Performance Analysis for a Body Area Network composed of IEEE 802.15.4a devices

Daniele Domenicali and Maria-Gabriella Di Benedetto
Infocom Department
School of Engineering
University of Rome La Sapienza
Rome, Italy, 00184
Emails: {dome, dibenedetto}@newyork.ing.uniroma1.it

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.This work analyzes the behaviour of a BAN composed of IEEE 802.15.4a ultra wideband (UWB) sensors. A Body Area Network architecture is proposed and investigated by simulation. Performance evaluation takes into account Bit Error Rate as a function of the number of nodes forming the BAN and of the asynchronism level between them.**

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. Since low-power transmission is required for body worn wireless devices, the human body can be used as a communication channel between wireless wearable devices to form a wireless network. Based on the information sent by a BAN worn by a particular patient, the hypothetical Healthcare Central System of the hospital can be continuously aware of the patient vital functions and is able to take the appropriate countermeasures in case of medical alert. For this purpose the Body Area Network must be capable of communicating with other wireless systems and the adoption of IEEE 802.15.4a sensors provides the beneficial effect of maintaining compatibility with future standards. Figure 1 shows a possible medical application of a Body Area Network. We can assume that interworking modules are present for interfacing the network layer of different wireless networks. Furthermore, since ultra wideband (UWB) sensors are considered for the network nodes, the consequent low transmission power requirements allow longer battery life for body worn units.

The paper is organized as follows. Section 2 introduces the signal format. Section 3 focuses on the network structure and organization. Section 4 describes simulation settings and results. Section 5 offers a final discussion and concludes the paper.

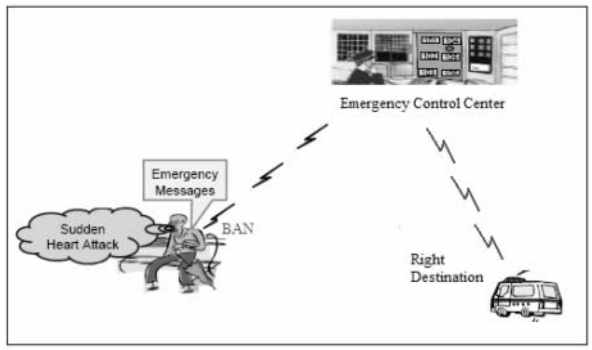

Fig. 1. Example of medical application for the Body Area Network.

II. SIGNAL FORMAT

The UWB physical layer uses an Impulse Radio based signaling scheme in which each information-bearing symbol is represented by a sequence 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. The modulation format implies a symbol duration of 1036.44 ns. A symbol period is composed of 32 time bursts. Each time burst is defined by 16 chip times. When a symbol has to be transmitted, a single time burst T_s is used among the 32 available. In this burst, each chip time is occupied by a transmitted pulse. The signal structure is represented in Figure 2. The transmission scheme foresees the use of Time Hopping (TH) codes to achieve multiple access. Pulse Position Modulation (PPM) is used for encoding the bits. PPM implies a time shift that is multiple of the temporal burst. The nominal temporal burst during which a single user has to transmit is defined by the user TH code value. This nominal time burst has to be used

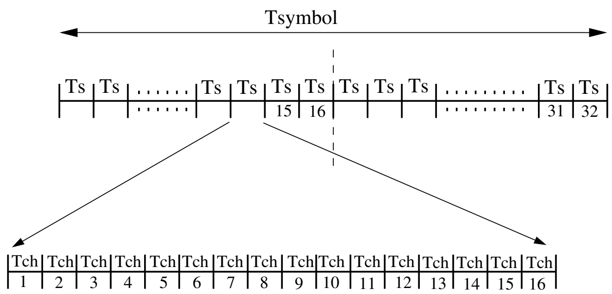

Fig. 2. Symbol period structure for the transmitted signal. The time burst and the chip time duration are evidentiated.

if the user wants to transmit the bit 0. If the user wants to transmit the bit 1, it has to use another temporal burst given by the nominal one plus the PPM shift. The useful temporal burst T_u can be written as follows:

$$T_u = c + 16\,T_s b \tag{1}$$

where $16\,T_s$ represents the PPM shift, b is the transmitted bit and c is the nominal time burst. The reference pulse used by the UWB physical layer is a root raised cosine pulse with roll-off factor set to 0.6.

