A Hybrid Channel Access Scheme for Coexistence Mitigation in IEEE 802.15.4-Based WBAN

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***Abstract*— Wireless body area network (WBAN) is a communication technology, which aims providing both medical and consumer electronics services through sensor devices in, on, or around a human body. Due to the absence of the IEEE 802.15.6-based RF modules, the IEEE 802.15.4, a typical low-power communication technology of which requirements are similar, is considered to implement WBANs. In the case where a lot of WBANs coexist, meanwhile, collisions and signal attenuations may lead to their communication performance degradation. However, the IEEE 802.15.4 does not provide any solutions to solve coexistence problems, and thus, coexistence mitigation schemes for the IEEE 802.15.4-based WBANs are necessary. In this paper, we perform preliminary experiments to identify aspects of coexistence problem among the coexisting IEEE 802.15.4-based WBANs. Based on the results of preliminary experiments, we also propose a hybrid channel access scheme to mitigate coexistence problems in WBANs. The proposed scheme can be classified into two phases. In the first phase, the proposed scheme provides probabilistic collision avoidance on the contention-free period. When the pre-defined requirements of reliability cannot be satisfied with performing the first phase, the proposed scheme performs the second phase, which helps to mitigate collision or interference through changing channel access method. To evaluate the performance of the proposed scheme, we implement our scheme and perform experiments by comparing with an IEEE 802.15.4-based WBAN.**

***Index Terms*— IEEE 802.15.4, IEEE 802.15.6. wireless body area network, data reliability, coexistence problem.**

I. INTRODUCTION

RECENTLY, wireless body area networks (WBANs) have been attended in a new communication technology for healthcare or lifecare services. To standardize WBAN, the IEEE 802.15 Working Group established the IEEE 802.15 Task Group 6 in November 2007, and completed the baseline document in February 2012 [1], [2]. In the baseline document, three different physical (PHY) layers and a medium access control (MAC) layer are defined in order to satisfy various and strict requirements such as QoS, ultra low power consumption, high communication reliability, and various transmission rate up to 10 Mbps. However, actual implementation works of radio frequency (RF) modules based on IEEE 802.15.6 are not completed yet. For this reason, there are a number of attempts to apply the IEEE 802.15.4 standard [3] to implementing WBAN because its characteristics and requirements are similar to IEEE 802.15.6 [4]–[11]. The IEEE 802.15.4 is one of representative short-range wireless communication which defines the PHY layer and the MAC layer specifications for low-complexity, low-data rate, and low-power consumption in personal operation space (POS) of 10m.

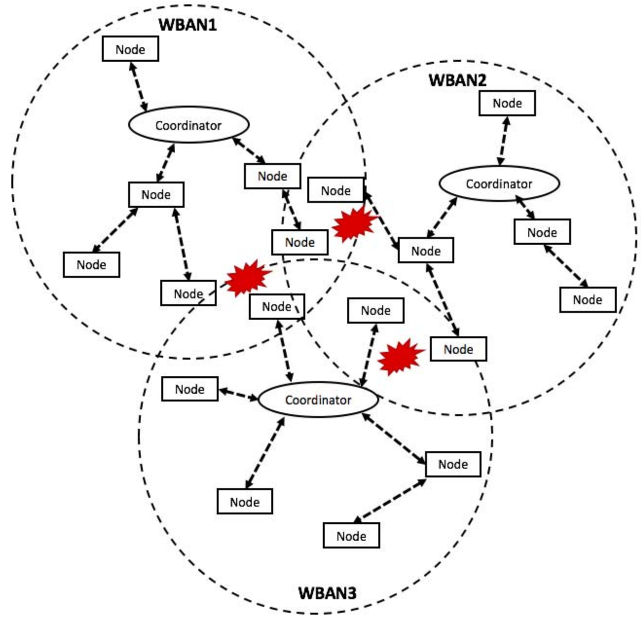

Fig. 1. Coexistence of multiple WBANs.

In general, WBANs are densely deployed in a populated area such as a hospital or healthcare center, and WBAN has inter-network mobility due to its body-centric operation. For this reason, WBAN may dynamically coexist with a varying number of other WBANs, and thus they may suffer from interference among them, which cause significant performance degradation as illustrated in Figure 1. In order to solve this problem, the IEEE 802.15.6 classifies coexistence situations into three different conditions (dynamic, semi-dynamic, and static) according to mobility of coexisting WBANs [2]. In addition, the IEEE 802.15.6 also defines three different coexistence mitigation guidelines (beacon shifting, channel hopping, and active superframe interleaving) to handle coexistence conditions. On the other hand, the IEEE 802.15.4 was designed without considering coexistence problem, thus

