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A Distributed Multi-Coloring Algorithm for Coexistence Problem in WBANs

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감사의 글

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2014년 마지막 날, 이 지은

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Abstract

A Distributed Multi-Coloring Algorithm for Coexistence Problem in WBANs

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A Wireless Body Area Network (WBAN) which consists of wireless sensors in/on/around human body requires high reliability for medical data. The coexistence problem which occurs when multiple-WBANs occupy the same channel at the same time declines the performance of the network. It is an important issue because this problem causes the collision of data among WBANs. For that reason, the IEEE 802.15.6 which was established for WBAN standardization defined guidelines to solve this problem, but these guidelines did not provide the detailed methods. To solve this problem, there are also a few related works by using graph coloring algorithm as a general theory to assign limited resources but they cannot satisfy the requirements of WBAN. In this paper, we propose a distributed multi-coloring algorithm to mitigate coexistence problems among WBANs. The proposed algorithm shows short transmission-cycle per WBAN through multiple coloring with a color sequence and the efficiency of the proposed scheme is verified by the simulation results which outperform existing works in multiple WBANs environment.

Key words

Wireless body area network, Coexistence problem, Graph coloring, Spatial utilization, Scheduling

1 Introduction

Recently, Wireless Body Area Network (WBAN) has attracted a lot of attention which is rapidly becoming an aging society [1]. WBAN is one kind of wireless sensor networks that consists of tiny wireless devices which exist in/on/around a human body. It provides both medical and entertainment services. To establish the standardization for WBANs, the IEEE 802.15 Tasking Group 6 was formed in 2007 and finished the standardization in 2011 [2].

In multiple WBAN environment, the performance of WBANs decreases when they use the same channel at the same time with the limited bandwidth, referred to as the coexistence problem. Hence, the coexistence problems are likely to occur in densely-populated area such as a hospital, welfare facilities for the aged, a subway station, and etc. This problem causes frequently data loss and also reduces channel efficiency. To solve this problem, the IEEE 802.15.6 standard classifies the mobility levels in coexistence environment as three states: static, semi-dynamic and dynamic. In addition, it also provides coexistence guidelines for WBAN such as Beacon Shifting, Channel Hopping and Active-Superframe Interleaving. Beacon Shifting and Channel Hopping are used for the semi-dynamic and dynamic states of WBANs. On the other hand, Active-Superframe Interleaving is used for the static state.

In this paper, we focus on the Active-Superframe Interleaving as one of the guidelines for the static state. This mechanism alternates Active period and Inactive period of superframe between multi-WBANs with the negotiating transmission time among their coordinators. It provides efficient resource allocation by using negotiating between coordinators. However, the detailed protocols are not provided in the standard.

A solution of a limited resource allocation has been widely studied for a long time. One of well-known theories in this study area is vertex coloring which is one of kind of graph coloring by coloring vertex with the rule such that no adjacent vertices share same color. This coloring is useful for assigning a limited resource.

There are some studies to allocate shared resource efficiently by using vertex coloring algorithm in Wireless Sensor Network (WSN) environment [3], [4]. In these works, they can allocate time-order to sensors to avoid data collisions and to reduce the power consumption. However, they are not suitable for WBAN environments because WBANs have their own characteristics such as a different sensor density, data latency, inter-mobility and various transmission-cycles unlike WSNs [1].

To overcome coexistence problems in WBAN environments, Random Incomplete Coloring (RIC) was proposed. This scheme relaxes the coloring rule by using uncolored node to improve spatial-reuse with a few number of colors used [5]. However, this algorithm is not suitable for the static state because it repeatedly performs the coloring algorithm for every superframe and consequently has a large overhead in the network. In addition, this scheme has low spatial utilization because they do not assign multi-colors to WBANs in a coloring cycle, although they have available colors which do not interfere with each other. Therefore, how to handle these reusable colors with low overhead of exchanging messages is very important to achieve high performance of network.

