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Human Body Perturbed Antenna Integration In Indoor Propagation Simulator

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Keywords

UWB antenna modeling, Spherical Harmonics, Physical Simulator, WBAN, Motion Capture, Radio Channel Simulation, Site specific modeling.

Abstract

This paper presents first results of simulation of a radio link between 2 antennas mounted on a the body. The body mobility is handled at two levels, the trajectory level and the body mobility level. A perturbed antenna model is used to acknowledge the effect of the body directly in the radiation pattern. Aggregated channel impulse response simulated in an Indoor environment is presented. The presented results validate the interest of the proposed approach for further integration with higher layer simulation.

Introduction

In the context of communication systems conception and design, the knowledge of the channel is always of importance. Especially, Body Area Networks (BAN) channels, since the transmission channel depends not only on the environment but it is also strongly affected by the body and its effect on body mounted antennas. In this work, for ease of the exposition, we

focus on a simple single agent, single link. However the presented tool has been designed to handle Body Area network (BAN) for multi-agent and multi-links situations. This requirement being necessary for addressing the location related scenario defined in CORMORAN project : Large Scale Individual Motion Capture (LSIMC) and Coordinated Group Navigation (CGN) [1].

The BAN channel is manifold as it may consist of different kind of links : On-body and Off-body, the later including body to infrastructure and body to body links. The used simulator implements classical ray tracing techniques [2] and handles the agents mobility in a specific layout, as well as the body mobility using realistic body abstraction obtained from motion capture files. The antennas are fully described in a compact form using spherical harmonics expansions as described in [3].

The chosen approach has two levels. A first level acknowledges the motion of the center of gravity of the body along realistic indoor trajectories using a Discrete Event Simulator (DES) and a second level superimposes the body mobility on the trajectory. All the link of interest for the scenario can be calculated and stored for further post processing. To this end, a perturbed antenna model assessing the pattern behavior when antenna is placed around the human body is presented. This approach assumes that the effect of the body presence is being taken into account in the antenna radiation pattern, avoiding to manage a body description into the ray tracing. The paper is organized as follows: Section 1 describes human body mobility model, based on motion capture files, as well as the dedicated antenna model, Section 2 presents first integration simulations results and a comparison between situations using a body-perturbed and a non body-perturbed antenna.

1 Human Mobility and Antenna Model Integration

In this section, the Body Area Network channels simulation is presented including a description of how are handled the human body mobility and the antenna model.

1.1 Modeling of Human Body Mobility

Different ways can be used to model the human body mobility. Traditionally, bio-mechanical models are used to represent the human mobility in a walking situation [4]. An alternative way is to make use of data coming from motion capture. Among the different existing motion capture data file formats, the C3D (Coordinates 3D) format is used here due to its compliance with most of motion capture systems. Among the data stored in C3D files are the whole 3D coordinates of a fixed number of points, representing human body sensors at very specific conventional location on the body at each time stamp. A 3D frame consists of a set of those 3D points. For example Figure 1.1 represents a 41 points' frame. The main advantage of using motion capture data is that it enables to investigate a large variety of motion situations, not only limited to walking scenario.

The data extracted from C3D files are then used to build a human body cylindric model. The C3D data are filtered and a limited number of points is used 16 instead of 41 for creating

a simplified cylindric model. This model being a good trade off between fidelity of the representation and simplicity of the implementation. Similar approaches are proposed in [5]. The body trajectory is obtain from DES force based multi agent simulator which can produce an arbitrary number of realistic human trajectories into the Layout. Once the trajectory has been calculated, the body is inserted at the good location in time and space. Once properly positioned it remains to handle the body mounted radiating element positioning and orientation in the global scene. This is done through the introduction of a chain of time dependent (except the global one) coordinates systems relating one to another via specific linear transformations (translation or rotation). The important aspect being to properly ponder the rays with the appropriate complex gain from the antenna pattern. The defined chain of coordinate systems is as followed:

$$GCS \rightarrow CCS(t) \rightarrow DCS(t) \rightarrow ACS(t) \quad (1)$$

Where

- GCS refers to the global coordinates system. The Layout and the rays from the ray tracing are expressed in this GCS.
- CCS refers to Cylinder Coordinates System: each cylinder of the body model is associated with a dedicated CCS. A CCS is obtained from the large scale trajectory and the body frame corresponding to a given time on the body trajectory.
- DCS refers to Device Coordinates System : this CS is a rotated and/or translated version of the CCS. The origin of this coordinate system is the device position. A device is non ambiguously placed on a body cylinder via 3 parameters $(l, h, cylId)$. $0 < l < 1$ is a parameterization of the length of the cylinder, h is the height of the device w.r.t to the cylinder of Id $CylId$.
- ACS refers to Antenna Coordinate System: it is an arbitrarily rotated version of the DCS that defines the antenna local coordinates system. The radiation pattern of the antenna is known in this ACS. One device could have theoretically several different ACS. This possible feature is not exploited in the following.

The Figure 1.1 shows the C3D frame (a), the body cylindric model built using C3D data (b), the body and all the CCS (c), and the body with the 2 selected DCS (d).

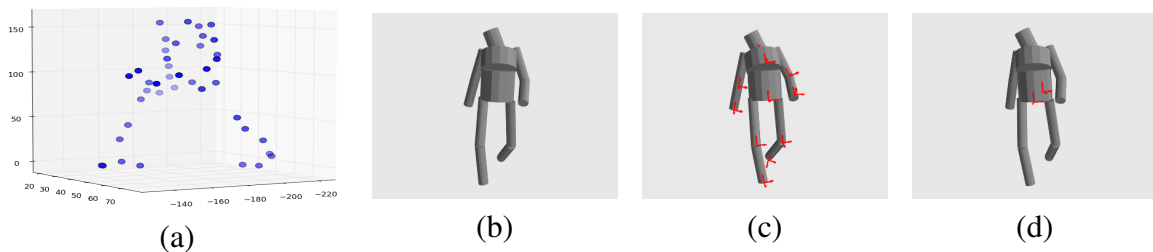


Figure 1.1: C3D frame (a) and body cylindric model(b) with 11 CCS (c) and 2 DCS (d)

1.2 Antenna Model

In the context of body area network radio channel simulation and modeling the knowledge of the antenna radiation pattern is fundamental. The human body disturbs in a considerable way the antenna pattern. One rigorous way to introduce the body effect in the physical simulator would be to apply an electromagnetic solver. However, for the purpose of higher level simulation we are addressing, this approach is too computationally intensive. As a compromise alternative, we proposed to account for the body effect in the antenna pattern itself in using an equivalent antenna obtained from the unperturbed free space antenna and parameters depending mostly of the distance of the antenna from the body.

To study the effect of a human phantom on a UWB antenna a measurement campaign was carried out to study the effect of the human presence on antenna, where the antenna is measured in free space and placed around a cylindrical human phantom at different distances [6].

It is well known that a natural and compact representation of the antenna pattern is based on spherical harmonic (SH) basis expansion. According to [3],[7], the far-field radiation pattern \mathbf{F} can be expanded in terms of scalar spherical harmonics with vector coefficients:

$$\mathbf{F}(\theta, \phi, f, d) = \sum_{l=0}^L \sum_{m=-l}^l \mathbf{c}_{lm}(f, d) Y_l^m(\theta, \phi), \quad (2)$$

where $Y_l^m(\theta, \phi)$ are the SH functions and \mathbf{c}_{lm} are SH coefficients. Using spherical harmonics (SH) expansion the antenna data is reduced to few SH coefficients. Exploiting the above spherical harmonics decomposition we have proposed a model which predicts in the spherical harmonics coefficients domain the perturbation of the complex pattern caused by the human presence. It is obtained from experimental data and consists in a simple linear model relating SH coefficients of a disrupted antenna to free space coefficients and antenna-phantom distance:

$$\tilde{\mathbf{C}}(d) = \mathbf{A}(d) \odot \mathbf{C}^{\text{fs}} \quad (3)$$

Where d is the antenna-phantom distance, \mathbf{C}^{fs} are SH coefficients of the antenna in free space, $\tilde{\mathbf{C}}(d)$ denotes the perturbed version of SH coefficients and $\mathbf{A}(d)$ is the linear model vector of parameters representing the perturbation. The Figure 1.2 shows the "Thomson" antenna patterns in the plane (x, y) at $f = 4\text{GHz}$ in free space (green) and around the human phantom (red) cases. We observe the perturbation brought out by the human phantom presence which is placed at the distance $d = 30\text{mm}$ from the antenna. This model is described with more details in [8]:

This model has been integrated in the indoor propagation simulator to simulate and model realistic BAN channel by taking into account the antenna perturbation.

