EFFECTS OF ANTENNAS CHARACTERISTICS ON UWB BODY AREA PROPAGATION CHANNEL*

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Accepted 11 July 2006

The effects of different UWB antennas on body area propagation channel is analyzed. Different orientations of directional antennas and different spacings between planar antennas and the body are investigated in an on-body scenario. Time domain channel parameters, e.g. mean delay and delay spread, are extracted from measurement data. The distribution of the channel parameters allows classification of the different antennas with respect to each parameter.

Keywords: UWB antennas; UWB channel measurements; body area networks.

1. Introduction

Wireless body area networks (WBANs) are becoming an increasingly important part of the wireless communications system. In such wireless communication system various electronic devices carried by a person on his body can be connected. Wearable computing and health monitoring are promising applications for WBANs. WBANs have special features and requirements in comparison to other existing wireless networks. Due to the close proximity to the body, the transmission power of the network should be low.

Ultra Wideband (UWB) is a promising communication technology for short-range communication scenarios. It is a low-power high data rate technology which facilitates the compatibility of such technology in WBANs.

Up to now, many efforts have been made and many measurements campaigns have been done in order to investigate the UWB body area channel. In [Zasowski et al., 2003], main channel parameters, such as e.g. path loss, delay spread and mean excess delay have been extracted. Results about the path loss for the body area channel have been reported in [Fort et al., 2005]. Recently, the main propagation mechanisms for one scenario around

*The Work has been partly funded within the project PULSERS.
the human head have been investigated [Zasowski et al., 2005]. However, less attention has
been paid to the antennas. Different antenna characteristics may lead to different behaviors
in a BAN scenario [Alomainy et al., 2005].

In this paper, we investigate the behavior of different types of UWB antennas in a BAN
scenario and their influence on the scenario main parameters such as e.g. attenuation, mean
delay and delay spread. One scenario between two antennas placed on the front side of the
body, one at hip height and the other one on the torso, has been studied. Since only the
body channel shall be studied, measurements were done in an anechoic chamber to avoid
effects caused by echoes from the environment. In Sec. 2 the on-body measurement set-up
is described and the antennas used for measurements are briefly presented. In Sec. 3, the
results for different antennas pairs are shown. Finally, Sec. 4 presents the major conclusions
and gives classifications of the different antennas pairs with respect to different channel
parameters.

2. On-Body Measurement Setup

Frequency-domain measurements were performed in the range from 2 to 12 GHz. An
HP8510C vector network analyzer (VNA) was used to measure the $S_{21}$ transmission coeffi-
cient between five different pairs of antennas placed on the body. The antennas were placed
on the front side of the body, one antenna at hip height and the other one on the torso.
The $S_{11}$ reflexion coefficient for each antenna was also measured. Measurements were per-
formed in an anechoic chamber to avoid effects caused by echoes from the environment.
For each configuration of each pair of antennas, two $S_{21}$ measurements were done in order
to get reproducibility information. Different types of antennas were used in the measure-
ments (Fig. 1). Three kinds of omnidirectional antennas: a shaped bicone antenna (37 mm
× 31 mm, [2.75–19] GHz input impedance bandwidth) [Ghannoum et al., 2005], a planar
dipole antenna (PD) (31 × 21.6 × 1.27 mm$^3$, [3.5–6] GHz bandwidth) [Roblin et al., 2005]
and a metal sheet stripline antenna (MSS) (40 × 24 × 3 mm$^3$, [2.9–7.9] GHz bandwidth)
[Bories et al., 2005] and two kinds of directional antennas: log-periodic dipole array antenna
(LPDA) (50 × 53 mm$^3$, [2–6] GHz bandwidth, mean gain = 4 dBi) [Ramsey Electronics] and
a F-probe triangular patch antenna (Fp) (55 × 55 × 16 mm$^3$, [3–6] GHz bandwidth, mean
gain = 6 dBi) [Lepage et al., 2004] were used; obviously the Bicone and Fp antennas are not
practical for WBANs due to their structure; they were, however, used in the measurements
to represent a certain type of antennas with a phase centre away from the body by con-
struction. The antennas placement on the body is shown in Fig. 2. Different spacing values
(s) between the body and the antennas were investigated in the case of low-profile antennas.
The spacing was controlled by putting foam blocks ($\epsilon_r = 1.08$) between the antennas and