III. Network Settings

We have studied a Body Area Network 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. In case of medical applications, sensors capable of monitoring some body vital functions, such as the electrical activity of the brain, will be included. The master node is able to communicate with the outside world using a standard telecommunication infrastructure such as Wireless Local Area Networks, Bluetooth or 2G-3G cellular networks, as shown in Figure 3. At network

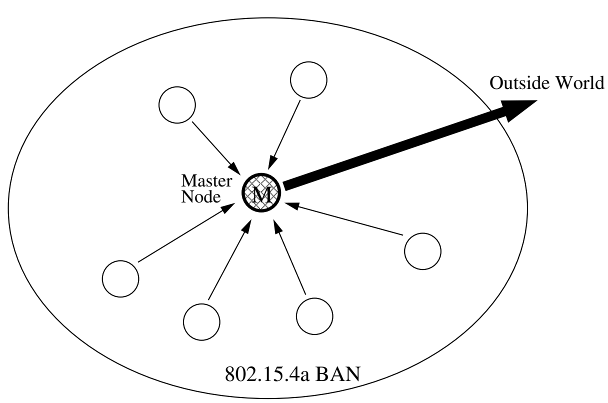

Fig. 3. Network architecture: the master node is supposed able to communicate with the outside world.

layer, in fact, a unique address format can be created for connecting nodes belonging to different underlying sub-networks. Thanks to the insertion of proper interworking modules, the packets originated by different subnets can be adapted to obtain a unified address format. In order to achieve this task, the interworking modules must work by combining information of the different IEEE communication structures involved. This adaptation takes place at network layer and makes the packet of the single sub-network fitted for being transmitted through an overlying network, for example an IP network. Each sub-network has its own physical layer and its own Medium Access Control (MAC) protocol, and they can exchange packets by means of the interworking unit functionalities at network layer, as represented in Figure 4. The considered network architecture is centralized. We have taken into account an average body extension while planning the sensors distribution: the body height has been set to 1.70 meters and the body width has been set to 35 centimetres. The adopted disposition of the nodes is shown in Figure 5.

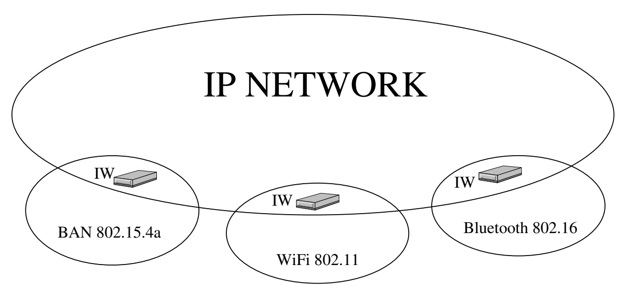

Fig. 4. Schematic view of the interoperability between different wireless networks. Node number 1 represents the reference node. The interworking modules (IW) are evidentiated.

IV. Simulation Settings and Results

A sensor node located on the patient neck transmits information to the master node, located on the abdomen left side, as represented in Figure 5. In Figure 6 the position of the nodes within the BAN is shown in detail. The useful transmission suffers from the interference of the nearby sensor nodes that are also transmitting their monitoring information to the master node. At physical layer an UWB technology compliant with the mandatory requirements of 802.15.4a has been used. The source of interference is represented by the Multi User Interference (MUI) provoked by the asynchronism between the BAN sensors. In fact, according to the signal structure described in Section 2, we have analyzed the situation in which the sensors are not perfectly synchronized. In this case, the signals belonging to two adjacent time bursts may be overlapped and dramatically damaged. The adopted data rate and frequency band for the transmitted signal are compliant with the mandatory

