Qos-Driven Power Control for Inter-WBAN Interference Mitigation

Xiaosong Zhao , Bin Liu , Chang Chen and Chang Wen Chen‡
Key Laboratory of Electromagnetic Space Information, Chinese Academy of Sciences, P. R. China
University of Science and Technology of China, School of Information Science and Technology
Email: zxswk , fl , c
‡University at Buffalo, State University of New York, Dept. of Computer Science & Engineering, USA
Email: chencw@buffalo.edu

—Wireless Body Area Networks (WBANs) are usually designed for pervasive healthcare applications. Since the prima- ry traffic in WBAN is vital physiological signals, guaranteeing the Quality of Service (QoS) is crucial while designing WBAN. However, QoS of WBAN will be degraded in strong inter-WBAN interference environment such as hospitals and senior communities, where WBANs are densely deployed. In this paper, by focusing on a more practical WBAN model, we propose a non-cooperative power control game to mitigate inter-WBAN interference, in which the cost function is well designed by considering both QoS requirement and energy constraint. The existence of at least one Nash equilibrium (NE) point for the game is proved and a sufficient condition for the uniqueness of the NE is derived. To guarantee non-cooperative among WBANs, an interference segmentation estimate (ISE) algorithm is proposed to obtain an approximation of the NE point. Simulation results demonstrate the effectiveness of the proposed ISE algorithm.

***Index Terms*—Wireless Body Area Network (WBAN), Quality of Service (QoS), Signal to Interference plus Noise Ratio (SINR), Power Control Game, Noncooperative**

I. INTRODUCTION

With the development of communications, microelectronics, integrated circuit technology, as well as the ardent expectation of people's health, Wireless Body Area Network (WBAN) has been widely adopted for health monitoring. WBAN is usually a star topology wireless network composed of a coordinator and multiple sensor nodes operating on, in or around the human body in order to monitor the vital physiological signals, such as ECG signals, blood pressure, body posture signals, etc [1]. The physiological signals gathered by the coordinator are then transmitted to the remote medical center for health management and disease treatment.

Due to the speciality of WBAN topology and WBAN applica- tions, some issues need careful considerations while designing the WBAN systems. First of all, WBAN is sensitive to the en- ergy consumption on account that the sensor nodes are battery- powered and in many cases it is either impossible or very hard to replace the battery. Hence it is strongly desired to improve the energy efficiency. Secondly, as one major application of WBAN, the mission of health monitoring is to acquire and transmit the vital physiological signals, and guaranteeing the Quality of Service (QoS) of WBAN is significant while trying to reduce the energy consumption. Furthermore, as the various requirements of applications, the heterogeneity of sensor nodes should also be concerned [2–4].

The QoS-driven design of single WBAN has been widely investigated in [5–7]. However, WBANs are usually densely deployed in hospitals, railway stations and senior communities, etc. As the frequency resource available for WBAN is limited [1], there may occur multiple WBANs taking up the same channel to send messages simultaneously, which will inevitably lead to coexistence interference. For the communications inside the WBAN, TDMA-based mechanism is usually introduced to solve intra-WBAN interference efficiently by arranging the sensor nodes to transmit in different time-slots. But inter-WBAN interference problem can not be easily solved due to the fact of independent resource management for each WBAN.

Some cooperative schemes have been proposed to mitigate the inter-WBAN interference in [8–10]. A random incomplete coloring (RIC) algorithm was proposed by Cheng *et al*. [8] to suppress the inter-WBAN interference, but strict assump- tion of perfect superframe synchronization may cause much expenditure to inactive WBANs. Wang *et al*. [9] and Kim *et al*. [10] gathered the information about transmission schedule of other interfered WBANs by exchanging with each other periodically, then made reasonable arrangement on transmission time-slot. However, it is usually difficult for WBANs to update transmission information of interfered WBANs in time due to the high mobility of WBANs. In addition, cooperation among WBANs also increases the energy overhead.

