Thesis for the Degree of Master of Science

A Static Bayesian Game Modeling for QoS Support in Overlapped WBAN Environment

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Advised by

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Submitted to the Department of Computer Engineering
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Abstract

As the next wireless communication networking is developing vigorously, Wireless Body Area Networks (WBANs) will take the leading position in the futures communication with service like medical supporting, health monitoring, and entertaining service. In generally, WBAN are located in some dense environments such as hospital and senior center, hence coexistence problem will occurred as a key challenge. In is paper, we focus on the coexistence problem where when geographically co-located WBANs share in contention free period in the overlapped WBAN environment. We figure out problems by introducing incomplete information game which is famous as static Bayesian game. We develop a Bayesian game model through assuming each WBANs as players in the game, they all attempt to choose a suitable strategy which benefited by incomplete information of other players. We defined a utility function for QoS (quality of service) in overlapped WBAN environment and analyze player's utilities related with QoS parameters. And we observe the change of resulting utilities according to a traffic priority classification in overlapped WBAN environment Based on defined utility function for QoS support with QoS parameters. We analyze suitable strategy selection for each WBAN in the game, and satisfy the basic data traffic QoS requirement with low influence between WBANs.

Thesis Supervisor: Jinsung Cho
Title: Professor

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Chapter 1

Introduction

Current health care systems are facing new challenges due to the rate of growth of the elderly population. In particular, u-healthcare/u-lifecare services are faced with new and evolving user requirements, such as customized healthcare. To support this demand, IEEE 802.15.6 WG provides the standardization of Wireless Body Area Networks (WBANs) [1]. A WBAN consists of a set of communicating devices, or nodes, which are located inside, on or around human body. For medical applications, these devices have sensors that monitor vital signs and body movements. In addition, a single hub controls communications within a WBAN. WBANs have been considered not only for medical and healthcare applications but also for sports and entertainment applications.

The IEEE 802.15.6 standard supports low complexity, low cost, ultra-low power, and highly reliable wireless communication for use in close proximity to or inside a human body (but this is not limited to just to humans) to satisfy a new set of entertainment and healthcare products and services. The standard defines a sophisticated Medium Access Control (MAC) protocol that mediates access to the channel. An allocated transmission period for devices that compose a WBAN are divided into two parts; contention and contention free periods. In contention free periods, reliable data transmission is guaranteed.

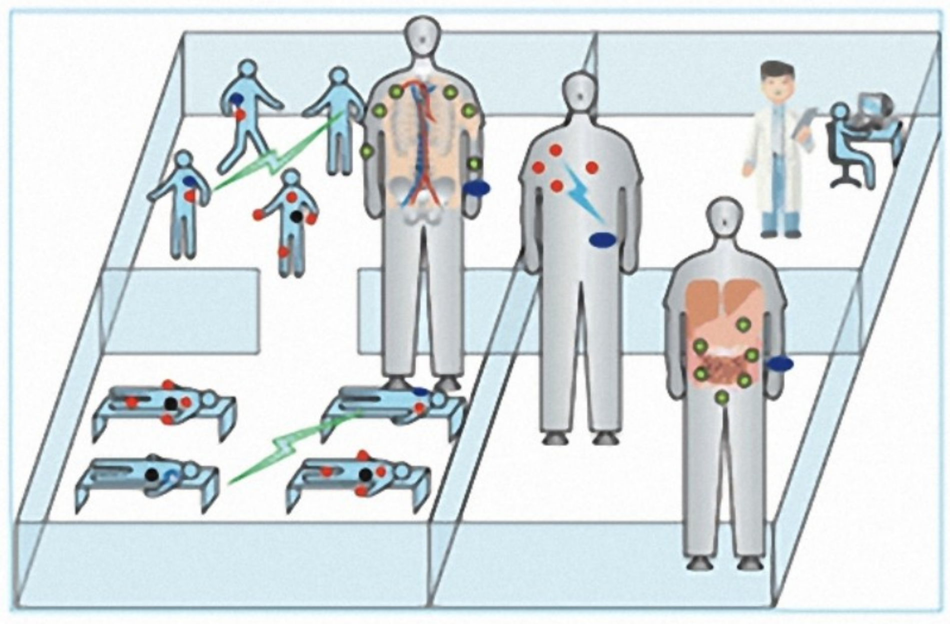
The superframe is made up by this period, and contention period utilizes DCF to transmit data.

The requirements of IEEE 802.15.6 standard include an operating range of 3 m and up to 10 co-located networks (called piconets) each with up to 256 nodes, within 216 m^3 [2]. In a dense WBAN environment, such as a hospital or a senior center, the coexistence problem exists among multiple adjacent piconets. Fig.1-1 illustrates the coexistence problem in an overlapped WBAN environment for a simple scenario with two WBANs sharing the same channel.

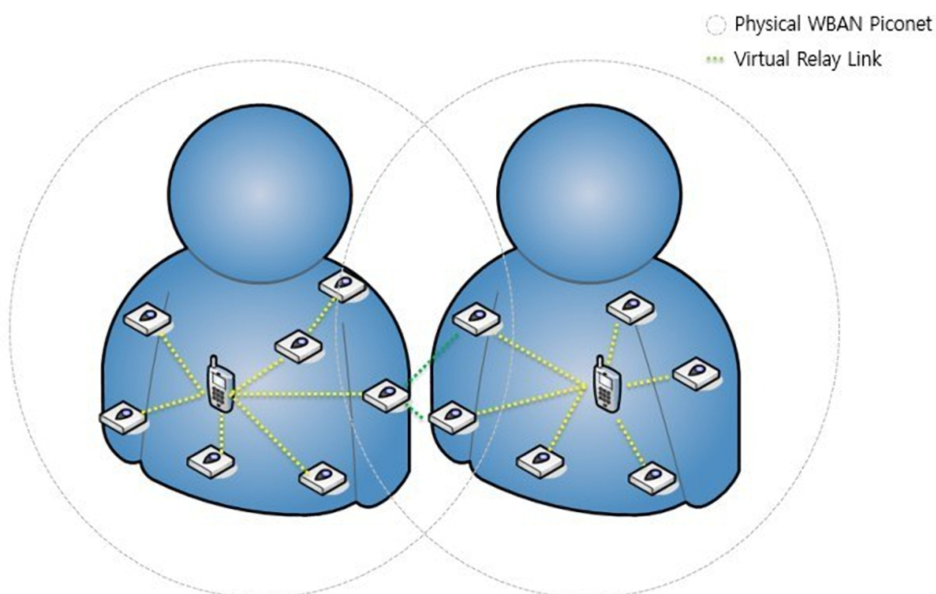
In this overlapped WBAN environment, collisions can occur between adjacent W-BANs during the contention free periods. Transmission failures of important physical and medical data caused by the coexistence problem may have a critical effect on us-er's life. Therefore, a transmission period in an overlapped WBAN environment should be efficiently and fairly allocated to ensure reliable communication within each WBAN. Such coexistence scenarios are not addressed in the IEEE 802.15.6 standard in providing support for Quality of Service (QoS).

