On the separability of "on-body" and "off-body" clusters in the modeling of UWB WBAN channels for various indoor scenarios

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Abstract— The Wireless Body Area Networks technology is a promising candidate for various potential applications in the domains of health, monitoring, sport, multimedia, entertainment, data transfer, etc. The optimization of WBANs at the system level requires an accurate knowledge of the propagation channel which plays a key role on the design of the PHY, MAC and Network layers. The explosive combinatorial due to the numerous sources of variability and the diversity of the situations should be reduced to be reasonably analyzed. One way is to try to separate the "on-body" cluster from the "off-body" clusters due to MPCs coming from the surrounding environment. This allows to analyze separately the proper sources of variability (population – gender, corpulence, size, age –, postures and movements, antennas – classes, distance from the body and polarization –, "micro-positioning" on the body, etc.) from the exogenous influence of the environment, reducing considerably the required experimental effort and simplifying the modeling process.

I. INTRODUCTION

The Wireless Body Area Networks technology targets applications in the fields of health, surveillance, monitoring, sport, multimedia, entertainment, data transfer, etc. A central research topic in WBAN system optimization lies in getting an accurate knowledge of the propagation channel which plays a key role on the design of the PHY, MAC and Network layers. The explosive combinatorial due to the numerous sources of variability and the diversity of the situations should be reduced to be reasonably analyzed. One way is to try to separate the "on-body" cluster (analyzable in an anechoic chamber) from the "off-body" clusters due to Multi-Path Components (MPCs) coming from the surrounding environment. This allows to analyze separately the proper sources of variability (population – gender, corpulence, size, age –, postures and movements, antennas – classes, distance from the body and polarization –, "micro-positioning" on the body, etc.) from the exogenous influence of the environment (type and size of rooms), reducing considerably the required experimental effort and simplifying the modeling process.

The idea of separating in the UWB BAN channel the on-body (MPCs) from MPCs originating from the surrounding environment has been first proposed by A. Fort in [1] and recalled in [2]: the tapped delay line model of the Channel Impulse Response (CIR) is the superposition of a correlated lognormal model for the MPCs travelling along the body and a modified SV model for the off-body MPCs. However, this model uses parameters which are not nonspecific, but dependent on the considered room. We propose here a statistical analysis to assess the conditions for which this cluster separation is possible or not, considering in particular several scenarios and premises (of clearly different types).

II. MEASUREMENT, SCENARIOS AND ENVIRONMENTS

Several UWB BAN measurement campaigns (over a very large bandwidth $BW_o = \{1, 12\}$ GHz) have been carried out in the frequency domain at ENSTA ParisTech [3] both in an anechoic chamber and in a small office, a laboratory and a large classroom. In the anechoic chamber, measurements have been performed for two scenarios – “Hip-to-Chest” (H2C) and “Hip-to-Wrist” (H2W), the central node being placed at left hip (18 cm from the navel) at a distance $\delta = 20$ mm from the body –, several sensor node antennas and distance $\delta$ from the body (3, 5, 7, 9, 11, 16 and 20 mm), in a standing still posture, arm along the body ($\vartheta = 0$). To enlarge the statistical set and take into account the body inhomogeneity, a “micro-local” sampling ($\mu$) has been performed, in the neighborhood of the sternum (reference position) for the H2C scenario (9 positions every 1.5 cm at a constant distance from the central node, $d = 31$ cm and 23 cm for subjects resp. n° 1 and n° 2) and for three positions (every 2 cm) near the wrist, and four "postures" (right arm back to ahead, i.e. for angles $\vartheta = \{-30, 0, 30\}$ and 60 degrees) for the H2W one. For the indoor premises, a third scenario, Hip-to-Toes (H2T), has been added, all three being measured simultaneously. Each room has been spatially sampled ($\ell$), considering several “macro-positions”, for each of the four preceding postures ($\vartheta$), but for a single antenna/body spacing of $\delta = 5$ mm. The Channel Transfer Functions (CTFs) are directly the measured $S$ parameters $S_{21}^i(f, \ell, \vartheta, \mu, s, Sc)$ in the anechoic chamber and $S_{21}^j(f, \ell, \vartheta, s, Sc)$ in indoor environments.
III. PROCESSING

