A Simulation Platform to Study Inter-BAN Interference

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***Abstract*—A Body Area Network (BAN) is a radio standard for wireless connectivity of wearable and implantable sensor nodes that are located inside or in proximity to the human body. Many applications of BANs (e.g. physiological monitoring) require reliable communication of information between the sensor nodes and their controller. As there are currently no coordinating mechanisms among multiple co-located BANs, interference caused by co-channel transmission in adjacent BANs could impact the reliability and in general the quality of the service experienced by a receiver node within an individual BAN. So far, few studies have been done to study the impact of such inter-BAN interference. A comprehensive study would eventually require an extensive measurement campaign with networks that have been implemented according to the BAN standard. Until then, a simulation platform that can allow researchers to gain more information about the impact of interference would be a valuable research tool. In this paper, we present a research platform that has been developed to perform simple statistical evaluation of inter-BAN interference. Initial results for the ISM frequency band (i.e. 2.4 GHz) have been provided here.**

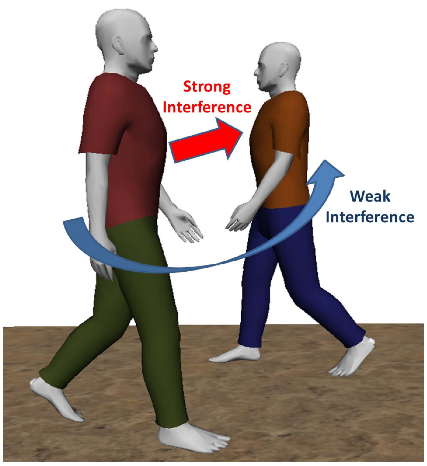
Keywords-body area network , reliability, inter-BAN interference

I. Introduction

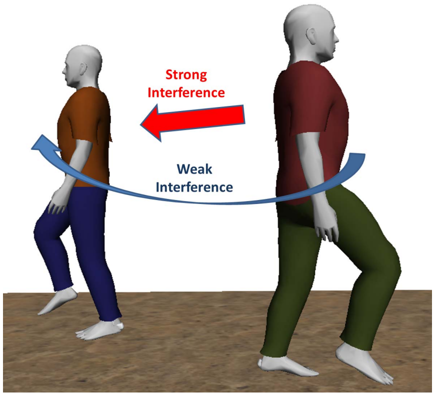
Body Area Networks (BANs) consist of multiple wearable (or implantable) sensors that can establish two-way wireless communication with a controller node that could be either worn or located in the vicinity of the body [1,2]. Considering the mobile nature of BANs along with their proposed operational frequency bands, these networks are expected to coexist with other wireless devices that are operating in their proximity. Therefore, interference from coexisting wireless networks or other nearby BANs could create problems for the reliability of the network operation.

Assuming that a single BAN uses a Time Division Multiple Access protocol to establish communication among its controller and body sensors, there will be no simultaneous transmission; and therefore, no interference among nodes of a single BAN. However, when several BANs are within close proximity of each other, interference may occur since no coordination across separate networks exists in general. Hence, the increasing number of such BANs in close proximity of each other could result in performance degradation of one or several communication links. Even when there is a small number of adjacent body area networks, the received signal strength from nearby interfering BANs may be too high, resulting in overwhelming of the desired signal within a particular BAN, causing performance degradation in detecting or decoding the transmitted data.

The complexity associated with BAN communication channels along with the mobility of the subjects wearing BANs could create various complicated scenarios where inter-BAN interference has a negative impact on the reliable reception of data within one BAN. Figure 1 illustrates this point with a simple scenario involving two people who are wearing multiple sensors on the front and back sides of their bodies. When the bodies are face-to-face (i.e. Fig. 1a), the line-of-sight channel among the two sensors that are located on their chest might lead to a strong cross-interference. As they cross each other, the shadowing created by the bodies would remove the interference on the chest sensors; however, clear line-of-sight among the back sensors (Fig. 1b) could lead to interference at that location.



(a)



(b)

Figure 1. Cross-interference instances among two BANs

Statistical knowledge of the amount and characteristics of the inter-BAN interference in various scenarios would be essential information to have in order to study communication link reliability in a body area network. So far, few studies have been done to study the impact of such inter-BAN interference. A comprehensive study would eventually require an extensive measurement campaign with networks that have been implemented according to the BAN standard. Until then, a simulation platform that can allow researchers to gain more information about the impact of interference would be an extremely valuable research tool. In addition, such a platform can be used to study the performance of various interference mitigation techniques such as link adaptation and coordinated (or un-coordinated) transmission scheduling algorithms. By distributing simultaneous (i.e. colliding) multi-BAN transmissions across several time slots, inter-BAN interference can be mitigated to some extent.