Therefore, this paper focuses on fair channel allocation for geographically co-located WBANs that share the same radio channel. This problem is addressed by introducing game theory. Game theory is a mathematical method used to analyze calculated circumstances where a person's success is based upon the choices of others. Some applications of game theory include economics, politics, science, and military strategy, and most recently, the computer science and engineering field [3], especially in the wireless network area.

Our previous work [4] already showed the effectiveness of using game theory to solve coexistence problem. However, it still suffers from some limitations in real life environment as the information of each player's strategy couldn't be shared easily. In this paper,



(a) WBANs in dense environment



(b) Overlapped WBANs

Figure 1-1: The coexistence problem in overlapped WBAN environment as an enhancement of our previous research, for solving coexistence problem in geographically co-located overlapped environment, we utilize a Bayesian game solution [5]. This game solution focuses on a more realistic environment by consider private information prediction of each player.

The structure of the paper is as follows: Section 2 introduces the IEEE 802.15.6 MAC protocol and basic concept of game theory as background. Section 3 introduces static Bayesian game and some related works for the coexistence problem of other network environment. The proposed model for the coexistence problem in overlapped WBAN environment is described in Section 4. In Section 5 we do the utility analysis for our proposed modeling. Conclusion of this paper is described in Section 6.

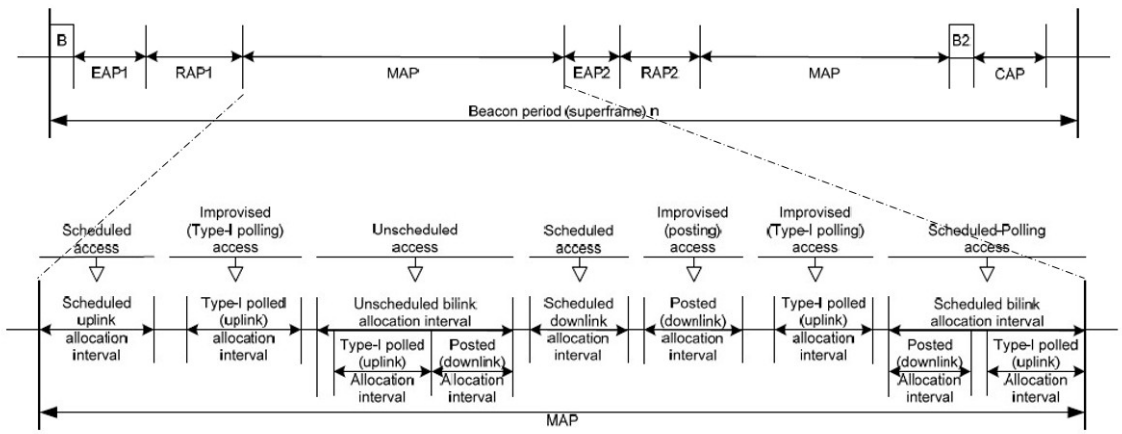
Chapter 2

Background

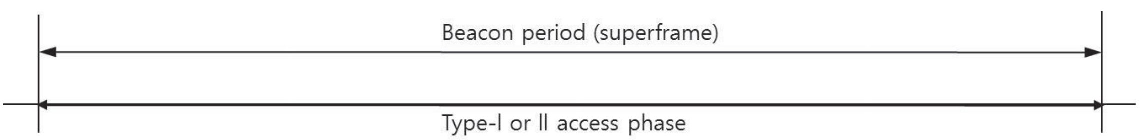
2.1 IEEE 802.15.6 MAC protocol

The IEEE 802.15.6 MAC protocol offers the contention free period to guarantee reliable transmissions for physical and medical data. Fig.2-1 shows the timing of MAC for IEEE 802.15.6, which operates using three access modes.

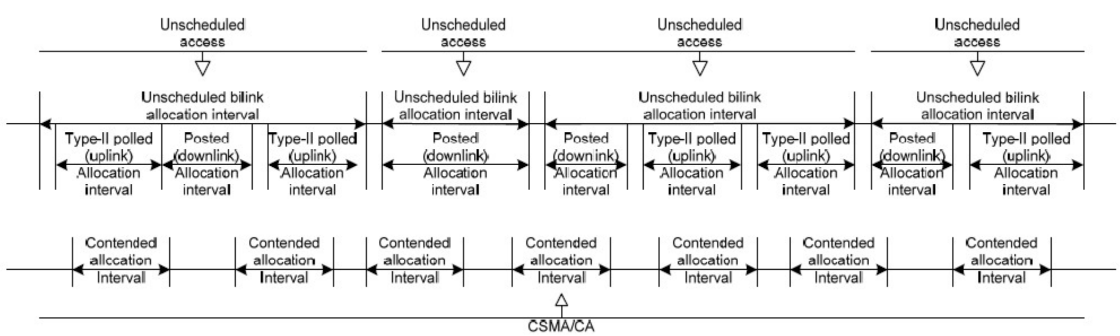
In beacon mode with superframe boundaries (see Fig.2-1(a)), the hub transmits a beacon (B) during each beacon period except during an inactive superframe, here one superframe can be referred to one beacon frame. Each superframe is divided into Exclusive Access Phase 1 (EAP1), Random Access Phase 1 (RAP1), Type I/II Access Phase 1, Exclusive Access Phase 2 (EAP2), Random Access Phase 2 (RAP2), Type I/II Access Phase 2, and Contention Access Phase (CAP). For EAPs, RAPs, and CAP, nodes con-tend for the channel using either Carrier Sense Medium Access with Collision Avoidance (CSMA/CA) or slotted ALOHA access procedure. EAP1 and EAP2 are used for the highest priority traffic, such as reporting emergency events, while RAP1, RAP2, and CAP are used for regular traffic. Type I/II Access Phases are used for uplink allocation interval,



