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

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Abstract

Wireless Body Area Networks (WBANs) are regarded as the leading future communication technology with services like medical/health-care and entertainment services. In this paper, we focus on the coexistence problem when geographically co-located WBANs share contention-free periods which are allocated to each WBAN in overlapped WBAN environment such as hospital and senior center. We figure out the problem by introducing static Bayesian game. We develop a Bayesian game model assuming WBANs are players in the game and they attempt to choose their suitable strategy which is benefited by incomplete information of other players. Based on the defined utility function with QoS parameters, we analyze the suitable strategy selection for each player in the game.

1. Introduction

The Wireless Body Area Network (WBAN) is a type of personal-centric network which is located in a small range around human body with a number of sensors. It can support many applications such as u-health and u-lifecare. IEEE 802.15.6 [1] has been developed as WBAN standard.

IEEE 802.15.6 standard defines a MAC protocol that controls access to the channel. To support time referenced allocations in WBAN, a hub shall establish a time base as specified to divide the time axis into beacon periods (superframe). Allocated transmit period are split into contention and contention free.

We focus on the coexistence problem of two WBANs located in dense environment such as hospital and senior center. Figure 1 shows an overlapped environment with two WBANs. Unfair resource allocation and failures of medical data delivery may impact on patients' safety. We figure out this kind of scenario and utilize a game theoretical analysis method.

Nowadays, game theory [2] is widely used to solve resource allocation problem in wireless networking. It mainly studies the interaction between formulaic incentive structures, then finding the optimization strategy by considering the forecasting behavior and actual behavior.

Our previous work [3] 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, as an enhancement of our previous research, for solving coexistence problem in geographically co-located overlapped environment, we utilize a Bayesian game solution [4] to classify each player's selection. This game solution focuses on a more realistic environment by consider information prediction of each player.

The structure of the paper is as follows: Section 2 introduces the static Bayesian game as background. The proposed model for the coexistence problem in overlapped WBAN environment is described in Section 3. In Section 4 we do the utility analysis for our proposed modeling. Conclusion of this paper is described in Section 5.

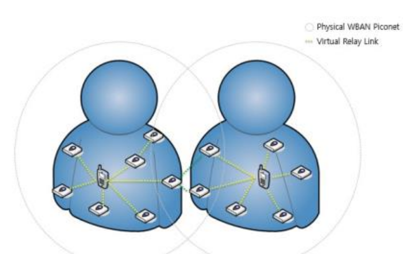

Figure 1. The coexistence problem in overlapped WBAN environment

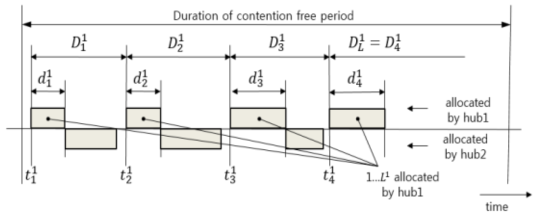

Figure 2. The coexistence model as single static game with certain duration

2. Background

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 [4]: the normal-form representation of an *n*-player static Bayesian game specifies the players' 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 's belief $P_i(t_{-i}|t_i)$ describes i 's uncertainty about the $n-1$ other players' possible types, t_{-i} , given i 's own type, t_i . We denote this game by

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

Just as its name implies, this game is related to Bayesian probability theory. As a key concept in the Bayesian game, Bayesian rule [5] is used to take incomplete information into account.

3. The 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 [6] [7].

3.1 Coexistence model

The game is defined with a set of players selecting rational action to maximize their expected payoff. Action of one player is the selection of a certain way of resource allocation by a hub, where each hub is one player in the game. At each game period, a player observes demand and action of its opponents together with its own payoff.

In this paper, we focus on the overlapped environment with two WBANs. In this environment, competing hubs of two piconets can be modeled as rational players attempting to maximize their payoffs within the modeling scheme. Payoff of each hub is defined as measurable quantity related to QoS (i.e., throughput, delay, and priority), wherein data traffic priority is the incomplete information of each opponent. It is defined as private information (PI) of each player, however, we have the probability information about what kind of priority can be taken by the opponent. We divide priority into high priority (PH) and low priority (PL). Through finding the priority critical value of each WBAN on the basis of Bayesian Nash equilibrium, we can get a priority classification to analyze suitable strategy.

Figure 2 illustrates a contention free period that we interpret as the single static game for two players.

3.2 Bayesian game modeling

The QoS parameters are throughput, delay, and traffic priority. We redefined them and normalized representations of QoS parameters: throughput Θ , delay Δ , and traffic priority P .

