Uncoordinated Scheduling Strategies for BAN-to-BAN Interference Mitigation

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Abstract—**A Body Area Network (BAN) is a radio standard for wireless connectivity of wearable and implantable sensors located inside or in close proximity to the human body. Medical and some other applications impose stringent constraints on battery powered BAN reliability, quality of service, and power consumption. However, lack of coordination among multiple co-located BANs in the current BAN standard may cause unacceptable deterioration of BAN reliability and quality of service due to high levels of inter-BAN interference. Assuming Time Division Multiple Access (TDMA), this paper proposes inter-BAN interference mitigation using several novel uncoordinated transmission scheduling algorithms. These algorithms use patterns of past and current interference for implicit coordination across multiple BAN transmissions. Simulation results demonstrate improvement in the performance and potential benefits of the proposed strategies.**

Keywords-body area network, interference mitigation, scheduling algorithms

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 is 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. The recently announced MBAN (Medical Body Area Networks) spectrum by FCC (Federal Communications Commission) [5] 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, it is important to study inter-BAN interference and mitigation strategies at this frequency.

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.

Due to the possible inefficiency of power control and the complexity issues 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 expected to be more sophisticated. However, they might result in better 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/technical document extends our work on smart scheduling algorithms (i.e. slot assignment) to mitigate inter-BAN interference. Assuming a TDMA-based MAC, we proposed a strategy to distribute simultaneous (i.e. colliding) multi-BAN transmissions across several time slots without any explicit coordination across interfering BANs. Our preliminary results in [7] showed that by 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. Using the platform in [6], here, we propose more uncoordinated scheduling strategies that can further enhance the system performance.

The rest of this paper is organized as follows. Section II describes the MIA_m (Minimum Interference Assignment) algorithm and its performance. Similarly, section III introduces the MRS (Minimum Required Signal to interference plus noise ratio) algorithm and evaluates its performance. Finally, section IV summarizes our results and outlines our plan for future research.

II. MIA Mitigation Algorithm & System Performance

In [7] we proposed uncoordinated scheduling algorithms as a mean to mitigate inter-BAN interference. The gist of the concept used to develop those uncoordinated approaches was to exploit channel correlations; and then, based on the experienced interference in the current frame decide the best (i.e. minimum interference) time 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 slot assignments in each BAN would converge to a better allocation that mitigates the interference from the adjacent BANs.

Here, we consider an extension of the proposed strategy where each BAN chooses its transmission scheduling for the upcoming frame on the basis of the experienced interference during the last m frames. 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 network. 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 scheduling strategy, referred to as MIA_m is an extension of the "Minimum Interference Assignment" presented in [7]. The algorithm flowchart is shown in Figure 1. For each BAN and at the beginning of each frame, MIA_m assigns transmission schedule for the frame by looking at the interference experienced during the previous m frames.

To evaluate the effectiveness of the MIA_m algorithm for various values of m, we first look at 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. Figure 2 shows a scenario with eight BANs moving toward each other. The arrows show the direction of the BANs moving toward center. Each Circle represents a BAN. The green square in each BAN indicates the controller node and small red circles denote body sensors.
As BANs gets physically closer, the amount of average Inter-BAN interference will monotonically increase and this in turn will affect the quality of the communication link at each BAN.

Figure 3 displays the probability that the experienced Signal to Interference Ratio (SIR) does not exceed a given threshold for the circle scenario shown in Figure 2 and different parameters m representing the number of past frames used for the algorithm operation. If the horizontal access is perceived as minimum required SIR, then the vertical access represents the link outage probability.