Non-cooperative strategy is more appropriate for inter-WBAN interference mitigation as WBANs are independent of each other. For example, channel hopping scheme in [1] can help to mitigate inter-WBAN interference by arranging the WBAN to hop to new channels periodically, but problem of limited channel resource can never be ignored. Another commonly used strategy is power control. The diminution of the transmission power can decrease the interference to other WBANs, but it also degrades the performance of WBAN. Hence, power control problem is usually modeled as a game and the solution of the game is called Nash equilibrium (NE), which is a state that each player get their best satisfied utility in current situation. Anyone who changes strategy alone will get a lower utility, so each rational participant will not have the urge to change its strategy unilaterally on the NE state. Non-cooperative power control games were proposed in [11, 12] to mitigate inter-WBAN in- terference, also the PAPU algorithm and Best Response scheme were introduced respectively, to gain the solution of the game. By utilizing the current interference, SINR and transmission

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Email:: zxswk , fl , c
‡University at Buffalo, State University of New York, Dept. of Computer Science & Engineering, USA
Email: chencw@buffalo.edu

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power, Fuzzy Power Controller (FPC) algorithm proposed in [13] could mitigate the inter-WBAN interference effectively. However, all these schemes only considered single link inside the WBAN, which is unpractical due to the different link gains and various QoS requirements of sensor nodes. Taking the property of multiple links inside the WBAN into consideration, a Bayesian game considering throughput and power consumption has been proposed in [14]. They achieved to maximize the utility while minimizing the energy consumption, but whether the WBAN was satisfied at obtained throughput performance was not considered in the literature. WBAN may get superfluous throughput performance than needed, and cause an unnecessary energy waste.

In this paper, following the nature of the QoS demand, a non-cooperative power control game is proposed to solve the inter-WBAN interference mitigation problem based on a more practical WBAN model. The utility function of the game is so well-designed that the QoS requirement could be approached with small energy consumption for each WBAN. Furthermore, we prove the existence of at least one NE point in the game and derive a practical sufficient condition to guarantee the uniqueness of the NE point. The exact value of NE point can not be easily obtained due to the non-cooperation manner among WBANs. To overcome this problem, we propose a non-cooperative interference segmentation estimate (ISE) algorithm based on the received historical interference information to obtain an approximation of the NE point, which guarantees zero information exchange among the coordinator of WBANs.

The rest of the paper is organized as follows. The system model is introduced in section II and the power control game is formulated in section III. In section IV, we theoretically derive the solution of the game. The description of the non-cooperative ISE algorithm and the evaluation of the algorithm are presented in Section V and Section VI, respectively. In Section VII, we conclude the paper.

II. SYSTEM MODEL

We consider the scenario, such as hospital or railway station, where WBANs are densely deployed and working in the same channel. Each WBAN contains one coordinator and several sensor nodes placed in different positions of human body for diverse applications. A typical structure of WBAN is shown in Fig. 1, where BNC stands for body network coordinator and BN denotes body node. Considering a more practical intra-

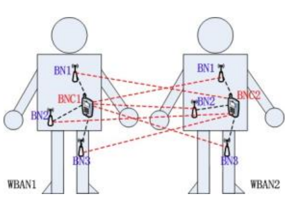

Fig. 1. Link architecture model of WBAN

WBAN model, we assume that there are multiple links inside the WBAN and sensor nodes have various QoS requirements. By the use of TDMA-based schemes, multiple-link interference inside WBAN can be avoided effectively. But there still exists the serious inter-WBAN coexistence interference while several WBANs are deployed in the vicinity.

