
A Distributed Coexistence Mitigation Scheme for IoT-Based Smart Medical Systems

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Abstract

Since rapidly disseminating of Internet of Things (IoT) as the new communication paradigm, a number of studies for various applications is being carried out. Especially, interest in the smart medical system is rising. In the smart medical system, a number of medical devices are distributed in popular area such as station and medical center, and this high density of medical device distribution can cause serious performance degradation of communication, referred to as the coexistence problem. When coexistence problem occurs in smart medical system, reliable transmitting of patient's biological information may not be guaranteed and patient's life can be jeopardized. Therefore, coexistence problem in smart medical system should be resolved. In this paper, we propose a distributed coexistence mitigation scheme for IoT-based smart medical system which can dynamically avoid interference in coexistence situation and can guarantee reliable communication. To evaluate the performance of the proposed scheme, we perform extensive simulations by comparing with IEEE 802.15.4 MAC protocol which is a traditional low-power communication technology.

Keywords

Channel Access, Channel Planning, Coexistence Mitigation, IoT, Smart Medical System

1. Introduction

Recently, rapid advances in wireless communication technology and wireless manufacturing technology have led to the proliferation of new communication paradigm, referred to as Internet of Things (IoT) [1]. IoT is an advanced communication system that enables to advance existing and to derive new applications through all objects which have computing and communication capabilities and connect with each other. In particular, interest in smart medical systems with IoT has heightened due to the advent of the aging era [2].

To implement smart medical systems, meanwhile, a concept of network structure in range of a human area was proposed under the name of wireless body area networks (WBANs). WBAN can be defined as a novel communication technology that aims to provide both medical and consumer electronics (CE) services through medical and non-medical sensor devices in, on or around human body. To standardize WBANs, the IEEE 802.15 Working Group (WG) launched Task Group 6 (TG6) in November 2007, and it finished the first version of the standard for WBANs [3].

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Manuscript received May 30, 2017; June 27, 2017; accepted August 2, 2017.

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In order to satisfy the requirements of medical and CE services, the IEEE 802.15.6 standard defines technical requirements of WBAN in technical requirement document (TRD) [4]. In the TRD, one of the most important requirements in TRD is the reliable communication of the medical service because communication reliability in the medical service that transmits user's biometric information is tightly linked to the user's life, especially in emergency situation, where the reliable communication is the most important factor in determining the fate of the user. Therefore, research on reliable data transmission techniques is urgently required.

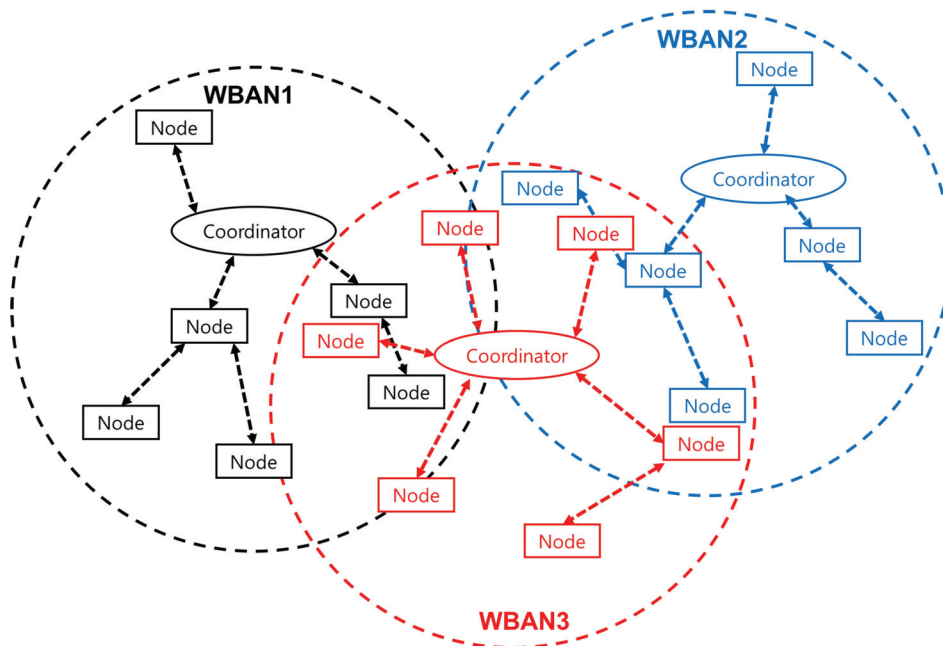


Fig. 1. An example of coexistence situation in WBANs.

