UWB Body Area Network Coexistence by Interference Mitigation

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***Abstract*—This work analyzes the performance of a BAN composed of IEEE 802.15.4a Ultra Wide Band (*UWB*) sensors in terms of Bit Error Rate (BER), BAN throughput and network lifetime. The BAN performance is evaluated in presence of an external Low Data Rate (LDR) interfering network, that we suppose represented by a second BAN operating in the same hospital room. Coexistence between the two wireless networks is discussed and the reference BAN performance is improved by the adoption of an optimized time hopping code assignment strategy. A possible strategy to extend the lifetime of the network is also introduced.**

I. Introduction

Body Area Networks consist of a number of wireless sensors located on the human body or in close proximity such as on everyday clothing [1]. The important role potentially played by these peculiar kind of wireless networks can be understood if one considers, as an example, a medical environment where, on the basis of the information sent by a BAN worn by a patient, the healthcare system of the hospital can be aware of the person vital functions and take the appropriate countermeasures in case of medical alert [2]. The BAN must be capable of providing detailed and reliable information about the patient status and to communicate and interoperate with other wireless systems located in the hospital building. Healthcare is not the only field where a wireless BAN appears particularly suited: sports monitoring and entertainment contents sharing seem to provide alternative and promising application frameworks for such networks [3]. As a consequence, a standardization task group focused on wireless BAN, named IEEE 802.15.6, has started its activity since December 2007. Though the standardization activity of IEEE 802.15.6 is far from being completed at the moment, some important indications have been provided:

- the fundamental importance of employing sensors characterized by low power consumption, in order to extend network lifetime and protect the human tissue;
- the need for a reliable and accurate response to external stimuli [4];
- necessity of a scalable MAC (TDMA-like) [3][5].

These prerequisites seem to be adequately met by the adoption of the Ultra Wide Band (*UWB*) technology, that grants a high temporal resolution, resistence to multipath, availability of inexpensive sensors, and low power requirements for extended monitoring periods [6]. Impulse Radio (IR) *UWB* is adopted by IEEE 802.15.4a standard, the main goal of which is represented on one side by the achievement of energy-efficient communications with data rates comprised between 10 kbits/s and several Mbits/s [7], and on the other by the introduction of accurate ranging capabilities not available in IEEE 802.15.4, enabling new applications based on information on distance and positions of the devices in the network. Though the standardization work in IEEE 802.15.4a was not in general focused on BANs requirements, the channel model includes a specific model for BANs. This model is considerably different from the other environments, since it has to take into account the effect of the human body on signal propagation. This specific channel model for BANs is used in this work for simulation activities. The adoption of IEEE 802.15.4a specifications provides a useful framework to test the performance of a wireless BAN based on IR-*UWB* technology with the beneficial effects of maintaining compatibility with existent and future wireless standards and of meeting the preliminary indications of IEEE 802.15.6. It is possible to assume that interworking modules (IW) would be present for interfacing the network layer of different wireless networks [8], as shown in Figure 1. While the performance of a single BAN in terms of number of sensor nodes and asynchronism level between the nodes of the network has been discussed in [8], this paper analyzes the reference BAN performance in terms of Bit Error Rate (BER) and throughput in presence of an external Low Data Rate (LDR) interfering network. We suppose that the interfering network is represented by a second BAN operating in the same hospital room. Coexistence between the

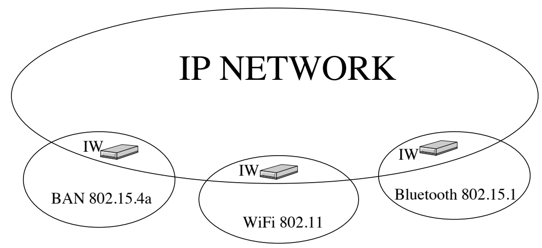

Fig. 1: Schematization of the interoperability between different wireless networks. The interworking modules (*IW*) are illustrated.

two wireless networks is discussed and the reference BAN performance is improved by the adoption of an optimized code assignment strategy. A possible strategy to extend network lifetime is also introduced. The paper is organized as follows. Section II explains the transmission model and the reference BAN architecture. Section III describes the proposed interfering scenario and provides a first set of simulation results. Section IV introduces an optimized code assignment strategy, and provides a second set of simulation results. Section V introduces an energy saving strategy for the BAN, and Section VI concludes the paper.

