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

Submission Title: [UWB Channel Model for Indoor Residential Environment]
Date Submitted: [2 September, 2004]
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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 based in several types of high-rise apartments. It consists of detailed characterization of the frequency-domain parameters, temporal-domain parameters, small-scale amplitude statistics and S-V clustering multipath channel 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 Model for Indoor Residential Environment

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Outline

- Measurement Setup & Environment
- Data Analysis & Post-Processing
- Measurement Results
- Large-Scale Parameters
- Small-Scale Parameters
- Conclusion

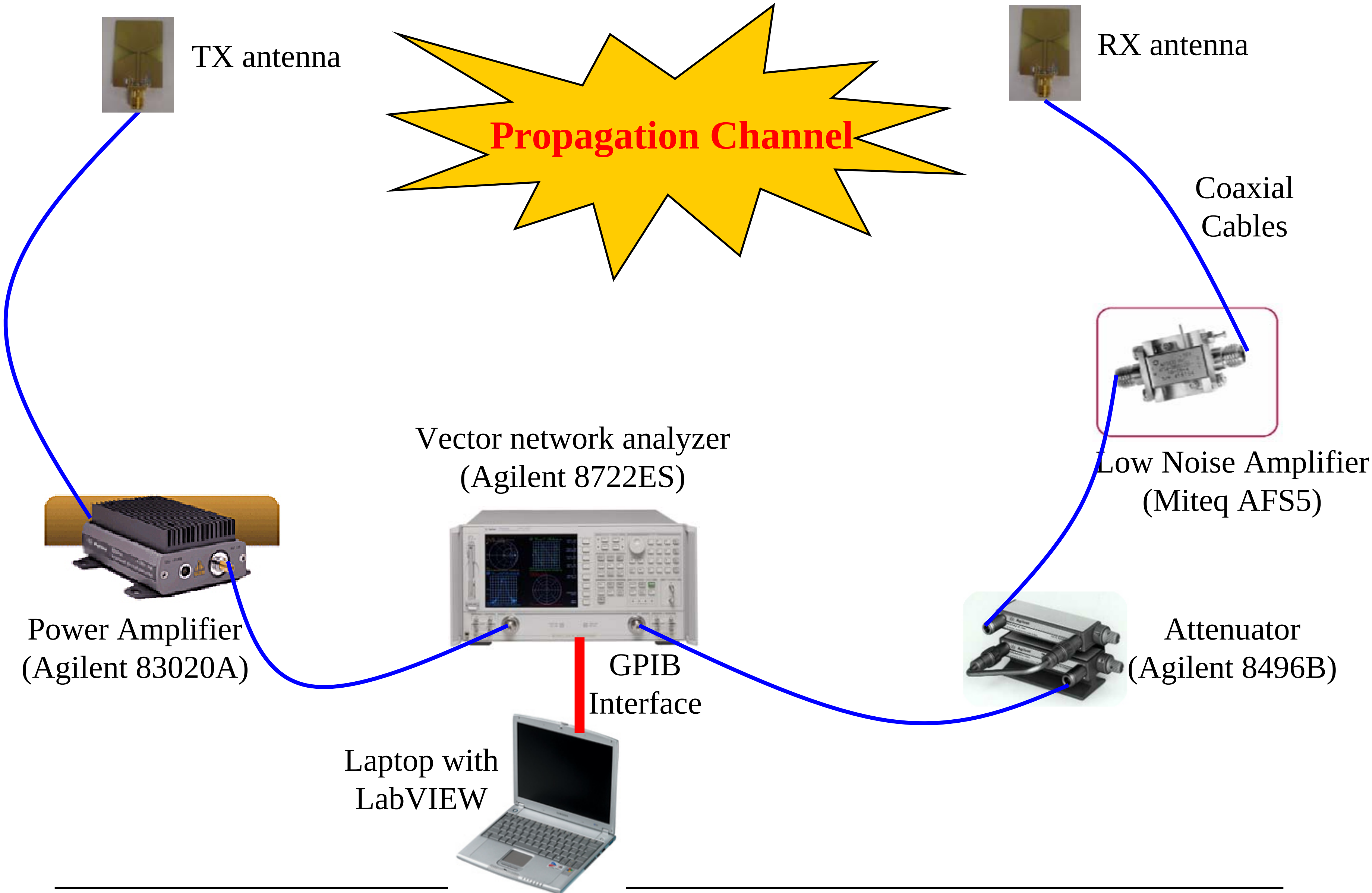
Measurement Setup (1)

- 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. $f_{d,max}=1/t_{sw}$)

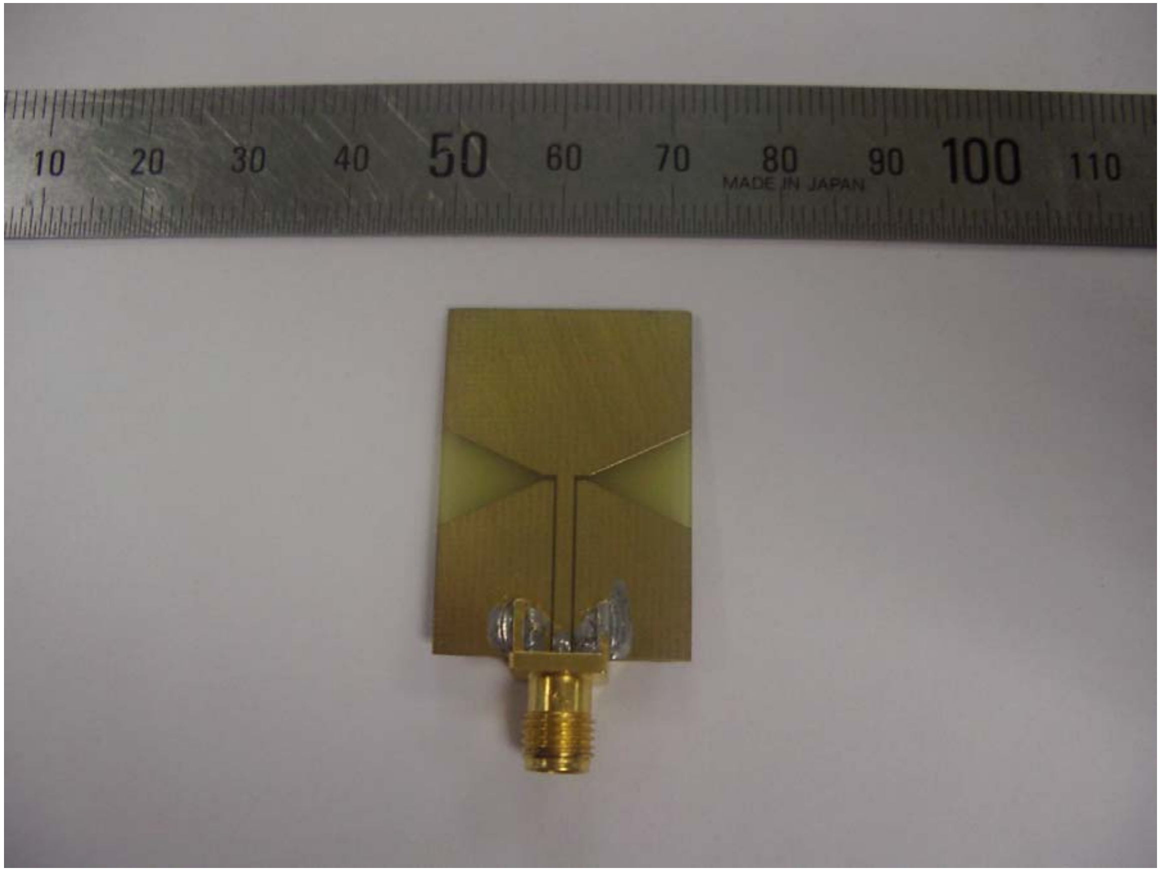
Measurement Setup (2)

- 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)



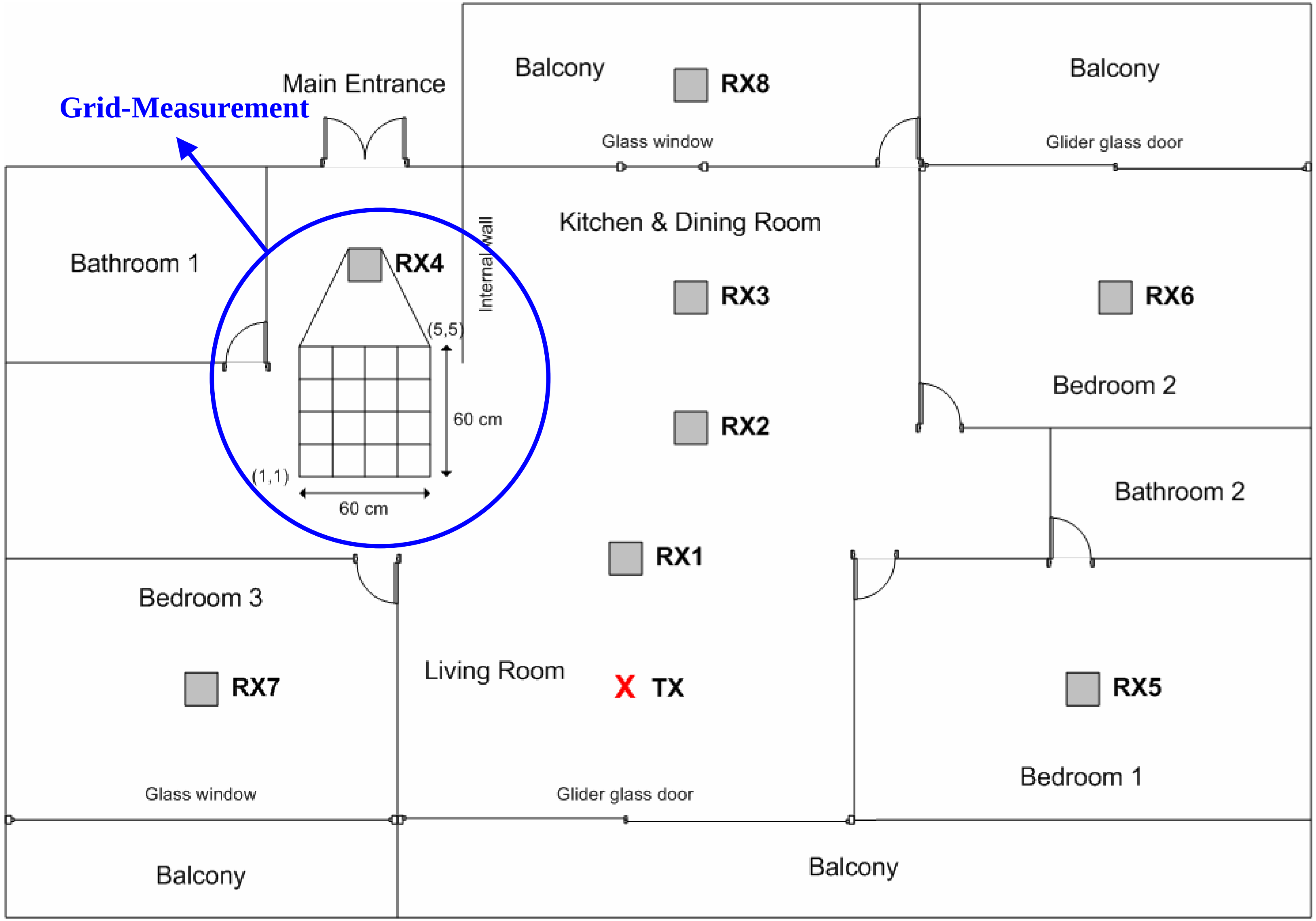
UWB Planar Dipole Antenna



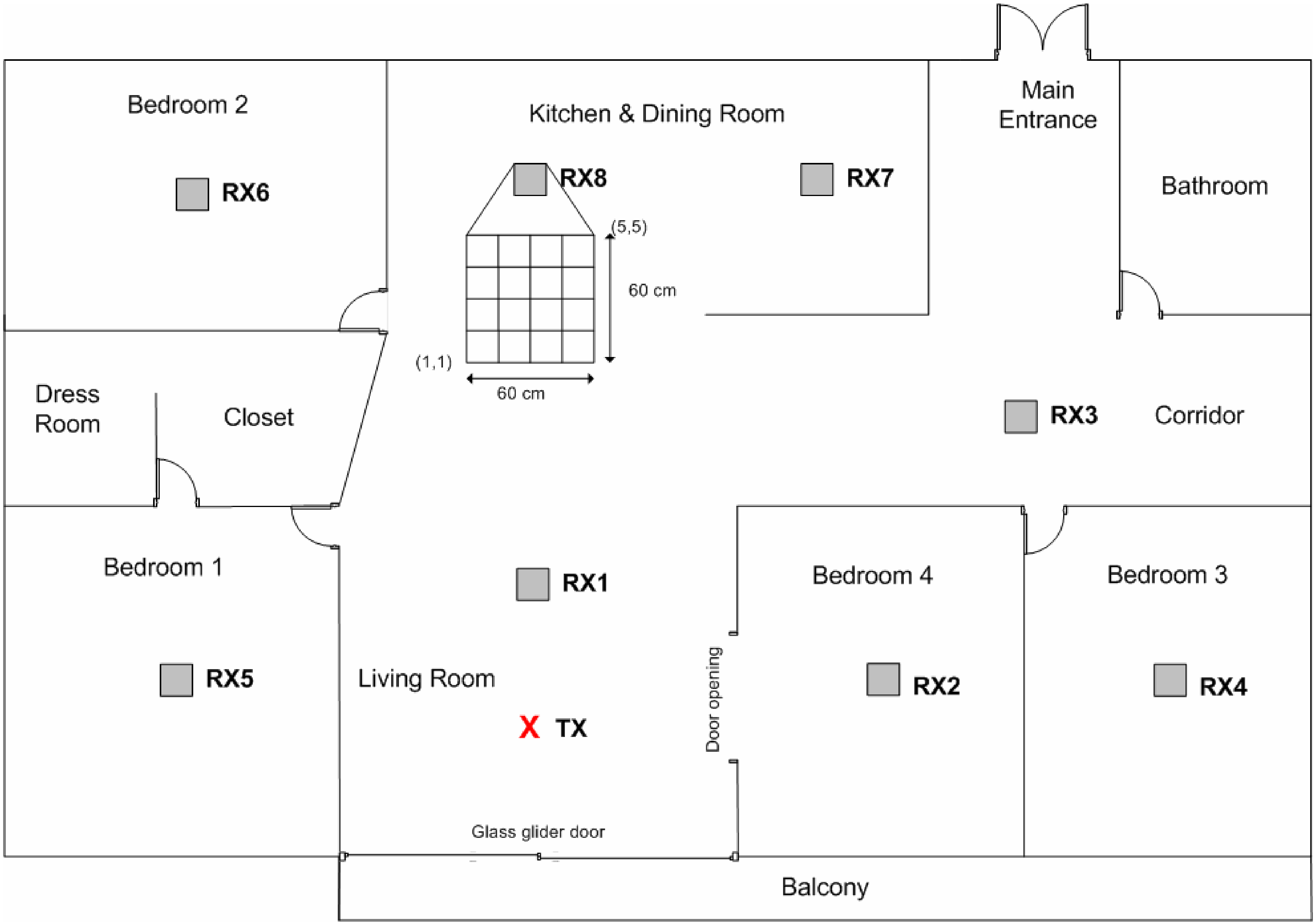
Measurement Environment

- 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 (Apart1)
  - 4-bedrooms (Apart2)
- Both **LOS** and **NLOS** configurations
- TX-RX antennas:
  - Separations: up to 25m
  - 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)
- **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



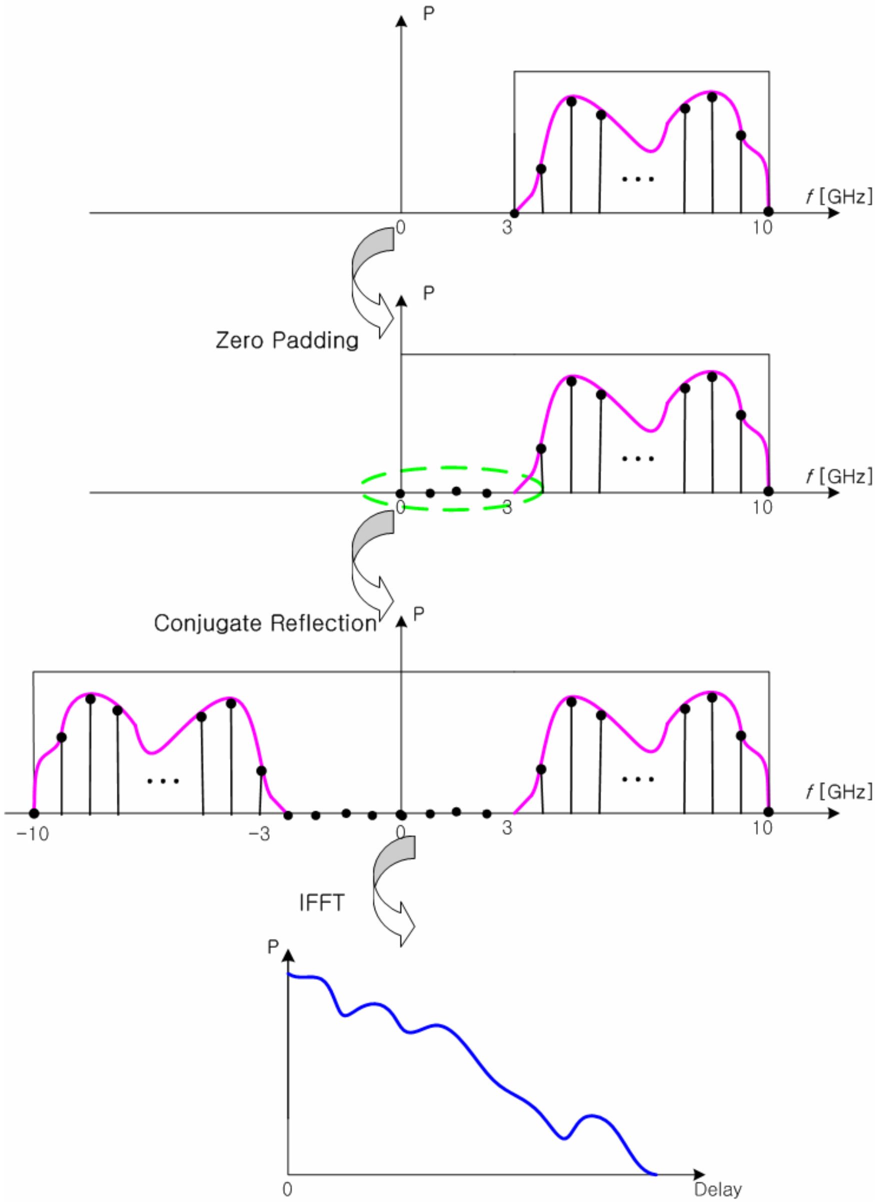
4-Bedroom Apartment



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

- Large-Scale Parameters:
  - Path loss and Shadowing
  - Frequency Decaying Factor
- Small-Scale Parameters:
  - Temporal Domain Parameters
  - S-V Multipath Channel Parameters
  - Small-Scale Amplitude Statistics

