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Priority-aware pricing-based capacity sharing scheme for beyond-wireless body area networks

Changyan Yi[a], Zhen Zhao[a], Jun Cai[a,*], Ricardo Lobato de Faria[b], Gong (Michael) Zhang[b,c]

[a] Department of Electrical and Computer Engineering, University of Manitoba, Winnipeg, MB R3T 5V6, Canada
[b] Seven Oaks General Hospital, Winnipeg, MB R2V 3M3, Canada
[c] Rizhao Hospital of Traditional Chinese Medicine, Rizhao, China

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ABSTRACT

In this paper, a radio resource allocation scheme for wireless body area networks (WBANs) is proposed. Unlike existing works in the literature, we focus on the communications in beyond-WBANs, and study the transmission scheduling under a scenario that there are a large number of gateways associating with one base station of medical centers. Motivated by the distinctions and requirements of beyond-WBAN communications, we introduce a priority-aware pricing-based capacity sharing scheme by taking into account the quality of service (QoS) requirements for different gateways. In the designed scheme, each gateway is intelligent to select transmission priorities and data rates according to its signal importance, and is charged by a price with regard to its transmission request. The capacity allocation is proceeded with guarantee of the absolute priority rule. In order to maximize the individual utility, gateways will compete with each other by choosing the optimal transmission strategies. Such decision process is formulated as a non-atomic game. Theoretical analyses show that our proposed pricing-based scheme can lead to an efficient Wardrop equilibrium. Through numerical results, we examine the convergence of strategy decisions, and demonstrate the effectiveness of our proposed mechanism in improving the utilities of gateways.

1. Introduction

With the growth of aging population [1] and the increasing demand for high quality of healthcare, exiting medical systems and hospital facilities have been confronting a burden of overload. To overcome this issue, electronic health (eHealth) [2] has been proposed as a promising paradigm, which adopts advanced information processing and communication technologies to enhance efficiency and flexibility of traditional medical services [3]. Wireless body area networks (WBANs) are key components in eHealth systems for pervasive and remote health monitoring. A WBAN generally consists of a few wearable, implantable, or portable biosensors, which are deployed on a patient for continuously sensing physiological signals, such as eletroencepalograph (EEG), Electrocardiograph (ECG) and Electromyography (EMG) data. The sensed signals are then aggregated at a gateway and forwarded to a remote medical center for interpretation and detection of abnormal health conditions. The gateway can be a patient's smart phone or any other smart device, and ordinarily has less stringent constraint on processing and power

* Corresponding author. Tel.: +12024746419.
E-mail addresses: changyan.yi@umanitoba.ca (C. Yi), zhaoz348@myumanitoba.ca (Z. Zhao), jun.cai@umanitoba.ca (J. Cai), rlobatodefaria@sogh.mb.ca (R. Lobato de Faria), gzhang@wrha.mb.ca (G. (Michael) Zhang).

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capabilities compared to sensors [4]. Besides eHealth, WBANs have also been widely applied in sports, entertainments and military [5–7]. In this paper, we will focus our discussions on medical applications only.

Although the WBAN-based wireless technology can provide advantages over the conventional healthcare systems, the specifications of medical signal transmissions also introduce new challenges in designing eHealth networks. In the literature, most of existing works [8–10] in this area focused on intra-WBAN communications, i.e., the transmissions of medical signals from body sensors to the gateway. However, the technical issues related to beyond-WBAN communications, i.e., the data transmissions between gateways and the remote medical center, have not been well addressed. The main reason is that most researches are based on a common assumption that the beyond-WBAN communications can be achieved via existing network technologies, such as 3G/4G/WiFi [11]. However, in fact, medical data transmissions are different compared with traditional wireless communications. For instance, unlike conventional wireless networks that are mainly designed for throughput maximization, medical signals have relatively low data rates so that transmission capacity is not the primary concern for medical networks [12]. In contrast, medical data should be reported to the medical center promptly and with low packet loss. Unfortunately, existing wireless technologies cannot meet these requirements for beyond-WBAN communications because they cannot guarantee “anytime” and “anywhere” connections due to their limited radio resources and a large population of other subscribed wireless users.

Moreover, since the health conditions of patients are unpredictable, wireless networking may become a potential hazard for medical applications if some severe signals cannot be successfully transmitted in a timely manner [13]. For example, in the beyond-WBANs, it is possible that multiple gateways may transmit medical data simultaneously. In this case, it is necessary to provide priorities to emergent health information over those with regular importance, called “medical-grade priority”. Otherwise, transmissions with critical healthcare information may suffer high chances of packet loss, which may further lead to serious consequences.

Thus, in order to address the aforementioned challenges, it is important to achieve appropriate radio resource allocation among multiple gateways [14]. Note that different from the intra-WBAN communications where the appropriate medium access protocols are ordinarily contention-based [15,16], gateways are able to adopt more advanced and complicated resource allocation algorithms. Furthermore, since the availability of radio resource is commonly limited due to the large number of gateways, and medical signal transmissions require exclusive resource usages rather than opportunistic access due to their requirements for stable wireless connections, introducing network economics [17,18] for solving the resource allocation problem in beyond-WBAN communications is an intuitive and feasible approach.

In this paper, we propose a pricing-based radio resource sharing scheme for eHealth networks with the consideration of the medical-grade priority. We limit our discussion in the scenario that there are multiple gateways communicating with a single base station (which is further connected with single/multiple medical centers through internet). In our network architecture, there is a regulator who determines the allocation of the transmission capacity among gateways in each time frame. We consider a static pricing scheme where the prices associated with different transmission priorities are pre-determined, and will not change with the variation of network traffic. During each time frame, gateways are intelligent to strategically select transmission priorities and rates (in kbps) according to their own medical signal severities. Based on the requirement for the medical-grade QoS, we design a mechanism which guarantees the absolute priority to each category of traffic (i.e., traffic in a lower priority level will be served only if all traffic with higher priority has been completely served). As a selfish buyer, each gateway may select a higher transmission priority and demand a higher transmission rate so as to obtain a better service and more benefits. However, choosing a higher transmission priority and transmitting in a higher rate will also be charged by a higher price. Therefore, gateways will compete with each other to make the optimal strategies. Considering that one base station is subscribed with a large number of gateways, we formulate such a decision process as a non-atomic pricing game [19], and analyze the equilibrium accordingly.

To the best of our knowledge, this work is the first that introduces the concept of network economics in the resource allocation for beyond-WBAN communications with the consideration of medical-grade priority. The main contributions of this paper are summarized as follows:

- A pricing-based capacity sharing scheme is proposed for the communications between multiple gateways and the base station of medical centers.
- Each gateway is allowed to determine its transmission priority based on its medical signal severity, so that the medical-grade priority is considered in the transmission scheduling.
- The strategy decision process is formulated as a non-atomic pricing game, and the corresponding Wardrop equilibrium is derived.
- Simulation results demonstrate the superiority of our proposed allocation scheme in improving the utilities of gateways under medical emergencies.

The rest of the paper is organized as follows: Section 2 presents a brief literature review of related works. Section 3 describes the proposed communication architecture and provides the justifications for the model we studied. A non-atomic pricing game is then formulated in Section 4 to investigate the decision process of gateways. The analysis of the Wardrop equilibrium is given in Section 5. Section 6 illustrates some simulation results, and Section 7 concludes the paper.

2. Related work

As an emerging medical service system, eHealth becomes increasingly popular in both scientific and industrial fields. For instance, the authors in [3] proposed an eHealth