(a) Beacon with superframe boundaries



(b) Non-beacon with superframe boundaries



(c) Non-beacon mode without superframe boundaries

Figure 2-1: IEEE 802.15.6 MAC access modes down link allocation intervals, and bi-link allocation intervals. These intervals mean the length of each allocated duration for uplink, down link and bi-link. In these phases, scheduled access and polling access are used for resource allocation.

In non-beacon mode with superframe boundaries (see Fig.2-1(b)), the entire superframe duration is covered by either a type I or a type II access phase, but not both phases. In non-beacon mode without superframe boundaries (see Fig.2-1(c)), a hub may provide unscheduled bi-link allocation intervals comprising to type II polled allocations and/or posted allocation.

During the contention access period that includes EAP1/2, RAP1/2, and CAP, physical and medical data have high priority than other traffic data. Thus, they have better chances to acquire the transmission period through contention even in an overlapped W-BAN environment.

As mentioned before in introduction section, WBAN is a network which consists of multiple devices with diversity allocated out/in human body, and support multipurpose communication services (i.e., medical or Consumer Electronics devices). therefore W-BAN MAC protocol should support flexibility between multiple devices or applications. In order to provide the flexibility, MAC protocol should satisfies some requirement [6] as below:

- The BAN should be able to recover from link and node failures.
- Typical link data rate should be some tens of kb/s in most of the cases. However, raw data rate up to 10 Mbps is expected in some applications, and low data rate of 10kbps should be supported in some medical applications.
- The power consumption shall allow for self-powered operating time without intervention from several hours to several years, depending on applications.

- The reliable QoS support shall be provided.
- Security shall be energy efficient with minimal overhead and support at least authentication, data integrity and encryption operations when needed.
- Coexistence between BANs, coexistence between BAN and other wireless technologies, and coexistence of BAN in medical environments (EMC/EMI) shall be addressed.

Our research focuses on solving coexistence problems between WBANs by utilizing a economic tool which is well known as game theory. When two WBANs coexisted in dense environment, they should reallocate allocation intervals of contention free period in limited transmission duration. Under a Bayesian game method, each WBAN can get reasonable interval allocation with lowest influence between each other, and also can guarantee the basic requirement for their data traffics.

2.2 Game Theory

A game theory technique, which is an efficient tool for resource allocation, can be applied to the coexistence problem. Game theory has been employed in analysis of resource management in telecommunication networks for 20 years. It is a branch of mathematic that research the theory and methodology of modeling a competitive phenomenon. It considers the forecasting behavior and actual behavior for each player in a game, and investigates their optimization strategy. In other words, game theory can model a multi-player decision making process and analyze how players interact with each other during the process. During the last years, game theory has been widely applied to networking. Usually, it is used to solve routing and resource allocation problems in a competitive environment. Recently, its application was introduced in wireless communications. Many wireless network related works utilize game theory to find an equilibrium in specific network environment so that can obtain a fair resource allocation, here equilibrium refers to balance which same as all related value are in steady state.

Chapter 3

Related Work

Most related work on the coexistence problem deal with various kinds of wireless networks, such as IEEE 802.15.4, IEEE 802.16, IEEE 802.15.1, etc., which coexist with IEEE 802.11 WLAN. Furthermore, they focus on the PHY-layer and propose radio channel allocation or power allocation methods to reduce channel interferences [7–9], including cognitive radio network of IEEE 802.22 [10]. As such, there only exist few proposals that deal with the coexistence problem in a WBAN environment. Francisco et al. present a coexistence study for WBAN and WLAN, which aims to evaluate the feasibility of W-BAN in realistic medical environment with emphasis on the PHY-layer interference [11]. Domenicali et al. discuss coexistence between two wireless networks and the WBAN performance is improved by the adoption of an optimized time hopping code assignment strategy [12]. However, they use one coding method on the basis of IEEE 802.15.4a s-tandard PHY-layer. The work closest to ours is by Elsawy et al., which is a method to increase the coexistence capability in IEEE 802.15.4 networks by scheduling superframe boundaries [13]. However, this is not an ultimate solution when contention free periods must be overlapped. Our paper focuses on fair and efficient contention free period allocation through a game theoretical model mathematical analysis applied to WBANs. Before our research there is no discussion about time-slot allocation in MAC-layer for the coexistence problem in overlapped WBAN environment. To the best of our knowledge, there is a latest work on MAC-layer solution for coexistence problem.

