Ultra Wideband Indoor Radio Channel Measurements

Matti Hämäläinen, Timo Pätsi, Veikko Hovinen

Centre for Wireless Communications
P.O.Box 4500
FIN-90014 University of Oulu, FINLAND
email: matti.hamalainen@ee.oulu.fi

ABSTRACT

UWB transmission techniques generate extremely wide bandwidth for the propagating radio signal. This allows one to utilize the technology in different kinds of applications that demand precise temporal or spatial resolution. Knowledge of the signal propagation mechanism in the channel is vital for the radio system design and the system performance analysis. However, currently published narrowband or wideband radio channel models do not offer spatial resolution high enough for the UWB applications and the real channel measurements are needed. This paper explains the ultra wideband (UWB) indoor radio channel measurement procedure performed at the main building at the University of Oulu, Finland. The measurement campaign included rooms with various sizes and layouts. The frequency responses of the radio channel were recorded using a vector network analyzer in a frequency sweep mode. The corresponding impulse responses of the radio channel were calculated by taking inverse Fourier transforms of the recorded radio channel frequency responses. Channel characterization and the statistical radio channel models will be generated from the impulse responses. This paper does not offer statistical UWB radio channel models but rather explains the measurement system, the measurement procedure and the environments where the radio channel soundings were performed.

1 INTRODUCTION

Ultra wideband (UWB) transmission techniques utilize extremely wide propagating radio signal bandwidth [1]. This allows one to use UWB technology in different kinds of applications that demand very accurate temporal or spatial resolutions. The applications can be, for example, indoor positioning systems or radar applications as well as high data rate communication links. The most important benefits of the UWB technology are good penetration capability combined with high accuracy. Low transmission power combined with a large bandwidth make the power spectral density of the transmitted signal extremely low, which allows UWB applications to use the same frequency bands as the existing radio systems are using (overlay).

Knowledge of the signal propagation mechanism in the channel is vital for the radio system design and the system performance analysis. However, currently published radio channel models do not offer spatial resolution high enough for the UWB applications. The existing radio channel models are generated using about 10 MHz to about 100 MHz bandwidths. This is why the specific UWB radio channel models are needed to characterize the radio channel with the bandwidth larger than 1 GHz. In our study the indoor radio channel sounding was carried out using frequency sweeping method. In post-processing the recorded radio channel frequency responses are inverse Fourier transformed to achieve channel impulse responses (averaged to delay profiles). Finally, the channel characterization and the statistical radio channel models are generated from the impulse responses.

2 ULTRA WIDEBAND RADIO CHANNEL MEASUREMENT TECHNIQUES

To gain knowledge of the UWB radio channel, there are two possible techniques to perform the channel sounding. Channel can be measured in frequency domain using a frequency sweep technique. The other method is a time domain measurement that is based on the impulse transmission. In the former technique, a wide frequency band is swept using a set of narrowband signals, and the channel frequency response is recorded with a network analyzer. This corresponds to a S_{21}-parameter measurement setup, where the device under test (DUT) is a radio channel. In the latter case, a narrow pulse is sent to the channel and the channel impulse response is measured using a digital sampling oscilloscope. The corresponding train of impulses can also be generated using a conventional direct sequence spread spectrum based measurement system with a correlation receiver. The drawback in this technique is that it needs very high chip rates to achieve bandwidths of several GHz. The ideas for the frequency domain and the time domain measurement concepts are presented in Fig. 1 and Fig. 2, respectively. Theoretically, having a static measurement environment, and occupying an unlimited bandwidth, both techniques end up in the same result.

In our study, the frequency domain measurement system was selected. The RF signal is generated and received by the network analyzer, which simplifies the measurement setup. Frequency domain approach also makes it possible to use wideband antennas, instead of special impulse radiating antennas. The physical indoor environment during the sounding was kept as static as possible, but no effort was made to control the radio interference from the other RF sources.

2.1 Measurement Setup

The radio channel measurement system consists of a vector network analyzer (Agilent 8720ES), a wideband amplifier (Agilent 83017A), a conical antenna pair and a control computer with a LabVIEW software. The network analyzer is operated in response measurement mode, where PORT1 is a transmitter port (TX) and PORT2 is a receiver port (RX). An external amplifier is connected to PORT1 to increase the transmitted power level. The antennas used in the measurements are CMA-118/A conical antennas by Antenna Research Associates, Inc [2]. Typical features of the conical antenna are omni-directional radiation pattern and a constant phase center. Both features are important in the radio channel sounding.

The sweep time is automatically adjusted by the analyzer, depending on the bandwidth and on the number of the measured frequency points within the sweeping band. Table 1 lists the main parameters of the measurements. The antenna gain is specified by the antenna manufacturer. The block diagram of the used measurement setup is presented in Fig. 3. The figure explains also the main features of a post-processing procedure.

