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UWB Body Area Networks: Coexistence Analysis and Performance Optimization

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Abstract: Body Area Networks (BANs) are wearable wireless sensor networks with a high potential for medical and sports applications. BANs appear to be a particularly appealing solution to provide information about the health status of a patient in medical environments such as hospitals or medical centres. Ultra Wide Band (UWB) technology grants a high temporal resolution, resistence to multipath, availability of inexpensive sensors and considerably low power requirements for extended monitoring periods. UWB is adopted by IEEE 802.15.4a standard, whose main goal is represented by the achievement of energy-efficient communications with data rates comprised between 1 kbits/s and several Mbits/s. This work analyzes the behaviour of a reference BAN composed of IEEE 802.15.4a UWB sensors in presence of a Low Data Rate (LDR) UWB interfering network represented by a second BAN located in the same room. An optimized code assignment policy to favour network coexistence is also introduced. Performance evaluation takes into account Bit Error Rate (BER) as a function of the number of nodes forming the reference BAN when a second BAN with a fixed number of nodes is present.

Keywords: Body Area Networks, Ultra Wide Band, Network Coexistence.

1. 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 particular wireless networks can be easily understood if one considers the application example provided by a medical environment where, on the basis of the information sent by a BAN worn by a particular patient, the hypothetical healthcare system of the hospital can be aware of the patient vital functions and can take the appropriate countermeasures in case of medical alert [2][3]. In order to play properly this extremely delicate and potentially life-saving role, the BAN must not only be capable of providing detailed and reliable information about the patient status, but also to dialogue and interoperate with other wireless systems located in the hospital building [4].

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 considerably low power requirements for extended monitoring periods [5]. Thanks to its peculiar features, UWB is adopted by IEEE 802.15.4a standard, whose main goal is represented by the achievement of energy-efficient communications with data rates comprised between 1 kbit/s and several Mbits/s. The IEEE 802.15.4a channel model includes a specific model for BANs, which is different from the other environments for several reasons. In fact since the devices composing this particular class of networks are practically worn by the users, the human body affects significantly the radio propagation channel characteristics and plays a primary role in the analysis of the wireless BANs performance. In addition to the effect due to the human body, the main scatterers are located in the nearfield of the antenna, at very short distances [6]. The overall effect is that the BANs-tailored channel model has to take into account different path loss, amplitude distribution, clustering, and inter-arrival time compared to the other channel models conceived in the framework of IEEE 802.15.4a [7]. The adoption of IEEE 802.15.4a provides the beneficial effect of maintaining compatibility with existent and future wireless standards. Based on the IEEE 802.15.4a compliance, it is possible to assume that interworking modules (IW) are present for interfacing the network layer of different wireless networks [8], as shown in Figure 1.

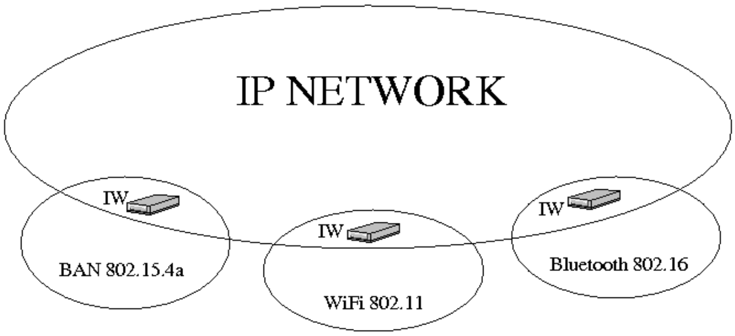

Figure 1. Schematization of the interoperability between different wireless networks. The Interworking Modules (IW) are evidentiated.

The adoption of an IEEE standard for the sensors of the BAN grants the compatibility at network layer. In this way, interoperability between the BAN and other UWB sensor networks or High Data Rate (HDR) systems can be provided.

The paper is organized as follows. Section 2 explains the signal structure. Section 3 gives information about the recently defined UWB emission constraints in Europe. Section 4 describes the adopted BAN architecture. Section 5 discusses simulation settings and provides simulation results. Section 6 introduces an optimized code assignment policy and provides simulation results for a typical BAN configuration. Section 7 concludes the paper.

