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

Submission Title: [UWB Channel Measurement Results in Indoor Residential Environment – High-Rise Apartments]

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Re: [Response to Call for Contributions on IEEE 802.15.4a Channel Models]

Abstract: [This contribution describes the UWB channel measurement results in indoor residential environment. Measurements were conducted in several types of high-rise apartments based in several cities in Korea. It consists of detailed characterization of the path loss and temporal-domain parameters of the UWB channel with bandwidth from 3 to 10 GHz.]

Purpose: [Contribution towards the IEEE 802.15.4a Channel Modeling Subgroup.]

UWB Channel Measurement Results in Indoor Residential Environment – High-Rise Apartments

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Outline

- Motivation
- Measurement Setup & Environment
- Data Analysis & Post-Processing
- Channel Measurement Description
- Measurement Results
- Conclusion
- Future Work

Motivation

- Study the UWB wave propagation characteristics in indoor residential environment
- Develop a channel model suitable for UWB applications in high-rise apartments
- Submit contributions to the IEEE802.15.4a channel modeling subgroup standardization activities

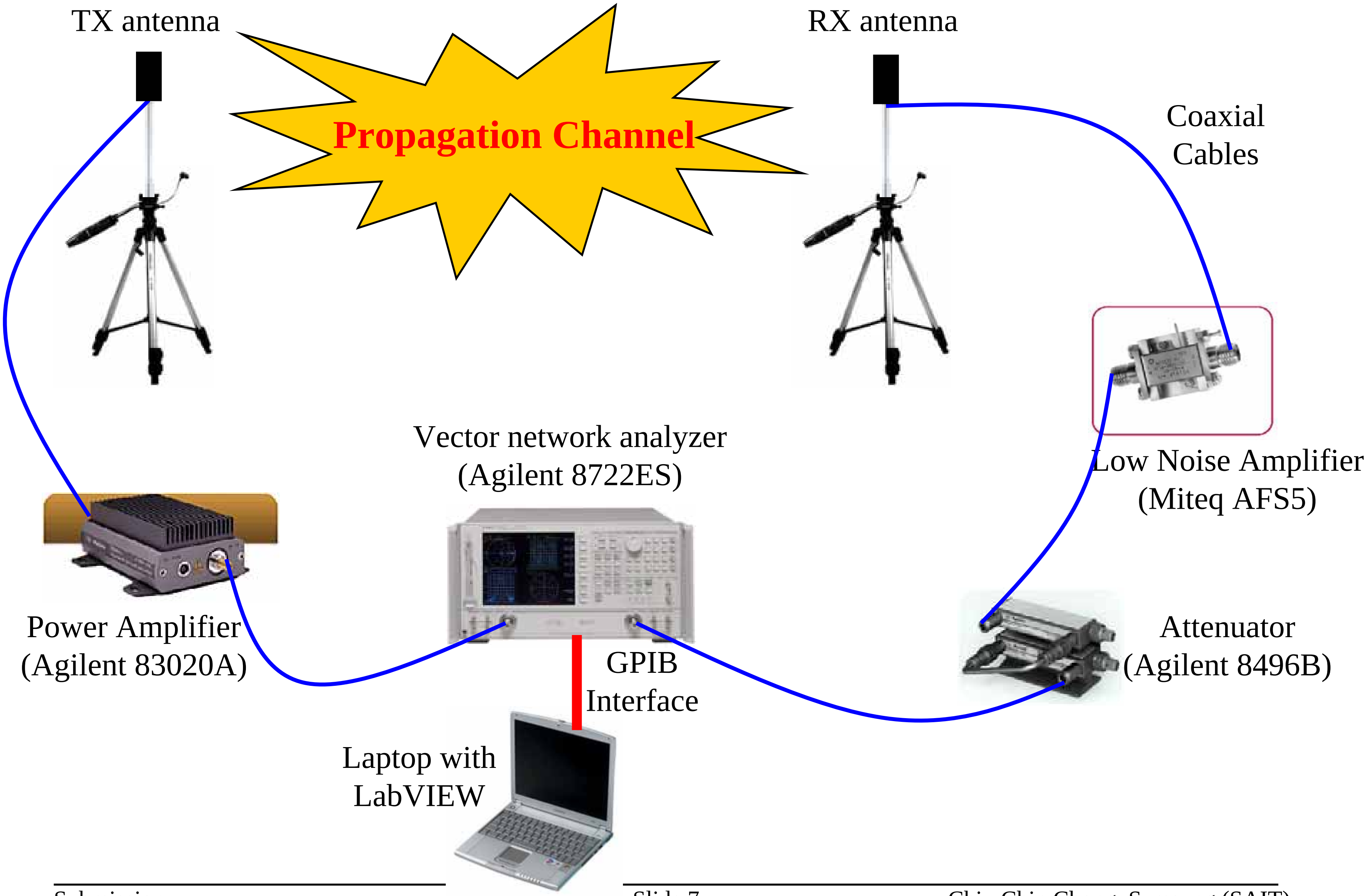
Measurement Setup (1)

- Frequency domain technique using VNA
  - Center frequency, f_c : 6.5GHz
  - Bandwidth, B : 7GHz (i.e. 3-10GHz)
  - Delay resolution, $\Delta\tau$: 142.9ps (i.e. $\Delta\tau$=1/B)
  - No. frequency points, N : 1601
  - Frequency step, Δf : 4.375MHz (i.e. Δf=B/(N-1))
  - Max. excess delay, τ_{max} : 229.6ns (i.e. $\tau_{max}=1/\Delta f$)
  - Sweeping time, t_{sw} : 800ms
  - Max. Doppler shift, $f_{d,max}$: 1.25Hz (i.e. $f_{d,max}=1/t_{sw}$)

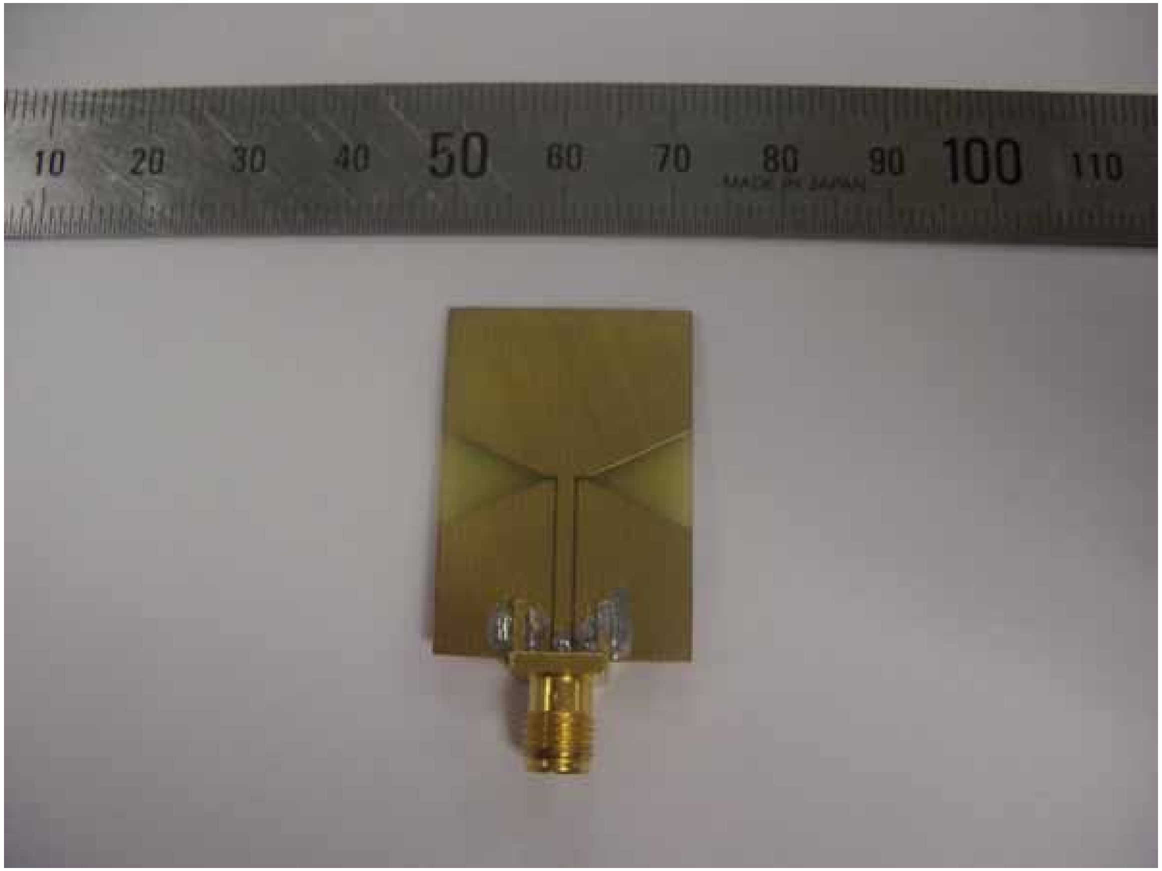
Measurement Setup (2)

