OUTDOOR ULTRA WIDEBAND PROPAGATION CHANNEL MODELING AT VHF/UHF BAND

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ABSTRACT

Due to the low power spectral properties of ultra wideband (UWB) signals, the technology is suitable to be used, e.g., in covert military applications. The open literature lacks of UWB radio channel models that are generated for outdoor use. This paper describes the radio channel measurement campaign carried out to increase the knowledge of the UWB propagation mechanisms in typical Finnish forest environment. The channel measurements were carried out in the bands of very high and ultra high (VHF, UHF) frequencies in the band of 230–390 MHz. The fractional bandwidth is more than 20%, which fulfils the FCC requirements given for UWB systems. The paper also describes propagation channel models which have been generated based on measurements. Basic channel parameters, such as mean excess delays, RMS delays and total excess delays, are presented. The results were found to be similar to the results of wideband channel measurements from a similar environment but the delay resolution is much better.

For each of the measured links, propagation channel models were generated using a tapped delay line structure. Each of the generated models consists of 20–30 taps. The models include information on the gain, delay and amplitude fading of the tap. The channels were not modelled to the noise level, because the delay resolution of an UWB channel is huge and the models would have consisted of too many taps for simulation purposes.

I. INTRODUCTION

Because UWB signal is noise like, it has excellent low probability of interception and low probability of detection properties. Therefore, UWB technique is a very promising candidate for the military communication where the systems should have a good protection against jamming and eavesdropping. Due to the low transmission power, UWB systems have a limited range. The data rate is inversely proportional to the processing gain, and in military communication, the high data rate is not always the most important property. Therefore, if the low data rates are used also the long distances in outdoor environment can be reached.

When studying the suitability of UWB technique in long distance communication, exact radio channel models are needed. Now, because UWB systems have an extremely large bandwidth, much larger than in typical wideband systems, the delay resolution is also better. This means that more multipath components can be distinguished. Existing wideband channel models do not offer delay resolution high enough for UWB applications, and therefore, new UWB channel models are needed. There are already numerous indoor UWB channel models, e.g, [1-4] which have been published worldwide but outdoor UWB channel models for long link distances have not been available previously in the open literature. The only published UWB outdoor campaign has been carried out using short, less than 20 m distances. The campaign is presented in [5].

In this paper, channel models that can be used in long distance outdoors UWB link performance studies are presented.

II. SOUNDING SYSTEM AND PARAMETERS

The radio sounding system used in the study was based on the modified frequency domain measurement technique introduced in [6]. Computer, which has the LabView™ software, controls all the measurement procedures. The receiver (RX) of the sounder was vector network analyser (VNA) which had wireless connection to the transmitter part of the system. The probing signal was sent by a standalone signal generator which was time and frequency synchronised to VNA. Triggering information between the transmitter (TX) and the receiver was sent by a radio connection, using a frequency outside of the probed band. The used antennas were vertical polarized Rohde & Schwarz HK014 antennas, which are omni-directional, and they have a constant phase centre, which are the features required for the antennas to be used in the channel sounding.

The measured frequency band was from 230 MHz to 390 MHz. The fractional bandwidth of the probing signal is 0.52, which satisfies the Federal Communications Commission (FCC) requirements for UWB systems [7]. Fractional bandwidth can be determined as

$$B_{\mathrm{f}} = 2\frac{f_{\mathrm{h}} - f_{\mathrm{l}}}{f_{\mathrm{h}} + f_{\mathrm{l}}} = 0.52\,, \tag{1}$$

where f_{h} is the upper −10 dB point and f_{l} is the lower −10 dB point in the spectrum. Table 1 lists the main parameters of the measurements. The given antenna gain is specified by the antenna manufacturer.

In the measurements, the frequency band of interest was swept using 1601 sample points, and the measured frequency response was used in the post-processing. The sweeping time was 4.8 s. The measurement procedure is therefore narrowband but the results ended up to UWB channel model. In contrast to the measurements carried out using conventional VNA approach, the modified system does not allow phase recovery from the raw data.