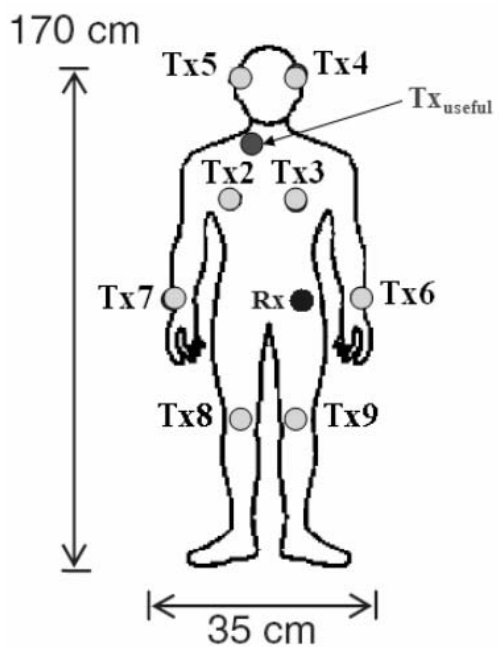

Fig. 5. Disposition of the nodes for the considered BAN. All the nodes transmit to the master node indicated with Rx, the reference transmitter is placed on the neck.

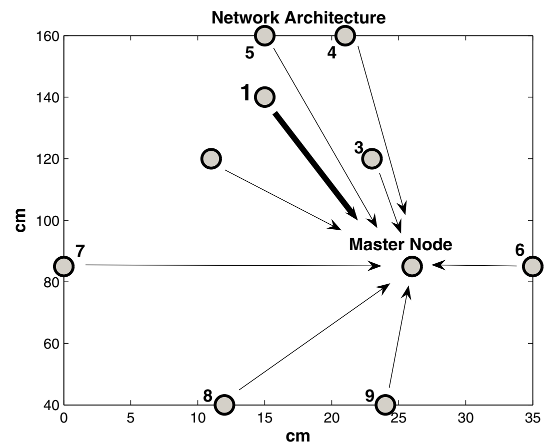

Fig. 6. The network architecture is centralized. Each node transmits towards the master node.

values indicated by IEEE 802.15.4a TG. The channel model for BAN applications provided by IEEE 802.15.4a has been adopted. The adoption of a specific channel is motivated by the fact that pulses transmitted from an antenna diffract around the body and can reflect far from the arms and shoulders. Thus, distances between the transmitter and the receiver has to be taken into account as for instance the distance along the perimeter of the body, rather than the straight-line distance through the body. Measurements performed by the IEEE 802.15.4a Task Group have also indicated that there are always two clusters of multi-path components, due to the initial wave diffracting around the body (there is no wave penetration), and the reflection of the ground. This suggests that in the BAN case we cannot approach the problem of the channel modelling in a stochastic way. The number of clusters is always 2 and does not need to be defined as a stochastic process as in the other wireless scenarios. Furthermore, the inter-cluster arrival times are also deterministic and depend on the exact positions of the transmitter and the receiver on the body. Finally, some important channel parameters depend on the position of the receiver on the body. From the measurements performed, it has been understood that there are three principal receiver positions that lead to significantly different channel parameters. Therefore three scenarios have been defined corresponding to a receiver placed on the *front*, *side*, and *back* of the body. Since the receiver position in our case is on the abdomen left side, we have modelled the channel impulse response associated to a single sensor considering the first scenario (*front*). Figure 7 shows the Bit Error Rate as a function of the asynchronism level between the nodes of the BAN when the reference transmitter and three interferers are transmitting to the master node. Simulation results show that for an asynchronism level smaller than T_s an acceptable Bit Error Rate value is obtained. In Figure 8 is shown the Bit Error Rate as a function of the number of active interferers when the asynchronism level can assume values between 0 and T_s.

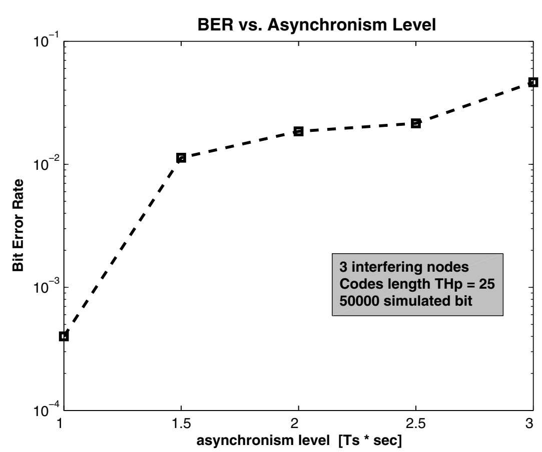

Fig. 7. Bit Error Rate measured at the master node receiver for different asynchronism levels of the network indicated as a multiple of T_s, the value of time burst characterizing the signal. The simulation includes 3 active interfering nodes and 50000 simulated bits for each node.