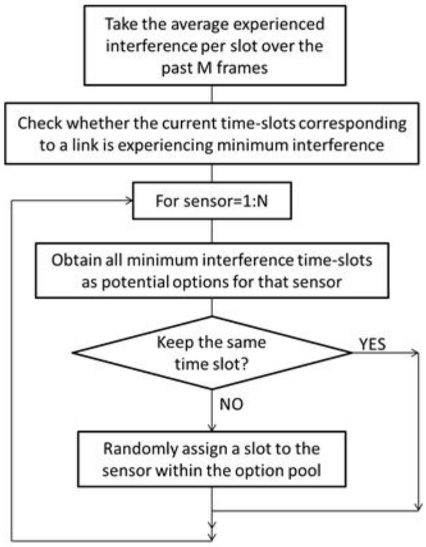

Figure 1. Minimum Interference Assignment (MIA_m) scheduling strategy

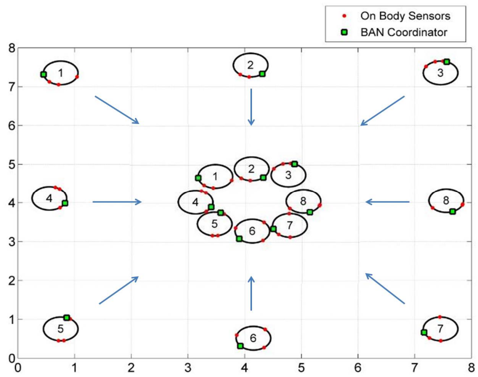

Figure 2. Sample multi-BAN scenario in an 8 m x 8 m room

The outage probability is evaluated as Cumulative Distribution Function (CDF) of the experienced SIR as different BANs relocate according to the circle scenario. Figure 3 demonstrates that compared to a Static slot allocation, the MIA_m algorithms significantly reduce the outage probability by intelligently distributing and re-allocating simultaneous and interfering transmissions in non- or less-interfering time slots. Taking into account longer history of interference (measured by the number of past frames m)

results in better performance. However, as it appears, if the minimum required SINR (Signal to Noise plus Interference Ratio) is below 2-3 dB, then considering longer history of interference profile might not lead to significant gain in the outage probability. The "optimal" parameter m depends on the coherence time of the inter-body channel. Unfortunately, currently sufficient information about the BAN-to-BAN wireless channels is not available. In our simulations, a coherence time of 110 msec which is roughly around 5 frame lengths have been considered. Also, in Figure 3, we have assumed correlated channels among various body-to-body links, corresponding to the multiple sensor locations on adjacent bodies.

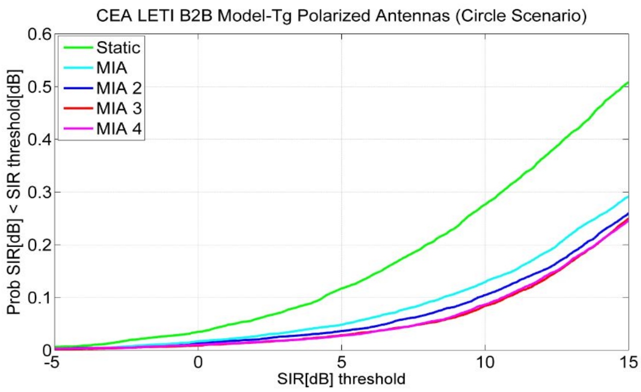

Figure 3. CDF of the experienced SIR (Correlated Channel, and Reassignment Probability of 0.2)

Figure 4 shows the performance of our algorithm using uncorrelated channels. As observed there is still a considerable gain compared to a static assignment. Furthermore, using higher values of m (i.e. longer interference history) could lead to more tangible gain in the outage probability in this case. 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.

III. MRS Mitigation Algorithm & System Performance

Using a MIA_m approach, the scheduling algorithm will try to assign each node a time slot which will lead to the highest signal to interference ratio. As several nodes might be competing for the same time slots, this approach allows limited options for slot reassignment in the new frame. Recognizing that merely satisfying the minimum required SINR is enough for reliable reception of data packets; we can relax the best slot selection in the MIA_m approach by allowing reassignment to all slots that meet the Min_SINR requirement. In this way, more options will be available for the scheduler at each time frame and more convenient reallocation of transmission slots can be expected. We refer to this approach as MRS (i.e. Minimum Required SINR). The flowchart in Figure 5 shows the steps taken in this algorithm.

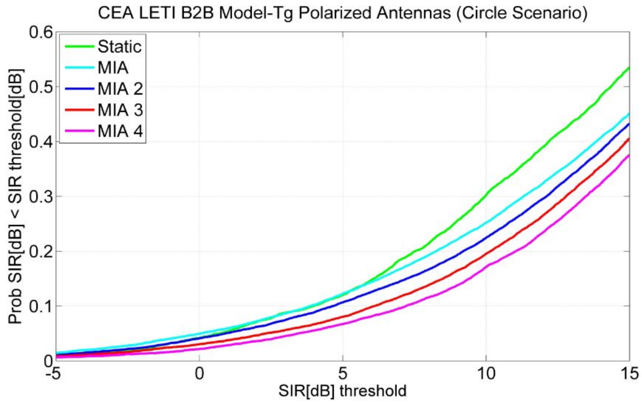

Figure 4. CDF of the experienced SIR (Uncorrelated Channel, Reassignment Probability of 0.5)