In IoT environment, in general, a large number of wireless devices are deployed in narrow and popular area such as hospital, medical center and subway station. This high density of deployment can cause significant degradation of performance due to interference among adjacent devices. This performance degradation phenomenon can be defined as 'coexistence problem'. Especially, WBANs are more susceptible to interference occurring in situation in coexistence problem, as shown in Fig. 1, since transmission power is weaker than other communication technologies. In addition, a WBAN in the smart medical system can be affected by interference from other WBANs because WBANs are more densely deployed in populated area than general IoT environments.

In general, wireless communication technologies such as WSNs (Wireless Sensor Networks) and WBANs enable multiple channels, which allow them to avoid interference [5,6]. In the environment that a number of sensor nodes are densely deployed in narrow area, however, there is many sensor nodes that use the specific channel. Therefore, exploiting multiple channel cannot resolve fundamental interference issues. Meanwhile, another method of resolving interference issues can be found in the channel access schemes on a single channel [5,6]. First, Time Division Multiple Access (TDMA) can help to perfectly avoid interference from homogeneous sensor nodes when a limited number of sensor

nodes use the same channel. However, it is not possible to respond to interference resulting from a heterogeneous communication technologies. Second, Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA), which is a contention-based channel access scheme, provides flexibility when multiple sensor nodes try to access the same channel. Although CSMA/CA has advantages over interference compared to TDMA, there is an overhead for contention to access channel. In addition, significant performance degradation may occur when an extreme large number of sensor nodes are try to access the same channel.

To solve coexistence problem WBANs, meanwhile, a number of studies have been conducted and they can be categorized. The first category exploits time scheduling manner for homogeneous WBANs. Deylami and Jovanov [7] proposed the dynamic coexistence management (DCM) scheme to improve reliability of medical data transmission in WBANs. The proposed scheme provides beacon shifting and channel switching schemes which can help to improve reliability for the medical data transmission. Similarly, the authors in [8] proposed an interference avoidance scheme by assuming TDMA-based WBANs. In this scheme, the authors induced avoiding interference among coexisting TDMA-based WBANs through cooperative scheduling with them. However, the proposed scheme cannot handle interference from heterogeneous communication technologies because it assumes beacon-enable superframe-structured MAC protocol which includes TDMA-based data transmission periods. The second category uses channel switching. Above-mentioned DCM [7] can be included into this category because it provides channel switching scheme. Kim et al. [9] proposed adaptive channel switching to control traffic load considering with coexistence situations between IEEE 802.15.4-based WBANs and the IEEE 802.11. This scheme monitors current channel utilization and decides state of the current channel. Based on the channel state, WBAN coordinator collects other channel utilization and switches its communication channel to the new channel which has the lowest channel utilization. These schemes have the advantage of avoiding interference from a specific complex channel, as well as from heterogeneous communication technologies. However, they are difficult to expect the overall performance of the network because they perform channel switching without considering the overall state of the network such as density, channel complexity and interference from other communication technologies.

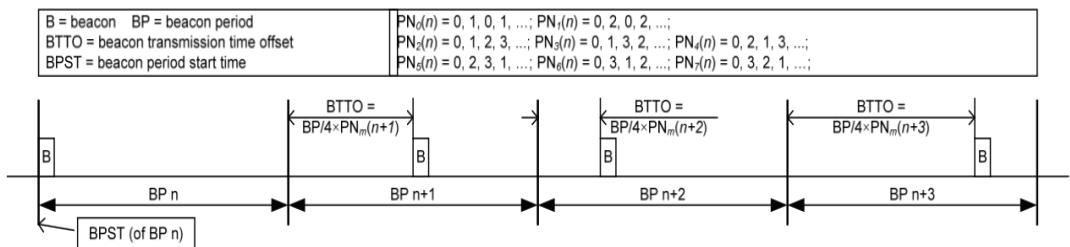


Fig. 2. Coexistence mitigation scheme in the IEEE 802.15.6 (beacon shifting).