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

$$\Theta_i = \frac{1}{Dur}\sum_{l=1}^{L^i} d_l^i \qquad (1)$$

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 $(0 \le \Delta_i \le 1)$. which represents the expected maximum delay between two allocated transmissions due to interrupting other hub's allocation.

$$\Delta_i = \frac{1}{Dur}\sum_{l=1}^{L^i-1} D_l^i \qquad (2)$$

Table 1. Static Bayesian game form for overlapped WBAN environment

		WBAN2	
		Delay	Throughput
WBAN 1	Delay	$1 - \left(\frac{1}{2} + \arctan\left(\Delta_{dem} - \Delta_{req}\right)\right) \times \frac{1}{\pi} + t_a$ $1 - \left(\frac{1}{2} + \arctan\left(\Delta_{dem} - \Delta_{req}\right)\right) \times \frac{1}{\pi} + t_b$	0 , 0
	throughput	0 , 0	$\frac{1}{2} + \arctan\left(\Theta_{dem} - \Theta_{req}\right) \times \frac{1}{\pi} + t_a$ $\frac{1}{2} + \arctan\left(\Theta_{dem} - \Theta_{req}\right) \times \frac{1}{\pi} + t_b$

In Eq. (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.

$$
\begin{aligned}
u(\Theta) &= \frac{1}{2} + arctan\left[\left(\Theta_{dem} - \Theta_{req}\right)\right] \times \frac{1}{\pi} \\
u(\Delta) &= 1 - \left(\frac{1}{2} + arctan\left[\left(\Delta_{dem} - \Delta_{req}\right)\right] \times \frac{1}{\pi}\right)
\end{aligned}
\tag{3}
$$

Depending on this game model, game form is defined in Table 1. There are two players, WBAN1 and WBAN2. Mixed strategies are not considered.

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. We describe the normal form as a static Bayesian game:

$$G = \left\{A_a, A_b; T_a, T_b; p_a, p_b; u_a, u_b\right\} \tag{4}$$

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 utility with probability $\frac{8-b}{8}$ and selects throughput 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 WBAN2's strategy is given, WBAN1's expected payoffs (PF) for playing delay and throughput are as follows:

$$PF_{de}^{1} = \frac{8-a}{8}\left[1 - \left(\frac{1}{2} + \arctan\left(\Delta_{dem} - \Delta_{req}\right)\right) \times \frac{1}{\pi} + t_a\right] + 0 \tag{5}$$

$$PF_{thr}^{1} = 0 + \frac{a}{8}\left[\frac{1}{2} + \arctan\left(\Theta_{dem} - \Theta_{req}\right) \times \frac{1}{\pi} + t_a\right] \tag{6}$$

According to above two formulas if and only if

$$t_a > \frac{1}{2a}\left[4 + a + \frac{8-a}{\pi}\arctan\left(\Delta_{dem1} - \Delta_{req1}\right) + \frac{a}{\pi}\arctan\left(\Theta_{dem1} - \Theta_{req1}\right)\right] = b \tag{7}$$

, delay utility function is the optimal selection. By the same way, if the WBAN1's strategy is given, WBAN2's expected payoffs from playing delay function and throughput function are

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

and

$$PF_{thr}^{2} = \frac{8-b}{8}\left[1 - \left(\frac{1}{2} + \arctan\left(\Delta_{dem} - \Delta_{req}\right)\right) \times \frac{1}{\pi} + t_b\right] + 0 \tag{9}$$

Thus throughput utility function is the optimal selection when Eq. (10) holds

$$t_b > \frac{1}{2b}\left[4 + b + \frac{8-b}{\pi}\arctan\left(\Delta_{dem2} - \Delta_{req2}\right) + \frac{a}{\pi}\arctan\left(\Theta_{dem2} - \Theta_{req2}\right)\right] = a \tag{10}$$

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

$$
\begin{cases}
\frac{1}{2a}\left[4 + a + \frac{8-a}{\pi}\arctan\left(\Delta_{dem1} - \Delta_{req1}\right) + \frac{a}{\pi}\arctan\left(\Theta_{dem1} - \Theta_{req1}\right)\right] = b \\
\frac{1}{2b}\left[4 + b + \frac{8-b}{\pi}\arctan\left(\Delta_{dem2} - \Delta_{req2}\right) + \frac{b}{\pi}\arctan\left(\Theta_{dem2} - \Theta_{req2}\right)\right] = a
\end{cases}
\tag{11}
$$

4. Numerical analysis

Based on the functions we obtained in Section 3.2, we develop a simulation to observe variations of a and b along with demanded utility's increment as shown in Figure 3. 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 3 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, WBAN1 always gets a lower critical value than WBAN2. Based on our pervious 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 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 4. 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.

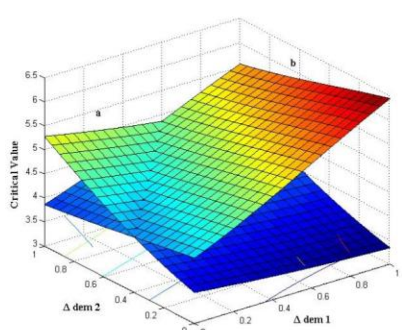

Figure 3. Analysis result of critical value on strategy selection

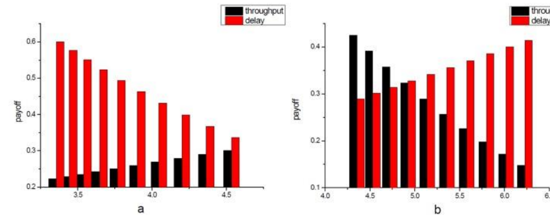

Figure 4. Payoff analysis for two WBANS

5. Conclusion

Our research focuses 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.

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