A Game Theory Model to Support QoS in Overlapped WBAN Environment

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ABSTRACT

Wireless body area networks (WBANs) have emerged as a key technology to provide real-time health monitoring and entertainment services. In high dense WBAN environment like hospital and senior center, however, there occurs coexistence problem which is caused by interference. Especially, contention free period of each WBAN may not be provided transmission opportunity due to channel interferences. In this paper, we focus on the coexistence problem when geographically co-located WBANs share the contention free period in the overlapped WBAN environment. In addition, we address the problem by introducing cooperative game theory based on the Cournot competition. An approach to model such a competition scenario is the static and strategic game model in which players try to maximize their benefits. We define the utility function for QoS support in overlapped WBAN environment and analyze player's utility related with QoS parameters (i.e., throughput, delay, and priority). We verify that the player's utility increases with increasing throughput and decreasing delay through a mathematical method by using the Cournot competition model. Finally, we observe the change of resulting utilities according to demanded throughput and traffic priority in overlapped WBAN environment.

Categories and Subject Descriptors
C.2.3 [**Network Operations**]: Network management modeling

General Terms
Theory

Keywords
WBAN, Game Theory, Coexistence Problem, Cournot Competition.

1. INTRODUCTION
Current health care systems are facing new challenges due to rate of growth of the elderly population (persons 65 years old and over). And u-healthcare/u-lifecare service has surfaced by user requirements like customized healthcare service. To support this, The Institute of Electrical and Electronics Engineers, Inc.(IEEE) develops the IEEE 802.15.6 as an Wireless Body Area Network (WBAN) standard. WBAN is a set of communicating devices are located inside, on or around the human body. In the case of medical applications, these devices are connected to sensors that monitor vital body parameters and movements. The WBAN have been considered not only for the medical and healthcare applications but as well as for sports and entertainment [1].

The MAC layer in the standard intends to define short range, wireless communication in and around the body area. The standard aims to support a low complexity, low cost, ultra-low power and highly reliable wireless communication for use in close proximity to, or inside, a human body (but not limited to humans) to satisfy an evolutionary set of entertainment and healthcare products and services. The standard defines a sophisticated MAC protocol that controls access to the channel. For time referenced resource allocations, the coordinator (or a hub) operates three access modes. Beacon mode with superframe boundaries, non-beacon mode with superframe boundaries, and non-baecon mode without superframe boundaries. The coordinator divides the time axis into a series of superframes with superframe boundaries mode or uses unscheduled polling access without superframe boundaries. Also, allocated transmission period of devices which compose the WBAN are split in two parts, contention periods and contention free periods.

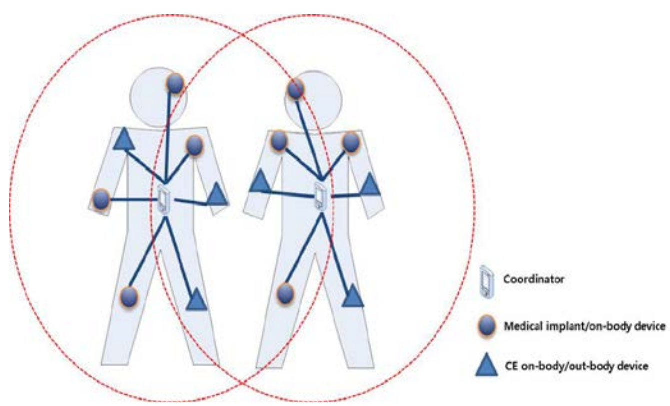

Figure 1. The coexistence problem in overlapped WBAN environment

The requirements of IEEE 802.15.6 include an operating range of 3m and up to 10 co-located networks (piconets), each with up to 256 nodes, within a 216 m^3 cube [2]. In dense WBAN environment like hospital and senior center, there occurs

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coexistence problem. Figure 1 shows that in overlapping scenario of multiple coexisting WBANs. The coexistence problem in overlapped IEEE 802.15.6 WBAN we are discussing here is illustrated for a simple scenario with two WBANs sharing the same channel.