Here we describe a MATLAB[1]-based research platform that can simulate movement of multiple body area networks. Using this platform, one can perform simple statistical evaluation of inter-BAN interference. Although the results provided here correspond to the ISM frequency band (i.e. 2.4 GHz), the platform can be used to study such interference at all other candidate frequency bands in body area networks (i.e. allocated to implants as well as wearable sensors).

This paper is organized as follows. Section II briefly describes the simulation platform and its capabilities along with the channel models used. Section III describes our initial results related to the 2.4 GHz frequency band for wearable sensors. Finally, section IV briefly summarizes various usage of this platform and outlines our plan for future research.

II. Simulation Platform

Consider a system comprised of N BANs. Each BAN consists of one controller and several sensor nodes (i.e. star topology according to the IEEE802.15.6 standard). The experienced Signal to Interference plus Noise ratio (SINR) at the receiver node $i=1,\dots,M$ (with transmitter node $l \neq i$) of BAN $k=1,..,N$ can be expressed by:

$$SNIR_{li}^{k} = p_l^k \xi_{li}^k / (\sigma_i^2 + I_i), \qquad (1)$$

where p_l^k is the transmission power for the transmitting node $l=1,\dots,M$ in BAN k, σ_i^2 is the noise power at receiver i, ξ_{li}^k denotes channel attenuation from a transmitting node l in BAN k to the receiver node i in BAN k and I_i is the interference at sensor i created by other BANs $j \neq k$ is

$$I_i = \sum_{j \neq k} p_{m_j}^j \xi_{m_j i}^j \qquad (2)$$

ξ_{mi}^j in equation (2) denotes channel attenuation from a single transmitting node m_j in BAN $j \neq k$ to the receiver node i in BAN k.

To emulate inter-BAN interference, we have developed a platform consisting of a virtual room (i.e. with definable dimension size) along with variable number of BANs. Each BAN includes a coordinator along with a variable number of sensor nodes. Sensors can be considered in-body or on-body; however, as there are currently no dynamic BAN-to-BAN channel model available involving implants, here we have only considered on-body sensors. Graphically, this is shown in Figure 2, where ovals represent BANs (i.e. cross-section of bodies wearing BANs). The green square in each BAN indicates the controller node and small red circles denote body sensors.

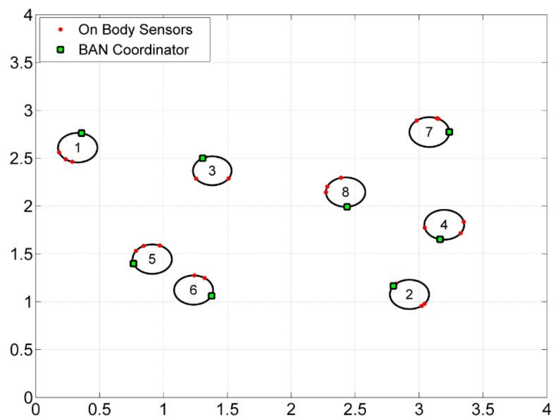


Figure 2. Sample multi-BAN scenario in a 4 m x 4 m rectangular room

Each BAN in this system is capable of moving in a given direction and with a definable speed. This represents movement of people who are wearing these BANs. To keep BANs confined in the virtual room (and therefore in proximity

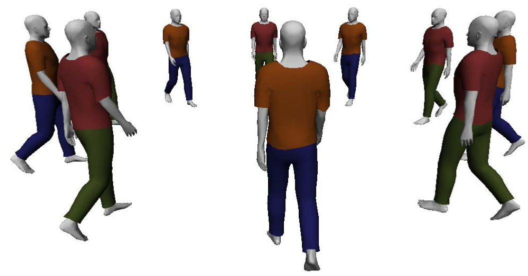
[1] MATLAB is registered trademark of the MathWorks, Inc. MATLAB has been used in this research to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standard and Technology, nor does it imply that this product is necessarily the best available for the purpose.

of each other), each BAN (i.e. user) is reflected from the boundaries of the virtual room as soon as they reach these boundaries. In addition, when two BANs reach within a certain distance of each other, they also reflect off of each other to avoid collisions. This is meant to imitate several people walking randomly (or with a desired pattern) inside a room. Initial position, speed, and reflection direction of all BANs are programmable within the platform.

