Body Area Network Channels Study Using a Deterministic Ray Tracing Based Simulator

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ABSTRACT
In this paper we aim to present the Body Area Network (BAN) channels simulation using the `PyLayers` physical simulation platform based on graph based ray tracing techniques and a simulation results comparison with measurements. In this work, different BAN channels, for instance, on-body and off-body are simulated in a walking scenarios in indoor environment for motion capture and group navigation applications. The simulated channels results are then compared to measured results carried out and shared by the NICTA laboratory.

Keywords
BAN channels, Ray-Tracing, Deterministic simulation, measurements.

1. INTRODUCTION
In the last years the interest in Body Area Networks is increasing and occupying many researchers and industrials mostly because of anticipated huge applications around the upcoming Internet of Things and nomadic connectivity . In general, in the context of communication systems conception and design, the study of the propagation channel characteristics is fundamental. This is especially true, in the Wireless BAN (WBAN) context, where the channel is considerably affected by the human body vicinity and motion [1].

The propagation channel study begins with measurements for extraction of specific statistical models with the depth required by the targeted use case. Besides, it is also important to build ADAP (As Deterministic As Possible) simulators to address the very large space of particular situations defined and parameterized by data, which are becoming, over time, more and more available at the application level. The desirable balance between deterministic and statistical description of the channel being strongly dependent on the context, e.g very different whether only localization or only communications is involved. Moreover, any design of a simulation strategy has to do compromises between computation time and level of physical description, mostly when dealing with upper layer abstractions. In that very purpose, the presented work is aiming to investigate how the anthropoid nature of the subject motion is "etched" into the multi link indoor WBAN radio channel and how good (or bad) deterministic simulations compare with real data. Thus, in this work a PyLayers [2],[3],[4] different BAN channel (on-body, off-body), motion capture based, multi link simulations have been compared to the corresponding scenario extracted from a sample of the measurement database carried out and shared by the NICTA laboratory,[5][6].

In this paper, the measurements campaign is presented in section 2. The section 3 recalls the used simulation setup. Finally, in the section 4 a comparison between simulation and measurement results is presented.

2. MEASUREMENT SETUP
A measurement campaign was carried out by the NICTA laboratory [6] aiming to study the different BAN channels (on-body, off-body...) in several configurations (standing, walking, running...) at different frequencies (400 MHz, 900 MHz and 2400 MHz) in indoor environment. In this work, the data relative to on-body and off-body links have been used. The measurement environment is an indoor office presented in Figure 1. The human subject is moving on a treadmill. In this work, the walking scenario at the speed = 3 km/h has been selected for comparison.

Regarding the frequency, the channels was measured at different frequencies bands. In this work, the simulation and comparison are performed at f = 2.4 GHz. At this frequency the used antenna, Octane BW-2400-2500, is approximately omni-directional. The antenna were worn such as the E-plane is perpendicular to the environment floor.

For the on-body measurement the devices are located on the

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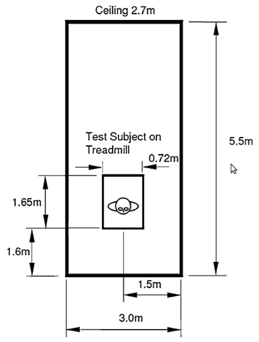

Figure 1: On-body experimental treadmill environment, including subject location (from [6])

different limbs (right/left wrists and ankles) and the trunk (front/back chest and left/right hip). This configuration, illustrated in Figure 2 allows the study of on-body dynamic and static channel characterization.

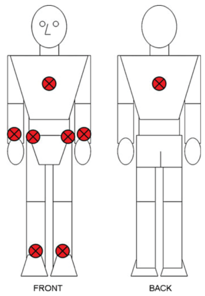

Figure 2: Devices positions on the subject (from [6])

Regarding the off-body measurements only the chest and right wrist devices are maintained on the body. The simulated links are the infrastructure to chest/right wrist.The infrastructure device is placed at different distances from 1 to 4 meters and for each distance the subject was facing in 4 different angles: 0, 90, 180 and 270 degrees with 0 degree representing the subject facing he infrastructure antenna and 90 degree indicating the subject moved 90 degrees clockwise with respect to the infrastructure device.

3. SIMULATION SETUP

3.1 Layout and Propagation Environment

The PyLayers simulation work-flow starts by defining the propagation environment. Here, the layout is a 3 meters × 5.5 meters room where the human subject is moving on a treadmill. Notice that in the presented results only the layout has been modeled but not the furniture present in the room as, for instance, the treadmill which may have had some effect on the propagation channel (see e.g fig 1(d) of [6]).

