A Channel Allocation Scheme based on Coloring Algorithm for Interference Mitigation in Coexisting WBANs

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Abstract

In practical operation environments of wireless body area networks (WBANs), coexistence problem is one of the most important problems which can cause significant performance degradation communication. To solve this problem, the IEEE 802.15.6 which is the wireless communication standard for WBAN defines three different coexistence conditions according to mobility among coexisting WBANs, and it also provides three interference mitigation guidelines. However, these guidelines do not provide detailed algorithms, and they only consider resource management in focusing on time-domain that cannot be fundamental solution for coexistence problem in WBANs. Meanwhile, a few number of attempts to handle coexistence problem in WBANs by using graph coloring algorithm is studied, but they cannot completely handle coexistence problem in WBANs due to the fact that they also consider resource assignment in focusing on time-domain. To improve efficiency of interference mitigation performance for coexisting WBAN, this paper considers applying coloring algorithm to channel allocation. The proposed channel allocation scheme can enable to improve channel utilization by uniformly allocating available channels to coexisting WBANs. Through introducing a case study, performance of the proposed scheme is validated.

Keywords*: WBAN, coexistence problem, interference mitigation, channel allocation, coloring algorithm*

1. Introduction

Recently, wireless communication and information technologies have been advanced, and these have led to emerging internet of things (IoT) which is a novel communication paradigm [1]. IoT aims to supporting wireless infrastructures to create new services through exchanging information among hyper-connected wireless devices. Therefore, everything around our life are composed of a number of sensor nodes, and they should have both computing and communication capacities.

Actually, IoT, a new communication paradigm, have been applied in various ICT applications. Especially, healthcare or lifecare are attracted as a target application to adopt a concept of IoT due to rapidly becoming a worldwide aging society [2, 3]. To reflect this trend, wireless body area network (WBAN), which aims to provide both medical and consumer electronics (CE) services through wireless sensor nodes in, on or around human body, has naturally received attention as a new type of communication technology for healthcare or lifecare system [4]. In addition, the IEEE 802.15 Task group 6 (TG6) started standardization of WBANs in November 2007, and it established a baseline document in February 2012 [5].

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In general, a number of WBANs which consist of a large number of sensor nodes are densely deployed in populated area such as hospital, healthcare center, and etc. In addition, each WBAN has both intra- and inter-network mobility due to body posture of a user and body-centric operation. In this situation, a WBAN may dynamically coexist with a large number of other WBANs, and thus it may suffer from interference which can cause significant performance degradation, referred to as the 'Coexistence problem' [6, 7]. In addition, interference among coexisting WBANs can appeared in diverse aspects due to intra- and inter-network mobility of WBANs which are major reasons of frequently changed network condition.

In order to solve coexistence problem in WBANs, the IEEE 802.15.6 defines three different coexistence conditions (dynamic, semi-dynamic, static) according to mobility among coexisting WBANs as shown in Figure 1, and the IEEE 802.15.6 also provides three different coexistence problem handling schemes (beacon shifting, channel hopping, active superframe interleaving) [5]. However, the IEEE 802.15.6 does not define criteria to decide current coexistence condition, and it also does not specify detailed algorithms for above mentioned coexistence problem handling schemes. In addition, the standard does not consider a variety of requirements for different target services and dynamically changed network conditions.