- UWB wideband planar dipole antennas
- Measurement controlled by laptop with LabVIEW via GPIB interface
- Calibration performed in an anechoic chamber with 1m reference separation
- Static environment during recording
- Both large-scale & small-scale measurements
  - Large-scale: different RX positions → “local point”
  - Small-scale: 25 (5x5) grid-measurements around each local point → “spatial point”
  - At each spatial point, 30 time-snapshots of the channel complex frequency responses are recorded

Measurement Setup (3)



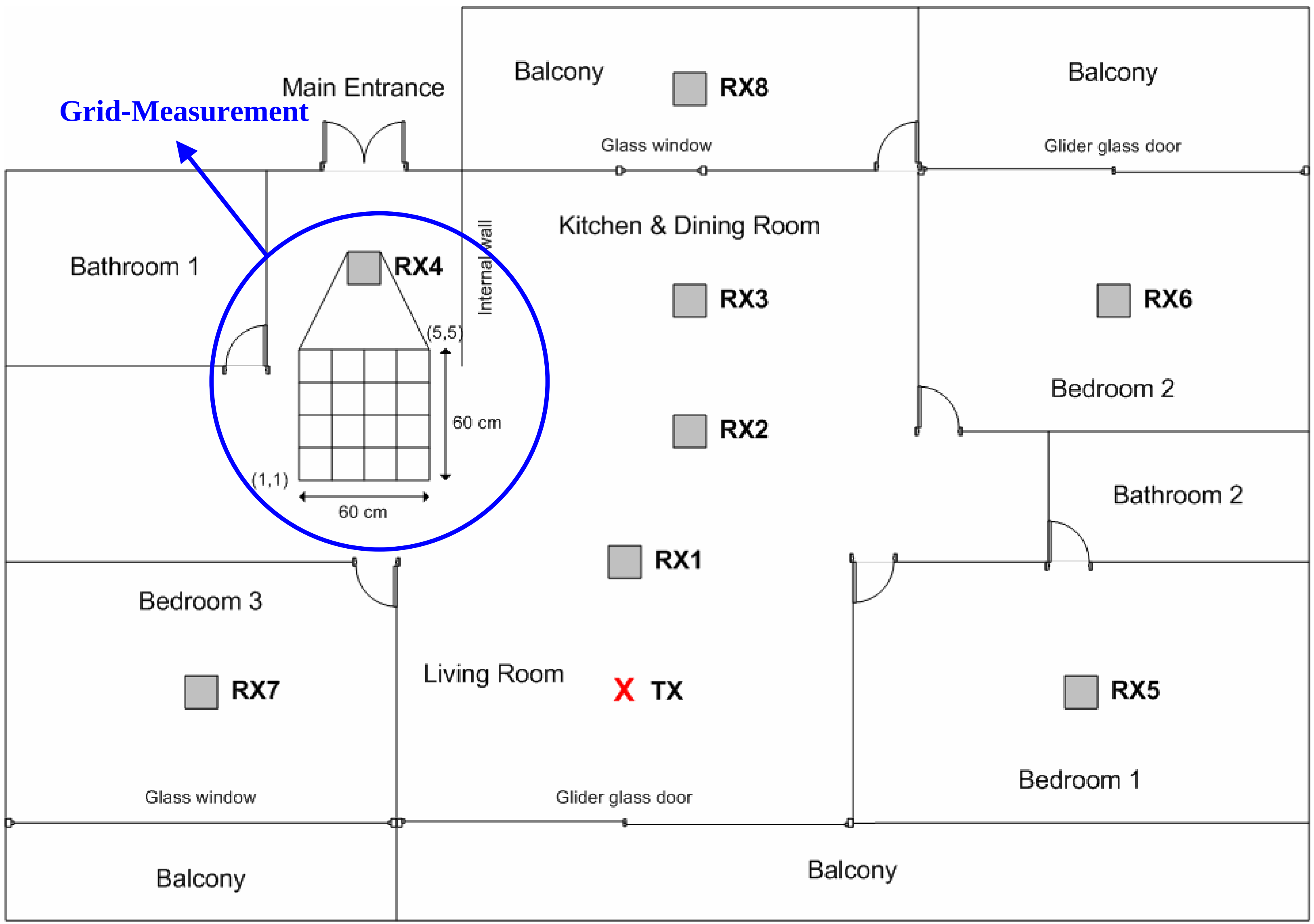
UWB Planar Dipole Antenna



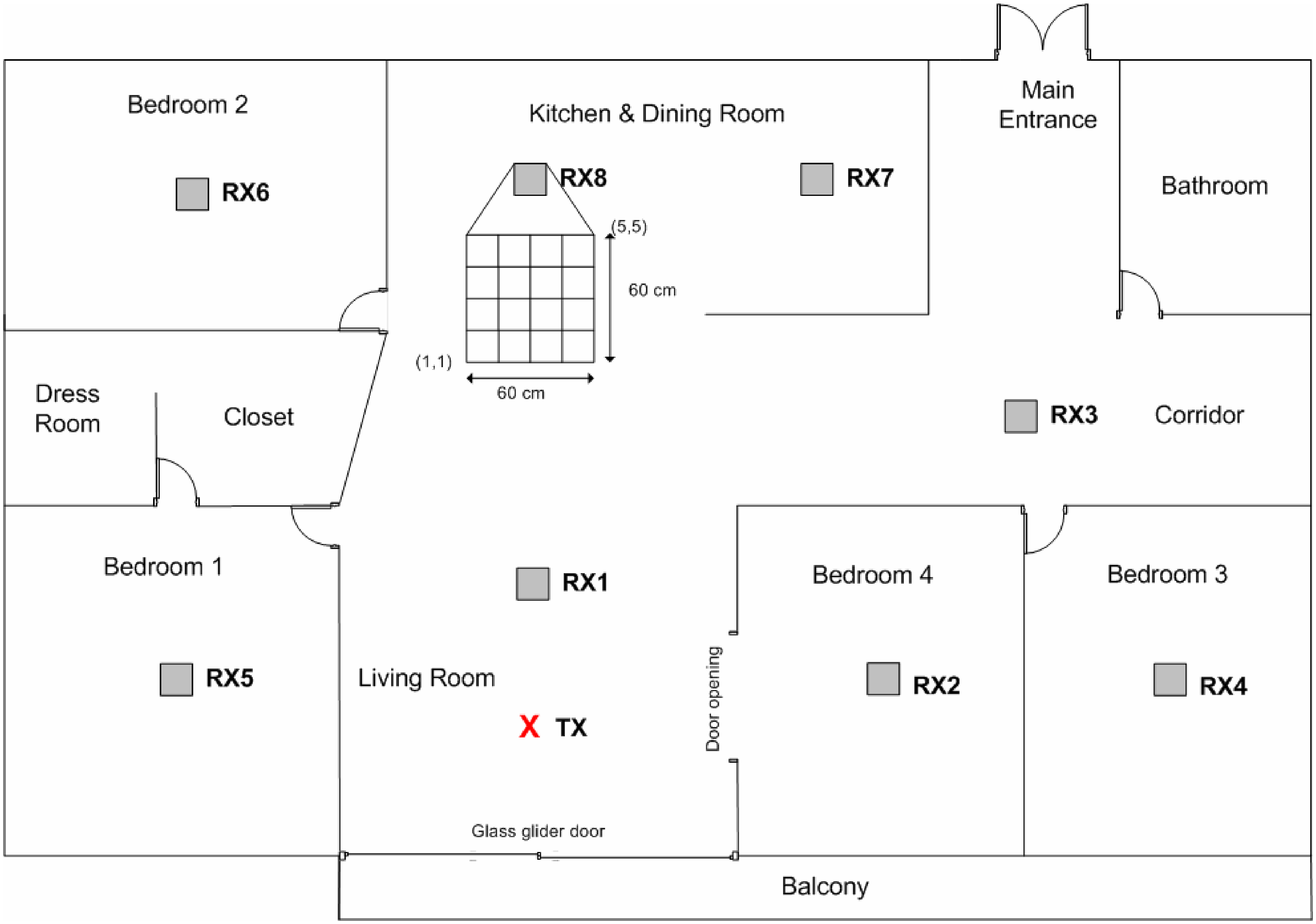
Measurement Environment

- Measurements in various types of high-rise apartments based on several cities in Korea → typical types in Asia countries like Korea, Japan, Singapore, Hong Kong, etc.
  - 3-bedrooms
  - 4-bedrooms
  - 5-bedrooms (to be done!)
- Both **LOS** and **NLOS** configurations
- TX-RX antennas:
  - Separations: up to 20m
  - Height: 1.25m (with ceiling height of 2.5m)
  - TX antenna: always fixed in the center of the living room
  - RX antenna: moved around the apartment (i.e. 8-10 locations)
- To date, in total of **12,000 channel complex frequency responses** are collected (i.e. 2 apartments x 8 RX local points x 25 spatial points x 30 time snapshots → 2x8x25x30=12,000)

