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INTER-BAN INTERFERENCE EVALUATION & MITIGATION: A PRELIMINARY STUDY

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Inter-BAN Interference Evaluation & Mitigation: A Preliminary Study

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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 quality of the service experienced by a receiver node within an individual BAN. Here, we present a simulation platform that allows for statistical evaluation of interference in multi-BAN scenarios and performance of possible mitigation algorithms. Currently, there are no mechanisms for interfering BANs to explicitly coordinate their transmissions. As our analysis show, this may result in unacceptably high interference; and therefore, high link outage probability by the intended receiver. We propose uncoordinated approaches that could help to ease cross-interference among multiple adjacent BANs. Simulation results in our preliminary studies support the effectiveness of our approach.**

Keywords-body area network, reliability, 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]. 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 on 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, 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 short proximity of each other could result into 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; and therefore, causing performance degradation in detecting or decoding the transmitted data.

Advanced signal processing using interference cancellation techniques has been proposed to minimize the impact of interference. However, there are two main problems with such techniques especially when it comes to their application in BAN. First is the high complexity of the receiver which makes the implementation of interference cancelation impractical unless the number of nodes is very small. Complexity is especially a critical issue for nodes in body area networks. As they mainly rely on battery power, prolonging the lifetime of these nodes are of prime importance. The second problem is that some interference cancellation schemes require knowledge of the channel condition (such as attenuation, phase, and delay) between each of the interferers and the receiver. Obtaining accurate estimates of the channel condition is extremely difficult for body area networks. Transmission power control has also been considered as an alternative for individual BANs to maintain reliable operation even in high interference environments. However, the complexity of the BAN channel environment and other stability issues indicate that power control alone may not be able to achieve an acceptable system performance [2].

Due to the possible inefficiency of power control and the stated problems with interference cancellation, interference mitigation techniques can be an attractive alternative, particularly in an environment with high interference level. These techniques can be classified into two groups: un-coordinated and coordinated mitigation. The coordinated schemes will require appropriate protocols for inter-BAN information exchange, and are envisioned to be more sophisticated. However, they might result in higher overall performance compared to uncoordinated schemes. The uncoordinated schemes require no inter-BAN communication and could result into simple implementation in the current IEEE802.15.6 international standard in Body Area Networking. Link layer adaptation is an example of an uncoordinated approach that can be used as an interference mitigation technique [2,3,4]. Although simple to implement, the trade-off for acquiring reliable simultaneous transmission in multiple BAN scenarios is lower transmission rates.

This paper proposes smart scheduling algorithms (i.e. slot assignment) as another alternative to mitigate inter-BAN interference. Assuming a TDMA-based MAC, the idea is to distribute simultaneous (i.e. colliding) multi-BAN transmissions across several time slots without any explicit coordination across interfering BANs. We assume that each receiver node of a BAN can measure the total interference that is experiencing at each time slot. The decision of which time slot to use in the next transmission frame, is the key to avoid potential interference by other BANs. Taking advantage of possible correlation in the propagation channel, multiple BANs can participate in judiciously selecting appropriate slot assignment (i.e. transmission schedule) in consecutive frames in order to avoid time-slots with high interference. This setting matches a Game Theory framework as multiple BANs are competing with each other to find the best transmission slot assignment that incurs the lowest interference for their target receiver [5].

This document 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 strategy to mitigate inter-BAN interference through smart scheduling algorithms in an uncoordinated environment. Preliminary system performance results are discussed in Section IV. Finally, section V briefly summarizes our results 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 Noise plus Interference ratio (SINR) at receiver node i of BAN $k = 1,.., N$ can be expressed by:

$$SNIR_{l,i}^{k} = p_{l,i}^{k}\xi_{li}^{k} / (\sigma_i^2 + I_i) \, , \qquad (2)$$

where $p_{l,i}^{k}$ is the transmission power for the transmitting node l 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

$$I_i = \sum_{j \neq k} p_{m,i}^{j}\xi_{mi}^{j} \qquad (3)$$

ξ_{mi}^{j} in equation (3) denotes channel attenuation from a transmitting node m in BAN $j \neq k$ to the receiver node i in BAN k.

To emulate inter-BAN interference, we have set up a platform consisting of a virtual room (i.e. with dimension X-Y meters) 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 1, where circles represent BANs. The green square in each BAN indicates the controller node and small red circles denote body sensors.