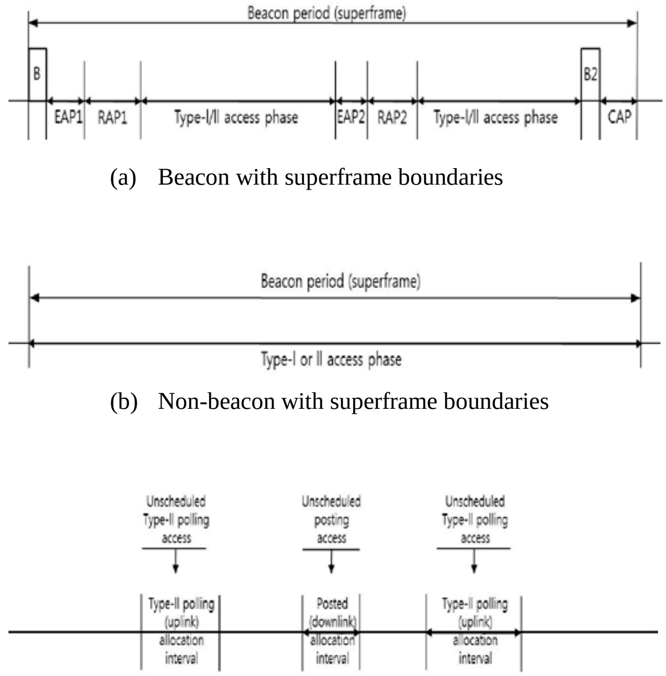
There is a conflict in the transmission periods by interference of overlapped WBAN. Transmission failure of physical and medical data caused by interference has a close relationship with the user's life. Thus, in overlapped WBAN environment, we should allocate the transmission period efficiently and fairly to ensure reliable transmission for each WBAN. Such coexistence scenarios are not addressed in standards like the popular IEEE 802.15.6 for quality of service (QoS) support.

We are able to find the solution to divide a limited resource fairly for each user through the game theory. Game theory is a mathematical method for analyzing calculated circumstances where a person's success is based upon the choices of others. The major applications of game theory are to economics, political, science, strategic military problems, and most recently computer science [3].

In this paper, we focus on the coexistence when geographically co-located WBANs share the same radio channel in the so-called overlapped WBAN environment, We address this problem by introducing cooperative game theory. Especially, we propose the coexistence modeling by using the Cournot model. Through this modeling, we allocate resources effectively for each WBAN to satisfy QoS requirements. The paper is outlined as follows. In the next section the upcoming standard IEEE 802.15.6 Medium Access Control (MAC) protocol is outlined. In Section 3, we propose coexistence modeling and utility function based on the Cournot model. Section 4 shows the simulation and discusses about the results. Section 5 concludes this paper.

2. IEEE 802.15.6 MAC

In 802.15.6 MAC protocol, WBAN offers the contention free period to guarantee the reliable transmission for physical and medical data. Figure 2 shows the MAC structure of IEEE 802.15.6, which operate three access modes. In beacon mode with beacon period superframe boundaries, the beacon transmits by the coordinator in each beacon period except in inactive superframe. This mode is divided into Exclusive Access Phase 1 (EAP1), Random Access Phase (RAP1), Type I/II phase, Exclusive Access Phase 2 (EAP2), Random Access Phase 2 (RAP2), Type I/II phase and a Contention Access Phase (CAP). In EAP, RAP and CAP, nodes contend for the resource allocation using either CSMA/CA or a slotted ALOHA access procedure. The EAP1 and EAP2 are used for highest priority traffic such as reporting emergency events. The RAP1, RAP2 and CAP are used for regular traffic only. The Type I/II phase are used uplink allocation interval, down link intervals, bilink allocation intervals. In Type I/II phases, scheduled access and polling access are used for resource allocation. In non-beacon mode with superframe boundaries, the entire superframe duration is covered either by a type I or a type II access phase but not by both phases. In non-beacon mode without superframe boundaries, the coordinator provides unscheduled Type II polled allocation. In the contention access period including EAP, RAP and CAP, physical and medical data has high priority.



(a) Beacon with superframe boundaries

(b) Non-beacon with superframe boundaries

(c) Non-beacon mode without superframe boundaries

Figure 2. IEEE 802.15.6 MAC access modes

Therefore, they have the better chances to acquire transmission period through contention in overlapped WBAN environment. On the other hand, Contention free period including scheduled access and polling access fails if there is more than one coordinator trying to occupy at the same channel. Thus, by using the proper allocation method has to assign the contention free period to each WBAN in order to allow the support of QoS in overlapped WBAN environment.

3. THE PROPOSED MODEL

In the following, we discuss a policy and modeling, which may solve this problem discussed in the previous section. This framework may allow the establishment of coexistence based on mutual support [4],[5].

3.1 Coexistence Model

We define a static game to study the coexistence problem. The game model comprises to a set of players, which choose their actions in each period of the game to maximize that period's expected own payoff, given their assessment of their opponent's actions in that particular period [3]. An action of a player is the selection of a certain way of resource of allocation by a coordinator. The game model is called dynamic as the players periodically adopt their action demand to the environment after each period of the game. At each game period, a player observes the demand and the action of its opponents together with its own payoff. It does not necessarily observe the payoff of other players.

