Estimation of Room Electromagnetics Reverberation Time for Ultra-Wideband Indoor Channels

Brecht Hanssens1, Maria-Teresa Martínez-Inglés2, Aliou Bamba1, Emmeric Tanghe1, Jose-Maria Molina-Garcia-Pardo2, Davy P. Gaillot3, Martine Liénard3, Claude Oestges4, Luc Martens1 and Wout Joseph1

1 INTEC, Ghent University/iMinds, Belgium, Brecht.Hanssens@INTEC.UGent.be
2 SiCoMo, Technical University of Cartagena, Spain, JoseMaria.Molina@UPCT.es
3 IEMN, University of Lille 1, France, Davy.Gaillot@Univ-Lille1.fr
4 ICTEAM, Catholic University of Louvain, Belgium, Claude.Oestges@UCLouvain.be

Abstract—In this work, an estimation of the reverberation time for Ultra-Wideband indoor communication is presented ranging from 2 to 10 GHz. Channel sounding measurements were performed in an indoor environment with a network analyzer and virtual arrays. The concept of a reverberation time is known from the theory of Room Electromagnetics, and can be calculated from the decay rate of the measured power delay profiles. It was found that this reverberation time depends on the used window function in order to shape the frequency-response measurements, and that it decreases with increasing frequency due to path loss.

Index Terms—room electromagnetics, reverberation time, ultra-wideband, channel sounding, indoor environment.

I. INTRODUCTION

Ultra-Wideband (UWB) is a promising new technology within Wireless Personal Area Networks (WPAN), which due to a large bandwidth allows for high data rates (> 2 Gbit/s) over a short distance. UWB systems are characterized by their ability to transmit small pulses with a very low power density (limited to -41.3 dBm/MHz) in a large frequency band (3.1-10.6 GHz). This allows such systems to harmlessly operate in frequency bands currently occupied by other applications. UWB technology is standardized in IEEE 802.15.3.

In this work, an estimation of the reverberation time for UWB indoor communication is presented based on wideband channel sounding measurements between 2-10 GHz. The concept of a reverberation time is known from the theory of Room Electromagnetics (RE) [1], which is related to the science of room acoustics. RE states that there is an exponential decay for the electromagnetic field in a room, under the assumption that the intensity of this field is direction-independent (rich scattering), and its energy density is constant across the entire room (valid for small rooms). A custom made algorithm was created in order to extract this reverberation time from the various measured power delay profiles. This reverberation time is assumed to be nearly constant across the entire room, depending only on the volume, surface area and an effective absorption coefficient. Such an approach easily allows to characterize the radio channel on a room-to-room basis.

II. MEASUREMENTS

A. Measurement environment

The indoor measurements were carried out in a laboratory of the Technical University of Cartagena, in Spain. In Fig. 1, the measured scenario is depicted, as well as the various positions over which the measurements were performed. The laboratory size is approximately 4.5×7×3 meters, and is furnished with several closets, shelves, desktops and chairs. Moreover, the laboratory is equipped with numerous computers and electronic devices. The walls are typical interior walls, made of plasterboard. The floor and ceiling are made of concrete.

B. Channel sounding procedure

Wideband channel sounding measurements were carried out in the UWB frequency band, where the complex gain between transmit- and receive antenna was calculated over a range from 2-10 GHz. In this frequency band, 2048 uniformly spaced frequency points were sampled. Both at the transmit- and receive-side of the measurement system, a virtual uniform linear array was created by an automated positioning system on which the antennas were mounted. In total, three different Tx-Rx links were measured, as depicted in Fig. 1. Further details about the measurement scenario can be found in [2].

