Preliminary UWB channel study for wireless body area networks in medical applications

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Abstract: Ultra wideband (UWB) communications is a promising technology for wireless body area networks (WBAN) due to its very low power emission and robustness against multipath fading characteristics. The use of WBANs in the areas of healthcare and telemedicine is being seriously considered as a way of increasing the quality of medical services and of keeping under control the associated costs. Because the human body has a complex shape and consists of different tissues it is expected that the propagation of electromagnetic signals will have different characteristics than the ones found in other environments, e.g., offices, streets, etc. The contribution of the work described in this paper is to expand the knowledge of the UWB channel, for WBAN applications, in the frequency range of 3-11 GHz under scenarios expected to be found in the medical care field. The experimental measurements are used to develop UWB channel models which can then be applied to the design of efficient communications protocols.

Keywords: wireless medical communications; wearable computing; medical wireless sensors; health monitoring.


Biographical notes: Attaphongse Taparugssanagorn joined the Centre for Wireless Communications in 2003. He received his Bachelor of Engineering from Chulalongkorn University, Thailand in 1997, his Master of Science in Electrical Engineering from Technische Universitt Kaiserslautern, Germany in 2001 and his Doctor of Technology from the Department of Electrical Engineering, University of Oulu, Oulu, Finland in 2007. Currently, he works as a Researcher in Medical ICT. His research interests are in radio channel modelling and channel estimation, MIMO system, UWB systems, wireless sensor networks and medical ICT. He has more than 25 international journal and conference papers.

Carlos Pomalaza-Ráez is an Electrical Engineering Professor at Indiana-Purdue University, Indiana, USA and a Visiting Professor at the University of Oulu, Finland. He received his BSME and BSEE from Universidad Nacional de Ingeniería, Lima, Peru in 1974, and his MS and PhD in Electrical Engineering from Purdue University, West Lafayette, Indiana, in 1977 and 1980, respectively. He has been a Faculty Member of the University of Limerick, Ireland, and of Clarkson University, Potsdam, New York. He has also been a member of the technical staff at the Jet Propulsion Laboratory of the California Institute of Technology.

Ari Isola received his Master of Science in Electrical Engineering from the Department of Electrical Engineering, University of Oulu, Oulu, Finland in 2008. Currently, he works as a Researcher and is a PhD student at Centre for Wireless Communications, University of Oulu, Finland.

Raffaello Tesi he received the ‘Laurea’ (MSc) degree in Telecommunication Engineering from the University of Florence, Italy in 2001, with a thesis on transmit diversity systems for Satellite-UMTS. In 2000, he joined the Centre for Wireless Communications of the University of Oulu, Finland, where he received the degree of Licentiate of Technologies (Lic.Tech.) in 2004, with a thesis on performance evaluation of ultra wideband systems in the presence of interference. His main fields of interest include UWB radio systems and medical ICT.
1 Introduction

Wireless medical telemetry has experienced continuous improvements in recent years (Ng et al., 2006). In this type of application, a patient's health is remotely monitored through the use of radio technology. Wireless telemetry has also the potential to reduce costs by decreasing the need of having medical personnel in close proximity to patients at all times. Recent advances in wireless technology have led to the development of wireless body area networks (WBAN), where a set of communicating devices are located around the human body (Coronel et al., 2004). For the case of medical applications, these devices are connected to sensors that monitor vital body parameters. By measuring and transmitting these vitals to a control node or station a WBAN allows for continuous monitoring of the patients' health without the burden of wires attached to their bodies or frequent visits by medical personnel.