![Fig. 1. Antennas used for the BAN measurements: (from the left) Bicone, PD, MSS, LPDA, and Fp.](image-url)
the body. The influence of the relative angle ($\theta$) between the antennas main lobe direction was also investigated for directional antennas cases (Fig. 2).

3. Measurement Results

Channel impulse responses based on the measured frequency transfer functions were computed by an inverse Fourier transform (after proper windowing). Based on the impulse responses, the mean delay and the delay spread were calculated over [0–7] ns. This interval is sufficient for characterizing the main propagation mechanism in our scenario. The choice of this interval was done after examining the different impulse responses to take also into account the impulse responses duration which we found relatively large in certain cases. The attenuation was also calculated directly from frequency averaged data, carried out over the useful bandwidth of the antennas on the body.

3.1. Antennas Tx/Rx: LPDA/LPDA

In this case, three different spacing values ($s = 0$, 1 cm and 2.5 cm) were investigated. For each spacing value, four different $\theta$ values ($0^\circ$, $30^\circ$, $45^\circ$, and $-45^\circ$) were investigated. As shown in Fig. 3 the input bandwidth of LPDA at hip height is almost independent of the spacing. Similar behavior of the return loss was also observed on the chest. The relatively

![Fig. 2. Antennas placement and orientation $\theta$.](image)

![Fig. 3. (a) Return Loss at hip height: (circle) $s = 0$, (dashed) $s = 1$ cm, (solid line) $s = 2.5$ cm, and (b) Channel Impulse Response ($s = 0$, $\theta = 0^\circ$).](image)
Table 1. Attenuation variation with $\theta$.

<table>
<thead>
<tr>
<th>$\theta$</th>
<th>Attenuation [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0^\circ$</td>
<td>55</td>
</tr>
<tr>
<td>$30^\circ$</td>
<td>56</td>
</tr>
<tr>
<td>$45^\circ$</td>
<td>60</td>
</tr>
<tr>
<td>$-45^\circ$</td>
<td>62</td>
</tr>
</tbody>
</table>

Table 2. Mean delay and delay spread ($\theta = 0^\circ$) [ns] variation with $s$.

<table>
<thead>
<tr>
<th>$s$</th>
<th>0</th>
<th>1 cm</th>
<th>2.5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean delay</td>
<td>3.8</td>
<td>3.2</td>
<td>3</td>
</tr>
<tr>
<td>Delay spread</td>
<td>0.92</td>
<td>0.95</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Table 3. Mean delay and delay spread ($s = 0$) [ns] variation with $\theta$.

<table>
<thead>
<tr>
<th>$\theta$</th>
<th>$0^\circ$</th>
<th>$30^\circ$</th>
<th>$45^\circ$</th>
<th>$-45^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean delay</td>
<td>3.8</td>
<td>3.7</td>
<td>4</td>
<td>3.1</td>
</tr>
<tr>
<td>Delay spread</td>
<td>0.92</td>
<td>0.93</td>
<td>0.92</td>
<td>0.85</td>
</tr>
</tbody>
</table>

long impulse response (Fig. 3) justifies the choice of [0–7] ns interval for channel parameters calculation. Table 1 contains the attenuation values calculated for the four $\theta$ values ($s = 0$). Due to the relatively large elevation beamwidth of the LPDA, the attenuation is almost the same for $\theta = 0^\circ$ and $30^\circ$ (Table 1). The mean delay decreases when the spacing between the antenna and the body increases (Table 2) due to less coupling; the delay spread is less sensitive to the spacing (Table 2) and to the antenna orientation (Table 3). This is due to the intrinsic dispersive behavior of the isolated LPDA.

