to the standard, the throughput of the whole network is improved in the proposed method. This is because the protocol is changed so that there are less contention using negotiation between coordinators. In addition, we can see that there is no difference between the overall throughput of the network in the case of average performance and in the case of gap between each UP.

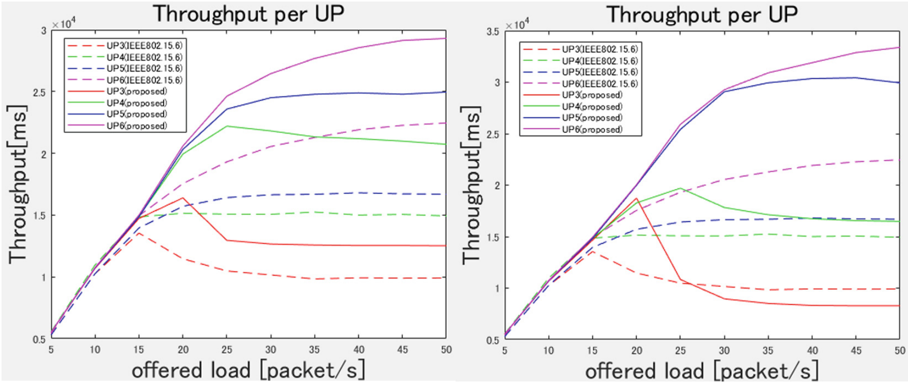

Fig. 7. Throughput per UP (left is average performance and right is making a gap between high UP and low UP)

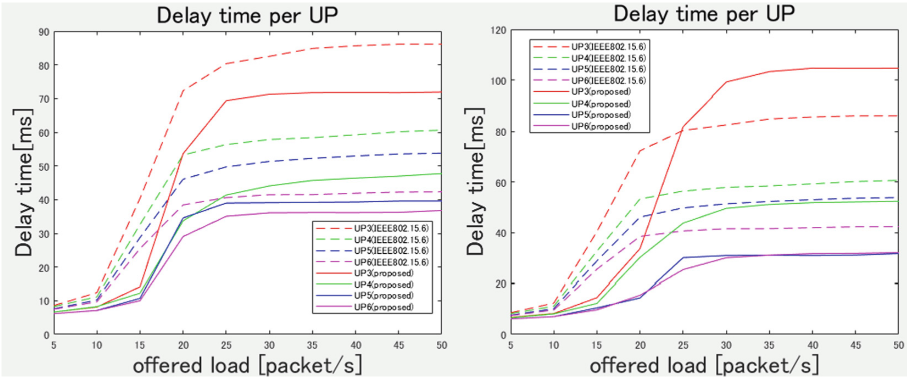

Fig. 8. Delay time per UP (left is average performance and right is making a gap between high UP and low UP)

Figure 7 show throughput characteristic per UP comparing IEEE802.15.6 and the proposed method. Left is average performance and right is making a gap between high UP and low UP. Similarly, the proposed method is superior to the throughput for each UP and the higher UP is, the larger throughput will be because collision can be avoided efficiently. It can be seen that the larger the offeredload is, the better the proposal method will be because the conventional method occur many collisions, if the offeredload is large due to that the number of attempts to send increases. In addition, it can be understood that it is possible to cope with the case of average performance and the case of gap between each UP. This is because the weight of UP was changed between the average case and the gap creation case. Specifically, the difference between the weights of medical packets and non-medical packets is increased.

Figure 8 show delay characteristic per UP comparing IEEE802.15.6 and the proposed method. Left is average performance and right is making a gap between high UP and low UP. Similarly, the proposed method is superior to the delay for each UP and the higher UP is, the smaller delay will be. In addition, it can be understood that it is possible to cope with the case of average performance and the case of gap between each UP. In making a gap between high UP and low UP case, proposed method is inferior at UP3. This is because medical packets sacrifice non-medical packets for high performance. Even in this case, it is necessary to change the protocol so that the performance is higher than the conventional method.

5 Conclusion

We have researched on MAC protocol for interference mitigation in WBAN. The object of comparison is IEEE802.15.6, which is the international standard of WBAN. In this research, as novelty, we proposed a MAC protocol that reduces inter-WBAN interference by negociating among coordinators and identifying and sharing interfering nodes. As a result, we show that the proposed MAC protocol has improved both the throughput characteristics and the delay characteristics compared with the standard. Also, when the design policy gives in two cases such as average performance for each UP and making is a gap between high UP and low UP, we showed that it is possible to cope with by changing algorithm.

References

1. IEEE Computer Society: IEEE standard for local and metropolitan area networks - part 15.6: wireless body area networks, pp. 1–256, February 2012
2. IEEE Computer Society: IEEE Standard for Local and metropolitan area networks Media Access Control (MAC) Bridges, pp. 1–269, June 2004
3. Movassaghi, S., Abolhasan, M., Lipman, J., Smith, D., Jamalipour, A.: Wireless body area networks: a survey. IEEE Commun. Surv. Tutor. **16**(3), 1658–1686 (2014)
4. Movassaghi, S., Majidi, A., Jamalipour, A., Smith, D., Abolhasan, M.: Enabling interference-aware and energy-efficient coexistence of multiple wireless body area networks with unknown dynamics. Access IEEE **4**, 2935–2951 (2016)
5. Shaik, M.F., Komanapalli, V.L.N., Subashini, M.M.: A comparative study of interference and mitigation techniques in wireless body area networks. Wirel. Pers. Commun. **98**, 2333–2365 (2017)
6. Huang, W., Quek, T.Q.S.: Adaptive CSMA/CA MAC protocol top reduce inter-WBAN interference for wireless body area network. In: IEEE 12th International Conference on Wearable and Implanted Body Sensor Networks (BSN) (2015)
7. Li, N., Cai, X., Yuan, X., Zhang, Y., Zhang, B., Li, C.: EIMAC: a multi-channel MAC protocol towards energy efficiency and low interference for WBANs. J. IET Commun. **12**(16), 1954–1962 (2018)
8. Bhandari, S., Moh, S.: A priority-based adaptive MAC protocol for wireless body area networks. Sensors **16**, 401 (2016)