Ultra wideband (UWB) communications is a promising technology for WBAN due to its particular characteristics (Cramer et al., 2002; Gezici and Sahinoglu, 2007). The monitoring of human vitals and movements requires a relatively low data rate (Arnon et al., 2003), which in the case of UWB translates into very small transmitting power requirements, i.e., longer battery life. This is a very desirable feature for electronic devices that are going to be close to the body and meant to be used for extended periods of time. To properly design WBAN UWB devices it is necessary to measure, and then model, the corresponding radio propagation channel in the frequency range of 3–11 GHz. For the case of indoor and outdoor scenarios, comprehensive studies of the UWB propagation channel have been performed (Cramer et al., 2002; Ghassemzadeh and Tarokh, 2002; Kannan et al., 2004). It is natural to expect that the channel characteristics for those cases will be different than the ones found in WBAN scenarios due to the effect of the human body with its complex shape and different tissues, each with a different permittivity (Klemm and Troester, 2006). Finite-difference time-domain (FDTD) numerical analysis methods have been used to investigate the UWB channel close to the human body (Fort et al., 2005). These studies have focused on scenarios that do not take into account the effect of the antennas and other conditions that are present in actual scenarios, i.e., walls, furniture, etc. UWB measurements around the human body have been carried out by various researchers (Alomainy et al., 2006; Zasowski et al., 2003; Fort et al., 2005; Reusens et al., 2007). However, no medical or technical reason has been given to justify those scenarios, e.g., using numerous antennas/transceivers very close to the human skin (Zasowski et al., 2003). On the contrary, deep concerns about EM interference in the ISM band within a hospital environment (Lauer et al., 2008) and the benefits of single room occupancy (Tuckey, 2008) support the presence of very few wireless devices around the body with the use of a gateway positioned above the height of medical equipment within a regular size room. The main contributions of the work reported in this paper are:

a experimental measurements under scenarios more likely to take place in the medical care field as shown in Figure 1

b the use of these measurements to develop UWB channel models.

Figure 1 WBAN channels: (A1) between sensor nodes, (A2) between sensor nodes and a gateway and (B) from the gateway to other wireless or wired networks (see online version for colours)
2 Channel measurement setup and scenarios

The channel measurement system used for this work consists of an HP Agilent 8720ES (Alliancetesteq, 2009), a vector network analyser (VNA), P200 BroadSpec™ antennas, 5 m long SUCOFLEX® RF cables (Hubersuhner, 2009) with 7.96 dB loss and a control computer with LabVIEW™ 7 software. The VNA is operated in a transfer function measurement mode, where port 1 and port 2 are the transmitting and the receiving port, respectively. This corresponds to an S21-parameter measurement set-up, where the device under test (DUT) is the radio channel. S21-parameters or channel transfer functions are converted to the time domain using an inverse fast Fourier transform (IFFT) and a Hamming window to reduce sidelobes. The BroadSpec™ antenna is a bottom fed UWB planar dipole antenna designed to radiate and receive UWB impulses. The antenna is azimuthally omni-directional with variations no more than 3 dB in the horizontal or azimuthal plane, and a null along the vertical axis. In addition, the antenna has the usual dipole nulls along the axis of the antenna top and bottom. Thus, this antenna provides good coverage in the plane normal to the axis of the antenna. The polarisation of the antenna is linear in the vertical direction. The antenna achieves a voltage-standing-wave-ratio (VSWR) of about 1.5:1 across its operating band with reflection down about –14 dB. Because the elevation pattern of the antenna is a bit tighter than that for a conventional dipole, the antenna achieves a +3 dBi gain. This is about 1 dBi better than a conventional dipole. The phase response of the antenna is linear, so it transmits with minimal distortion. The efficiency of the antenna is on the order of about 90% or better. Figures 2 and 3 show the peak power antenna patterns in the both azimuthal and elevation planes. The sweep time of the network analyser depends on the number of frequency points within the sweep band and is automatically adjusted by the VNA. The frequency band used in the measurements is from 3.0 GHz to 11 GHz covering both the Industrial Scientific and Medical (ISM) frequency bands (5.725-5.875 GHz) as well as the whole range of frequency bands of the UWB mask allotted by the FCC (3.1–10.6 GHz). Therefore, the bandwidth B is 8 GHz. The maximum number of frequency points per sweep M is 1601, which can then be used to calculate the maximum detectable delay \( \tau_{\text{max}} \) of the channel as:

\[
\tau_{\text{max}} = \frac{(M-1)}{B}.
\]

Using (1), the maximum detectable delay, \( \tau_{\text{max}} \) of the channel is 200 ns, which corresponds to 60 m in free space distance. Two different cases are considered:

1. when the antennas are attached to the body
2. when there is a separation, a 1.2 cm dielectric, between the body and the antennas.

