Characterization of a computer board-to-board ultra-wideband channel

Kåredal, Johan; Singh, Amit; Tufvesson, Fredrik; Molisch, Andreas

Published in:
IEEE Communications Letters

DOI:
10.1109/LCOMM.2007.061661

2007

Characterization of a Computer Board-to-Board Ultra-Wideband Channel

Johan Karedal, *Student Member, IEEE*, Amit P. Singh, Fredrik Tufvesson, *Member, IEEE*, and Andreas F. Molisch, *Fellow, IEEE*

***Abstract*— In this paper we present the results of an extensive ultra-wideband (UWB) measurement campaign performed inside the chassis of two desktop computers. The purpose of the campaign is to analyze the possibility of board-to-board communications, replacing cable connections. Measurements of the propagation channel are performed over a frequency range of $3.1 - 10.6$ GHz using a vector network analyzer and antennas small enough to enable integration on a circuit board. The results show that the propagation environment is very uniform, with small variations in the path gain between different positions within a computer. We also performed interference measurements, showing that the interference is restricted to certain subbands.**

***Index Terms*— Ultra-wideband, channel measurements, interference, statistical model, wireless communications.**

I. Introduction

THE interest in ultra-wideband (UWB) communications has increased dramatically in recent years, with applications being found both for high-data-rate and low-data-rate communications. The attractiveness of UWB systems stems from properties such as low-power transmission, low-cost circuitry, and high possible data rates [1], [2]. The use of a large transmission bandwidth results in robustness to frequency-selective fading and allows using a low spectral density, which in turn enables a system with low interference to other wireless systems.

One of the many envisioned applications is the usage of UWB transmissions for communications between different circuit boards in desktop computers. Using small antennas that are integrated on the circuit boards, wireless UWB links can replace the currently used cable connections, thus simplifying automated installation and integration of a card into a computer. With the cable connections being removed, the usage of a new card would be one step closer to true "plug-and-play." A number of generic UWB transceiver schemes have been proposed in the past, which could be used for such board-to-board communications, including impulse radio with simplified Rake receivers, direct-sequence CDMA, multiband impulse radio with noncoherent detection, and OFDM. However, the relative merits of such schemes strongly depend on the propagation channels in which they operate [3], as well as the characteristics of the interference. Thus, the first step in designing a board-to-board communications system has to be an understanding of the UWB propagation channel, as well as the interference, within desktop computers.

This letter presents the (to our knowledge) first-ever measurements of UWB propagation channels within desktop computers.[1] We present extensive measurement results (some 4200 impulse responses) in two desktop computers, and derive a statistical model that can be used for system design and evaluation of transceiver performance.

II. Measurement Setup and Evaluation

Two computers were used for the measurements, in order to investigate the impact of different interior design. Both were brand new and based on current consumer market technologies (year 2006). One computer, by HP™ (Media Center PC, Model No. EP080AA-ABS), was factory assembled and had a very crowded interior. The second computer was bought in parts and assembled by the buyer (henceforth referred to as the assembled, or asb., computer), and had more empty space inside. Inside each computer, several realistic Tx/Rx positions (on the circuit boards, or locations on the outside of CD drive, hard drive, etc.) were selected. Each location was used as transmitter or receiver in different measurements. To attach the antennas on the circuit board, thin (3 mm) LEGO™ pieces were used (see Fig. 1). One LEGO piece was glued to e.g., the circuit board, with the other being glued to the antenna. This way, several channel samples could be taken at each Tx/Rx position (referred to as "Tx/Rx blocks"), with a well-defined separation, by translating the LEGO pieces on antenna and board relative to each other. Also, since the LEGO piece supports a $90°$ rotation, performing measurements with different orientations of the antennas was possible. Due to the crowded interior architecture of the computer, at some positions measurements were only possible using one of the orientations. In total, 1435 channel measurement (using 8 Tx/Rx blocks) were made in the HP computer and 2840 measurements (9 Tx/Rx blocks) were made in the assembled computer.

Measurements of the propagation channel between Tx and Rx were performed in the frequency domain using a vector network analyzer (HP 8720C) sweeping the frequency range $3.1 - 10.6$ GHz. With the frequency band being divided into 1601 points, this implies a delay resolution of 0.13 ns (i.e., 4 cm path resolution) and a maximum resolvable delay of 210 ns. The antennas were small-sized PIFA-like UWB antennas from SkyCross™ (Model No. SMT-3TO10M), small enough to allow for integration on a circuit board in a real application.

