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

Submission Title: [Characterization of Ultra-Wideband Channels: Large-Scale Parameters for Indoor & Outdoor Office Environments.]

Date Submitted: [14 July, 2004]

Source: [Kannan Balakrishnan, Kim Chee Wee, Sun Xu, Chiam Lee Chuan, Francois Chin, Chew Yong Huat, Chai Chin Choy, Tjhung Tjeng Thiang, Peng Xiaoming, Michael Ong and Sivanand Krishnan]
Company: [Institute for Infocomm Research (I^2R)]]
Address: [21 Heng Mui Keng Terrace, Singapore 119613]
Voice: [65-68745684], FAX: [65-67768109], **E-Mail:** [kannanb@i2r.a-star.edu.sg]

Re: [Response to Call for Contributions by 15.4a Channel Modeling Subgroup]

Abstract: [This contribution describes a path loss model that is adopted by the IEEE 802.15.4a channel modeling sub-committee for evaluating large-scale parameters from the empirical data collected in indoor & outdoor office environments. It consists of detailed characterization of the path loss model for ultra-wideband channels in the 3-6GHz frequency range.]

Purpose: [For IEEE 802.15.SG4a to adopt the path loss model and use it in link budget calculations for validation of throughput and range requirements of UWB PHY proposals.]

Notice: This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.

Release: The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.

Ultra-Wideband Channel Models: Large-Scale Parameters

B. Kannan & Francois Chin
Digital Wireless Dept.,
Institute for Infocomm Research(I^2R, A*STAR)

Outline

- Motivation
- Equipment Setup
- Environments
- Path Loss Model
- Extraction of Parameters
- Conclusion

Motivation

- To extract statistical parameters of UWB channels from empirical data in indoor and outdoor office environments.
- These parameters will be used
  - To simulate various UWB channels' propagation behavior.
  - To validate the range and throughput requirements of 15.4a UWB PHY proposals in various environments.
  - To help to design appropriate modulations and coding schemes to combat the ill-effects of multipaths.

Equipment Setup

- Measurements were taken in frequency domain using VNA (Agilent 8753E)
  - Center Frequency: f_c = 4.5GHz
  - Bandwidth: BW = 3GHz
  - Frequency bins: N = 1601
  - Delay resolution: $\Delta\tau \approx$ (1/BW) = 0.33ns
  - Frequency step: Δf = BW/(N-1) =1.875MHz
  - Max. excess delay: τ_{max} = 1/ Δf = 533.3ns (160m)
  - Sweeping time: t_{sw} = 600ms
  - Max. Doppler shift: $f_{d,max}$ = 1/ t_{sw}
  - IF bandwidth: IF_{BW} = 3.7kHz
  - Antenna type: Omni-directional Cone antennas(3-6GHz)
  - Antenna heights: 1.2m

Equipment Setup

- Fig. (1) shows the equipment setting. Frequency domain data are collected by a laptop with Agilent IntuLink VNA software via GPIB interface.
- This equipment setup (without antennas) is calibrated using the 8753E calibration kit.
- For the outdoor measurements, an amplifier with 10 dBm gain is used at the Tx.