3.2 Large Scale and Body Scale Mobility

PyLayers simulator has been designed to handle large scale mobility [4], i.e, the mobility of an agent, considered as summarized to its center of gravity. In this paper this feature is not fully exploited because the center of gravity of the subject is assumed steady above the treadmill. After describing precisely the position and orientation of each device on the body, the trajectory is centered to simulate the walking on treadmill trajectory during the same 60 s measurement time and at speed = 3 km/h.

In order to simulate the BAN channel, the human motion has to be superimpose over the introduced. This has been done using the motion capture files C3D (Coordinates 3D) of a walking sequence [7]. The corresponding body sequence (PyLayers topos concept) is presented in Figure 3. This walking sequence is generic and do not correspond to the actual motion of the subject during the measurement. This is a source of deviation between the simulated and measured data. Further work should investigate such comparison in exploiting the actual motion capture of the subject under test.

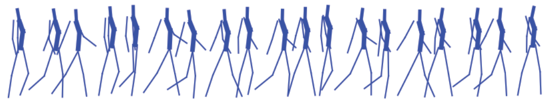

Figure 3: Motion capture sequence from [7]

The data extracted from these files is plugged in the PyLayers simulator and synchronized with the large scale mobility. In the current case the trajectory is limited to the center of gravity of the body. Then, the same devices configuration as measurements, in Figure 2, is set up.

3.3 Perturbed Antenna Model

The antenna modeling is a key in the presented approach. Aiming the comparison with the Octane BW-2400-2500 antenna used in measurements a patch antenna radiating at f = 2.4GHz with similar radiation pattern has first been modeled using HFSS simulator, Figure 4.

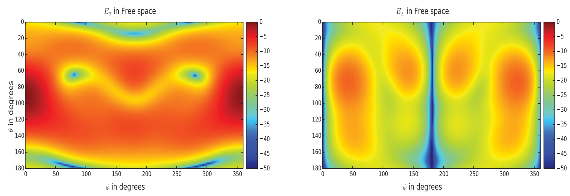

Figure 4: Simulated antenna in free space

The antenna pattern is expanded in terms of spherical harmonics coefficients [8],[9]. This approach reduces the amount of data required for describing the full antenna pattern. This has been the chosen manner for describing the antenna pattern in the PyLayers simulation platform.

The ray tracing is used to take into account the interaction on walls of the environment. This is much more questionable to apply the ray tracing for the on-body channel. There is current investigation in that direction [10], but this is not this approach which has been chosen here.

The direct link between the different nodes on the body is taken into account by a proper modification of the antenna radiation pattern in the spherical harmonics space. We introduce a perturbation on the antenna, modeling the human presence. This approach is detailed in [11]. The free space antenna spherical harmonics coefficients are modified directly to generate the coefficients representing the perturbed antenna by the human body presence. By resorting to this approach, we avoid the ray tracing on the body and the body effect is taken into account into the antenna pattern itself. The Figure 5 shows the perturbed antenna outcome obtained from the perturbed model. In this figure the antenna has been placed at a distance of 5 mm from a 70 mm diameter cylinder. One all the aforementioned elements are set up, a ray tracing simulation is done for each link of interest and for each time-stamp.

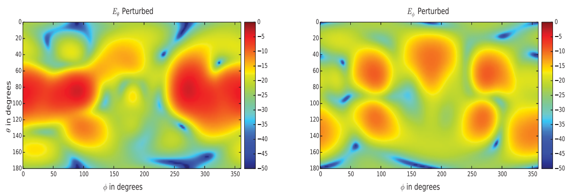

Figure 5: Simulated antenna perturbed by the model

4. SIMULATIONS VS MEASUREMENTS COMPARISON

4.1 On-Body Channels Results

This subsection presents a comparison in terms of path loss amplitude of a multi links time series and the corresponding cumulative distribution functions (CDF) both for the measurements and simulations of the above described walking scenario.

The physical simulator generates the channel impulse response evaluated over the defined bandwidth. The time varying channel impulse response is expressed as:

$$h(t,\tau) = \sum_{k=0}^{K(t)} \alpha_k(t)\delta(\tau - \tau_k(t)) \quad (1)$$

where $K(t)$ is the number of paths, $\alpha_k(t)$ and τ_k are the amplitude and the arrival time of the k^{ith} path. The path loss at each instant of time is given by:

$$PL(t) = \sum_{k=0}^{K(t)} |\alpha_k(t)|^2 \quad (2)$$

The figure 6 shows the path loss relative to the different links simulated using free space antenna patterns. As it can be expected, the channel gain level is not recovered properly for links that are highly affected by the body shadowing such as the back to chest link. Besides the variation of the path loss of the dynamic links such as the wrist is due to the distance variation not the body effect.

