ACESS: Adaptive Channel Estimation and Selection Scheme for Coexistence Mitigation in WBANs

BeomSeok Kim and Jinsung Cho
Dept. of Computer Engineering
KyungHee University
Yongin 446-701, Korea
{passion0822, chojs}@khu.ac.kr

Dae-Young Kim
Dept. of Software Engineering
Changshin University
Changwon 51352, Korea
kimdy@cs.ac.kr

Ben Lee
School of Electrical Engineering and Computer Science
Oregon State University
Corvallis 97331, OR, USA
benl@eecs.orst.edu

ABSTRACT

A Wireless Body Area Networks (WBAN) is a communication network that provides both medical and consumer electronics (CE) services by using sensor devices in, on, or around a human body. To provide reliable communication with low power consumption for in-body communication, the IEEE 802.15.6 provides Medical Implant Communication Service (MICS) band and defines its communication policy. However, MICS band communication suffer from the coexistence problem, which causes significant performance degradation due to high-density deployment and network-level mobility of WBANs. In addition, existing coexistence mitigation schemes in IEEE 802.15.6 do not consider the MICS band. To overcome the coexistence problem, numerous studies have been conducted for multi-channel usage in WBANs, but they just include simple channel selection schemes which do not provide reliable channel selection. This paper proposes an Adaptive Channel Estimation and Selection Scheme (ACESS) for coexistence mitigation in WBANs. The proposed method maintains a history table and predicts the conditions of available channels based on two-state Markov chain with an exponentially controlled channel history, which can control the sensitivity of prediction. Our simulation study show that the proposed scheme can improve communication performance in terms of Packet Reception Ratio (PRR) under coexistence environments with multiple WBANs.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Protocols—*Protocol verification*

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General Terms

Algorithms

Keywords

Channel selection, adaptive channel estimation, multi-channel, WBAN

1. INTRODUCTION

Wireless Body Area Network (WBAN) is a communication technology that provides both medical and Consumer Electronics (CE) services by using sensor devices in, on, or around a human body. In order to standardize WBAN, the IEEE 802.15 Working Group first published the IEEE 802.15 Task Group 6 in 2007, and this was standardized in 2012 [3]. The IEEE 802.15.6 standard defines three different Physical (PHY) layers and the Medium Access Control (MAC) sublayer to satisfy a number of requirements for WBANs. In addition, it defines a set of requirements to provide both medical and Consumer Electronic (CE) services [4]. In particular, providing reliable communications for medical services is crucial because medical data directly affects human life.

To provide reliable medical services, IEEE 802.15.6 exploits the Medical Implant Communications Service (MICS) band as the exclusive frequency band for in-body communications, and it also defines *MICS band communication mechanism* based on a single channel. However, a WBAN that performs MICS band communication is vulnerable to interference from other WBANs that are densely deployed in a populated area [5] as shown in Figure 1, which is referred to as the *coexistence problem.* Moreover, mobility dynamically changes interference characteristics of WBANs and aggravates the coexistence problem.

In order to solve the coexistence problem in WBANs, the IEEE 802.15.6 classifies coexistence environment into three different conditions (dynamic, semi-dynamic, and static) and also provides three different coexistence mitigation schemes (beacon shifting, channel hopping, and active superframe interleaving) to handle different coexistence conditions. However, these coexistence mitigation schemes do not consider

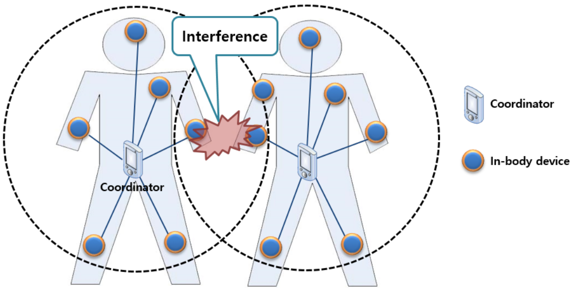

Figure 1: The coexistence problem in overlapped WBAN environment

communications in the MICS band.

There have been a number of attempts to solve the coexistence problem in WBANs [6, 7]. These studies mostly consider multi-channel usage by maintaining a list of available channels and selecting one channel from the list to avoid congested channels. However, these methods are based on simple channel selection schemes that not consider the conditions of available channels. In addition, these studies cannot be directly applied to the MICS band communication because they do not consider aforementioned characteristics of the MICS band.

This paper proposes the *Adaptive Channel Estimation and Election Scheme* (ACESS) to overcome the coexistence problem for MICS band communication in WBANs. The proposed ACESS maintains a history table and adaptively predicts the conditions of available channels based on two-state Markov model. Based on results of channel prediction, the coordinator can choose the best channel which probably stay on idle channel state.