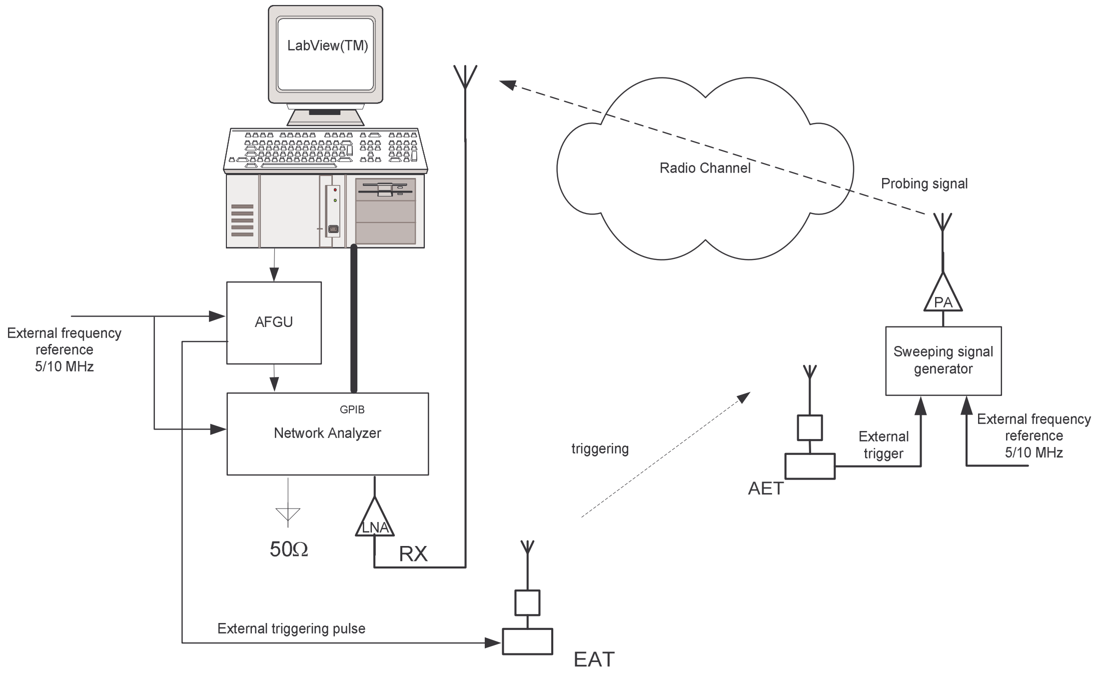

Figure 1. The modified frequency domain measurement setup.

However, an impulse response with the amplitude variation can be obtained. The modified frequency domain measurement technique is presented in Figure 1.

Impulse response of the sounder set-up was measured in an anechoic chamber. This data was used as a calibration data to compensate the impact of the measurement devices from the real measurement data.

The delay resolution of the measurement system is 6.25 ns which correspond to distance resolution of 1.875 m which is much better than the previous outdoor wideband and narrowband channel models have.

Table 1. Measurement parameters

Parameter	Value
Frequency band	230 to 390 MHz
Bandwidth	160 MHz
Number of points over the band	1601
Sweep time	4.8 s
Transmitted power	40 dBm = 10 W
Cable loss (max)	5 dB
Amplifier gain	40 dB
Antenna gain	2 dBi (typical)
Polarization of antennas	vertical
EIRP (min)	37 dBm = 5 W

III. MEASUREMENT ENVIRONMENT

Channel measurements were carried out in a typical Southern Finnish forest area during the late summer 2003. The measurement environment was slightly hilly and covered by coniferous and deciduous forest and open peatlands. During the whole measurement campaign, the RX antenna position was installed at the highest point of the area to make measurements possible in all directions and the TX antenna was moved into seven different positions. For small scale analyse purposes, five independent measurements were carried out in each TX position by moving the TX antenna about two meters. To improve the measurements statistical reliability, 100 sweeps were recorded at each antenna position.