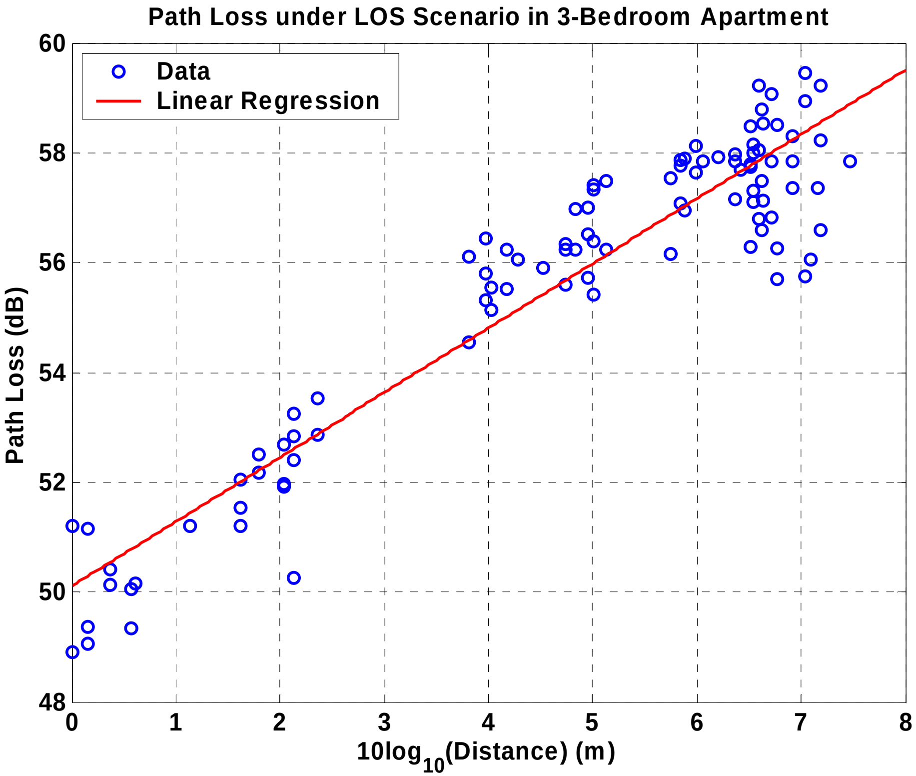
Path Loss and Shadowing

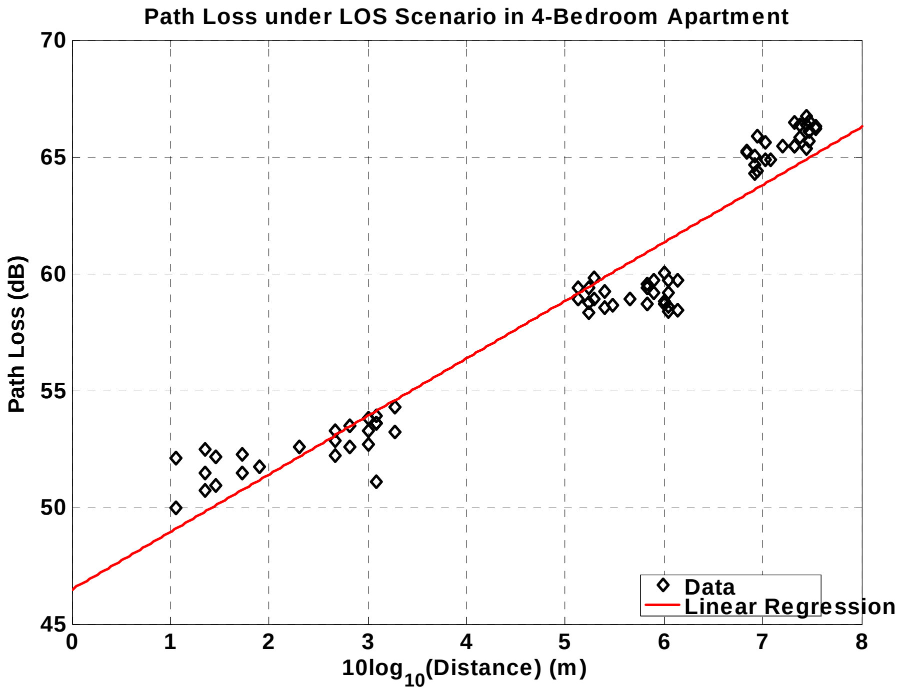
- Path loss (PL) vs. Distance (d):

$$PL(d) = PL_0 + 10 \cdot n \cdot \log_{10}\left(\frac{d}{d_0}\right) + S; \quad d \geq d_0$$

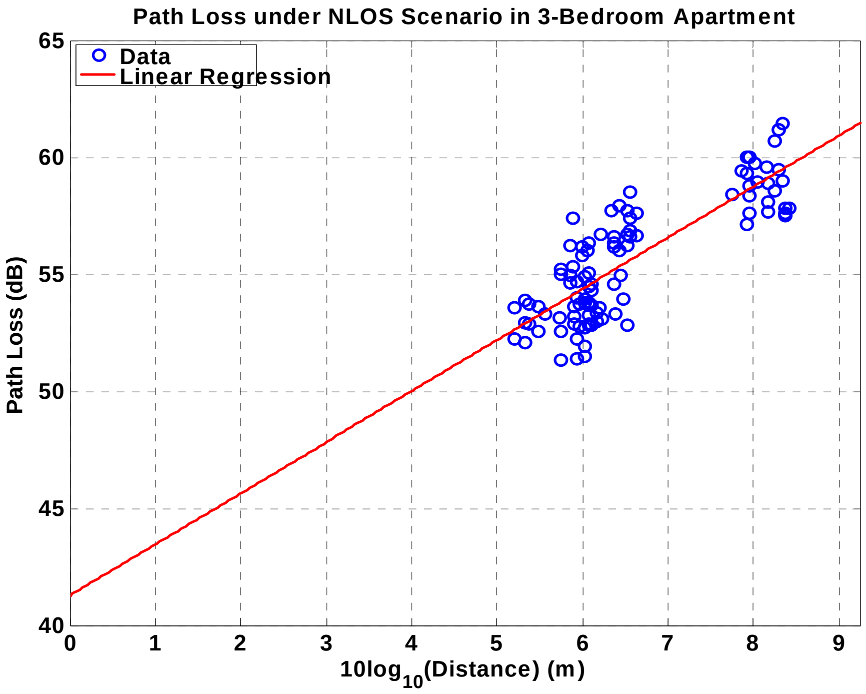
  - d_0 = 1m
  - PL_0 : intercept
  - n : path loss exponent
  - S : Shadowing fading parameter
- Perform linear regression to the above equation with measured data to extract the required parameters

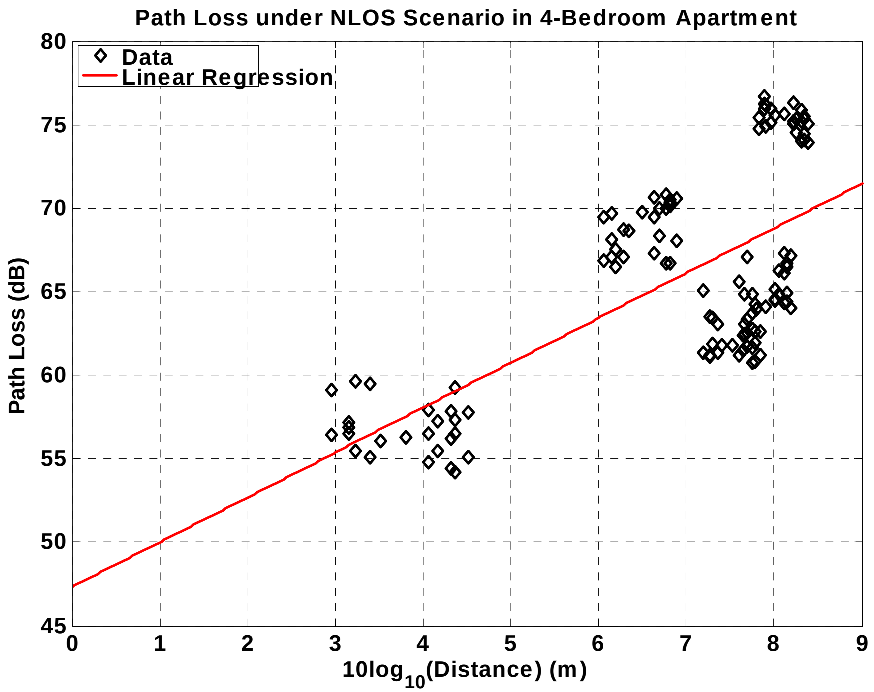
Path Loss vs. Distance – LOS





Path Loss vs. Distance – NLOS





Frequency Decaying Factor

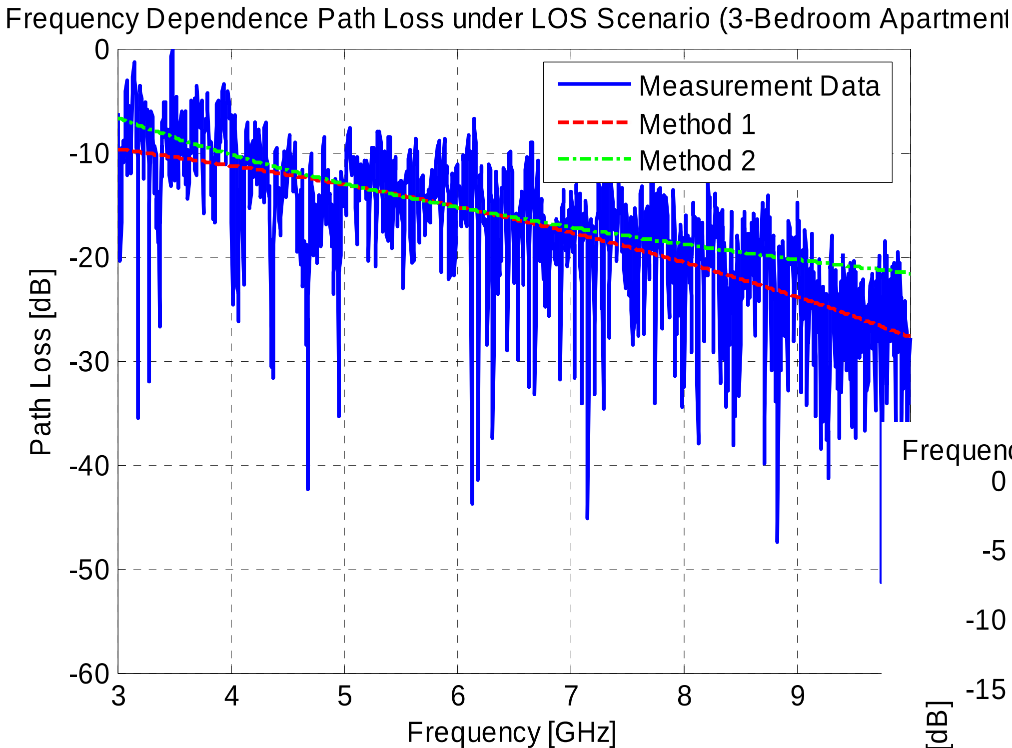
- Path loss (PL) vs. Frequency (f):

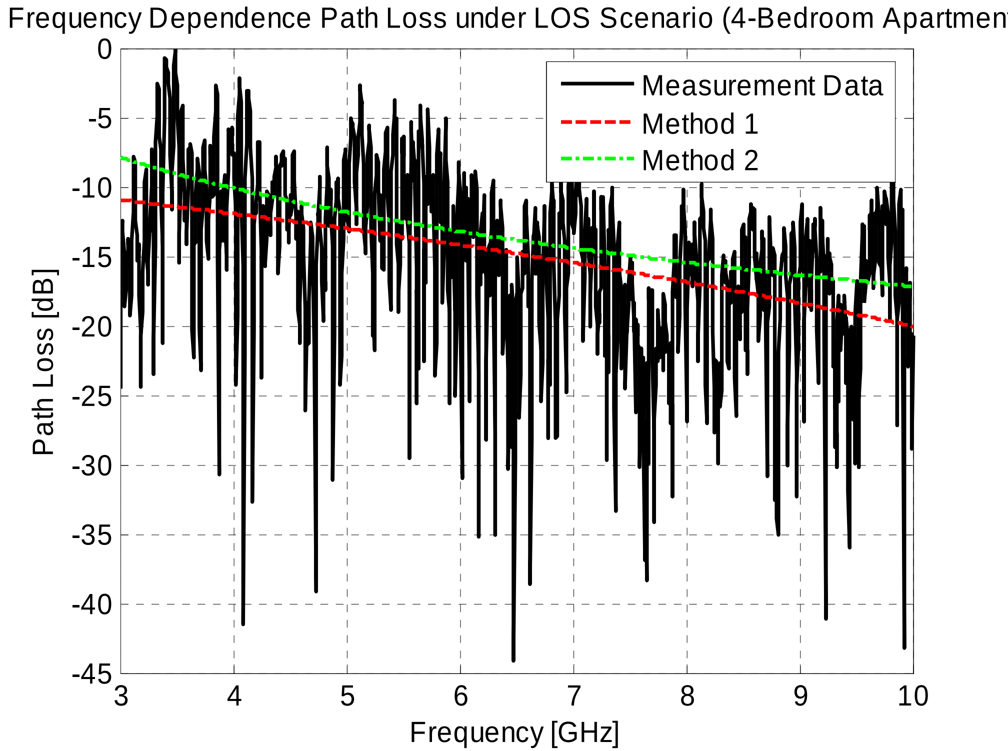
$$PL(f) \propto \exp\left(-\delta_1 \cdot f\right) \qquad \text{(Method 1)}$$

or

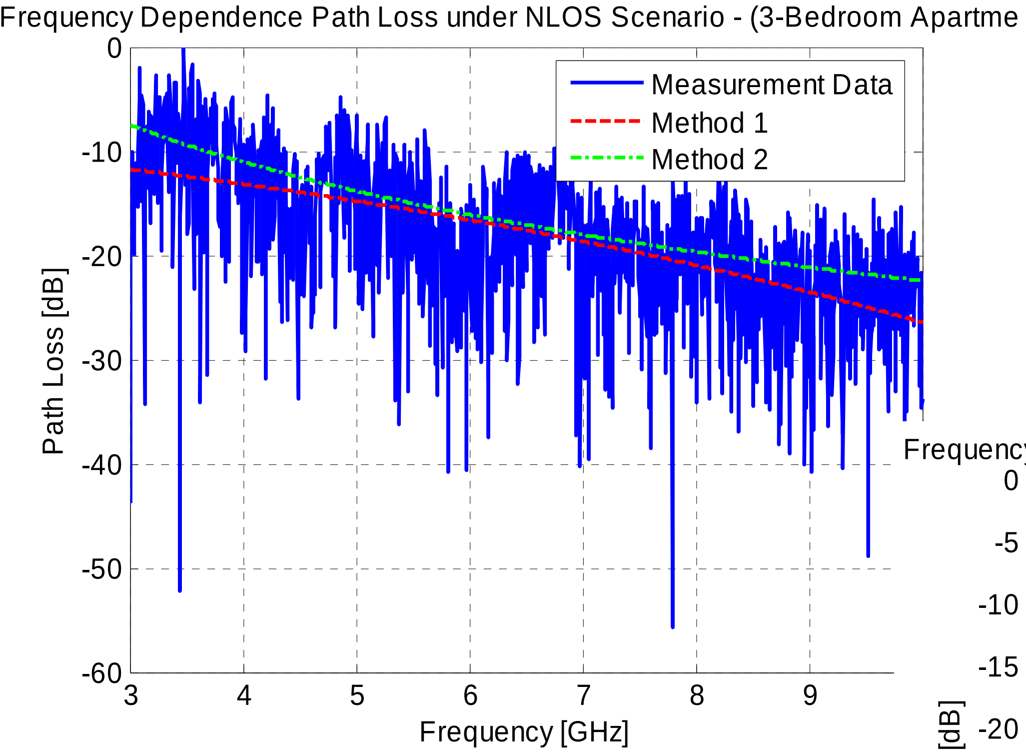
$$\sqrt{PL(f)} \propto f^{-\delta_2} \qquad \text{(Method 2)}$$

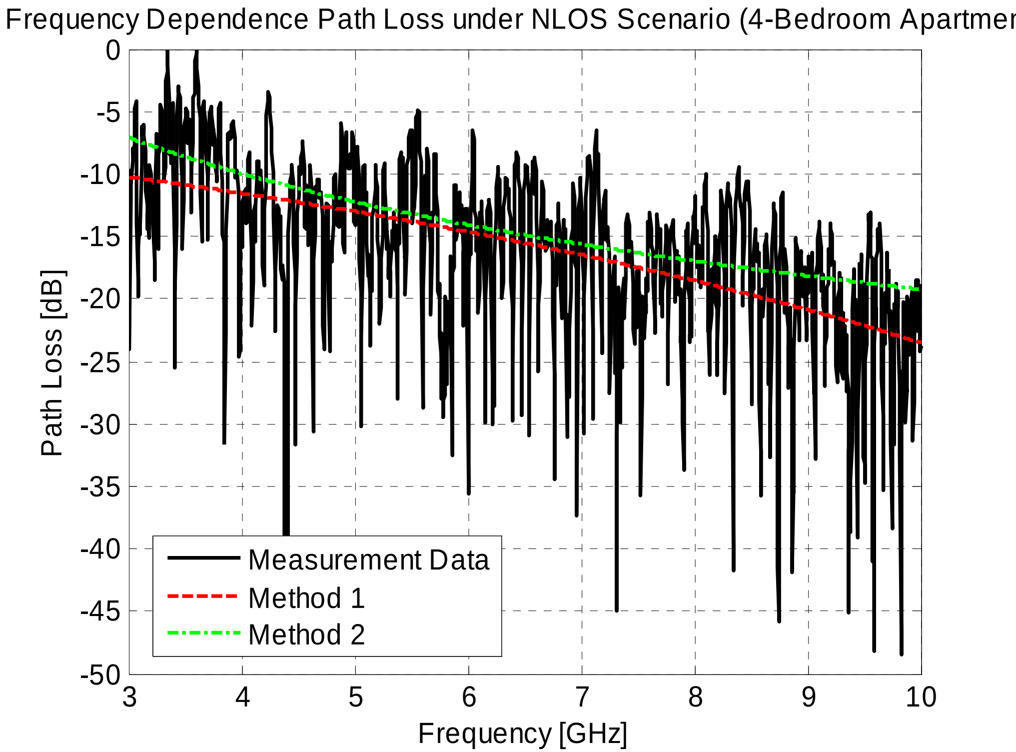
Frequency Decaying Factor – LOS





Frequency Decaying Factor – NLOS





Large-Scale Parameters

Scenario/ Environment	n	PL_0	σ_S	δ_1		δ_2	
				μ_{δ_1}	σ_{δ_1}	μ_{δ_2}	σ_{δ_2}
LOS (3-Bedroom Apartment)	1.18	50.1	0.93	0.14	0.01	1.25	0.14
NLOS (3-Bedroom Apartment)	2.18	41.3	1.43	0.08	0.03	1.54	0.39
LOS (4-Bedroom Apartment)	2.48	46.5	1.50	0.08	0.09	0.98	0.09
NLOS (4-Bedroom Apartment)	2.69	47.3	4.69	0.10	0.02	1.51	0.25