From the measured channel transfer functions $H(f)$, we obtain by inverse Fourier transformation (using a Hanning window to suppress sidelobes) the channel impulse responses

Manuscript received October 11, 2006. The associate editor coordinating the review of this letter and approving it for publication was Dr. Biao Chen.

J. Karedal and F. Tufvesson are with the Department of Electroscience, Lund University, Box 118, SE-221 00 Lund, Sweden (e-mail: Johan.Karedal@es.lth.se).

A. P. Singh is with the Department of Electronics and Computer Engineering, Indian Institute of Technology, Roorkee-247667, India.

A. F. Molisch is with the Department of Electroscience, Lund University, Box 118, SE-221 00 Lund, Sweden, and with Mitsubishi Electric Research Labs, 201 Broadway, Cambridge, MA 02139, USA.

Digital Object Identifier 10.1109/LCOMM.2007.061661.

[1] After our paper was accepted, we learned that parallel to our work, Chen and Zhang also performed similar measurements [4].

Fig. 1. An inside view of the HP computer. The eight circled Tx/Rx blocks (of various sizes) can be seen scattered over the computer. Block 6 is located in the horizontal plane, on the mother board, whereas block 7 is located in the vertical plane, on the hard drive (around 7 cm above the mother board). Also, inset in the top right corner is a (magnified: note the size of the SMA connector) picture of the SkyCross antenna.

$h(\tau)$, whose square magnitude $|h(\tau)|^2$ gives the power delay profiles (PDPs).[2] Averaging over the PDPs belonging to one Tx/Rx block combination, we obtain the average power delay profile (APDP). The step increment between two positions on a LEGO block is 8 mm, which with $5-7$ positions per block equals a total length of only $30-50$ mm. Since half a wavelength ($\lambda/2$) at 3.1 GHz is 48 mm, whereas $\lambda/2$ at 10.6 GHz corresponds to 14 mm, it should be pointed out that this implies an averaging over a rather small spatial area; the effects of this will be discussed later in the paper.

Since a running computer can be expected to produce interference, disturbing the radio link, we also performed interference measurements at all measurement positions in each computer. These measurements were performed with the computers running only the operating system (Windows XP; no other software applications were ran) inside a shielded chamber in order to avoid any unwanted signals. We used a spectrum analyzer (Rohde&Schwartz FSU) set to a resolution bandwidth of 3 kHz to sweep the measurement frequency range (divided into 2501 frequency points), and the measurements were made using the max peak detector in order to analyze the worst case interference power level at each frequency point.

III. Results

A. *Propagation Channel Measurements*

Our first observation concerns the path gain, i.e., $E\left\{(1/B)\int_B |H(f)|^2 df\right\}$, where $B = 7.5$ GHz, and the expectation is taken over the positions within a Tx/Rx block combination. It turns out that the path gains are very similar, regardless of what Tx and Rx block positions are considered. The measured *mean* path gain (taken over all Tx/Rx block combinations) in the HP computer is -29.1 dB, with a standard deviation of 2.1 dB, whereas in the assembled computer, a mean path gain of -28.7 dB with a standard deviation of 1.4 dB, was measured. It is noteworthy that despite the different distances between Tx and Rx, and despite the possibility of shadowing by metallic objects (component casings, fans, etc.) the variation of the path gain is extremely small.[3] We also note that the mean path gain is almost the same in both computers, despite their different interior layout.

Next, we analyze the delay dispersion. We note that the APDPs of our measurements include a small period of "soft onset" (generally less than 1 ns; see Fig. 2a), a phenomenen that has been observed and modeled in [6]. However, since a soft onset is mainly of interest for ranging techniques (which is not amongst the applications targeted in this paper), we find it more tractable to use a simpler approach; the single exponential decay. Hence, we model the APDPs as