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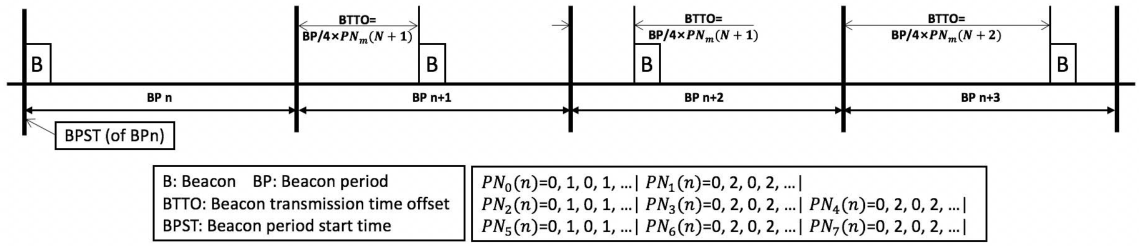

Fig. 2. Beacon shifting.

communication performance of IEEE 802.15.4-based WBANs may be degraded significantly under coexistence environment [3]. In addition, most existing studies for coexistence problem just focus on mitigating interference among heterogeneous networks, and a few schemes for coexisting problem among WBANs were proposed [12]–[15].

First, in this paper, to identify the effects of coexistence among IEEE 802.15.4-based WBANs, we perform a preliminary study. Next, we propose a scheme to mitigate the harmful effects of coexistence which are obtained from the results of our preliminary study. The proposed scheme consists of two phases: the first phase and the second phase. In the first phase, the beginning time of contention free period (CFP) is shifted based on pre-defined sequences, and CFP slots are divided into mini-slots to probabilistically avoid interference and collisions. Although the first phase of the proposed scheme is performed, however, coexistence problems cannot be solved completely when a number of WBANs are densely deployed. The second phase of the proposed scheme can solve this problem to change channel access mode from contention-free to contention-based. To evaluate performance of the proposed scheme, we implement both IEEE 802.15.4-based WBAN and the proposed scheme on practical environment, and we can verify that the proposed scheme can guarantee reliable communication under coexistence situations.

The rest of this paper are organized as follows: Section II describes the previous studies for solving problems of coexisting WBANs. Section III analyzes the result of preliminary experiment to identify causes and side effects of coexistence problems on IEEE 802.15.4-based WBANs. Section IV presents the proposed scheme that consists of two phases based on the results of Section III, Section V discusses our experimental results, and Section VI concludes the paper.

II. Background and Related Work

A. Coexistence Mitigation Schemes in IEEE 802.15.6

To deal with coexistence problems in WBANs, IEEE 802.15.6 defines three different coexistence mitigation schemes [2]. In general, collision of beacon transmission means that coordinator cannot communicate with its member nodes until unit communication time because beacon message is used to announce essential information for communication between coordinator and member nodes. In this point of view, to guarantee successful beacon transmissions, IEEE 802.15.6 defines the first coexistence mitigation scheme, *Beacon shifting*, that shifts beacon transmission time to avoid potential repeated beacon collisions among neighboring WBANs which operate in the same channel. Figure 2 shows details of *Beacon shifting* scheme. In *Beacon shifting*, the coordinator selects one of *Beacon shifting index* (m) which indicates a set of *Beacon shifting phase* (PN_m) and *Beacon shifting sequence* for each beacon period (BP). After selecting *Beacon shifting index*, coordinator obtains beacon transmission time offset (BTTO) based on combination of BP number and *Beacon shifting index*.

The second coexistence mitigation scheme in the standard is *Channel hopping*. In the coexistence situation, the coordinator can change its operating channel in the operating frequency band periodically by choosing particular channel hopping sequence that is not being used by its adjacent WBANs. To hop to a new channel, the coordinator generates a channel hopping sequence based on the maximum-length Galois linear feedback shift register (LFSR). After receiving the channel hopping sequence, the coordinator performs channel scanning over a given list of candidate channels in a specific frequency band. At the end of channel scanning, the coordinator selects an unused channel as the new operating channel. If there is no free channel, coordinator randomly select a new channel and operates other coexistence mitigation schemes for the selected channel to avoid congestion.

Actually, a WBAN may share the same operating channel with its neighborhoods with or without interleaving their active superframes. In this situation, coexisting WBANs should avoid interference among them. To solve this problem, IEEE 802.15.6 also provides *Active superframe interleaving* which alternates Active period and Inactive period of superframe among coexisting WBANs with negotiating transmission time among their coordinators as shown in Figure 3.

B. IEEE 802.15.4 MAC

The IEEE 802.15.4 uses a superframe structure in a beacon-enable mode as shown in Figure 4 [3]. The superframe is divided into *Active period* and *Inactive period*. *Active period* consists of contention access period (CAP) and contention-free period (CFP). In CAP, beacon frame is broadcasted by coordinator to announce the start of the superframe and to inform the parameters of the superframe. On the contrary, CFP consists of guaranteed time slots (GTSs) which operates with time division multiple access (TDMA). To satisfy the low power requirement, IEEE 802.15.4 can optionally configure *Inactive period* so that every node in the network goes to sleep mode.