Temporal Domain Parameters

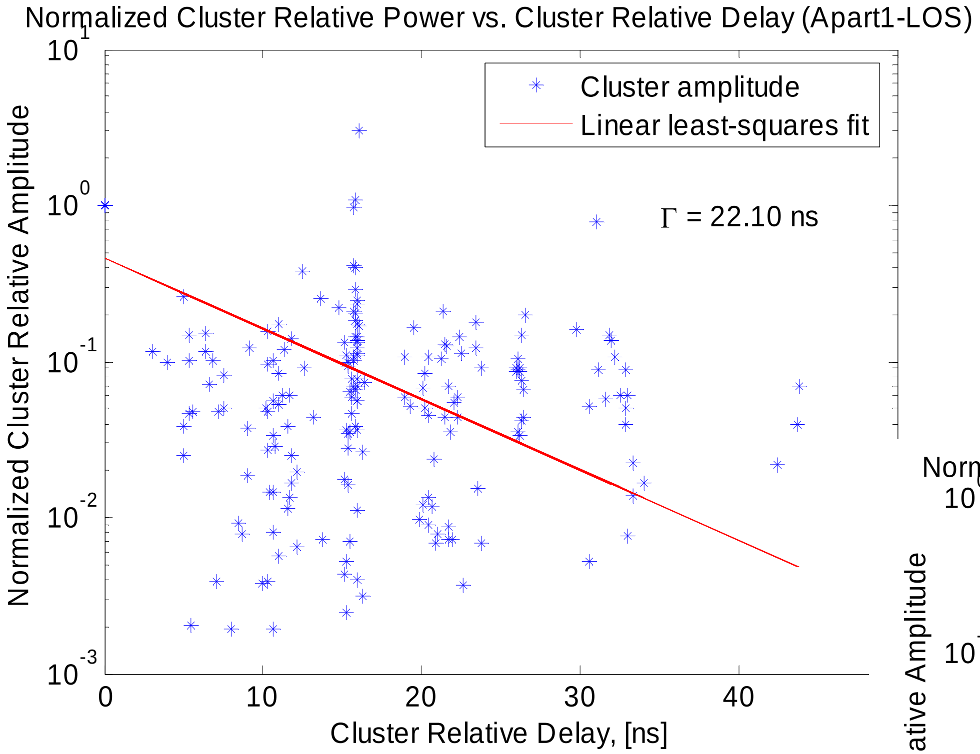
- These parameters were obtained after taking frequency domain Hamming windowing, passband IFFT & temporal domain binning

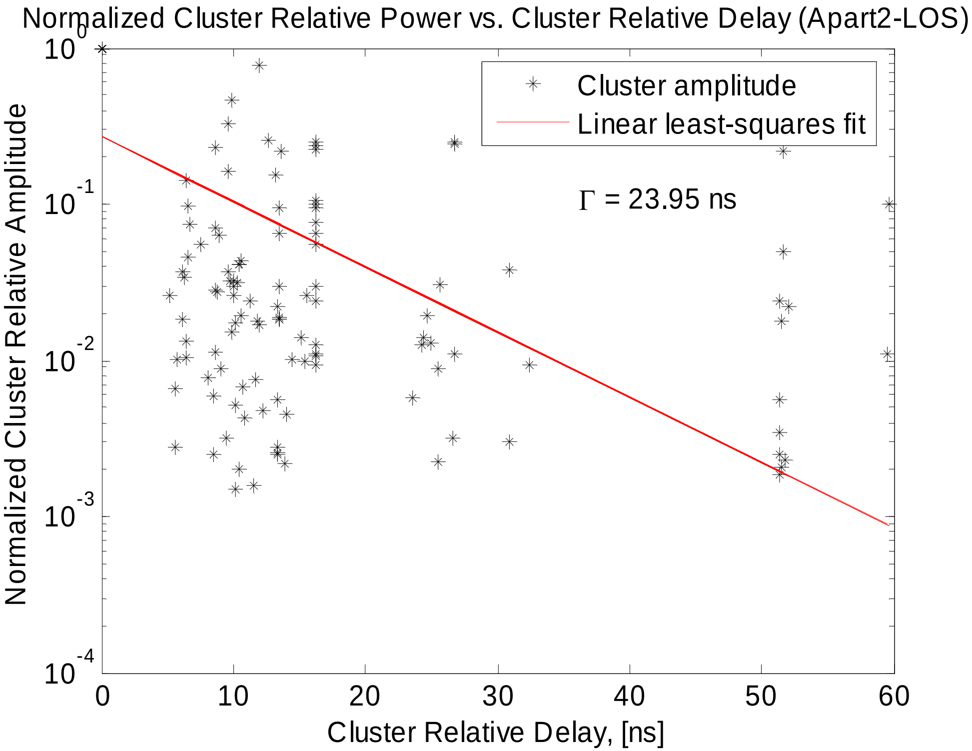
Location	τ_m		τ_{rms}		$NP10dB$		$NP20dB$		$NP30dB$	
	μ_{τ_m}	σ_{τ_m}	$\mu_{\tau_{rms}}$	$\sigma_{\tau_{rms}}$	μ_{NP10dB}	σ_{NP10dB}	μ_{NP20dB}	σ_{NP20dB}	μ_{NP30dB}	σ_{NP30dB}
LOS (3-Bedroom Apartment)	5.88	1.25	14.00	1.53	4.04	1.53	29.91	11.15	145.38	38.89
NLOS (3-Bedroom Apartment)	36.09	15.48	38.61	8.03	19.58	7.64	141.63	42.23	512.57	76.28
LOS (4-Bedroom Apartment)	5.01	0.64	12.48	1.87	5.97	1.96	37.21	9.20	161.02	31.59
NLOS (4-Bedroom Apartment)	24.95	8.47	26.51	5.22	23.51	10.75	139.95	50.14	424.78	93.77

S-V Multipath Channel Parameters

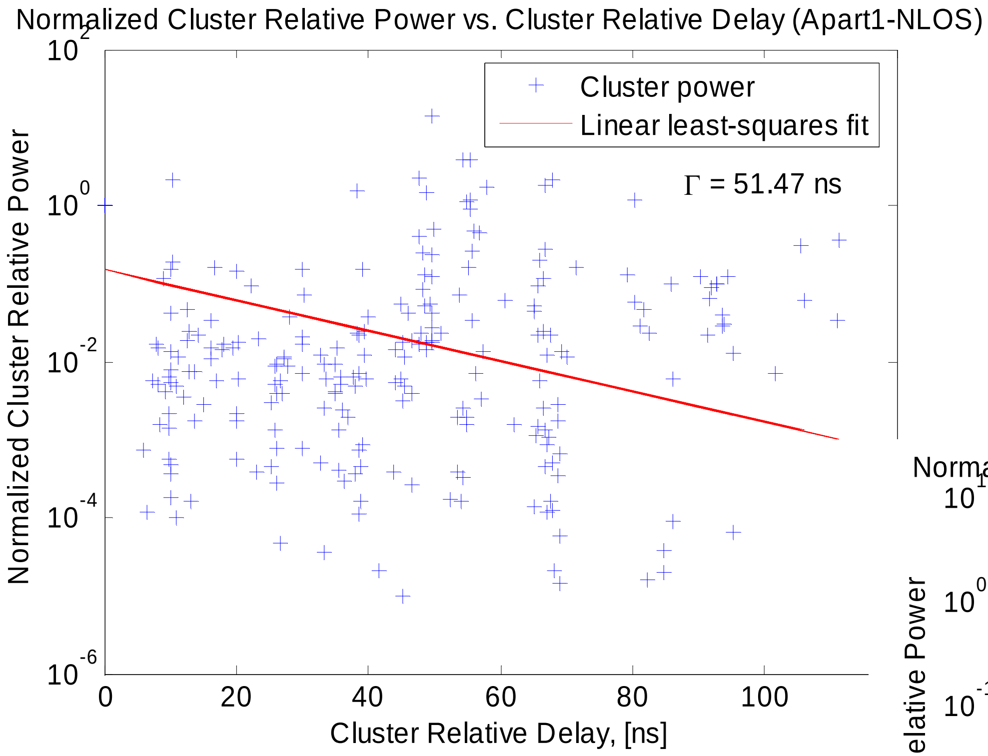
- Saleh-Valenzuela model described by the following parameters:
  - Γ : cluster decay factor
  - γ : ray decay factor
  - Λ : mean cluster arrival rate
  - λ : mean ray arrival rate
  - σ_a : standard deviation of lognormal distributed path powers (dB)
  - L_{mean} : Mean number of clusters
  - μ_{Kl} : Mean of the exponential distributed number of MPCs per cluster

