To be submitted to COST273 Workshop in Helsinki, May 29-30, 2002

ULTRA WIDEBAND RADIO CHANNEL MODELLING FOR INDOORS

Veikko Hovinen, Matti Hämäläinen
Centre for Wireless Communications (CWC), University of Oulu, Oulu, Finland
veikko.hovinen@ee.oulu.fi

Abstract: *Most of the wideband radio channel models available today are not accurate enough for ultra wideband (UWB) applications occupying an extremely large bandwidth. In this paper, a procedure for indoor UWB radio channel measurements and modelling is presented. The example discussed here is based on the measurements carried out in the main building of the University of Oulu, Oulu, Finland. An average size lecture room was selected to represent typical university environment, and various radio links were measured for statistical variance. A radio frequency band from 2 to 8 GHz was covered by a vector network analyzer, and the measured* S_{21} *data were inverse Fourier transformed to achieve the corresponding impulse responses.*

Introduction

In this paper, ultra wideband (UWB) radio channel measurements and procedures for channel modelling are presented. Statistical indoor UWB radio channel models are utilized in radio system simulators to enhance the accuracy of system performance evaluations. There is a rare supply of channel models covering several gigahertz frequency band, and the need of the UWB radio channel modelling is obvious.

The example of the general radio channel modelling presented here is a case study based on the measurements that were carried out in the main building of the University of Oulu during summer 2001. Several sizes and different types of rooms, starting from the small meeting rooms to big auditoria, were then selected for the radio channel measurements. The areas of the rooms were between 30 m^2 and 500 m^2, and the direct link separation varied between 1.5 m and 13 m. The frequency responses of the channel were recorded using a vector network analyser and the impulse responses were calculated via inverse discrete Fourier transform. The channel characterization and finally the channel models will be generated from the delay profiles (averaged impulse responses.)

Methods for Radio Channel Measurements

The key element of radio channel measurement is the coherence time of the channel, and the sounding has to be done within this limit. Otherwise the channel characteristics will change too much and the statistical presumptions do not hold.

There are several techniques for wideband radio channel sounding. The ideal way for the UWB radio channel sounding is to use impulse transmission technique presented in Figure 1 [1]. This is a time domain sounding system, where the transmitted signal is a single impulse or a train of impulses and, for example, a digital sampling oscilloscope is used as a receiver to directly measure the channel impulse response. The advantage of this technique is that the probing bit sequence can be the same as the one used also in the final applications. The environment do not need to be static within the recordings but the coherence time assumptions still need to be valid.

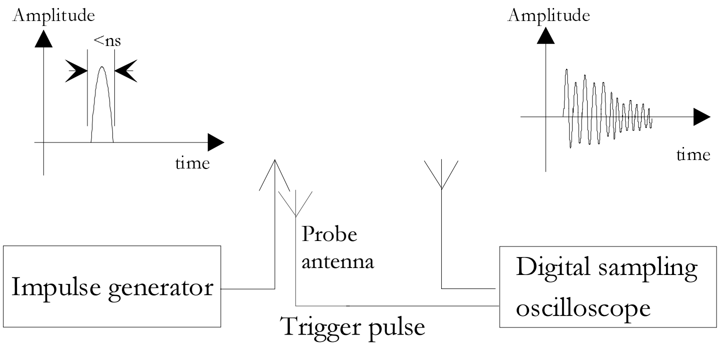


Figure 1. Radio channel measurement system based on pulse transmission.

Radio channel can also be measured in a frequency domain using a network analyser to measure the channel frequency response. Using this technique the radio channel is sounded by sweeping a sinusoidal carrier over the frequency band of interest. This corresponds to a conventional S_{21}-parameter measurement setup, where the radio channel is the device under test (D.U.T.). The block diagram of the sounding system is presented in Figure 2. The long sweeping time requires the channel coherence time to be relatively large, and in practise measurements can be carrier out only in static environments. A channel transfer function and a channel impulse response are Fourier transform pairs so the channel is known if one of those functions is known. The time domain presentation of the recorded signal is achieved by applying appropriate windowing and inverse Fourier transform to complex valued S_{21}.