In order to solve coexistence problem we mentioned, we propose a static Bayesian game model for coexistence problem in overlapped WBAN environment. Static Bayesian game refers to incomplete information static game; it talks about that players in the game are not aware of complete information about opponent's payoff function. The normal formula of Bayesian game can be defined as below:

Definition 3.1. *[5]: the normal-form representation of an n-player static Bayesian game specifies the players i' action spaces* A_1,...,A_n*, their type spaces* T_1,...,T_n*, their beliefs* P_1,...,P_n*, and their payoff function* u_1,...u_n*. Player* i*'s type,* t_i*, which is privately known by player* i*, determines player* i*'s payoff function,* u_i(a_i,...,a_n;t_i)*, and is a member of the set of possible types,* T_i*. Player* i *i's belief* $P_i(t_{-i}|t_i)$ *describes* i*'s uncertainty about the* $n-1$ *other players i's possible types,* t_{-i}*, given* i*'s own type,* t_i*. We denote this game by:*

$$G = \{A_1, ..., A_n; T_1, ..., T_n; p_1, ...p_n; u_1, ..., u_n\} \quad (3.1)$$

Just as its name implies, this game is related to Bayesian probability theory. As a key concept in the Bayesian game, Bayesian rule [14] is used to take incomplete information into account. In order to process this game, we should reference a important concept which is called Harsanyi Transformation.

Incomplete information game can be expressed as imperfect information game: each player can predict that what type are opponents belonged to and also the probability distribution of each type.

$$t_i \in T_t, i = 1, ..., n,\ \ probability : P_t(t_{-i}|t_i)$$

In order to process this game, John Harsanyi(1967,1968) assumed that the type and probability distribution of opponents' payoff as been known. The essence of Harsanyi Transformation is doing the simplified process to the problem when the opponent's situation is unknown. this process is on the basis of Bayesian expression. Therefore, under the Harsanyi Transformation, incomplete information game can be called as Bayesian game and the equilibrium of it can be called as Bayesian Nash equilibrium.

The concrete method of Harsanyi transformation is as below:

- One virtual participant "Nature", first Nature will determine the type of participants, attach the type vector of every participants $t = (t_1, \cdots, t_n)$, in it, $t_i \in T_i, \quad i = 1, \cdots, n$.
- Nature will tell participant i it's own type, but didn't notice the type of other participants.
- All the participants will select action simultaneous, every participants i can select action strategy a_i form practicable set A_i.
- The payoff obtained by participants: $u_i(a_1, \cdots, a_n; t_i)$.

Harsanyi transformation is the standard method so solve incomplete information game.

For the Bayesian Nash equilibrium, the main idea of it is simple and easily to understand. every strategy of each participant is the optimal response for others.

Definition 3.2. *[5]: In the static Bayesian games*

$$G = \{A_1, \cdots, A_n; T_1, \cdots T_n; p_1, \cdots p_n; u_1, \cdots, u_n\}$$

, the strategy $s^* = (s_1^*, \cdots, s_n^*)$ area (pure-strategy) Bayesian Nash equilibrium if for each player i and for each of i's types t_i in T_i, i, $s_i^*(t_i)$ solves

$$\max_{a_i \in A_i} \sum_{t_{-i}} \{u_i[(s_1^*(t_1), \cdots, \ s_{i-1}^*(t_{i-1}), \ a_i, s_{i+1}^*(t_{i+1}) \ \cdots, s_n^*(t_n); t_i] p_i(t_{-i} \, | t_i)\}$$

that is no player wants to change his or her strategy, even if the change involves only one action by one type. Therefore, through finding a Bayesian Nash equilibrium, we can obtain a suitable strategy combination with best responses between players.

Chapter 4

Proposed Model

In the following, we discuss a modeling for coexistence problem based on static Bayesian game. This framework allows establishment of coexistence based on mutual support [15, 16].

4.1 Coexistence Model

The game is defined with a set of players that they select rational action to maximize their expected payoff. An action of a player is the selection of a certain way of resource allocation by a hub. Here, we assume that each hub be the players in the game. The game is called static game as each player doing action simultaneously or even they have sequence the back player isn't aware of the action of front player. At each game period, a player observes the demand and the action of its opponents together with consideration of its own payoff.

In the previous work [4], we have modeled coexistence problem by Cournot model which require complete information of both players. Unfortunately, in the real overlapped

WBAN environment, by considering the personal privacy or security issue, it's difficult to get complete information of other WBANs before game beginning. In this paper, we discuss the coexistence problem by a more comprehensive game model which is a typical example in static Bayesian game. Based on the assumption that we focus on overlapped environment with two WBANs, competing hubs of two piconet can be modeled as rational players attempting to maximize their payoffs within the Bayesian game modeling scheme. Payoff of each hubs are defined as measurable quantity related to QoS (i.e., throughput, delay, and priority), here data traffic priority is the incomplete information of participants. We defined it as private information (PI) of each player, and however, we predict the information about the probability of that what kind of priority can be taken by opponents. We divide the priority in high priority (PH) and low priority (PL), and through finding the priority critical value of each WABN based on Bayesian Nash equilibrium, we can get a priority classification to support most suitable strategy to get reliable payoff to each player in the game. Strategies in the game modeling is defined as delay payoff strategy and throughput payoff strategy, for the game modeling utilization in real-life WBAN environment, we assumed that when a player expect a delay payoff strategy, it means that the expected utility for throughput demand is lower. Strategies are dependent on the level of traffic priority, and priorities is mentioned as incomplete information, so they all can selfishly express that their priority is high. And in order to guarantee the most basic requirement of data traffic, some high priority traffic data such as ECG (Electrocardiograph) and EEG (electroencephalogram) demand lowest delay to ensure that traffic data can be processed in time. This kind of traffics can endure drawback of lower throughput. By the same way, for the low priority traffic data such as the background data, high throughput will be more necessary than low delay guarantee. It is the basic scenario we defined for the game modeling for real network environment.