Dynamic range mentioned in Table 1 is given as reduced to the output of the RX antenna. Specified dynamic range for the network analyzer is 100 dB [3] but the cable losses diminished 20 decibels of the dynamic range.

Upper bound limit for the detectable delay of the channel in time domain, τ_{max}, can be defined by the number of frequency points per a sweep and by the used bandwidth B (frequency span) as [3]

$$\tau_{max} = (\text{number of points} - 1)/\, B. \qquad (1)$$

Using the parameter values from Table 1, Eq. 1 yields 1600/(6 GHz) = 266.6 ns that corresponds to 80 m, which is quite reasonable value for the indoor environments.

2.2 Calibration and verification

The vector network analyzer requires a calibration with the same cables and adapters as will be used in the measurement. To be able to carry out a magnitude and a phase information of the transmitted signal the enhanced response calibration is required [4]. Since the amplifier is isolated in reverse direction, it has to be removed from the setup for the time of calibration. After performing the calibration, the amplifier is reconnected. The amplifier frequency response is measured independently and it is taken into account in the post-processing.

Long cables and the adapters connected to the TX port of the analyzer cause a frequency dependent variation to the transmitted signal level. TX power varies linearly from +10 dBm to +3 dBm within the used frequency band. This variation is, however, compensated in the calibration procedure.

The calibration procedure sets the time reference points from the analyser ports to the calibration points which, in our study, are at the end of the cables. When the time reference is shifted to the end of the cables (to the antenna connectors), the resulting delay profiles include only the propagation delays that are coming from the radio channel.

The measurement setup has been verified in a corridor environment. The physical dimensions of the corridor are presented in Fig. 4. The impulse response calculated from the recorded frequency response is presented in Fig. 5. Reflections coming from END I, END II and END III of the corridor (see Fig. 4), as well as the main reflections from the walls, the floor and from the ceiling can be found with simple calculations. Comparing the estimated propagation delays with the impulse response (Fig. 5), one can notice a clear conformity between the results.

The operation of the analyzer and applicability of the inverse Fourier transform has been verified by recording the channel using short cables. The verifications show that the measurements using the short cables (about 1 m) and the long cables (max. 30 m) give the same result for the channel impulse response. Preliminary UWB results having high delay resolution generally conform with the narrowband results for indoor cases.

2.3 Setup requirements

Vector network analyzer can be used in the radio channel measurements providing the following requirements are satisfied.

Firstly, the calibration algorithm may fail to remove some of the error sources if the cable lengths exceed the width of the maximum delay window, defined by Eq. 1.

Another possible source of disturbance is the frequency shift caused by the propagation delay in long cables. In frequency sweep mode the sounding signal is rapidly swept through the whole band of interest. Long propagation delay will cause the receiver to sample at a frequency that is a bit higher than the received frequency at the antenna. This frequency shift Δf is a function of the propagation time t_{tr} (time of flight), the frequency span B and the sweep time t_{sw} as [5]

$$\Delta f = t_{tr}\left(\frac{B}{t_{sw}}\right). \qquad (2)$$

Δf has to be smaller than IF bandwidth of the analyser. Using the sweep time from Table 1, span $B = 6$ GHz and 3 kHz IF bandwidth, Eq. 2 yields maximum propagation time 400 ns.

3 MEASUREMENT ENVIRONMENTS

Preliminary UWB radio channel measurements have been performed in different types and in various sizes of rooms at the premises of the University of Oulu.

The idea of the indoor measurement is to set the TX-antenna into the middle of the room and to move the RX-antenna to different positions. To get reliable channel models the sweep time should not exceed the coherence time of the channel.

In our study, the frequency response at each RX-position has been recorded with three antenna heights in both ends. This gives in all nine (3∗3) transmission links for each RX-position. For statistical reasons, the frequency band was swept and recorded 500 times for each transmission link. All movements inside the room were frozen during the recording time.

The distances between TX-antenna and RX-antenna (length of the transmission link) were between 1.5 m … 13 m. The first measurement campaign covered the situations where transmitting and receiving antennas were in the same room. Both the line-of-site (LOS) and the non-LOS links were recorded. The research will continue with the measurements where TX-antenna and RX-antenna are located at the different rooms (through-wall measurement).

4 CONCLUSION

This paper presents a vector network analyser measurement procedure for the ultra wideband radio channel modelling. The impulse responses of the radio channel can be calculated from the recorded frequency responses. A relatively large number of impulse responses will be used to generate a set of statistical radio channel models. Long cables and connectors cause frequency dependent attenuation, and also cause constant frequency shift during the sweeping process. However, most of the cable effects can be calibrated out from the system. The final setup of the parameters is a compromise of the desired delay resolution and the maximum detectable delay which both are defined by the number of frequency points, sweeping bandwidth and the IF bandwidth.