3-Bedroom Apartment

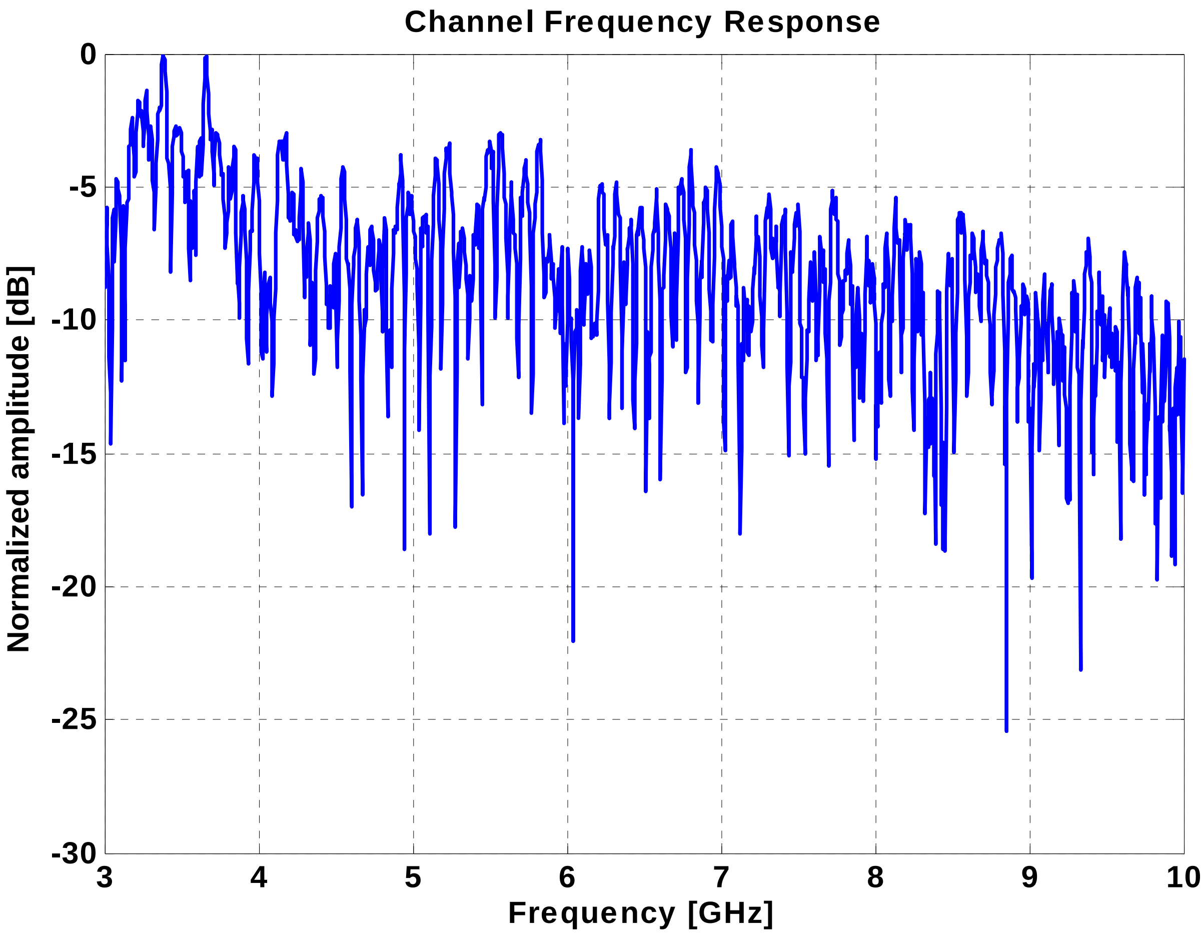


4-Bedroom Apartment (1)

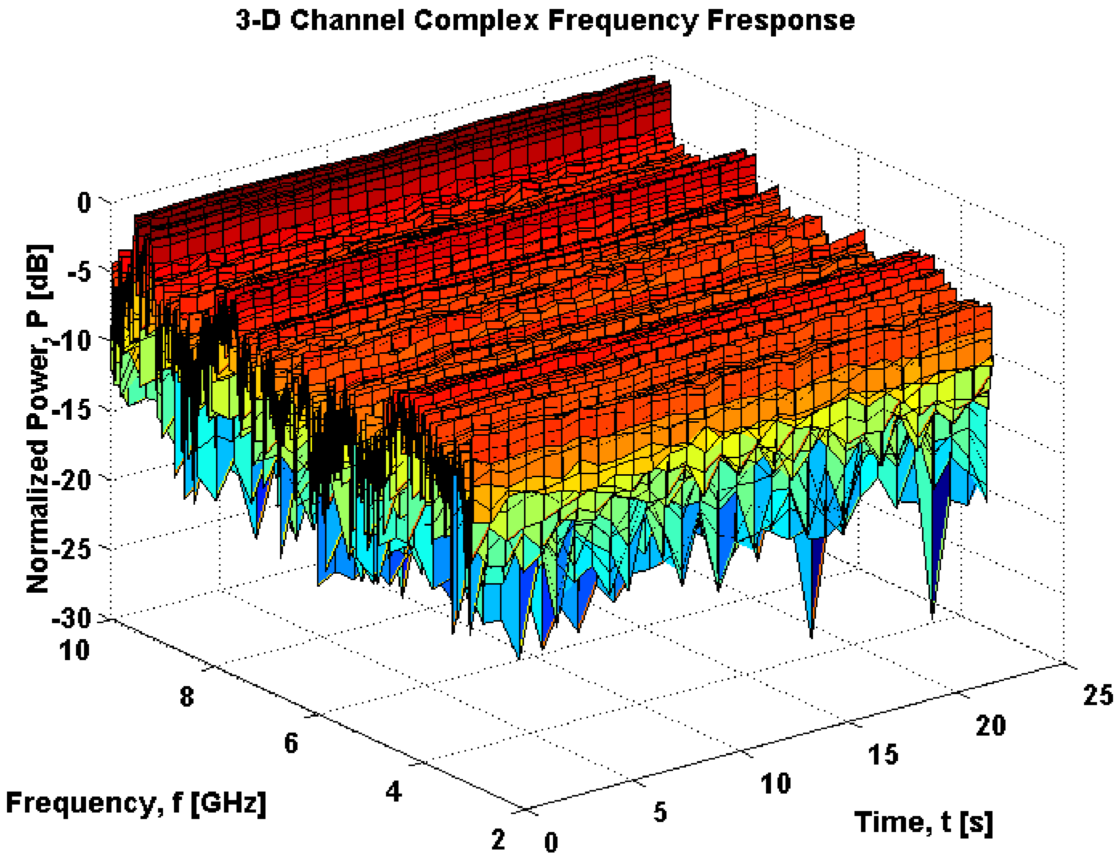


4-Bedroom Apartment (2)

Measurement Results (1)