V. Conclusion

Body Area Networks have the potential to significantly improve health care by allowing unobtrusive health monitoring for extended periods of time. A wireless BAN composed of at most ten 802.15.4a sensor nodes has been considered and studied. The nodes have been placed in significant body sides in perspectives of medical (or sports) applications. Network architecture has been thought as centralized. Therefore, all the sensor nodes are capable of performing data acquisition and transfer information towards the master node. The master node is able to interact with other wireless networks. The BAN compliance with 802.15.4a grants interoperability with other telecommunication infrastructures. The Body Area Network has been investigated in terms of Bit Error Rate as a function of the number of nodes and of the asynchronism level between the nodes, in order to provide useful thresholds for specific parameters to test the performance of the considered network architecture. Below the threshold, the investigated parameters make the adopted network architecture suitable for BAN applications. Therefore, we can maintain the hypothesis of a single cluster for the network topology. The first investigation led us to the consideration that Multi User Interference is the main source of interference suffered from the BAN. The BER perceived at the master node in presence of an elevated asynchronism level could be unacceptable for many applications. In particular, we have studied the scenario characterized by a reference sensor node transmitting to the master node in presence of 3 interferers. The simulations have highlighted that satisfying performance can be obtained in case the level of network asynchronism results limited in the interval between 0 and T_s (that is, the transmission time burst of the 802.15.4a mandatory modulation). This result suggests to study in more depth the sets of TH codes used by the nodes for transmission. In fact, according to the IEEE 802.15.4a signal format, the destroying overlaps perceived at the master node receiver significantly depend on the adopted TH codes. Based on the first simulations results, a second investigation has been made for understanding the impact of the number of nodes on network performance. The final result is shown in Figure 9. An explicit performance threshold is provided on the basis of the obtained simulation results. When the asynchronism level is limited between 0 and T_s, an acceptable BER value is achievable when the number of active interferers is smaller than 6.

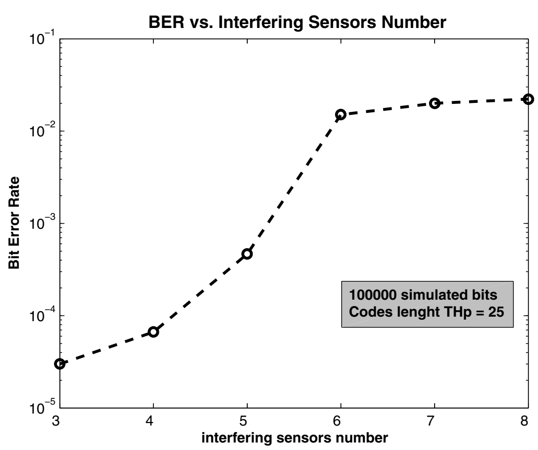

Fig. 8. Bit Error Rate measured at the master node receiver for an increasing number of interferers in the network. The simulations have been performed using 100000 simulated bits for each node. The asynchronism level can assume values between 0 and T_s.

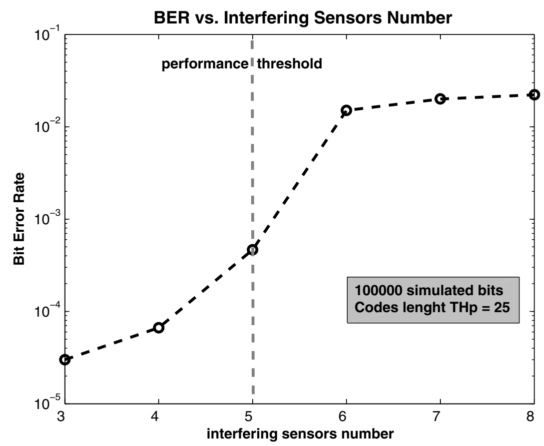

Fig. 9. Bit Error Rate measured at the master node receiver for an increasing number of interferers in the network. A threshold is displayed to point out the maximum number of interferers leading to an acceptable BER value when the asynchronism level is limited between 0 and T_s.

Acknowledgment

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