Meanwhile, the IEEE 802.15.6, the standard of WBANs, also defines three difference coexistence mitigation schemes in the baseline document [3]. The first scheme is *beacon shifting* which is similar to beacon shifting in DCM as shown in Fig. 2 [7]. The second scheme is *channel hopping* which is designed for resolving channel conflict problem. In the channel hopping, the coordinator periodically changes its communication channel through pre-defined channel hopping sequence. The last scheme is active

superframe interleaving which re-allocates coexisting WBANs by negotiating among them as shown Fig. 3. Despite the standard provides above three different coexistence mitigation scheme, however, they cannot be used in practical environment because their detail protocols are not defined.

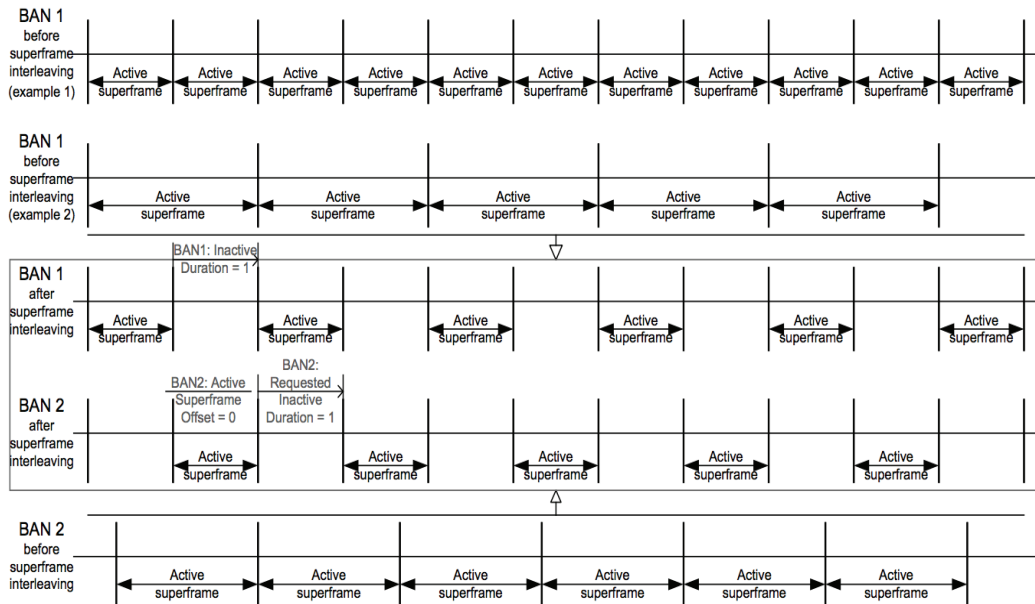


Fig. 3. Coexistence mitigation scheme in the IEEE 802.15.6 (active superframe interleaving).

In this paper, we propose a distributed coexistence mitigation scheme for IoT-based smart medical systems. The proposed consists two phases: channel planning phase and medium access adjustment phase. In the first phase, coordinator selects its communication channel to helps that coexisting WBANs, which is interfered with each other, provide a balance in the use of available channels. The second phase determines the channel access scheme, depending on the number of WBAN using the channel which is selected in the first phase. Through the proposed scheme, coexisting WBANs can dynamically avoid interference in coexistence situation and can guarantee reliable communication in distributed manner. To evaluate the performance of the proposed scheme, we perform extensive simulations by comparing with IEEE 802.15.4 MAC protocol which is a traditional low-power communication technology.

The rest of the paper is organized as follows: Section 2 briefly introduce existing coexistence mitigation schemes for WBANs. Section 3 depicts the proposed distributed coexistence mitigation scheme for IoT-based smart medical systems, and the performance of the proposed scheme is evaluated in Section 4. Finally, Section 5 concludes the proposed scheme with future direction.

2. Existing Coexistence Mitigation Schemes

As mentioned above, coexistence problem in smart medical systems can cause significant degradation of performance, and can be fatal to the user's life. In this section, we introduce existing coexistence

mitigation schemes for WBANs. These existing works can be categorized two types: frequency domain and time domain. Detailed analysis is as follows.