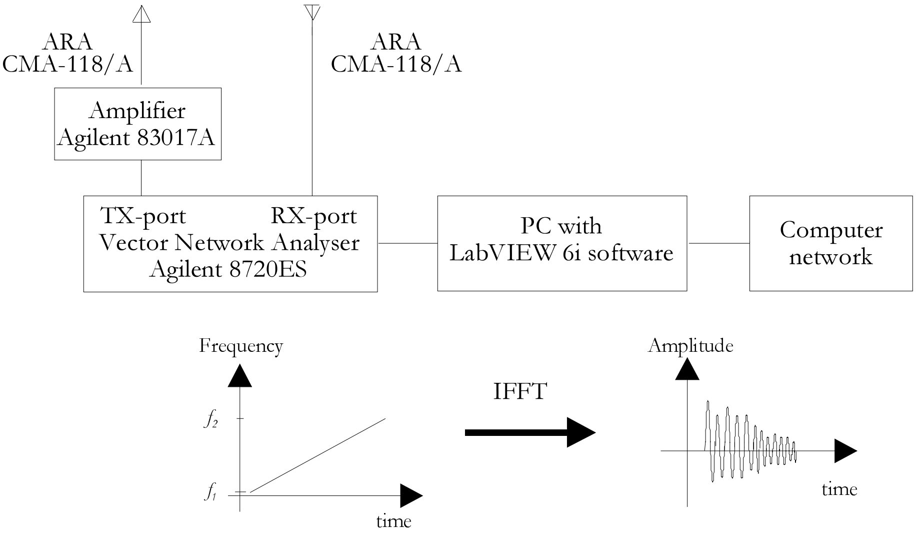


Figure 2. An example of a radio channel measurement system based on frequency sweeping.

The most common sounding technique is based on direct sequence spread spectrum (DS-SS) concept, where pseudo random maximum length code is used to spread the probing signal over the wide frequency band. A correlation detector is used at the receiver end. The whole of the bandwidth is covered simulaneously, and this is the reason DS-SS is widely used in environments where the channel coherence time is relatively small. Typically the effective bandwidth in this case is from a few tens to several hundreds of MHz. This method can also be used in moving environments. In the case of UWB, the exploitation of this technique is limited by the high chip rate requirements to achieve bandwidths over several gigahertz.

Measurement System and Parameters

In our study, the radio channel has been sounded using a frequency domain measurement system sketched in Fig. 2. The core of the system is Agilent 8720ES vector network analyser [2]. The power level at the feed of the TX-antenna is raised to 10 mW using Agilent 83017A wideband amplifier. The antennas are CMA-118/A wideband conical antennas by Antenna Research Associates, Inc [3]. The system is controlled by LabView software which automate the measuring procedure.

The vector network analyzer is operated in response measurement mode, where port 1 and port 2 are the transmitter port and the receiver port, respectively, and S_{21} is the parameter to be recorded. Frequency band from 2 GHz to 8 GHz was covered using 1601 equally spaced points, which yields a 3.75 MHz frequency step between the consecutive sample points. The parameters for the measurements setup are collected to Table 1.

Parameter	Value
Frequency band	2 to 8 GHz
Bandwidth (frequency span)	6 GHz
Number of points over the band	1601
Sweep time	800 ms
Dynamic power range	80 dB
Average noise floor	-120 dBm
Transmitted power @ 2 GHz	+ 10 dBm ± 1 dB
Amplifier gain	36 dB ± 1 dB
Antenna gain	0 dBi (typical)

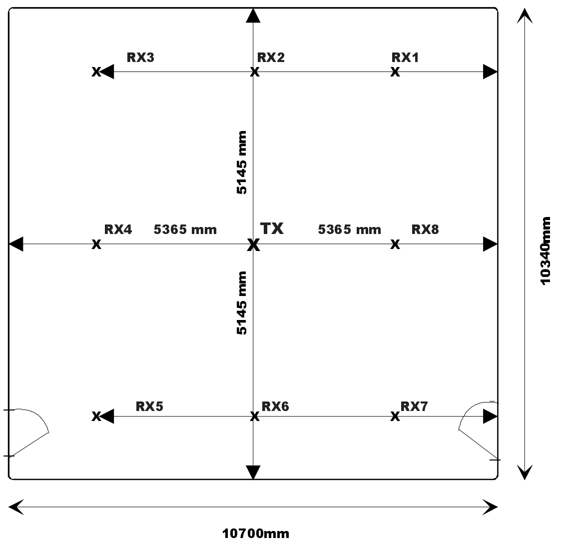
Table 1. Measurement setup parameters.

The antennas were 600 mm, 1100 mm and 2200 mm above floor in both ends allowing totally nine links per antenna position. One frequency sweep through the specified band takes 800 ms and, for statistical reliability, every link was measured 500 times. Together with the frequency settling time this means that the total recording time is 33 minutes per link. During the recording all movement inside a room was frozen, but no effert was taken to suppress the transmissions of the other radio systems. The measured frequency band is above the bandwidths of the broadcasting networks, the cellular networks, and of other commonly used radio systems, so the influence of the interfering systems can be considered negligible in indoor environment.

Measured Sites

During the measurement campaign radio channel in several rooms in the main building at the University of Oulu were measured. This paper is focused to one specific room, SÄ118, which is a medium sized rectangular lecture room, illustrated in Figure 3. Room height is 3450 mm and the other dimensions are presented in the blueprint. The walls, the ceiling and the floor are painted or plactic covered concrete, and the room was furnished as usual during the measurements giving realistic results for the sounding. The room has no windows, except small dome-shaped windows in the ceiling.