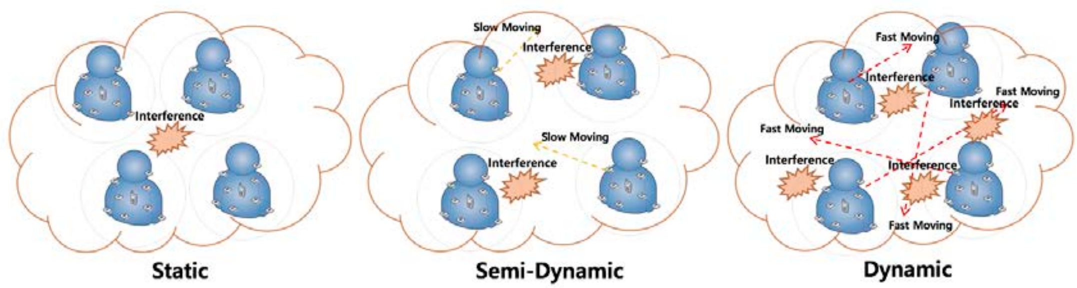

Figure 1. Three different coexistence conditions

Meanwhile, vertex coloring algorithm which is one of kind of graph coloring theory is widely exploited as a general solution to allocate limited resources [8]. Especially, vertex coloring is frequently utilized to efficiently allocate resource in wireless sensor networks (WSNs) which is similar to WBANs [9, 10]. In these studies, vertex coloring is used to allocate non-overlapped transmission time to sensor nodes in order to avoid collisions and to improve communication efficiency. However, they are not suitable to be directly applied to WBANs environments due to the fact that requirements and network characteristics are totally different from WSNs. In addition, they only focus on how to allocate time slots for coexisting networks. In the case that a number of WBANs use the same channel, the coexistence problem cannot be solved due to limited bandwidth. Therefore, applying vertex coloring algorithm in terms of frequency-domain should be considered to achieve optimal solution for the coexistence problem.

There is an attempt to solve the coexistence problem in WBANs by using vertex coloring algorithm. S. H. Cheng et al. proposed random incomplete coloring (RIC) algorithm which loose the rule of vertex coloring algorithm that exploits uncolored nodes based on the fewer number of colors than traditional vertex coloring algorithm [11]. However, RIC does not define criteria for deciding the number of colors in the pallet that is closely related to performance of this algorithm. Moreover, this algorithm cannot be optimal solution for the coexistence problem in WBANs because it also focuses on only resource allocation in time-domain manner.

This paper proposes coloring algorithm based channel allocation scheme for interference mitigation among coexisting WBANs. The proposed scheme consists of three steps: Channel scanning, Two-hops discovering and Channel allocation. In the first step, coordinator firstly scans all channels and performs random value selection for giving priority to each vertex. After performing the first step, two-hop discovery process is performed to collect two-hop information with their available channel lists. Based on two-hop color table and its pre-selected random value, coordinate finally performs channel allocation through vertex coloring algorithm which can guarantee uniformly distributed channel usage for all coexisting WBANs and improvement of channel utilization.

The rest of the paper is organized as follows: Section 2 explains background and introduces related work. Section 3 illustrates detailed algorithm of the proposed channel allocation scheme, and Section 5 shows provides case studies. Finally, Section 5 concludes the paper and discusses the future work.

2. Background and related work

2.1. Coloring algorithm

Graph coloring is one of the most well-known algorithms in graph theory which is used to conflict resolution with the limited resources. This algorithm can be divided into several categories based on certain constraints. For example, every two adjacent vertices or edges in a graph should have different color. In the first step, graph coloring algorithm creates a map which means adjacent vertices have different color in color pallet over a graph where denotes vertex set and is edge set; constraint can be defined that where if with chromatic number required the minimum number in the graph.

Vertex coloring, which is a kind of graph coloring algorithm, is well-known theory to solve resource allocation problem through allocating colors to vertices in graph with certain constraints [8]. In detail of this algorithm, each vertex selects a random color from the color pallet which contains available colors, and they check whether it has the same color as its neighbors which are linked by an edge. If two or more than two adjacent vertices have the same color, they select a random color from the color pallet and check whether duplicated color exists. This procedure is recursively performed until every two vertices linked by an edge have different colors.

2.2. Related work

In both WSN and WBAN environment, efficiency of allocating wireless resources is one of the major research topics as a way to improve communication performance. Especially, a number of studies adopt coloring algorithm which is regarded as an optimal solution for allocating shared wireless resources [9-11].