2.1 Coexistence Mitigation Schemes on Time Domain

To avoid coexistence problem, several studies attempt to apply TDMA to the transmission time scheduling for coexisting networks. These attempts can avoid interference between coexisting WBANs because they determine the transmission time of each WBAN on time domain.

In [7], the author proposed the DCM scheme to improve reliability of medical data transmission in WBANs. The author focused on the reliability issues caused by beacon collisions and data collisions, and analyzed both of beacon and data collision in coexistence situations with multiple WBANs. Based on the result of performing analytical model, the author proposed DCM which consists of beacon replacement and channel switching. First, the proposed scheme attempts to detect beacon collisions. If a beacon collision is detected, the proposed scheme monitors the beacon collision on the current channel during pre-defined period, and it try to shift beacon transmission time if beacon transmission is possible to avoid active periods of the coexisting WBANs. Meanwhile, the solution for data collision in the proposed scheme is channel switching. At the end of CFP (Contention Free Period), WBAN coordinator reviews results of data transmission in current superframe, and it tries to switch its current channel to candidate channel when data loss is detected. To evaluate the performance of the proposed scheme, the author performs extensive simulations, and he gets the results that the proposed DCM can improves successful data transmission rate by 20%–25%.

Mahapatro et al. [8] also proposed TDMA-based coexistence mitigation scheme. In this scheme, a common TDMA schedule creation mechanism is performed on each WBAN. After creating the scheduling information, the coordinator periodically monitors whether signal-to-interference ratio (SIR) exceeds the threshold to calculate the interference probability of the coordinator. If the interference probability is high, the coordinator exchange its scheduling information with its neighbors, and it re-schedules its TDMA schedule based on exchanged information. The authors evaluate the performance of the proposed scheme through extensive simulations, and they can observe increased packet reception ratio (PRR).

However, these schemes are difficult to consider applying practical environment, because they cause high latency when a large number of WBANs coexists, as well as they do not consider interference from heterogeneous wireless communication technologies.

2.2 Coexistence Mitigation Schemes on Frequency Domain

As mentioned earlier, frequency bands used in wireless communications technologies are divided into several channels, and wireless communication devices can utilize multiple channels. There are a number of coexistence mitigation based on this multi-channel exploitation.

Lee et al. [10] proposed a multi-channel MAC protocol for communication between in-body and out-body devices. They consider channel management mechanism on medical implanted communication service (MICS) band which is exploited for communication of implant medical devices. The authors assume that the one channel is used to control network and other nine channels are used for data transmission. The control channel consists of nine beacons slots, and the proposed scheme performs

one-to-one mapping between the beacon slot and the data channel. Based on beacon frame with one-to-one mapping information, each in-body sensor node recognizes its communication channel. The simulation results show that the proposed scheme can reduce time of idle listening and can improve throughput.

Ivanov et al. [11] proposed a cooperative multi-hop transmission, and extends it to MAC layer. The proposed scheme includes Cooperative Asynchronous Multi-channel MAC Avoiding Redundant Channel Blocking (CAM-MAC-ARCB) to avoid unnecessary blocking of available channels and to gain reliable data transmission.

However, these schemes cannot provide a balance of available channel usage and can cause increased complexity in a particular channel. In addition, this phenomenon leads to partial coexistence problem in homogeneous networks.