5 ACKNOWLEDGEMENTS

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[2] http://www.ara-inc.com/
[3] Agilent 8720E Family, Microwave Vector Network Analyzers, Data sheet. Agilent Technologies, 35 p.
[4] Microwave Network Analyzers Documentation Set. Agilent Technologies, 2000
[5] Response from Agilent Technical Support

Table 1. Measurement setup parameters.

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 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)

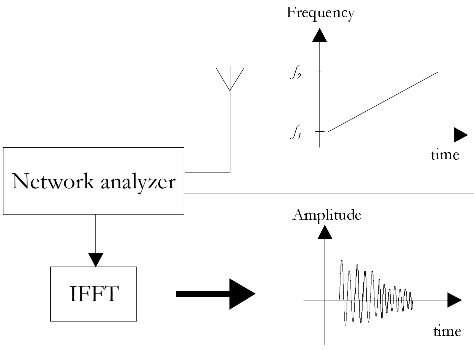


Figure 1. Radio channel measurement system based on frequency sweeping.

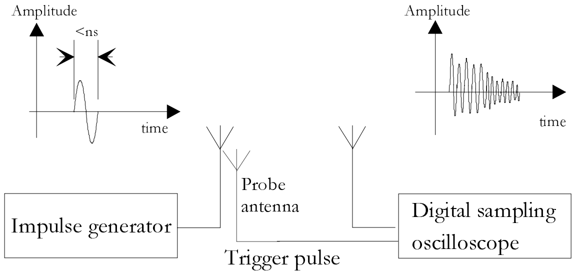


Figure 2. Radio channel measurement system based on pulse transmission.

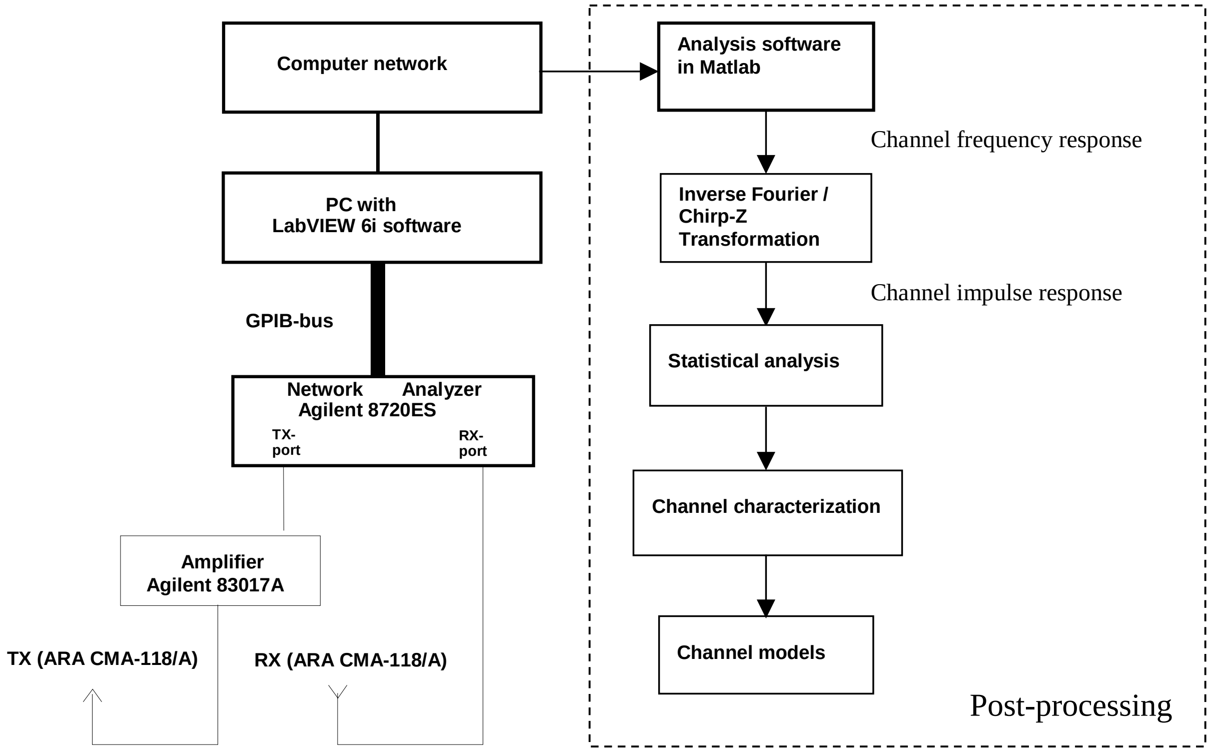
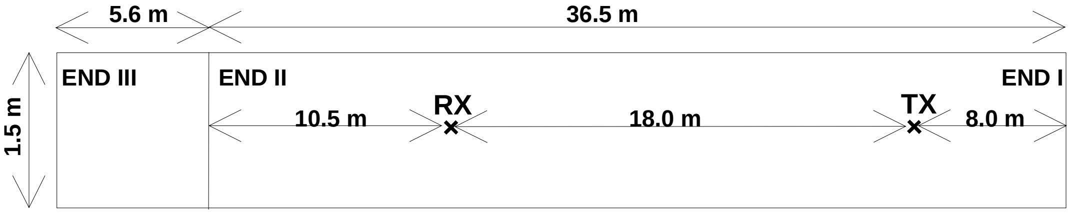