3.2. **Antennas Tx/Rx: MSS/PD**

The positioning of the antennas with respect to the body is shown in Fig. 4. As seen a configuration with parallel antenna axes was chosen. The axes of both antennas are perpendicular to the direct propagation path on the body (Fig. 4). It should be noted that MSS and PD antenna are linearly polarized with the electric field direction parallel to the antenna axis. In this case, two different spacing values ($s = 0$ and 1 cm) were investigated. The influence of the body on the input bandwidth of the MSS antenna is shown in Fig. 5(a). As seen, the return loss behavior when the antenna is directly placed on the body ($s = 0$) is very interesting. The lowest part of the bandwidth is shifted from around 3 GHz to less than 2 GHz, whereas the upper part is only slightly shifted (7 GHz instead of 7.7 GHz). This suggests a potential reduction of the antenna size for an operating bandwidth of 3–8 GHz and beyond. A comparable behavior is observed for the PD antenna as illustrated in Fig. 5(b).
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Fig. 4. Antennas placement on the body: MSS antenna at hip height and PD antenna on the torso.

Fig. 5. (a) Return loss of MSS antenna. (circle): at hip height, $s = 0$; (dashed): at hip height, $s = 1$ cm; (solid line no marker): without the body and (b) return loss of PD antenna. (circle) at hip height, $s = 0$, (cross) at hip height, $s = 1$, (no marker) without the body.

frequency bandwidth is shifted downwards; the shift is more pronounced when the antenna is directly placed on the body ($s = 0$). In this figure, only measurements at hip height are presented; however, the same effect of the body on both antennas input bandwidth is observed when the antennas are placed on the chest. On the other hand, the attenuation drops by 5 dB when the antennas are placed 1 cm away from the body (Table 4). This is due to the fact that the coupling between the antennas and the body decreases when the spacing increases. The mean delay is found to be more sensitive to the spacing than the delay spread (Table 4).

3.3. Antennas Tx/Rx: Bicone/Bicone, and Bicone/LPDA

In this case, the antennas were directly placed on the body ($s = 0$) with the Bicone axis always perpendicular to the direct propagation path on the body (Fig. 6). For the Bicone/LPDA case, the LPDA's main lobe direction pointed towards the Bicone-like
Table 4. Influence of spacing s.

<table>
<thead>
<tr>
<th>s</th>
<th>0</th>
<th>1 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attenuation [dB]</td>
<td>63</td>
<td>58</td>
</tr>
<tr>
<td>Mean delay [ns]</td>
<td>2.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Delay spread [ns]</td>
<td>0.6</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Fig. 6. (a) Bicone/Bicone configuration and (b) Bicone/LPDA configuration.

antenna (Fig. 6(b)). The return loss of the Bicone antenna varies with its placement on the body (Fig. 7) but the input impedance matching criterion is respected over [2.75–12] GHz approximately in all cases (on the arm, on the shoulder, on the torso, on the leg). Note that the bandwidth of this particular antenna is extremely large. Consequently, the insensitivity of the input bandwidth behavior with respect to the antenna positioning should not be considered as a general behavior (in particular for smaller antennas). The attenuation for the Bicone/Bicone case is 58 dB and it drops to 52 dB when a LPDA replaces one of the Bicone antennas. Due to the dispersive behavior of the LPDA, the mean delay and the delay spread are lower for the Bicone/Bicone case than for the Bicone/LPDA one (1.33 ns compared to 2.33 ns for the mean delay and 0.25 ns compared to 0.5 ns for the delay spread).

3.4. Antennas Tx/Rx: Fp/Fp

Unlike the previous cases, the antennas are placed orthogonally with respect to the body (patch plane normal to the body). In this case the coupling between the antennas and the body is relatively weak. Thus, the return loss is moderately affected by the body (Fig. 8). The relative angle between the antennas main lobes was varied and three different $\theta$ values ($0^\circ$, $-45^\circ$ and $45^\circ$) were investigated. The influence of the latter parameter on the mean delay and the delay spread is found to be essentially negligible (Table 5). The attenuation for this case (Table 6) is much smaller than the other cases due to the antennas gain and to less coupling between the antennas and the body.