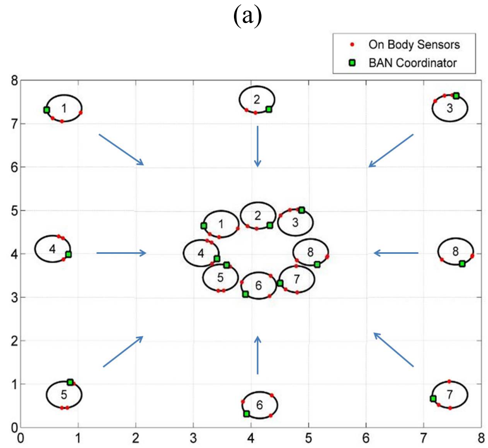
An essential component of the above simulation platform is the channel model across various nodes of the BANs. Several statistical channel models that represent on-body and BAN-to-BAN propagations have been incorporated in the platform to create channel realizations that are needed to evaluate inter-BAN interference [3,4,5]. These statistical channels models have been obtained using measurements at 2.4 GHz. In some cases, the channel models have been developed using on-body antennas with various polarizations (i.e. Normal and Tangential); therefore, the impact of such polarization in the amount of inter-BAN interference can also be studied using this platform [5]. The recently announced MBAN spectrum by FCC [6] uses a frequency band that is very close to 2.4 GHz and it is intended for on-body sensors within hospitals or other indoor environments. Hence, we have selected this frequency as the first candidate to study possible inter-BAN interference issues. Our platform can also be used to study multi-BAN interference at other BAN frequency bands; and, as more channel models become available, we can naturally extend our studies to those bands as well. This simulation platform has been used to obtain a variety of information such as distribution of inter-BAN interference, Signal to Interference plus Noise Ratio, outage probability due to interference and impact of the BAN antenna on the interference profile. We will briefly discuss these results in the next section

III. RESULTS

Two scenarios have been considered to evaluate inter-BAN interference using the platform discussed in section II. One scenario is specifically designed to produce monotonically increasing interference and is depicted in Figure 3. Having such benchmark scenarios will help researcher to evaluate the performance of their interference mitigation algorithms. In this case, several people who are wearing BANs are initially standing around a circle and as time goes on, they walk closer to each other (as shown in Figures 3a & 3b). We have allocated three on-body sensors per user and the room size has chosen to be 8mX8m in dimension. Figure 3c is an example of the Signal to Interference ratio (SIR) that a typical link might experience in this scenario. As BANs get closer, the average interference increases or equivalently the average SIR decreases. As an accurate knowledge of the coherence time of the BAN-to-BAN channel is not available, an approximate value (i.e. multiple of frame length) can be considered for this simulation. The impact of this coherence time could be very important especially when mitigation algorithms are being studied.



(a)



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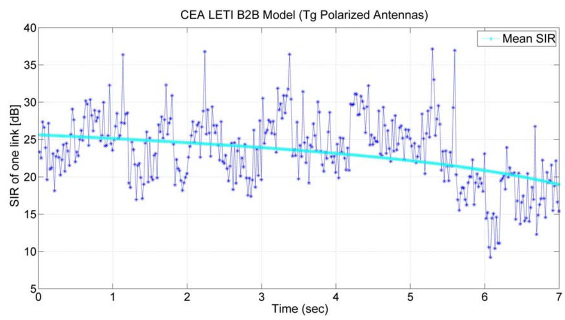

(c)

Figure 3. (a) Sample circle scenario for inter-BAN interference, (b) Implementation in the simulation platform (c) Sample SIR of a link

Figure 4 shows the distribution of inter-BAN interference for the scenario just described. This information can be used to calculate link outage probability if a minimum SIR is desired for reliable link operation in the body area network. Figure 5 demonstrate such results for the 8 users around a circle scenario. For example, if zero dB is the minimum desired SIR, then, in our example, 20% of the time a typical link is experiencing poor performance (i.e. outage). This might be unacceptably high for certain applications of BAN and therefore some sort of interference mitigation algorithm might be used to improve the situation. As mentioned earlier, performance of such algorithms can also be evaluated on our test platform. It should be mentioned that the experienced interference heavily depends on many factors such as number of BANs, number of sensors per BAN, their locations on the body, the velocity of the people, the amount of traffic or equivalently the channel utilization ratio of each BAN, etc.

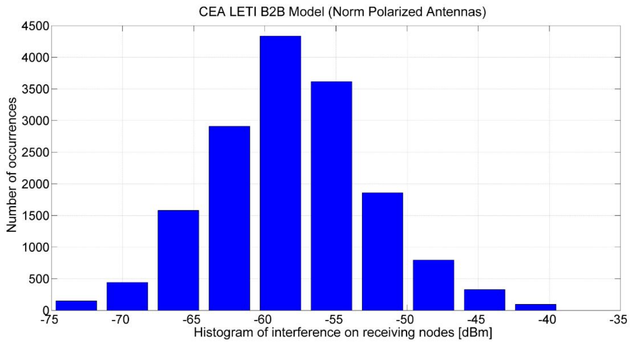

Figure 4. Distribution of experienced interference for the circle scenario

Other typical scenarios such as random movement of people within an indoor environment can also be emulated in our platform. For example, Figures 2 shows 8 people/BANs that are randomly moving around a 4m by 4m virtual room. The speed of movement and number/location of the on-body sensors can all be defined by the platform user. For this simulation, there are 6 communication links per BAN i.e. 3 links for data transmission from the body sensors to the coordinator and 3 links from the coordinator to the body sensors. Figure 6 highlights the distribution of the experienced SIR for all the 48 links in this scenario. As stated before, the operating frequency in this scenario is also 2.4 GHz.