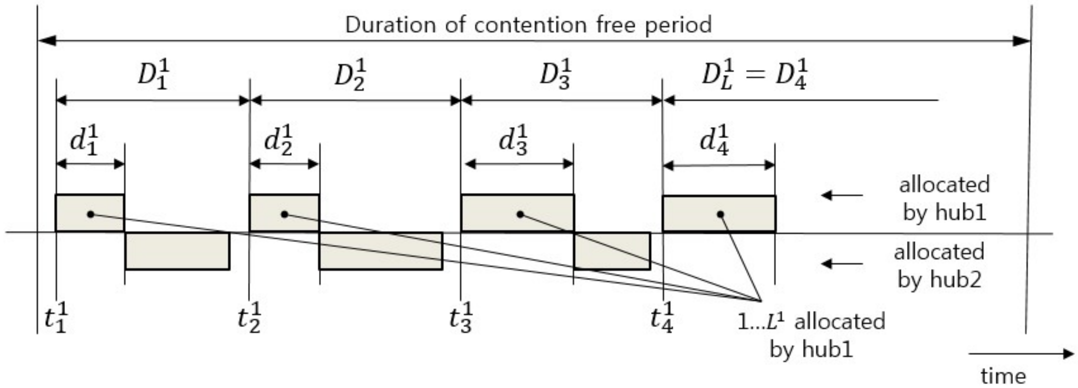


Figure 4-1: The proposed model as single static game with certain duration

Fig. 4-1 illustrates a contention free period that can be interpreted as a single static game for two players. A hub is modeled as a player. The utilization of the radio channel is attained through selected actions and determines the player's observed payoff. Suppose that the beacon is successfully transmitted by one of the competing hubs. L^i means the sequence and total number of allocated transmission duration in contention free period. As presented in Fig. 3, the L^1 which allocated by hub1 in contention free period is 4, and L^2 which allocated by hub2 is 3. D means the duration of allocated transmission duration which allocated to transmit traffic.

4.2 Bayesian Game Modeling

As stated above, the QoS parameters are given by throughput, delay, and traffic priority. A node's QoS demand is obtained from the traffic specifications of the streams that are currently being transmitted in the contention free period. We define the following three abstract and normalized representations of the QoS parameters; throughput Θ, delay Δ, and priority P.

Throughput Θ_i is defined as the shared capacity player i 's demands. $0 \leq \Theta_i \leq 1$

$$\Theta_i = \frac{1}{Dur} \sum_{l=1}^{L^i} d_l^i \tag{4.1}$$

Where L is the number of allocated transmission period for each transmission duration; Dur is the total duration of contention free period; d_l^i is the duration of allocated transmission period for player i. Delay is defined as Δ_i. $(0 \leq \Delta_i \leq 1)$. which represents the expected maximum delay between two allocated transmissions due to interrupting other hub's allocation.

$$\Delta_i = \frac{1}{Dur} \sum_{l=1}^{L^i-1} D_l^i \tag{4.2}$$

In Eq. 4.2, D_l^i is the duration between two allocated periods l and $l+1$ of player i.

Utility functions of each player are defined as below. Θ_{dem} and Δ_{dem} present the demanded factor in single WBAN, which is the transmission slots requested by each WBAN for data transmission. Then Θ_{req} and Δ_{req} represent the level of QoS that is required in overlapped WBANs environment. We can obtain the gained utility by using utility of throughput and delay as below, where traffic priority is not defined in the following utility function as priority is defined as private information of each WBAN which are unknown to other players.

$$\begin{aligned} u(\Theta) &= \tfrac{1}{2} + arctan\,[(\Theta_{dem} - \Theta_{req})] \ \times \tfrac{1}{\pi} \\ u(\Delta) &= 1 - \left(\tfrac{1}{2} + arctan\,[\,(\Delta_{dem} - \Delta_{req})] \ \times \tfrac{1}{\pi}\right) \end{aligned} \tag{4.3}$$

Depending on this game model, game form is defined in Table.4.1. There are two players, WBAN1 and WBAN2. Here, we don't consider the mixed strategy that they expect different action on the basis of the scenario we mentioned before. So we defined payoff (delay, throughput) and (throughput, delay) are (0, 0). It is suitable to accord with modeling. And if they all expect reliable delay strategy utility, the payoff of WBAN1 and WBAN2 is

$$\begin{aligned} &1 - \left(\tfrac{1}{2} + arctan\,[\,(\Delta_{dem} - \Delta_{req})] \ \times \tfrac{1}{\pi}\right) + \mathrm{t}_a \\ &1 - \left(\tfrac{1}{2} + arctan\,[\,(\Delta_{dem} - \Delta_{req})] \ \times \tfrac{1}{\pi}\right) + \mathrm{t}_b \end{aligned} \tag{4.4}$$

and for throughput strategy utility

$$\begin{aligned} &\tfrac{1}{2} + arctan\,[\,(\Theta_{dem} - \Theta_{req})] \ \times \tfrac{1}{\pi} + t_a \\ &\tfrac{1}{2} + arctan\,[\,(\Theta_{dem} - \Theta_{req})] \ \times \tfrac{1}{\pi} + t_b \end{aligned} \tag{4.5}$$

We define t_a and t_b as the private information of each player, which are mutually independent. For simple analysis, we assume that t_a and t_b are uniformly distributed in the priority range [0,7] which is defined in IEEE 802.15.6 shown in Table.4.2. We describe the normal form as a static Bayesian game:

$$G = \{A_a, A_b; T_a, T_b; p_a, p_b; u_a, u_b\} \tag{4.6}$$

Table 4.1: Static Bayesian game form for overlapped WBAN environment

		WBAN2	
		Delay	**Thoughput**
WBAN1	**Delay**	$1-\left(\frac{1}{2}+arctan\left[\,(\Delta_{dem}-\Delta_{req})\right]\ \times\ \frac{1}{\pi}\right)+\mathrm{t}_a$ $1-\left(\frac{1}{2}+arctan\left[\,(\Delta_{dem}-\Delta_{req})\right]\ \times\ \frac{1}{\pi}\right)+\mathrm{t}_b$	$0,0$
	Thoughput	$0,0$	$\frac{1}{2}+\arctan\left(\Theta_{dem}-\Theta_{req}\right)\times\frac{1}{\pi}+t_a$ $\frac{1}{2}+\arctan\left(\Theta_{dem}-\Theta_{req}\right)\times\frac{1}{\pi}+t_b$

The action space is A_a = A_b = (delay, throughput), the type space is $T_a = T_b \in [0, x]$, and both t_a and t_b are type inference. We construct the pure-strategy Bayesian Nash equilibrium of this model, under the assumption that the private information is not shared between players. Values of a and b are determined by prediction of opponent's behavior. When t_a exceeds a critical value, WBAN1 tends to delay utility function. Otherwise throughput utility function will be delayed. WBAN2 executes throughput utility function if t_b exceeds a critical value b and executes delay utility function otherwise.