III. EVALUATION

At each Tx position in the virtual array, the network analyzer measures the $S_{21}$ scattering parameter (complex gain between both antennas) in order to obtain one power delay profile (PDP) per Tx-Rx combination. Since there are 95 Tx and 8 Rx, we obtained 760 PDPs in total, which are then averaged to acquire the average PDP (APDP) as follows:

$$\text{APDP}(t)\text{[dB]} = 10\log\left(\frac{|S_{21}\text{[dB]}(t)|^2}{W_g}\right)$$

(1)
In (1), $S_{21}^{\text{av}}(t)$ is the average PDP over all 760 Tx-Rx combinations. The $S_{21}$ parameter in the frequency domain is translated into the time domain by using an IFFT operation with various window functions (Rectangular, Hann, 4-term Blackman-Harris and Hamming). We divide $S_{21}^{\text{av}}(t)$ by the coherent gain $w_{\text{coh}}$ of each window function $w$ in order to compensate for the normalized DC gain of that window.

In indoor propagation, multiple reflections and scattering give rise to a tail in the APDP with an exponential decay, and a time constant noted as the reverberation time $\tau_r$, as follows:

$$\text{APDP}(\tau) = \alpha_1 \exp \left( -\frac{\tau - \tau_0}{\tau_r} \right) \quad (\tau > \tau_r) \quad (2)$$

In (2), $\alpha_1$, $\tau_0$ and $\tau_r$ respectively are the peak power, the onset time, and the reverberation time of the APDP.

In order to enhance the amount of observations, we divided the total frequency band in sub-bands of 500 MHz (delay resolution of 2 ns), with an overlap factor of 1/10 between two adjacent sub-bands. In each such band, we calculated the APDP and extracted $\tau_r$. As shown in Fig. 2, the experimentally determined APDP (in dB) does not have a perfect linear tail because of effects such as the noise level of the network analyzer, measurement uncertainties, etc. We therefore created a custom algorithm in order to extract $\tau_r$ in a certain delay range, over which the APDP tail (in dB) can be approximated by linear regression. This range spans from the mean power delay bin to the first delay bin of which the power level was 3 dB above the noise floor (assumed as the minimum measured power level). The resulting reverberation time as a function of frequency is shown in Fig. 3, which was based on the measurement data of Tx-Rx link 2. In this figure, the effect of the various used window functions is also illustrated.

From Fig. 3 we clearly see that the estimated reverberation time depends on the used window function. This effect is more profound at lower frequencies, whereas at higher frequencies the results tend to converge. Each window function has its own characteristics, and specifically shapes the course of the APDP. Because we rely on the spectral analysis of our data (frequency-response measurements) to estimate the reverberation time, we choose to rely on the results of the Hann-window for its good frequency resolution and reduced spectral leakage. Secondly, we can also notice that $\tau_r$ varies in function of frequency. Looking at Fig. 2, this can be explained by the varying course of the APDP at different frequencies. Higher frequencies result in more path loss, and a faster decreasing slope of the APDP. Consequently, $\tau_r$ decreases with frequency.

The estimated reverberation time in this work is in good agreement with the values reported in [3], which found $\tau_r$ to lie between 23.8 and 28.2 ns for 2.3 GHz. Values between 16.7 and 18.4 ns were reported in [4] for 5.2 GHz. To the best of the author’s knowledge, no accurate estimations for $\tau_r$ were reported for higher frequencies at the time of writing. The difference with our estimated $\tau_r$ can be explained by the rather small room dimensions in our measurement scenario.

IV. CONCLUSION

This work presented an estimation of the reverberation time for UWB indoor communication, based on wideband channel sounding measurements with virtual arrays ranging from 2-10 GHz. A custom made algorithm was developed in order to estimate the reverberation time from the sounding data.

We found that the reverberation time known from the theory of room electromagnetics depends on the used window function, in order to shape the frequency-response measurements. Secondly, it was found that the reverberation time decreases with increasing frequency due to path loss, where the results for various window functions converge from 8 GHz onwards.

ACKNOWLEDGMENT

Brecht Hansens is funded by the Institute for the Promotion of Innovation by Science and Technology in Flanders (IWT). This research was supported by the project IAP BESTCOM, “Belgian network on STochastic modelling, analysis, design and optimization of COMmunication systems”.

REFERENCES