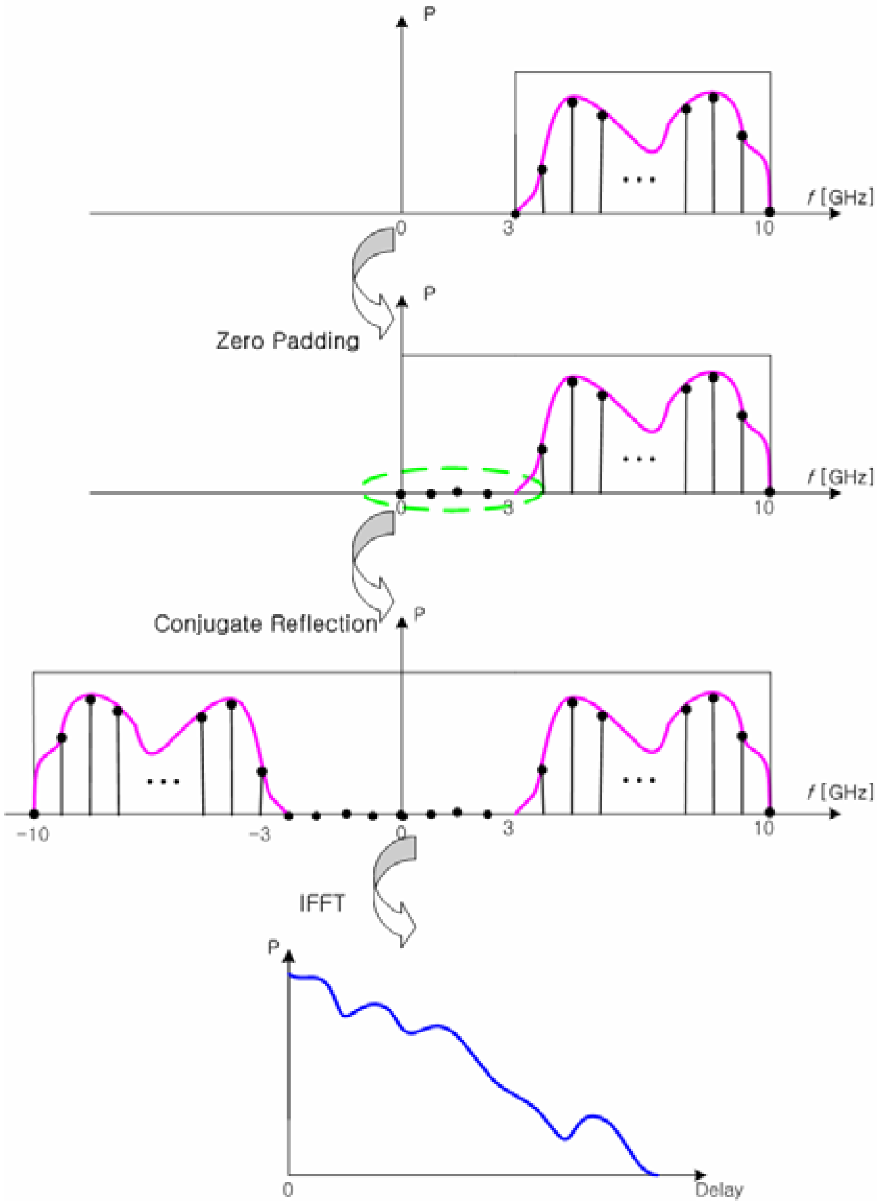
Measurement Results (2)



Data Analysis & Post-Processing

- All measurement data are calibrated with the calibration data measured in anechoic chamber to remove effect of measurement system
- Perform frequency domain windowing to reduce the leakage problem
- Complex passband IFFT is deployed to transform the complex frequency response to complex impulse response
- Perform temporal domain binning before extract channel parameters

Complex Passband IFFT



Channel Model Description

- Path loss
- Temporal-domain parameters:
  - RMS delay spread, τ_{rms}
  - Mean excess delay, τ_m
  - No. of paths within 10dB of peak, NP10dB
  - No. of paths within 20dB of peak, NP20dB
  - No. of paths within 30dB of peak, NP30dB

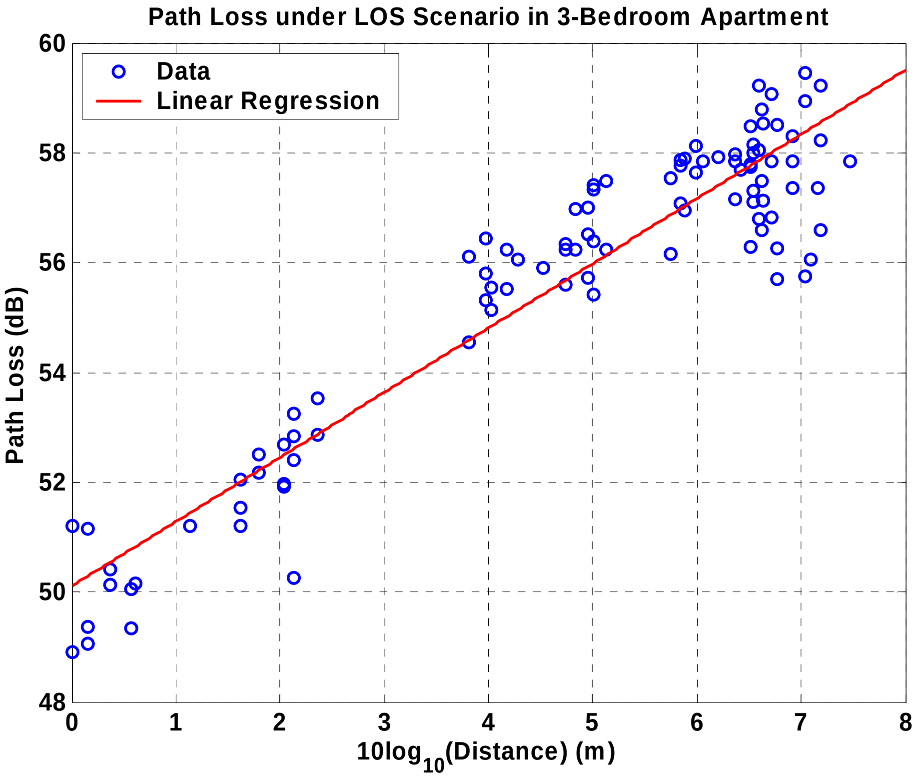
Path Loss

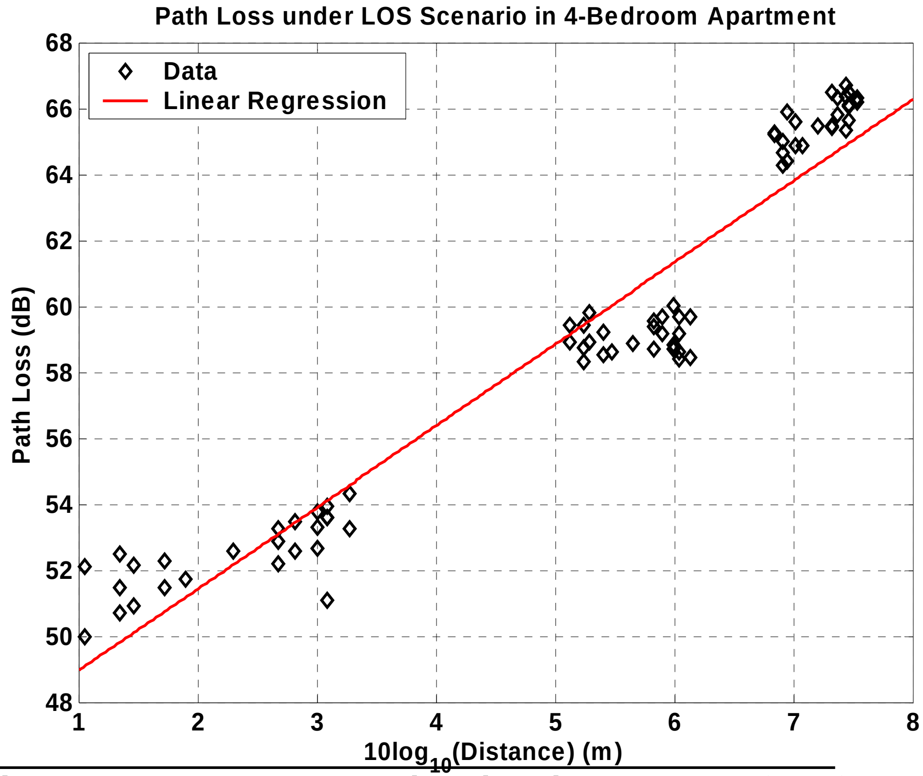
- Path loss (PL) vs. Distance (d):