Equipment Setup

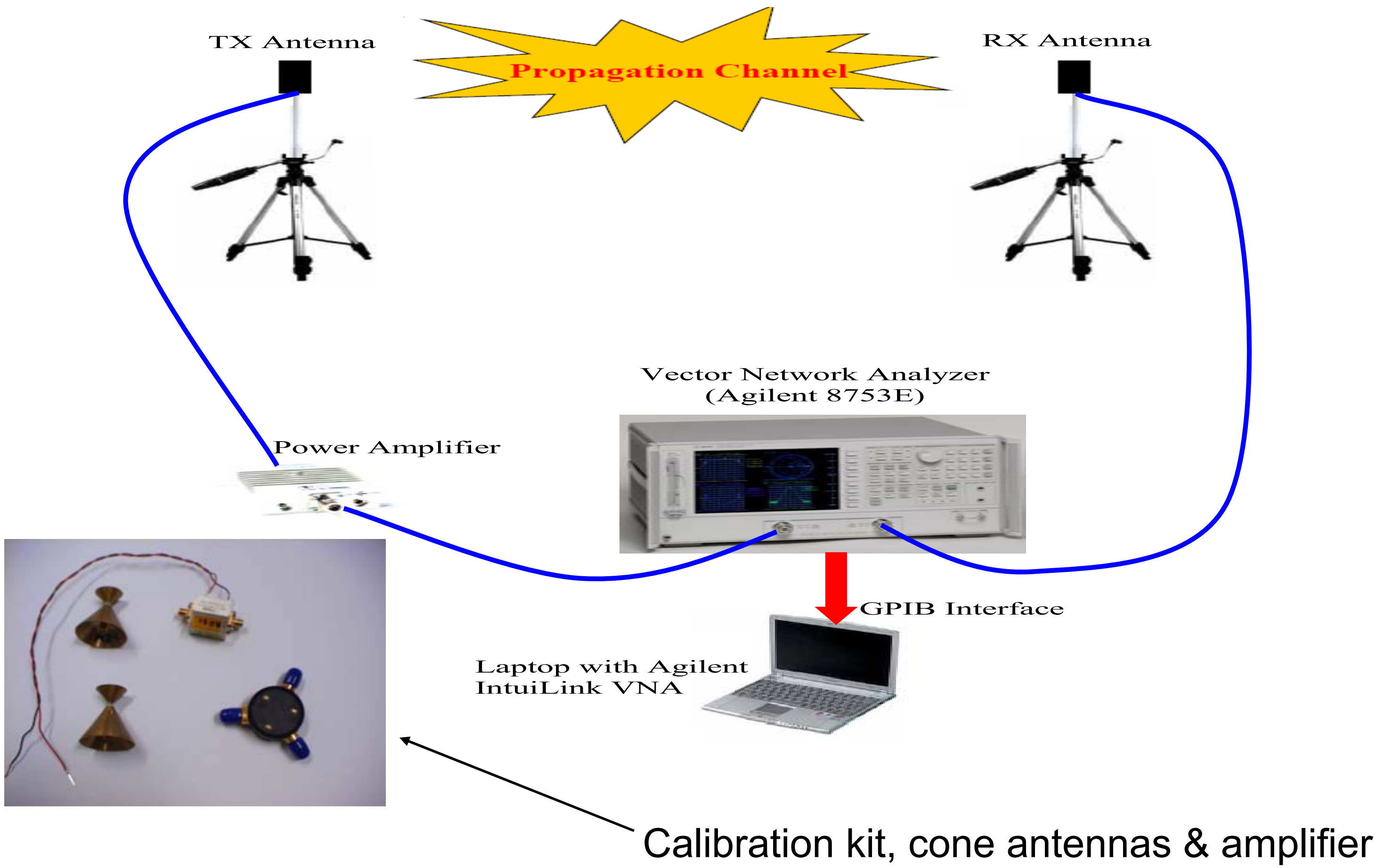

Fig. (1): Equipment Setup

Environments (Indoor Office)

- Indoor office environments: OFF_LOS, OFF_SOFT_NLOS and OFF_HARD_NLOS.
  - Tx-Rx separations ranging from 5m to 18m.
  - Number of locations: OFF_LOS - 39, OFF_SOFT_NLOS - 48 and OFF_HARD_NLOS -17.
  - At each location, measurements are taken over a square grid of K (= 9) spatial points (5cm inter-distance).
  - Figs. (2), (3) & (4) show the Tx/Rx locations for OFF_LOS, OFF_NLOS and RM_NLOS measurements respectively.

Environments (Outdoor Office)

- Outdoor office environments: OUT_LOS .
  - Tx-Rx separations ranging from 3m to 24m.
  - Number of locations: OUT_LOS-41 locations.
  - At each location, measurements were taken over a square grid of K (= 9 or 49) spatial points (5cm inter-distance) .
  - Figs. (5) shows the Tx/Rx locations for OUT_LOS measurements.