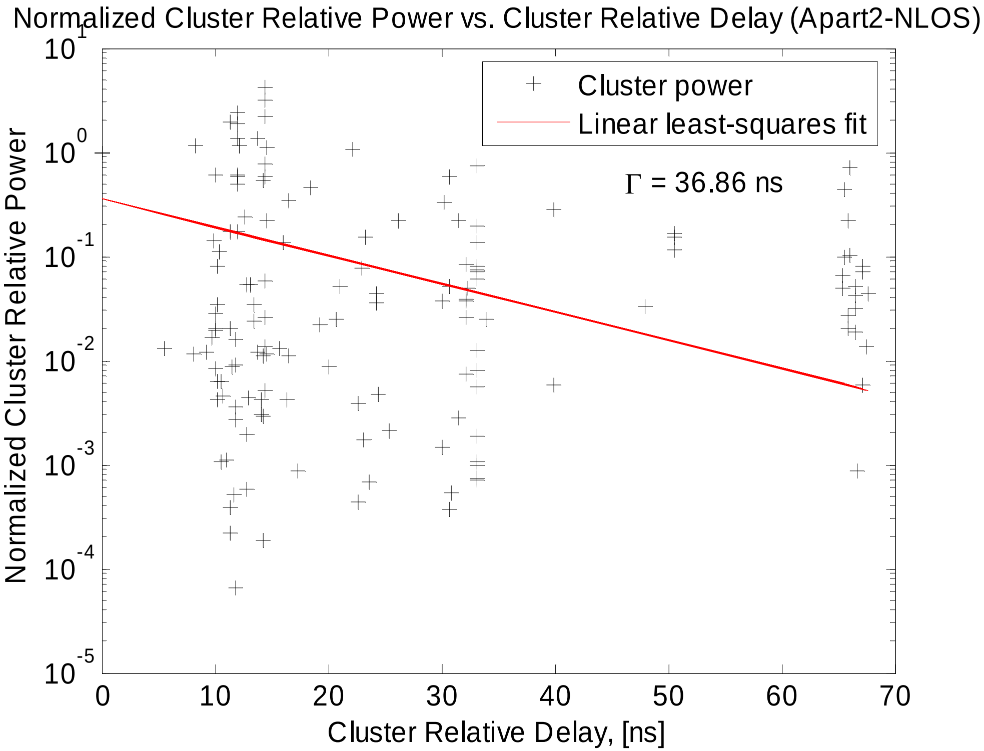
Cluster Decay Factor, Γ – LOS



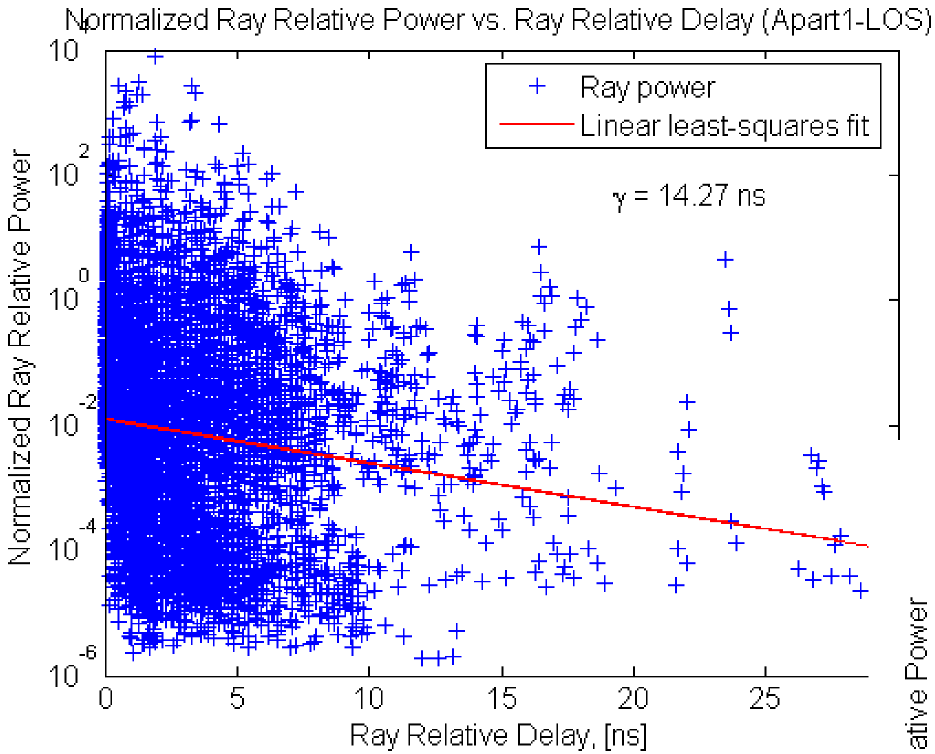


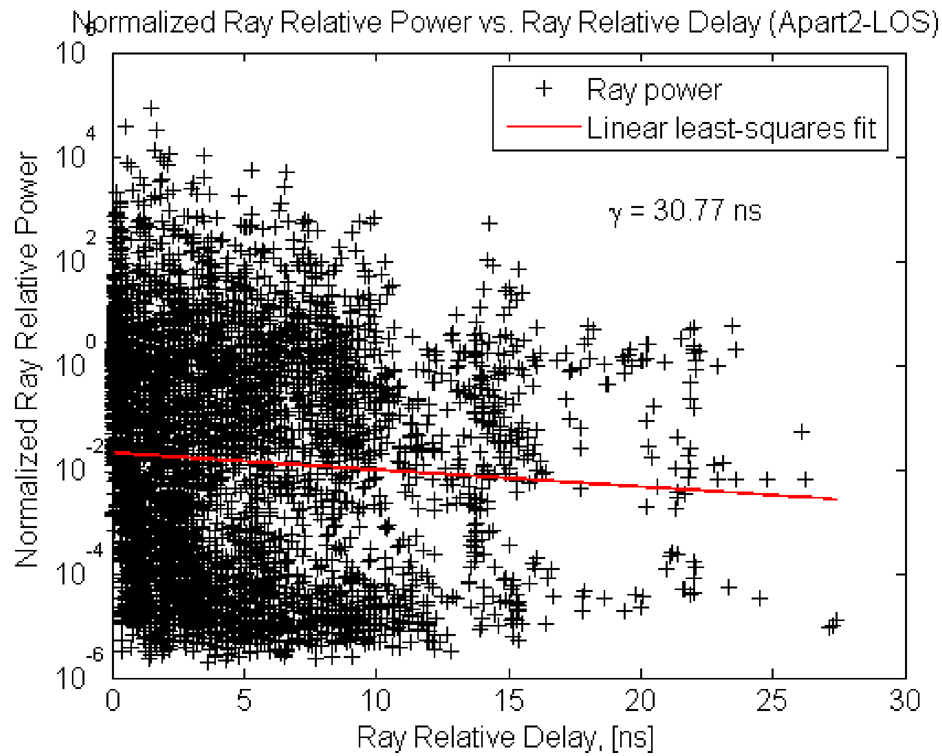
Cluster Decay Factor, Γ – NLOS



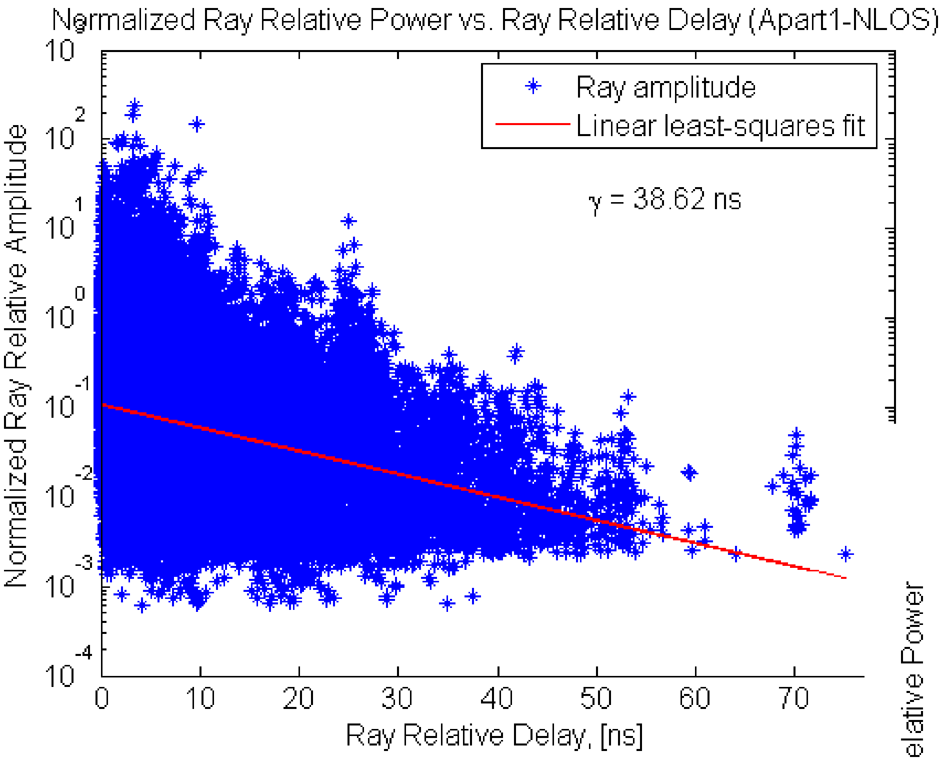


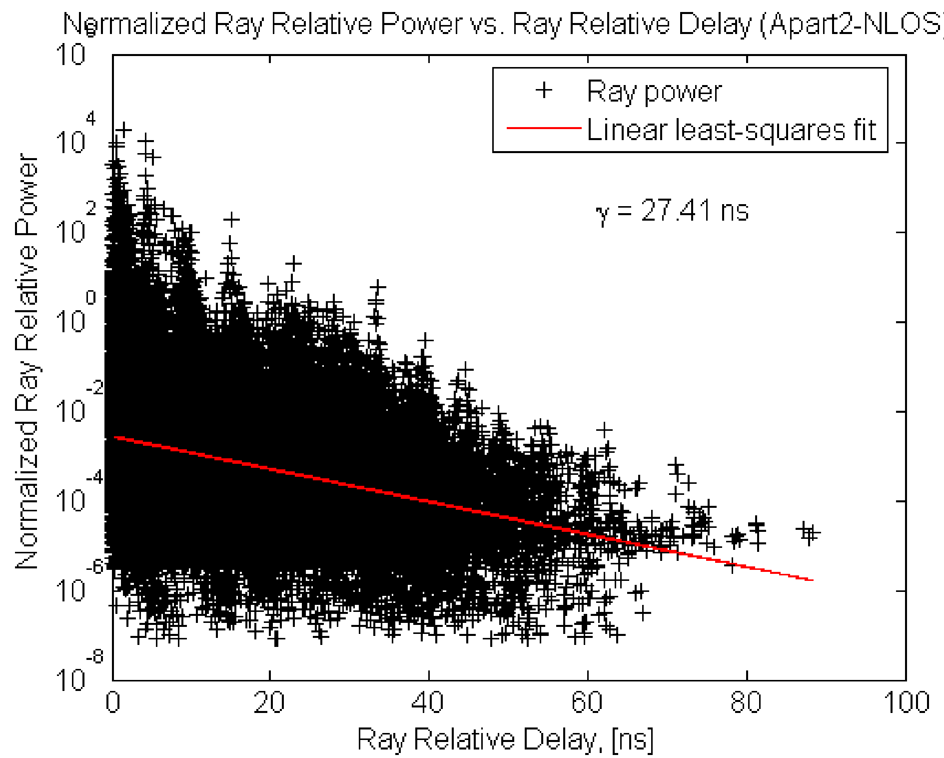
Ray Decay Factor, γ – LOS



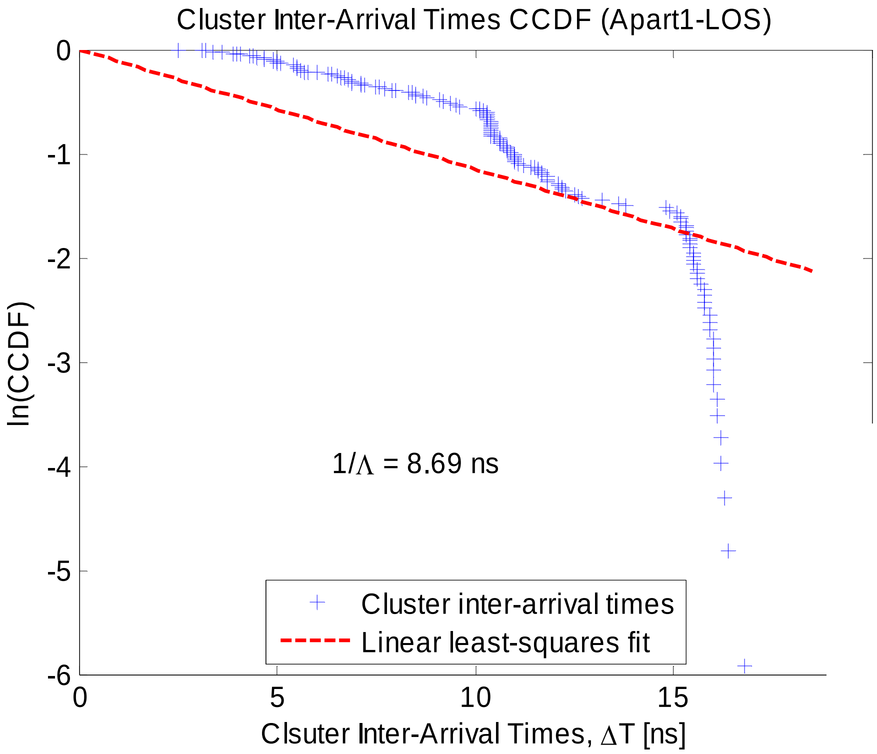


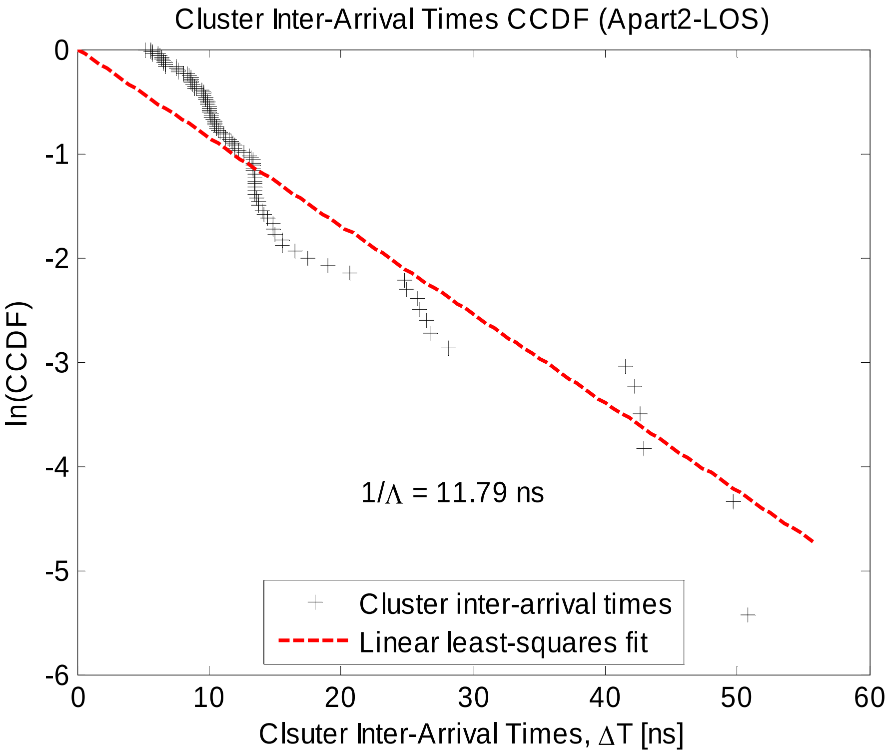
Ray Decay Factor, γ – NLOS



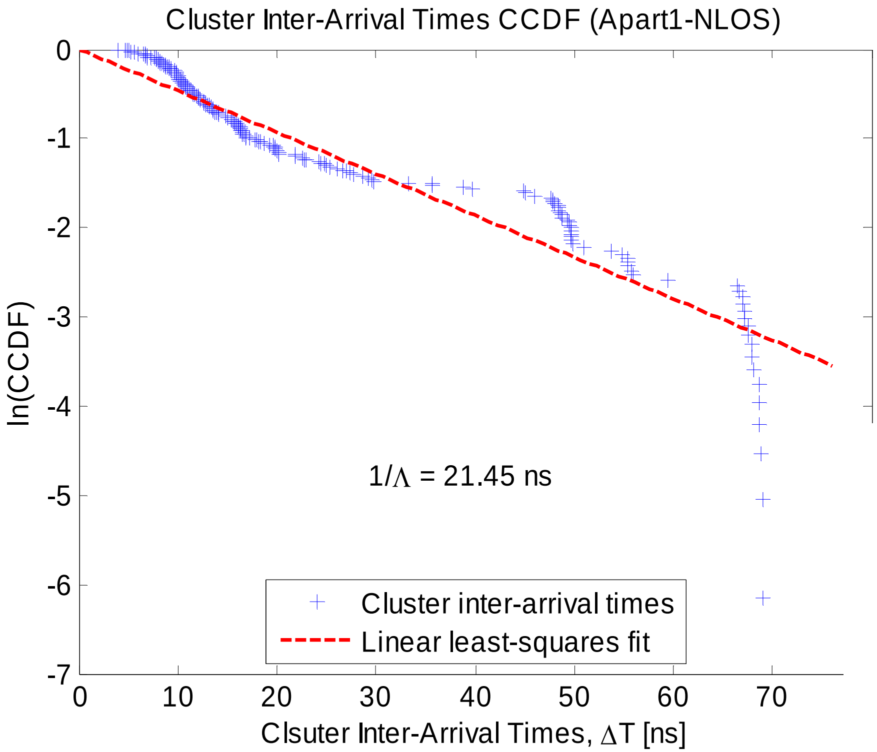


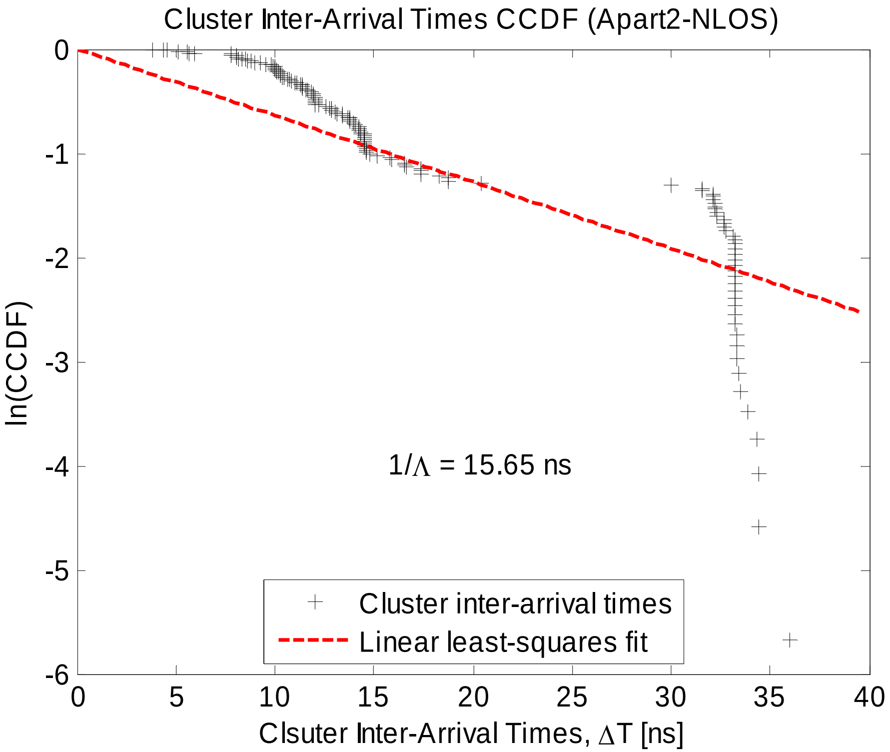
Cluster Arrival Rate, Λ – LOS



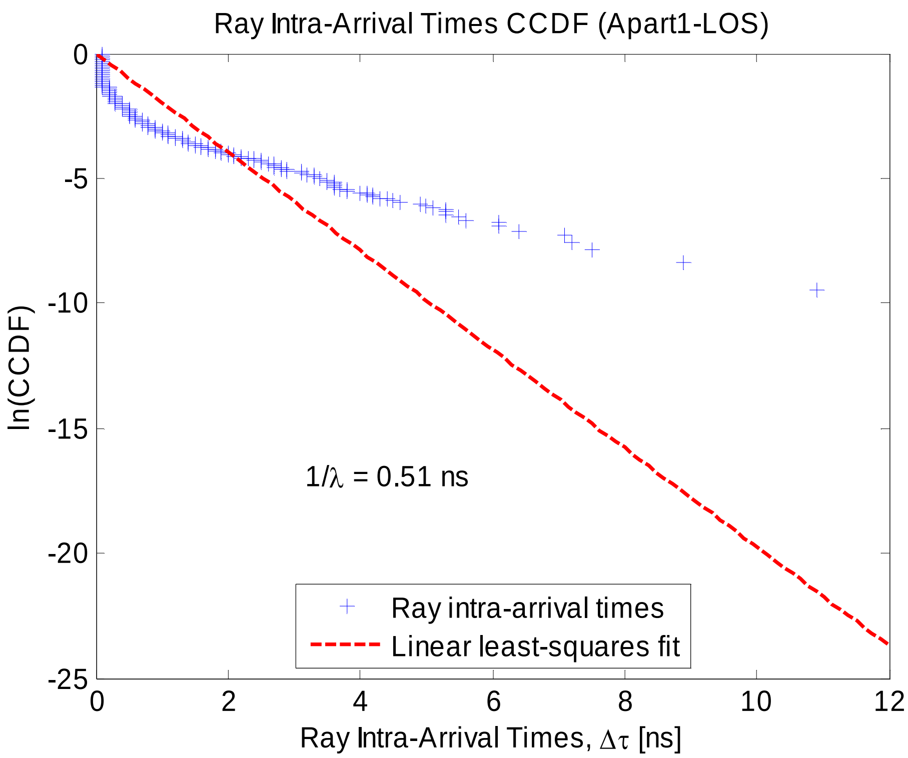


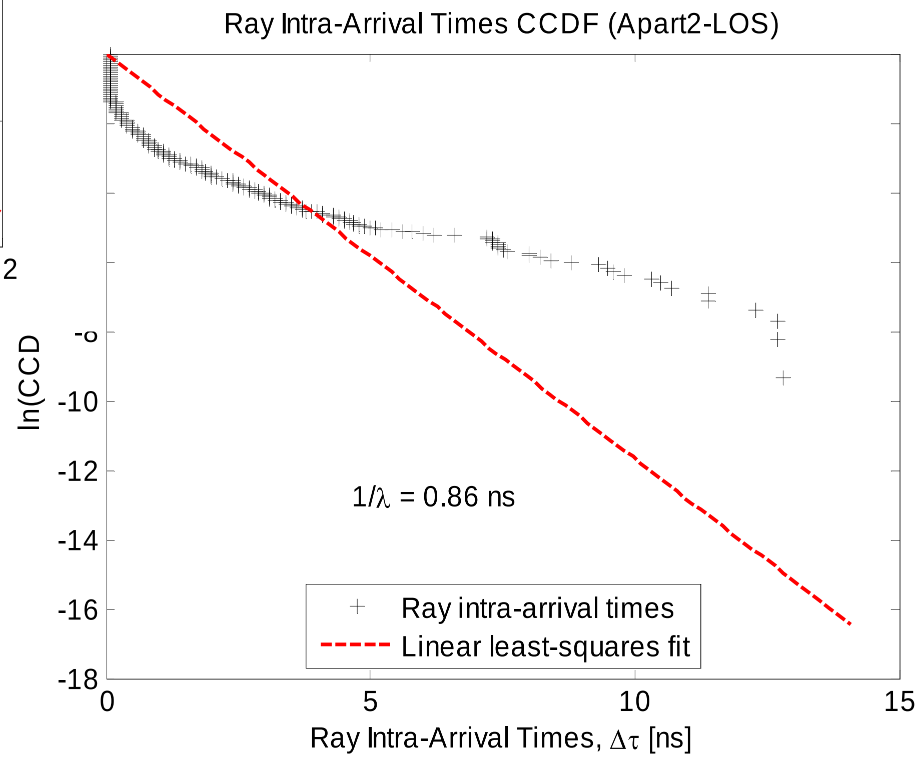
Cluster Arrival Rate, Λ – NLOS



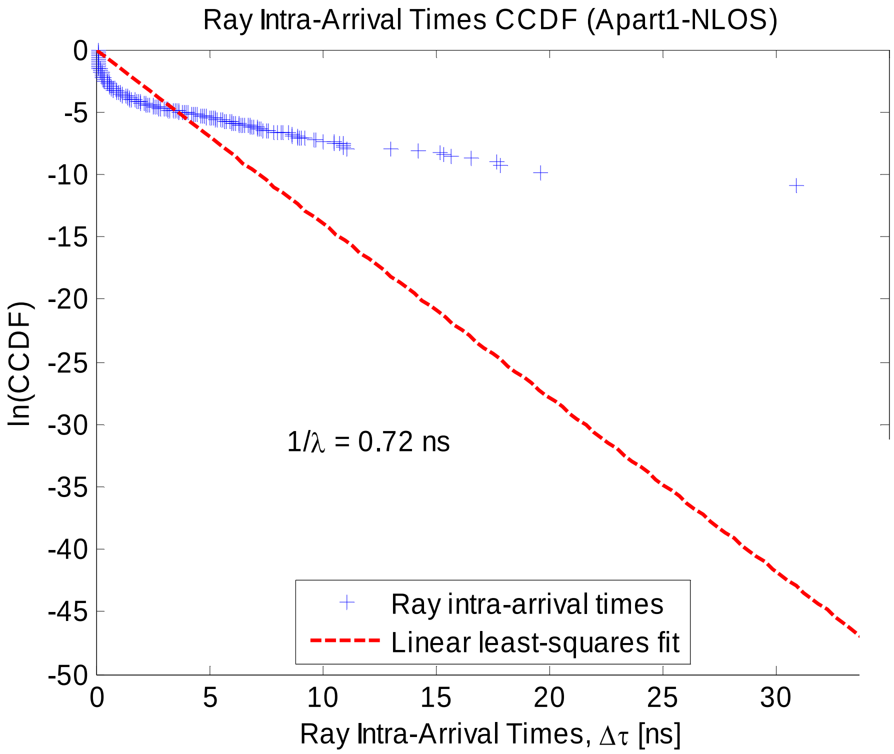


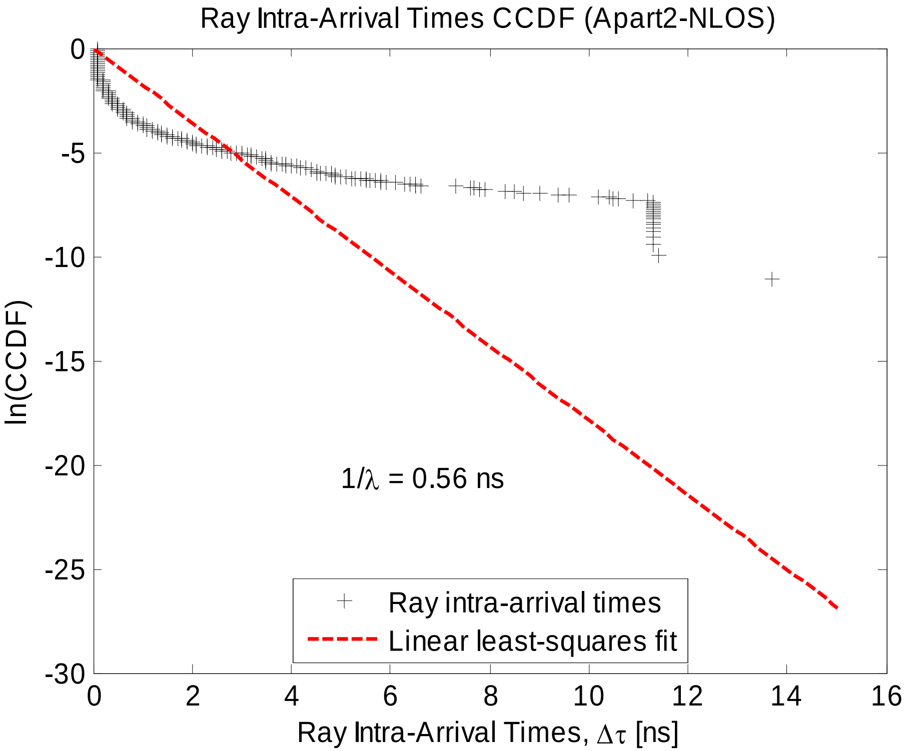
Ray Arrival Rate, λ – LOS





Ray Arrival Rate, λ – NLOS





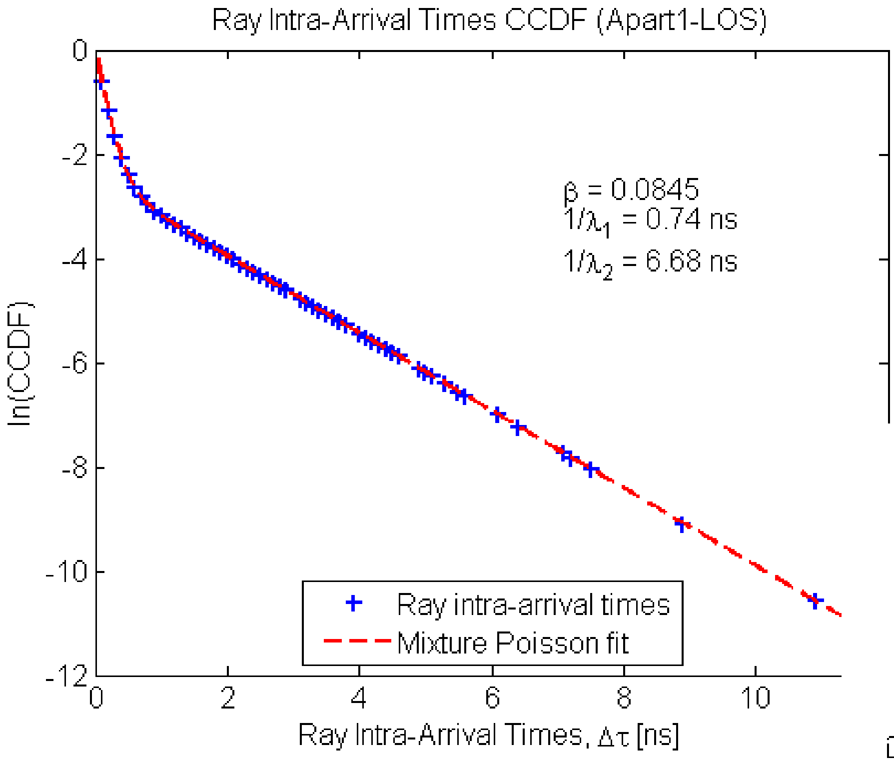
Mixture Poisson Distribution

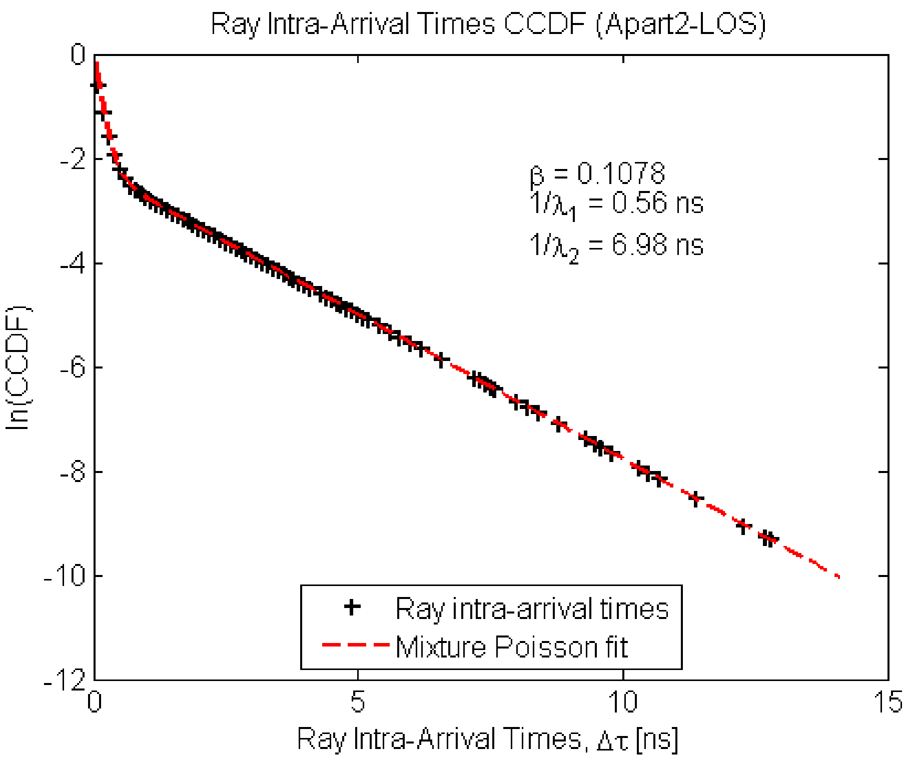
- Fitting the ray arrival times to a mixture of 2 Poisson distributions similar to [1]:

$$p\left(\tau_{k,l} \mid \tau_{(k-1),l}\right) = \beta\lambda_1 \exp\left[-\lambda_1\left(\tau_{k,l} - \tau_{(k-1),l}\right)\right] + (\beta - 1)\lambda_2 \exp\left[-\lambda_2\left(\tau_{k,l} - \tau_{(k-1),l}\right)\right]$$