The remainder of the paper is organized as follows. Section 2 discusses the existing channel selection schemes related work. Section 3 presents the proposed scheme, and Section 4 presents the performance evaluation. Finally, Section 5 concludes the paper.

2. RELATED WORK

This section discusses the MICS band communication of the IEEE 802.15.6 standard to help readers better understand the motivation of the proposed scheme. In addition, this section discusses the related work on solving the coexistence problems in WBAN that utilize multi-channels.

2.1 MICS Band Communication

To provide reliable communication with low power consumption for communicating implant data, the IEEE 802.15.6 standard considers the MICS band [3]. The MICS band is divided into 10 channels and communication is performed based on the listen-before-talk (LBT) protocol, and supports channel switching in the MICS band. Due to this channel composition, a WBAN can simultaneously transmit with their neighbor WBANs at the same time when they does not use the same channel of the WBAN. In addition, communications in the MICS band do not suffer interference from different communication technologies due to the fact that the MICS band is a licensed band for only the medical implant communication service. Therefore, in-body communication in the MICS band is more stable than any other frequency bands, such as Industrial, Scientific, and Medical (ISM) band and Ultra Wide Band (UWB).

Due to the aforementioned advantages of the MICS band, IEEE 802.15.6 defines communication policy on the MICS band, referred to as *MICS band communication*. To provide reliable medical implant communication service with low communication complexity and low-power consumption, MICS band communication uses polling-based channel access mechanism with a single channel, which means that the MICS band communication does not provide a way to select a new channel when current channel is congested due to interference from neighboring WBANs. However, a WBANs are densely deployed in a populated area such as a hospital or a healthcare center. Moreover, interference dynamically changes due to network-level mobility of WBANs. In this situation, WBAN significantly suffers from performance degradation in spite of aforementioned advantage of the MICS band.

2.2 Existing Studies on Multi-Channel MAC Protocols

One solution for the coexistence problem is multi-channel MAC protocols, which allow simultaneously data transmission in a coexistence environment. In general, multi-channel MAC protocols maintain an available channel list and select a channel to use in a random manner. Zhang and Li proposed MMSN [8], which is a well-known multi-channel MAC protocol for WSNs. This protocol selects the least chosen channel from an available channel list, and it also randomly selects a channel when multiple least chosen channels exist. To provide multiple channel usage, Abdeddaim *et al.* proposed MCCT (Multi-Channel Cluster Tree) [9], which considers similar network structure to WBAN. This scheme also randomly selects a channel in order to reduce the complexity of channel selection. However, in the MICS band of WBAN, channel condition is dynamically changed due to high-density deployment and network-level mobility of WBANs.

Meanwhile, there have been few attempts to improve the performance of WBANs by using multi-channel MAC protocol. Lee *et al.* proposed an efficient multi-channel management protocol for WBANs to provide communications between in-body devices and out-body devices [6]. This protocol reserves the channel using a one-to-one mapping between the beacon slot and the data channel. In addition, it also performs channel aggregation that allocates indiscrete channels to an in-body device to be used as a single wide channel. However, they only focus on improving performance of a single WBAN, and do not consider coexistence environment in WBANs. In addition, their method does not provide a way to select a channel to communicate, which is an important issue to maintain stable performance in coexisting WBAN environments. Ivanov *et al.* proposed a cooperative wireless sensor environments to support WBANs [7]. To improve communication performance, this scheme builds a virtual topology and allocates channel through redundant channel blocking. This scheme also extends the cooperation at the MAC layer to a cross-layered gradient based routing solution, which is determined in order to ensure data delivery from WBANs to a distant gateway. However, they also do not consider the coexistence problem in the MICS band of WBANs. Thus, properly selecting the best channel on the MICS band is necessary to not only improve the performance multi-channel MAC protocols but also to solve the

Table 1: **History table (HT)**

Channel ID	TI	History of Channel States				
		$N-(HW_{max}-1)$	$N-(HW_{max}-2)$	...	N-1	N
1	3	I	B	...	I	I
2	4	B	B	...	B	I
3	2	I	B	...	I	B
4	6	I	I	...	B	B
...	...	...	...	...	...	...

coexistence problem.

3. PROPOSED SCHEME

The goals of the proposed ACESS scheme is to mitigate the coexistence problem and improve performance by using calculating criterion of channel selection. The detail of ACESS is described below.

First, a coordinator maintains a *History table*, which stores the history of channel states for all the channels as shown in Table 1. The history table contains Channel ID, Transition Index (TI), and *History of Channel States* for all channels. TI, a criterion for channel stability, is used to control the size of the *History Window (HW)* for adaptively estimating channel condition. *History of Channel States*, HW_{max}, is the maximum length of HW representing the list of channel states for the latest HW_{max} times.