2. Signal Structure and Transmission Model

According to the IEEE 802.15.4.a 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. The standard defines six different data rates, but only 0.811 Mb/s is mandatory so far. In this work the mandatory rate will be adopted for BANs analysis and simulation activity. 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 [7][8]. 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 494 MHz). The modulation format implies a symbol duration of 1036.44 ns. A symbol period is composed of 32 time bursts. Each time slot is defined by 16 chip times. When a symbol has to be 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 [5][8]. The signal structure is represented in Figure 2. Pulse Position Modulation (PPM) is used for encoding the bits. PPM implies a time shift that is multiple of the temporal burst.

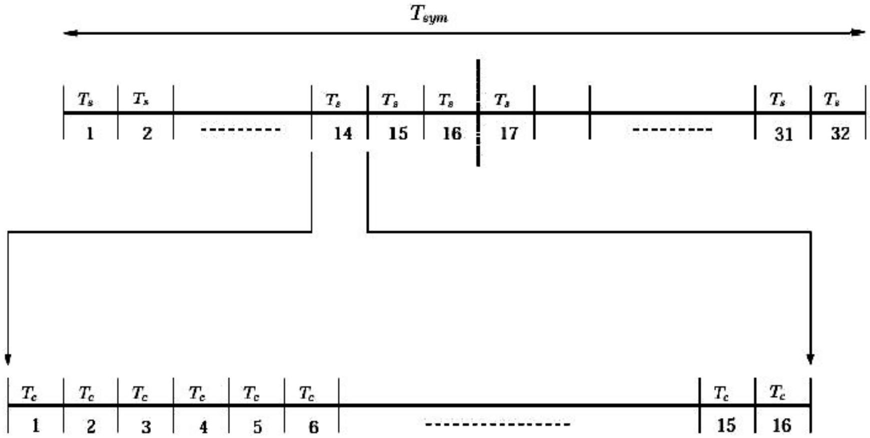

Figure 2. Symbol Period Structure for the Transmitted Signal. The Time Burst and the Chip Time Duration are Evidentiated.

The nominal temporal burst during which a single user has to transmit is defined by the user TH code value. This time slot has to be used if the user wants to transmit the bit 0. If the user wants to transmit the bit 1, he has to use another temporal burst given by the nominal temporal burst plus the PPM burst shift. The reference pulse used by the UWB-PHY is a root raised cosine pulse with roll-off factor of $\beta = 0.6$. Within each symbol period 16 root raised cosine pulses are present in the slot defined by both the TH code and the transmitted bit. The exact analytical expression of the pulse can be found in [7].

Table 1. European UWB Emission Constraints

Frequency Range (GHz)	Max mean EIRP density (dBm/MHz)	Max peak EIRP (dBm/50 MHz)
Below 1.6	-90.0	-50.0
1.6 to 3.4	-85.0	-45.0
3.4 to 3.8	-85.0	-45.0
3.8 to 4.2	-70.0	-30.0
4.2 to 4.8	-41.3 (until Dec 31, 2010)	0.0 (until Dec 31, 2010)
4.2 to 4.8	-70.0 (beyond Dec 31, 2010)	-30.0 (beyond Dec 31, 2010)
4.8 to 6.0	-70.0	-30.0
6.0 to 8.5	-41.3	0.0
8.5 to 10.6	-65.0	-25.0
Above 10.6	-85.0	-45.0

3. European UWB Power Constraints

In May 2007 the European Commission has issued details of the licensing regulations for UWB networking in Europe. Table 1 provides the maximum mean EIRP density per frequency band . Note that in some cases the displayed values will change in a few years. 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 FCC for UWB emissions in the frequency range between 3.1 and 10.6 GHz. It is of interest to note that the mandatory high frequency band in IEEE 802.15.4a is included in the 6-8.5 GHz interval, as highlighted by Table 1. As a consequence of the European emissions constraints shown in Table 1, a signal that exploits the -41.3 dBm/MHz allowed EIRP in the high frequency mandatory band of IEEE 802.15.4a has been adopted in this paper. A portion of the PSD of the used signal in the IEEE 802.15.4a high frequency mandatory band is displayed in Figure 3.