WSNs consist of a number of sensor nodes which collect sensing data from the target area and transmit collected data to base station (BS) over wireless medium. To transmit collected data without collision or interference, BS schedules transmission time or communication channel to all sensor nodes through exchanging information and negotiation. There are some solutions efficient way based on coloring algorithm to allocate wireless resources in WSNs. Ryouhei *et al.* introduced their sensing function allocation scheme which exploits coloring algorithm [9]. In this scheme, probabilistic color change algorithm is performed to allocate different time slots to each sensor node. However, the performance of this scheme closely depends on density of sensor nodes deployment which is a major factor to decide how many colors are needed. In addition, this scheme is not an optimal approach because it focuses on only time resource allocation. Meanwhile, Paradis *et al.* also consider time resource allocation in WSNs. They proposed timely sensor data collection using distributed graph coloring (TIGRA) [10]. In this scheme, network is constructed to tree topology, and a parent node performs coloring algorithm to allocate a transmission time-slots to its child nodes. However, this scheme cannot be guarantee differentiated color allocation among adjacent nodes which have different parent nodes.

Cheng *et al.* proposed time-slot reservation scheme based on random incomplete coloring (RIC) algorithm which is improved algorithm of traditional vertex coloring algorithm [11]. This scheme consists of random-value coloring and incomplete coloring phase. In the random-value coloring phase, each vertex selects a random value to get its priority. After performing random-value coloring phase, incomplete coloring phase is operated that allocates a non-overlapped color to each vertex. Operation sequence of incomplete coloring phase is similar to traditional coloring algorithm, but it has a special characteristic that allows performing coloring algorithm with the fewer number of colors than traditional coloring algorithms. In other words, it allows to be uncolored vertex when only $k < X(G)k < X(G)$ colors are used. Uncolored vertices have no transmission time-slot until specific coloring cycle. The incomplete coloring algorithm is repeatedly performed until there are no colors in a color pallet. The RIC can enable decrease of coloring overhead and increase spatial reuse. However, this scheme only outperforms when the given number of colors in color pallet is fewer than the essential number of colors in traditional coloring algorithm, and a way to decide the number of colors is not defined. Moreover, it only considers time-slot reservation that cannot be optimal solution for coexistence problem in WBANs.

3. The proposed channel allocation scheme

As aforementioned, existing studies cannot be optimal solutions to solve coexistence problem in WBANs because they only focus on allocating resource allocation in the time-domain point of view. To overcome this limitation, this paper proposes a channel allocation scheme based on coloring algorithm to help to mitigate interference for coexisting WBANs. In the first stage of the proposed scheme, coordinator scans all channels and lists all available channels. After scanning channels, coordinator generates its own color pallet which contains available colors, k, and each color in color pallet is mapped to available channels. In this stage, this paper allows the fewer number of k than the maximum degree of a graph, Δ, because communication channel can be shared when contention-based channel access is exploited. After that, network coordinator selects a random value to give color priority which will be exploited in the third stage of the proposed scheme. The range of the random value is initialized from 0 to 100.

In the second stage, network coordinator first discovers its one-hop neighbors. To discover its neighbors, coordinator broadcasts *NeighborDiscover* message and waits for *NeighborDiscover* messages from its one-hop neighbors until a pre-defined waiting time. When the pre-defined waiting time is expired, coordinator creates a color table which contains one-hop neighbor information such as network ID, channel usage and selected random value, and it broadcasts *OnehopInfo* message based on the color table. The coordinator who receives *OnehopInfo* messages from its all one-hop neighbors can complete creating its color table and can obtain its two-hop color graph based on the color table.