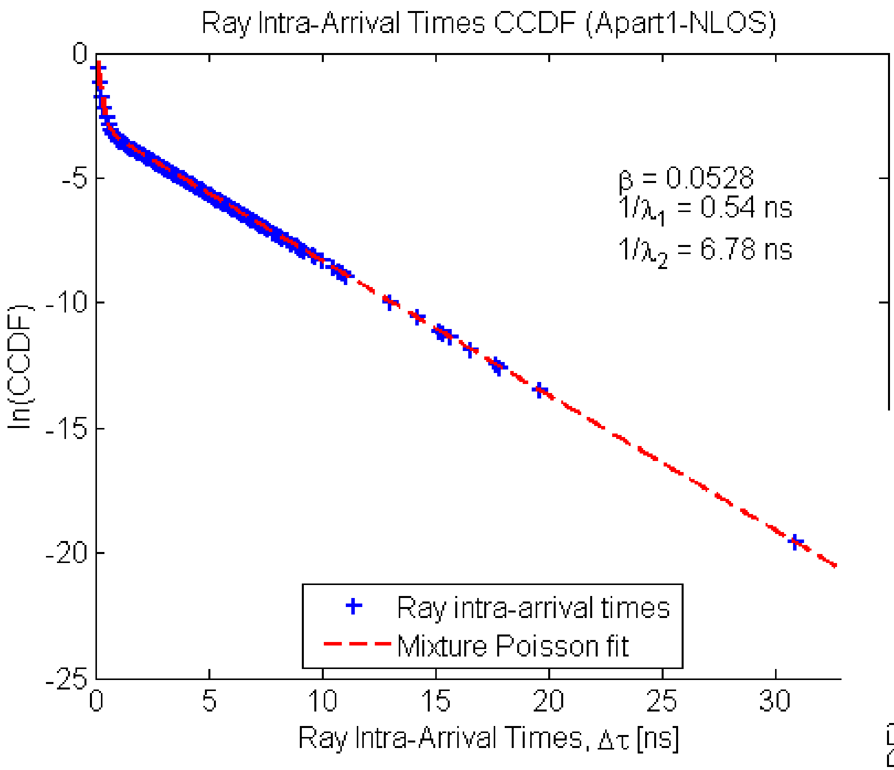
  - β: mixture probability
  - λ_1 & λ_2: ray arrival rates

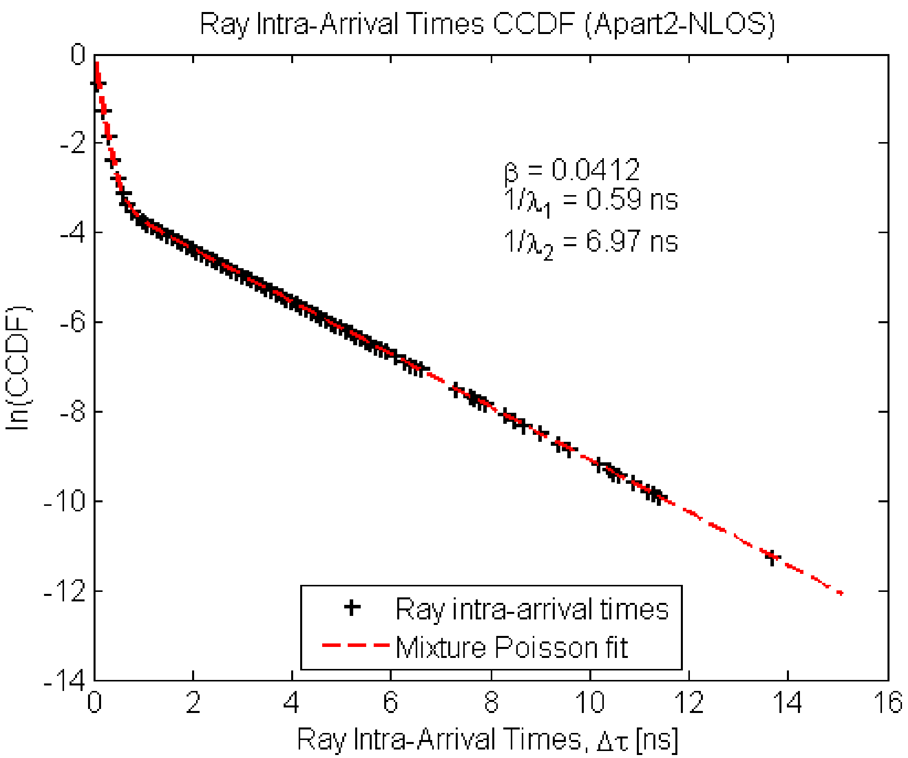
Mixture Poisson Distributions – LOS



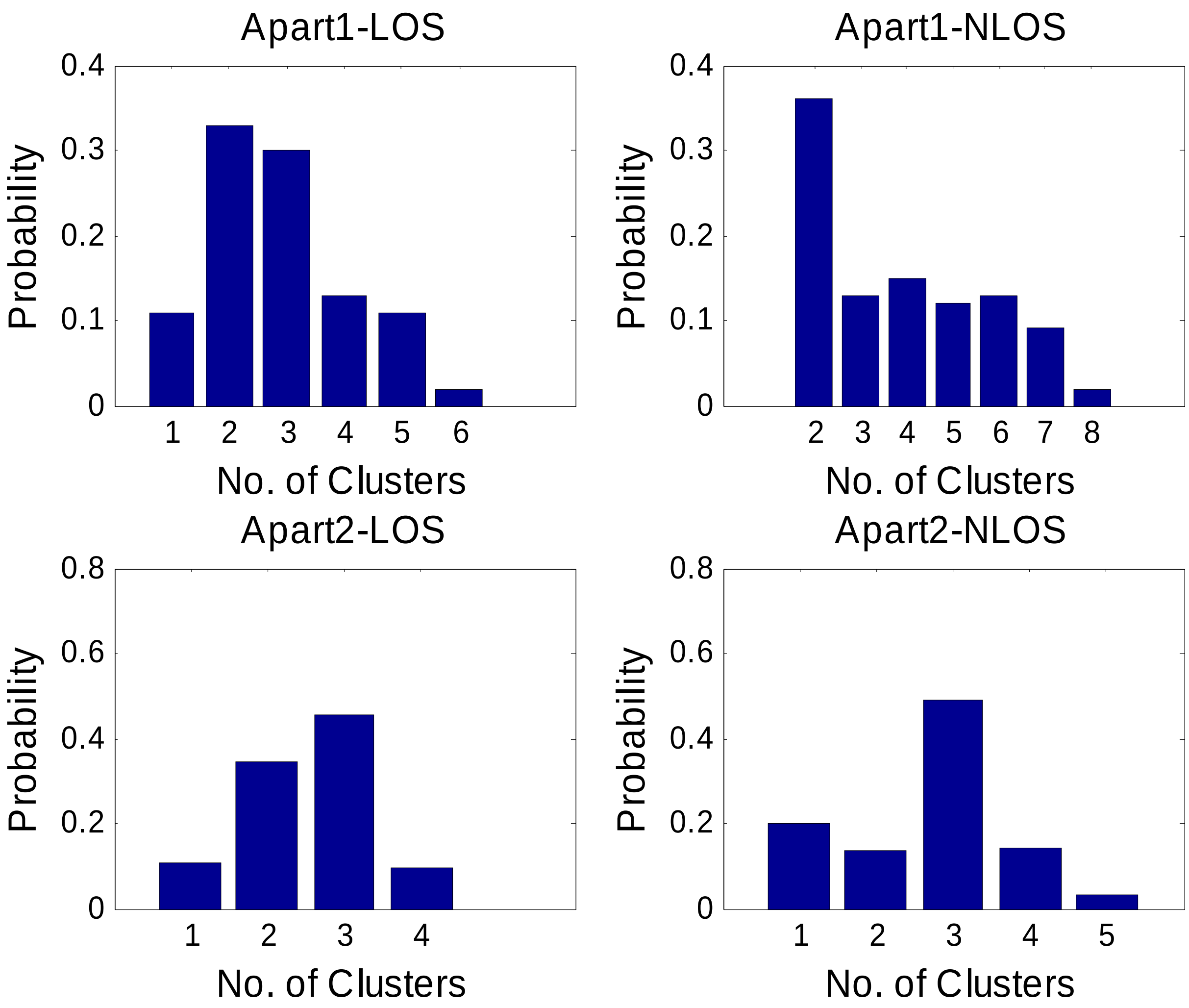


Mixture Poisson Distributions – NLOS

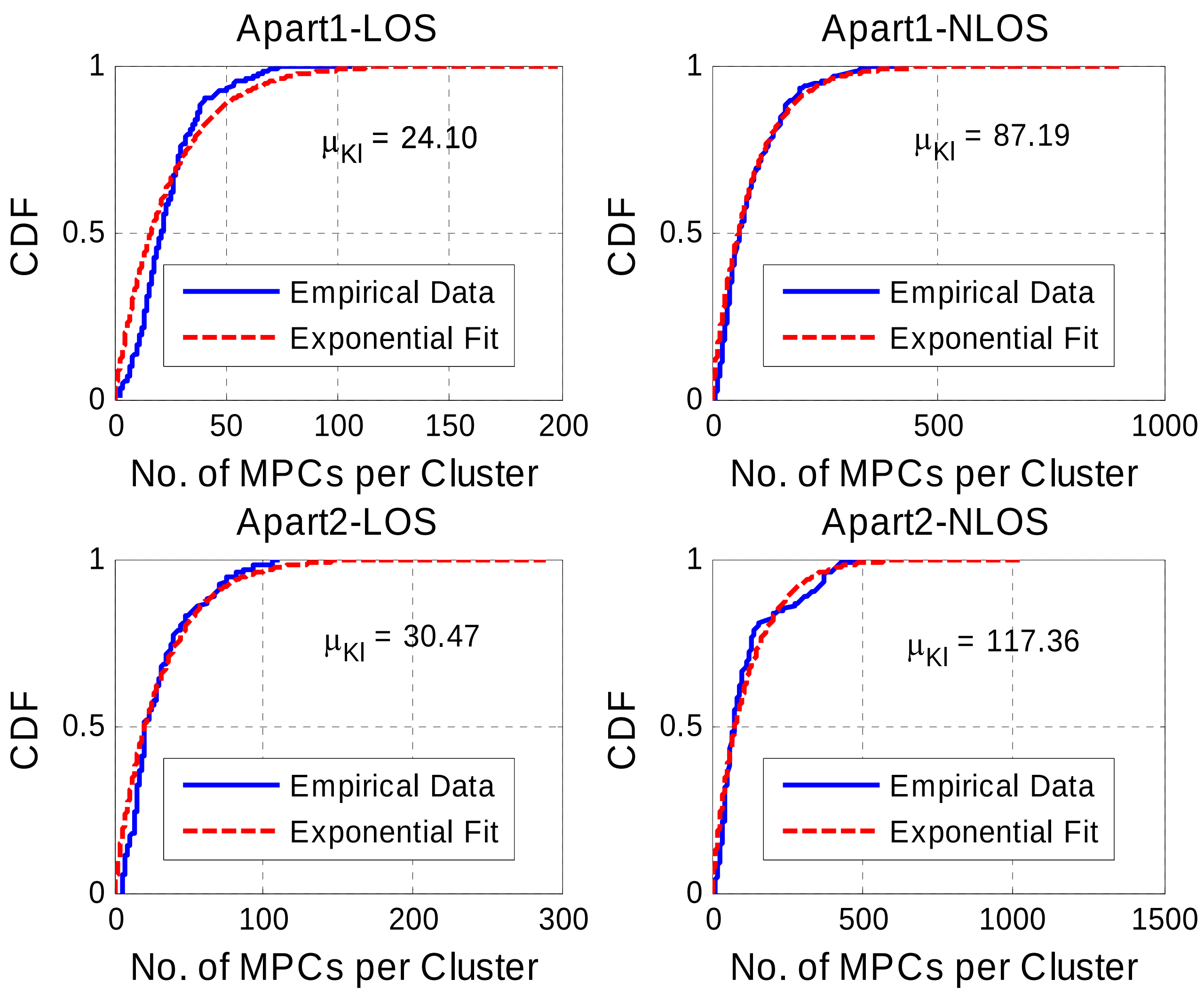




Number of Clusters



Number of MPCs per Cluster



S-V Multipath Channel Parameters

Parameters	Apart1-LOS	Apart1-NLOS	Apart2-LOS	Apart2-NLOS
$\overline{L}$	3	4	3	3
μ_{K_l}	24.10	87.19	30.47	117.36
Γ [ns]	22.10	51.47	23.95	36.86
γ [ns]	14.27	38.62	30.77	27.40
$1/\Lambda$ [ns]	8.69	21.45	11.79	15.65
$1/\lambda$ [ns]	0.51	0.72	0.86	0.56
σ_a [dB]	0.87	0.94	0.85	0.89
β	0.08	0.05	0.11	0.04
$1/\lambda_1$ [ns]	0.74	0.54	0.56	0.59
$1/\lambda_2$ [ns]	6.68	6.78	6.98	6.97

Small-Scale Amplitude Statistics

- Comparison of empirical **path amplitude** distribution with the following four commonly used theoretical distributions:
  - Lognormal
  - Nakagami
  - Rayleigh
  - Ricean
  - Weibull
- The goodness-of-fit of the received signal amplitudes is evaluated using Kolmogorov-Smirnov (K-S) test & Chi-Square (χ^2) test with 5% and 10% significance level, respectively.