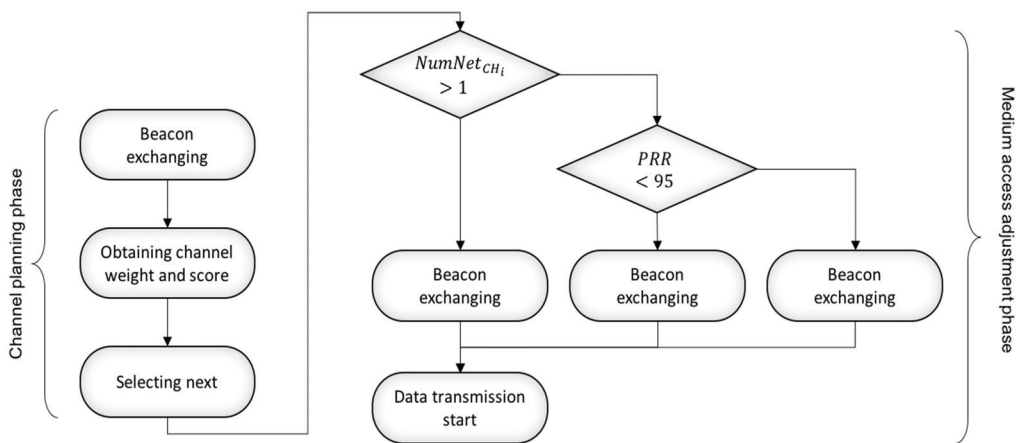


Fig. 4. Overall algorithm of the proposed scheme.

3. Proposed Scheme

As mentioned above, coexistence problem in IoT-based smart medical system is one of the most important issues because it is closely related to user's life. To solve this problem, we propose a distributed coexistence mitigation scheme. The proposed scheme consists of two phases: channel planning phase and medium access adjustment phase. The overall algorithm for the proposed scheme is shown in Fig. 4 and details of the proposed scheme are as follows.

In the channel planning phase, the coordinator exchange beacon frame with its neighbor WBANs. The beacon frame includes its current communication channel ID and pre-measured packet reception ratio (PRR). After exchanging beacon frame, the coordinator calculates the weight for each available channel (ω_i), based on the collected channel ID, and obtains score of channel i (S_i). The formulas for calculating the weight of the available channel and channel score is as follows.

$$\omega_i = 1 - \frac{NumNet_{CH_i}}{NumNet_{Total}}, \quad (1)$$

$$S_i = \omega_i * PRR_i^{Avg}, \tag{2}$$

where $NumNet_{CH_i}$ indicates the number of WBANs in the i th channel, $NumNet_{Total}$ defines the number of coexisting WBANs including itself, and PRR_i^{Avg} is average PRR in the i th channel. Through Eqs. (1) and (2), the proposed channel planning phase can fully reflect interference in both homogeneous and heterogeneous network environments, because $NumNet_{CH_i}$ indicates channel complexity and potential interference situations in the use of use of channels between homogeneous networks, and PRR_i^{Avg} is a measure of the degree of interference that can occur from both homogeneous and heterogeneous networks. One the channel score calculation for the available channels is completed, the coordinator determines the channel with the highest channel score as next communication channel and broadcast the result.

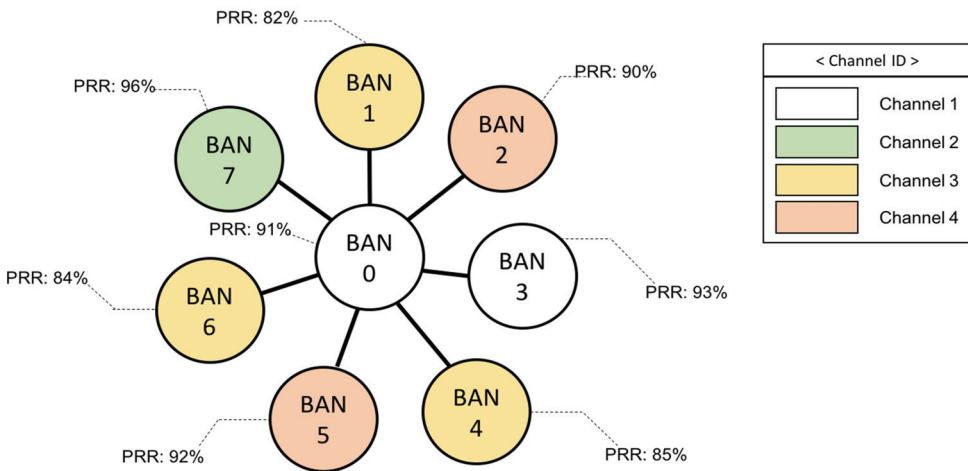


Fig. 5. An example: channel planning scheme.