Environments

- OFF_SOFT_NLOS environment: There are cubicles between the Tx & Rx, where **fabric panels** separate the cubicles.
- OFF_HARD_NLOS environment: Tx & Rx are separated by 1 or 2 walls which are made of **gypsum** material.
- OUT_LOS environment: In the middle of two connected buildings (metal plated concrete walls with small/large glass windows) and has some trees around.

OFF_LOS Tx/Rx Locations

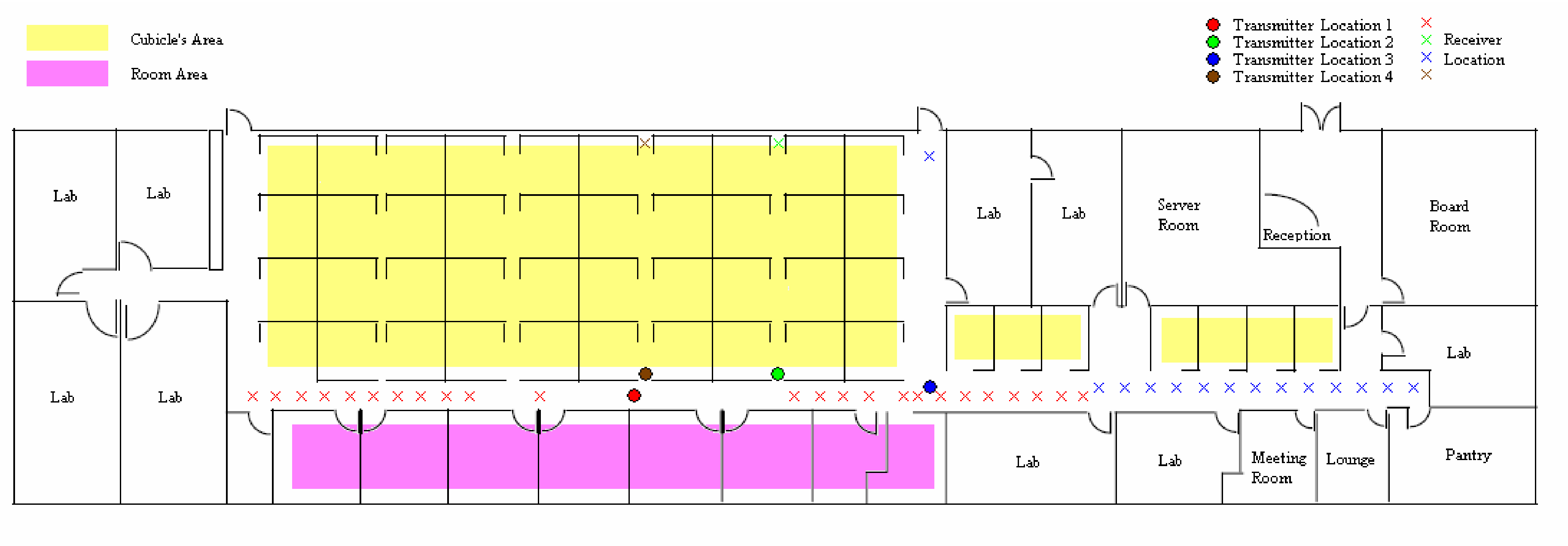

Fig. (2): Tx/Rx locations for OFF_LOS

OFF_SOFT_NLOS_S Tx/Rx Locations

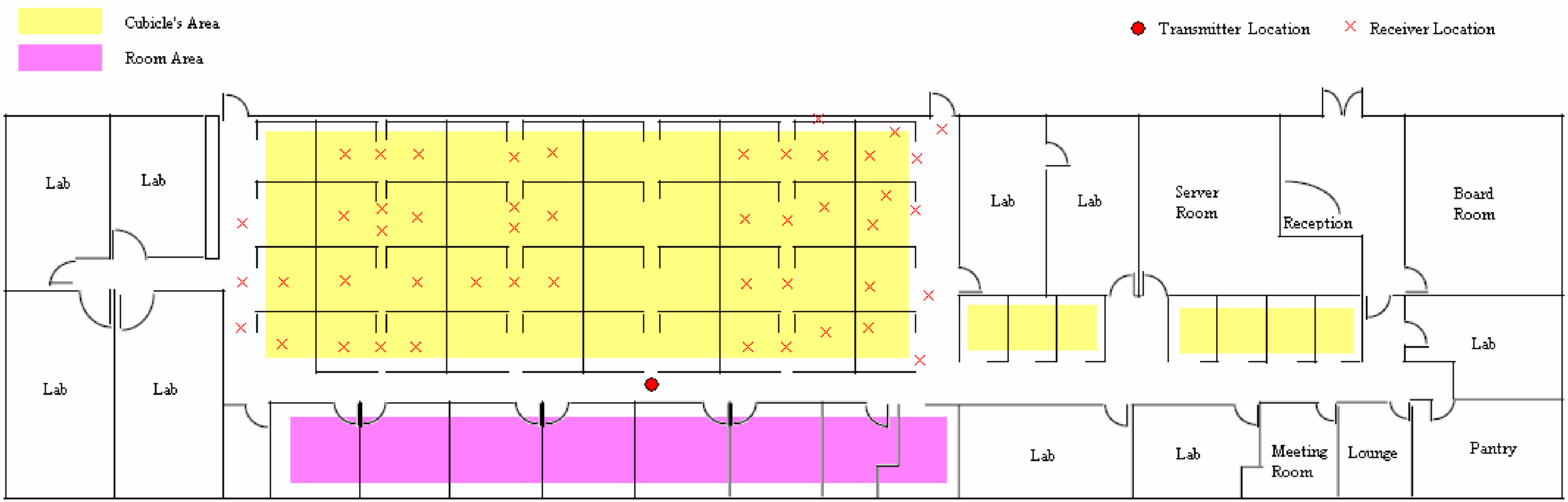

Fig. (3): Tx/Rx locations for OFF_SOFT_NLOS

OFF_HARD_NLOS Tx/Rx Locations

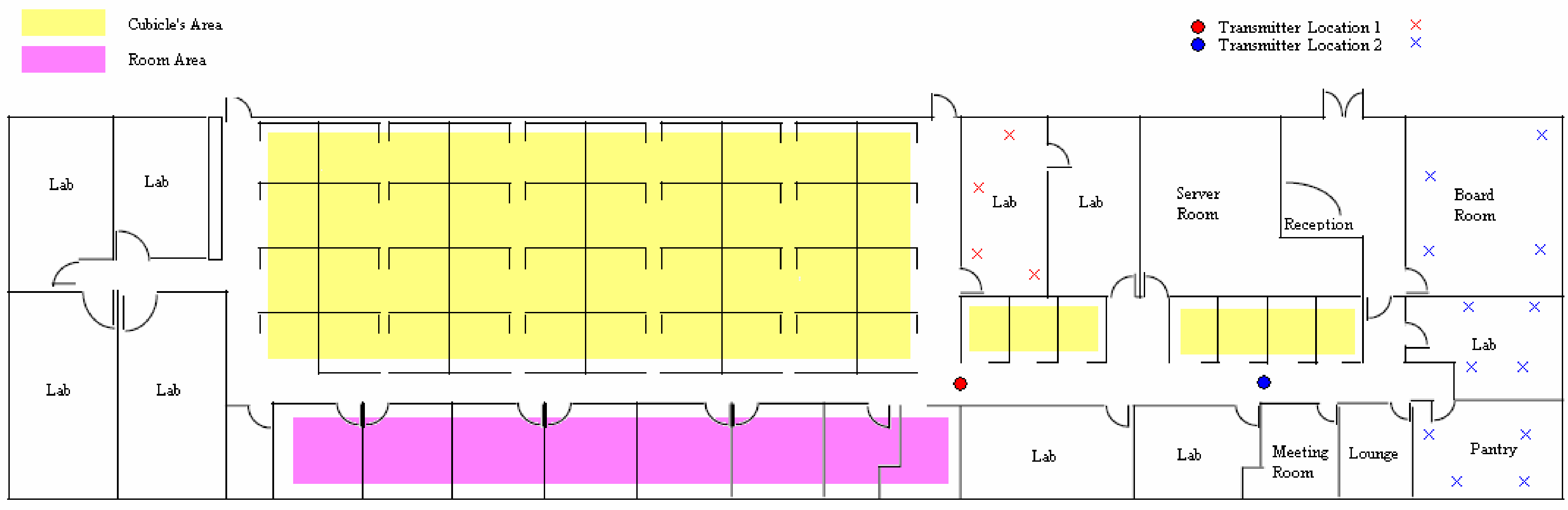

Fig. (4): Tx/Rx locations for OFF_HARD_NLOS

OUT_LOS Tx/Rx Locations

Fig.(5a): OUT_LOS environment

OUT_LOS Tx/Rx Locations

Fig.(5b): OUT_LOS environment

Path Loss Model

- In this report, we use the following traditional path loss model:

$$PL(d) = \left[PL_0 + 10\nu \log_{10}\left(\frac{d}{d_0}\right)\right] + n_2\sigma; \qquad d \geq d_0 \qquad (1)$$

  - d_o is a reference distance, e.g., $d_o = 1$ m.
  - PL_0 is the intercept and ν is the path loss exponent.
  - $n_2\sigma$ is the shadowing component and is assumed to be a zero-mean Gaussian variate with standard deviation σ dB.

Path Loss Model

- PL(d) (in dB) is given by

$$PL(d) = 10\log 10\left(\frac{1}{KN}\sum_{i=1}^{N}\sum_{k=1}^{K}\left|H^k(f_i;d)\right|^2\right) \quad (2)$$

where K= number of spatial points & N=1601.

- IEEE 802.15.4a channel modeling sub-committee adopted a generalized model where ν and σ are modeled by Gaussian random variable as shown below:

$$\nu = \mu_\nu + n_1\sigma_\nu, \sigma = \mu_\sigma + n_3\sigma_\sigma$$

- ν and σ change randomly between homes and locations respectively. n_1 and n_3 are Gaussian random variates with zero means and unit variances. However, in our campaign we used the traditional model.

Path Loss Model

- The frequency dependency of the path loss PL(f) is generally modeled by one of the following two functions:

$$PL(f) = \frac{1}{K}\sum_{k=1}^{K}\left|H^{k}(f;d)\right|^{2}$$

$$\propto \left[\frac{f}{1GHz}\right]^{-r} \qquad (3)$$

$$\propto \exp\left[-\delta \frac{f}{1GHz}\right] \qquad (4)$$

where δ and r are constants.

- In the path loss calculations above, spatial averaging is used to normalize the fading effects.

Extraction of Parameters

- Large-Scale Parameters to be extracted:
  - ν: distance dependent path loss exponent
  - σ: shadowing variance (dB)
  - PL_0: path loss at 1m
  - r , δ: frequency dependent path loss constants.
- Figs. (6-7) shows the PL(d) vs distance graph for all the environments studied in the channel measurements campaign.
- Figs. (8-9) shows the PL(f) vs frequency (Hz) graph for the OFF_LOS and OUT_LOS environments.

v: Dist. Dep. Path Loss Exponent (OFF)