TX-antenna position was at the middle of the room and eight RX-antenna positions were selected (Figure 3.)



[mm]	**RX from TX**	**RX from wall**
RX1	4400	2465
RX2	3420	5355
RX3	4320	8235
RX4	2910	8235
RX5	4480	8415
RX6	3330	5435
RX7	4400	2565
RX8	2990	2465

Figure 3. The layout of the room and the dimensions for the antenna positions.

Radio channel modelling procedure

The recorded complex transfer function data were converted into Matlab format and inverse Fourier transformed into time domain. After transformation, each burst of data contained 500 impulse responses and the maximum delay is 267 ns, including the initial delay that comes from the antenna separation. A Hanning window was applied before transformation to make it easier to estimate the initial delay of the line-of-sight (LOS) component. The data was simultaneously transformed into delay domain using no windowing, and the channel models were generated from this data.

The system noise level was estimated from initial delay range 0 ns — 3 ns, and was found to be around –105 dBm limiting the dynamic power range typically to 40 dB. The initial delay for each of the radio links was extracted using the average delay profile of 500 impulse responses (small-scale statistics). Initial delay was removed from the results, and the statistical parameters were extracted from this data.

The excess delay was limited to 70 ns, which corresponds to 420 samples in delay domain. The limit was found by removing the strongest reflections and plotting average delay profiles from various data sets. This corresponds to large-scale statistics represented in Figure 4, where the reflections are plotted in dark gray shade, and the average delay profile is plotted in black.

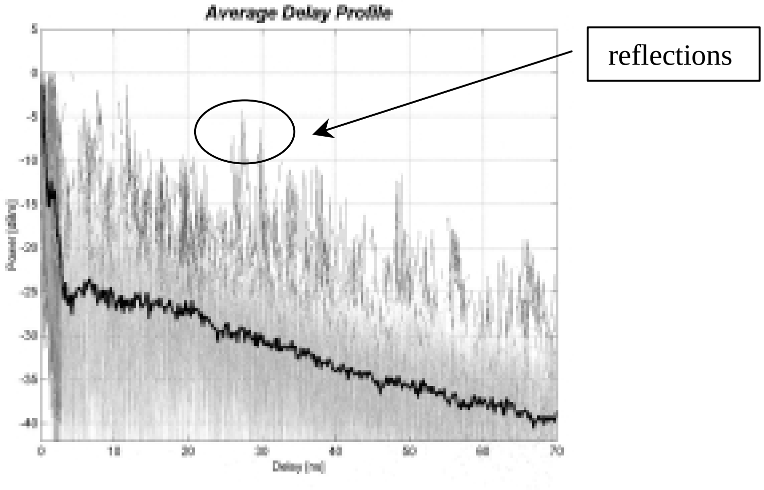


Figure 4. An example of average delay profile.

Radio channel models

A discrete model for a time-variant fading multipath channel is

$$h(t) = \sum_n a_n(t) s(t - \tau_n(t)), \qquad (1)$$

where $s(t)$ is the transmitted signal, $a_n(t)$ is the amplitude gain of the n^{th} multipath channel and $\tau_n(t)$ is the corresponding excess delay. The indoor environment with no moving scatterers and with fixed antenna positions $a_n(t)$ and $\tau_n(t)$ are assumed to be constant during the observation time. Measurements recorded in various antenna positions give an estimate of the average static indoor channel. Movement of scatterers or altering the length of radio link will introduce Doppler shift, which in turn reduces the coherence time t_{coh} of the channel. The channel can be measured, if the measurement time is shorter than the coherence time. This assumption is valid in static indoor measurements.

Multipath channels is typically modeled as a linear tapped delay line (a FIR filter), with complex tap coefficients [4]. In computer simulation the time variance of the channel filter is realized by mixing multiplicative white noise through a bandpass filter directly to the tap coefficients.

A realistic assumption for a static indoor channel is a Rician fading model. Rician fading signals have amplitude $a_n(t)$ that is distributed according to [5]

$$p_{\mathrm{R}}(a) = \frac{a}{\sigma^2} \exp\left(-\frac{a^2 + s^2}{2\sigma^2}\right) I_0\left(\frac{as}{\sigma^2}\right), a \geq 0, \qquad (2)$$

where σ is the standard deviation and I_0 is the zeroth order modified Bessel function of the first kind. The non-centrality parameter s is defined by [8]

$$s^2 = \left\|\overline{a}(t)\right\|^2, \qquad (3)$$

where $\overline{a}$ is mean complex amplitude.

