Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [A proposal for a selection of indoor UWB path loss model]
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Source: [ULTRAWAVES - Philips, Wisair, Centre for Wireless Communications]
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Re: [Response to Call for Contributions on Ultra-wideband Channel Models, Doc. IEEE P802.15-02/208r1-SG3a.]
Abstract: [This document provides FUBS and ULTRAWAVES UWB Path Loss Model for IEEE P802.15.3 Study Group. The proposed path loss models are based on the measurements performed at the University of Oulu, Finland. Frequency range is 2 - 8 GHz and 3.1 - 8 GHz. Both LOS and NLOS results are presented.]
Purpose: [Use for establishing the indoor UWB radio channel model of the Alternative PHY for IEEE 802.15.3.]

A proposal for an indoor UWB path loss model

Made by:

ULTRAWAVES consortium

Philips, Wisair, Univ. of Oulu, Radiolabs, ENSTA, Univ. of Chalmers, Armines

Main Contributors:

Centre for Wireless Communications

University of Oulu, FINLAND

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ULTRAWAVES Path Loss Model

- An Indoor Ultra WideBand (UWB) path loss model is proposed as part of the definition of the IEEE 802.15.3Sga Channel Model
- ULTRAWAVES path loss is based on an indoor radio channel measurement campaign performed at the Univ. of Oulu in 2001 and 2002
- Frequency bands:
  - **Corridor 1**: 2.0 GHz - 8.0 GHz (BW = 6.0 GHz)
  - **Corridor 2 & Lecture hall**: 3.1 GHz - 8.0 GHz (BW = 4.9 GHz)
  - **Through-wall**: 2 GHz - 8 GHz (BW = 6.0 GHz)

ULTRAWAVES Path Loss - EU features

- All the measurements have been done in a typical European environment (in Finland)
- Differences are usual in set of measurements done in US and EU, due to the different nature of materials used in buildings.
- A good channel model aiming to be suitable for international adoption must also take into consideration the path-loss effectively registered in Europe.
- Europe is a huge market for consumer electronics, and very important segment for large manufacturers (CE+IC) like Philips, TI, Sony, STMicro...

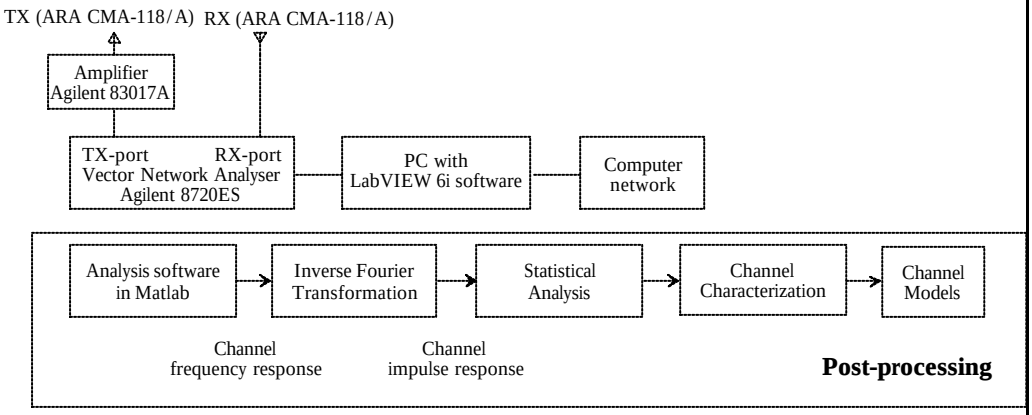
Measurement Setup (1)

- Vector network analyzer: Agilent 8720ES
- Wideband amplifier: Agilent 83017A
- Antennas: CMA-118/A
  (Antenna Research Associates, Inc.)
- Measurement controlled by LabView ®
- Post-processing in Matlab®
- Static environment during recordings

Measurement Setup (2)

- 1601 frequency points within band
  - frequency step 3.75 MHz
  - uniformly distributed
- Complex channel frequency response is recorded
- Line-of-sight and through-wall measurements
- Total received power is studied
- Antenna heights used in both ends: 110 cm
  - in through-wall measurements h_{TX}= 220 cm and h_{RX} = 60 cm, 110 cm and 220 cm
  - the effects of the antennas are included in the results

Measurement Setup (3)