Figure 3. The actual radio channel measurement setup used in the study.



END II and END III are glass doors with metal grids

Figure 4. Measurement in a corridor

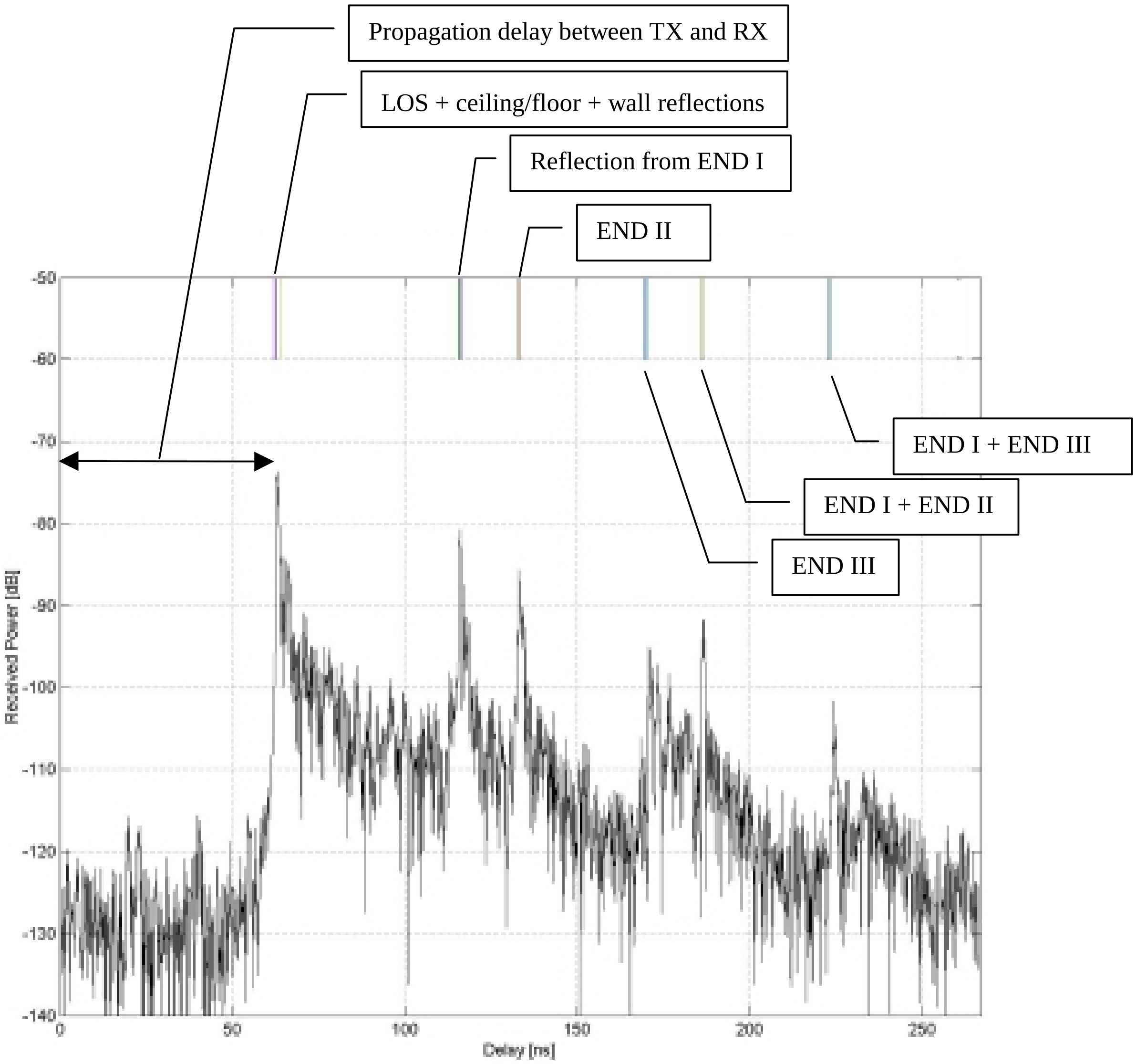


Figure 5. Impulse response measured in the corridor.