Figure 5 shows an example of coexistence situation between two IEEE 802.15.4-based WBANs. In this scenario,

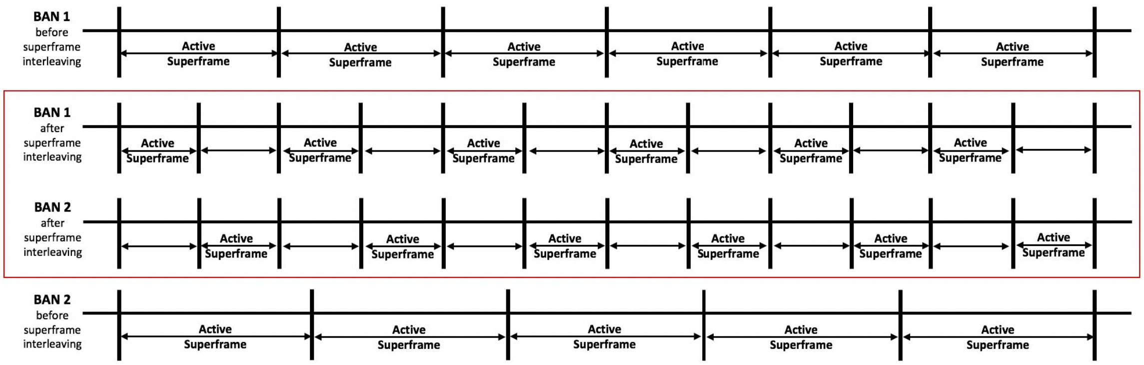

Fig. 3. Active superframe interleaving.

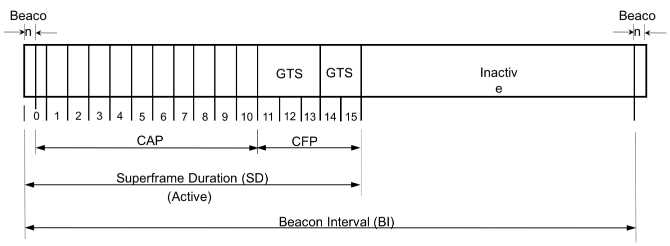

Fig. 4. Superframe structure of the IEEE 802.15.4.

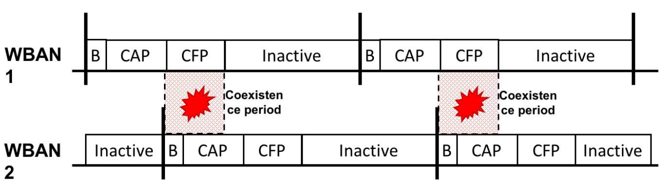

Fig. 5. Coexistence period of IEEE 802.15.4-bassd WBAN.

both active periods of two WBANs are overlapped, and transmitted data frames will be collided. In IEEE 802.15.6 standard, communication reliability in CAP is barely influenced by interference from neighborhoods because it operates based on CSMA/CA, acknowledge (ACK) message, and retransmission. On the other hand, successful data transmissions in CFP cannot be guaranteed due to absence of recovery process for failed transmission. Therefore, IEEE 802.15.4-based WBAN cannot guarantee reliable transmission due to the fact that it does not consider coexistence problem in CFP.

C. Related Work

To solve the problem about absence of coexistence handling in the IEEE 802.15.4, there are some existing works [12]–[15]. J. Mahapatro *et al.* proposed an interference mitigation scheme for TDMA-based WBANs [12]. This work considers that all WBANs operate in TDMA manner, and this scheme takes an advantage that coexisting WBANs efficiently use time slots through exchanging time schedule. However, data processing overhead of this scheme is quite large because coordinator manages scheduling information of its neighborhoods as the number of coexisting WBANs.

Meanwhile, M. Deylami proposed a dynamic coexistence management (DCM) mechanism to avoid interferences or collisions when IEEE 802.15.4-based WBANs detect coexistence situation [13]. In this scheme, when coexistence is detected, the coordinator scans the current channel during its beacon interval to get complete information of the current channel and reschedules its beacon transmission time. Through beacon rescheduling and channel switching, the proposed mechanism can significantly improve the reliability of the WBANs in the dynamic coexistence situation. However, this mechanism consumes large amount of power because it should monitor channel state for long time whenever WBAN detects coexistence.