To help understanding algorithm of the channel planning, we introduce a simple example as illustrated in Fig. 5. This simple example assumes that BAN_0 coexists with seven other WBANs and there are four available channels. In addition, value of PRR are also defined. In the channel planning, BAN_0 may collect channel information from other WBANs including channel ID and PRR value. After collecting neighbors channel information, BAN_0 calculates weight value and score for all available channels. For the case of the third channel (ID: 3), BAN_0 can calculate ω_3 ($\omega_3 = 1 - \frac{1}{8} = 0.875$), and it can also obtain score for third channel by $0.875 \times 96 = 84.0$. In this way, BAN_0 can obtain weight and score for all channels, and the result of calculating is shown in Table 1.

Table 1. An example: channel planning results of BAN_0

Channel ID	$NumNet_{CH_i}$	ω_i	S_i	Result
1	2	0.75	69	×
2	1	0.875	84	Selected
3	3	0.625	52.29	×
4	2	0.75	68.25	×

After performing channel planning phase, coordinator performs medium access adjustment phase. In this phase, the coordinator decides which channel access scheme to transmit based on the both coexistence situation and pre-defined PRR threshold specified in TRD [4]. If there are no coexisting WBANs who uses selected channel, the coordinator sets channel access scheme to TDMA. Otherwise, the coordinator checks PRR_i^{Avg} . If PRR_i^{Avg} is less than the pre-defined PRR threshold (=0.95), the coordinator decides CSMA/CA and otherwise selects a hybrid channel access scheme. When the coordinator selects a hybrid channel access, it divides its communication duration into several slots and decides which slot to use based on the number of coexisting WBANs in the selected channel.

4. Performance Evaluation

To evaluate the performance of the proposed scheme, we performed extensive simulations comparing with the IEEE 802.15.4-based WBANs. In the simulation, we assume that coexisting WBANs are randomly deployed in $6\text{ m} \times 6\text{ m} \times 6\text{ m}$ area and communication range of each WBAN is 3 m and the number of available channels is 5. Both proposed scheme and the IEEE 802.15.4-based WBAN operate based on beacon-enabled superframe structure without inactive period, and superframe duration is set to 245.76 milliseconds which is same to the length of the superframe when BO is set to 4. For a fair performance evaluation, in addition, we also assume that all other simulation parameters are equal to the IEEE 802.15.4 standard. Each WBAN consists of 10 medical devices and they transmit 40 bytes of medical data to coordinator at intervals of 10 ms. In order to confirm the variation in transmission reliability according to the density of coexisting WBANs, the number of WBANs in the assumed area is set to 5, 10, and 20. The criteria for measuring performance are the number of transmission including retransmission, PRR, and collision ratio. The simulations were implemented based on OMNET++, and the total simulation was performed 5 times by 1,000,000 seconds to derive the mean value of the results.

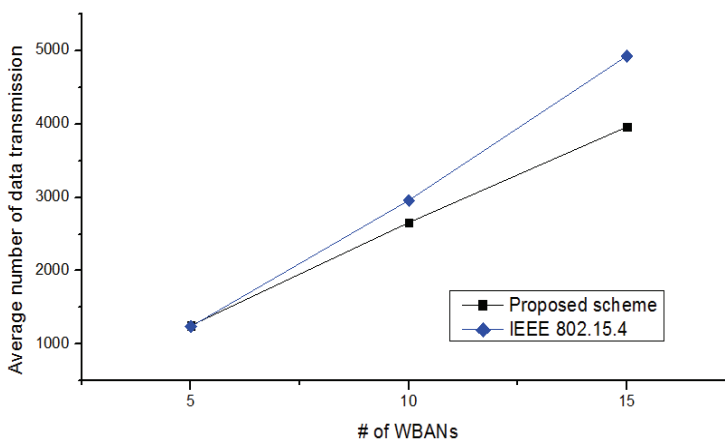


Fig. 6. Simulation results: average number of data transmission.

Fig. 6 illustrates the number of data transmission of both the proposed scheme and the IEEE 802.15.4-based WBAN. As the number of coexisting WBANs increases, the average number of data transmission in both of two different scheme also increase. In a closer look, the average data

transmission of the proposed scheme can be seen as more gradual than the IEEE 802.15.4-based WBAN, because not only the proposed scheme can provide a balanced channel usage that leads to disperse traffic load, but also it can adaptively adjust channel access scheme that allows effectively avoiding interference from adjacent WBANs. On the other hand, IEEE 802.15.4-based WBANs represents the higher average number of data transmission because it randomly selects communication channel and thus cannot distribute traffic load.