This paper proposes a distributed multi-coloring algorithm to promote spatial utilization. The proposed algorithm consists of initial coloring algorithm and multi-coloring algorithm. In initial coloring algorithm, the 2-hops discovery process is performed to gather two-hop neighbor information, and all WBANs have their initial color using random coloring algorithm with their priority. After initial coloring algorithm phase, multi-coloring algorithm makes color sequences which mean the color ordering list of available colors based on initial color. As a result, each WBAN has multi-colors and the proposed algorithm improves spatial utilization.

The rest of this paper is organized as follows: Section 2 provides background and discusses related work. The distributed multi-coloring algorithm for solving the coexistence problems is proposed in Section 3. Section 4 shows the performance evaluation of the proposed algorithm. Finally, Section 5 concludes this paper and discusses the future work.

2 Background and Related work

2.1 Graph coloring

Graph coloring is one of well-known general graph theory. It is one of graph labeling which means allocating color to graph with certain constraints. There are some coloring methods under a given constraint; e.g. vertex coloring which means that two adjacent vertices of a graph have not the same color, edge coloring which means that two adjacent edges of a graph have not the same color and etc. In other words, graph coloring algorithm is used for conflict resolution with the limited resources [6]. Graph coloring consists of a graph $G = (V, E)$ with vertex set V and edge set E. A coloring is a map $F: V \rightarrow N$, which means adjacent vertices have distinct colors in N; $F(u) \neq F(v)$ where if u, $v \in V$ with chromatic number $X(G)$ required minimum number in graph.

Vertex coloring algorithm which is known as typical graph coloring has been researched for a long time. A well-known distributed vertex coloring algorithm is used with fixed $\Delta + 1$ colors in a distributed manner [7]. This algorithm is repeatedly operated based on random selection until the interference between adjacent vertices does not occur. Due to the possibility of simply applying to various applications, it is actively used in many research fields such as scheduling and resource allocation problems dealing with a limited resource to avoid conflict and register allocation to optimize the compiler of computer program.

2.2 Related work

The coloring algorithm is more commonly used for the resource allocation in the WSN and WBAN environments. There are numbers of studies on coloring algorithm to allocate shared resource efficiently.

In WSN environments, many sensor nodes to get the sensing data is scattered in the target monitoring area and the sensed data is then transmitted to a base station(BS) to observe the target monitoring. These sensor nodes decide their own sensing task to obtain environmental information by using negotiation with the neighboring sensor nodes. Ryouhei et al. proposed a sensing function allocation method by using graph coloring algorithm [3]. The proposed method allocates different time slot to each sensor node by coloring with probability of color change. However, to change color causes a large overhead of network in the environment to require many colors. Paradis et al. proposed Timely sensor data collection using distributed graph coloring (TIGRA) [4]. In TIGRA algorithm, a parent node allocates a color to a child node in a tree topology to receive data by using graph coloring algorithm. Consequently, they cause a conflict when non-related pairs of nodes have the same color. Therefore, it is not suitable to WBAN environments. Cheng et al. presented improved coloring algorithm for WBAN environment [5]. They proposed Random Incomplete Coloring (RIC) algorithm to realize quick and high spatial reuse. The proposed algorithm consists of proposed random-value coloring and incomplete coloring. Firstly, random-value coloring adopts a random value comparison to generate instant priority between all adjacent vertices. Secondly, they are allowed to be uncolored when only $k < X(G)$ colors are used. Uncolored vertices imply that there is no transmission among wireless nodes. If a node selects the same color with neighbor node, they compare their random values and the node which has the higher value will obtain the coloring chance. If a node is not colored until a coloring cycle is done, it is uncolored node. However, this algorithm is efficient only when the given number of colors area is small. Moreover, this algorithm has also high complexity because they repeatedly perform coloring algorithm for every superframe in each coloring cycle.