II. Transmission model and reference BAN architecture

A. Signal structure

According to the IEEE 802.15.4a the *UWB* physical layer (*UWB*-PHY) operates in a mandatory Low Frequency Band (LFB) centered at 4.4928 GHz and in a mandatory High Frequency Band (HFB) centered at 7.9872 GHz [7]. The standard defines six different data rates, but only 0.85 Mbits/s is mandatory so far. In this work, the mandatory rate was adopted for BANs analysis and simulation activity. The IEEE 802.15.4a modulation baseline allows a simple and scalable modulation format. It provides Time Hopping (TH) codes in order to achieve multiple access [9]. The *UWB*-PHY uses an IR-based signaling scheme in which each information-bearing symbol is represented by a sequence/burst of short time duration pulses. The duration of an individual pulse is nominally considered to be the length of a chip. Chip duration is equal to 2.02429 ns (chipping rate of 499.2 MHz). The modulation format implies a symbol duration of 1025.64 ns. A symbol period is composed of 32 time bursts, the first half for transmitting a 0, the second half for transmitting a 1. Each time slot is defined by 16 chip times. When a symbol is transmitted, a single temporal burst is used among the 32 available time bursts. In this burst, each chip time is occupied by a transmitted pulse. The TH codes are used for assuring multiple access [9]. Due to the symbol period subdivision, the cardinality of the TH code associated to a single sensor is limited to 16 [7]. The signal structure is represented in Figure 2. In October 2008, the European Commission has issued new details of the licensing regulations for *UWB* networking in Europe. Table 1 provides the maximum mean EIRP density per frequency band. Note that in the frequency range comprised between 6 GHz and 8.5 GHz, the allowed EIRP is the same as the value indicated by the Federal Communication Committee (FCC) for *UWB* emissions in the frequency range between 3.1 and 10.6 GHz. The European Commission reports indicate that the range 6-8.5 GHz is the most likely long-term regulatory solution for UWB in Europe. It is of interest to note that the mandatory high frequency band in IEEE 802.15.4a is included in this frequency interval. Based on of the European emissions constraints shown in Table 1, a signal that exploits the $-41.3\,\text{dBm/MHz}$ allowed *EIRP* in the high frequency mandatory band of IEEE 802.15.4a has been adopted in this paper. Each baseband chip is represented by

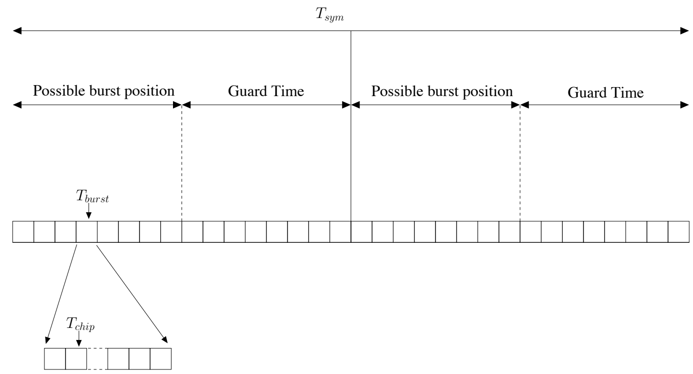

Fig. 2: Symbol period structure for the transmitted signal. The time burst and the chip time duration are illustrated.

a raised-cosine pulse shape with roll-off factor β = 0.6, given by the following expression:

$$p(t) = \frac{4\beta}{\pi\sqrt{T_p}} \frac{\cos\left((1+\beta)\pi t/T_p + \frac{\sin((1-\beta)\pi t/T_p)}{4\beta t/T_p}\right)}{(4\beta t/T_p)^2 - 1}, \quad (1)$$

where T_p is the pulse duration. Figure 3 shows a portion of the signal PSD containing the frequencies of interest for the mandatory HFB.

B. BAN structure and organization

We have considered a BAN composed of a set of small wearable devices distributed along the body. Each node is able to perform data acquisition and communicate with a central node (*master node*) worn on the body. The *master node* is able to communicate with the outside world using a standard telecommunication infrastructure. The considered network architecture is centralized [8]. Sensors capable of monitoring some key vital functions, such as the electrical activity of the brain, are included. We have taken into account an average body extension while planning the sensors distribution. The disposition of the sensors is characterized by a couple of sensors located on the patient head; a couple of sensors located on the chest at the heart level; two sensors attached to the wrist of each arm; two sensors attached just above the knee of each leg, as shown in the reference BAN schematization of Figure 4. The *master node* is located on

Frequency range (GHz)	Max mean EIRP density(dBm/MHz)
below 1.6	-90.0
3.1 to 4.2	-41.3 (with DAA)
4.2 to 4.8	-41.3
4.8 to 6.0	-70.0
6.0 to 8.5	-41.3
8.5 to 9	-41.3 (with DAA)
9.0 to 10.6	-65
above 10.6	-85.0

TABLE I: European UWB Emission Constraints.