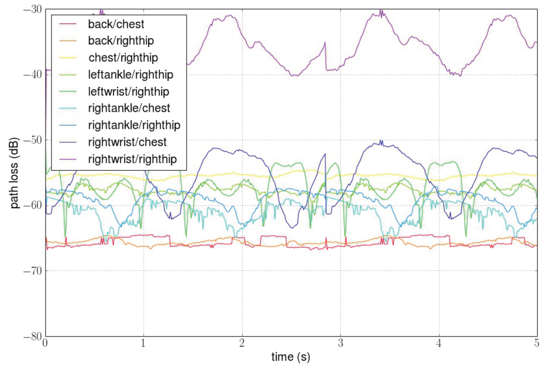

Figure 6: Path loss for walking sequence from simulations using free space antennas

The Figures 7 and 8 show the variation of the measured and simulated path loss (integrating this time the body effect) during a walking sequence in indoor environment for the different on-body links. The Figures 9 and 10 represent the corresponding CDF evaluated over 5 seconds of walking sequence. Those 4 Figures show that the simulation are quite close to the measurement data at least on a relative scale. However, the breadth of the shadowing is clearly underestimated in the simulation. The current interpretation of this effect is that the trunk shadowing is underestimated by the perturbed antenna model which has been used. The dependency of the model with the radius of the equivalent cylinder associated to the trunk is clearly not properly handled and should be calibrated. The NICTA dataset is perfectly suited for this calibration task. Notice that in the presented measurement/simulation comparison there was no ad-hoc effort for having an absolute fitting of the channel gain.

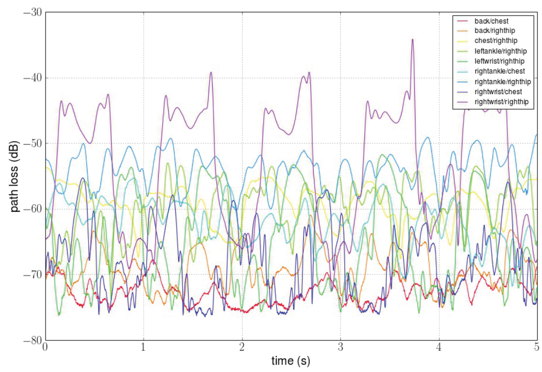

Figure 7: Path loss for walking sequence from measurements

Several interesting aspects can be underlined. The link characteristic (reliable or not ...) and variation during the walking motion is well recovered. As it is observed in the measurement data, the best link is right hip to right wrist (purple

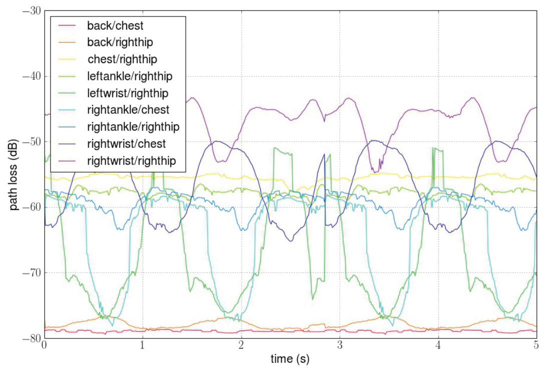

Figure 8: Pathloss for walking sequence from PyLayers simulation using perturbed antennas