3 Proposed Coloring Algorithm

As mentioned earlier, existing works are unacceptable to WBANs in the static state because they have high complexity due to a large exchanging messages overhead. In addition, they generally provide low spatial utilization. To solve these problems, we propose a distributed multi-coloring algorithm. Above all, to perform the proposed algorithm, we assumed that the number of $k \geq \Delta$ (Δ means maximum degree of a graph) is a known to all WBANs and the size of color palette which means color set is k. In addition, a color is expressed as integer number that starts from one. Lastly, the period per color is superframe period with synchronization. The proposed algorithm consists of the initial coloring phase and the multi-coloring phase. In the initial coloring phase, a WBAN assign an initial color to all WBANs by using random coloring selection with a priority of the WBAN and gathers 2-hops neighbor information. After the initial coloring phase, a WBAN schedules the color sequence based on the initial color and available colors in the multi-coloring phase. The detailed operations of the initial coloring phase and the multi-coloring phase will describe in the following subsections.

3.1 Initial Coloring phase

In this phase, a WBAN firstly can calculate a priority of a WBAN using Table 1 [2] and Table 2. The IEEE 802.15.6 standard classifies traffic type and priority as shown Table 1. We defined traffic volume priority which means traffic volume per a second as shown Table 2. We defined that a network has n WBANs. We also defined that w_n (A priority of WBAN), $p1_m$(Traffic type priority) as shown in Table 1, and $p2_m$(Traffic volume priority) as shown in Table 2. Based on these values, a WBAN can calculate a priority of a WBAN as follow:

$$w_n = \frac{(p1_n + p2_n)}{2} \tag{1}$$

Secondly, each WBAN randomly selects a color in color palette and compares their colors and priorities with neighbors. If they choose the same color, the WBAN which has higher priority wins and then will be colored. When they have the same priority, they will select a random integer value in range (1,100). The WBAN who has the higher integer value obtains the color. If the selected random values are equal, the random value range is performed with a doubled size of the range and repeat this process until the random value is different. This prevents infinite contention to obtain color using different priority. Lastly, a WBAN gathers 2-hops neighbor information. Each WBAN broadcasts own information and then broadcasts the received information again. Then, each WBAN knows their 2-hops neighbor information. All WBANs will be colored through the repeated process and have initial color respectively.

Table 1. Traffic Type Priority Level

Degree	Traffic Type Priority	Traffic Type
Low	0	Background (BK)
↓	1	Best Effort (BE)
	2	Excellent Effort (EE)
	3	Control Load (CL)
	4	Video (VI)
	5	Voice (VO)
High	6	Medical data/Network Control
	7	Emergency/Medical Event Report

Table 2. Traffic Volume Priority Level

Degree	Traffic Volume Priority	Traffic Volume/second
Low	0	0-50 kb
↓	1	51-100 kb
	2	101-150 kb
	3	151-200 kb
High	4	201-250 kb

3.2 Multi-Coloring phase

To improve spatial utilization, we proposed multi-coloring algorithm to allocate colors several times. The proposed multi-coloring uses a color sequence of a WBAN with the information from initial coloring phase. The color sequence means that each WBAN can use a unique color list, as illustrated at Step 10 of Fig. 1. To make the color sequence, a WBAN calculates maximum overlapped degree (O_n) which indicates the overlapped neighbor number between 1-hop and 2-hops neighbor information of a WBAN. If the difference of initial color number between neighbors with same O_n is equal to their O_n, the WBANs have to reselect other initial color. Finally, Each WBAN makes own color sequence through multi-coloring algorithm as Fig. 1.