In particular, we take the Cournot competition model approach [3],[6]. A Cournot game in a strategic form consists of a finite set of players, a feasible set of actions for each player, Utility functions that give payoffs for each action. Competing coordinators of each piconet are modeled as rational players attempting to maximize their payoffs within the Cournot modeling

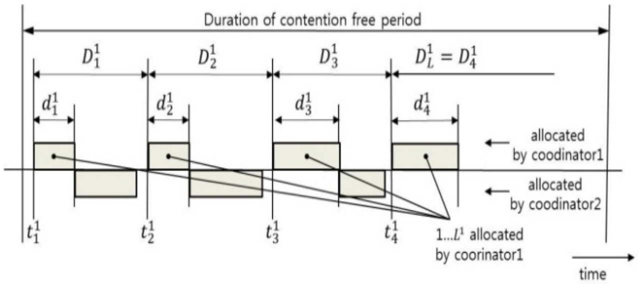


Figure 3. The coexistence model as single static game with certain duration

scheme. A payoff is a measurable quantity related to QoS (i.e., throughput, delay, and priority) a player observes after playing the game. The Cournot competition model relies on the assumption of rational players. Rationality of players means in general that players select the best response to their belief of what action the opponent players select. In other words, a rational player that selects the best response does select that action that maximizes its payoff, given the action of the opponent players. This requires that a rational player knows its opponents' actions before the decision taking of what action to select.

Figure 3 illustrates a contention free period that we interpret as the single static game for two players. A coordinator is modeled as a player. The gained utilization of the radio channel is attained through selected actions and determines the player's observed payoff. We suppose that the beacon is successfully transmitted by one of the competing coordinators. A successfully transmitted beacon begins each single static of the game.

3.2 Quality of Service as Utility

As previously stated, the QoS parameters are throughput, delay and traffic priority. the player's QoS demands are taken from the traffic specifications of the streams that are currently carried within contention free period. We define three abstract and normalized representations of the QoS parameters, (1) the throughput Θ, the delay Δ, and the priority P.

The throughput Θ_i represents the share of capacity player i's demands. $\Theta_i \in [0 \ldots 1]$.

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

where L is the number of allocated transmission periods per transmission durations, and Dur the duration of this contention free period. The parameter d_i is duration of allocated transmission period. See Figure 3 for an illustration the parameters. The delay Δ_i specifies the maximum delay that tolerates. In particular, this delay describes the expected maximum delay between two allocated transmissions due to interrupted other coordinator's allocations. $\Delta_i \in [0 \ldots 1]$.

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

where $D_l^i = t_{l+1}^i - t_l^i$ is the time between the starting points of the two allocated periods l and $l+1$ of player i. The priority parameter is mean of allocated traffic priority. The parameter ρ represents each allocated traffic priority. $P_i \in [0 \ldots 1]$. Table 1 shows traffic priority of WBAN in IEEE 802.15.6.

$$P_i = \frac{1}{\rho_{highest}} \cdot \frac{1}{L_i}\sum_{l=1}^{L} \rho_l^i$$

A utility function for player i is defined over the closed set of actions. We define the utility function as below. Θ_{dem} and Δ_{dem} is demanded factor in single WBAN. Demanded factor means that each WBAN asks transmission slots for relaxable data transmission. On the other hand, Θ_{req} and Δ_{req} means the level of QoS that is required in overlapping WBANs environment. We are able to calculate gained utility by using utility of throughput and utility of delay as below. In section 3.1, we proposed the coexistence model for two players. Like the preceding we define the utility function for two players. First, we've divided the utility in half. And then, each WBAN adds or subtracts own utility to take into account parameters (i.e., priority, demanded factor and required factor). Utility of throughput starts from scratch. Because, throughput is zero before allocating transmission period. On the other hand, utility of delay descends from the one. Because, delay is one before allocating transmission period.

$$u_i = u(\Theta) \cdot u(\Delta), \text{ with}$$

$$u(\Theta) = \frac{1}{2} + arctan\left[P \cdot \left(\Theta_{dem} - \Theta_{req}\right)\right] \cdot \frac{1}{\pi}$$

$$u(\Delta) = 1 - \left(\frac{1}{2} + arctan\left[P \cdot \left(\Delta_{dem} - \Delta_{req}\right)\right] \cdot \frac{1}{\pi}\right)$$

A typical utility function is shown Figure 4. Its shape depends on the QoS requirements (i.e., throughput Θ_{req}, delay Δ_{req}, and priority P) of the player. Depending on its demand, a player's utility increases with increasing throughput and decreasing delay.