$$P(\tau) = P_0 e^{-\tau/\gamma}$$

where P_0 is the power at delay $\tau = 0$, and γ is the decay time constant. The variations of γ within each computer are small, though we note that there is some difference between the two computers. This difference is likely due to the HP computer being more crowded (with scatterers), than the more empty assembled one, which hence has a slightly slower decay. We fitted the distribution of γ both to a normal distribution and a lognormal distribution [5]. While the normal distribution gave a marginally better fit, the lognormal distribution has the advantage that even theoretically, negative decay constants are not possible. We thus suggest to model $\gamma' = 10\log_{10}(\gamma/1\text{ ns})$, the decay constants on a dB scale, as normally distributed, $\gamma' \sim \mathcal{N}(\mu_{\gamma'}, \sigma_{\gamma'})$. The HP computer has a mean decay time constant $\mu_{\gamma'} = 5.42$ dBns with a standard deviation $\sigma_{\gamma'} = 0.11$ dBns, whereas the assembled computer has $\mu_{\gamma'} = 7.34$ dBns and $\sigma_{\gamma'} = 0.09$ dBns (see Fig. 2b). The corresponding linear mean values of γ, 3.49 ns and 5.44 ns, gives an approximate $0.5-$coherence bandwidth of 79 MHz for the HP computer, and 51 MHz for the assembled one.

We thus find that both the path gain, and the shape of the APDPs is essentially the same, regardless of which Tx/Rx blocks are considered. This leads to the conclusion that the propagation environment between two arbitrary pairs of Tx/Rx blocks inside the computer chassis is very similar, and fading margins to account for large-scale phenomena can be very small. Also, since different combinations of Tx/Rx blocks imply a different amount of LOS/NLOS, this also means that there is no significant difference between LOS and NLOS situations and subsequently no separation into LOS and NLOS has been made in our analysis. Finally, we find that rotating the antenna has no significant influence on the transmission. This latter effect is most likely due to the omnidirectional properties of the antennas, a result that also justifies our

[2]To compensate for the different runlengths of different Tx/Rx combinations, we have adjusted the delay axis of each impulse response according to the geometric distance between Tx and Rx [5]. Hence, the first component of an impulse responses is counted as the one arriving at the delay corresponding to the LOS distance.

[3]Actually, our measurement results slightly overestimate the path gain variance due to shadowing: some residual influence of small-scale fading is present, because the number of independent spatial samples within a Tx/Rx block is small. However, the importance of this effect is somewhat limited, since the measured path gains are averaged both over spatial samples and frequency samples.

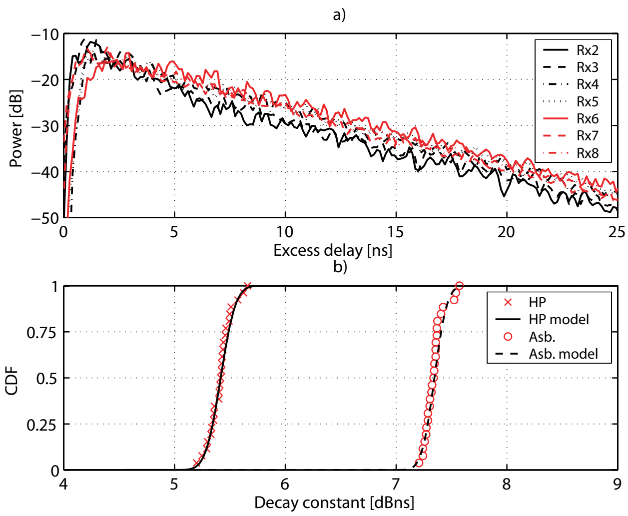

Fig. 2. a) The APDPs measured from Tx block 1 to all other (Rx) blocks in the HP computer. Each APDP is normalized so that the total power within the APDP is unity. The two lowest curves (Rx2 and Rx3) are measurements that are considered LOS (see Fig. 1). In b), the distribution of decay constants, as measured and modeled, respectively, is shown.

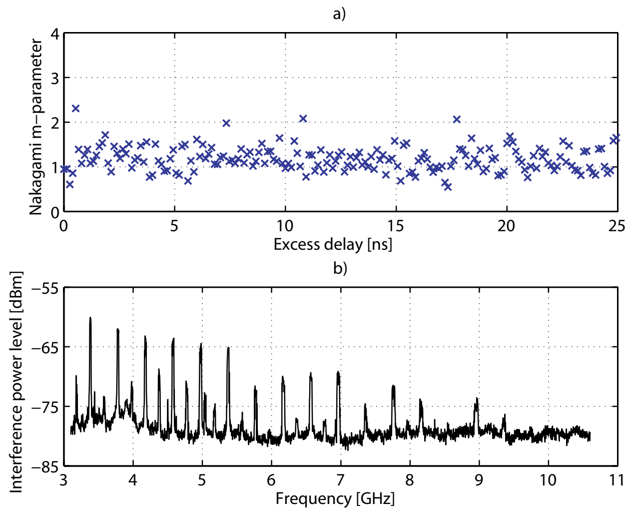

Fig. 3. a) The Nakagami m-parameter estimates of the amplitudes measured between Tx/Rx blocks 1 and 7 in the HP computer (note that $m = 1$ corresponds to a Rayleigh distribution). b) The maximum interference power level measured at Tx/Rx block 6 of the HP computer.