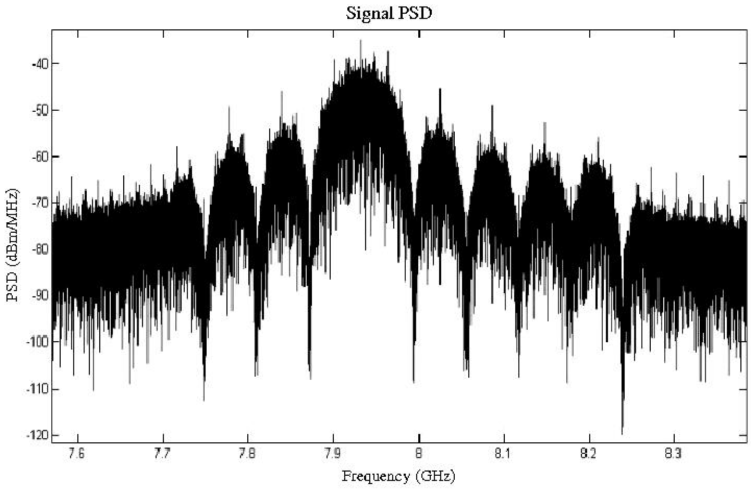

Figure 3. PSD of the emitted signal in the high frequency mandatory band indicated by IEEE 802.15.4a.

4. Network Architecture and Organization

We have considered a BAN composed of a set of small wearable devices distributed along the body. This network comprises a series of small sensor nodes each of which has its own energy supply, consisting of storage and energy scavenging devices. Each node is able to perform data acquisition and communicate with a central node (master node) worn on the body [8]. The master node is able to communicate with the outside world using a standard telecommunication infrastructure. The considered network architecture is centralized. services can include the management of chronic disease, medical diagnostic, home monitoring and biometrics. Possible services can also regard sports and fitness tracking. In case of medical applications, sensors capable of monitoring some body vital functions, such as the electrical activity of the brain, will be included. We have taken into account an average body extension while planning the sensors distribution [8].

We have considered a network scenario in which a sensor node located on the patients neck transmits information to the master node, located on the abdomen left side. Obviously, 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. A variable number of nodes in the reference BAN has been considered, in order to analyze the effect of asynchronism between nodes and of the specific BAN radio channel for a set of different possible configuration, spanning from a basic monitoring activity (few active nodes) to an extensively monitoring BAN (10 nodes BAN). Each transmission link has been associated to a IEEE 802.15.4a BAN channel impulse response realization during every simulation run. The transmitted signal will travel along the body till it will be received by the master node.

At the receiver side, the maximum likelihood approach for decoding the incoming signal is adopted. Note that the receiver structure exploits the maximum likelihood decoding procedure [5]. The receiver works under the assumption that all the assigned TH codes are known by the master node of the BAN.

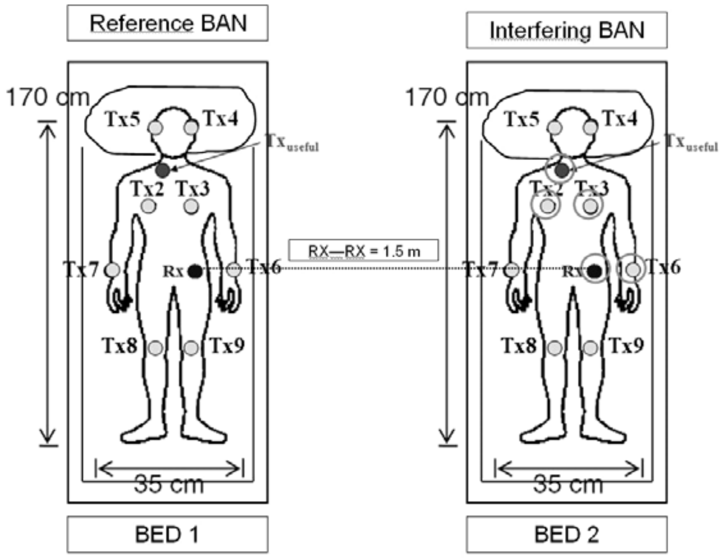

Figure 4. The LDR UWB interfering network is represented by a second BAN. The circles indicate the active nodes in the interfering network. The reference BAN structure is provided by the configuration on the left.

The correlator computes the cross-correlation between the received signal and the known transmission signal, made of 16 root raised cosine pulses. In particular, the master node knows which temporal bursts are being used for transmitting the bit 0 or the bit 1 by the generic sensor. In fact, it knows which TH code integer value is being used for transmitting the actual bit. According to this, the decoding procedure implies the cross-correlation only between the signal received in these two temporal bursts and the known signal.