Given G with 11 vertices in Fig. 2 can be fully colored by initial coloring phase when k is defined as 4. Then vertices can allocate multi-colors based on their color sequence which depends on the number of k. Table. 3 shows an example of the multi-coloring within network topology in Fig. 2. To simply check the performance of the proposed scheme, we logically perform incomplete, complete, and proposed multi-coloring scheme, and the results are shown in Fig. 3 and Fig. 4. In detail, the results of both incomplete and complete coloring also show that they allocate only once a color in a coloring cycle. On the other hand, the proposed scheme shows higher utilization than both incomplete and complete coloring scheme because the proposed scheme allocates multiple colors by using color sequence.

```
Proposed Multi-Coloring Algorithm
k ← Defined # of color; O_n ← Overlapped degree
C_n ← Color of node; c ← Initial integer of color
value ← For calculating value; n, α ← Count value
Seq ← Sequence of node

C_n=c
n=α=0
i=0
WHILE i<k DO
    value = c + (n*O_n)
    Add 1 to n
    IF(!(k*α < value ≤ k*(α+1)))THEN
      Add 1 to α
    ENDIF
    Seq[i] = value−(k*α)
    Add 1 to i
 ENDWHILE
```

Figure 1. Pseudo code for Multi-Coloring

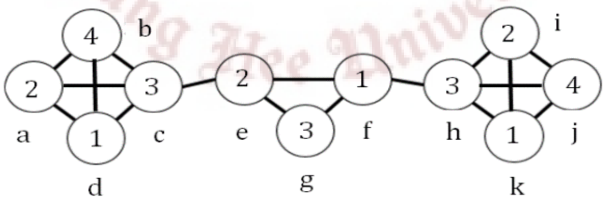

Figure 2. An example of distributed multi-coloring

Table 3. A color sequence of Fig. 2

# of WBAN(vertex)	Sequence	
	k = 4	**k = 5**
1	3 - 3 - 3 - 3	3 - 2 - 1 - 5 - 4
2	2 - 2 - 2 - 2	2 - 1 - 5 - 4 - 3
3	4 - 4 - 4 - 4	4 - 3 - 2 - 1 - 5
4	1 - 1 - 1 - 1	1 - 5 - 4 - 3 - 2
5	3 - 2 - 1 - 4	3 - 1 - 4 - 5 - 2
6	1 - 4 - 3 - 2	1 - 4 - 2 - 5 - 3
7	2 - 1 - 4 - 3	2 - 5 - 3 - 1 - 4
8	2 - 2 - 2 - 2	2 - 1 - 5 - 4 - 3
9	3 - 3 - 3 - 3	3 - 2 - 1 - 5 - 4
10	4 - 4 - 4 - 4	4 - 3 - 2 - 1 - 5
11	1 - 1 - 1 - 1	1 - 5 - 4 - 3 – 2

R	G	B	Y	R	G	B	Y	R	G	B	Y	R	G	B	Y	R	G	B	Y
4	2	1	3	4	2	1	3	4	2	1	3	4	2	1	3	4	2	1	3
6	7	5	6	7	5	6	7	5	6	7		6	7	5	6	7	5	6	7
11	8	9	10	11	8	9	10	11		9	10	11	8	9	10	11	8	9	10

(a) Proposed coloring

R	G	B	Y	R	G	B	Y	R	G	B	Y	R	G	B	Y	R	G	B	Y
4	2	1	3	4	2	1	3	4	2	1	3	4	2	1	3	4	2	1	3
6	7	5		6	7	5		6	7	5		6	7	5		6	7	5	
11	8	9	10	11	8	9	10	11	8	9	10	11	8	9	10	11	8	9	10

(b) Complete coloring

R	G	B	Y	R	G	B	Y	R	G	B	Y	R	G	B	Y	R	G	B	Y
4	2	1	3	4	2	1	3	4	2	1	3	4	2	1	3	4	2	1	3
6	7	5		6	7	5		6	7	5		6	7	5		6	7	5	
11	8	9	10	11	8	9	10	11	8	9	10	11	8	9	10	11	8	9	10

(c) Incomplete coloring

Figure 3. Comparison (k = 4)

R	G	B	Y	W	R	G	B	Y	W	R	G	B	Y	W	R	G	B	Y	W
4	2	1	3	4	2	1	3	4	2	1	3	4	2	1	3	4	2	1	3
6	7	5	6	7	5	6	7	5	6	7		6	7	5	6	7	5	6	7
11	8	9	10	11	8	9	10	11		9	10	11	8	9	10	11	8	9	10