2 Simulation and Results

In this section, we consider the link hip to right wrist. Comparisons between using a perturbed antenna and a free space antenna are presented. The simulation is made in a defined layout and for a specific trajectory in a walking scenario shown in figure 2.1. There are 3 different regimes in this trajectory. The agent starts to move in a room, then goes into a long corridor,

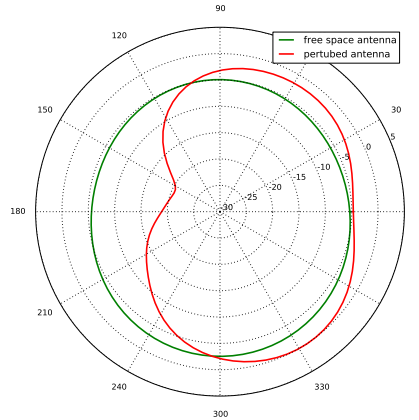


Figure 1.2: Perturbed (red) and free space (green) antenna pattern at $f = 4GHz$ in the plane (x, y)

and finally reach an other room on the other side of the corridor. The overall trajectory time is $10s$ and the sampling period along the trajectory is $10ms$.

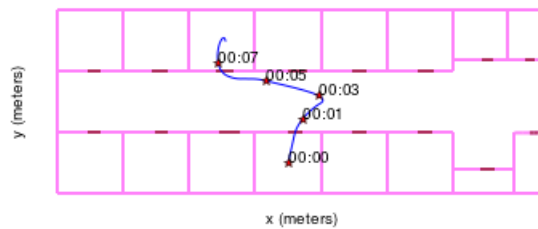


Figure 2.1: Simulation Layout and Agent 10 s trajectory from one room to another

At each instant the rays between the transmitter and the receiver are identified and evaluated.

The antennas are applied with their proper orientation and the transmission channel impulse response $h(t, \tau)$ is evaluated. The two pattern which has been used are presented in Figure 1.2.

The pattern used for the perturbed antenna is obtained using a phantom modeling of the antenna in the vicinity of a human arm. This same pattern has also been used for modeling of the antenna mounted on the hip which is of course less justified. However, for the purpose of the illustration of the approach this is not an issue. Any more realistic antenna pattern coming from a rigorous simulation or measurement could be used instead if more realism is needed.

The Figure 2.2 represents the body cylindric model with antenna placed on the body. The chosen pattern radiates mostly toward the half space opposite to the body members (arms in this case). In fact, by using these antennas the human body presence is taken into account without requiring to actually represent the body in the global scene. Notice that this is an approximation which do not capture everything from the propagation phenomena appearing

on the body.

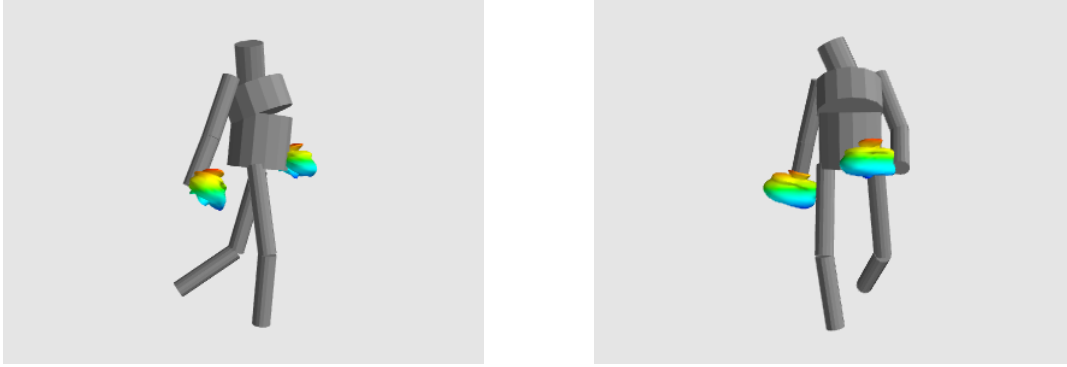


Figure 2.2: Body cylindric model with perturbed antenna

The channel impulse response is evaluated over a bandwidth from 3GHz to 6GHz allowing UWB waveform simulation. The time varying channel impulse response is expressed as:

$$h(t, \tau) = \sum_{k=0}^{K(t)} \alpha_k(t) \delta(\tau - \tau_k(t)) \quad (4)$$

where $K(t)$ is the number of paths, $\alpha_k(t)$ and τ_k are the amplitude and the arrival time of the k^{th} path.