The measurements setups are designed with more realistic scenarios in mind. This means that the number of antennas/transceivers near the body should be small. Only comfortable locations on the body are selected for placing the antennas. The level of radiated EM power should be below the maximum recommended by the various standards organisations such as the IEEE (Draft Standard IEEE P1528, 2003). In the measurements the transmit (Tx) power is 1 mW (0 dBm) the same as the one used by Bluetooth class 3.

Figure 2 Peak power pattern, azimuthal plane

Figure 3 Peak power pattern, elevation plane: (a) edge on and (b) face (see online version for colours)
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The first three sets of experiments were conducted in an anechoic chamber to investigate the effect of the human body without the effect of the environment. For these cases, we will only consider the first 20 ns of the response, i.e., at most 6 m away from the body. The fourth set of measurements were conducted in a classroom and in a real hospital environment.

The first set of measurements (channel link A1 around the body) were taken at two different levels of the torso, at the chest level (level 1) and at the abdomen level (level 2) as illustrated in Figure 4. At each level, the Rx antenna (the rectangle in Figure 4) is fixed at the middle front of the torso and the Tx antenna (the circle in Figure 4) is placed at various positions at distances of 10 cm. The results were obtained for three men and two women. The age span of the subjects was from the mid 20s to the mid 50s. One of the three men has a titanium alloy aortic valve implant.

Figure 5 shows the arm positions for the second set of measurements with the Tx antenna at the middle front of the torso and the Rx antenna on the left wrist, these locations are comfortable for most patients and they are potential places for antennas/transceivers connected to ECG sensors and a pulse oximeter. The third set of measurements aims to measure channel link A2. As shown in Figure 6, the subject stands 2 m away from a 2 m high pole where the Rx antenna is placed. The Tx is placed at the middle front of the torso, which is 1.25 m high from the floor.

Finally, the fourth set of measurements were done in a classroom (7.2 m × 5 m × 3 m) and also in a regular hospital room (6.3 m × 7.2 m × 2.5 m). Both Tx and Rx antennas are placed with a dielectric separation. Measurements for the fourth case were also done for sitting and sleeping position scenarios.
Figure 7  Average channel impulse responses of the first set level 1: without dielectric separation and with dielectric separation

Figure 8  Average channel impulse responses of the first set for three males, one with an aortic valve implant

Figure 9  Average channel impulse responses of the first set for males and females

Figure 10  Average channel impulse responses of the 2nd set of measurements

Figure 11  Average channel impulse responses of the third set of measurements

Figure 12  Average channel impulse responses, when the subject is standing

Note: The Tx is at level 1 position 2

Note: Tx is at level 1 position 2

Note: The Rx antenna and the Tx antenna are at the middle front of the torso and at the left hand wrist, respectively.
3 Measurement results and analysis

3.1 Average channel impulse response

One hundred individual realisations of the channel impulse responses were measured and averaged for each position. Since the energy of the responses close to the human body decays rapidly we focused only on the first 20 ns of each channel impulse response for the measurements in the anechoic chamber (first to third sets). Figure 7 compares the average channel impulse responses in the first set, level 1, when the antennas are directly attached to the clothes and when there is a dielectric separation between the body and the antenna. The propagation link is significantly improved when there is a dielectric separation. In Figure 8, one can see that the average channel impulse response of the subject with an aortic implant has more pronounced peaks and drops off more quickly. A possible explanation is the scattering caused by the metallic aortic valve. The difference between the average channel impulse responses of the male and female subjects is shown in Figure 9. The second peak for the female cases was found to be caused by their brassieres and not by their gender (the response of a male subject with a brassiere had also such a peak). Figure 10 shows the average channel impulse responses for the second set of measurements comparing different arm positions (Figure 5). At positions 2 and 3, the magnitudes of the average channel impulse responses are smaller than the ones at position 1 because of the antenna polarisation mismatch due to the misalignment of the Tx and Rx antennas.

Figure 11 compares the average channel impulse responses for the third set of measurements. As expected, the amplitude of the average channel impulse responses has the smallest gain, when the subject turns their back towards the Rx antenna. Figure 12 shows the results for different scenarios when the subject is standing with the Rx antenna at the middle front of the torso and the Tx antenna on the left hand wrist. The variations in the channel characteristics depending on the presence or absence of a human body are clearly seen. The effect of the human body and the effect from the environment are separated by the interval $T$. Figure 13 compares the results when the Rx antenna is on the pole and for different positions, i.e., standing, sitting, and lying down in the classroom. The propagation channel of the lying down posture shows more delay ($\sim 3$ ns) than the others due to the difference in distance and it has a lower response because of the polarisation mismatch between the Tx and Rx antennas.