Goodness-of-Test: LOS

Apart1-LOS

Distributions	K-S Test		χ^2 Test	
	5%	10%	5%	10%
Lognormal	97.67	91.33	70.04	54.65
Nakagami	94.84	92.31	86.50	77.00
Rayleigh	61.73	51.92	60.69	49.23
Ricean	52.65	44.94	46.31	33.50
Weibull	99.79	99.15	89.75	80.71

Apart2-LOS

Distributions	K-S Test		χ^2 Test	
	5%	10%	5%	10%
Lognormal	97.35	92.74	70.86	54.64
Nakagami	94.86	92.54	87.78	79.18
Rayleigh	62.86	52.13	61.31	49.82
Ricean	40.61	33.14	35.69	26.24
Weibull	99.13	97.82	88.78	79.38

Goodness-of-Test: NLOS

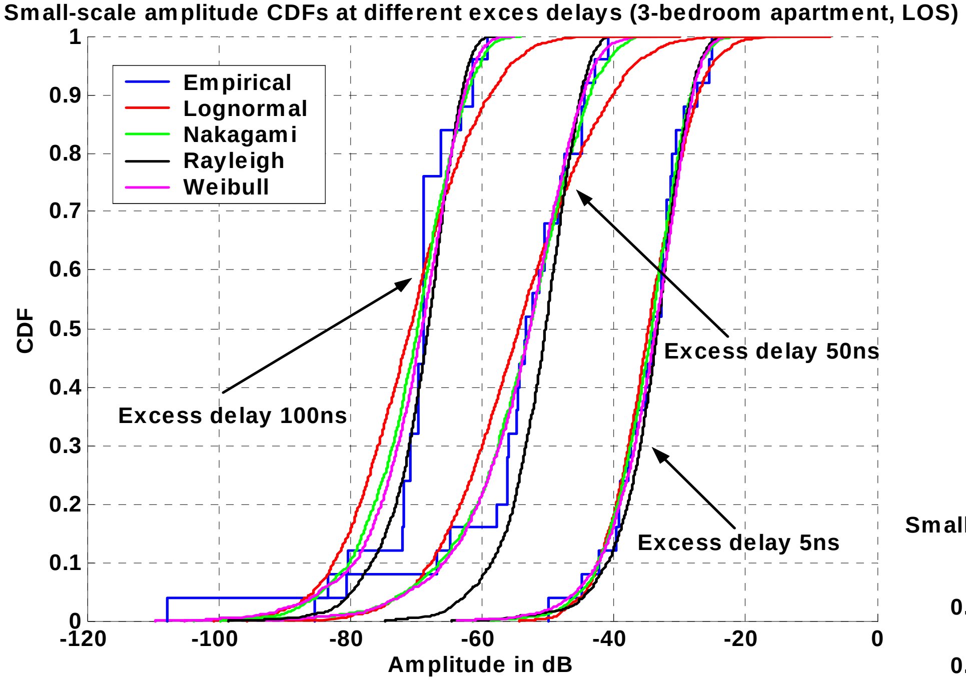
Apart1-NLOS

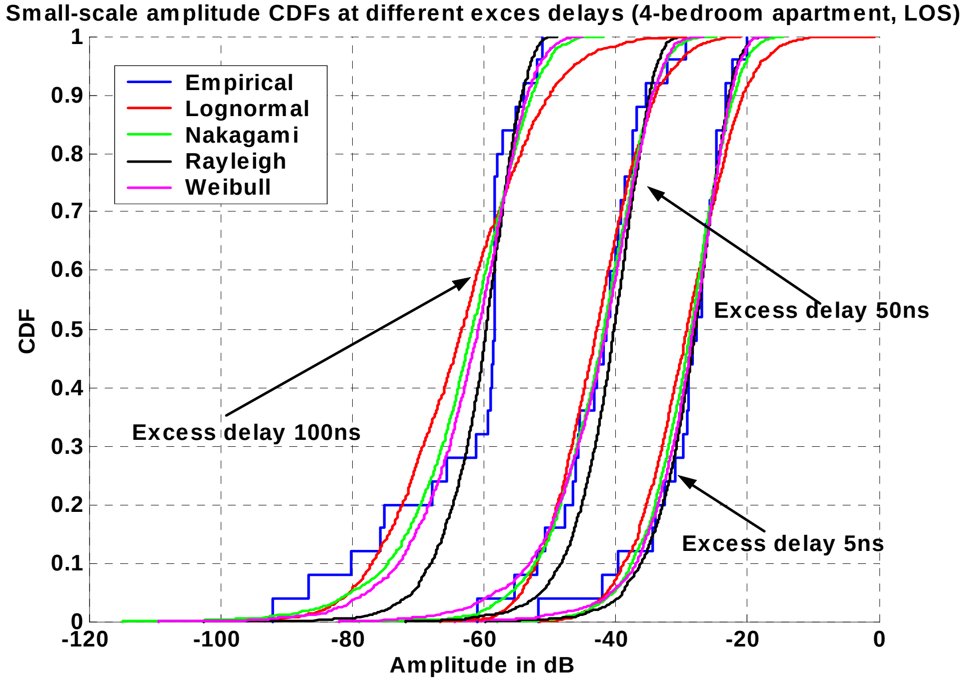
Distributions	K-S Test		χ^2 Test	
	5%	10%	5%	10%
Lognormal	92.50	83.54	55.28	41.39
Nakagami	90.07	85.77	65.43	54.37
Rayleigh	46.98	37.61	46.15	34.68
Ricean	42.46	34.15	35.21	24.89
Weibull	91.54	86.19	67.56	55.81

Apart2-NLOS

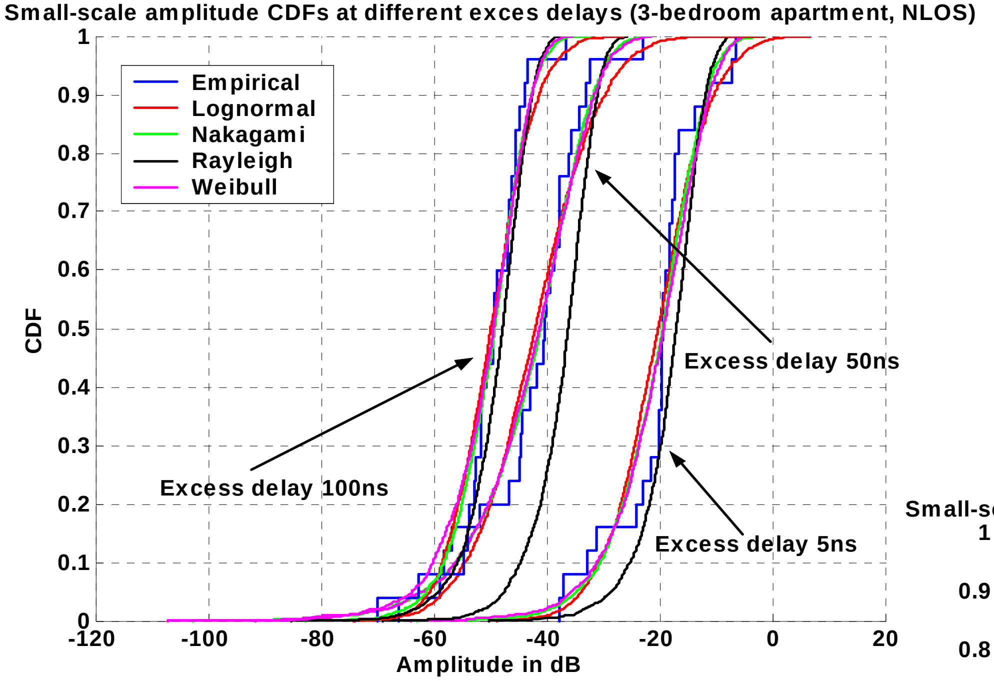
Distributions	K-S Test		χ^2 Test	
	5%	10%	5%	10%
Lognormal	91.27	84.15	57.61	44.20
Nakagami	92.41	88.22	76.24	65.86
Rayleigh	45.53	36.12	46.87	36.40
Ricean	39.46	31.18	34.45	29.91
Weibull	88.74	84.23	70.68	60.41

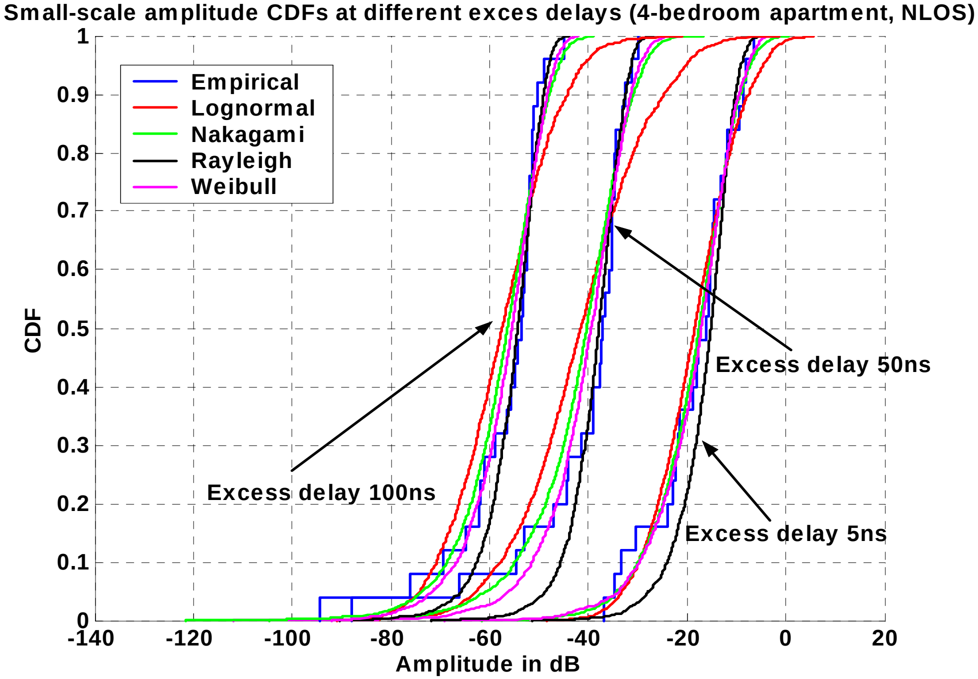
CDF of Path Amplitude – LOS





CDF of Path Amplitude – NLOS

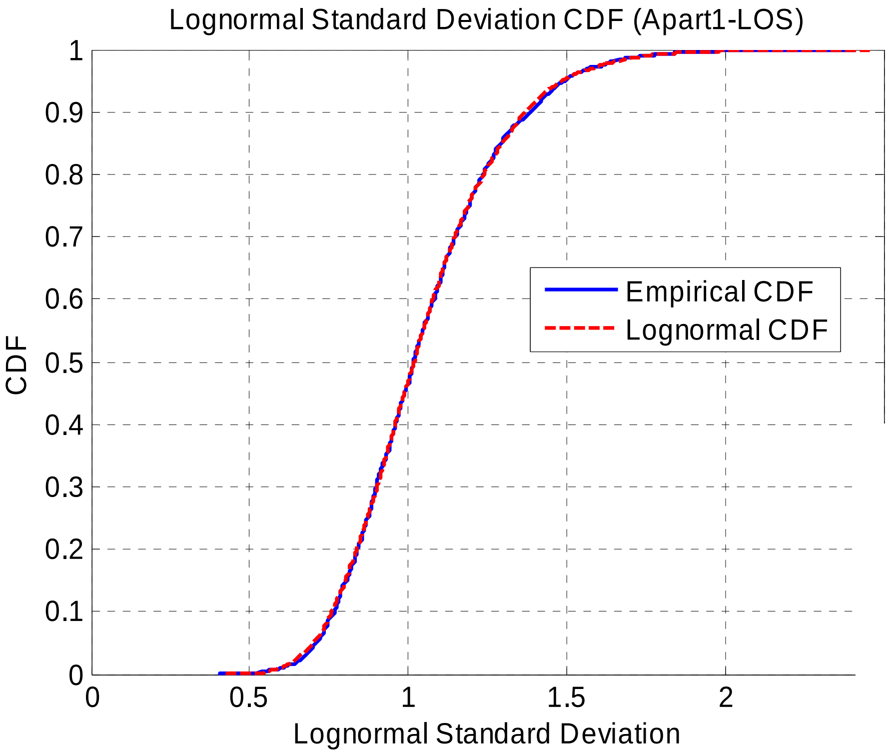


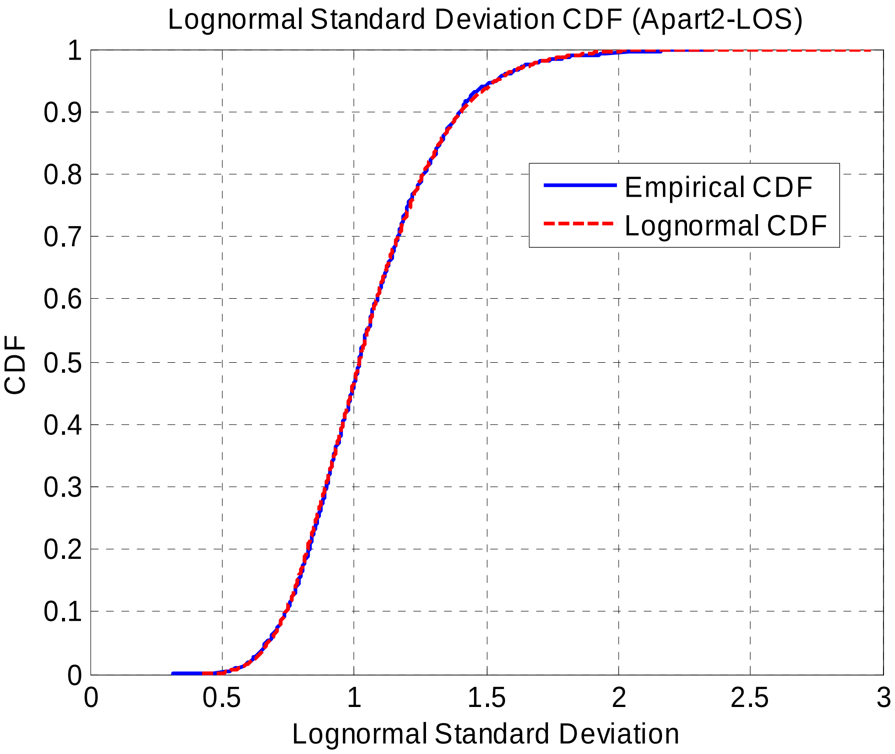


Small-Scale Amplitude Statistics Parameters

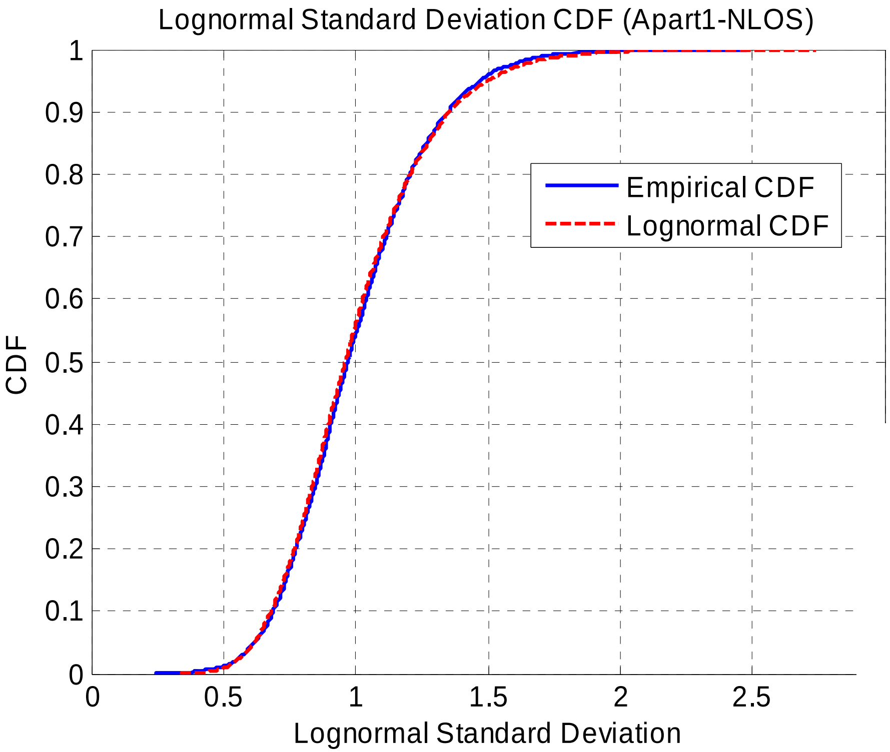
- The results demonstrate that lognormal, Nakagami and Weibull fit the measurement data well.
- Parameters of these distributions (i.e. standard deviation of lognormal PDF, m-parameter of Nakagami PDF and b-parameter of Weibull PDF) can be modeled by a lognormal distribution
- These parameters are almost constant across the excess delay

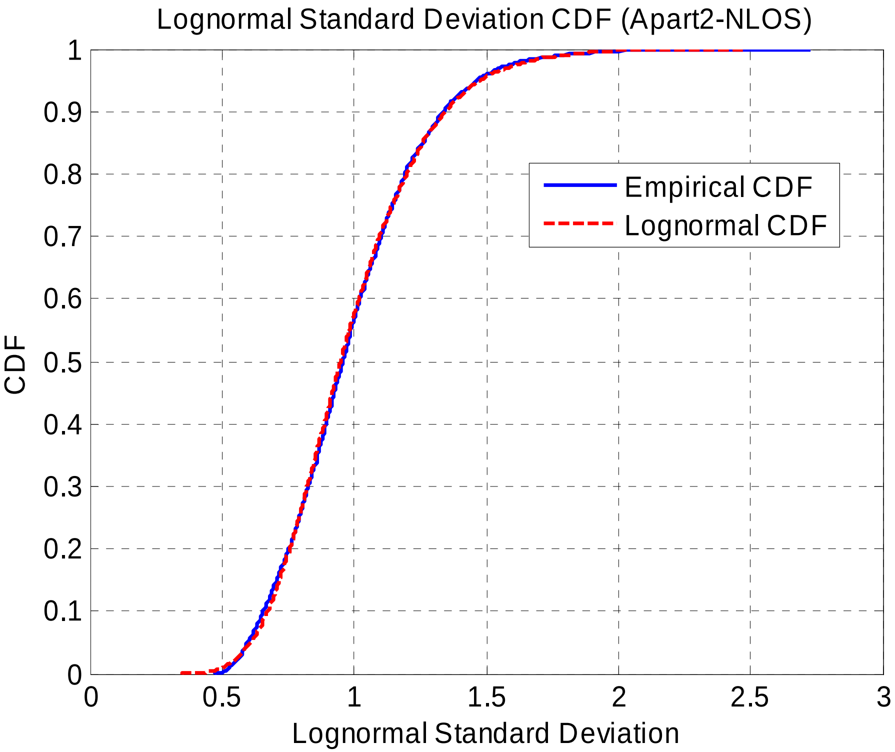
Standard Deviation of Lognormal PDF – LOS



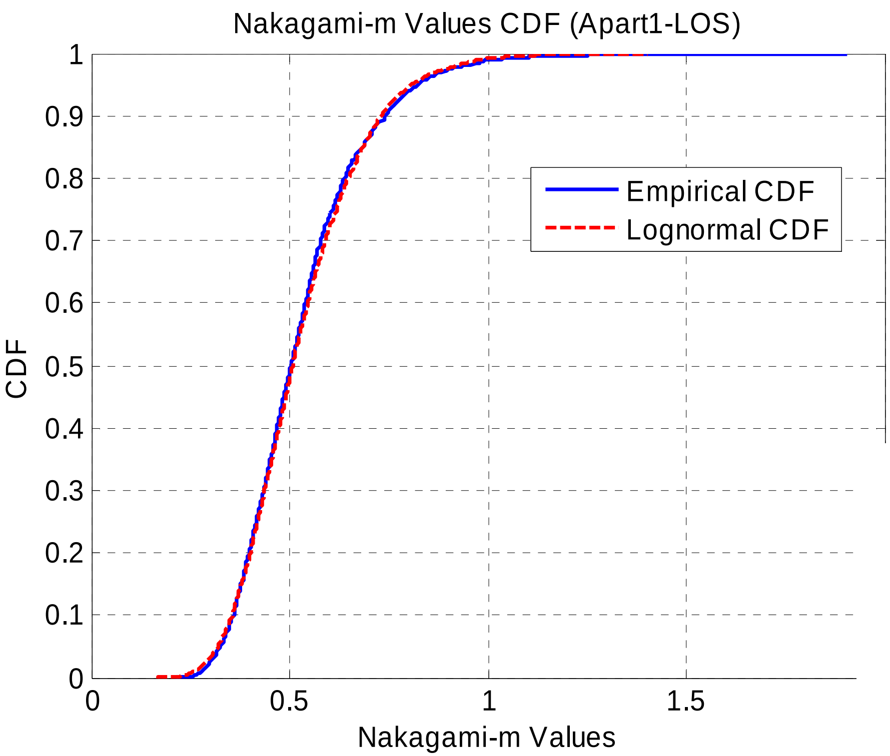


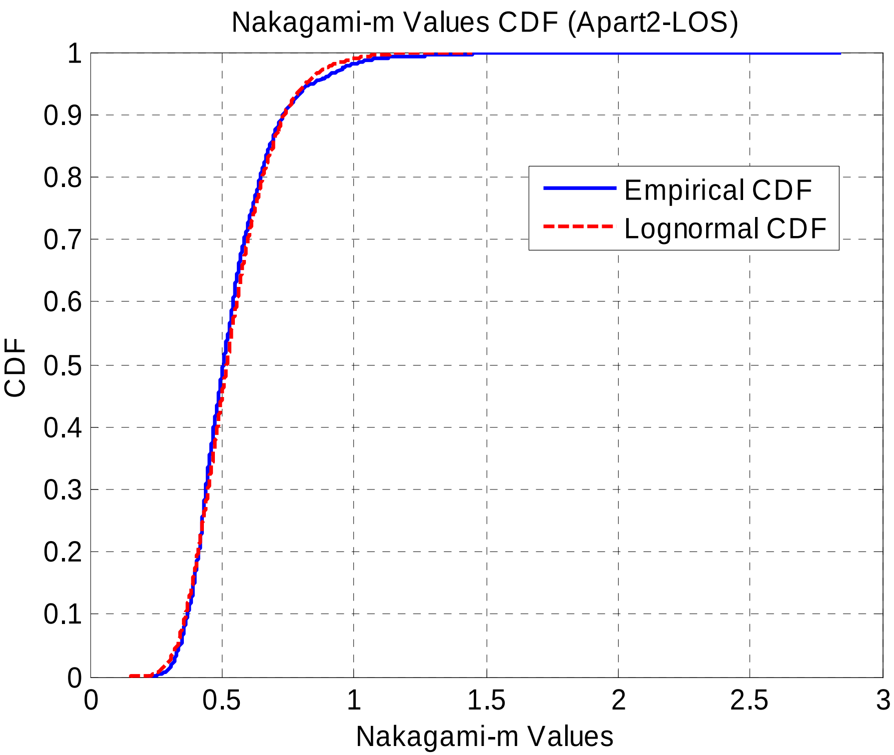
Standard Deviation of Lognormal PDF – NLOS