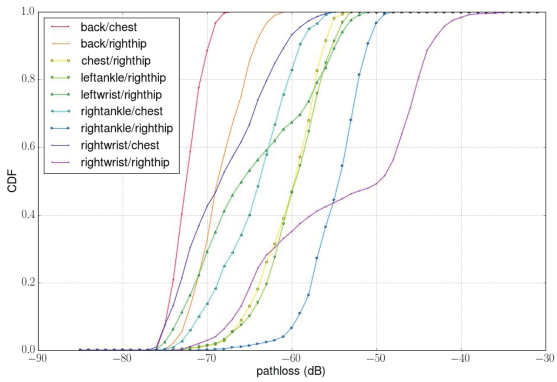

Figure 9: CDF of the path loss from NICTA measurements

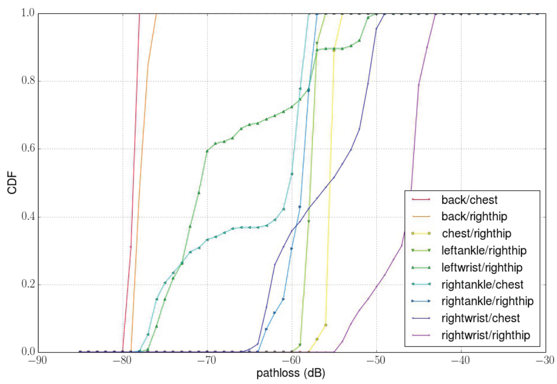

Figure 10: CDF of the path loss from PyLayers simulations

curve in Figure 7). Interestingly the shape of the channel gain is very well retrieved with a peak appearing when both link antennas are in close vicinity, just before digging in the shadow region. This shape is probably very dependent from one subject to an other depending on the subject gait. Further statistical analysis on that point would probably be of interest. This observed relatively good agreement in the multi link structure argues for the relevance of the approach which is potentially a good compromise between efficient implementation and physical realism.

The front/chest to back/chest link which is static and intrinsically NLOS is well retrieved and of course those results would be completely impossible to model if the antenna patterns were kept unperturbed. Interestingly, the adopted approach exploits actual data from the knowable free space, far field antenna pattern. This means that the proposed approach could benchmark different antenna design in complex WBAN scenario, ceteris paribus.

However, other links are not well retrieved, for example the right hip to chest link. In fact, the simulated path loss is overestimated compared to the measurements. This link is more reliable in simulation because of the antenna perturbation model which introduce, here, the perturbation of the member on which the antenna is placed. This might be admitted for the antenna on the trunk but it is not the case of the antenna on the wrist which is perturbed by the trunk too.

4.2 Off-Body Channels Results

In this subsection the off-body channels comparison is presented. The off-body links are chest and right wrist to infrastructure device which are placed at different distances and angles. The comparison, as for the on-body, results is done in terms of path loss amplitude and CDF. The off-body channels were measured for different scenario (standing, walking...). In this case, the presented results are relative to the walking scenario (speed = 3 km/h).

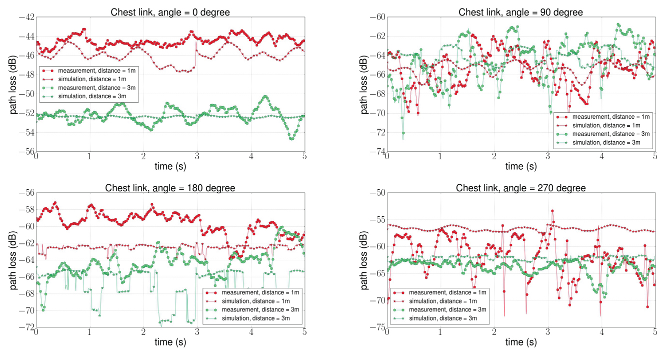

Figure 11: Measured vs simulated path loss : Chest link

The Figures 11 and 12 present the measured and simulated path loss for the different angles (0, 90, 180 and 270) at the distance 1 and 3 meters during 5 seconds of walking sequence in indoor environment. The Figures 13 and 14 represent the corresponding CDF. The results show that, as for on-body channels, the simulated channels are quite close to the measured channels.

The most important retrieved results are:

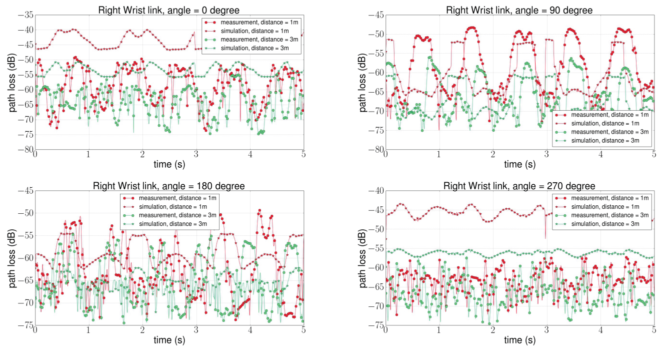

Figure 12: Measured vs simulated path loss : Right Wrist link

- Channels variation with respect to the distance:

The Figures show that the effect of the subject-infrastructure distance is well retrieved and this is valid for the different angles configurations. This is clear for the chest link results where the channels are almost well estimated compared to the measurements.

- Body Shadowing:

The chest link variation with the angle configuration assesses that the body shadowing is well considered. It confirms the interest of using the perturbed antenna pattern since for the different angles the simulations present results close to the measurement. In some configurations is very precise since the channel depends on the antenna pattern perturbation model which is elaborated with a cylinder smaller than the trunk.

