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A two-stage game theoretical approach for interference mitigation in Body-to-Body Networks☆

Amira Meharouech, Jocelyne Elias*, Ahmed Mehaoua

LIPADE Laboratory, Université Paris Descartes - Sorbonne Paris Cité, 75006 Paris, France

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ABSTRACT

In this paper, we identify and exploit opportunities for cooperation between a group of mobile Wireless Body Area Networks (WBANs), forming a Body-to-Body Network (BBN), through inter-body interference detection and subsequent mitigation. Thus, we consider a dynamic system composed of several BBNs and we analyze the joint mutual and cross-technology interference problem due to the utilization of a limited number of channels by different transmission technologies (i.e., ZigBee and WiFi) sharing the same radio spectrum. To this end, we propose a game theoretical approach to address the problem of Socially-aware Interference Mitigation (SIM) in BBNs, where WBANs are "social" and interact with each other. Our approach considers a two-stage channel allocation scheme: a BBN-stage for inter-WBANs' communications and a WBAN-stage for intra-WBAN communications. We demonstrate that the proposed BBN-stage and WBAN-stage games admit exact potential functions, and we develop a Best-Response (BR-SIM) algorithm that converges to Nash Equilibrium points. A second algorithm, named Sub-Optimal Randomized Trials (SORT-SIM), is then proposed and compared to BR-SIM in terms of efficiency and computation time. series We further compare the BR-SIM and SORT-SIM algorithms to two power control algorithms in terms of signal-to-interference ratio and aggregate interference, and show that they outperform the power control schemes in several cases. Numerical results, obtained in several realistic mobile scenarios, show that the proposed schemes are indeed efficient in optimizing the channel allocation in medium-to-large-scale BBNs.

1. Introduction

Body-to-Body Networks (BBNs) have recently emerged as a promising solution for monitoring the people behavior and their interactions with the surrounding environment [2].

The BBN consists of several WBANs, which in turn are composed of sensor nodes that are usually placed in the clothes, on the body or under the skin [3]. These sensors collect information about the person and send it to the sink (i.e., a Mobile Terminal (MT) or a PDA), in order to be processed or relayed to other networks (Fig. 1) .

BBNs are widely adopted in several mission-critical scenarios: (i) rescue teams in a disaster area, (ii) groups of soldiers on the battlefield [4], and (iii) patients in a healthcare center, whose Wireless Body Area Networks (WBANs) interact with each other. Yet, the BBN can be implemented in both medical and non-medical applications. Indeed, BBNs represent the novel trend for future, ubiquitous healthcare systems, in which the remote monitoring of patients carrying bodyworn sensors and relaying each others physiological data up to the medical center, could greatly

☆ Very preliminary results of this work have been presented in [1].

* Corresponding author. Tel.: +33 183945813.
E-mail addresses: amira.meharoueche@etu.parisdescartes.fr (A. Meharouech), jocelyne.elias@parisdescartes.fr, jocelyne.elias@gmail.com (J. Elias), ahmed.mehaoua@parisdescartes.fr (A. Mehaoua).

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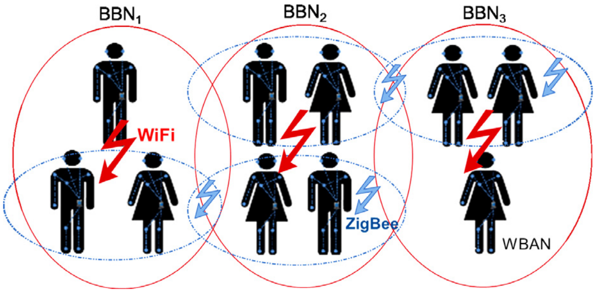

Fig. 1. Three-BBN interfering scenarios: each BBN is composed of several WBANs which use different transmission technologies (i.e., ZigBee and WiFi) sharing the same radio spectrum.