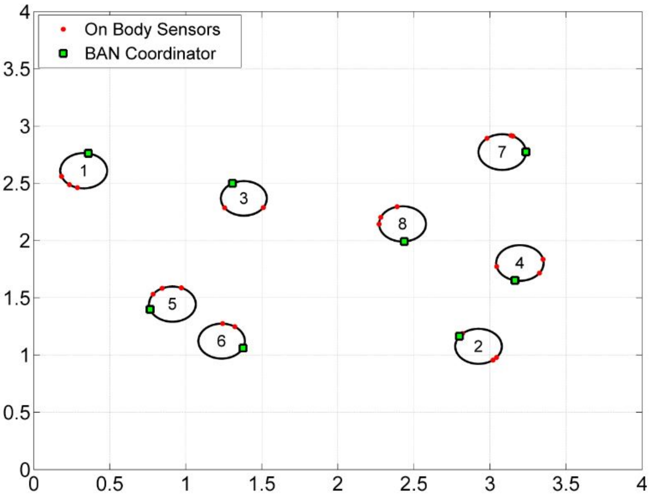

Figure 1. Sample multi-BAN scenario in a 4 m x 4 m rectangular room

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 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 used to create channel realizations that are needed to evaluate inter-BAN interference [6,7,8]. These statistical channels models have been obtained using measurements at 2.4 GHz. The recently announced MBAN spectrum by FCC [9] 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. Therefore, 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 have been used to obtain a variety of information such as distribution of inter-BAN interference, Signal to Noise & Interference Ratio (SINR), outage probability due to interference and impact of the BAN antenna on the interference profile [10].

III. Mitigation Algorithms & System Performance

Assuming a simple TDMA transmission protocol for each BAN, we have done preliminary studies on uncoordinated slot assignment strategies that can help to mitigate and ease inter-BAN interference to the extent possible. Our first simple approach is to use a semi-random strategy to re-allocate the transmission slots in every frame. In this method, a new random slot assignment is chosen first. Then, if the total interference experienced by all the receiver nodes (based on the random assignment) is less than the current time slot, the assignment for the next frame is changed according to the selected random assignment. If that is not the case, the current transmission schedule stays unchanged for the next time slot. The idea here is that random re-distribution of slot assignment might help to alleviate interfering i.e. colliding time slots. An important assumption here is that each BAN node can monitor and measure the interference at each time slot and somehow report it to the controller node that is in charge of the transmission slot assignment for the whole BAN. The implementation and complexity associated with this assumption has not been considered for now, as our intention is first to evaluate the possible gain or benefit in using such algorithms.

The second approach hereafter referred to as “Minimum Interference Assignment” (MIA) is more sophisticated and tries to re-allocate the slot assignment according to a protocol with the flowchart in Fig. 2:

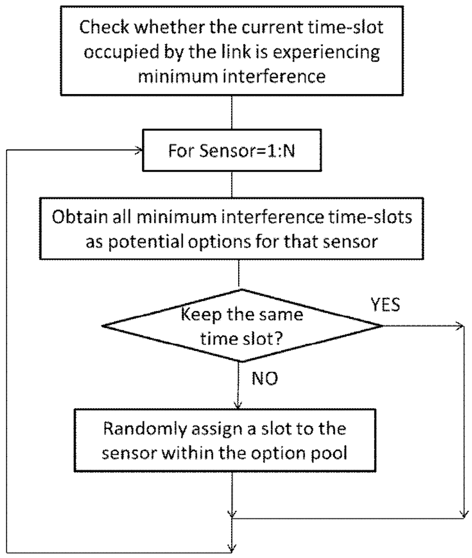

Figure 2. Minimum Interference Assignment (MIA) Strategy

The gist of the concept used to develop our uncoordinated approach is to exploit channel correlations and based on the experienced interference in the current frame decide the best (i.e. minimum interference) times slots that are least likely to collide with other BAN interferers. As each BAN decides the schedule for the next frame independently, there is always a chance for an individual BAN to make the wrong decision; however, as time goes on and on average slots assignments in each BAN seem to converge to a better allocation that mitigates the surrounding environment interference.

IV. Preliminary Results

To demonstrate the effectiveness of our slot assignment strategies, first we have created a scenario where average interference is expected to rise for all nodes in the system. In this way, we can observe whether the proposed assignment strategy can improve the communication link reliability or equivalently decrease possible outages due to interference in a consistent manner. Consider eight users that are standing around a room, forming a circle and then moving toward the center of the room. With all probability, one can expect a monotonically increasing average interference for all nodes of all the BANs in this scenario. Figure 3 is showing this scenario with 8 BANs. The arrows show the direction of the BANs moving toward center. As BANs gets physically closer, the amount of interference will increase and this in turn will affect the quality of the communication link at each BAN.