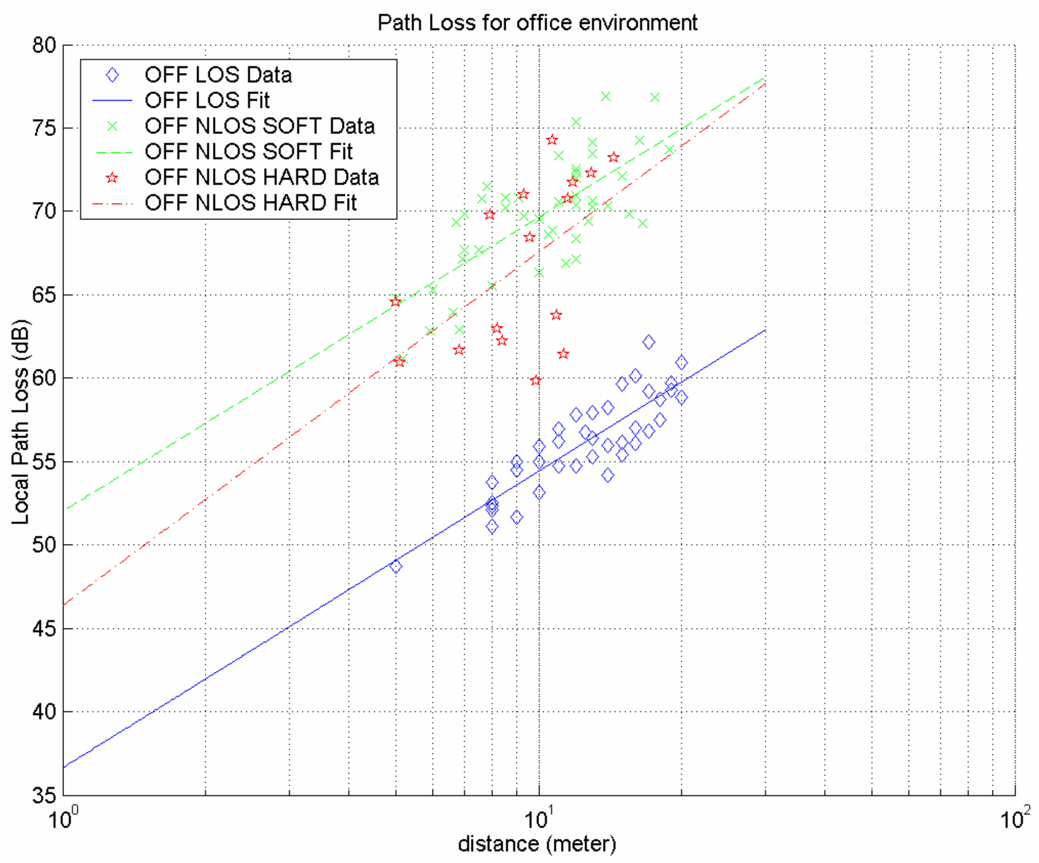

Fig. (6): PL(d) vs distance graph

ν: Dist. Dep. Path Loss Exponent (OUT)