5. Simulations Settings and Results

Simulation activity has at first been performed for the single reference BAN, in order to update the results obtained in [8] when a signal compliant to the European constraints shown in Table 1. The other set of simulations foresees the presence of a second LDR UWB interfering network in the same hospital room. The UWB interfering network is represented by a second Body Area Network. This simulation scenario is motivated on one hand because it offers the possibility of studying the effect of an interfering UWB network on the reference candidate BAN, in particular for the case of two patients in the same room, on the other hand because IEEE 802.15.4a foresees the possibility of analyzing two BANs sharing the same channel. Simulation activity has been carried out using MATLAB software for representing the BAN structure, the transmitted signals compliant with the IEEE 802.15.4a and the IEEE 802.15.4a channel impulse responses.

Specific MATLAB scripts and functions are in charge of providing each single detail such as TH code and impulse response assignment, topology creation, BER evaluation at receiver side. In Figure 4 the reference BAN is placed on the left, while the interfering BAN is on the right, the two master modes (receiver nodes) being characterized by a distance of 1.5 meters. For both simulation sets the assumption is made that the asynchronism between nodes belonging to the same network is moderate and cannot exceed T_S , while the average asynchronism level is set to $T_S/4$ (see Figure 2). In order to guarantee a reasonable BER value not greater than 10^{-3} for an acceptable monitoring performance, the obtained results lead to a performance threshold that limits the number of nodes of the reference BAN in presence of a second BAN (with a standard number of transmitting nodes) or, more in general, of a IEEE 802.15.4a interfering LDR UWB network. Figure 6 shows the allowed BAN configuration in terms of monitoring nodes when the BER performance threshold is set.

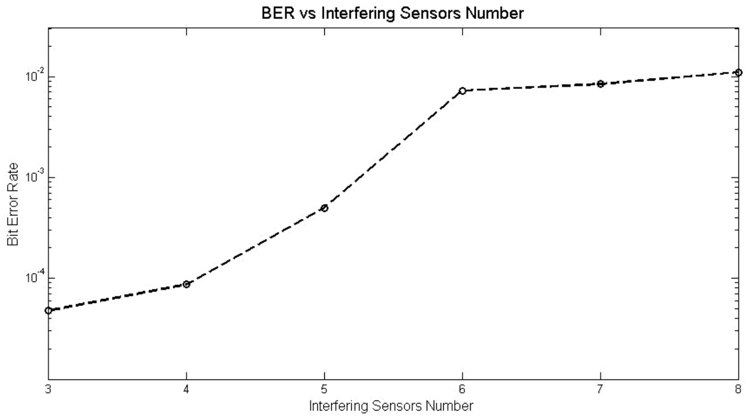

Figure 5: Bit ErrorRate measured at the master node receiver for an increasing number of interferers in the network when the signal compliant with the European contraints is used.

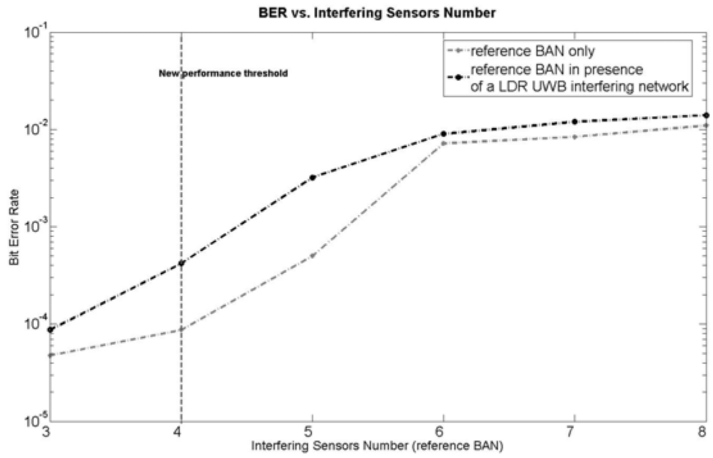

Figure 6. Reference BAN in presence of a LDR UWB interferer (second BAN) compared to the single reference BAN case. The UWB interfering network is always characterized by five active nodes, while the number of nodes in the reference BAN varies. The performance threshold is displayed.

The obtained results, obtained simulating the networks activity using MATLAB, show that it is still possible to obtain an acceptable performance level for the reference BAN in presence of the UWB interfering network when the maximum number of sensors is set to 5 (the useful node and four interfering nodes in the candidate BAN) when the performance threshold constraint is considered.