According to above analysis, WBAN1 selects delay utility payoff with probability $\frac{8-a}{8}$, and selects throughput utility payoff with probability $\frac{a}{8}$. As well, WBAN2 selects delay function utility with probability $\frac{8-b}{8}$ and selects throughput function utility with probability $\frac{b}{8}$.

Next, we determine values of a and b in order to ensure that this strategy is a Bayesian Nash equilibrium. When WBAN2s strategy is given, WBAN1s expected payoffs (PF) for

Table 4.2: WBAN traffic priority

Priority	User Priority	Traffic designation
Lowest	0	Backgroung(BK)
	1	Best effort(BE)
	2	Excellent effort(EF)
	3	Video(VI)
	4	Voice(VO)
	5	Medical data or network control
	6	High-priority medical data or network control
Highest	7	Emergency or medical implant event report

playing delay and throughput are as follows:

$$PF_{de}^{1} = \frac{8-a}{8}\left[1-\left(\frac{1}{2}+\arctan\left(\Delta_{dem}-\Delta_{req}\right)\right)\ \times\ \frac{1}{\pi}+t_a\right]+0 \tag{4.7}$$

$$PF_{thr}^{1}{=}0+\frac{a}{8}\left[\frac{1}{2}+\arctan\left(\Theta_{dem}-\Theta_{req}\right)\ \times\ \frac{1}{\pi}+t_a\right] \tag{4.8}$$

According to above two formulas if and only if

$$t_a > \frac{1}{2a}\left[4+a+\frac{8-a}{\pi}\arctan\left(\Delta_{dem1}-\Delta_{req1}\right)+\frac{a}{\pi}\arctan\left(\Theta_{dem1}-\Theta_{req1}\right)\right]\ = \ b \tag{4.9}$$

,delay utility function is the optimal selection. By the same way, if the WBAN1s strategy is given, WBAN2s expected payoffs from playing delay function and throughput function are

$$PF_{de}^{2} = 0 + \frac{b}{8}\left[\frac{1}{2} + \arctan\left(\Theta_{dem} - \Theta_{req}\right) \ \times \ \frac{1}{\pi} + t_b\right] \tag{4.10}$$

and

$$PF_{thr}^{2} = \frac{8-b}{8}\left[1 - \left(\frac{1}{2} + \arctan\left(\Delta_{dem} - \Delta_{req}\right)\right) \ \times \ \frac{1}{\pi} + t_b\right] + 0 \tag{4.11}$$

Thus throughput utility function is the optimal selection when Eq.4.12 holds

$$t_b > \frac{1}{2b}\left[4 + b + \frac{8-b}{\pi}\arctan\left(\Delta_{dem2} - \Delta_{req2}\right) + \frac{a}{\pi}\arctan\left(\Theta_{dem2} - \Theta_{req2}\right)\right] \ = a \tag{4.12}$$

Finally, we can obtain the expected values of a and b through simultaneous equations as:

$$\begin{cases} \frac{1}{2a}\left[4 + a + \frac{8-a}{\pi}\arctan\left(\Delta_{dem1} - \Delta_{req1}\right) + \frac{a}{\pi}\arctan\left(\Theta_{dem1} - \Theta_{req1}\right)\right] = b \\ \frac{1}{2b}\left[4 + b + \frac{8-b}{\pi}\arctan\left(\Delta_{dem2} - \Delta_{req2}\right) + \frac{b}{\pi}\arctan\left(\Theta_{dem2} - \Theta_{req2}\right)\right] = a \end{cases} \tag{4.13}$$

In order to simplify above formulas, we defined as below:

$$\begin{aligned} p_1 &= \arctan\left(\Delta_{dem1} - \Delta_{req1}\right) \\ q_1 &= \arctan\left(\Theta_{dem1} - \Theta_{req1}\right) \\ p_2 &= \arctan\left(\Delta_{dem2} - \Delta_{req2}\right) \\ q_2 &= \arctan\left(\Theta_{dem2} - \Theta_{req2}\right) \end{aligned} \tag{4.14}$$

Chapter 5

Numerical analysis

Based on the functions we obtained in Section 3.2, we develop a numerical analysis to observe variations of a and b along with demanded utility's increment as shown in Figure.5-1. The demanded delay of each player is increased from 0 to 1. We assume that the priority of WBAN1 is higher than WBAN2, so WBAN1 requires more demands of delay utility. We set required parameters in the simulation and get the result of critical values a and b. We can find that the curved surface of a and b are closed in the range of [3, 6]. In the QoS requirement factor, the applications with high priority is sensitive to delay utility.

Figure.5-1 represents the game with two WBANs for delay utility competition. We can observe that in the situation where players don't know utility function of others, W-BAN1 always gets a lower critical value than WBAN2. Based on our previous assumption, it means that WBAN1 has higher probability to select delay utility function as its strategy than that of WBAN2.