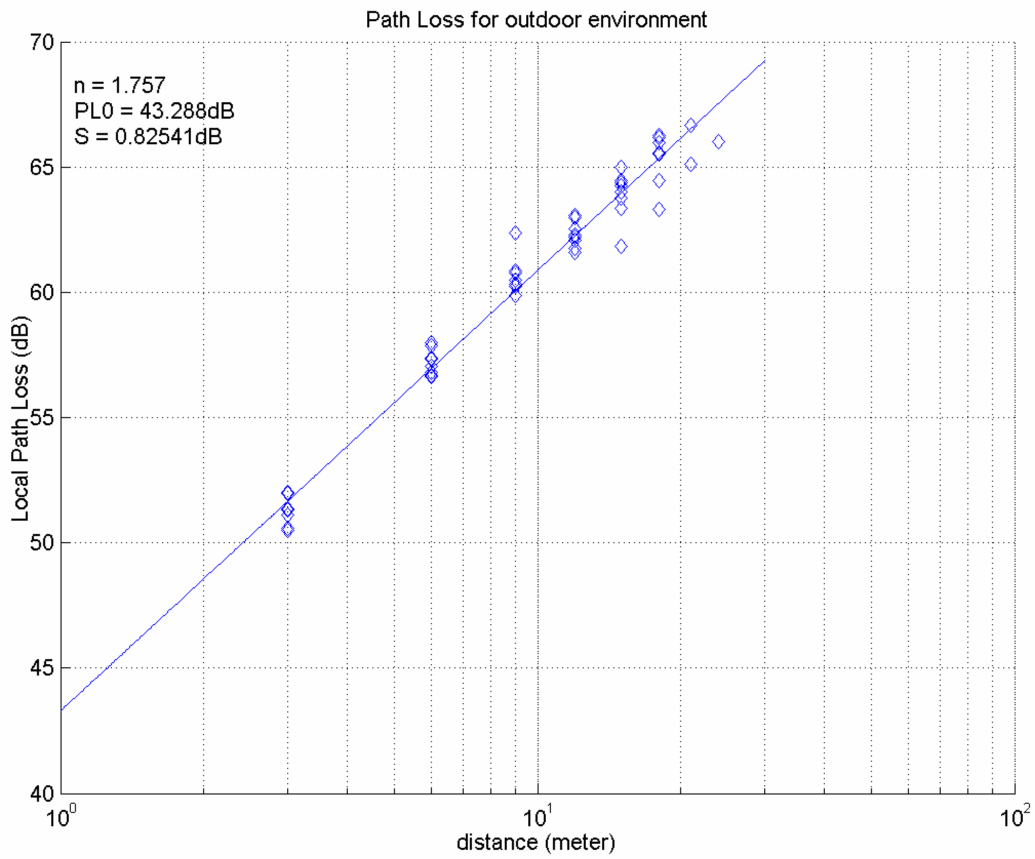

Fig. (7): PL(d) vs distance graph

r: Freq. Dep. Path Loss Exponent (OFF_LOS)

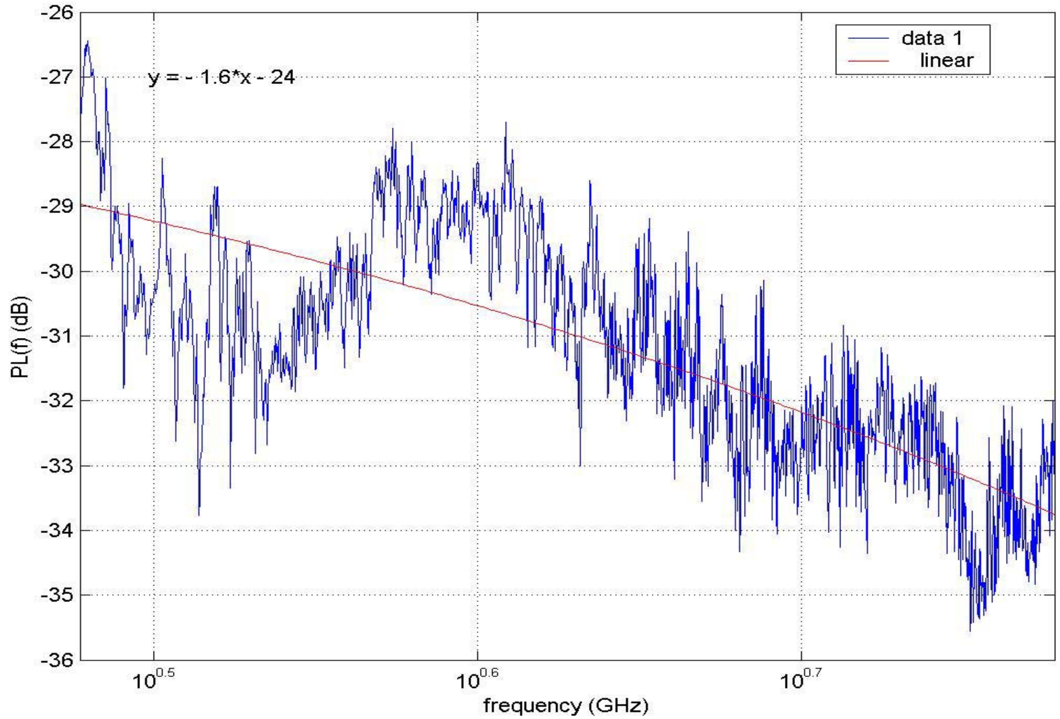

Fig. (8): PL(f) vs frequency graph

r: Freq. Dep. Path Loss Exponent (OUT_LOS)