The altitude of the measurements area varies from 94 m up to 154 m above a sea level (a.s.l.). The RX antenna was located at 158 m a.s.l. The link distances between TX and RX varied from 0.5 km to 5.6 km. Both antenna heights were 4.5 m above the ground.

IV. MULTIPATH CHANNEL MODELS

All the data post-processing was carried out using Matlab 6.5 software. The inverse discrete Fourier transform (IDFT) was used to transform the frequency domain data into the time domain, and the delay power spectrum was attained. During the IDFT, the Hamming windowing was used to suppress the side lobe level. During the measurements other radio transmissions were noticed as spurious peaks in the measured frequency responses. These peaks raised noise level in impulse response and therefore they were removed. Examples of the measured frequency response and power delay profile (PDP) are presented in Figure 2 and Figure 3.

Measured data from all the TX antenna positions were analysed and some channel parameters were calculated. NP_{10dB} is the number of multipath components within 10 dB related to the strongest component. Mean excess delay τ_M, RMS delay spread τ_{RMS} and maximum excess delay τ_{tot} were also calculated. τ_M can be defined as

$$\tau_{\mathrm{M}} = \frac{\sum_{n=1}^{l_r} (\tau_n - T_A) |h(t,\tau_n)|^2}{\sum_{n=1}^{l_r} |h(t,\tau_n)|^2}, \qquad (2)$$

where τ_n is the delay of the n^{th} tap, l_r is number of separable paths and T_{A} is the arrival time of the first received multipath component. RMS delay can be defined as

$$\tau_{RMS} = \sqrt{\frac{\sum_{n=1}^{l_r} (\tau_n - \tau_{\mathrm{M}} - T_{\mathrm{A}}) |h(t,\tau_n)|^2}{\sum_{n=1}^{l_r} |h(t,\tau_n)|^2}}. \qquad (3)$$

Maximum excess delay τ_{tot}, which is also called a multipath spread, is the width of the power delay spectrum.

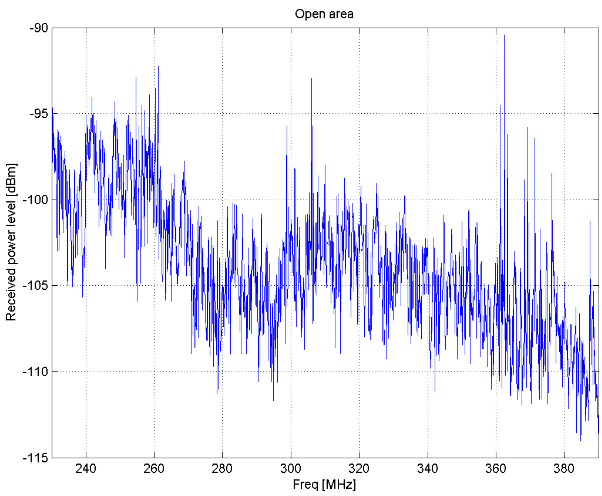

Figure 2. Example of the measured frequency response.

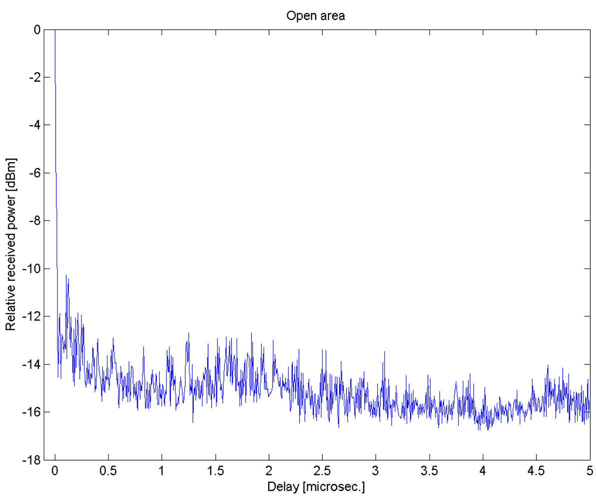

Figure 3. Example of the measured PDP.