Furthermore, for single WBAN, by considering its own demand of delay, it assumes that it is the worst strategy for itself when opponent wants to get optimal payoff. Then it selects suitable strategy based on determining the probability of opponent's strategy

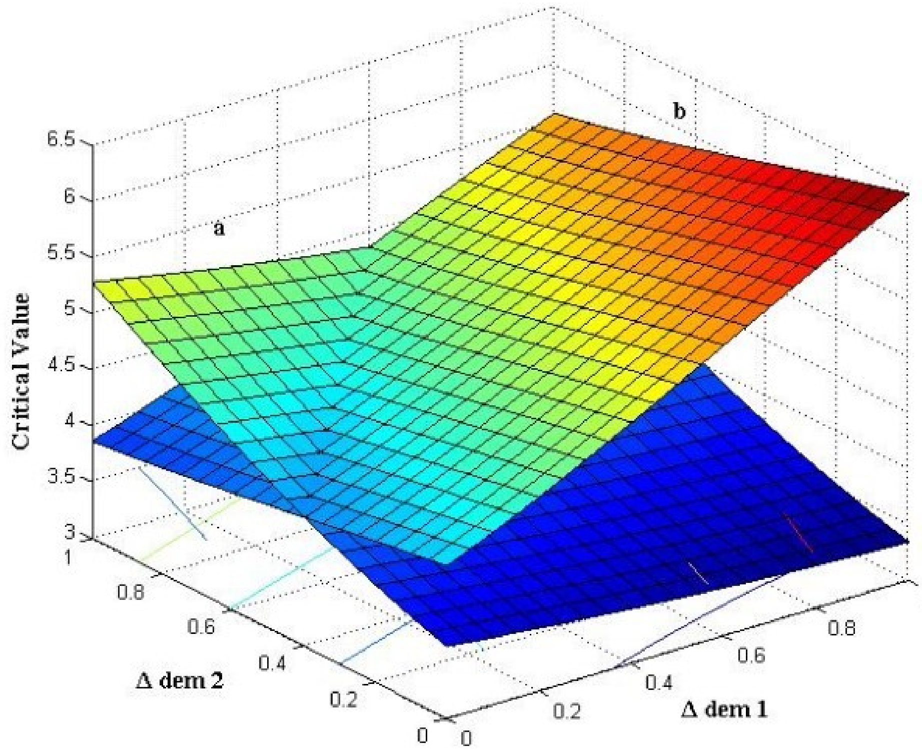
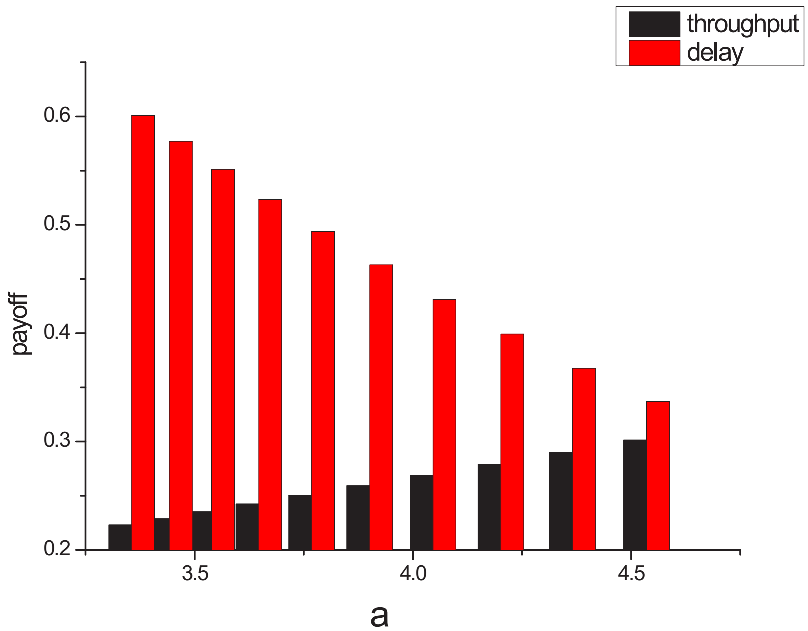


Figure 5-1: Analysis result of critical value on strategy selection

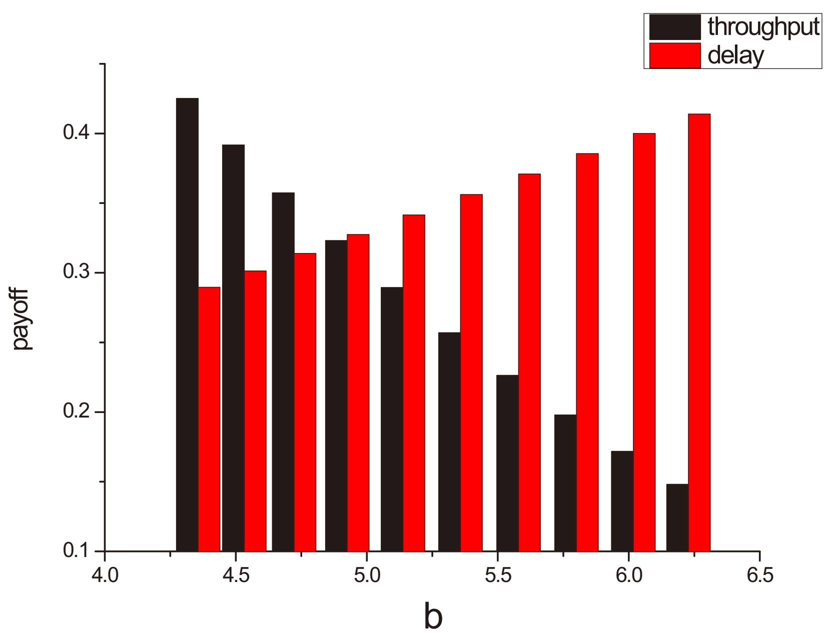
selection.

We also analyze the changes of throughput payoff and delay payoff on the basis of critical values for two WBANs. The result are shown in Figure.5-2. For two WBANs, we can see that when the value of a and b are close to 5, the payoffs of throughput and delay are relative fair. This conforms to the theoretical basis. As we mentioned before, the priority of WBAN1 is higher than WBAN2, thereby we can see that WBAN1 is more sensitive to delay payoff than WBAN2.