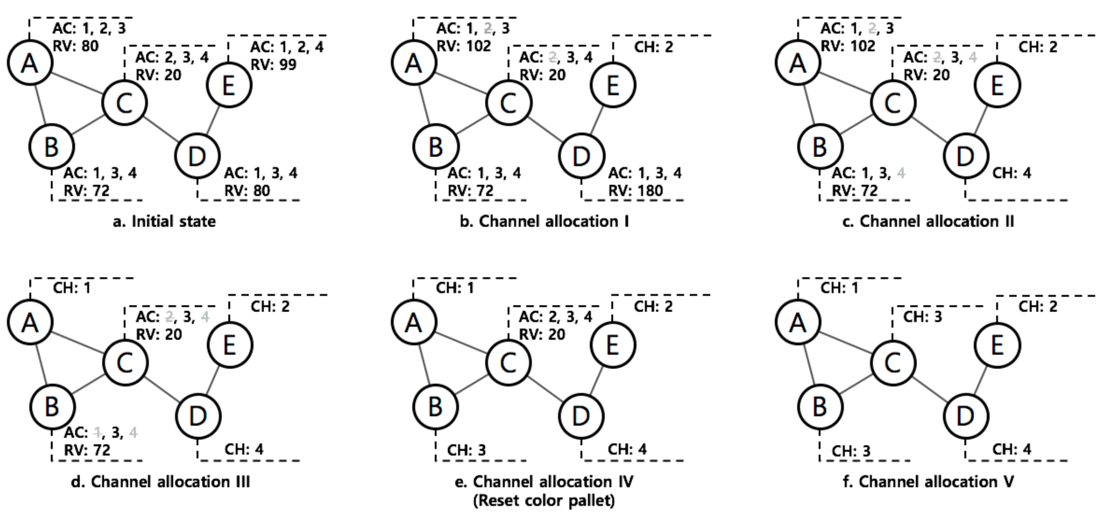

Figure 2. An example of the proposed scheme

In the last stage, each coordinator compares its pre-selected random value with values which selected by one- and two-hop neighbors by referring its color table. When pre-selected random value is the higher value than other random values of its neighbors, the coordinator selects a random color (channel) from color pallet and broadcasts *ChannelSelectionInfo* message which contains information of its selected color. Neighbors who receive *ChannelSelectionInfo* message compares selected color with its color table and it updates color table if the same color is exist in its color table. After that, it broadcast *UpdateColorTable* message which contains updated color table. If there exist same random values which are selected by neighbors, both the coordinator and its neighbors perform again selecting random value in range from previous highest value to 100×2^n, where n is the trying number of selecting random value. The last stage is repeatedly performed until all coexisting WBAN coordinators have a non-overlapped color (channel) or there is no color in color pallet. In case that coordinators who have no color and no color exists in color pallet, the proposed scheme allows duplicated color allocation because multiple WBANs can share its communication channel through contention-based channel access method such as CSMA/CA and Aloha. Therefore, non-colored coordinators reset their color pallet and perform the last stage until all non-colored coordinator do not exist.

To help readers easily understand the proposed scheme, this paper introduces an example of the proposed scheme as illustrated in Figure 2. In this example, there are five WBANs are coexisted in narrow area. Figure 2 shows the results of performing the first and the second stage in the proposed scheme. Based on the results of both the first and second stage, all coordinators of coexisting WBANs repeatedly perform the last stage, and results of each allocating steps are illustrated in Figure 2 b, c, d, e and f. In each step, coordinators of coexisting WBANs select their communication channel based on available channel (AC) and random value (RV). More specifically, the first channel allocation step (b) shows both A and D re-select their random value in range (80, 200), and the coordinator of network D preferentially selects its communication channel due to higher RV than the coordinator of network A. In the fourth step (e), the coordinator of network resets its color pallet (AC) because its color pallet is empty after the coordinator of network B selects its communication channel to 3. Based on initiated AC, the coordinator of network C randomly selects its communication channel, and the result of the channel allocation of the coordinator C is 3.

In summary, the proposed scheme enable that all WBANs can have their communication channel, and the results of performing the proposed scheme shows that distribution of channel usage for all coexisting WBANs is uniformly appeared. In other words, the proposed scheme can improve channel utilization in coexisting WBANs through fairly allocating available channels to coexisting WBANs. In addition, the proposed scheme can be used in dynamic coexisting situation by periodic performing.