The situation we are studying is an on-body channel, in the sense that transmitter and receiver are placed on the body. However the part of the channel we are considering is obtained via off-body interactions. In this example the pure on body contribution is not fully taken into account especially in the delay domain. There exist a delay gap in the delay domain between the direct path and the first path coming to off body contribution (reflection on the environment). In this section the preliminary results obtained for human body mobility and antenna model obtained with the WBAN physical simulator are presented as well as a comparison between aggregated infinite bandwidth CIR obtained using a perturbed antenna and a free space antenna.

The Figure 2.3 shows the different paths amplitude and delays while the agent is traveling during the trajectory using free space antenna (right) and using a perturbed antenna (left). It shows the different regimes in the trajectory and how the channel structure varies with the environment. We notice that the global channel structure is nearly the same. However, we observe a dissimilarity in terms of paths amplitude since they are weighted differently according to the used antenna.

At the beginning of the trajectory during the 2 first seconds, the agent is walking in a small room the channel structure do not exceed $50ns$ which corresponds to the vertical band on the left. Then the agent goes out from the room, almost in the middle of the corridor, the two reflection at both end of the corridor are almost superimposed. Then the agent goes on the right until time $3s$, then the delay from the reflection from corridor right wall is decreasing while delay from the left wall is increasing. Finally, the agent reach another room and the multi-path structure observed during the first second is re-established.

The major effect of the body perturbed antenna is observed in to two specific region. The first one is the corridor region where the rays weights difference is clear and it illustrates well the body shadowing of one reflected path coming from the back. Thus, this simple approach is in fact able to capture correctly what would be observed in practice.

The second region and the most important difference is when zooming and observing the first paths affect by the body presence during $3s$ which corresponds to approximately to 3 human steps in Figure 2.4. It shows that the first paths amplitude do not vary in considerable manner when using the free space antenna. The observed variation is due to distance variation between the receiver and the transmitter, relative to the arm movement in a walking scenario, not the human body shadowing which is quite well reproduced with the perturbed antenna case where the line of sight, non line of sight and even the transition region are observed.

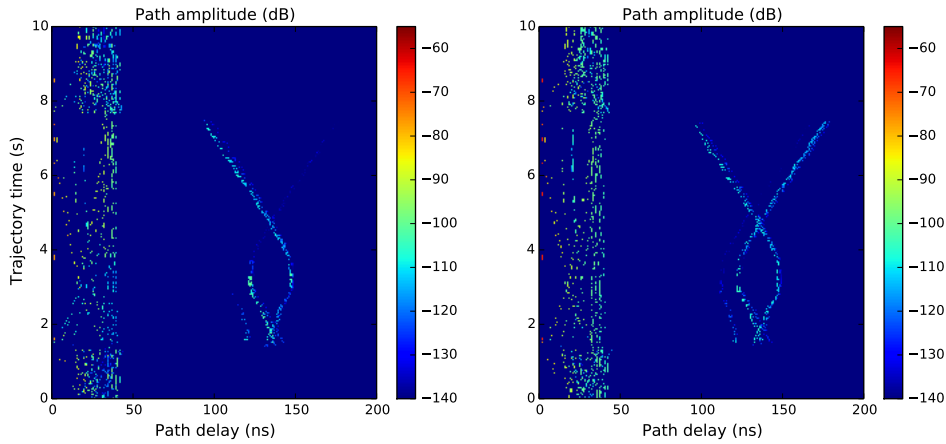


Figure 2.3: Paths amplitude during trajectory time using perturbed antenna (left) and free space antenna (right).

This result might be well observed when representing the total received power P_r at each instant given by:

$$P_r(t) = \sum_{k=0}^{K(t)} |\alpha_k(t)|^2 \quad (5)$$

where $K(t)$ is the number of paths at t and $\alpha_k(t)$ is the k^{th} path amplitude.