A. Channel Impulse Response and Power Delay Profile

The proportion of the energy in the on-body cluster and in the off-body clusters, and the excess delay (or bin number) up to which the cluster separation may or may not be carried out is analyzed in the following. For this purpose, real CIRs are computed from the CTFs by IFFT after DC-padding (zero-padding from DC to 1 GHz) following a Blackman windowing. The last reduces the strongest sidelobe level by 58 dB and degrades the time resolution by a factor $\beta = 2.13$ (6 dB BW, or Bins from Harris [4]); the effective time resolution is consequently $\delta t ~ 0.0417$ ns. The real CIR sampling time being $\delta t = 1/F_s$ $~ 0.2083$ ns is chosen slightly larger than $\delta t$, corresponding to the integration of the energy over 5 samples for the computation of the PDP.

B. First Bin detection

The 1st Bin detection method is elementary, but contrary to e.g. [1], it is not performed manually by simple visual inspection. The 1st Bin is detected as the maximum of each PDP in a time window centered on the delay corresponding to the direct “optical” path length in the immediate vicinity of the body, i.e. along the body (creeping waves) or in free space.

IV. RESULTS AND ANALYSES

A. Anechoic chamber

The H2C APDP (averaged over $\mu$ and multi-sweep $\sigma$) is presented figure 14. After the on-body cluster (excess delay less than $\sim 3$ ns) a residual diffuse scattering from the anechoic chamber is observable between 7 and 42 ns. The slope of the PDP between 1.7 (1st bin) and 5.5 ns is about $-15$ dB/ns.

The small scale statistics are given as the CDF of the 1st bins (Fig. 2). The PDPs are normalized to the maximum of the APDP, and, for each realization the 1st bin is detected as the strongest. The amplitude is lognormally distributed at least up to an excess delay of $\tau = 3.75$ ns (Fig. 2).

Fig. 1 (a) Small office (SO), (b) laboratory (Lab) and (c) large classroom (LC), showing “macro-positions” (distances in m).

Fig. 2 H2C in anechoic chamber: empirical CDFs and normal fits.
TABLE I
H2C & H2W IN ANECHOIC CHAMBER: FIRST BINS MOMENTS (dB).

<table>
<thead>
<tr>
<th>Bin</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>9</th>
<th>11</th>
<th>13</th>
<th>15</th>
<th>17</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ₁₀₀₀</td>
<td>3.66</td>
<td>5.85</td>
<td>3.64</td>
<td>4.30</td>
<td>4.89</td>
<td>4.78</td>
<td>5.39</td>
<td>4.52</td>
<td>4.55</td>
<td>3.71</td>
</tr>
</tbody>
</table>

The slope of the H2W PDP between 2 (1st bin) and 3 ns is about −13 dB/ns.

**B. Indoor premises**

The PDPs, APDPs and amplitude statistics are given in the following figures for the large classroom (11.3 × 9.3 × 4.4 m³), having a very high ceiling and a few scatterers, the (strongly reverberating) laboratory (6.65 × 5.05 × 3.14 m³) and the small office (4.95 × 2.85 × 3.14 m³) presenting close reflectors and scatterers, walls and furniture.

1) **Hip-to-Chest**

For the large classroom, as can be observed figure 4, a departure from the normality starts to appear beyond the 11th bin (Δτ of about 2 ns). The quasi-linear decay of the mean (see also Fig. 15) stops beyond the 7th one. For the laboratory, a departure from the normality starts to appear beyond the 9th bin (Fig. 7), and the end of the linear decay of the mean beyond the 11th bin (Fig. 7 and 15). As expected, things are more complicated for the small office: MPCs are more rapidly entangled. Normal fits are acceptable only for a few bins, about to the 5th (although it reappears for the 19th bin), and the linear decay of the mean remains only up to the 6th or 7th one. Beyond that excess delay, at least up to the 19th bin, the mean remains almost constant, showing the dominant behavior of the MPCs due to the environment.