Y. Kim *et al.* proposed an adaptive load control algorithm for IEEE 802.15.4-based WBAN/IEEE 802.11 coexistence environment [14]. In this scheme, WBAN coordinator has both IEEE 802.15.4 and IEEE 802.11 radio module, and thus it can cooperate with IEEE 802.11 AP to mitigate coexistence problem on IEEE 802.15.4-based WBAN. To guarantee the delay requirement which depends on interference from the IEEE 802.11, WBAN coordinator monitors the channel to observe the current channel utilization and the received signal strength from each IEEE 802.11-based node and decides the state of the current channel. If the current channel state is 'Busy', the coordinator informs channel utilization information and channel state, and requests controlling traffic load from IEEE 802.11 nodes. However, this algorithm cannot be directly applied to coexisting WBANs because it only focuses on IEEE 802.11 traffic and does not consider other communication technologies which share the same frequency bands with the IEEE 802.15.4. In addition, the performance of this algorithm may decrease in real communication environments because the authors do not consider operational characteristics of medium access mechanisms and they assume that PER (Packet Error Ratio) depends only on signal strength, BER (Bit Error Rate) and SINR (Signal and Interference to Noise Ratio).

E. Sarra *et al.* were proposed to avoid interference from IEEE 802.11 by reducing the size of packet and backoff time [15]. In this scheme, the authors point out that the small size of packet and frequent channel sensing can help to reduce transmission error. However, this scheme can increase contention complexity which causes huge latency in the coexistence among homogeneous networks.

III. PRELIMINARY STUDY

As mentioned above, IEEE 802.15.4-based WBAN cannot handle coexistence problem because the IEEE 802.15.4 is

TABLE I
EXPERIMENTAL SCENARIOS

	Interfered (Scenario 1)	Non-interfered (Scenario 2)	Interfered (Scenario 3)	Non-interfered (Scenario 4)
Measurement WBAN	Non-beacon CAP	Non-beacon CAP	Beacon-enabled CFP	Beacon-enabled CFP
Interfering WBAN	Non-beacon CAP	-	Non-beacon CAP	-

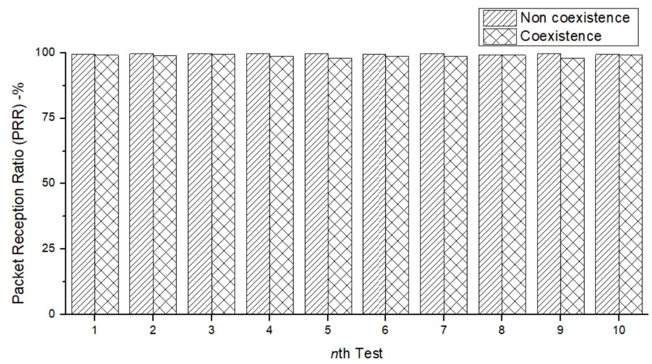

Fig. 6. Results of scenario 1 and 2 (non-beacon CAP).

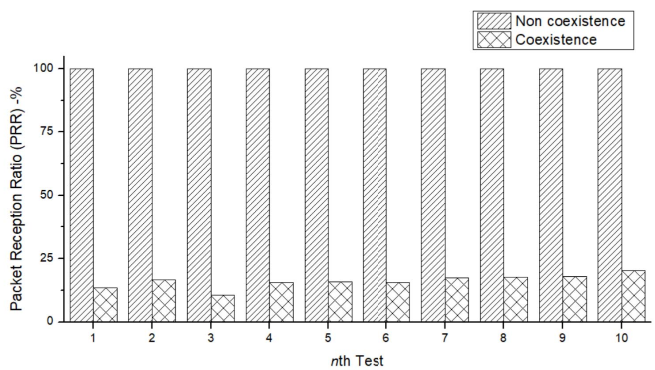

Fig. 7. Results scenario 3 and 4 (beacon-enable CFP).

designed without considering coexistence problem. In this section, we perform a preliminary study to identify aspects of coexistence problem among coexisting IEEE 802.15.4-based WBANs.

To perform preliminary study, we have constructed experimental environment which composes two WBANs are based on ZigbeX-II platform which contains ATmega128 and CC2420 [16]. To compare performance of coexisting WBANs and non-coexisting WBAN according to channel access schemes, we consider four different scenarios as shown in Table I and measure the packet reception ratio (PRR).