$$PL_{dB}(d) = PL_0 + 10n\log_{10}\left(\frac{d}{d_0}\right)$$

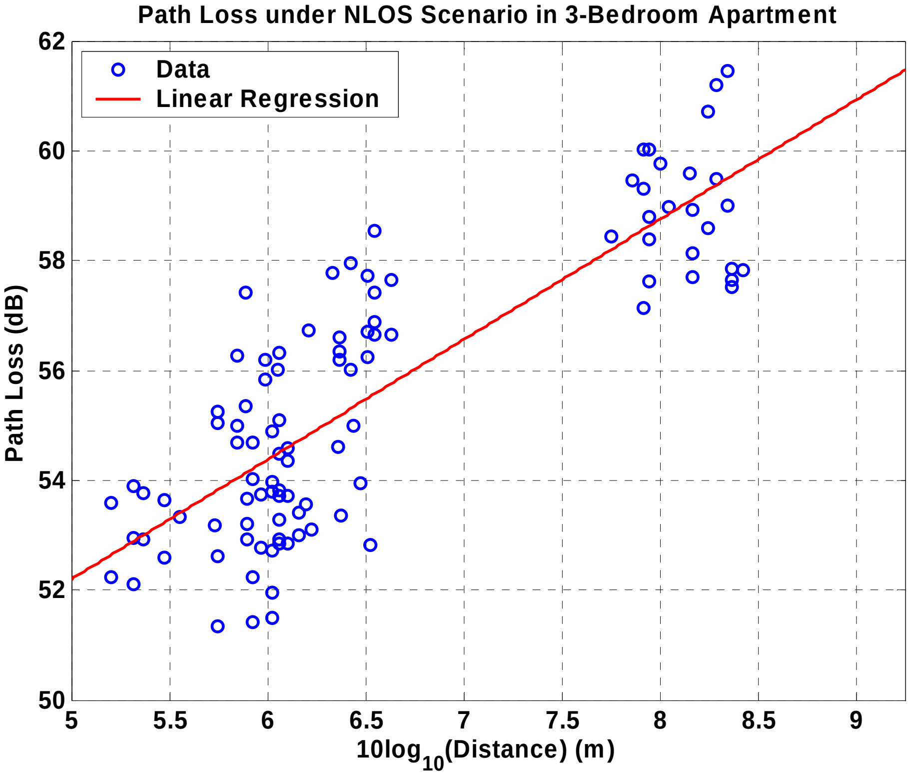
  - d_0 = 1m
  - PL_0 : intercept
  - n : path loss exponent
- Perform linear regression to the above equation with measured data to extract the required parameters

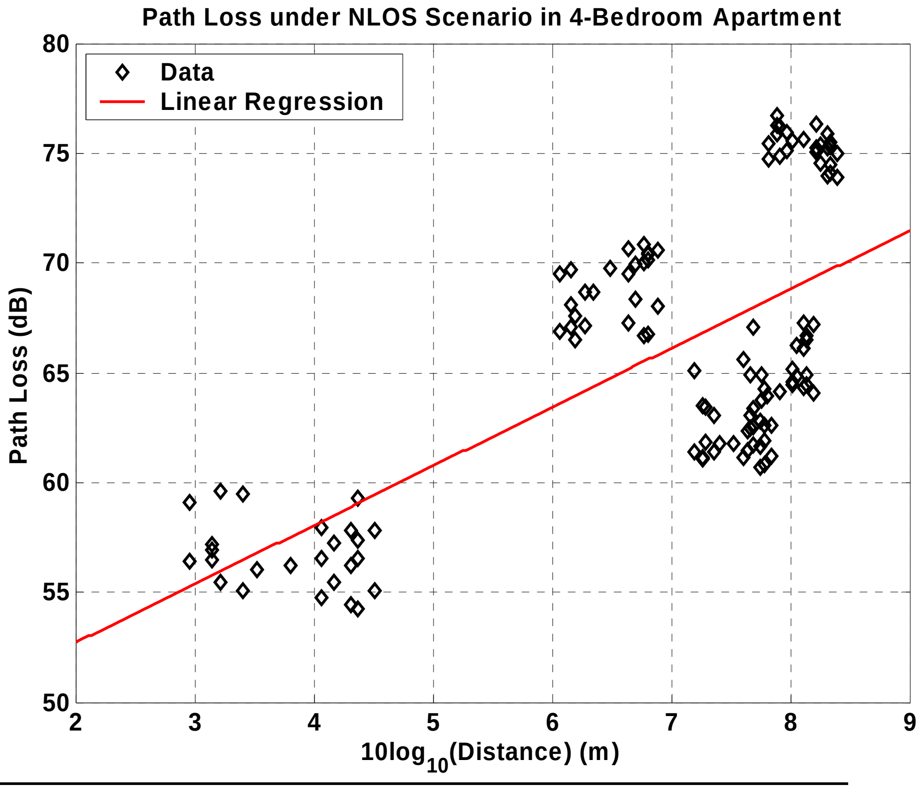
Path Loss vs. Distance – LOS





Path Loss vs. Distance – NLOS





Path Loss Results

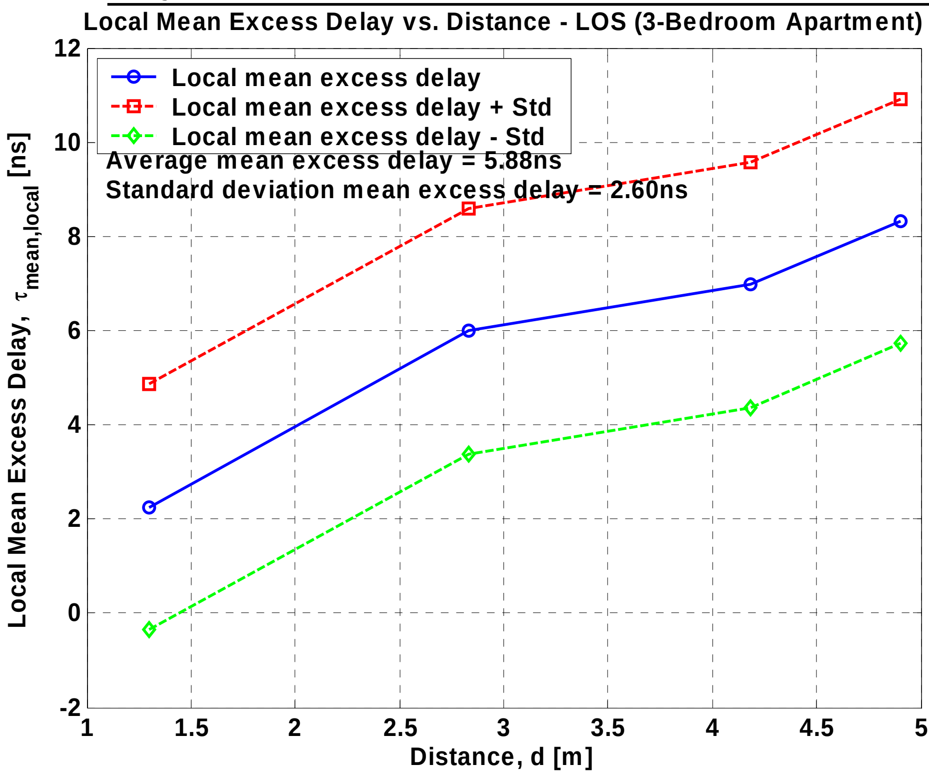
Scenario	3-Bedroom Apartment		4-Bedroom Apartment	
	n	PL_0	n	PL_0
LOS	1.18	50.1	2.48	49.7
NLOS	2.18	52.2	2.69	52.7

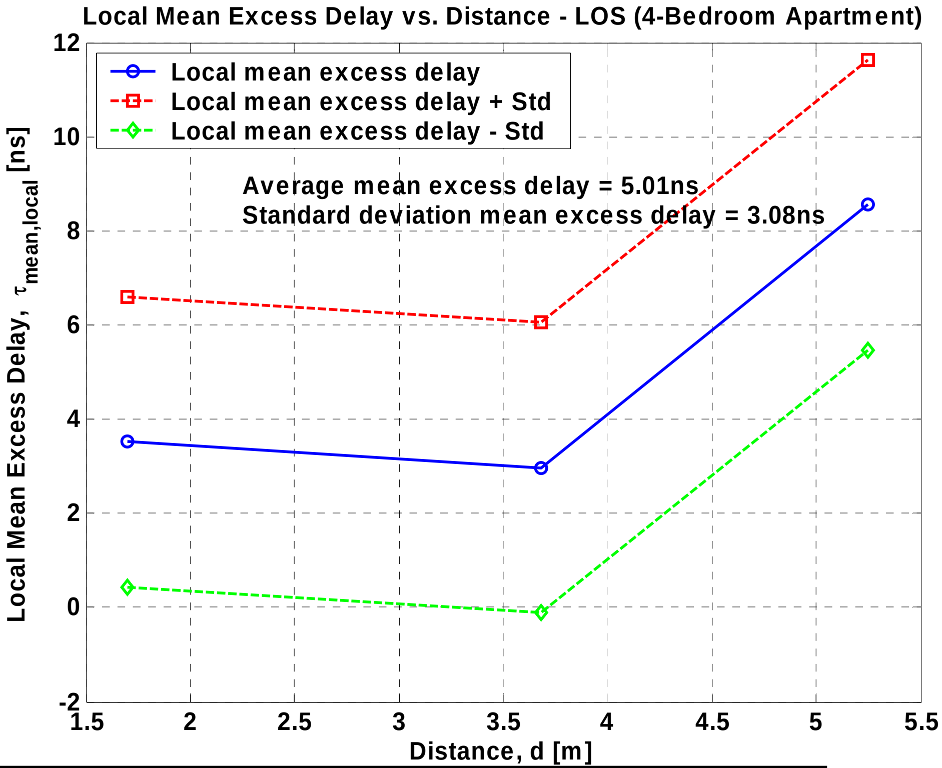
Temporal-domain Parameters

- These parameters were obtained after taking frequency domain Hamming windowing, passband IFFT & temporal domain binning with bin size 100ps