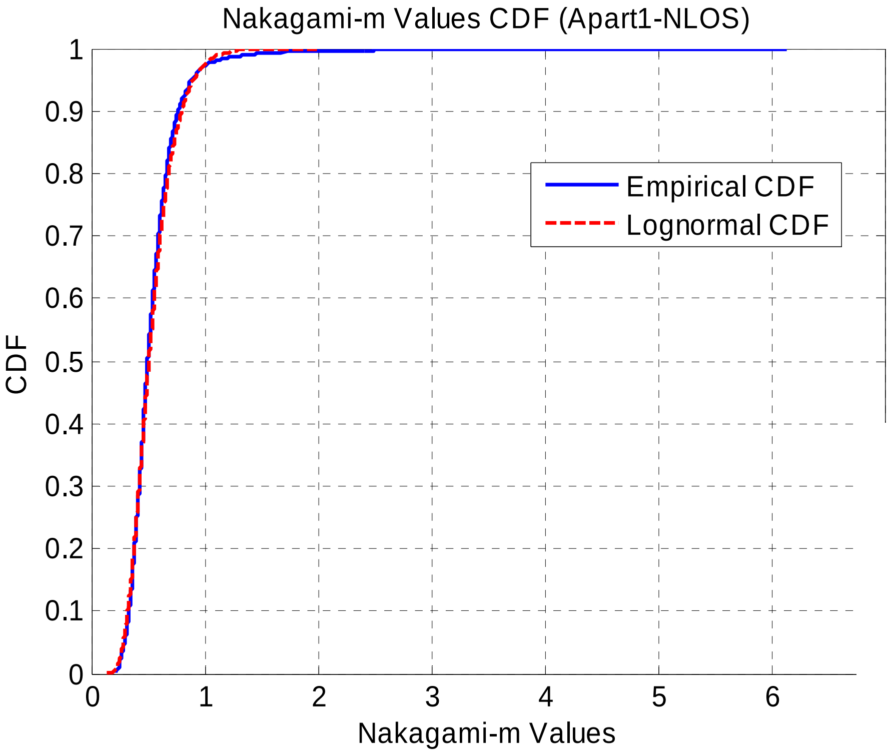


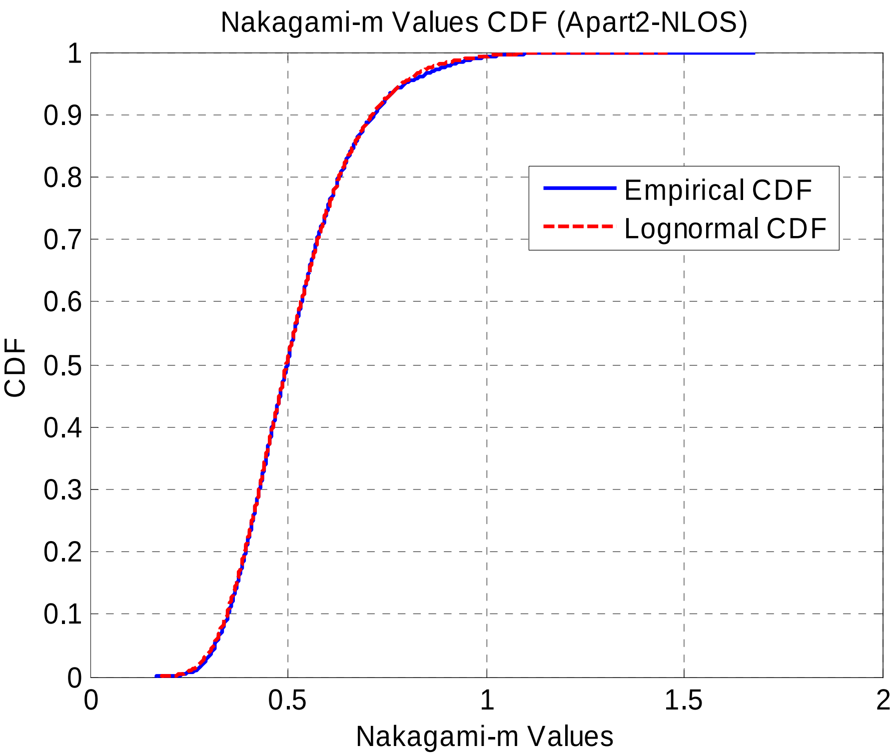
m-Nakagami Parameter – LOS



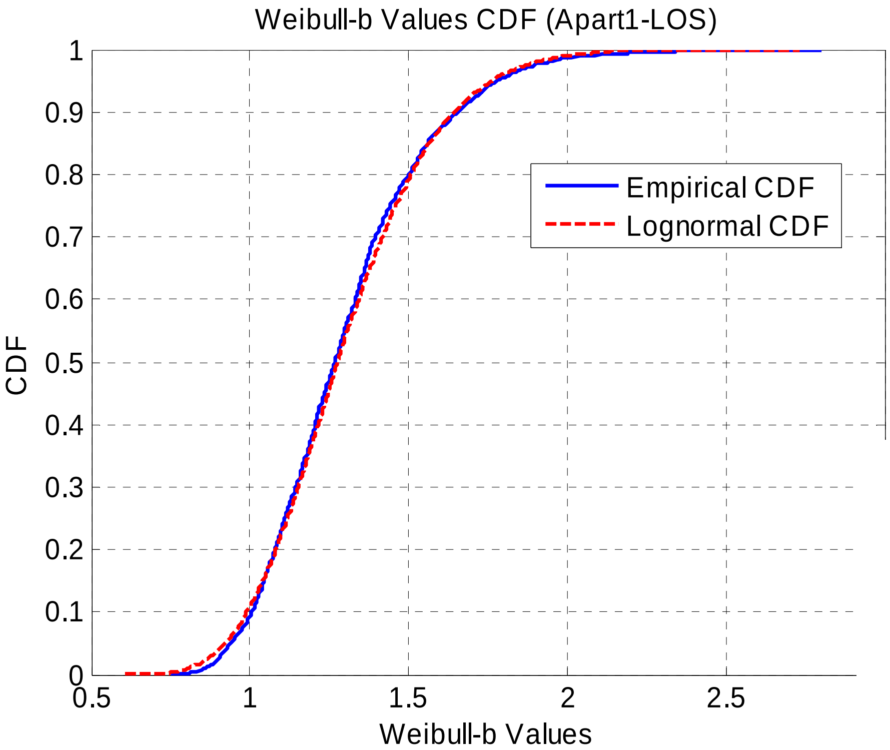


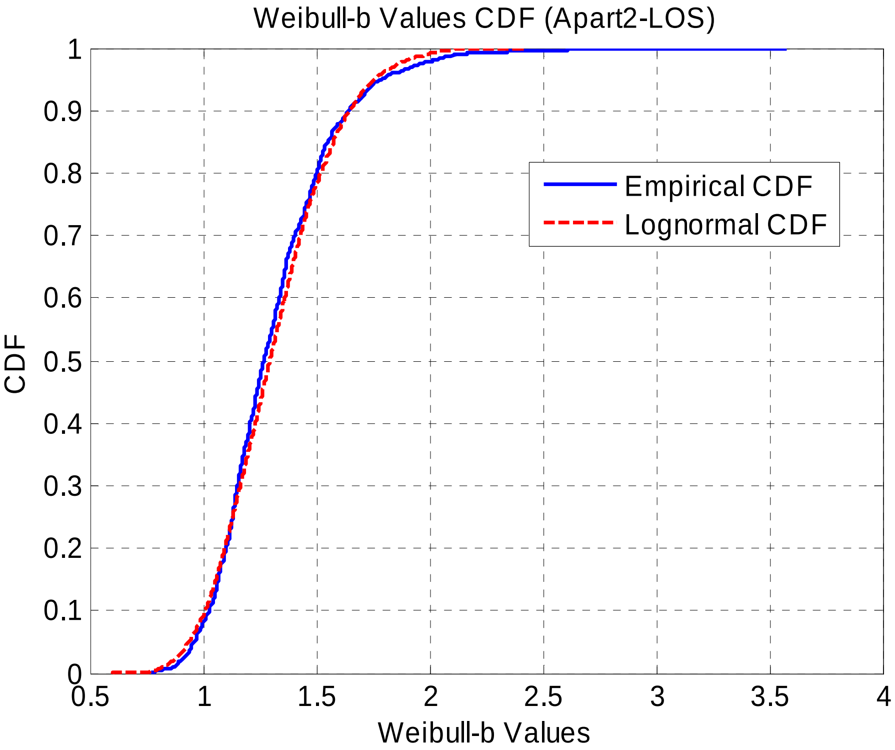
m-Nakagami Parameter – NLOS



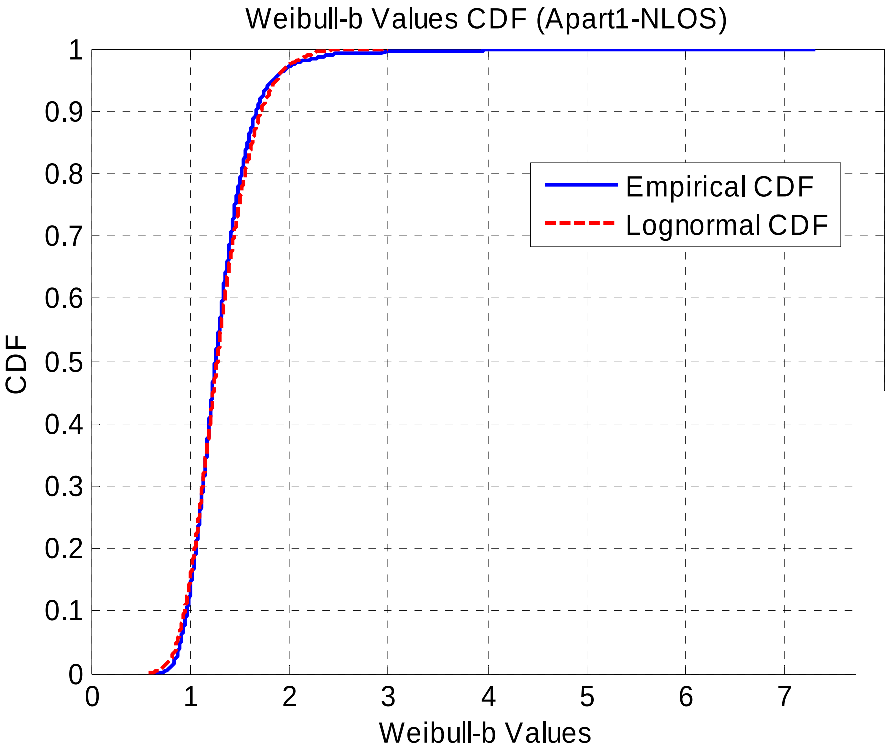


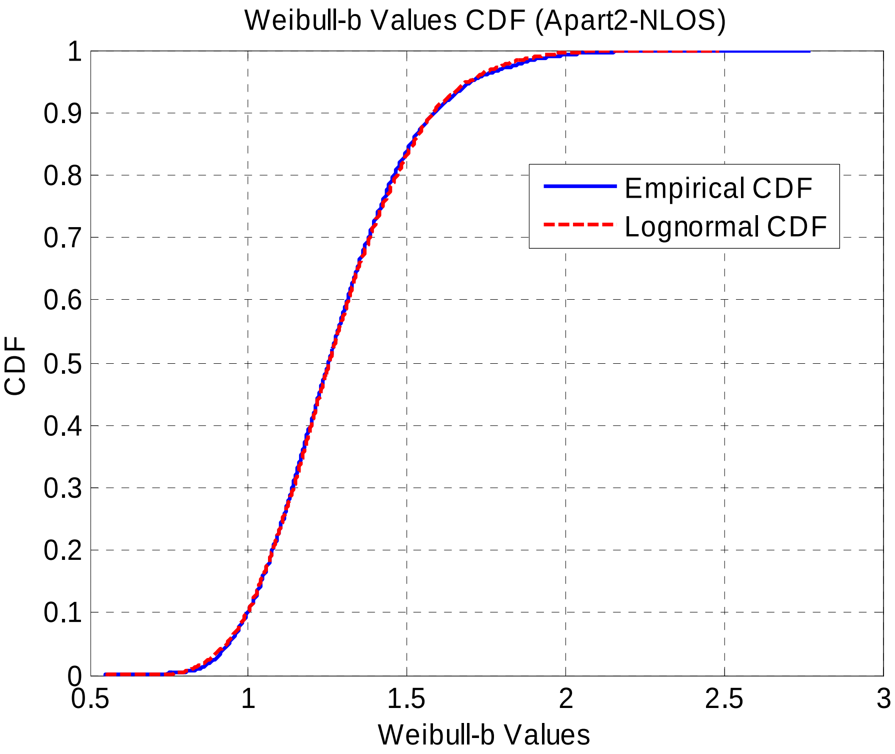
b-Weibull Parameter – LOS



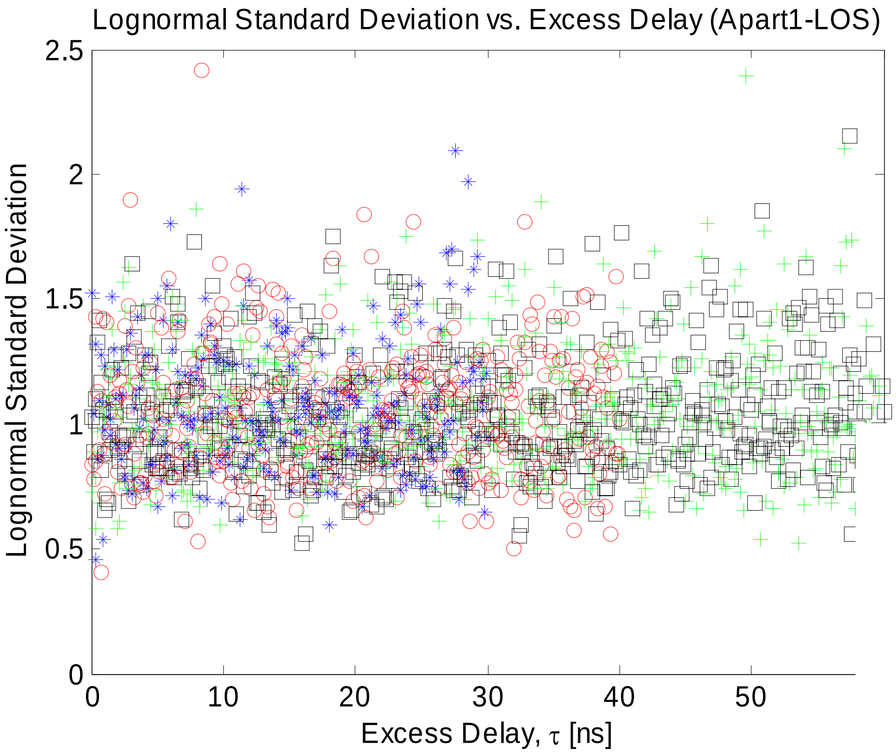


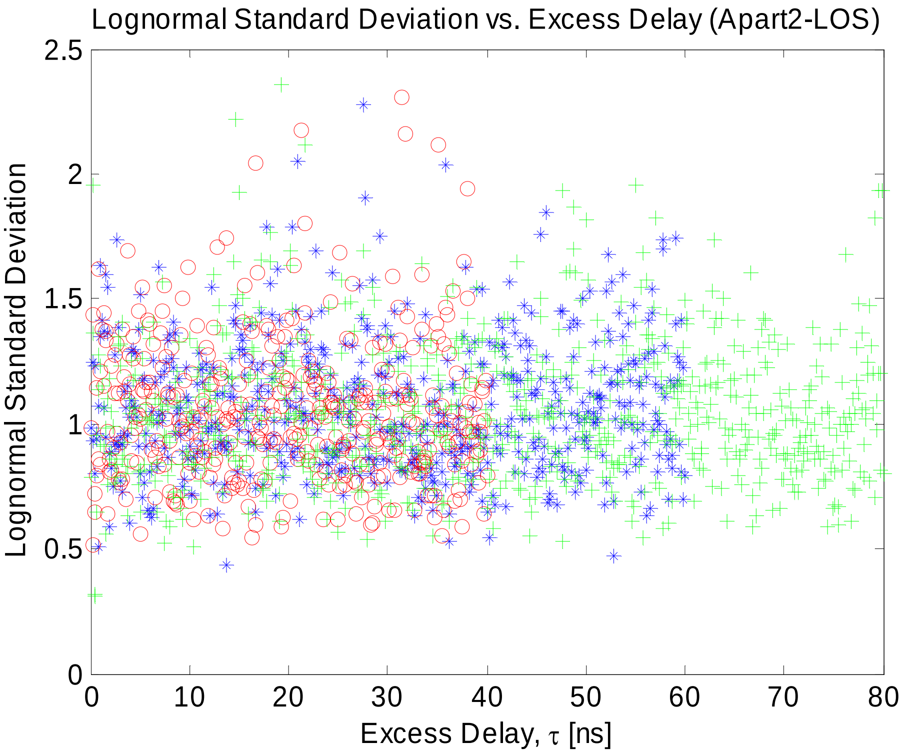
b-Weibull Parameter – NLOS



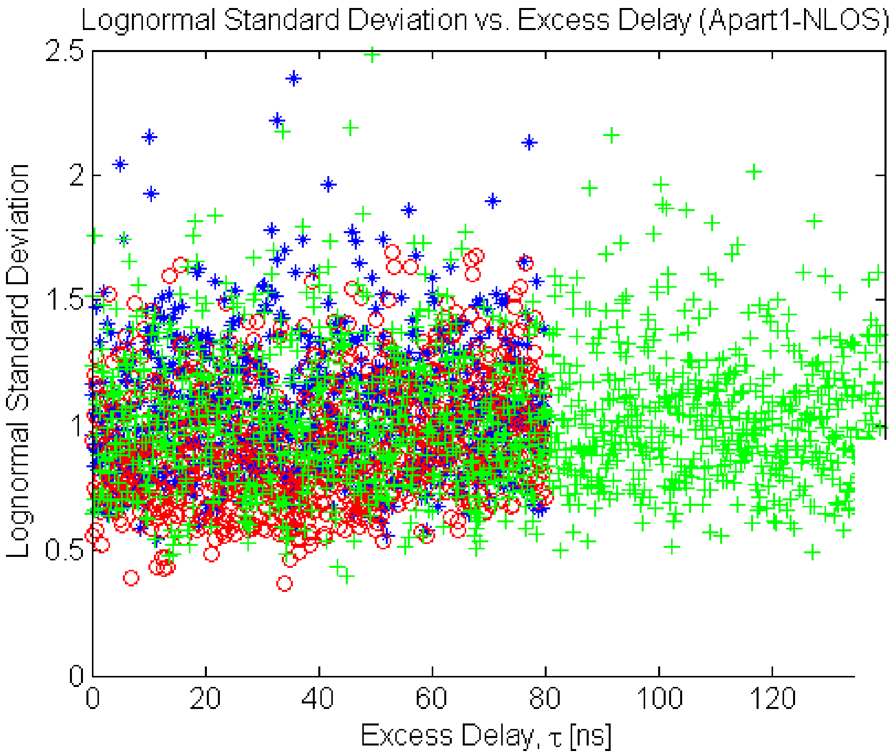