Figure 6 and 7 illustrates results of Scenario 1, 2 and 3 respectively. When there is no interfering WBAN (Scenario 2 and 4), more than 90% of PRR is obtained. On the contrary, PRR in Scenario 1 and 3 is decreased due to interfering WBANs. Especially, in Scenario 4 (beacon-enable CFP mode with interfering WBAN), PRR decreases dramatically because CFP operates based on time-slot reservation (GTS allocation), and it does not provide recovery process for failed transmission. Based on these experimental results, we can confirm that WBANs based on CAP mode is relatively strong to interference or collision due to CSMA/CA. On the other hand, WBANs based on CFP mode are sensitive to other

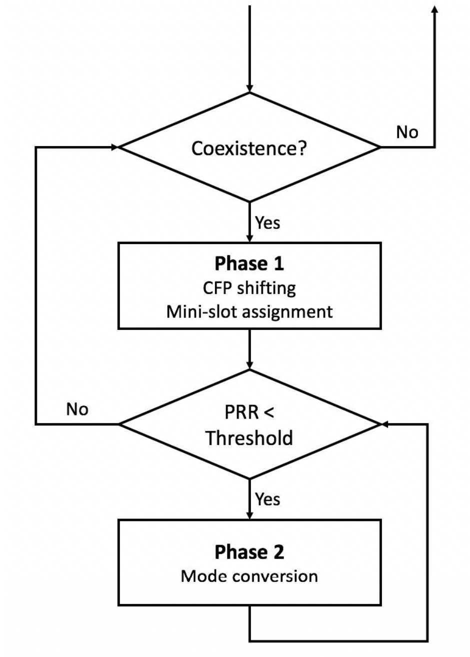

Fig. 8. Flow chart of the proposed scheme.

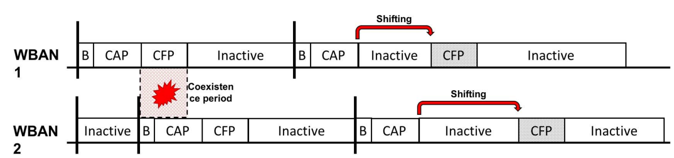

Fig. 9. CFP shifting.

coexisting WBANs because it is designed without considering external interferences.

In summary, through the preliminary study, we have found that IEEE 802.15.4-based WBANs may suffer from coexistence problem which occurs low transmission reliability. Especially, external interferences significantly influence reliability and performance of WBAN when it operates based on CFP mode.

IV. PROPOSED SCHEME

In this section, we propose a hybrid channel access scheme for coexistence mitigation in IEEE 802.15.4-based WBANs. Due to the fact that the high complexity of MAC protocol may cause bottlenecks in the communication performance, we have simply designed the proposed scheme. Figure 8 illustrates the operating sequence of the proposed scheme.

In the first phase, the coordinator avoids collisions opportunistically on overlapped CFP between WBANs by performing the *CFP shifting* and *Mini-slot assignment*. If PRR is less than pre-defined threshold during the first phase, the coordinator changes its operating mode from the first phase to the second phase which converts channel access mode from CFP to CAP.

Figure 9 illustrates detailed operations of the *CFP shifting* in the first phase. If coexisting WBAN detects interference or collision, the coordinator randomly selects one of *Shifting sequence* ($SS(T)$) which is a pre-defined set of

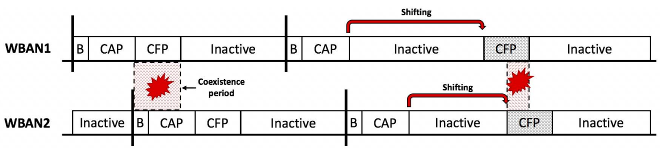

Fig. 10. Remained coexistence problem after performing CFP shifting.

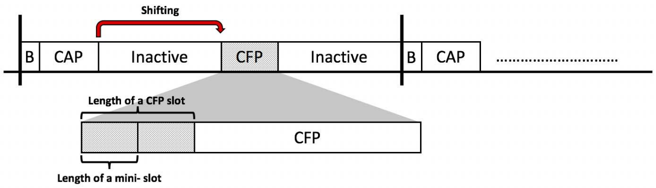

Fig. 11. Mini-slot assignment.

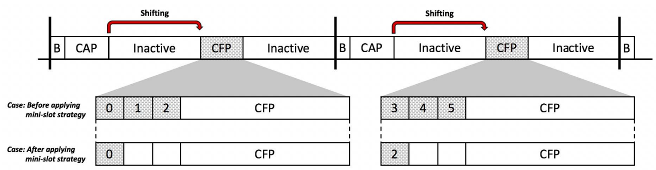

Fig. 12. Data latency problem on Mini-slot assignment.

shifting time value. Selected shifting sequence holds until several beacon transmission. After selecting the shifting sequence, the coordinator also chooses a shifting time value ($SS(T)_i$) among shifting time values in the selected shifting sequence and obtains *CFP shifting time* (ST) value by modulo N check of current beacon sequence to shift CFP. For example, if the current beacon sequence is 7 and selected shifting time value is $SS(3)_4$ (assumption: the coordinator selects T as 3 and i as 4 when the third shifting sequence is $SS(3) = \{5, 2, 7, 9, 4\}$), *CFP shifting time* ($ST$) can be obtained as 2. After obtaining ST, the coordinator shifts the start time of CFP in the next superframe to two time slots.