<table>
<thead>
<tr>
<th>Positions of Tx</th>
<th>Number of paths ($L$) (delay bins)</th>
<th>$\mu$, $\sigma$</th>
<th>$\mu$, $\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45, 2.45</td>
<td>0.0746, 0.0041</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>22, 1.64</td>
<td>0.1863, 0.0268</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8, 3.85</td>
<td>0.4197, 0.1067</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5, 2.08</td>
<td>0.3241, 0.0809</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>24, 1.35</td>
<td>0.2343, 0.0377</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>30, 1.89</td>
<td>0.0841, 0.0081</td>
<td></td>
</tr>
<tr>
<td>2, male with implant</td>
<td>8, 2.90</td>
<td>0.2963, 0.0346</td>
<td></td>
</tr>
<tr>
<td>2, female 1</td>
<td>32, 1.97</td>
<td>0.1590, 0.0315</td>
<td></td>
</tr>
<tr>
<td>2, female 2</td>
<td>31, 1.79</td>
<td>0.1275, 0.0369</td>
<td></td>
</tr>
<tr>
<td>1 with separation</td>
<td>85, 7.76</td>
<td>0.0691, 0.0011</td>
<td></td>
</tr>
<tr>
<td>2 with separation</td>
<td>43, 2.39</td>
<td>0.1013, 0.0174</td>
<td></td>
</tr>
<tr>
<td>3 with separation</td>
<td>10, 1.22</td>
<td>0.1238, 0.0348</td>
<td></td>
</tr>
<tr>
<td>4 with separation</td>
<td>8, 2.12</td>
<td>0.8964, 0.4667</td>
<td></td>
</tr>
<tr>
<td>5 with separation</td>
<td>6, 3.05</td>
<td>0.9166, 0.3547</td>
<td></td>
</tr>
<tr>
<td>6 with separation</td>
<td>11, 1.468</td>
<td>0.1623, 0.0298</td>
<td></td>
</tr>
<tr>
<td>7 with separation</td>
<td>51, 2.98</td>
<td>0.0771, 0.0049</td>
<td></td>
</tr>
<tr>
<td>8 with separation</td>
<td>83, 6.80</td>
<td>0.0642, 0.0019</td>
<td></td>
</tr>
</tbody>
</table>

3.2 Delay dispersion parameter

Delay dispersion implies frequency selective fading and inter-symbol interference (ISI). No serious ISI is likely to occur if the symbol duration is longer than ten times the rms delay spread (Cramer et al., 2002). To evaluate the delay dispersion within the channel a value of interest is the root mean square (RMS) delay spread $\tau_{\text{RMS}}$, which is the standard deviation of the delay of the paths (Cramer et al., 2002). To calculate it, all measured channel impulse responses are first truncated above the noise threshold, set to four times of the noise standard deviation, i.e., 108.2 dB. The mean $\mu$ and the standard deviation $\sigma$ of the number of arrival paths $L$ above the noise threshold as well as the $\tau_{\text{RMS}}$ of the first set of measurements are summarised in Table 1. It can be observed that with the slight dielectric separation the channel link is improved by increasing $L$ and decreasing $\tau_{\text{RMS}}$ due to less coupling between the electromagnetic waves and the human body. The $L$ is the
number of resolvable paths lying along the time delay axis into resolvable delay bins of length 1/Δ, where all contributions falling into one such bin cannot be resolved and are thus simply superposed (added up). The interaction of multipath components (MPCs) falling into the same delay bin gives rise to small-scale fading. This can be in a constructive way, and sometimes in a destructive way, depending on the relative runtimes (phases) of the MPCs. If a large number of (approximately) equally strong components fall into one bin, the central limit theorem becomes applicable, and the probability density function (pdf) of the complex amplitudes become complex Gaussian. This implies that the pdf of the absolute amplitude become Rayleigh.

