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A lightweight distributed scheme for mitigating inter-user interference in body sensor networks

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ABSTRACT

Inter-user interference deteriorates reliable communication in body sensor networks (BSNs) when multiple BSNs are transmitting simultaneously in close proximity to each other. This paper presents a lightweight and distributed inter-user interference mitigation (IIM) scheme, that can be easily integrated with the IEEE 802.15.4 protocol stack. The proposed scheme takes into consideration the generic property of low channel utilization in BSNs and enables affected BSNs to adaptively reschedule their transmission time or switch channels. Based on the detected information from neighboring BSNs, BSNs reschedule their transmissions in a distributed and coordinated manner, so that wireless channels can be effectively utilized by multiple BSNs. Moreover, the IIM scheme is performed only when the performance of the BSN is degraded to an unacceptable level due to severe interference to reduce the rescheduling cost. Simulation results show that the proposed scheme improves the network throughput by 18% and reduces the energy consumption by 22% as compared with the existing beacon schedule scheme.

1. Introduction

Body sensor network (BSN) enables wireless communications between several miniaturized body sensors and a single coordinator worn on the human body. Since a BSN provides remote and continuous health monitoring for patients without constraining their movements, it plays a crucial role in next generation healthcare applications [1,2].

As physiological information is transmitted in BSNs, reliable data transmission is crucial. Inter-user interference, which is incurred by simultaneous transmissions of multiple BSNs in the same vicinity, deteriorates reliable communication of BSNs. Natarajan et al. [3] highlighted the existence of inter-user interference, and found that such interference reduces packet delivery rate by 35% in the presence of eight or more interfering BSNs. In our previous work [4], we investigated the prevalence and severity level of inter-user interference in a realistic BSN deployment in a hospital scenario, and showed that only 68.5% of data transmission can meet the reliability requirement even in the off-peak period. Such a situation is aggravated when more BSN applications are deployed [4]. Therefore, it is imperative to devise an effective inter-user interference mitigation scheme for BSNs.

The existing interference mitigation methods designed for other networks are inappropriate for BSNs due to the following reasons:

First, the BSN communication has stringent requirements such as reliability and energy efficiency in healthcare applications. The commonly used contention-based carrier sense multiple access with collision avoidance (CSMA/CA) method [5] may not be able to satisfy the communication requirement of BSNs due to its unreliable clear

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channel assessment (CCA), traffic correlation, and severe collisions [6].

Second, exchange of messages exists only within the cluster of sensor nodes in a BSN and there is no message exchanges among BSNs. Without inter-BSN communication, it is challenging for BSNs to collect the surrounding information and take actions in a coordinated manner to reduce interference. For example, the mesh election algorithm is effectively used in the IEEE 802.16 wireless mesh network [7,8] to avoid collisions among nodes by using the neighborhood information obtained by inter-device coordination. However, such coordination is inapplicable in BSNs.

Third, BSNs are usually mobile which differentiates them from most other wireless sensor networks (WSNs). In WSNs, inter-cluster interference can be minimized by a self-organizing medium access control (MAC) allocation scheme based on the feedback derived from collisions experienced by the local nodes within a cluster [9]. This method is difficult to apply in BSNs, as the delay for the feedback becomes intolerable when mobility is involved. Another similar example is the cluster scheduling and collision avoidance problem in IEEE 802.15.4 beacon-enabled cluster-tree WSNs [10], in which beacons from different clusters are assigned to transmit in their dedicated time slots using time division method. However, a static and predefined deployment of wireless nodes is assumed, making it inapplicable in the mobile BSN scenarios.

The above mentioned challenges motivate us to design a lightweight and distributed inter-user interference mitigation (IIM) scheme explicitly for BSNs. In this paper, we propose an IIM scheme, which takes into consideration the generic property of low channel utilization in BSNs and enables BSNs to adaptively reschedule their transmission time or channel if interference occurs. It includes dynamic detection of inter-user interference, collection of neighboring information, and rescheduling of transmission accordingly.

The main contributions of this paper are as follows. Firstly, we model the inter-user interference in BSNs and calculate the rescheduling time of a BSN in two dimensions, target to mitigate the interference with the shortest latency. Secondly, we propose a scheme to mitigate inter-user interference in a distributed manner without relying on any centralized synchronization mechanism. The proposed scheme is reservation-based, while the benefits of reservation-based and contention-based schemes are combined to reduce the rescheduling cost. Thirdly, we conduct extensive performance evaluation through simulations and prove that the proposed scheme significantly improves throughput and energy consumption, as spectrum utilization is improved by rescheduling the transmissions of multiple BSNs on the same channel for the low loading BSN scenarios.

The remainder of this paper is organized as follows. In Section 2, we review the related work in interference mitigation schemes for BSNs. Section 3 describes the network model and then formulates the inter-user interference. Section 4 introduces our scheme to mitigate inter-user interference. Then the performance of the proposed mitigation scheme is analyzed in Section 5. Section 6 compares the performance of the proposed scheme with the existing approaches through simulations. Finally, Section 7 concludes this paper.

2. Related work

The existing interference mitigation schemes for BSNs mainly fall into several categories: frequency division multiple access (FDMA), power control, and time division schemes.

Sergio and Chen [11] proposed a FDMA approach, where each BSN is assigned a different frequency channel at the network initialization phase. This approach allows monitoring as many patients as available channels, but radio channels are hard to be reused in a dynamic way. To increase the number of monitored BSNs and enable them to move freely, an alternative approach is to allocate channels dynamically in the small-scale deployment of BSNs. Silva et al. [12] developed an infrastructure-based scheme, where BSNs are reallocated channels by a fixed infrastructure when they move into the radio range of each other. This scheme reduces interference effectively if the number of congregated BSNs within the interference range is fewer than the number of available channels. However, besides the infrastructure cost, this approach leads to frequent channel switching, which incurs much overhead and is thus unsuitable for occasional and short-term interference.

Power control is another approach to reduce the interference in multi-user environments. Wu et al. [13] proposed a power control approach for interference mitigation, where each BSN measures the interference from other BSNs and then selects a suitable channel and transmission power by utilizing non-cooperative game theory and a no regret learning algorithm. A major drawback of this method is the long iteration period (more than 20 iterations) to reach the optimal point. As such, the utilized channels and transmission powers may be changed frequently during the long computing period which makes the system unstable. Power control improves spatial utilization of channels, but it may compromise transmission performance with a reduced transmission power [4].

In healthcare applications, the channel utilization of a BSN is usually low for energy conservation. Kim et al. [14] proposed a distributed flexible beacon schedule scheme to reduce the interference. By employing carrier sensing before each beacon transmission, collisions can be avoided if other BSNs attempt to access the channel at the same time. This scheme consumes additional energy in the channel access as multiple carrier sensing iterations are possibly conducted before each beacon transmission. Considering the periodic data characteristics in most BSN applications, a reservation-based scheme outperforms a contention-based scheme in terms of energy conservation and throughput enhancement, because overhead and collisions are significantly reduced in the reservation-based approach. As such, our proposed IIM scheme utilizes the reservation-based approach, where reservations are made dynamically based on the information acquired from channel listening. The simulation results in Section 6 show that