Fig. 3 H2W in anechoic chamber: empirical CDFs.

Fig. 4 PDPs and APDP for the Hip-to-Chest scenario in the large classroom.

Fig. 5 H2C in the large classroom: empirical CDFs and normal fits.

Fig. 6 PDPs and APDP for the Hip-to-Chest scenario in the Laboratory.

Fig. 7 H2C in the laboratory: empirical CDFs and normal fits.
amplitude statistics: Hip scenario in the small office.

2) Hip-to-Wrist

One example is given (Fig. 10) for the H2W case, showing in particular that the 1st path is not necessarily the strongest.

Fig. 8 PDPs and APDP for the Hip-to-Chest scenario in the small office.

Fig. 9 Amplitude statistics: Hip-to-Chest in the small office.

Fig. 10 PDPs and APDP for the Hip-to-Wrist scenario in the small office.

Fig. 11 Amplitude statistics: Hip-to-Wrist in the small office.

3) Hip-to-Toes

Fig. 12 PDPs and APDP for the Hip-to-Wrist scenario in the Large classroom.

Fig. 13 Amplitude statistics: Hip-to-Toes in the large classroom.

V. SCENARIOS AND ENVIRONMENTS COMPARISON

For each radio link, the APDPs are compared between the environments. The short term behavior is analyzed through the 1st bins (Fig. 15 & 17), assessing the excess delay beyond which exogenous MPCs contribute, whereas the long term behavior is characterized by the PDP decay which is essentially exponential for all cases (Fig. 16, 18). For the on-body cluster, the decay is also exponential with slopes respectively between −14 and −18 dB/ns for the H2C (Fig. 14 & 15), −17 and −25 dB/ns for the H2W (Fig. 16 & 17), and −16 and −26 dB/ns (small office excluded) for the H2T (Fig. 18). For off-body clusters, the power decay in the tail depends essentially on the environment, i.e. the room properties, and almost not on the radio link. The regression slopes of the diffuse scattering contributions are given in Table III. They are directly related to the “reverberation time” (related to the delay spread for a Rayleigh channel).
TABLE III
EXPERIMENTAL DECAY SLOPES AND “REVERBERATION TIMES”.

<table>
<thead>
<tr>
<th>dB/ns / ns</th>
<th>H2C</th>
<th>H2W</th>
<th>H2T</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC</td>
<td>-0.260 / 16.7</td>
<td>-0.278 / 15.6</td>
<td>-0.278 / 15.6</td>
</tr>
<tr>
<td>Lab</td>
<td>-0.366 / 11.9</td>
<td>-0.341 / 12.7</td>
<td>-0.375 / 11.6</td>
</tr>
<tr>
<td>SO</td>
<td>-0.476 / 9.1</td>
<td>-0.435 / 10.0</td>
<td>-0.448 / 9.7</td>
</tr>
</tbody>
</table>

Fig. 14 Normalized average PDPs for the Hip-to-Chest scenario in: Anechoic chamber, Classroom, Laboratory and Office.

Fig. 15 H2C: Mean relative amplitudes per bin (from the lognormal model).

Fig. 16 Normalized average PDPs for the Hip-to-Wrist scenario in: Anechoic chamber, Classroom, Laboratory and Office.

VI. CONCLUSIONS
First results show that, as expected, the larger the room, the easier the cluster separation. For a small room the situation is more intricate and difficult to process. It is also more complicated for more variable scenarios such as H2W. The on-body cluster decay is specific to the radio link whereas the diffuse scattering one is related to the environment properties.

REFERENCES