3.3 Small scale fading

In an UWB channel the number of physical MPCs that make up one resolvable MPC is generally much smaller than the ones in wideband or narrowband channel, due to the fine delay resolution. This has important effects on the small-scale fading statistics, which the central limit theorem does not hold. Consequently, the pdf of the complex amplitudes is not anymore complex Gaussian.

To find out a distribution that best fits the amplitude of a delay bin, we apply the Akaike information criterion (AIC), which calculates the discrepancy between a candidate model \( j \) \((j = 1, 2, \ldots, J)\) with pdf \( g^{(j)}_{\Theta} \) of the given data \( X = [x_1, x_2, \ldots, x_N]^T \), and is given by Schuster et al. (2005) as:

\[
AIC = -2 \sum_{n=1}^{N} \log g^{(j)}_{\Theta}(x_n) + 2U, \tag{2}
\]

where \( \Theta \) indicates the maximum-likelihood (ML) estimate of the \( U \)-dimensional parameter vector \( \Theta \) of the pdf. The minimum AIC (min, AIC\(_{\text{min}}\)) corresponds to the best fit. The difference \( \Delta_j = \text{AIC}_{\text{min}} - \text{AIC}_j \) is defined to compare the goodness-of-fit for each model. Consequently, the Akaike weights are defined as (Schuster et al., 2005):

\[
w_j = \frac{e^{-\frac{1}{2}\Delta_j}}{\sum_{i=1}^{J} e^{-\frac{1}{2}\Delta_i}}, \quad j = 1, 2, \ldots, J. \tag{3}
\]

Figure 14 shows that the log-normal distribution excellently fits the measured amplitude of delay bin 1, 3, 5, 80, 100 and 120 with standard deviations \( \sigma = 2.5, 2.0, 3.1, 2.3, 4.1 \) and 3.8, respectively. This is validated by the AIC approach (Schuster et al., 2005), where for the Akaike weight of the log-normal distribution the closest is to 1 implies a better fit. Figures 15(a) and 15(b) show the correlation between delay bins of the channel link A1 for the fourth set of terms of the correlation matrix \( R \) of \( h_{\text{truncated}} \), where \( h_{\text{truncated}} = [h[1]h[2] \ldots h[L]] \) is the measured channel vector corresponding to L delay bins. Figure 15(a) shows that there is a high correlation between the earlier delay bins that are related to the human body effect, whereas Figure 15(b) shows little correlation between the later delay bins which are related to the room effect. Table 2 summarises the amplitudes distribution of the first eight delay bins for the range of the human body effect and the first eight delay bins for the range of the room effect as well as the means of all entries of \( R \) for the channel links A1 and A2. The results for all the environments, i.e., the anechoic chamber, the classroom and the regular hospital room, are compared.

3.4 Large scale fading

The path loss in dB versus distance for the first set for both cases, with and without dielectric separation, is illustrated in Figure 16. Unlike the typical exponential path loss observed for common indoor scenarios (Ghassemzadeh and Tarokh, 2002; Kannan et al., 2004), the path loss of the first set is best modelled as directly proportional to \( d \),

\[
PL_{\text{dB}}(d) = PL_0 + \gamma (d - d_0) + S_d; \quad d \geq d_0, \tag{4}
\]

where \( d_0 \) is the reference distance = 10 cm, \( PL_0 \) is the path loss at the reference distance, \( \gamma \) is the slope in units of dB/m, and \( S_d \) is a shadowing (large-scale) fading defined as the variation of the local mean around the path loss \( X \), is a Gaussian-distributed random variable with zero mean and standard deviation \( \sigma \) in dB). The path loss for the case with dielectric separation is smaller and has a higher slope.