(a) Proposed coloring

R	G	B	Y	W	R	G	B	Y	W	R	G	B	Y	W	R	G	B	Y	W
4	2	1	3		4	2	1	3		4	2	1	3		4	2	1	3	
6	7	5			6	7	5			6	7	5			6	7	5		
	8	9	10	11		8	9	10	11		8	9	10	11		8	9	10	11

(b) Complete coloring

R	G	B	Y	W	R	G	B	Y	W	R	G	B	Y	W	R	G	B	Y	W
4	2	1	3		4	2	1	3		4	2	1	3		4	2	1	3	
6	7	5			6	7	5			6	7	5			6	7	5		
	8	9	10	11		8	9	10	11		8	9	10	11		8	9	10	11

(c) Incomplete coloring

Figure 4. Comparison (k = 5)

4 Performance Evaluation

In this section, we evaluate the performance of the proposed algorithm through simulation. Results obtained from simulation compared with complete coloring [8] and incomplete coloring [5].

4.1 Simulation Model

To develop simulatation, we define that 10 and 20 WBANs are randomly deployed in simulated area $20 \times 20\,m^2$ fields, and the transmission range of the coordinator is set to 3m. In addition, MAC communication assumes idle state and WBANs have not mobility.

4.2 Simulation Result

Based on simulation model, we simulate each scheme when k is set to 4 to 8, and the results are shown in Fig. 5 and Fig. 6 in terms of transmission-cycle and vertex-per-color elements. In addition, Fig. 7 shows simulation results in terms of cumulative exchanging messages which indicate the complexity of algorithms.

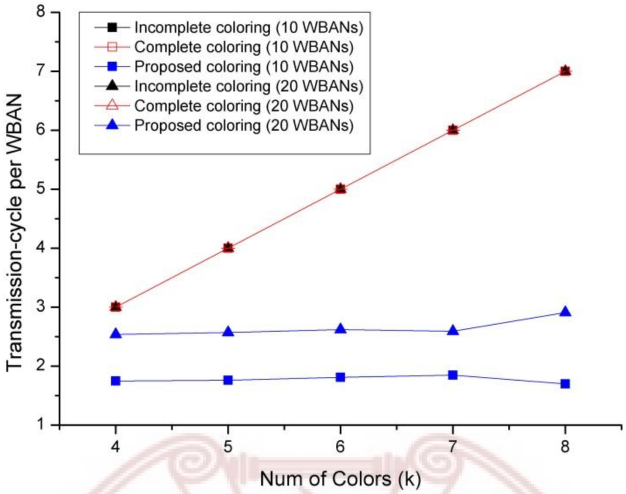

Figure 5. Simulation result for transmission-cycle

Fig. 5 presents the transmission-cycle which means average waiting time for next superframe of WBANs. When k increased linearly, the transmission-cycle of WBANs which scheduled by incomplete coloring and complete coloring also linearly increases because they do not allocate the multi-colors to a WBAN although they have available colors. In Fig. 3 and Fig. 4, in detail, the results of both incomplete and complete coloring also show the same results and these schemes allocate only once a color in a coloring cycle. On the other hand, the transmission-cycle of WBANs which scheduled by the proposed algorithm considering with available colors consistently shows about 1.7 time slot when deployed 10 WBANs. In addition, the proposed scheme maintains about 2.5 time slots when deployed 20 WBANs. In other words, the proposed scheme relatively maintains the short transmission-cycle although k increases.