The Fp/Fp channel impulse response is relatively short (Fig. 9).
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Fig. 7. Return loss of Bicone antenna on the body, (cross) on the arm, (dashed) at hip height and (solid line) without the body.

Fig. 8. Return loss of Fp antenna: (circle) on the torso, (dashed) at hip height and (solid line no marker) without the body.

Table 5. Mean delay and delay spread.

<table>
<thead>
<tr>
<th>θ</th>
<th>0°</th>
<th>45°</th>
<th>−45°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean delay</td>
<td>1.78</td>
<td>1.8</td>
<td>1.7</td>
</tr>
<tr>
<td>Delay spread</td>
<td>0.23</td>
<td>0.24</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Table 6. Attenuation variation with θ.

<table>
<thead>
<tr>
<th>θ</th>
<th>Attenuation [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>29</td>
</tr>
<tr>
<td>45°</td>
<td>31</td>
</tr>
<tr>
<td>−45°</td>
<td>38</td>
</tr>
</tbody>
</table>
4. Conclusions and Classification of the Antennas

In addition to the mean delay \( \text{MD} \) and the delay spread \( \text{DS} \), two other observation parameters were extracted from the measurements: the arrival time of the strongest echo \( t_s \) and the time \( t_{90} \) corresponding to a captured energy of 90%. The distribution of the four latter parameters is shown in Fig. 10. All of the measurements presented above were taken into account. It should be noted that the different pairs of Tx/Rx antennas are not equally represented, e.g. the LPDA/LPDA scenarios are over-represented. Furthermore, the considered “antenna populations”, and, more generally, the overall amount of data remain still insufficient to allow a complete statistical analysis. Nevertheless, based on the distribution of each parameter, clear tendencies can be observed, and a classification of the Tx/Rx pairs is here proposed. For each parameter, three different groups are extracted (Fig. 10).

With respect to the mean delay, Bicone/Bicone, Fp/Fp (\( \forall \theta \)) and MSS/PD (\( s = 1 \) cm) show the best behavior (Group1). All of these antennas present a short intrinsic response. Combining one antenna having a short intrinsic response (Bicone) with another much more dispersive one (LPDA), leads to an intermediate behavior (Group2). The worst behavior (Group3) corresponds to the use of dispersive antennas (LPDA/LPDA, \( \forall \theta, \forall s \)) or of planar antennas with strong coupling to the body (MSS/PD, \( s = 0 \)). In Group3, for the LPDA/LPDA case, the LPDAs which are away from the body (\( s = 2.5 \) cm) and aligned (\( \theta = 0^\circ \)) behave the best; the behavior of LPDAs far from the body and mis-aligned or close to the body and aligned, is intermediate; the worst behavior is for LPDAs close to the body (\( s = 0 \)) and mis-aligned. Classification obtained for the delay spread is almost the same. Concerning \( t_s \), omni-directional antennas behave the best (Group1). Intermediate behavior is observed for Fp/Fp, Bicone/LPDA and for LPDA/LPDA when LPDAs are aligned and far from the body. The classification with respect to \( t_{90} \) is almost the same as that of the mean delay except for planar antennas MSS/PD that behave better than LPDAs even in case of strong coupling to the body (\( s = 0 \)). Globally, intrinsically non-dispersive antennas with moderate coupling to the body (Bicone and Fp) behave the best. The behavior of
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Fig. 10. Distribution of (a) MD, (b) DS, (c) ts and (d) t90.

1 planar intrinsically non-dispersive antennas (MSS/PD) is good or intermediate depending on its spacing from the body. Intrinsically dispersive antennas (LPDA) that could strongly couple to the body are the worst behaved.

References