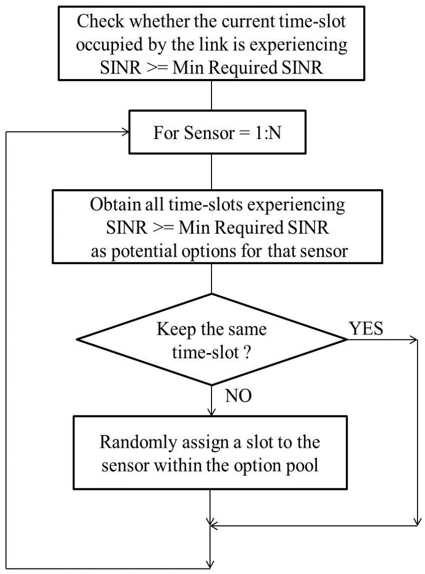

Figure 5. Minimum Required SINR Assignment (MRS) Scheduling Strategy

In general, MRS strategy operates similar to the MIA algorithm; however, by allowing all time slots that meet the minimum SINR requirement into the reassignment pool (as opposed to only the highest SINR slots), there will be more opportunity for possibly simultaneous transmissions across multiple BANs to avoid collision and therefore less Inter-BAN interference. Depending on the application requirements, the minimum SIR threshold, for example, can be obtained as in [10]; using one of the IEEE802.15.6 Standard reference values for receiver sensitivities ($P_{R\min}$) for different modulation and coding schemes [8] as shown in Table 1. In general this threshold can also change adaptively. Lower threshold will result in larger pool size for relocation i.e. more options for reassignment. However, too many slot reassignments (i.e. low threshold and high reassignment probability) by each BAN could have a negative impact on the scheduler convergence speed. The choice of persistent/non-persistent strategy to transmit the packets at every frame could also affect the optimal value for this threshold.

MCS	Modulation	Information Data Rate [Kbit/sec]	P_{Rmin} [dBm]	$SIR\|_{min}$ [dB]
0	π/2-DBPSK	121.4	-95	-2
1	π/2-DBPSK	242.9	-93	0
2	π/2-DBPSK	485.7	-90	3
3	π/4-DQPSK	971.4	-86	7

Table 1. IEEE 802.15.6 Modulation and Coding Schemes

To evaluate and compare the performance of the MRS algorithm, we considered the sample scenario shown in Figure 2 as well as a scenario with 8 BANs distributed and moving randomly in the same size room. As mentioned before, each BAN includes 3 sensor nodes in addition to the controller. Each frame is assumed to be 20 time slots in length and each communication link in a BAN has a packet to transmit during every frame. Figure 6 depicts the CDF of the experienced SIR for the mentioned scenarios obtained with tangentially polarized antennas channel model [9].

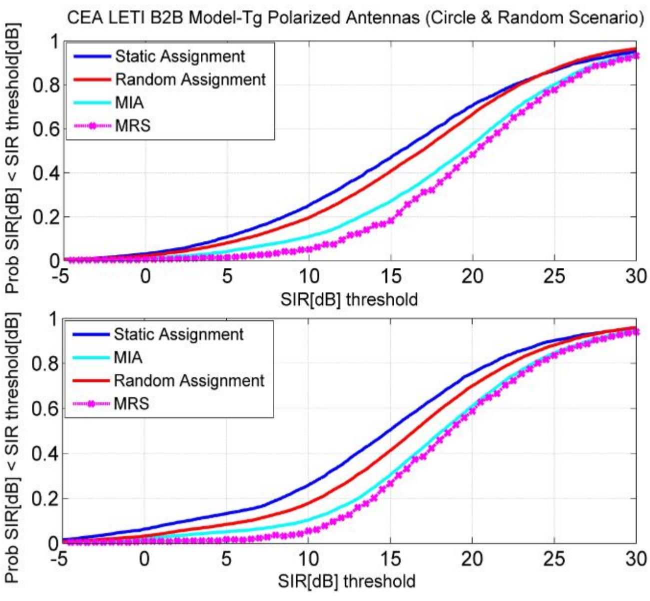

Figure 6. CDF of the experienced SIR for the circle scenario (upper graph) and the random scenario (lower graph)

As observed, using MRS scheduling algorithm improves the performance for both scenarios. MRS also outperforms MIA algorithm as expected i.e. the link outage probability is significantly reduced for SIR values between 0 and 20 dB. It was shown in [7] that use of tangentially polarized antenna results in much less inter-BAN interference compared to a normally polarized antenna. Therefore, in these simulations, we have used the channel model associated with tangentially polarized antenna as described in [8]. Similar results were obtained with channel model obtained through the use of a normally polarized antenna. For brevity, here we are omitting those results.