Signal-to-noise ratio (SNR) of a Rician fading signal is defined as

$$k = \frac{s^2}{2\sigma^2} = \frac{s^2}{\eta^2}, \qquad (4b)$$

which in logarithmic scale is

$$k = s_{dB}^2 - \eta_{dB}^2. \qquad (4b)$$

Rayleigh fading channel is a special case of Rician channel with $k = 0$. It has been shown [6] that the Rician fading channel becomes effectively Rayleigh fading when k becomes smaller than 5 dB.

A large scale (long-term) model is constructed from data that has been collected in various locations. Because antenna positions and room sizes vary, we need to separate pure reflections from the random part of the model. In other terms, the channel model contains a deterministic environment dependent ray-tracing part (DM) and a statistical environment independent Rician fading part (SM), as shown in Figure 5.

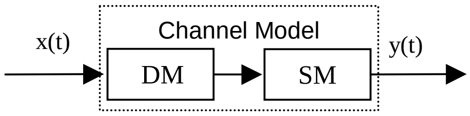


Figure 5. Channel Model.

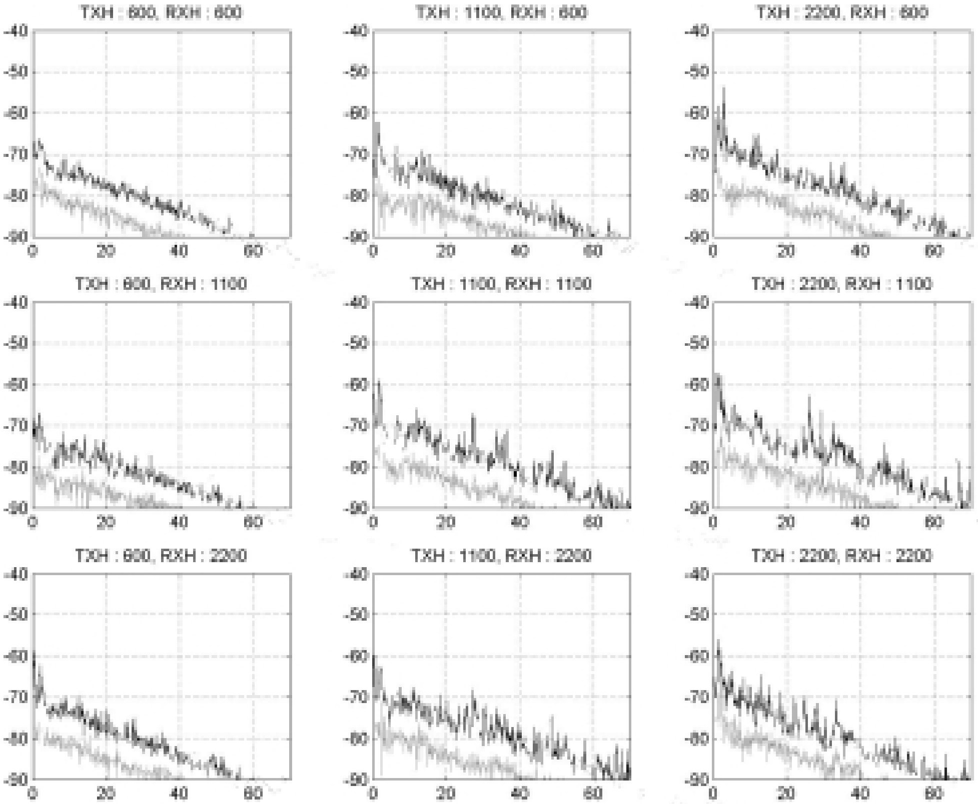


Figure 6. Average impulse responses of different radio links.

Average impulse responses of the radio links measured in SÄ118 are plotted in Figure 6. Data has been separated to deterministic model (printed in black) and statistical model (printed in gray) parts by comparing the small-scale average to its linear estimate at range 6 ns — 70 ns and selecting 100 most significant paths into deterministic model and leaving everything else into statistical model. The plots show that the transmitter height largely rules the behavior of the impulse response, and suggests that the channel models can be grouped to three distinctively different mechanisms. This however can be better judged when the statistics of the radio links have been figured out. This work is currently being done and the results are expected to be available in near future.

Conclusions

This paper discusses the UWB indoor radio channel measurement campaign being carried out at the University of Oulu, Finland. The measurements have been executed using vector network analyzer based radio channel sounding device. The average impulse responses for measured radio links are presented as an example. This presentation describes data recorded in one selected room. Further studies will complete the modeling of the radio channels for the radio link configurations that were not covered here.

Acknowledgements

This work is funded by the National Technology Agency (Tekes), Nokia, Elektrobit and the Finnish Defence Forces. Authors would like to thank the sponsors for their support. M.Sc. Timo Pätsi is appreciated for his contribution by performing the channel measurements. Prof. Seppo Karhu and Prof. Jari Iinatti are valued for the many discussions during the measurement campaign. M.Sc. (Tech.) student Niina Laine is appreciated for her assistance during the data post-processing.

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