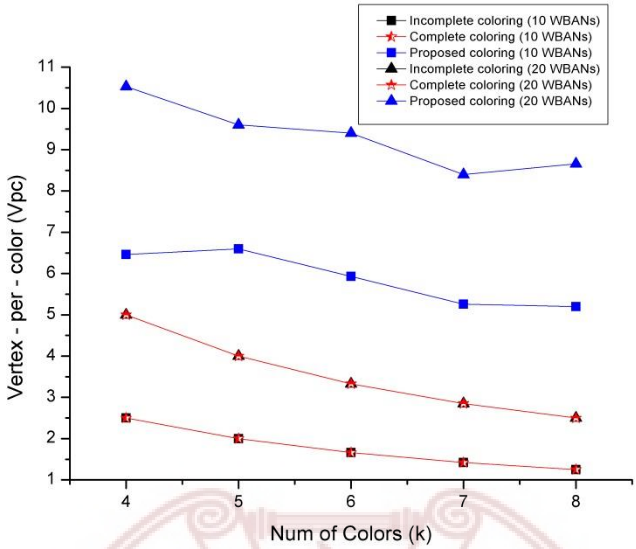

Figure 6. Simulation result for vertex-per-color

Fig. 6 presents vertex-per-color (V_{pc}) which indicates the number of WBANs per a color. In Fig. 6, V_{pc} of incomplete coloring and complete coloring dramatically decreased when k increases because they do not use available colors. On the other hand, V_{pc} of the proposed coloring on average has 5.89 values when deployed 10 WBANs because the proposed scheme uses a color sequence which can allocate multi-colors to a WBAN. Also, V_{pc} of this scheme shows remarkably high values about 9.31 when deployed 20 WBANs.

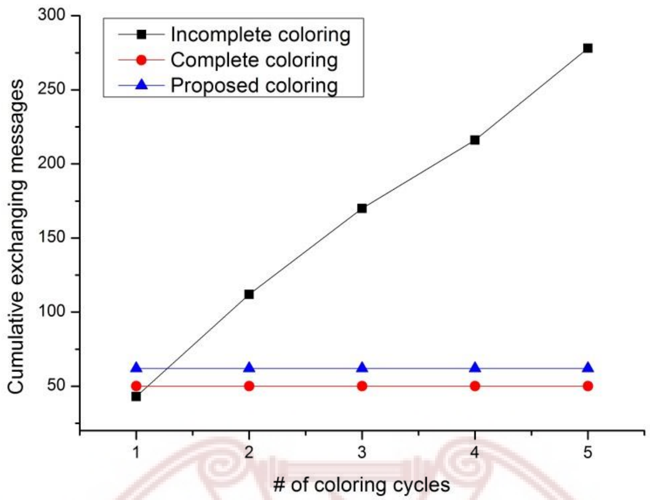

Figure 7. Simulation result for cumulative exchanging messages

Lastly, Fig. 7 shows cumulative exchanging messages during 5 coloring cycles. Incomplete coloring linearly increases cumulative exchanging messages as time passes because this scheme repeatedly performs coloring algorithm for every superframe in each coloring cycle. On the other hand, both complete coloring and proposed coloring maintains constant values because they only perform their coloring algorithm in the initial stages. Consequentially, the proposed coloring algorithm has low complexity besides high performance.

In summary, both incomplete and complete coloring schemes cannot provide short transmission-cycle and high V_{pc} when k increases more than Δ due to the fact that they do not take advantage of available colors in their scheduling. Contrastively, the proposed scheme schedules more colors per WBAN than other schemes and can provide high spatial utilization.

5 Conclusion

In multiple WBAN environments, the coexistence problem can occur and it causes huge degradation of network performance. To solve this problem, there are a few related works by using coloring algorithm. However, these works are not suitable for a WBAN environment due to their low spatial utilization and high complexity. To improve network performance in multiple WBAN environments, we proposed a distributed coloring algorithm which consists of initial coloring algorithm and multi-coloring algorithm. The proposed scheme provides a high spatial utilization by using a color sequence which is scheduled based on the initial color and available colors. To evaluate performance of the proposed scheme, we showed simulation results considering with incomplete and complete coloring algorithms, and we can verify efficiency of the proposed scheme in terms of transmission-cycle, vertex-per-color, and the number of exchanging messages elements. In our future work, we will try to perform without the fixed number of color, and reduce the overhead. In addition, we also will implement a simulation in various scenarios.

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