In the measured links, where the transmitter antenna was sited in open peatlands and where no reflectors were nearby, the maximum excess delay was from 0.5 µs to 0.7 µs. The measured links, where the forest density was high, τ_{tot} varied from 1.5 µs to 2.5 µs. The parameters are presented in Table 2.

Table 2. Channel parameters

Parameter	Open	Dense
τ_{M} [µs]	0.16–0.25	0.57–0.85
τ_{RMS} [µs]	0.15–0.22	0.45–0.73
τ_{tot} [µs]	0.5–0.7	1.5–2.5
$NP_{10\mathrm{dB}}$	3–7	3–7

Channel models were generated separately to each measurement sites. The models are based on the average power delay profiles, and they are characterised using tapped delay lines. Each generated model consists of 20–30 of the strongest paths, all being inside 10.5 dB – 15 dB dynamic range, which is the ratio between the strongest tap and the noise level. The channels were not modelled up to the noise level because the delay resolution of the UWB channel is huge. Therefore, the models would consist of too many taps for simulation purposes. In [8] it has been studied that depending on the receiver algorithm, in modified Saleh-Valenzuela channel [9] 4–20 selective rake fingers will give the optimum bit error rate results. Selective rake is receiver which takes only the strongest paths of the channel [10]. In Figure 4, example of average power delay profile and modelled taps for one of the measured link is presented.

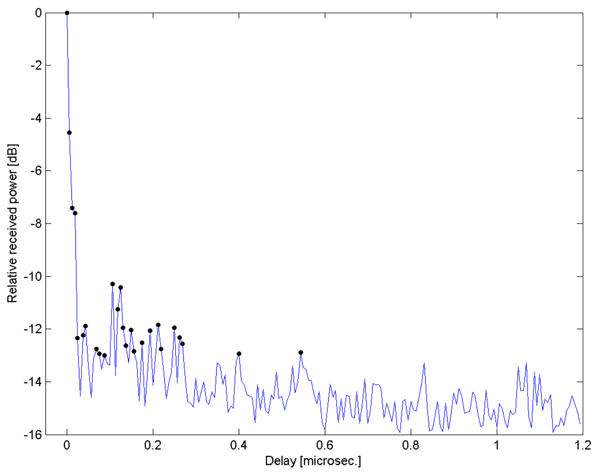

Figure 4. Example of normalized average PDP and modelled taps for one of the measured link.

For the amplitude fading analysis, all recorded data from one measurement place were collected together. This could be done because the transmitter movement between the consecutive positions was only about 10 meters, which is less than a few tens of the maximum wavelengths. Amplitude fading mechanism was selected using a distribution that fits best to the experimental data with 95 % confidence interval using Kolmogorov-Smirnov test [11]. The test selects a theoretical distribution, which minimizes the absolute value of a linear error of the theoretical and measured cumulative distribution functions (CDF) [11].

In the post-processing phase, it was found that the empirical distribution of the path amplitudes mostly fits best to Rice distribution. In Table 3, the pass rates of the Kolmogorov-Smirnov test for the three best fit distributions have been compared.

As one can notice, the amplitude fading of the measured data fit to the Rice distribution with the pass rates varied from 26% to 78%. The data from two of the measured links fit, however, better to lognormal distribution (44% and 61%) or to Nakagami distribution (37% and 64%) than to Rice distribution (43% and 26%). Other distributions were also studied but they did not fit as well as the listed ones. Rice distribution is also quite simple to apply to computer simulations for performance studies of UWB systems and that is why it is preferred when possible.