In CFP shifting, WBANs do not exchange information with their neighborhoods (i.e., they operate in distributed manner). Therefore, if only *CFP shifting* is performed, interference or collision can occur as shown in Figure 10. To deal with this problem, we also propose *Mini-slot assignment* with *CFP shifting* which reduces the probability of collision or interference. Figure 11 shows an example of *Mini-slot assignment* operation. A time slot is divided into mini-slots, and then data communication is performed on selected one of mini-slots. To select a mini-slot, the coordinator performs *Mini-slot allocation* which is similar to *CFP shifting*. The coordinator randomly selects *Mini-slot sequence*, is a set of available mini-slot number, for every beacon interval and also randomly selects mini-slot per sensor node. After allocating mini-slots for sensor nodes, the coordinator transmits beacon frame with information of min-slot allocation at the start of next superframe, and each sensor node transmits frames during assigned mini-slot.

As shown in Figure 12, however, *Mini-slot assignment* may increase latency because it takes more mini-slots. To reduce latency, proposed scheme uses *CFP extension* until inactive period as illustrated in Figure 13. CFP can be extended up to the number of mini-slots, and it helps to prevent large latency.

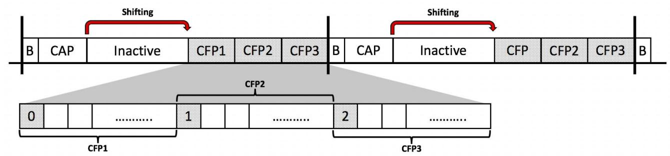

Fig. 13. Solution of data latency problem on Mini-slot assignment.

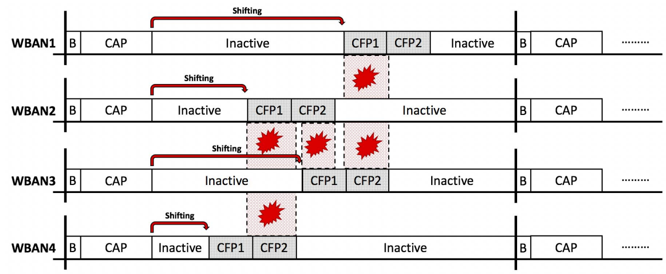

Fig. 14. An example of poor coexistence condition.

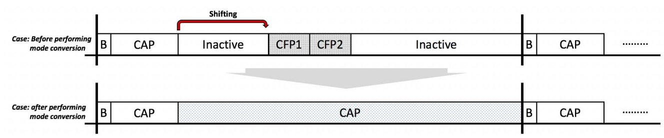

Fig. 15. Mode conversion.

Meanwhile, *CFP shifting* and *Mini-slot assignment* cannot solve coexistence problems completely in dense coexistence environment as shown in Figure 14. When a number of WBANs are deployed densely in small area, the reliability of communication through the first phase cannot be guaranteed. In this case, WBANs perform *Mode conversion* from the first phase to the second phase. Figure 15 shows that detailed operation of *Mode conversion*. When PRR is lower than the pre-defined threshold value until performing the first phase, the condition of *Mode conversion* is satisfied and WBAN changes to the channel access mode from CFP to CAP. Because CAP is more endurable against to external interferences than CFP, as revealed in our preliminary experiments in Section III, it can increase reliability in dense coexistence environment.

V. Performance Evaluation

To verify the performance of the proposed scheme which operates along the first phase (*CFP shifting* and *Mini-slot assignment*) and the second phase (*Mode conversion*), we perform three different experiments as follow:

1) Standard IEEE 802.15.4.
2) Only the first phase of the proposed scheme
3) Two phases of the proposed scheme

In all experiments, WBAN consists of a coordinator and 5 sensor nodes which is developed in ZigbeX-II mote. To construct coexistence environment, up to three WBANs are deployed 1 *m* apart from each other. In addition, experimental parameters are set as shown in Table II. Based on these environments, each experiment is performed four times during 120 minutes.

Figure 16 shows measured PRR of IEEE 802.15.4-based WBAN. In non-coexisting WBAN, most frames are

TABLE II
EXPERIMENTAL PARAMETERS

	Standatd (The IEEE 802.15.4)	The first phase (Proposed)	Both the first and the second phase (Proposed)
# of WBAN	1, 2, 3		
Data rate (bps)	128, 256, 384, 512		
BO:SO	7:6 (2 second/beacon)		
# of Mini-slot	None	2	2
Threshold for Mode convertion	None	None	95
Experiment time	10 minutes		

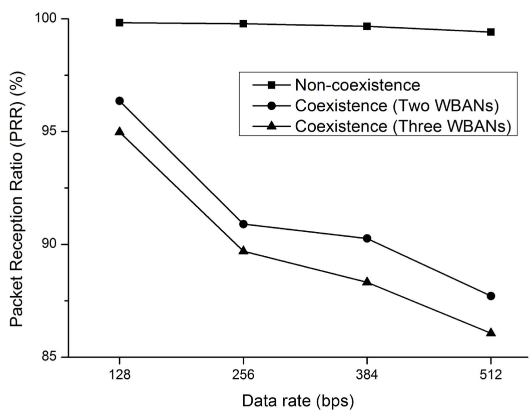

Fig. 16. Experimental result of the IEEE 802.15.4.