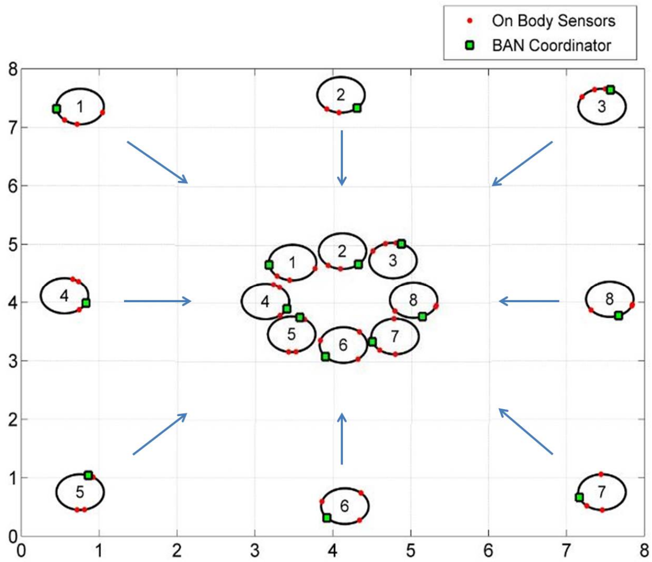

Figure 3. Sample multi-BAN scenario in an 8 m x 8 m room

Figure 4 depicts the histogram of the experienced Signal to Interference ratio (SIR) for channel models obtained in [8]. As observed the distribution of the SIR tends to shift to the right for both random and MIA approaches. This means that nodes under these assignments are generally experiencing higher SIR values. Also, the two channel models used to obtain these results are identical except for the polarization of the on-body antenna used in their experiment [8]. As observed, and also expected, tangentially polarized antenna results in much less inter-BAN interference compared to a normally polarized antenna.

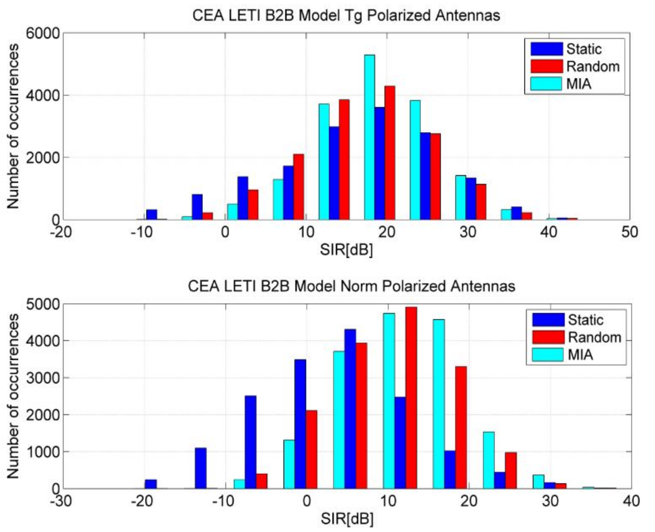

Figure 4. Histogram of the experienced SIR for the circle scenario

Figure 5 demonstrate the CDF of the experienced SIR for the circle scenario. These graphs show the improvement in the system performance in a more tangible way. If the horizontal access is perceived as minimum required SIR, then the vertical access represents the link outage probability. The MIA algorithm clearly reduces the outage probability by intelligently distributing and re-allocating simultaneous and interfering transmissions in non- or less-interfering time slots.