- Motion Capture:

The right wrist results show that the right arm movement is well captured at different distances and angles. This is very useful for the targeted application, for instance, the individual motion capture and group navigation. Thus besides the results presented previously, the different components (distance, direction, relative position) which are necessary for processing localization estimations are well modeled.

However, in some configurations (angle = 0 and 270 degrees), the right wrist channel is overestimated. These configurations represent the cases where the antennas are facing each other. Thus the reason behind these results might be the antenna gain amplitude. Besides, the arm rotation is not handled in the presented simulation.

5. CONCLUSIONS

This paper has presented a comparison between real data from a WBAN walking experiment and the simulation from the site specific simulator PyLayers. The results are in quite good agreement if we consider that the used human motion corresponds in each case to different subject. The relative level of the different link is quite well retrieved. It

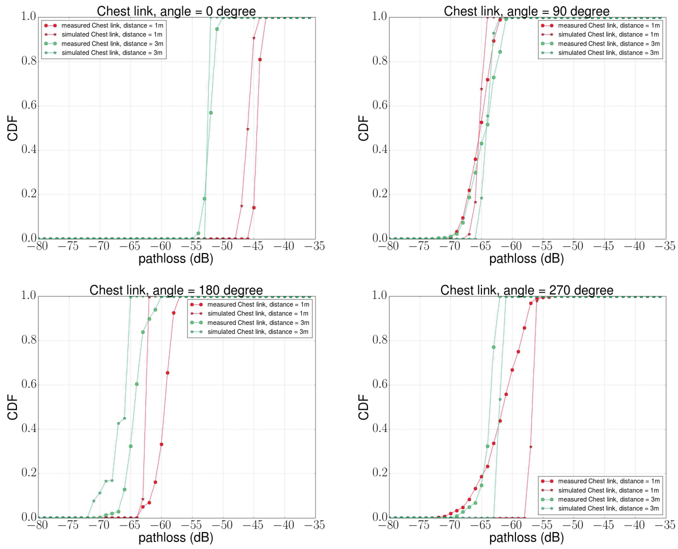

Figure 13: Measured vs simulated path loss CDF : Chest link

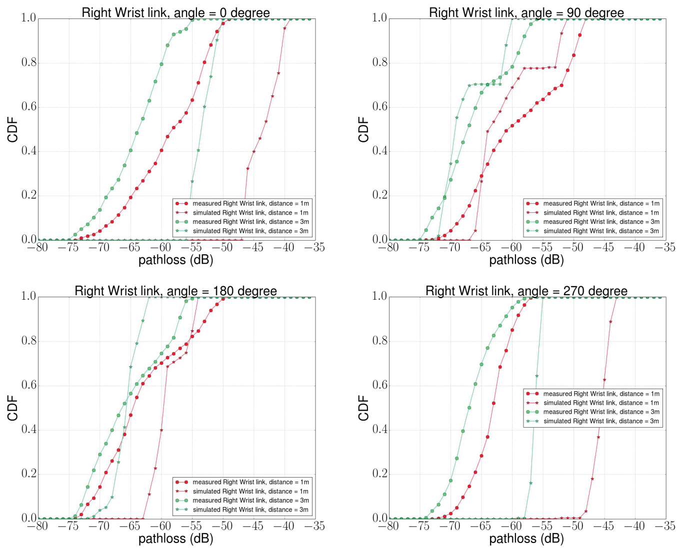

Figure 14: Measured vs simulated path loss CDF : Right Wrist link

has to be noticed that PyLayers simulator can provide a much richer information about the channel as e.g angular and delay structure of the channel over ultra wide bandwidth. This comparison confirms a well admitted fact that the very nature of the multi link variation is strongly related to the human motion which can be captured and digitized for semi deterministic simulation. The motion captured is a key technology for decoding the rich information carried out by the multi-link variation observed in the BAN.

In this comparison the large scale motion of the problem has been removed because the subject is staying at the same place. The quality of the obtained results is strongly dependent on the manner the radiation pattern is handled. This is the key factor behind the presented comparison. This first validation paves the way for investigations of far more sophisticated scenarios as those which are currently investigated in the French ANR CORMORAN project as indoor group navigation.

In the future work we aim to simulate other UWB BAN channel, for instance, Body-to-Body channels. Further steps are :

- to produce improved antenna model describing better the trunk perturbation and to introduce the statistic model described in [12] for the on body channel because the current implemented approach cannot give access to the correct CIR delays.
- to apply the same simulation approach on joint motion capture vs radio links dataset.

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