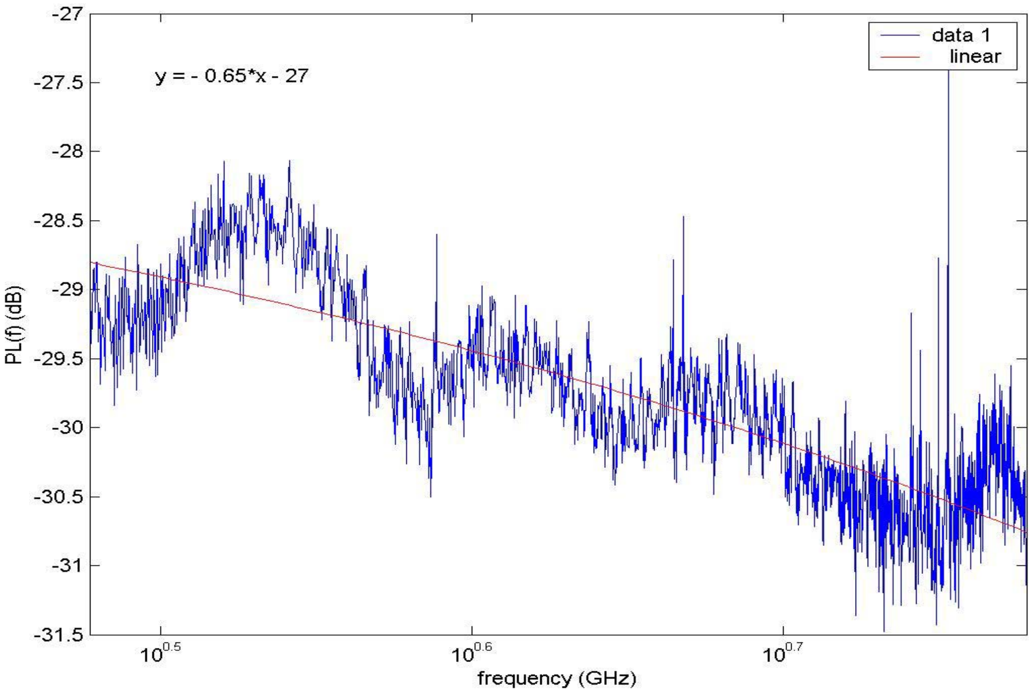

Fig. (9): PL(f) vs frequency graph

Conclusions(1)

- Tab. (1) shows the large-scale parameters extracted from empirical data collected in various office environments

	OFF_LOS	OFF_SOFT_NLOS	OFF_HARD_NLOS	OUT_LOS
ν	1.78	1.76	2.12	1.76
σ (dB)	1.45	2.43	4.21	0.83
PL_0 (dB)	36.62	52.00	46.35	43.29
r (μ_r , σ_r)	(0.4752, 0.1243)	(1.8277, 0.1526)	(0.88349, 0.1345)	(0.6350, 0.1241)
δ (μ_δ , σ_δ)	(0.1156, 0.0063)	(0.4208, 0.0079)	(0.1904, 0.0070)	(0.1477, 0.0066)

Tab(1): Large-scale parameters

Conclusions(2)

- We performed propagation experiments to characterize the UWB path loss in indoor and outdoor office environments in the 3-6GHz frequency range.
- The results show that the distance dependent path loss exponent, ν varies from 1.76 in the LOS environment to 2.12 in the NLOS environment where the LOS signal is blocked by some walls. If the walls are made of concrete or thick materials, ν might take larger values.
- The shadowing component, σ increases from 0.83 dB in the LOS (outdoor) case to 4.2 dB in the NLOS (indoor) case.
- The results also show that the frequency dependent path loss exponents r and δ take larger values in the NLOS environments compared to the LOS environments.
- Random variations of ν and σ can be characterized by taking measurements over several office buildings/locations.
- Measurements are underway for OUT_NLOS environments and the results will be made available to the group in the near future.