Table 1. WBAN traffic priority

Priority	Traffic priority	Traffic designation
Lowest	0	Background (BK)
	1	Best effort (BE)
↓	2	Excellent effort (EE)
	3	Controlled load (CL)
	4	Video (VI)
	5	Voice (VO)
Highest	6	Medical data or network control
	7	Emergency or medical event report

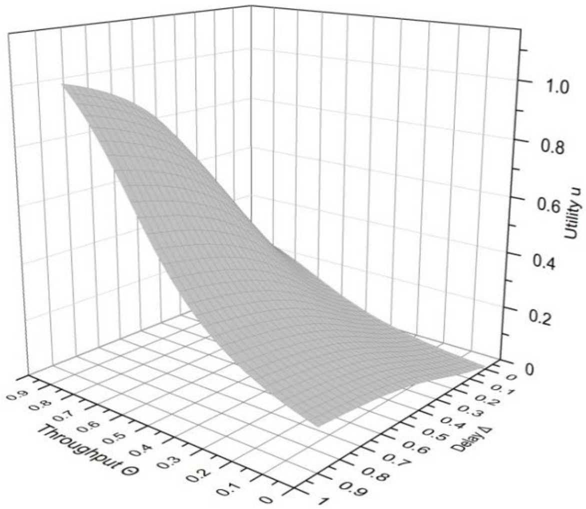


Figure 4. Utility function

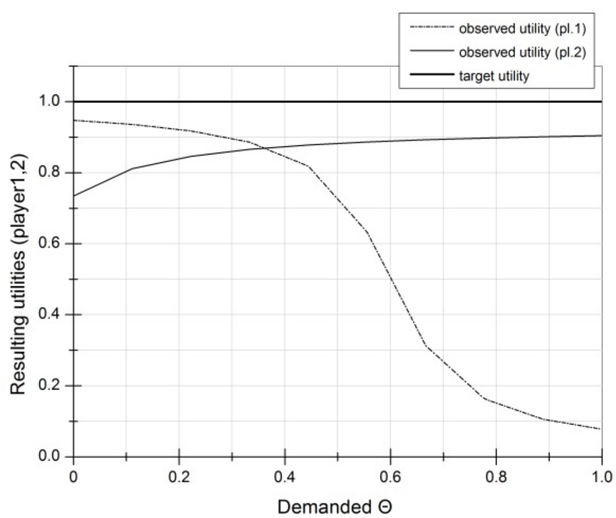


Figure 5. Observed utility vs. throughput demand of both players

4. ANALYSIS OF UTILITIES

The two players operate with their own utility functions. The demand of a player is calculated at the beginning of a coexistence based on the overhearing beacon or poll message. We assume that the player knows the opponent's information before starting the game (decision making). In general, not all demanded transmission period can be successfully allocated by both players due to competitive access. To illustrate the influence of the QoS parameter on the allocation of both players and in particular their observed utilities, we assume that player2 has higher priority than player1, and parameters of QoS requirement are both players about the same. The demanded throughput of player1 and player2 are increased from 0 to 1.0. At the beginning of a single static game, both players calculate their demanded transmission periods based on their QoS parameter set and attempt to allocate them. Figure 5 shows the observed utilities of the two players. Until both player's total demanded Θ is close to target utility, they have high resulting utilities. However, utility of player1 drops sharply from when both player's total demanded Θ is over the target utility. Because it can be overloaded channel. If so, why player1 drop sharply. Because, player2 has higher priority than player1. As mentioned in Section 3.1, the Cournot competition model is attempting to maximize rational player's payoff. Thus, player1 has the right to receive better QoS.

5. CONCLUSION

The transfer of solution concepts from game theory and social science to the competition of radio resource sharing in wireless networks enriches our research with a new interdisciplinary aspect. Especially, the coordination of multiple QoS parameters in the player's coordination efforts is a decisive step toward a realization as extension of QoS supporting wireless communication protocols. We proposed a game theory model based on the Cournot competition for the analysis of coexistence of WBAN based on IEEE 802.15.6. We defined the utility function for QoS support in overlapped WBAN environment. And, the analysis of the model indicated that player's utility have closely related with QoS parameters (i.e., throughput, delay, and priority). We verified that the player's utility increases with increasing throughput and decreasing delay through a mathematical method by using the Cournot competition model. Finally, we observed the change of resulting utilities according to demanded throughput and priority in overlapped WBAN environment.

6. ACKNOWLEDGMENTS

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