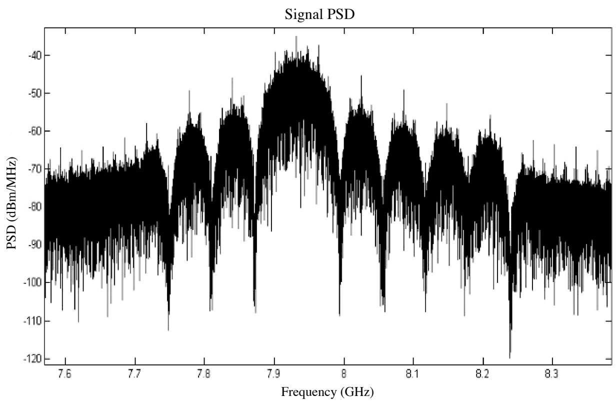

Fig. 3: PSD of the emitted signal in the high frequency mandatory band indicated by IEEE 802.15.4a.

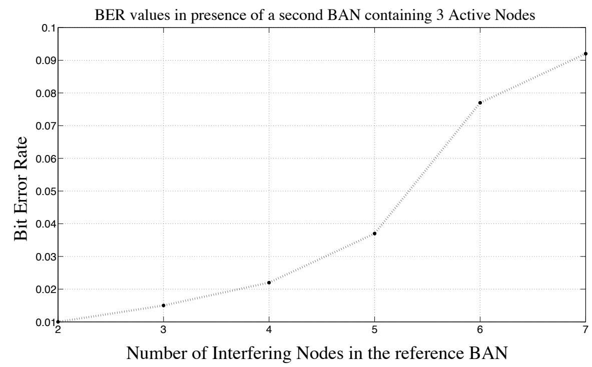

Fig. 5: Performance of the reference BAN in terms of average BER as a function of the number of interfering nodes in presence of a second interfering BAN.

the abdomen left side. The useful transmission suffers from the interference of the nearby sensor nodes that are also transmitting their monitoring information to the *master node*, due to loss of orthogonality during network operation. The *master node* is an intelligent sensor capable of communicating with other wireless networks. Figure 4 (right-side) provides a MATLAB representation of the sensors disposition for the reference BAN.

III. Interfering scenario and simulation results

A. Interfering scenario details

The chosen simulation scenario is motivated by the possibility of studying the effect of an interfering *UWB* network on the reference candidate BAN. A reference BAN composed of at most 10 active sensor nodes has been considered. The simulation scenario foresees the presence of a second Low Data Rate (LDR) interfering network in the hospital room. The *UWB* interfering network is represented by a second BAN. The interfering BAN contains a fixed number of active nodes, set to 3, since 3 monitoring nodes are in general capable of providing the basic patient vital information. The number of interfering nodes of the reference BAN varies from 3 to

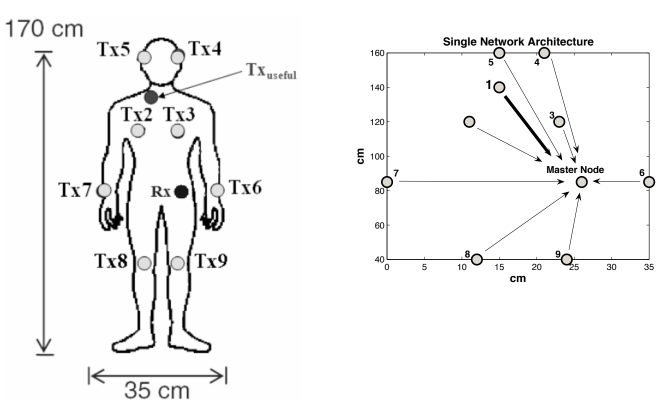

Fig. 4: BAN Sensors positions and corresponding MATLAB representation.

8 during simulation activity. The distance between the two master nodes (receiver nodes) is set to 1.5 meters, supposing the two patients lying in two beds located in the same hospital room. The maximum asynchronism level between the nodes of the reference BAN is set to T_s (the transmission temporal burst). This accounts for loss of orthogonality between the transmitting nodes in the reference BAN, that we suppose initially characterized by randomly generated orthogonal TH codes. A completely random generation of the orthogonal codes represents a simplified approach with respect to the way codes are assigned in IEEE 802.15.4a, where a specific polynomial is used to generate a pseudo random binary sequence [7].