Table 3. Comparison of the pass rates of amplitude fading distribution for different measured links

Link number	Lognormal [%]	Rice [%]	Nakagami [%]
1	60.7	42.9	64.2
2	44.4	25.9	37.0
3	18.5	77.8	40.7
4	14.8	48.2	22.2
5	37.0	74.1	48.2
6	3.7	70.4	7.4
7	26.9	69.2	34.6

The probability density function (PDF) p_ξ of the Rice distributed random variable is

$$p_\xi(x) = \frac{x}{\sigma^2} e^{-\frac{x^2+s^2}{2\sigma^2}} I_0\left(\frac{sx}{\sigma^2}\right), \qquad (4)$$

where I_0 is the modified Bessel function of the first kind and 0^{th} order, s is the dominant signal component and σ^2 is the power in the random part.

Rice distribution is often described in terms of a K-value. It can be interpreted as a ratio of the dominant signal power to the power in the multipath components. The parameter K can be defined in dB as

$$K = 10\log_{10}\left(\frac{s^2}{2\sigma^2}\right), \qquad (5)$$

where $s^2/2$ is the power in the constant part.

In Figure 5, 100 independent channel impulse responses are presented using the channel model that is generated from the measurement data. The described channel model consists of 26 taps within maximum delay spread of 0.5 µs. Taps gain dynamic range is 13 dB and the K-value of the Rice distribution varies from 8.1 to 14.5.

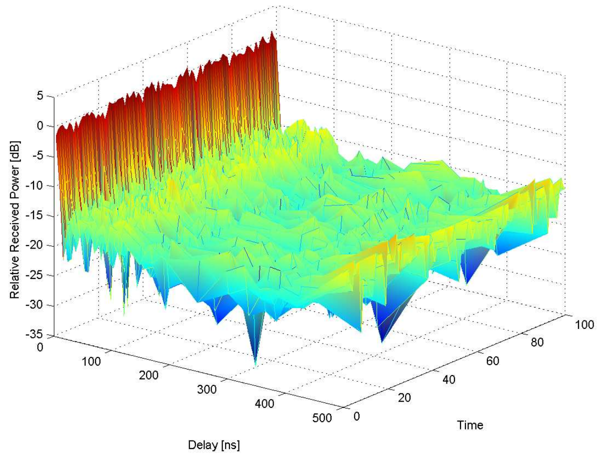

Figure 5. Example of generated outdoor channel profiles.

In Table 4, the average values for the first five taps that are generated from the models are presented. Range and average values of tap gains and Rice distribution K-values are tabled. As one can notice, first four taps are averagely inside in 10 dB from the strongest tap. The rest of the modelled taps are averagely around –11…–12 dB and Rice K-factor is less than 10 dB.

Table 4. Channel model's first five taps delay, gain and Rice distribution K-value

Delay [ns]	Tap gain [dB]	Aver. tap gain [dB]	Rice K-value [dB]	Aver. K-value [dB]
0	0	0	14.1–18	16.8
6.25	-3.5 – -4.8	-3.6	14.3–17.9	16.5
12.5	-7.4 – -11.7	-9.4	7.6–14.7	10.9
18.75	-7.6 – -12.3	-9.7	7.3–18.3	13.1
31.25	-10.3– -13.4	-11.4	8.1–10.2	8.8

V. Conclusion

In this paper outdoor channel models for UWB systems have been generated. The measured frequency band was from 230 MHz to 390 MHz fulfilling the fractional bandwidth definition, which FCC has given for UWB systems. The UWB radio channels´ multipath properties are studied using long (0.5–5.6 km) link distances. The studies are based on frequency response measurements using fixed links. Based on the measured data analysis, the general radio channel parameters were calculated for the measured links and for each of them the channel models using tapped delay line structure were generated. It was found that all the models consist of only four strong taps and they all arrive just after the first arrive multipath component. The found amplitude fading were Rice distributed.

VI. Acknowledgements

This work is funded by the National Technology Agency of Finland (Tekes), Elektrobit and the Finnish Defence Forces. Authors would like to thank the sponsors for their support.

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