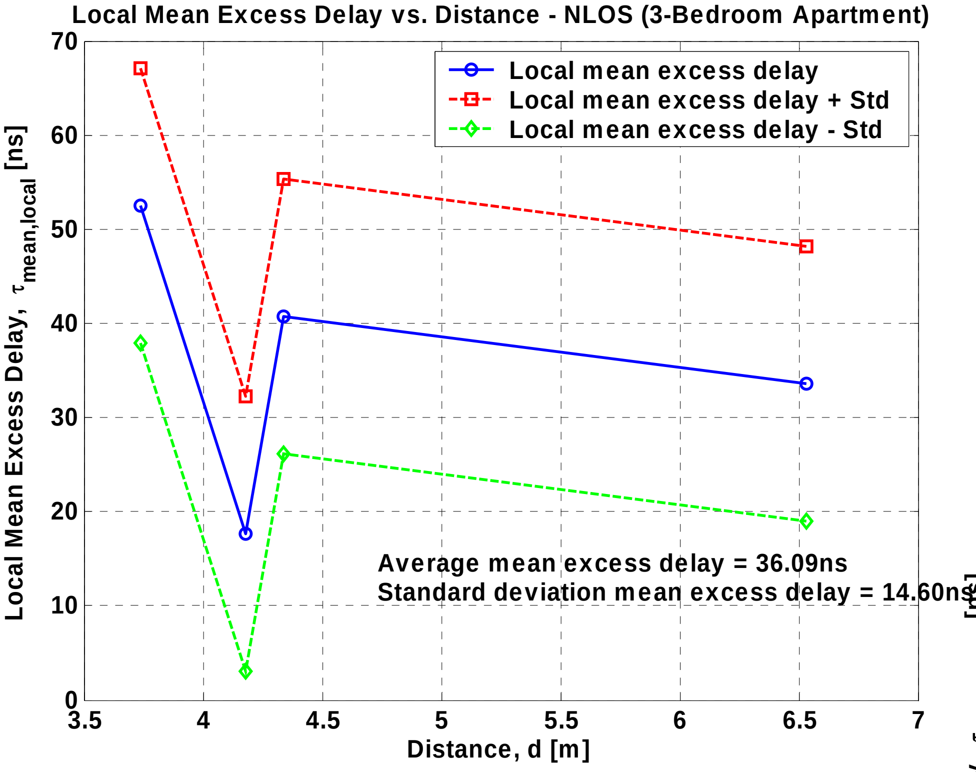
	3-Bedroom Apartment										4-Bedroom Apartment									
Location	τ_{rms} [ns]		τ_m [ns]		NP10dB		NP20dB		NP30dB		τ_{rms} [ns]		τ_m [ns]		NP10dB		NP20dB		NP30dB	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
LOS	14.00	1.53	5.88	1.25	4.04	1.53	29.91	11.15	145.38	38.89	12.48	1.87	5.01	0.64	5.97	1.96	37.21	9.20	161.02	31.59
NLOS	38.61	8.03	36.09	15.48	19.58	7.64	141.63	42.23	512.57	76.28	26.51	5.22	24.95	8.47	23.51	10.75	139.95	50.14	424.78	93.77