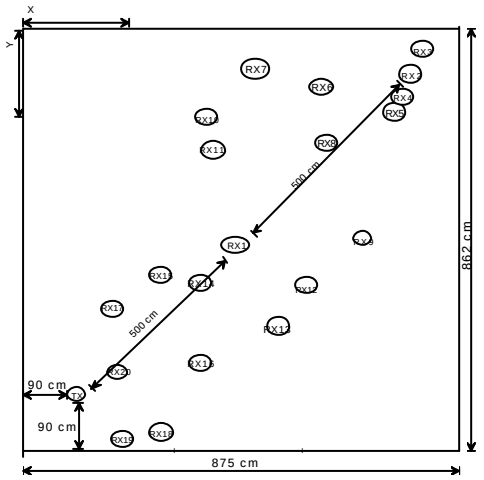


Measurement and modeling procedure

Measurement Environments (1)

- Indoor buildings at the University of Oulu (Finland)
- 2 different corridors
  - Concrete walls and floors, plaster/concrete ceilings (**Corridor1**)
  - Plasterboard walls, plaster floor (**Corridor2**)
- 1 lecture room
  - 2 brick walls, 2 plasterboard walls, parquet floor
    - Size: 8.80 m x 8.60 m x 3.54 m
- Through-wall (NLOS) Measures

Measurement Environments (2)



Lecture hall

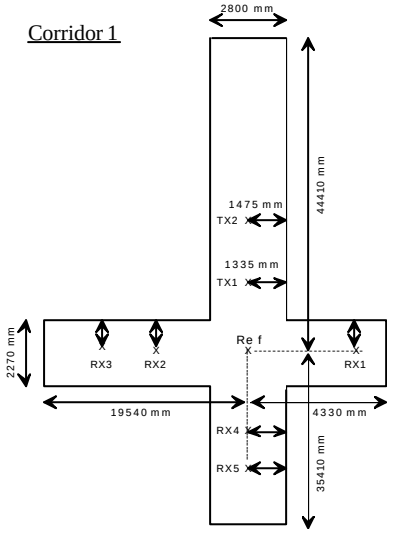
Transmitter height: 110 cm

Receiver height: 110 cm

	X (cm)	Y (cm)
RX1	480	423
RX2	801	74
RX3	842	36
RX4	771	110
RX5	765	173
RX6	590	88
RX7	487	74
RX8	622	237
RX9	701	404
RX10	365	180
RX11	392	254
RX12	576	503
RX13	522	621
RX14	389	502
RX15	292	487
RX16	378	660
RX17	203	550
RX18	294	797
RX19	197	803
RX20	205	673

Measurement Environments (3)

Corridor 1



Corridor - measurement

Transmitter height: 110 cm

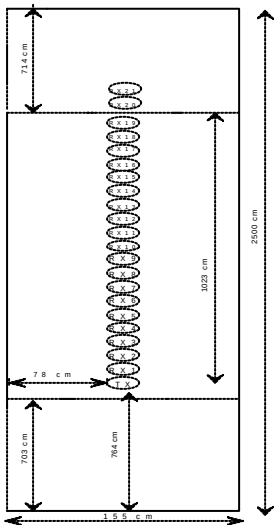
Receiver height: 110 cm

	from Ref	**from wall**
TX1	5025	1335
TX2	15025	1475
RX1	3725	1095
RX2	5025	1135
RX3	10025	1135
RX4	5025	1345
RX5	10025	1395

Corridor height: 3890 mm

No windows between the measured link relays

Measurement Environments (4)



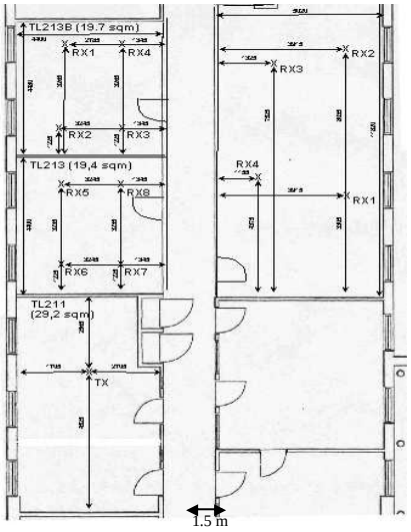
Corridor 2

	Distance from TX (cm)
RX1	100
RX2	150
RX3	200
RX4	250
RX5	300
RX6	350
RX7	400
RX8	450
RX9	500
RX10	550
RX11	600
RX12	650
RX13	700
RX14	750
RX15	800
RX16	850
RX17	900
RX18	950
RX19	1000
RX20	1050
RX21	1100

Corridor - measurement

Transmitter height:	110 cm
Receiver height:	110 cm
Corridor height:	228 cm

Measurement Environments (5)