Similar to the MIA_m strategy, we also studied the extension of the MRS transmission scheduling by considering the experienced interference during the last m frames. MRS_m decides the new slot assignment schedule by keeping track and taking the average of the experienced SIR values over the past m frames. Figure 7 and 8 show the performance of the MRS_m algorithm for correlated and uncorrelated channels respectively. The graphs also display the impact of a parameter (i.e. RP) that signifies the probability of reassignment to one of the eligible slots (i.e. slots with SIR > Minimum Required SIR) in the option pool (see Figure 5). There are two observations from these results. First, unlike the MIA_m, the MRS_m algorithm does not provide any gain in the overall system performance. This is probably due to the fact that MRS_m allows for a wider selection of slot options (i.e. bigger pool) for reassignment in the new frame. Therefore, keeping track of the past m frames does not lead to any improvements.

The second observation is that the choice of the RP parameter could make a significant impact in the link outage probability. In our simulations, higher values of RP results in a better performance. This seems to be the case for both correlated and uncorrelated channel assumptions. In general, this parameter affects the convergence speed of the scheduling algorithm. Higher values result in a more aggressive slot re-allocation. The choice of an optimal value for this parameter should depend on the channel characteristics e.g. coherence time.

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 (i.e. persistent transmission). One can also consider a non-persistent strategy where a link transmission is blocked when there are no slots with the minimum required SINR available. This methodology results in less overall system inter-BAN interference in exchange for possibly longer packet delays. 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.

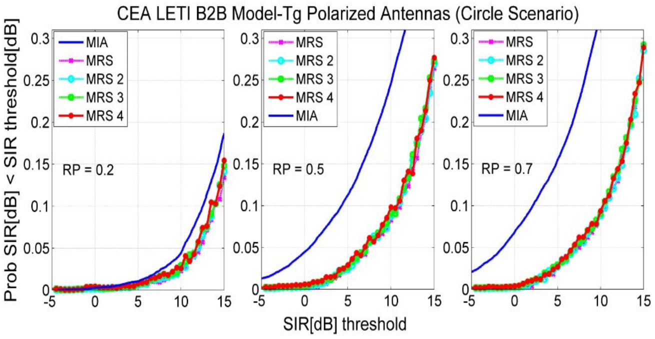

Figure 7. CDF of the experienced SIR for the MRS_m algorithm (correlated channels)

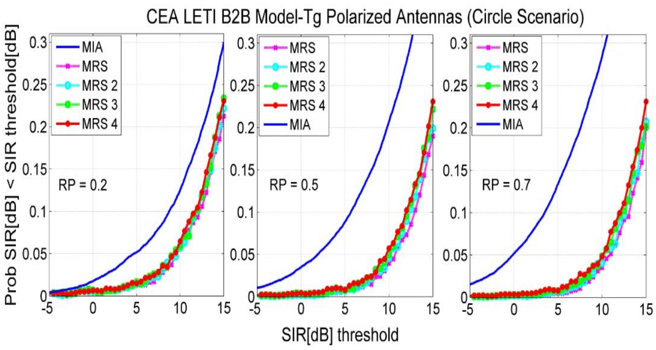

Figure 8. CDF of the experienced SIR for the MRS_m algorithm (Uncorrelated channels)

IV. Conclusions and Future Plans

This paper is proposing scheduling algorithms strategies that can mitigate inter-BAN interference without explicit inter-BAN coordination. The simulation results suggest that these adaptive scheduling algorithms may result in significant inter-BAN interference reduction in body area networks. We have used a simulation platform, which has been developed for modeling inter-BAN interference and performance evaluation of possible mitigation strategies. Our scheduling algorithm implementation achieves interference mitigation by taking advantage of the history of interference experienced by each BAN. The proposed algorithms clearly reduce the outage probability by intelligently distributing and re-allocating simultaneous and interfering transmissions in non- or less-interfering time slots. In this study, we have analyzed the performance of the scheduling strategy, when one or more frames are included in the slot assignment decision for the upcoming frame. The simulation results suggest that appropriately designed adaptive scheduling algorithms could result in significant inter-BAN interference reduction in body area networks. More detailed studies and experiments are needed to determine the feasibility and effectiveness of each strategy in mitigating potential interference. In our future research, we plan to explore the performance of these uncoordinated algorithms along with various link adaptation schemes.

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 coordinated mechanism might result into even better performance for interference mitigation; of course, as a trade-off with more complexity. The authors also plan to investigate possible strategies that require multi-BAN coordination.

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