using all available measurements (per block) in the previous derivations of APDPs and path gains.

We next analyze the small-scale fading, by fitting the amplitude distribution belonging to all measurements of each Tx/Rx pair to the Nakagami$-m$ distribution, which is in widespread use for UWB (see [3] and references therein). Thus, for each delay, we estimate the $m-$parameter using the inverse normalized variance estimator [7]. An example plot of the result is shown in Fig. 3a, where the estimate can be seen to be close to 1, which corresponds to a Rayleigh distribution, for almost all delays. The mean value (over delay and all measurements) of the $m-$estimate was 1.19 for the HP computer, and 1.11 for the assembled one.

B. Interference Measurements

The results of the interference measurements show great variations in the power levels at different frequencies. Fig. 3b shows an example plot of the maximum interference power level, that can be seen to be essentially restricted to certain subbands. The subbands are approximately 30 MHz wide, and (with a few exceptions) separated by 400 MHz. The same behavior, probably caused by the memory bus, is observed at all Tx/Rx blocks of both computers, with only small variations in power level of the frequency peaks.

This result has two important consequences: (i) due to the similarity of interference level at different Tx/Rx blocks, no locations within the chassis are more suitable than another, in an applications sense (this is especially true in conjunction with the path gain and APDP results from the previous section), (ii) some bands of the frequency spectrum are very unsuitable for radio transmission, which serves as a motivation for using band-notch filters or OFDM-like systems, for this type of application.

IV. Conclusions

We have presented results from a UWB measurement campaign performed inside two different computer chassis. The measurements were made over a frequency range of $3.1-10.6$ GHz and show several interesting points:

- The propagation environment inside the computer chassis is very uniform, with similar values for the path gain regardless of antenna position.
- No significant large-scale fading effects was observed.
- The orientation of the antenna elements has no significant effect on the results.
- The power delay profile is given by a single exponential decay, with a decay constant that can be well described by a log-normal distribution.
- The amplitude statistics within the chassis is well described by a Rayleigh distribution.
- The interference caused by the computer is mainly restricted to certain subbands; however, the frequency spacing of the interference lines is less than 500 MHz.

The results can thus serve as basis for the design and performance simulation of UWB board-to-board communications systems.

References

[1] R. C. Qiu, H. Liu, and X. Shen, "Ultra-wideband for multiple access communications," *IEEE Commun. Magazine*, vol. 43, no. 2, pp. 80–87, Feb. 2005.

[2] G. di Benedetto *et al.*, *UWB Communications Systems: A Comprehensive Overview*. EURASIP Publishing, 2005.

[3] A. F. Molisch, "Ultrawideband propagation channels - theory, measurement, and modeling," *IEEE Trans. Veh. Technol.*, vol. 54, no. 5, pp. 1528–1545, Sept. 2005.

[4] Z. M. Chen and Y. P. Zhang, "Inter-chip wireless communication channel: Measurement, characterization, and modeling," *IEEE Trans. Antennas Propag.*, vol. 55, no. 3, pp. 978–986, Mar. 2007.

[5] D. Cassioli, M. Z. Win, and A. F. Molisch, "The ultra-wide bandwidth indoor channel: from statistical models to simulations," *IEEE J. Sel. Areas Commun.*, vol. 20, no. 6, pp. 1247–1257, Aug. 2002.

[6] A. F. Molisch et al., "IEEE 802.15.4a channel model - final report, Tech. Rep. Document IEEE 802.15-04-0662-02-004a, 2005.

[7] A. Abdi and M. Kaveh, "Performance comparison of three different estimators for the Nakagami m parameter using Monte Carlo simulation," *IEEE Commun. Lett.*, vol. 4, no. 4, pp. 119–121, Apr. 2000.