The Figure 2.5 shows explicitly the human trunk shadowing in hip to right wrist link in a walking scenario and confirms the paths amplitude results. It shows that the total received power variation when using free space antenna is around $5dB$ which do not consider the human body presence, it only a distance variation effect. However, with perturbed antenna P_r variation is around $15dB$ which is more realistic in BAN channels. This variation in received power values and even behavior are coherent with measurement results in [9] which confirm that the shadowing variation in almost same condition (hip to right wrist link, walking scenario) but in anechoic chamber is around $10dB$.

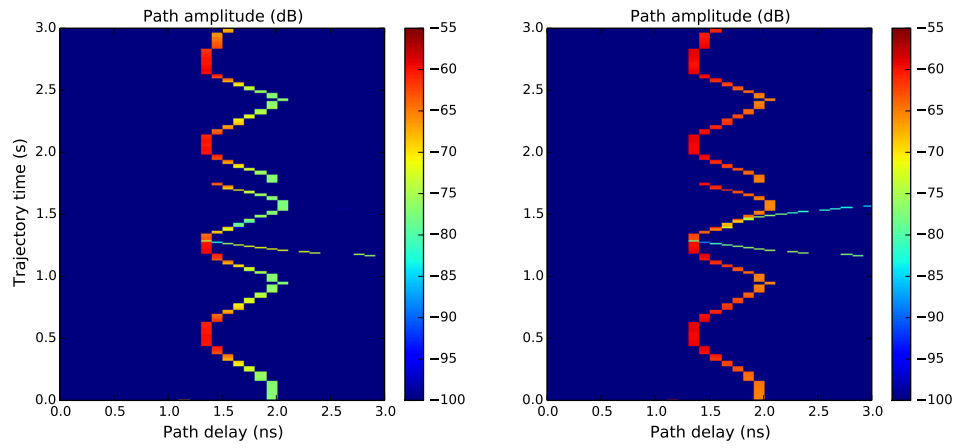


Figure 2.4: First Path amplitude during trajectory time using perturbed antenna (left) and free space antenna (right).

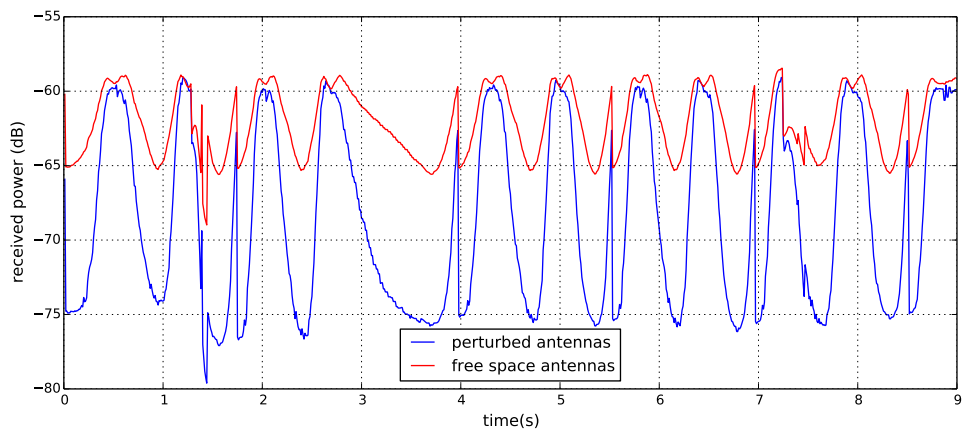


Figure 2.5: Shadowing for the link hip to right wrist for a walking sequence

3 Conclusion and perspectives

This paper has presented a full simulation of a radio link between two antennas mounted on the body integrating realistic large scale mobility and body mobility. An original technical choice for the integration of perturbed antenna model by a human phantom in the physical simulator PyLayers has been presented. The results show that the proposed approach provides realistic range in terms of received power and provides realistic radio observable variation. These observables can be always produced with ground truth values of the position and orientation of radiating element on the devices.

Further step is to produce improved antenna describing better the trunk perturbation and to introduce the statistic model described in [9] for the on body channel because the current implemented approach cannot give access to the correct CIR delays. An other immediate perspective is to study the body to body channel in realistic indoor human motion and exploitation of produced traces for evaluating various MAC layer scheme suited for BAN localization scenario of the CORMORAN project.

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