To adaptively control the sensitivity of channel prediction, the coordinator adjusts TI based on the latest channel state transitions within the range 1 to TI_{max}, where TI_{max} represents the maximum value of TI. For example, if the next channel state of channel 3 in Table 1 transitions to a different state (e.g., Busy → Idle) indicating that the next channel state of channel 3 will be probably changed to different state, the proposed scheme regards channel 3 is unstable channel. In this case, recent channel transitions of channel 3 should be considered to provide higher prediction sensitivity for channel 3. Therefore, TI set to 2 for decreasing HW of channel 3 in half. On the other hand, if the next channel state of channel 3 stays at Busy indicating that the next channel state of channel 3 will be probably stay in the same state, the proposed scheme regards channel 3 is stable channel. In this case, a greater number of channel transitions should be considered to improve prediction accuracy. Therefore, TI set to 4 to double HW of channel 3.

After obtaining TI, the History Window for the i^{th} channel, HW^i, can be calculated as

$$HW^i = 2^{TI^i-1} \times HW_{min}, \quad (1)$$

where TI^i represents the transition index of the i^{th} channel, and HW_{min} denotes the minimum value of HW.

Based on History table, the coordinator applies a two-state Markov model to adaptively predict channel conditions of the all channels as shown in Figure 2. The two-state Markov model consists of *Idle* (I) state, *Busy* (B) state, and transition probabilities p and q. The state I and state B denote the channel conditions, and p is the transition probability from state I to state B. In contrast, q represents the transition probability from State B to State I.

Based on Equation 3, the coordinator counts all the possible state transitions for all the channels within the range of $(N-(HW^i-1))^{th}$ channel condition to N^{th} channel condition. The counts of all possible state transitions for the

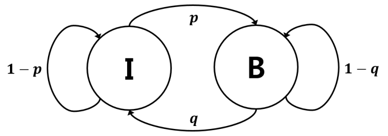

Figure 2: Two-state Markov model in the proposed scheme

i^{th} channel are defined as

$$\begin{aligned}
\alpha^i &= \#\text{ of transitions from state } I^i \text{ to state } I^i, \\
\beta^i &= \#\text{ of transitions from state } B^i \text{ to state } I^i, \\
\gamma^i &= \#\text{ of transitions from state } I^i \text{ to state } B^i, \\
\delta^i &= \#\text{ of transitions from state } B^i \text{ to state } B^i.
\end{aligned} \quad (2)$$

From Equation (2), transition probabilities of the i^{th} channel, p^i and q^i, can be expressed as

$$\begin{aligned}
p^i &= P[X_N^i = Busy \mid X_{N-1}^i = Idle] = \frac{\gamma^i}{\alpha^i+\gamma^i}, \\
q^i &= P[X_N^i = Idle \mid X_{N-1}^i = Busy] = \frac{\beta^i}{\beta^i+\delta^i}.
\end{aligned} \quad (3)$$

According to Geometric stochastic process, the stationary probability of State I for the i^{th} channel, ρ^i, can be obtained as

$$\rho^i = P[X_N^i = Idle] = \frac{q^i}{p^i+q^i}. \quad (4)$$

Based on Equation (4), the coordinator can select the best channel, which has the highest ρ^i. Since HW^i exponentially increases or decreases based on recent channel transitions, the proposed scheme simultaneously considers both stability of channel state and estimated channel condition.

4. PERFORMANCE EVALUATION

Performance evaluation of the proposed ACESS was performed using a simulator written in C++. The simulator models a WBAN consisting of a coordinator and 20 in-body sensor nodes that periodically transmit data through the selected channel of the MICS band, and the coordinator performs ACESS at every 100 ms.

The proposed method was compared against both single channel scheme in the IEEE 802.15.6 [3] and random channel selection scheme [6, 7, 8, 9], which is the traditional channel selection scheme for multi-channel MAC protocol, in terms of Packet Reception Rate (PRR).

The two-state Markov model shown in Figure 2 is used to modeled the wireless channel condition, and this model is performed in every *Channel Interval* period. In this model, the stationary probability of each state, $P[X = Good]$ and $P[X = Bad]$, is defined as

$$\begin{aligned}
P[X = Good] &= \frac{q}{p+q}, \\
P[X = Bad] &= \frac{p}{p+q}.
\end{aligned} \quad (5)$$

From Equation (5), the probability of successful data transmission, P_s, can also calculated as

$$P_s = (1-per)P[X = Good], \quad (6)$$

Table 2: Simulation parameters

Parameters	Values
Simulation time	10000 sec
Channel Interval	5 sec
Channel Selection Interval	100 ms
Transmission period	10 ms
per	0.01
p	$\mathcal{U}(0.7, 0.9)$ for Good $\mathcal{U}(0.1, 0.3)$ for Bad
q	$\mathcal{U}(0.2, 0.4)$ for Good $\mathcal{U}(0.6, 0.8)$ for Bad
Initial TI	1
TI_{max}	5
HW_{min}	5
HW_{max}	80