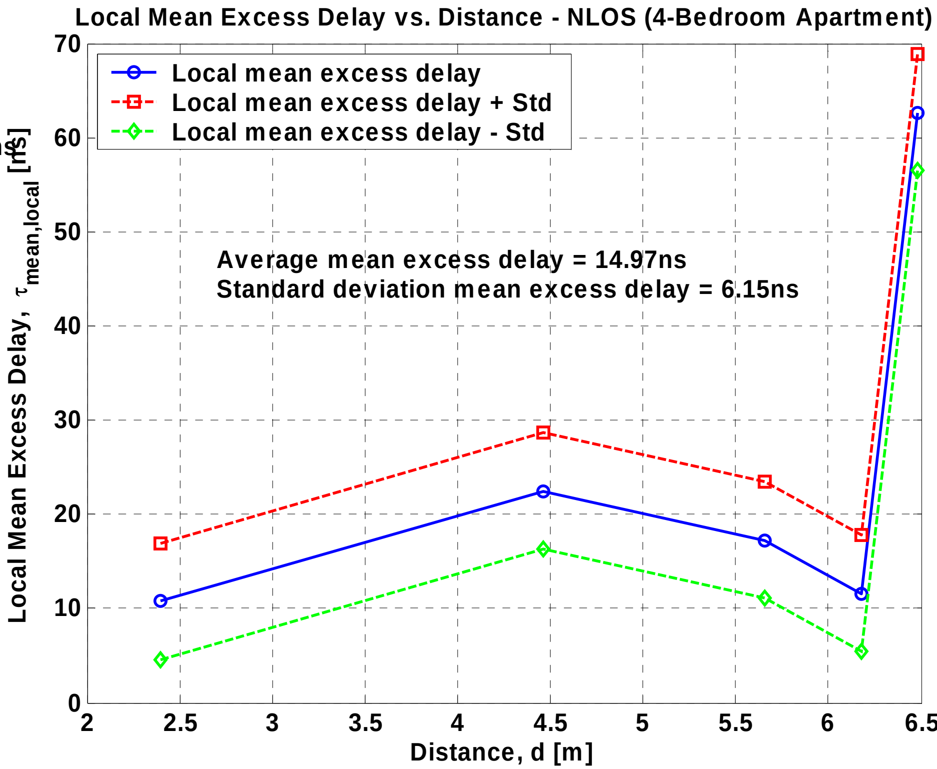
Mean Excess Delay vs. Distance – LOS



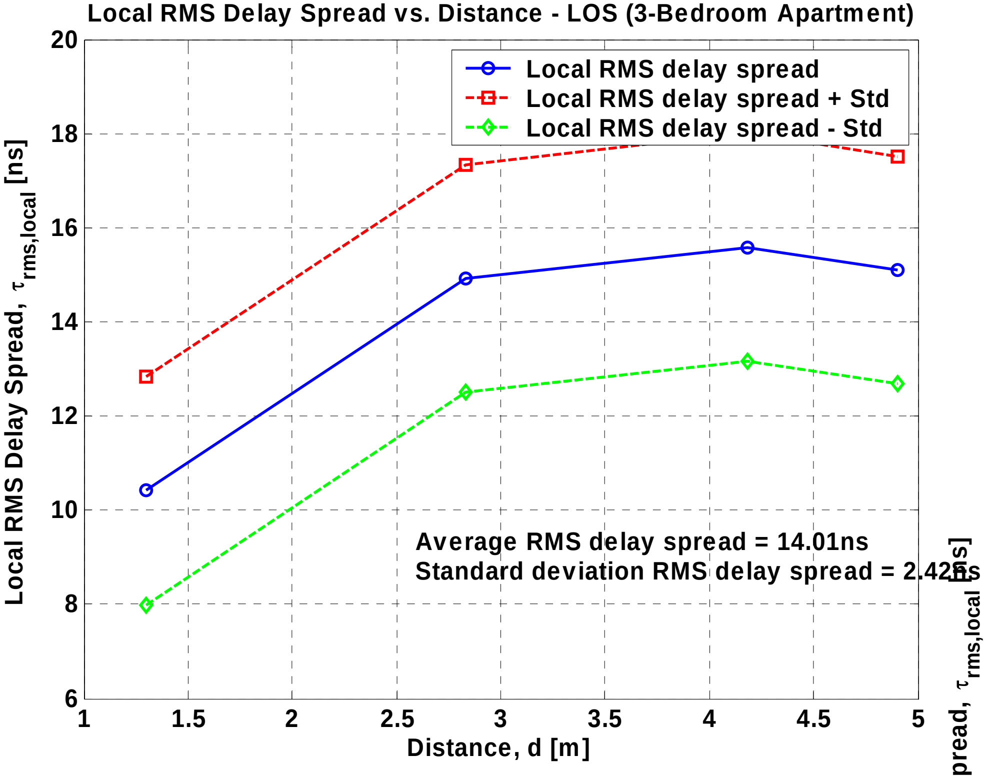


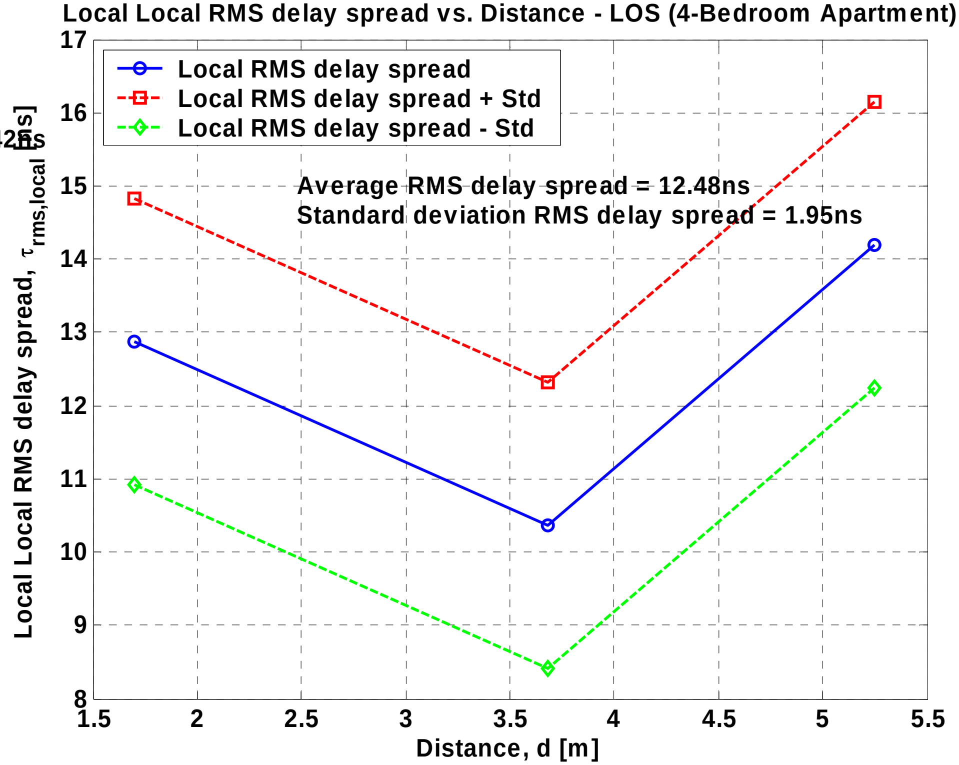
Mean Excess Delay vs. Distance – NLOS



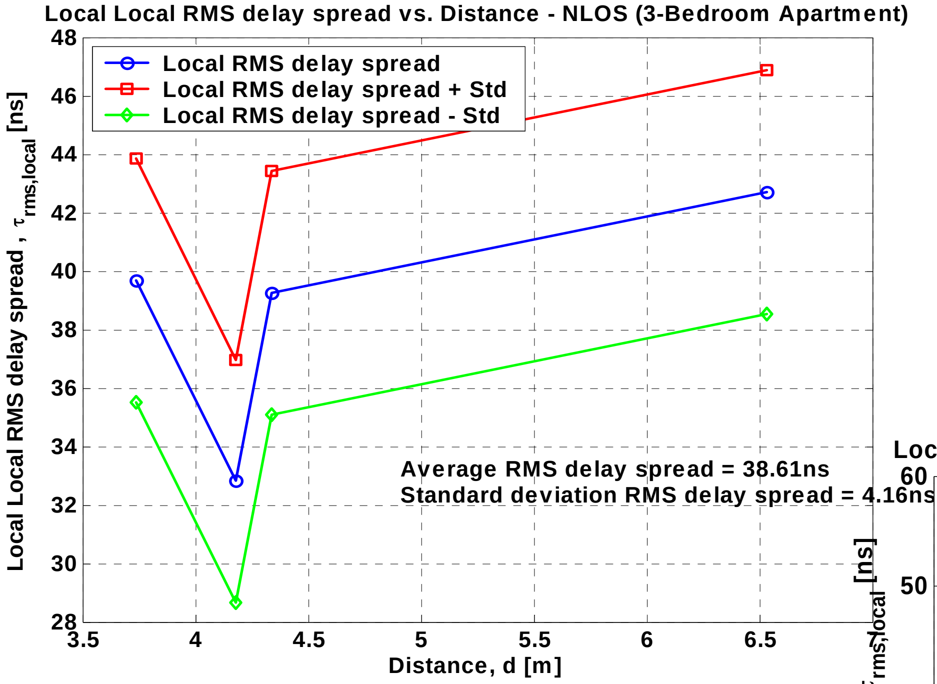


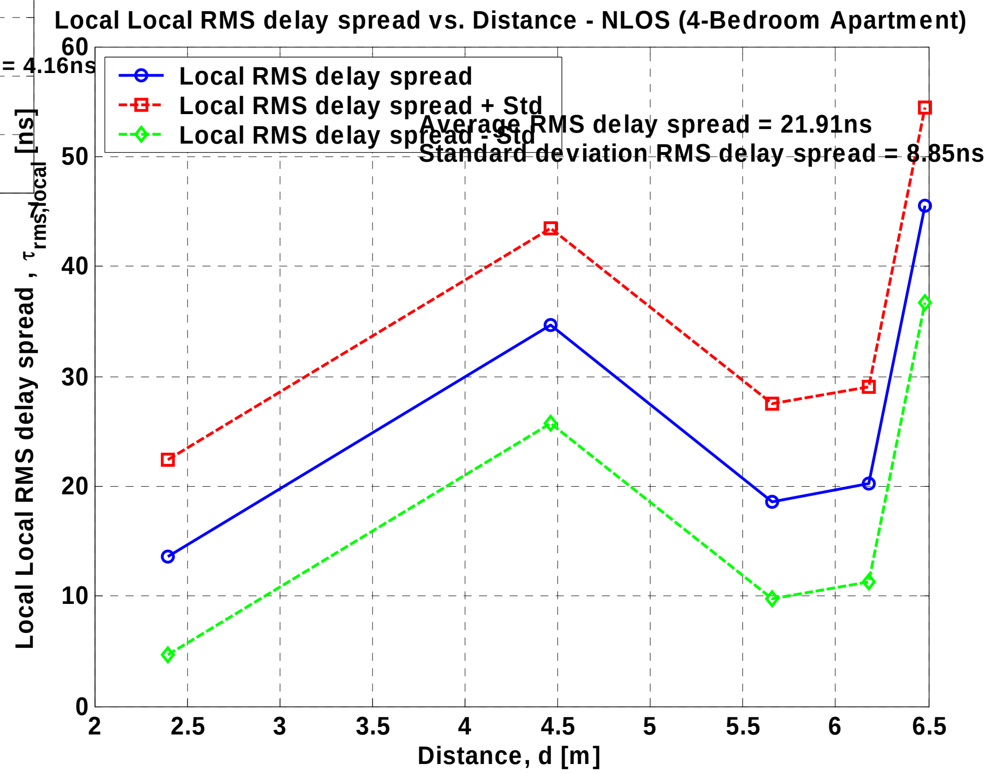
RMS Delay Spread vs. Distance – LOS



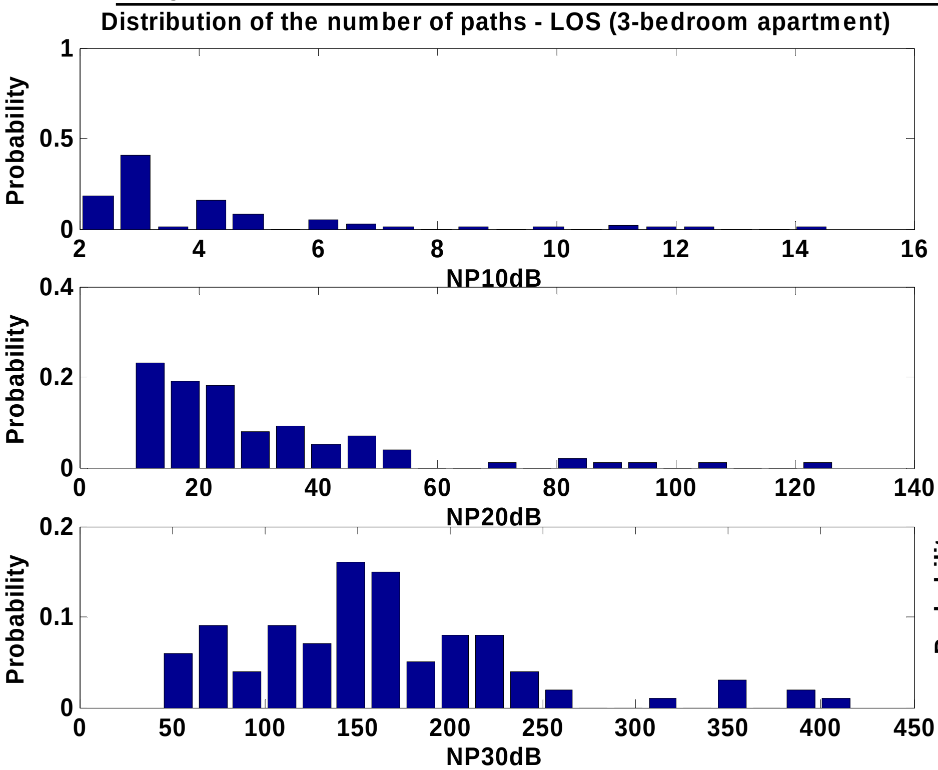


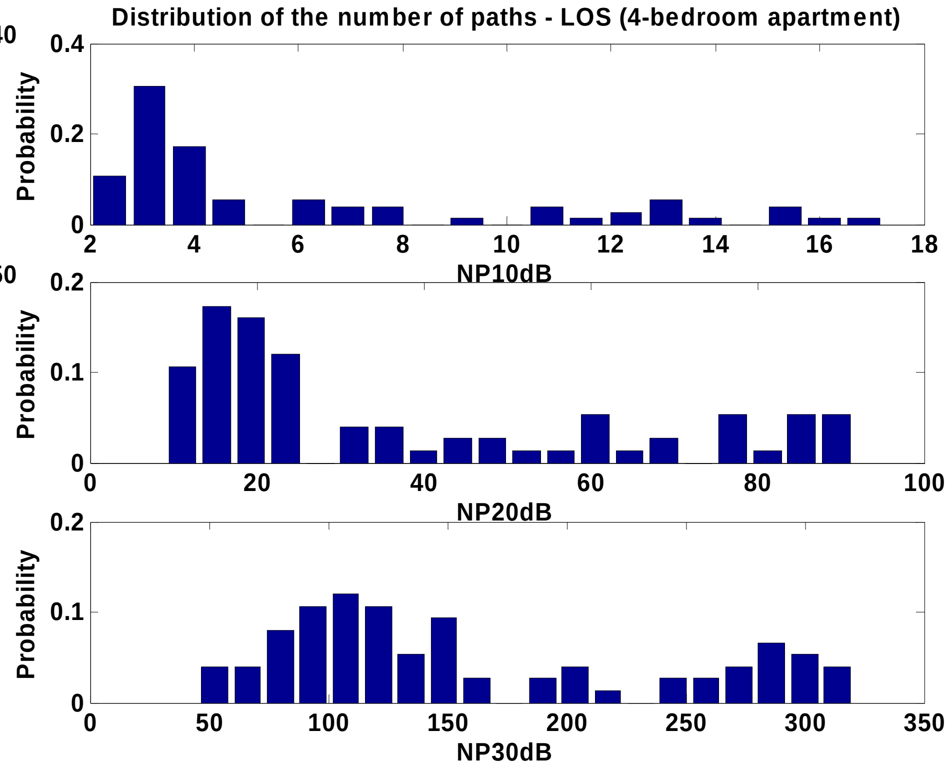
RMS Delay Spread vs. Distance – NLOS



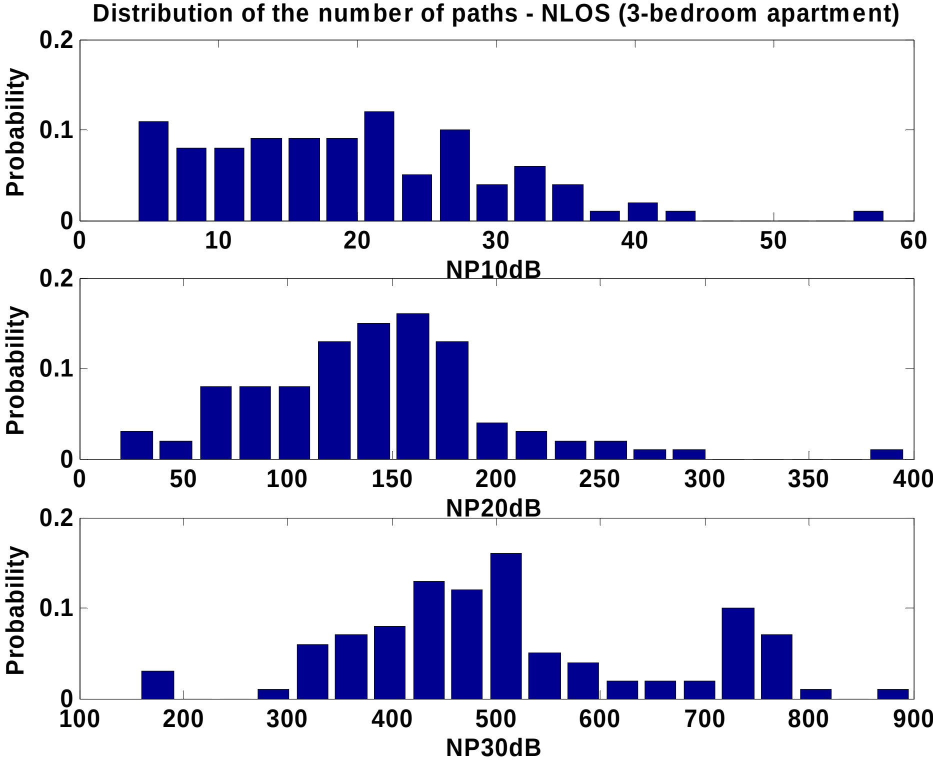


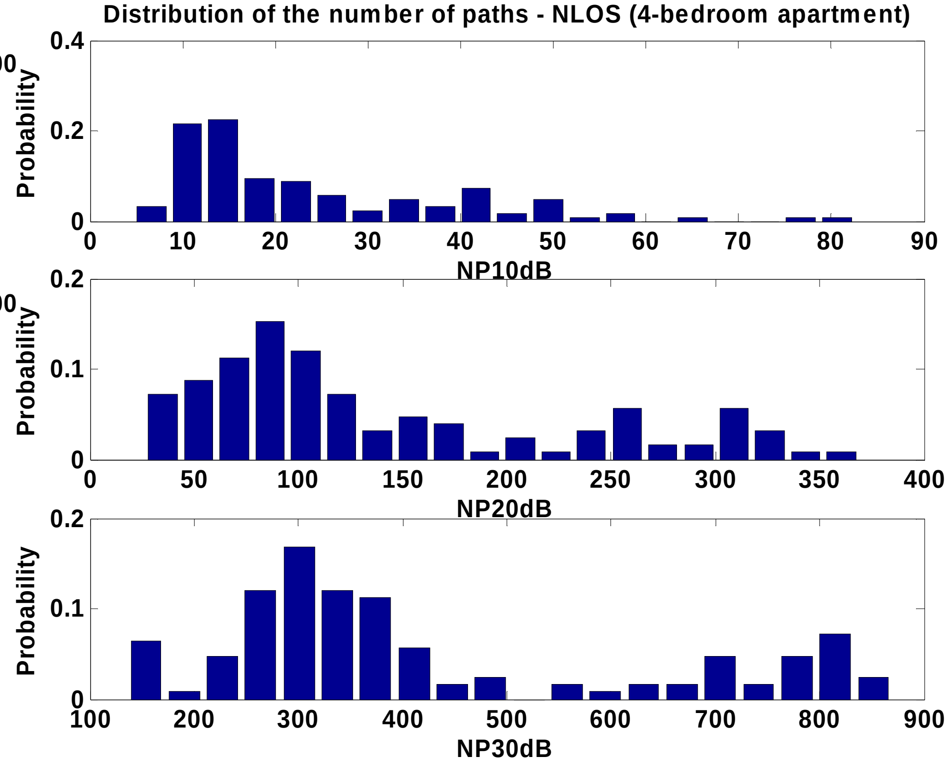
Distribution of No. of Paths – LOS





Distribution of No. of Paths – NLOS





Conclusion

- Frequency domain technique UWB measurement campaign has been carried out in various types of high-rise apartments covering frequencies from 3 to 10 GHz.
- Measurement covered both LOS & NLOS scenarios.
- Channel measurement results for path loss and temporal-domain parameters (e.g. mean excess delay, RMS delay spread, number of paths) are .presented

Future Work

- Extract S-V channel parameters
- Extract small-scale amplitude statistics
- Propose a suitable statistical channel model