Through-wall (NLOS) measurements:
- frequency band: 2 GHz - 8 GHz

RX from TX (mm)		
	TL213B & TL213	TL212
RX1	10450	10050
RX2	8400	13500
RX3	8500	11500
RX4	10550	8750
RX5	5850	
RX6	3850	
RX7	4050	
RX8	6000	

Room height:

TL213B & TL213	2730 mm
TL212	2760 mm

Data Analysis

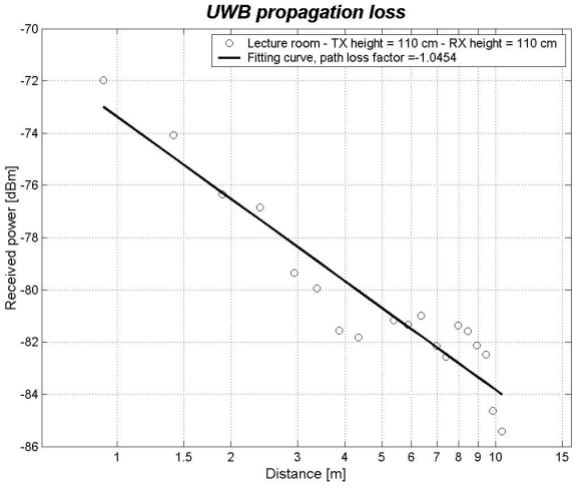
- Fitted exponential curve in absolute distance scale corresponds to straight line in logarithmic scale. A linear regression line is therefore fitted to measured power data points using the Equation:

$$P(d) = k \cdot 10\log_{10}(d) + c$$

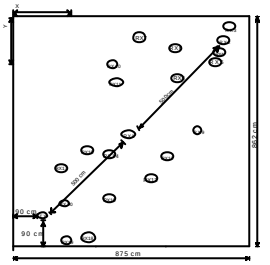
where *k* corresponds to path loss factor, *d* is distance and *c* is a power scaling constant

- *k* = -2 corresponds to free space.

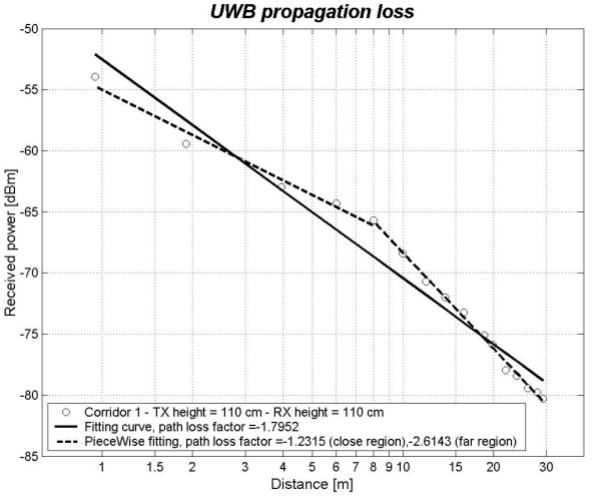
Path loss measurements - Lecture Hall



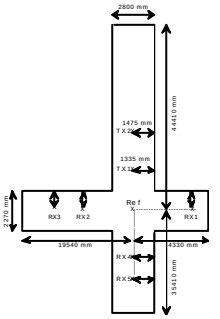
Attenuation has been calculated from the total received power



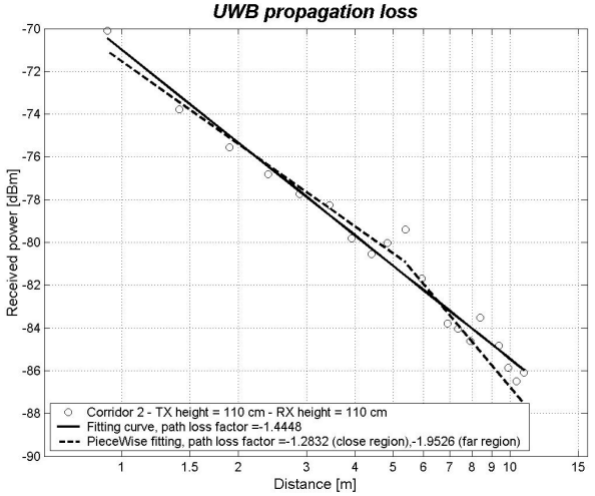
Path loss measurements - Corridor 1



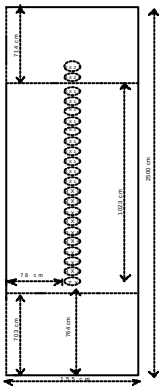
Attenuation has been calculated from the total received power