6. Reference BAN Performance When an Optimized Code Assignment Strategy is Adopted

In this section simulation results obtained by code optimization are presented. 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 detail in [7]. Figure 7 shows possible overlapping due to asynchronism caused by multiple nodes transmitting the same symbol (for example a 0 in the figure) using adjacent time slots for transmission.

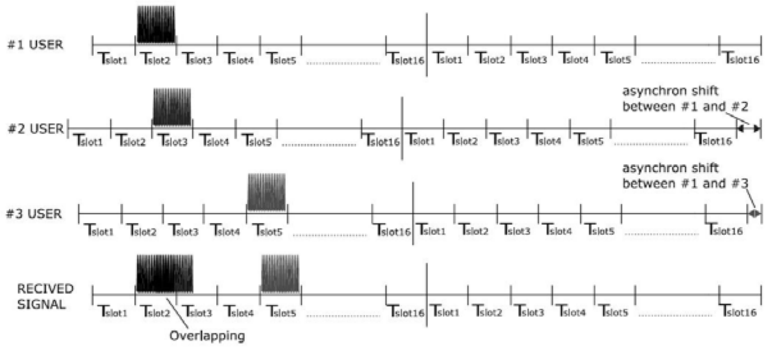

Figure 7. Asynchronism Effect in Presence of Orthogonal Non-Optimized TH-Codes

The optimized code maximizes the relative distances between the active nodes transmission (previous simulations were characterized by generic orthogonal codes), 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). In case the the number of users is an odd number, the optimized set of distances will contain a single distance that is bigger than the other ones. Another issue taken into account while performing simulation activity is that overlapping can occur when a 0 and a 1 are transmitted by different users within the same symbol period and also when a 1 and a 0 are transmitted in different symbol periods. The proper code assignment can be applied once the effective number of needed active nodes is provided. Figure 8 shows the effect of the use of optimized TH coding for a single BAN characterized by the presence of 4 interfering sensors. Note that only a high level of asynchronism between the nodes can affect significantly the overall performance.

7. Conclusions

Body Area Networks have the potential to significantly improve health care or sports tracking by allowing unobtrusive health monitoring for extended periods of time. A typical wireless BAN consists of a number of inexpensive, lightweight, and small sensor nodes. A reference wireless BAN composed of IEEE 802.15.4a sensor nodes has been considered and studied in different operating scenarios. The considered BAN is capable of interacting with already existing wireless networks. We have designed the BAN as composed of at most 10 nodes located in some significant body sides in perspectives of medical or sports applications. The network architecture has been thought 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. 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. Results show that two BANs sharing the same channel and placed in the same hospital room can coexist if both characterized by at most 5 sensors each (6 including the master node receiver).

The effect of a high asynchronism level between the BAN sensors have been also taken into account, testing by simulation a new code assignment strategy capable of improving the BAN performance. This set of simulation was scheduled based on the observation that the destroying overlaps perceived at master node receiver significantly depend on the adopted TH codes. 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. In this case it will 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. Once the optimization of the physical layer performance is obtained, the resulting higher layers behaviour will be considered in order to provide a complete performance framework.

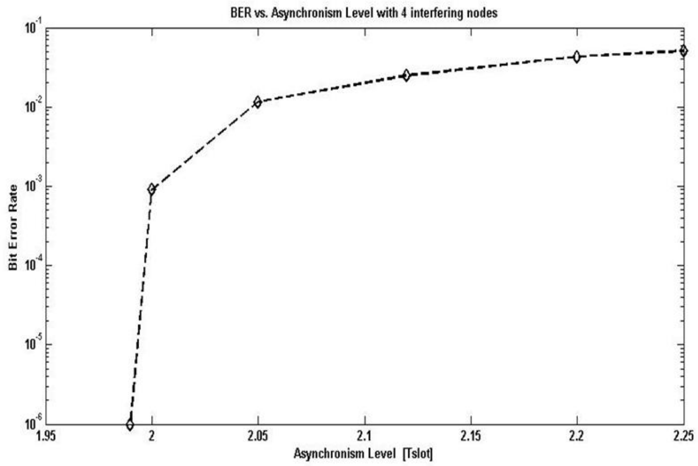

Figure 8. Asynchronism Effect with Optimized Codes for a BAN with 4 Interferers

Acknowledgment

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