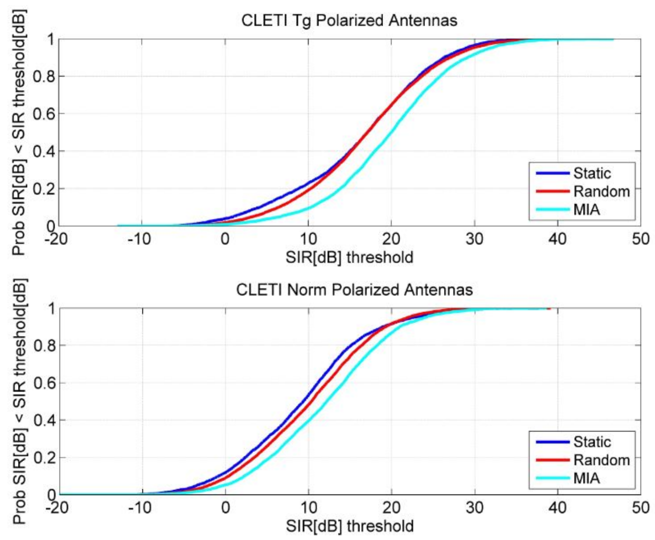

Figure 5. Histogram of the experienced SIR for the circle scenario

We have also repeated our simulation for another scenario which involves several users/BANs that are moving randomly around the room. The corresponding results are shown in Figures 6 and 7. Similar to the circle scenario, the improvement in the overall experienced SIR or equivalently outage probability is evident using the MIA or even random algorithms.

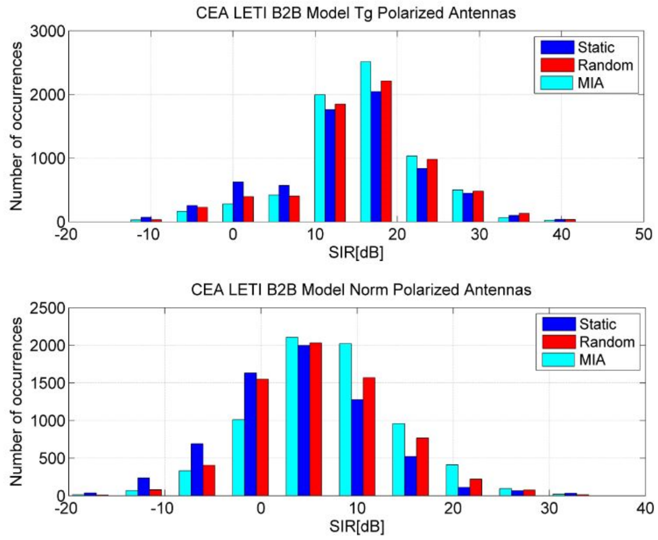

Figure 6. Histogram of the experienced SIR for the random scenario

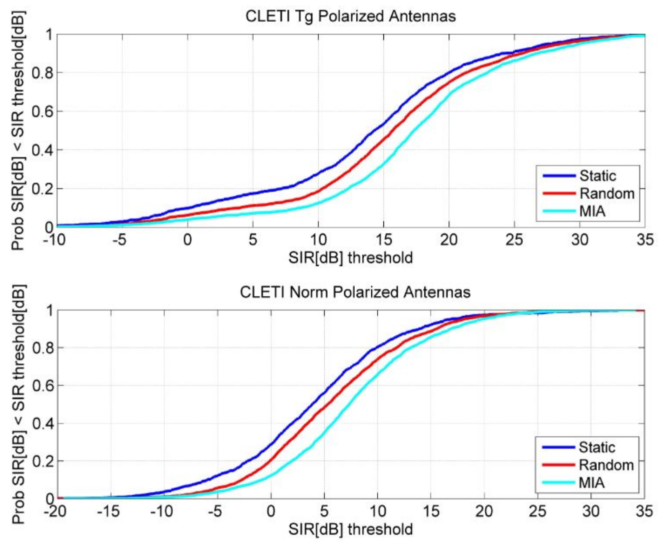

Figure 7. Histogram of the experienced SIR for the random scenario

For the above results, a frame size of 20 slots has been assumed. Each BAN carries 3 sensor nodes in addition to the controller. Also, it is assumed that each link in a BAN has one packet transmission during each time frame. Further studies are required to investigate the impact of all of these parameters on the performance of the assignment algorithm. The authors plan to continue this study and provide the results in a future publication.

V. Conclusion and Future Plan

The simulation platform presented here can assist researchers to study and analyze inter-BAN interference and evaluate the performance of possible mitigation strategies. 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 adopted by the platform and results can be re-evaluated. The results on our proposed uncoordinated slot assignment strategies show the performance improvement in mitigating cross-interference among uncoordinated BANs. Although the current version of the BAN radio interface standard (i.e. IEEE802.15.6) does not have any provision to support inter-BAN coordination, it is conceivable that any coordination might result into even better performance; of course, as a trade-off with more complexity. More detailed studies and experiments are needed to determine the feasibility and effectiveness of each strategy in mitigating potential interference.

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