3.5 Channel modelling

We have developed models for the UWB radio channel near the human body based on the experimental results. Figure 17 illustrates the block diagram of a correlated fixed tapped-delay-line channel model generator consisting of the amplitude of the channel impulse response, the correlation factor and the phase of the channel impulse response. As shown in Figures 14–15, the amplitudes of the channel impulse responses near the human body tend to be correlated log-normally distributed. A standard way to generate correlated (normal distributed) random numbers with a given correlation matrix \( R \), defined in Section 3.3, is done by finding a matrix \( U \) such that \( U^T U = R \). Using \( U \), one can generate a correlated channel vector \( h \) from a scaled uncorrelated log-normal random vector \( x \), with the standard deviation \( \sigma \), by multiplying it with \( U \). To compute \( U \), a Cholesky decomposition \( \text{chol} \) of the correlation matrix \( R \) is carried out, i.e.:

\[
h = xU = x\text{chol}(R). \tag{5}
\]

This approach is applied for both ranges of the channel impulse response with the corresponding average intra-range interval (T) reported in Table 2. Finally, the phase of the channel impulse response is assumed to be uniformly distributed. As seen in Table 2, the larger values for \( T \) indicate that the human body effect is more clearly separated from the environment effect for channel link A1 than for channel link A2.
Table 2  Amplitude distribution and mean of all entries of $R$ for the channel links A1 and A2

<table>
<thead>
<tr>
<th>Measurement scenario</th>
<th>Amplitude distribution</th>
<th>Mean of all entries of $R$</th>
<th>Inter-range interval $T$ (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Delay bin 1-8 &amp; Delay bin 41-48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Link A1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anechoic chamber</td>
<td>log-normal</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Classroom</td>
<td>log-normal</td>
<td>log-normal</td>
<td>-</td>
</tr>
<tr>
<td>Regular hospital room</td>
<td>log-normal</td>
<td>log-normal</td>
<td>-</td>
</tr>
<tr>
<td>Link A2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anechoic chamber</td>
<td>log-normal</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Classroom</td>
<td>log-normal</td>
<td>log-normal</td>
<td>-</td>
</tr>
<tr>
<td>Regular hospital room</td>
<td>log-normal</td>
<td>log-normal</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurement scenario</th>
<th>Delay bin 1-8 &amp; Delay bin 41-48</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link A1</td>
<td></td>
</tr>
<tr>
<td>Anechoic chamber</td>
<td>-</td>
</tr>
<tr>
<td>Classroom</td>
<td>log-normal</td>
</tr>
<tr>
<td>Regular hospital room</td>
<td>log-normal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurement scenario</th>
<th>Delay bin 1-8 &amp; Delay bin 41-48</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link A2</td>
<td></td>
</tr>
<tr>
<td>Anechoic chamber</td>
<td>-</td>
</tr>
<tr>
<td>Classroom</td>
<td>log-normal</td>
</tr>
<tr>
<td>Regular hospital room</td>
<td>log-normal</td>
</tr>
</tbody>
</table>

Figure 14 The amplitude distribution for the delay bins 1, 3, 5, 80, 100 and 120 of the channel link A1 in the fourth set of measurements and the fitting log-normal distribution with corresponding standard deviation $\sigma = 2.5, 2.0, 3.1, 2.3, 4.1$ and 3.8.

Figure 15 The upper and the lower triangular parts of two correlation matrices $R$ of $h_{\text{truncated}}$ for the channel link A1 for the fourth set, (a) the correlation between the first eight delay bins, (b) the correlation between the first eight delay bins due to the reflection off the regular hospital room.

Figure 16 The path loss versus distance for the 1st set: with and without separation.

Figure 17 The block diagram of a correlated log-normal tapped delay line channel model generator.

Figure 18 The average power dispersion profile (dB relative to bin 1) for the channel link A1 in the fourth set.
Figure 18 shows an example of how to evaluate the proposed channel model. The average measured power dispersion profile of channel link A1 in the fourth set is compared to the simulated one. The results from the proposed channel model fit excellently the measurement results.

4 Conclusions

We have conducted a series of UWB WBAN measurements in the frequency range of 3–11 GHz in scenarios that are expected to be found in medical situations. The results highlight the importance, for medical applications, of carrying out a comprehensive study of the nature of signal propagation when it takes place close to the human body. It was found that for certain scenarios the UWB channel characteristics are distinctively different depending on the gender or the medical conditions of the subjects. In a realistic environment, difference between the human body effects and the environment effects can be easily seen. The log-normal distribution tends to fit very well the distribution of the amplitude of the delay bins for both ranges, of the human body effects and of the environment effects. In addition, a high correlation between the delay bins is observed for the range of the human body effects. The measurements obtained in this study can be used to estimate channel parameters needed to build communications systems for WBAN medical applications.

References


