Socially-Aware Interference Mitigation Game in Body-to-Body Networks

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***Abstract*—Wireless wearable devices have recently gained increasing attention from industry in fields such as health, fitness, and entertainment. In this paper, we consider a dynamic system composed of several Body-to-Body Networks (BBNs) based on wearable technology, 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. Our approach considers a two-stage channel allocation scheme: a BBN-stage for inter-WBANs' communications and a WBAN-stage for intra-WBAN communications, involving mutual and cross-technology considerations at each stage. We develop best response algorithms that converge fast to Nash equilibrium points. Simulation results show the efficiency of SIM game in optimizing the channel allocation in BBNs.**

Index Terms*—Body-to-Body Networks, 2.4 GHz ISM band, Cross-Technology Interference, Channel Allocation, Game Theory, Nash Equilibrium.

I. Introduction

Body-to-Body Networks have recently emerged as promising solutions for the monitoring of people behavior and their interaction with the surrounding environment [1]. BBNs may represent a number of scenarios: (i) different rescue teams in a disaster area, (ii) groups of soldiers on the battlefield, and (iii) different patients in a healthcare center, whose Wireless Body Area Networks (WBANs) interact with each other. 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 [2]. 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.

Due to the scarce wireless channel 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. Furthermore, 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 focus of the paper. Whereas in [3], this problem has been tackled in a completely centralized way, in the present work we address the interference issue in BBNs using concepts from Game Theory within a distributed model.

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.
- A detailed expression of *Signal-to-Interference Ratio* is proposed to define the payoff function of the players.
- We develop a best response algorithm to compute the channel allocations, that converges fast to Nash Equilibrium (NE) points.
- We perform the performance analysis of the BBN- and WBAN-game stages under different system parameters.

II. Two-stage game theoretical approach for interference mitigation in BBNs

We consider a multi-BBN scenario where every single WBAN's MT is muniequipped with one WiFi antenna and one ZigBee antenna and should dispose of non overlapping WiFi and ZigBee channels. We divide the operating time of the whole system into a set T of consecutive epochs. Let $\mathcal{C}^w$ and $\mathcal{C}^z$ denote, respectively, the set of WiFi and ZigBee channels in the ISM band. No interference is present within a WBAN; we assume a TDMA-based medium access control implemented in each WBAN to deal with collisions. The interference between overlapping WiFi and ZigBee channels is represented by the matrix A, of size $|\mathcal{C}^w|\times|\mathcal{C}^z|$, whose element is a binary value: $a_{c_1c_2} = 1$ if WiFi channel c_1 overlaps with ZigBee channel c_2 (0 otherwise). The degree of interference between overlapping WiFi channels is represented by the matrix $\mathcal{W}$, of size $|\mathcal{C}^w| \times |\mathcal{C}^w|$, whose element $w_{c_1c_2} \in [0, 1]$ is a fractional value, defined in [4]. The set $\mathcal{L}^w(t)$ represents all WiFi unidirectional links established by mobile terminals during the epoch $t \in T$, and $\mathcal{L}^z$, represents the ZigBee unidirectional links used for intra-WBAN communication among the sensor nodes. To preserve the connectivity within the BBN, a unique WiFi channel is required by each *connex component*, i.e., the set of connected WBANs over WiFi links of the same BBN referred to as *sub-BBN*. Representative WBANs (delegates) decide the allocation of the needed WiFi channels for themselves and the underlying sub-BBNs. Such connectivity is represented using the $|\mathcal{L}^w| \times |\mathcal{L}^w|$ matrix B, whose element is a binary value: $b_{ij} = 1$ if WiFi links i and j belong to the same sub-BBN (0 otherwise).

Thereby, we can define the BBN-stage of the SIM game such as the *players* are the set of BBNs represented by their delegates, each assimilated to its WiFi link $l \in \mathcal{L}^w$, the *strategy/action*, $s^l(t) = x^l_{c_1}(t)$, is to choose a WiFi channel c_1 to WiFi link l from the set of available channels in $\mathcal{C}^w$ at time epoch $t \in T$, and the *utility function* consists in the worst SIR values perceived by the two radio interfaces, WiFi and ZigBee. We propose the following expression of SIR that considers interfering transmitters using different technologies:

$$SIR^w(x^l_{c_1})(t) = 10log(\frac{g_{ll}p^l_w}{I^w_{c_1}(x^l_{c_1}) + I^w(x^l_{c_1}) + I^{wz}(x^l_{c_1})}), \quad (1)$$