B. Simulation results in terms of BER and throughput

Simulation results are presented in Figure 5. Results reported in this section provide a first indication of network performance. In particular, the average BER values do not take into account the fact that bit errors occur as burst-errors due to the different nature of the monitored parameters. On the basis provided by the average BER values only, coexistence with the second BAN seems not feasible even from a quick analysis of Figure 5, and also the reference BAN on its own shows an acceptable performance only with few active interferers [8], if we consider for example a minimum performance threshold set to $BER_{max} = 10^{-3}$. Therefore we have studied and analyzed the BAN performance in terms of packet error rate, including Reed-Solomon (RS) channel coding and the occurrence of burst errors. In particular RS (63,55) codes, as foreseen by IEEE 802.15.4a standard, are used for simulation activity, under the hypothesis that the packet contains approximately one *RS* block, that is 378 bits for the present case (each block being composed of 63 6-bits symbols). On the basis of the error correction properties of the adopted coding, we are capable of deriving the average PER corresponding to the average BER presented in the previous section. According to the BAN structure previously described, a single hop is sufficient to reach the receiver (the *master node*) from the reference node. Based on this observation, we can derive the throughput value as 1-PER. Simulations results are presented in Figure 6. We have supposed that the *master node* considers one third of the nodes of critical importance (and therefore always transmitting their data), while for the rest of the sensors the *master node* opts for more relaxed monitoring requirements (from 30% to 70% of simulation time). This introduces a degree of burstiness in the BER that affects the performance of the RS (63,55) coding when we evaluate the throughput. The RS coding is in fact more effective when correction is applied to burst errors and since the body parameters monitored by the BAN are typically significantly different and their values need to be refreshed as frequently as their variability and their importance for the patient health requires, we have included this aspect while performing simulation. Figure 6 shows that satisfying throughput values ($>90\%$) can be obtained when up to six (the reference transmitter and five interfering nodes) sensors are present.

IV. TH CODING OPTIMIZATION

The effect of asynchronism between the nodes within the single BAN is reduced by optimizing time slots assignment as a function of the interfering nodes number, exploiting the IEEE 802.15.4a UWB signal structure described in Section 2 and represented in Figure 2. The optimized code maximizes the mutual code distances between the active nodes transmission, as shown in Figure 7, making the asynchronism effect significant only if its maximum value is comparable to the optimized distance between two adjacent time slots (the optimized distance is a multiple of T_s). Possible overlapping events due to asynchronism can occur when multiple nodes are transmitting the same symbol (for example a 0) utilizing adjacent time slots for transmission. The proper code assignment can be applied once the effective number of needed active nodes is provided. If the *master node* is able to assign the optimal code to the reference BAN sensors, the performance of the reference BAN with respect to asynchronism between its nodes is obviously drastically improved, especially for a network configuration characterized by a limited number of sensors. It is of interest to test this new code assignment policy when the second interfering network is present, in order to analyze the effect on the throughput performance of the reference BAN, given the fact that the interfering BAN code assignment policy is not affected by code optimization in the reference BAN. Figure 8 shows simulation results in terms of the reference BAN throughput, when the optimized code assignment strategy is applied and burst errors are taken into account. When the optimized code assignment is used, the performance of the reference BAN results acceptable, even when 7 interferers are present and the interfering BAN is active. Throughput values are always greater than 80% and network coexistence is improved even for critical multiuser interference scenarios.

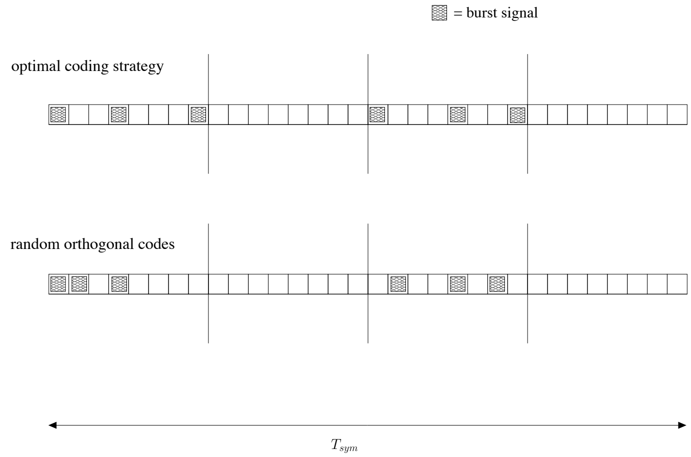

Fig. 7: Simple and optimized code assignment strategies in presence of six different transmitting nodes.