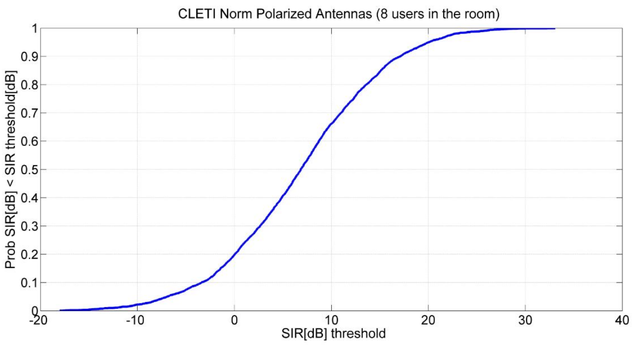

Figure 5. CDF of the experienced SIR for the circle scenario

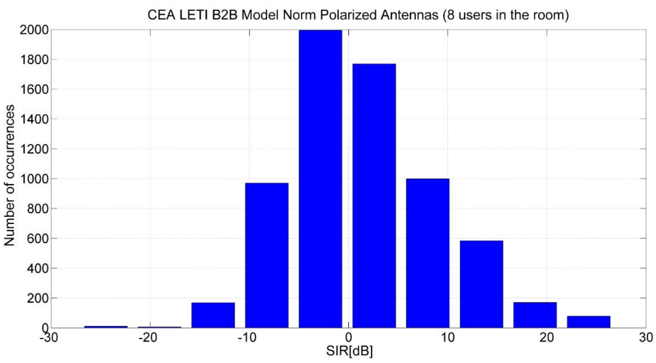

Figure 6. Distribution of experienced SIR for the random scenario

Also, as choice of the BAN antenna impacts off-body communication; and therefore, the potential inter-BAN interference, our simulation platform can be used to compare the effect of various antennas or their polarization on the link outage probability. For example, for the random scenario discussed here, the outage probability for the normally polarized antenna is much higher compared to that of tangentially polarized antenna. This is shown in Figure 7. Further results and details for these scenarios are being omitted for brevity.

IV. Conclusion and Future Plans

Although the channel utilization for most typical medical applications in body area networks could be low, the desired reliability may still be very high. As commercial utilization of BANs increases, the cross interference among multiple BANs could have a negative impact on their operation. For example, multiple people in a bus, airplane, classroom or walking in shopping malls are examples of scenarios where inter-BAN interference could occur. Here, we have presented a simulation platform that can provide statistical knowledge of such interference. This is valuable information to design and evaluate performance of various interference mitigation algorithms. The authors plan to use this platform along with their research on Link Layer Adaptation [7,8,9] to better understand the effectiveness of such techniques in mitigating interference. Also, the effectiveness of smart scheduling algorithms for packet transmission can be easily evaluated using this platform. The authors are currently studying the effectiveness of such uncoordinated algorithms.

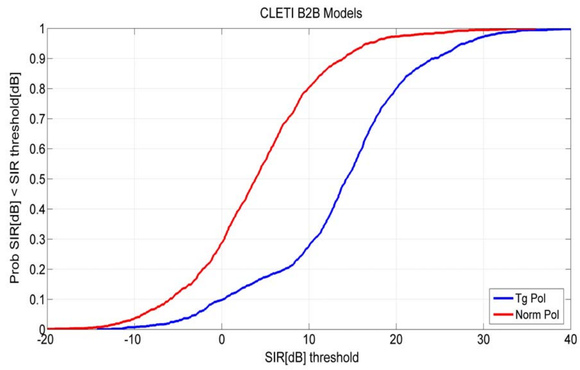

Figure 7. CDF of the experienced SIR for the random scenario with Normal and Tangentially polarized antennas

Several dynamic channel models have been included in the current version of the platform; however, as more accurate models become available, they can be easily integrated into the platform and results can be re-evaluated. The authors also plan to extend the current simulation platform to a virtual reality domain as described in [10]. In doing so, the dependence of the current platform on statistical channel models will be eliminated. In addition, more valuable information that directly relates to the placement of the body sensors can be obtained. Also, possible cross-interference among implants can also be studied by such extension.

Studying link reliability and system performance when each BAN is using a CSMA (Carrier Sense Multiple Access) protocol is another objective for the future. Specifically, evaluating the additional packet transmission delay incurred by the interference is an important topic for delay-sensitive applications in body area networks.

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