Without loss of generality, we assume that there exist M WBANs occupying the same channel, and the m-th WBAN is represented by W_m, which contains $|W_m|$ sensor nodes. Each sensor node works in a fraction of time arranged by the coordinator. We define a M-tuple $\boldsymbol{w} = \{\omega_1, \omega_2, \cdots \omega_m \cdots \omega_M\}$ as a node synchronous working set to indicate the node set of all WBANs working in the same time, in which the index of m-th WBAN's current working sensor node is expressed as ω_m. Obviously, ω_m is a integer and $1 \le \omega_m \le |W_m|$. We further define a node synchronous working set group $\boldsymbol{W}$ as all $\prod_{i=1}^{M} |W_i|$ cases of $\boldsymbol{w}$. In addition, we use $\boldsymbol{w}_{ij} = \{\boldsymbol{w} | \omega_i = j\}$ to stand for the node set working simultaneously with i-th WBAN's j-th sensor node. Then the synchronous working group of the i-th WBAN's j-th node can be expressed as $\boldsymbol{W}_{ij}$ containing all $\prod_{k=1,k\neq i}^{M} |W_k|$ cases of $\boldsymbol{w}_{ij}$.

Assuming the current working node in the i-th WBAN is j, the received SINR of the i-th WBAN's coordinator for any $\boldsymbol{w}_{ij}$ can be defined as:

$$\gamma_{ij}(p_{ij}, \boldsymbol{w}_{ij}) = \frac{g_{iij} p_{ij}}{\sum_{k=1,k\neq i}^{M} g_{ik\omega_k} p_{k\omega_k} + \sigma_i^2} \tag{1}$$

where p_{ij} denotes the transmission power of the i-th WBAN's j-th sensor node, and $g_{ik\omega_k}$ denotes the channel gain from the k-th WBAN's ω_k-th node to the i-th WBAN's coordinator. σ_i^2 denotes the background white noise power at the i-th WBAN's coordinator.

In order to achieve inter-WBAN interference mitigation to guarantee nodes' QoS requirements, we take into account the satisfaction degree of nodes SINR, which has direct relations with important QoS metrics such as throughout, delay, etc. We use the notation γ^{tar} to represent the target SINR ensuring that sensor node works most satisfactorily and each one tries to approach it. The SINR squared error, expressed as $(\gamma_{ij}^{tar} - \gamma_{ij}(p_{ij}, \boldsymbol{w}_{ij}))^2$, is introduced to character the closeness of $\gamma_{ij}(p_{ij}, \boldsymbol{w}_{ij})$ to the γ_{ij}^{tar}. Moreover, considering the limited energy, sensor node should try to reduce the energy consumption while meeting the requirement of γ^{tar}. Since the power is not restricted in the SINR squared error, we further introduce the power constrains and utilize parameter β to balance the importance of SINR squared error and transmission power. The cost function of the i-th WBAN's j-th sensor node for any $\boldsymbol{w}_{ij}$ is then defined as:

$$U_{ij}(p_{ij}, \gamma_{ij}(p_{ij}, \boldsymbol{w}_{ij})) = (\gamma_{ij}^{tar} - \gamma_{ij}(p_{ij}, \boldsymbol{w}_{ij}))^2 + \beta_{ij} p_{ij} \tag{2}$$

Each sensor node tries to choose a transmission power to minimize its cost when scheduled to transmit. However, due to the independence among different WBANs, optimal power allocation for one WBAN may not be good for other WBANs. It motivates us to choose game theory to conquer the inter-WBAN interference problem.

III. FORMATION OF POWER CONTROL GAME

Here we propose a power control game based on the scenario considered in Section II to mitigate the interpower, Fuzzy Power Controller (FPC) algorithm proposed in [13] could mitigate the inter-WBAN interference effectively. However, all these schemes only considered single link inside the WBAN, which is unpractical due to the different link gains and various QoS requirements of sensor nodes. Taking the property of multiple links inside the WBAN into consideration, a Bayesian game considering throughput and power consumption has been proposed in [14]. They achieved to maximize the utility while minimizing the energy consumption, but whether the WBAN was satisfied at obtained throughput performance was not considered in the literature. WBAN may get superfluous throughput performance than needed, and cause an unnecessary energy waste.

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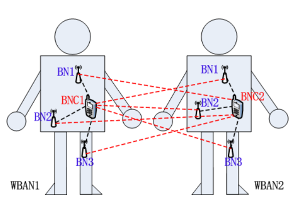

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