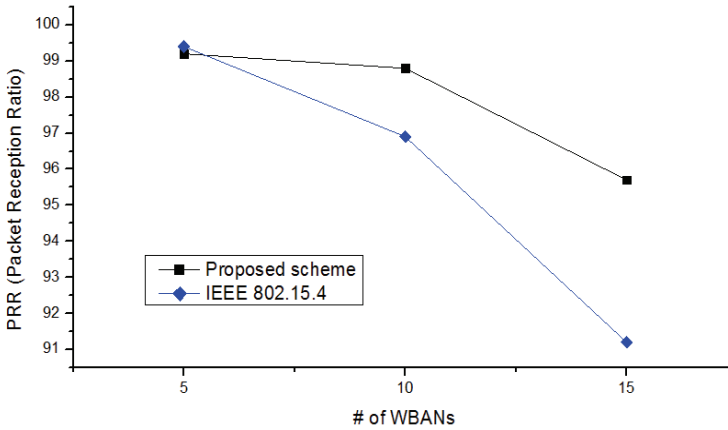


Fig. 7. Simulation results of PRR (Packet Reception Ratio).

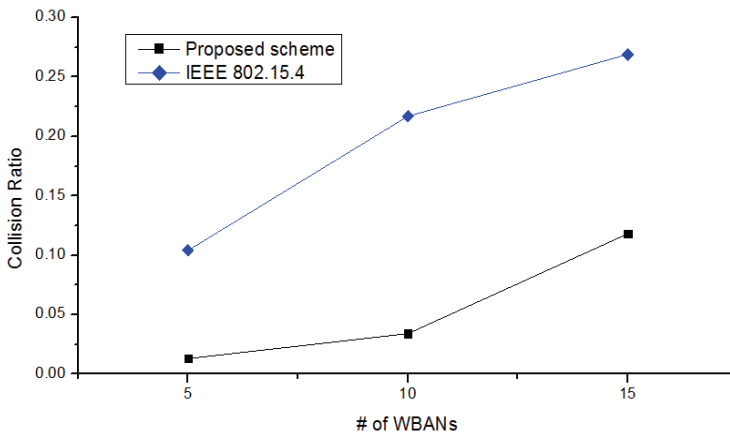


Fig. 8. Simulation results of collision ratio.

Figs. 7 and 8 represent simulation results of PRR and collision ratio. As mentioned above, IEEE 802.15.4-based WBAN selects its communication channel in random manner. For this reason, the number of adjacent WBANs that use a specific channel may increase, meaning that the allocation of channels across overall network is disproportionate. Since there is no solution to the complexity of channel access (contention) that occurs when multiple channels are used for a particular channel, furthermore, the PRR value of the IEEE 802.15.4-based WBAN is sharply decrease and the collision is dramatically increased. On the contrary, the PRR value of the proposed scheme can be seen to decrease

steadily and the collision ratio of the proposed scheme is slowly increased despite the increasing number of coexisting WBANs, because the average number of coexisting WBANs using the same channel is less than the IEEE 802.15.4-based WBANs, and the WBANs which use the same channel adaptively select channel access scheme considering with interference.

5. Conclusions

Coexistence problem in IoT environment is a major reason of communication performance degradation. Especially, communication reliability issues in the smart medical system are directly linked human lives. However, existing works cannot solve fundamental coexistence problem. To deal this reason, we proposed a distributed coexistence mitigation scheme for smart medical systems. The proposed scheme consists channel planning phase and medium access adjustment phase. In the first phase the coordinator collects channel information and select its next communication channel. After performing the first phase, the coordinator performs the second phase which decides channel access scheme based on average PRR value of selected channel. To evaluate performance of the proposed scheme, we perform extensive simulations comparing with the IEEE 802.15.4, and we can prove that the proposed scheme can guarantee reliable communication in coexistence situations.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science, ICT & Future Planning) (No. NRF-2017R1C1B5016530).

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