4. Conclusion

In the practical environment of WBANs, a number of networks may coexist in populated area and they may suffer from interference which can cause significant performance degradation, as referred to coexistence problem. To handle this problem, the IEEE 802.15.6 defines three different coexistence conditions and proposes three coexistence handling schemes, but these schemes do not provide detailed algorithms. Meanwhile, a few studies based on coloring algorithm are proposed to solve coexistence problem. However, these schemes cannot satisfy requirements of the WBANs because they only focus on resource reservation in time-domain point of view. To solve this problem, this paper considers frequency-domain resource reservation which can help to improve efficiency of channel utilization. Based on this consideration, this paper proposes a channel allocation scheme based on coloring algorithm for coexisting WBANs. The proposed scheme can provide uniformly distributed channel usage. The simple case study shows that the proposed scheme can improve channel utilization. In our future work, we will try to reduce message exchange overhead of the proposed scheme, and we also will perform extensive simulations to validate performance of the proposed scheme.

5. References

[1] D. Bandyopadhyay, J. Sen, "Internet of things: Applications and challenges in technology and standardization," *Wireless Personal Communications*, Vol. 58, No. 1, pp. 49–69, May 2011.

[2] A. Milenkovic, C. Otto, E. Jovanov, “Wireless sensor networks for personal healthcare monitoring: Issue and an implementation,” *Computer communications.*, Vol. 29, No. 13-14, pp. 2521–2533, Aug. 2006.

[3] R. Cavallari, F. Martelli, R. Rosini, C. Buratti, R. Verdon, “A survey on wireless body area networks: Technologies and design challenge,” *IEEE Communications Survey & Tutorials,* Vol. 16, No. 3, pp. 1635–1657, Feb. 2014

[4] IEEE 802.15 WPAN Task Group 6 (TG6) Body Area Networks. http://www.ieee802.org/15/pub/TG6.html

[5] IEEE Standard for local and metropolitan area networks – Part 15.6 (2012). Wireless body area networks. In: *IEEE Std 802.15.6-2012* (pp. 1–271).

[6] M. Deylami, “A distributed scheme to manage the dynamic coexistence of IEEE 802.15.4-based healthcare monitoring WBANs.” *IEEE Journal of Biomedical and Health Informatics*, Vol. 18, No. 1, pp. 327–334, Aug. 2014.

[7] Y. Kim, S. Lee, S. Lee, “Coexistence of ZigBee-based WBAN and WiFi for health telemonitoring systems,” *IEEE Journal of Biomedical and Health Informatics*, Vol. 20, No. 1, pp. 222–230, Jan. 2016.

[8] F. Kuhn, R. Wattenhofer, “On the complexity of distributed graph coloring,” in Proc. of the Name of Conf. (Abbreviated Conf.), City of Conf., Abbrev. State (if given), year, pp. xxxxxx.

[9] L. Barenboim, M. Elkin, “Distributed ($\Delta + 1$)-coloring in linear (in Δ) time,” in Proc. of the 41st ACM Symposium on Theory of Computing (STOC), Washington, DC, 2009, pp. 111–120

[10] R. Kawano, T. Miyazaki, “Effective sensing function allocation using a distributed graph coloring and a slot allocation algorithm in wireless sensor networks,” in Proc. of the IEEE International Conference on Advanced Information Networking and Applications (AINA), Bradford, UK, 2009, pp. 906–913.

[11] L. Paradis, Q. Han, “TIGRA: Timely sensor data collection using distributed graph coloring,” in Proc. of Sixth annual IEEE International Conference on Pervasive Computing and Communications (PerCom), Hong Kong, 2008, pp. 264–268.

[12] S. H. Cheng, C. Y. Huang, “Coloring-based inter-WBAN scheduling for mobile wireless body area networks,” IEEE Transactions on Parallel and Distributed Systems, Vol. 24, Iss. 2, pp. 250–259, Feb. 2013.