Figure.5-3 show the probability changing process of different strategy selection for WBAN1 and WBAN2. We can also observe that even the probability to select delay

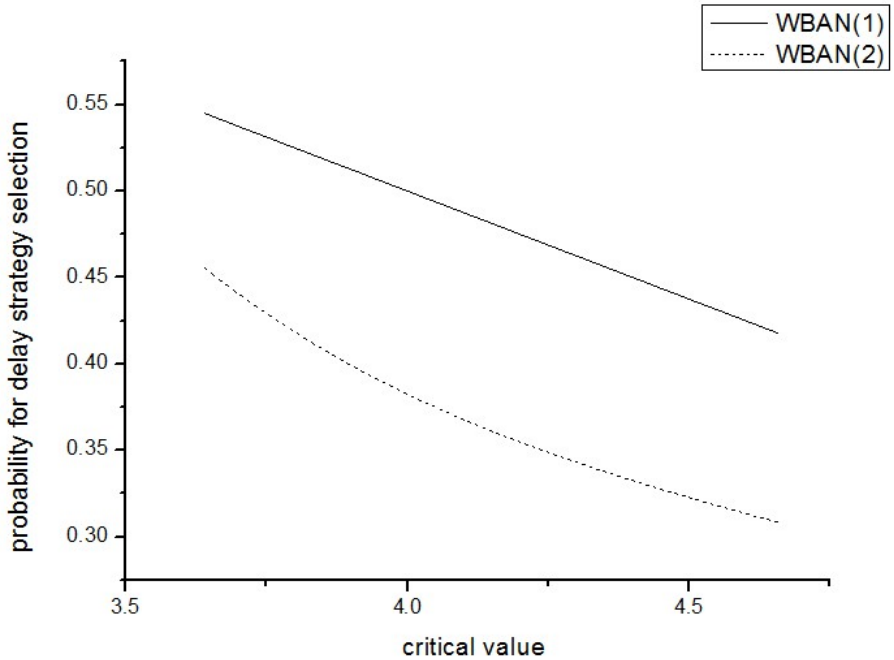


(a) Payoff of WBAN1

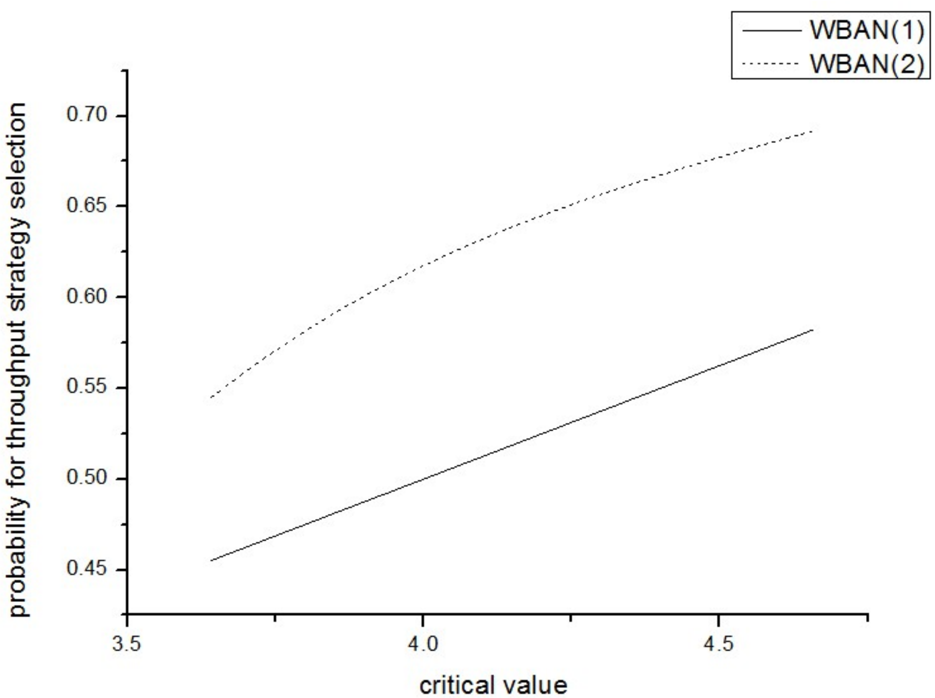


(b) Payoff of WBAN2

Figure 5-2: Payoff analysis for two WBANs



(a) probability for delay strategy selection



(b) probability for delay strategy selection

Figure 5-3: Probability classification for strategy selection strategy is decreased with increment of critical value, WBAN1 still always has high probability for delay strategy selection than WBAN2. All this numerical analysis is under the Bayesian Nash equilibrium, which means that the strategy selection of each WBAN is the best response to other WBANs.

Chapter 6

Conclusion

Our research focused on finding an efficient method to analyze coexistence problem in overlapped WBANs environment. We proposed a game model based on the Bayesian game for the coexistence analysis of WBANs under IEEE 802.15.6 standard. We defined the utility function for QoS support in overlapped WBAN environment. In addition, our analysis of game model indicated that there is close relation between player's utility and QoS parameters. Through mathematical analysis, we observed the change of result which is based on analysis of strategy selection probability. By this analysis, each WBAN can decide an efficient and suitable selection of strategy, and thus, get a favorable payoff. Finally, players in the game can decide the most suitable strategy under incomplete information of other players. And on the basis of Bayesian Nash equilibrium, suitable strategy selection support lowest inference between each WBAN and satisfy basic requirement for data traffic of each WBAN in overlapped environment.

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Appendix A

List of Publications

- Weidong Su, Sangbea Shin, Jingsung Cho, "A Static Bayesian Game Modeling for QoS Support in Overlapped WBAN Environment", *International conference, CAIPT, 2013.*
- Sangbea Shin, Weidong Su, Jingsung Cho, "A Game Theory Model to Support QoS in Overlapped WBAN Environment", *Information conference, ICUIMC, 2012.*
- Weidong Su, Sangbea Shin, Jingsung Cho, "Contention Free Period Allocation by Axiomatic Bargaining Game in Multi-WBAN Overlapped Environment", *National Conference , KCC, 2012.*
- Zilong Jin, Weidong Su, Jingsung Cho, "An Analytic Model for the Optimal Number of Relay Stations in Two-hop Relay Networks", *IEEE International Journal, Communication letter, 2012.*