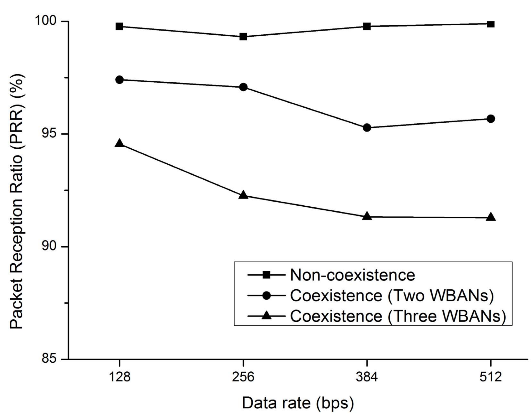

Fig. 17. Experimental result of the proposed scheme (applying only the first phase).

transmitted successfully to the coordinator without loss regardless of data rate. In contrast, PRR decreases according to data rate when two or more WBANs coexist. This shows that IEEE 802.15.4 does not handle coexistence problem.

On the other hand, results of applying only the first phase presents a relatively higher PRR compared to the previous results as shown in Figure 17. We can find that the first phase can avoid interference or collision through performing *CFP shifting* and *Mini-slot assignment*. However, PRR is less than 95% when three WBANs are coexisting because the first phase stochastically avoids interference or collision in distributed manner and it cannot solve coexistence problem completely.

Figure 18 illustrates results of the last scenario which applies both the first and the second phase of the proposed scheme. As mentioned above, the first phase cannot guarantee reliability when a number of WBANs are coexisting in a small

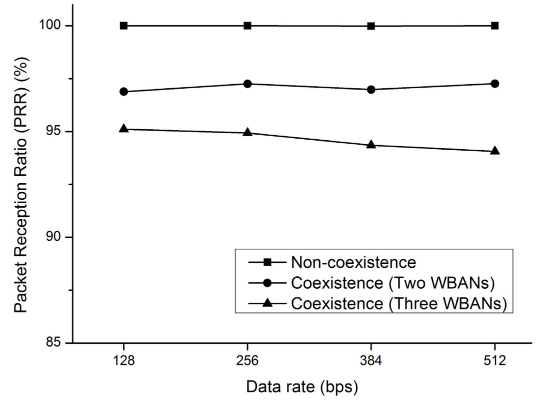

Fig. 18. Experimental result of the proposed scheme (applying both the first and second phase).

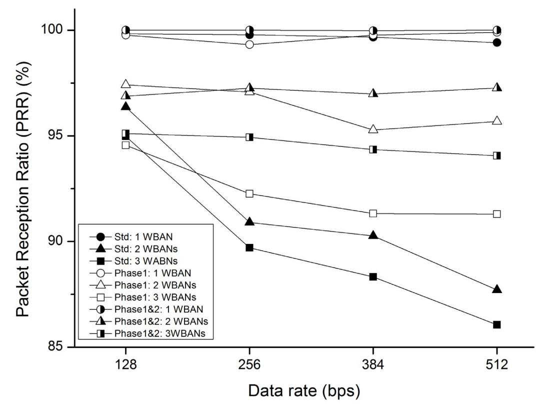

Fig. 19. Comparison with all experimental results.

area. On the other hand, when both phases are performed, PRR hardly decreases although more than two WBANs coexist because *Mode conversion* in the second phase helps to increase reliability by converting channel access mode from CFP to CAP when PRR is lower than the pre-defined threshold.

Figure 19 presents comparison among results of three experimental scenarios. Communication reliability of IEEE 802.15.4-based WBAN dramatically decreases according to data rate and the number of coexisting WBANs. On the contrary, the proposed scheme can guarantee reliability in spite of coexistence or high data rate.

In summary, IEEE 802.15.4-based WBAN suffers from coexistence situation due to absence of coexistence handling methods in IEEE 802.15.4. The proposed scheme can increase reliability compared with IEEE 802.15.4-based WBAN due to the first phase which provides opportunistic transmission through *CFP shifting* and *Mini-slot assignment* and the second phase which performs *Mode conversion* that changes channel access mode from CFP to CAP in dense coexistence situation.