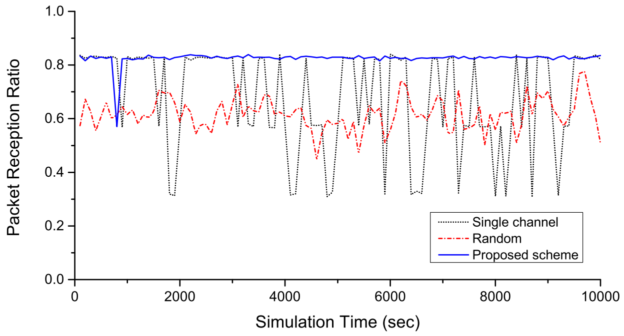

Figure 3: Simulation results: Packet Reception Radio (PRR)

where per denotes Packet Error Rate (PER), which is required to be at most 1% for IEEE 802.15.6 [3].

The parameter used for the simulation study are shown in Table 2.

Figure 3 shows PRRs for the single channel scheme for IEEE 802.15.6, random channel selection, and the proposed ACESS scheme. Due to absence of dynamically changing channel state, both the single channel scheme and the random channel selection scheme are unstable and result in low PRR. The single channel scheme in particular shows more drastic changes in PRR because it does not provide channel switching function. On the other hand, PRR for the random channel selection is more stable than the single channel scheme because the random channel selection probably mitigate congested channel by channel switching. However, the random channel selection exhibits lower PRR than the proposed scheme because it switches channel without considering expected channel states. In contrast, ACESS shows more stable PRR than the other two schemes, which indicates that the proposed channel estimation model helps in selecting the best channel.

5. CONCLUSIONS

In this paper, we proposed ACESS for coexistence mitigation in WBANs. The proposed scheme maintains history table and predicts states of available channels based on 2-state Markov chain with an exponentially controlled channel history which can control sensitivity of prediction. Since estimation of channel conditions based on dynamically controlled channel history, the proposed scheme can help to select the best channel among available channels. Our simulation study shows that the proposed scheme provides significant higher PRR compared to existing studies that does not consider channel conditions.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] W, Li. J, Bao. and W, Shen. Collaborative Wireless Sensor Networks: Survey. in *International Conference on System, Man, and Cybernetics (ICSMC 2011)*, IEEE, 2614–2619. DOI:http://dx.doi.org/10.1109/ICSMC.2011.6084070

[2] R, Cavallari. F, Martelli. R, Rosini. C, Buratti. and R, Verdone. 2014. A Survey on Wireless Body Area Networks: Technologies and Design Challenge. *IEEE Communications Survey & Tutorials*, 16, 3 (Third Quarter 2013), 1635–1657. DOI:http://dx.doi.org/10.1109/SURV.2014.012214.00007

[3] IEEE Standard for Local and metropolitan area networks - Part 15.6: Wireless Body Area Networks. *IEEE Std 802.15.6-2012*, pages 1–271, Feb. 2012.

[4] B, Zhen. M, Patel. S, Lee. E, Won. and A, Astrin. TG6 Technical Requirements Document (TRD). IEEE P802.15-08-0644-05-0006, Sept. 2008.

[5] E, Sarra. H, Moungla. S, Benayoune. and A, Mehaoua. 2014. Coexistence Improvement of Wearable Body Area Network (WBAN) in Medical Environment. In *2014 IEEE International Conference on Communications (ICC 2014)*. IEEE, 5694–5699. DOI:http://dx.doi.org/10.1109/ICC.2014.6884229

[6] W, Lee. S, H, Rhee. Y, Kim. and H, Lee. 2009. An Efficient Multi-channel Management Protocol for Wireless Body Area Networks. in *Proc. International Conference on Information Networking (ICOIN 2009)*. IEEE, 1–5.

[7] S, Ivanov. D, Botvich. and S, Balasubramaniam. 2012. Cooperative Wireless Sensor Environment Supporting Body Area Network. *IEEE Transactions on Consumer Electronics*, 58, 2 (May 2012), 284–292. DOI:http://dx.doi.org/10.1109/TCE.2012.6227425

[8] H, Zhang. and S, Li. A Practical Design of Multi-channel MAC for Cluster-tree WSN, *6th International Forum on Strategic Technology (IFOST 2011)*, IEEE, 22–24. DOI:http://dx.doi.org/10.1109/IFOST.2011.6021133

[9] N, Abdeddaim. F, Theoleyre. F, Rousseau. and A, Duda. Multi-Channel Cluster Tree for 802.15.4 Wireless Sensor Network. in *Proc. 23rd IEEE International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC 2012)*, IEEE, 590–595. DOI:http://dx.doi.org/10.1109/PIMRC.2012.6362853