Similarly, the WBAN-stage game is defined such as the WBANs are the players, each assimilated to its ZigBee link $h \in \mathcal{L}^z$, the strategy/action $s^h(t) = y^h_{c_2}(t)$, is to choose a ZigBee channel c_2 to ZigBee link h from the set of available channels in $\mathcal{C}^z$. Finally, the utility function consists in the SIR considering the ZigBee interface which is used for intra-WBAN communications, given by:

$$SIR^z(y^h_{c_2})(t) = 10log(\frac{g_{hh}p^h_z}{I^{wz}(y^h_{c_2}) + I^z(y^h_{c_2})}), \quad (2)$$

where

$$I^w_{c_1}(x^l_{c_1}) = \sum_{\substack{k \in \mathcal{L}^w \\ b_{kl}=0}} x^l_{c_1} x^k_{c_1} g_{lk} p^k_w\text{: WiFi co-channel interference}$$

$$I^w(x^l_{c_1}) = \sum_{\substack{k \in L^w \\ b_{kl}=0}} (\sum_{\substack{c \in C^w \\ c \neq c_1}} w_{c_1 c} x^l_{c_1} x^k_c) g_{lk} p^k_w \text{ : WiFi mutual interference}$$

$$I^{zw}(x^l_{c_1}) = \sum_{\substack{k \in L^z \\ k \neq h}} (\sum_{c \in C^z} a_{c_1 c} x^l_{c_1} y^k_c) g_{lk} p^k_z \text{ : ZigBee cross-interference}$$

$$I^{wz}(y^h_{c_2}) = \sum_{\substack{k \in \mathcal{L}^w \\ b_{kl}=0}} \sum_{c \in \mathcal{C}^w} a_{cc_2} x^k_c y^h_{c_2} g_{hk} p^k_w \text{ : WiFi cross-interference}$$

$$I^z(y^h_{c_2}) = \sum_{k \in \mathcal{L}^z} y^k_{c_2} y^h_{c_2} g_{hk} p^k_z \text{ : ZigBee co-channel interference}$$

g_{ll} and g_{hh} are respectively the channel gains of links l and h, g_{lk} the link gain from the transmitter k to the receiver l, p^k_w and p^k_z are the WiFi and ZigBee transmit power, respectively. We demonstrate that, when a player $l \in \mathcal{L}^w$ deviates from a strategy s^l to an alternate strategy $\hat{s}^l$, the change in a defined potential function exactly mirrors the change in l's utility. The same applies to player $h \in \mathcal{L}^z$. Therefore, the two-stage SIM game is an exact potential game, then, according to [5], it admits at least one pure Nash Equilibrium.

III. Best-Response algorithm for channel allocation in BBNs

Motivated by the Finite Improvement Property (FIP) of potential games, we propose an iterative algorithm that implements a best-response dynamics for our SIM game. The algorithm is processed at time epoch $t \in T$ and starts with the initialization of WBANs with random WiFi and ZigBee channels, with respect to the connectivity criterion within BBNs. Then, the algorithm iteratively examines whether there exists any player that is unsatisfied, and in such case a greedy selfish step is taken so that such player l changes his current strategy $s^l(\tau)$, $\tau < t$, to a better strategy $s^l(\tau+1)$ with respect to the current action profile of all other players. The same applies to the ZigBee best-response update, except that the strategy domain of the ZigBee player h is delimited to the set of available ZigBee channels $C^z_h(t)$, i.e., not overlapping with its WBAN WiFi channel assigned at time epoch t. Due to the FIP property, such algorithm is guaranteed to converge in a finite number of iterations to a BBN-stage NE, and then to a WBAN-stage NE where no player has an incentive to deviate from his best-response choice.

IV. Performance evaluation

Different BBN scenarios have been simulated using the Scilab software package. We refer to the BBN-specific channel gain model in [6]. The mobile WBANs, which number varies in the range [20,40], are randomly deployed in a $1000 \times 1000m$ area, and divided into four overlapping BBNs. The mobility is simulated using the common *random waypoint model*. We specifically evaluate the effect of the WBANs density within the BBNs on the dynamics of the SIM game algorithm. As expected, increasing the BBN density results in increasing the network overall interference and then the number of iterations to reach an equilibrium. Besides, Fig.1 and Fig.2 display the evolution of the average signal-to-interference ratios by each BBN, for the BBN stage and WBAN stage respectively. Accordingly, our best-response algorithm is proved to ensure a rather fair, socially-aware channel allocation, so that both WiFi and Zigbee SIRs tend to be quite close to a mean value at the Nash Equilibrium. Finally, it has been observed that the best-response SIM algorithm quickly converges to a stable operational point in few iterations (less than 10), thus representing a practical solution for interference mitigation in realistic BBN scenarios.

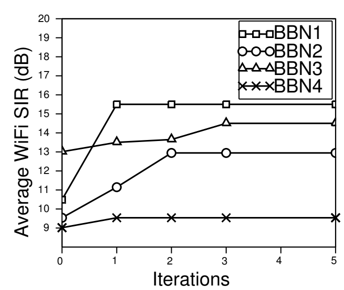

Fig 1: WiFi SIR dynamics.

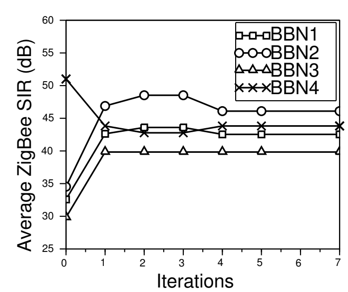

Fig 2: ZigBee SIR dynamics.

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