VI. CONCLUSION

When IEEE 802.15.4-based WBANs are coexisting, interference or collisions can occur. However, IEEE 802.15.4 does not provide solutions for coexistence problem. In this paper, we first analyze problems of coexisting IEEE 802.15.4-based WBAN to discover aspects of coexistence problem among coexisting WBANs through preliminary experiments. In the preliminary study, we identified aspects of coexistence problem that CFP is significantly influenced from interference which causes degradation of reliability. Based on this result, we proposed the scheme which modifies CFP over two phases to mitigate coexistence problem. In order to guarantee reliability, the proposed scheme tries to avoid interference or collision by performing the first phase which provides *CFP shifting* and *Mini-slot assignment*. Despite performing the first phase, WBAN cannot guarantee the requirements of communication reliability in WBANs. To deal with this problem, we also proposed the second phase which performs *Mode conversion* that changes channel access mode from CFP to CAP. To evaluate the performance of the proposed scheme, three different experiments are performed by comparing with IEEE 802.15.4-based WBAN on real platform. The experimental results show that the proposed scheme can increase communication reliability dramatically in coexistence situation.

REFERENCES

[1] *IEEE 802.15 WPAN Task Group 6 (TG6) Body Area Networks*. Accessed: Mar. 1, 2017. [Online]. Available: http://www.ieee802.org/15/pub/TG6.html

[2] *IEEE Standard for Local and Metropolitan area Networks—Part 15.6: Wireless Body Area Networks*, IEEE Standard 802.15.6-2012, Feb. 2012, pp. 1–271.

[3] *IEEE Standard for Local and Metropolitan Area Networks—Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs) Amendment 1: MAC Sublayer*, IEEE Standard 802.15.4e-2012 (Amendment to IEEE Standard 802.15.4-2011), 2012, pp. 1–225.

[4] S. Moulik, S. Misra, and D. Das, "AT-MAC: Adaptive MAC-frame payload tuning for reliable communication in wireless body area networks," *IEEE Trans. Mobile Comput.*, vol. 16, no. 6, pp. 1516–1529, Jun. 2016.

[5] J. Kamble and A. Vidhate, "Improved MAC protocol for emergency handling in WBAN," in *Proc. Int. Conf. Autom. Control Dyn. Optim. Techn. (ICACDOT)*, Sep. 2016, pp. 1025–1029.

[6] A. Argyriou, A. C. Breva, and M. Aoun, "Optimizing data forwarding from body area networks in the presence of body shadowing with dual wireless technology nodes," *IEEE Trans. Mobile Comput.*, vol. 14, no. 3, pp. 632–645, Mar. 2015.

[7] F. Martelli and R. Verdone, "Coexistence issues for wireless body area networks at 2.45 GHz," in *Proc. 18th Eur. Wireless Conf.*, Apr. 2012, pp. 1–6.

[8] S. Weon, S. Lee, Y. Park, H. Lee, and D. Hong, "Energy efficient interference avoidance strategy in 802.15.4 wireless body area network," in *Proc. IEIE Conf. Inst. Electron. Inf. Eng.*, Jul. 2013, pp. 409–412.

[9] J. Han, T. Kim, and Y. Lee, "Robust transmission of the IEEE 802.15. 4 signal in the presence of co-channel interference," in *Proc. IEEE Wireless Commun. Netw. Conf. (WCNC)*, Apr. 2013, pp. 53–58.

[10] B. Kim, B. Lee, and J. Cho, "ASRQ: Automatic segment repeat request for IEEE 802.15. 4-based WBAN," *IEEE Sensors J.*, vol. 17, no. 9, pp. 2925–2935, Mar. 2017.

[11] E. Sarra, H. Moungla, S. Benayoune, and A. Mehaoua, "Coexistence improvement of wearable body area network (WBAN) in medical environment," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Jun. 2014, pp. 5694–5699.

[12] J. Mahapatro, S. Misra, M. Manjunatha, and N. Islam, "Interference mitigation between WBAN equipped patients," in *Proc. Int. Conf. Wireless Opt. Commun. Netw. (WOCN)*, Sep. 2012, pp. 1–5.

[13] M. Deylami, "A distributed scheme to manage the dynamic coexistence of IEEE 802.15.4-based health monitoring WBANs," *IEEE J. Biomed. Health Informat.*, vol. 18, no. 1, pp. 327–334, Aug. 2014.

[14] Y. Kim, S. Lee, and S. Lee, "Coexistence of ZigBee-based WBAN and WiFi for health telemonitoring systems," *IEEE J. Biomed. Health Informat.*, vol. 20, no. 1, pp. 222–230, Jan. 2016.

[15] E. Sarra and T. Ezzedine, "Performance improvement of the wireless body area network (WBAN) under interferences," in *Proc. Int. Conf. e-Health Netw., Appl. Services (Healthcom)*, Sep. 2016, pp. 1–6.

[16] Hanback Electronics Co. *Ubiquitous Sensor Network ZigbeX-II*. Accessed: Mar. 1, 2017. [Online]. Available: http://www.hanback.co.kr

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