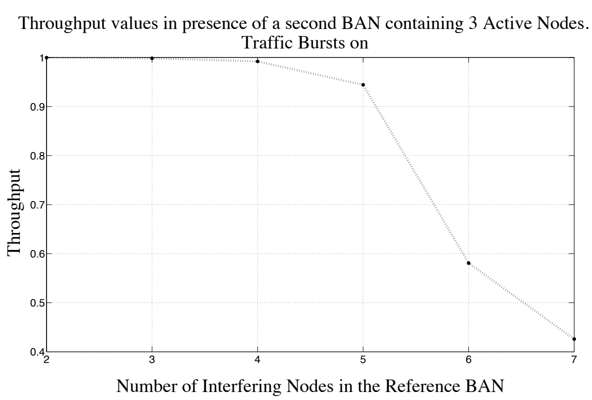

Fig. 6: Performance of the reference BAN in terms of average throughput as a function of the number of interfering nodes in presence of a second interfering BAN. Burst-errors are taken into account.

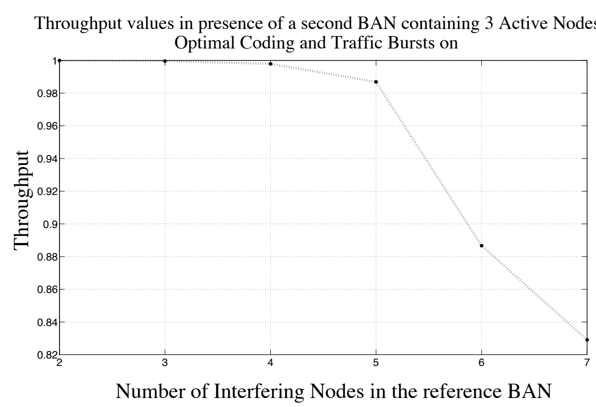

Fig. 8: Performance of the reference BAN in terms of average throughput as a function of the number of interfering nodes in presence of a second interfering BAN. Burst-errors are taken into account and the optimized code assignment strategy is applied.

V. Energy saving strategy

In order to extend the network lifetime, we suggest that the *master node* should be aware of the residual battery life of the nodes in the network, for example by reading periodically the nodes residual energy from the received data packets. If network lifetime falls below a given threshold, the *master node* can impose a variation in the duty cycle of the nodes and in case a consequent change in the transmission rate. The new transmission rate can be for instance selected between the optional rates foreseen by IEEE 802.15.4a, up to 27 Mbits/s. The threshold value depends on the seriousness of the patient health status, since some critical parameters should be monitored more frequently than others. The *master node* is able to impose the correct duty cycle to the nodes on the basis of the received parameters values and on the information retrieved from the healthcare center (for example a computer located inside the hospital). This strategy is not however been included in the simulation investigation presented in this work, and network lifetime is therefore determined by the sensors that are always kept in an active state by the *master node*.

VI. Conclusion

A reference wireless BAN composed of *UWB* IEEE 802.15.4a sensor nodes has been considered and analyzed. The network architecture has been conceived as centralized. All the sensor nodes are capable of performing data acquisition and transfer the information towards the *master node*. The *master node* is able to interact with other wireless networks, and to apply a network transmission strategy aimed at preserving network lifetime while granting reliable monitoring information. A scenario foreseeing the reference BAN in presence of a LDR-*UWB* interfering network has been analyzed and discussed. The considered *UWB* interfering network was represented by a second BAN placed in the same hospital room. The reference BAN performance has been evaluated in terms of BER and throughput in presence of Reed-Solomon channel coding when burst-errors occur due to the described BAN monitoring strategy. An optimized code assignment strategy has been introduced to improve performance and favour network coexistence. The adoption of the introduced code assignment strategy will be further investigated in the future for scenarios of increasing complexity, characterized by heterogeneous wireless interferers. The impact of parameters such as the distance between different codes on the obtained throughput will be the object of future studies. A promising energy saving strategy has been finally introduced in order to extend the lifetime of the network: a set of simulations has been scheduled in order to prove its effectiveness, foreseeing the possibility that the required duty cycle of the single nodes may vary with time according to the patient health status, that is according to the vital parameters values stored in the recent monitoring activity records. The evaluation of the impact of this approach on network lifetime requires a deep understanding of the single vital parameters in order to preserve the reliability of the information sent by the sensors. While the strategy basic principles have been provided in this paper, results and possible advantages will therefore be discussed and analyzed in future work. As a final consideration, it certainly would be of interest to consider a *master node* capable of sensing the radio environment in order to optimize the BAN performance both selecting the more appropriate channel and optimizing code assignment within the single channel and at the same time maximizing network lifetime while preserving information reliability.

Acknowledgment

This work was partially supported by the Integrated Project PULSERS Phase II (contract FP6-027142).

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