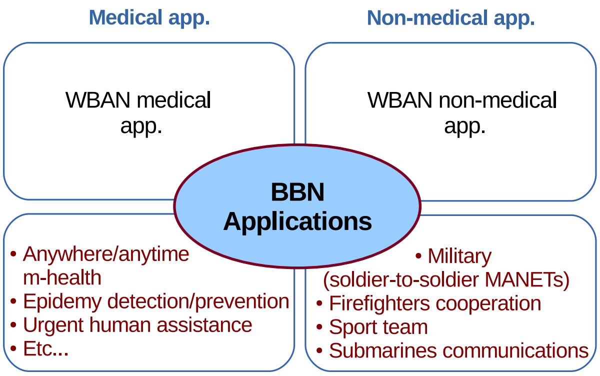

Fig. 2. Application area extensions from WBAN to BBN.

reduce the current strain on health budgets and make the Government's vision of ubiquitous healthcare for distant patients a reality. For example, when a patient is at home or far from the medical center, and feels a sudden trouble, she will be able to broadcast a distress call and bring out an urgent human assistance from his neighborhood. Hence, the sensors could be embedded into mobile handsets, portable electronic devices, cars, and clothing. Due to low-power Body-to-Body Networks, people would no longer need to be in the range of a cellular tower to make a call or transmit data. Fig. 2 sorts the different BBN applications into medical and non-medical classes, and lists the new intended applications by the deployment of BBN networks.

Due to the scarce wireless resources, many existing wireless technologies, like IEEE 802.11 (WiFi), IEEE 802.15.1 (Bluetooth) and IEEE 802.15.4 (ZigBee), are forced to share the same unlicensed 2.4 GHz Industrial, Scientific and Medical (ISM) band. Hence, mutual as well as cross-technology interference may occur between these technologies.

Indeed, the interference issue is already handled by the Bluetooth Low Energy (BLE) standard [5], which defines three channels as advertising channels, used for device discovery and connection establishment, and have been assigned center frequencies that minimize overlapping with IEEE 802.11 channels 1, 6 and 11, which are commonly used in several countries. Then, an *adaptive frequency hopping* mechanism is used on top of the 37 data channels in order to face interference and wireless propagation issues, such as fading and multipath. This mechanism selects one of the 37 available data channels for communication during a given time interval, so as to avoid interference with neighboring wireless links. Furthermore, a number of previous works enhanced the existing frequency hopping mechanism and implemented further schemes, such as the OverLap Avoidance (OLA) proposed in [6].

Coexistence and interference mitigation between WBANs are also considered by the IEEE 802.15.6 standard. Three mechanisms are defined: *beacon shifting*, *channel hopping* and *active superframe interleaving* [7]. Yet, our choice for ZigBee aims at effectively and theoretically tackling the cross-technology interference problem between WiFi (802.11) and ZigBee (802.15.4) technologies.

Since WiFi transmission power can be 10 to 100 times higher than that of ZigBee, ZigBee communication links can suffer significant performance degradation in terms of data reliability and throughput. In addition to the previously mentioned challenging issues, the mobility of WBANs in their surrounding environment and their interactions with each other make the interference mitigation in Body-to-Body networks a very interesting and mandatory problem to address. This is indeed the main focus of our work.

In this paper we consider a multi-BBN scenario (an example scenario, with 3 BBNs, is illustrated in Fig. 1), composed of a set of WBANs that share the same ISM band, and we address the mutual and cross-technology interference mitigation problem introducing a new game theoretical approach. The proposed approach consists of two nested games. The first game aims to allocate WiFi channels for inter-WBANs' wireless communications. Specifically, special players (which are called "delegates" or "leaders") decide the allocation of the needed WiFi channels for themselves and the underlying subnetworks by maximizing an utility function, which is a function of mutual and cross-technology Signal-to-Interference Ratio (SIR) metric. The second proposed game is a WBAN-stage SIM game that allows players (or WBANs) to choose the needed ZigBee channels for intra-WBAN communications, taking into account the allocations performed by the BBN-stage SIM game.

The main contributions of our work are the following:

- We propose a novel game theoretical approach for mutual and cross-technology interference mitigation in BBNs.
- We provide a detailed expression of the *Signal-to-Interference Ratio* to define players' payoff functions, capturing all main interference components, namely the co-channel, the mutual, and the cross-technology interference.
- We demonstrate that our games admit at least one pure strategy Nash Equilibrium (NE) since they are exactly potential, and we develop best response algorithms (BR-SIM) to compute the channel allocations, which converge fast to NE solutions.
- We propose a second algorithm, called Sub-Optimal Randomized Trials (SORT-SIM), that trades-off between efficient channel allocation process and short