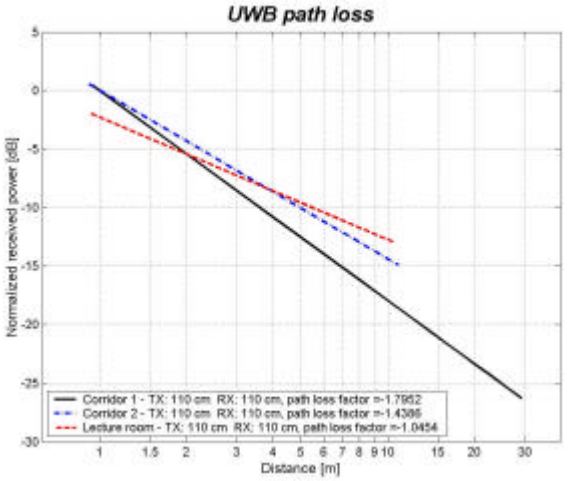
Path loss measurements - Corridor 2



Attenuation has been calculated from the total received power

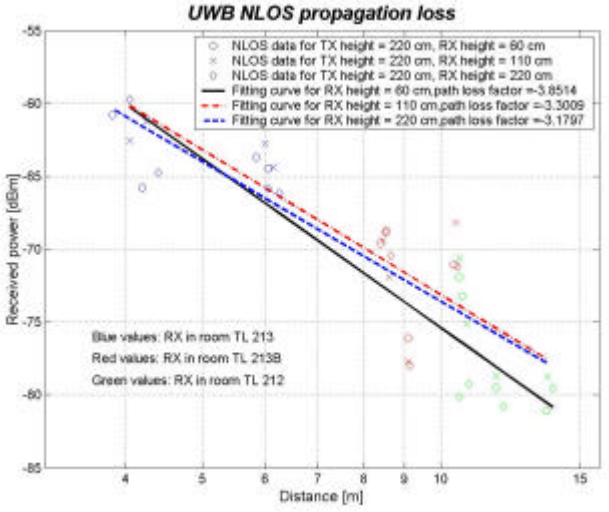


Path loss measurements - Summary LOS Indoors

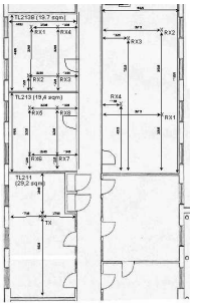


Attenuation has been calculated from the total received power

Path loss measurements - Through-wall (NLOS)



Attenuation has been calculated from the total received power



Summary of results

$$P(d) = k \cdot 10 \log_{10}(d) + c$$

k = path loss exponential slope
c = received power at 1 meter distance from the TX

Location	TX height (cm)	RX height (cm)	k
Lecture hall	110	110	-1.0454
Corridor 1	110	110	-1.7952
Corridor 2	110	110	-1.4386
Through wall (NLOS)	220	60	-3.8514
Through wall (NLOS)	220	110	-3.3009
Through wall (NLOS)	220	220	-3.1797

More References about the indoor UWB Channel Modelling by CWC

- M.Hämäläinen, T.Pätsi, V. Hovinen: *Ultra Wideband Indoor Radio Channel Measurements*. The 2nd Finnish Wireless Communication Workshop (FWCW'01), Tampere, Oct 23-24, 2001
- V.Hovinen, M.Hämäläinen, T.Pätsi: *Ultra Wideband Indoor Radio Channel Models: Preliminary Results*. The 2002 IEEE Conference on Ultra Wideband Systems and Techniques, Baltimore, May 20-23, 2002
- V.Hovinen, M.Hämäläinen: *Ultra Wideband Radio Channel Modeling For Indoors*. COST 273 Workshop, Helsinki, May 29, 2002

Documents can be downloaded at the address:
http://www.ee.oulu.fi/~mattih/published.php

Acknowledgments

- The measurement campaign has been funded by Nokia, Elektrobit, the Finnish Defense Forces and the National Technology Agency of Finland (Project FUBS in CWC).

- This submission is done via the Ultrawaves consortium (and EU project IST-2001-35189), and is fully sustained by its industrial partners Philips and Wisair.

Conclusions

- The ULTRAWAVES consortium (Philips, Wisair, Univ. of Oulu, Radiolabs, ENSTA, Univ. of Chalmers, Armines) is convinced of the need for a path loss representation which accurately describes also typical European buildings.
- A set of measurements have been conducted at the University of Oulu and they give clear indications for the slow variations of signal strength in European corridors and lecture theatres.
- A simple path-loss formula is proposed and well suited for UWB propagation in EU environments