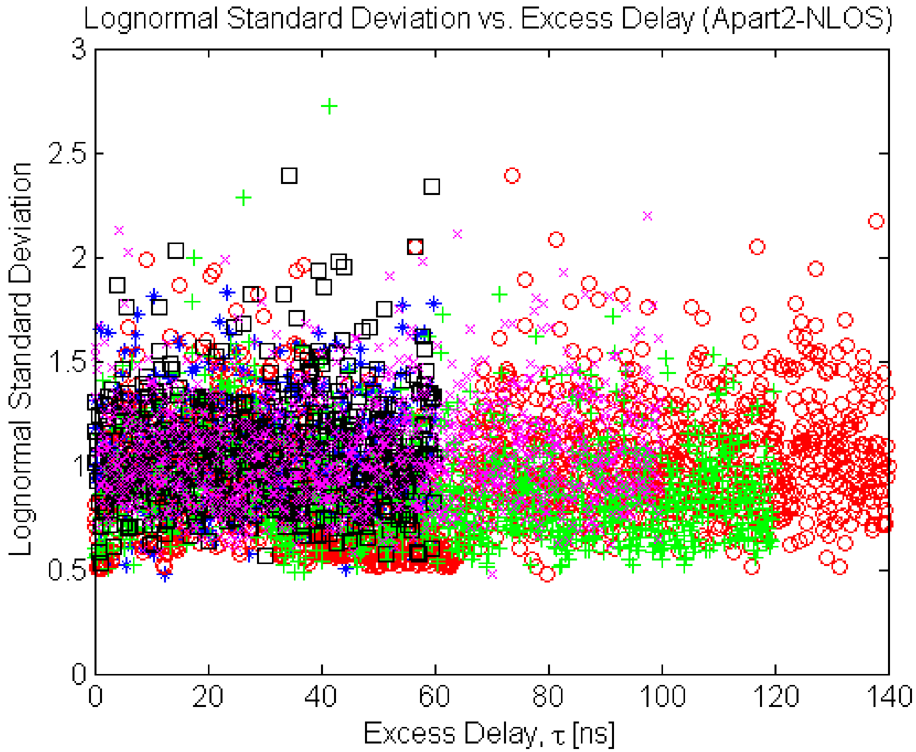
Variations of Lognormal-σ with Delay – LOS



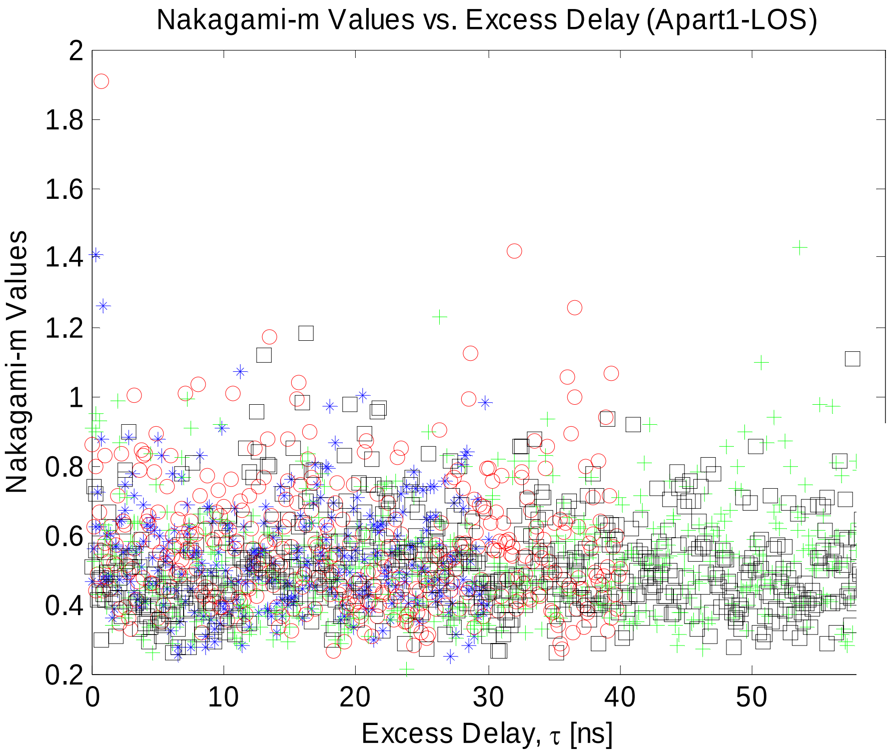


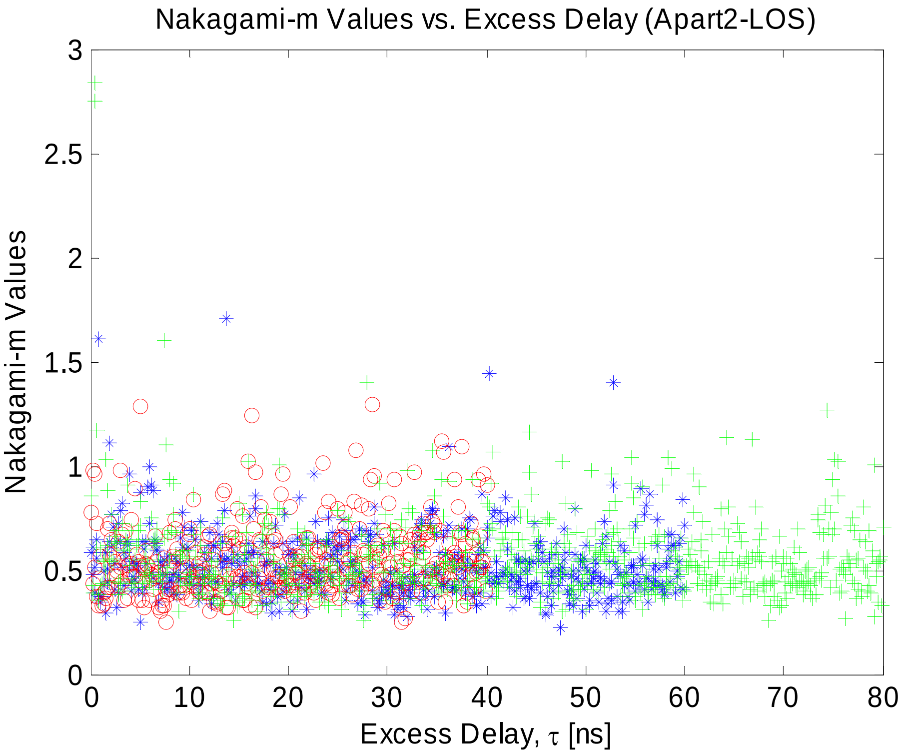
Variations of Lognormal-σ with Delay – NLOS



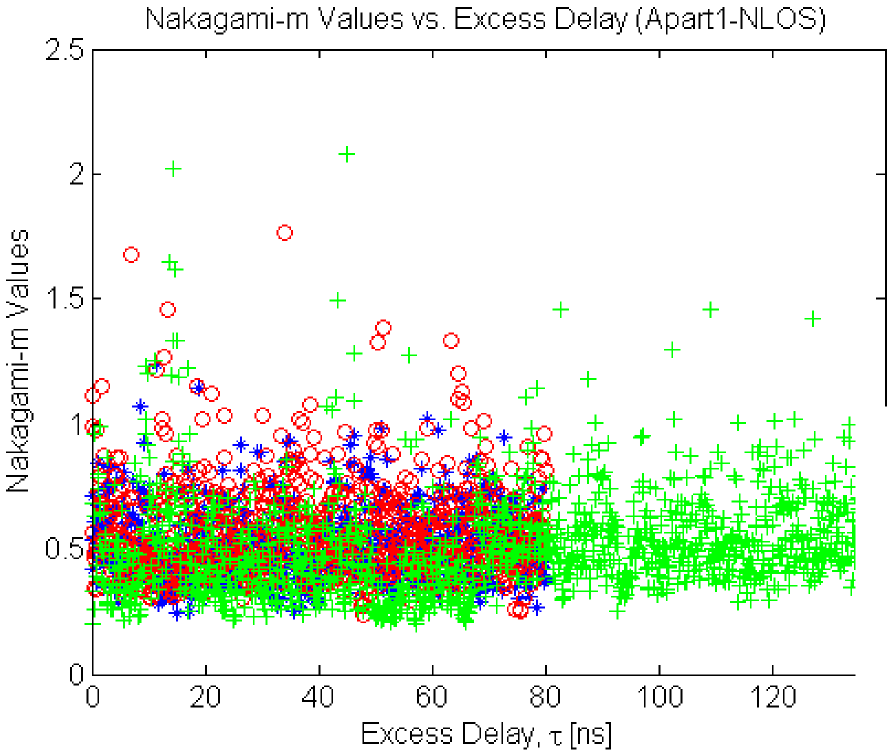


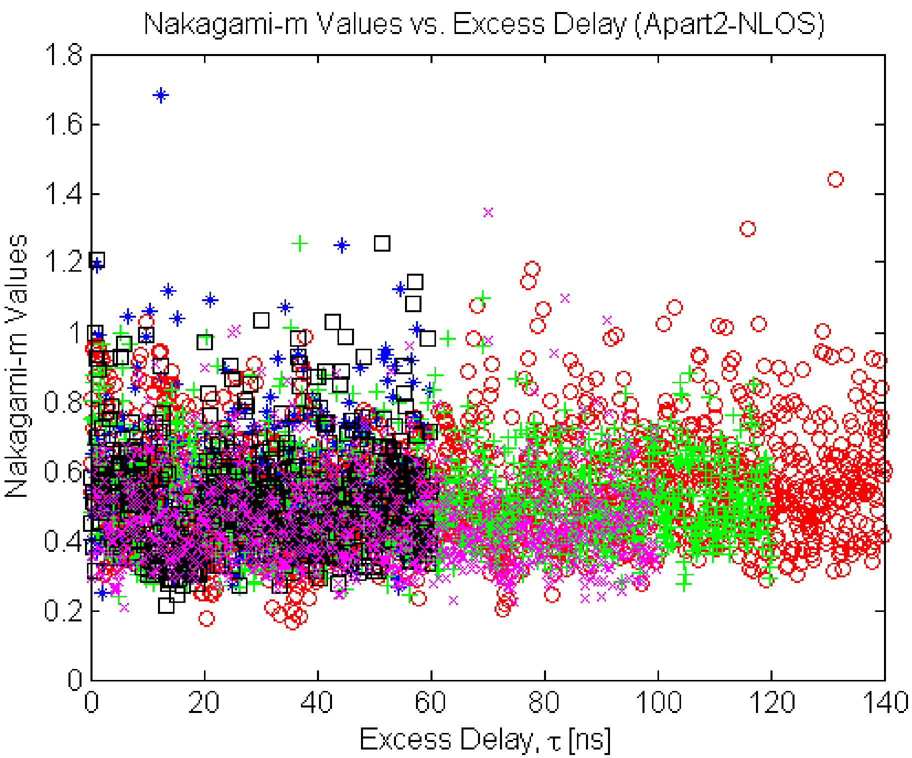
Variations of Nakagami-*m* with Delay – LOS



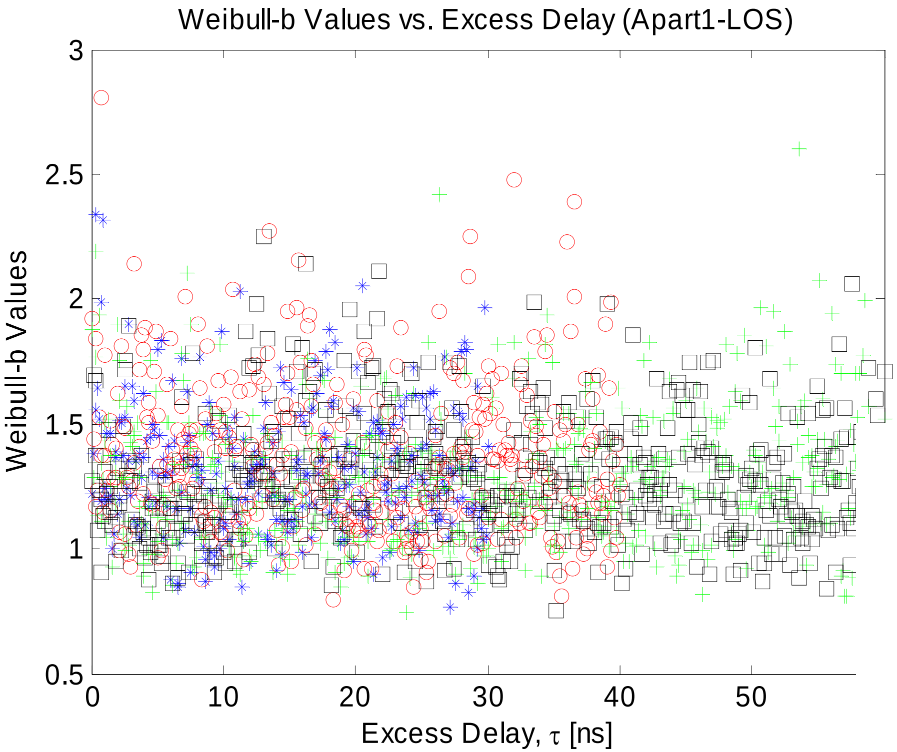


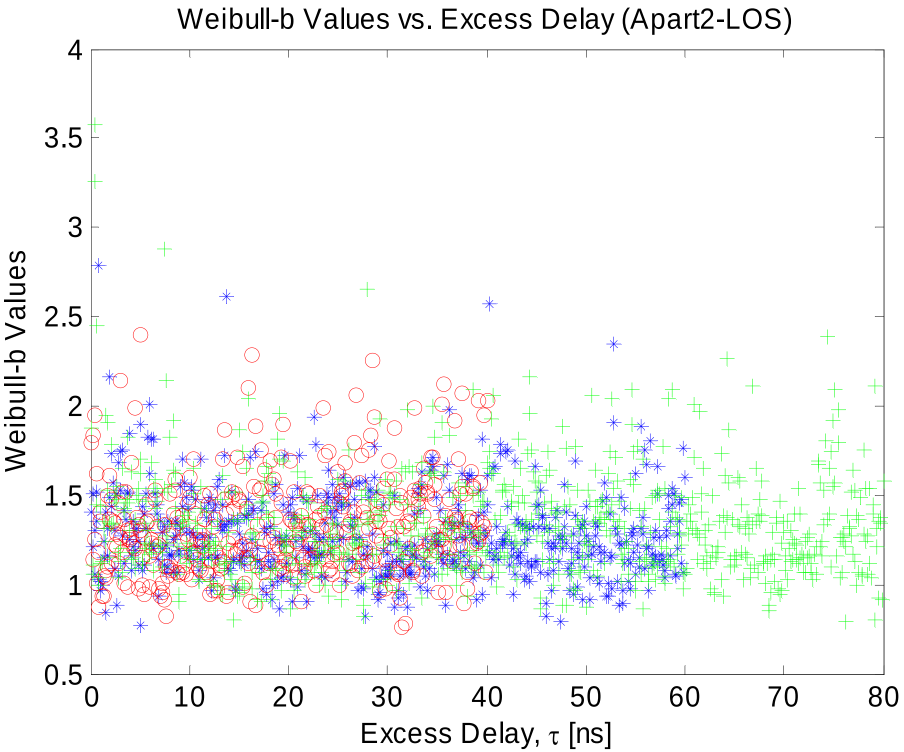
Variations of Nakagami-*m* with Delay – NLOS



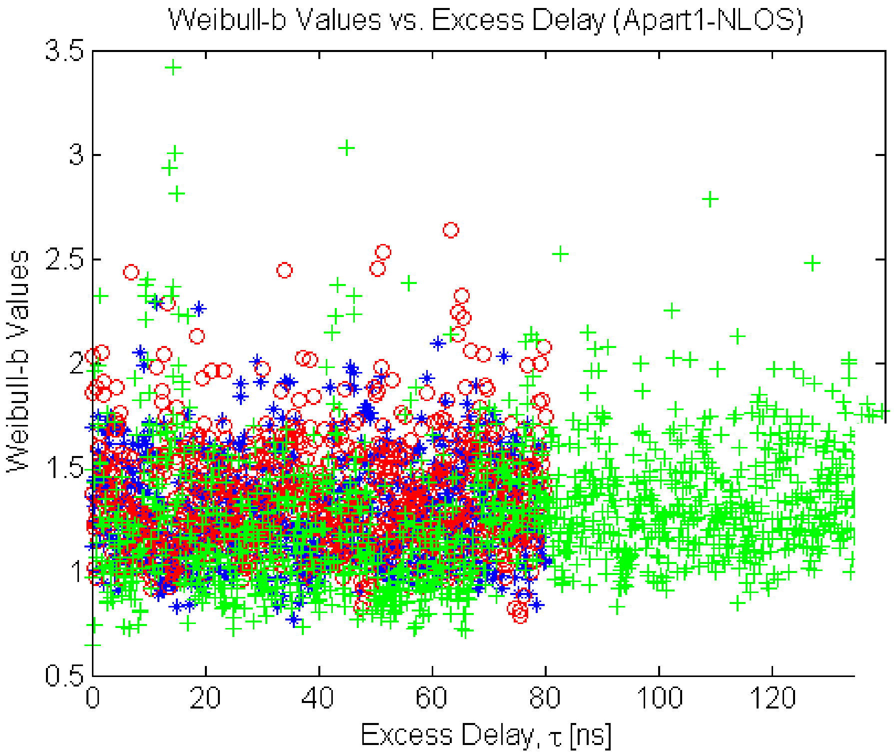


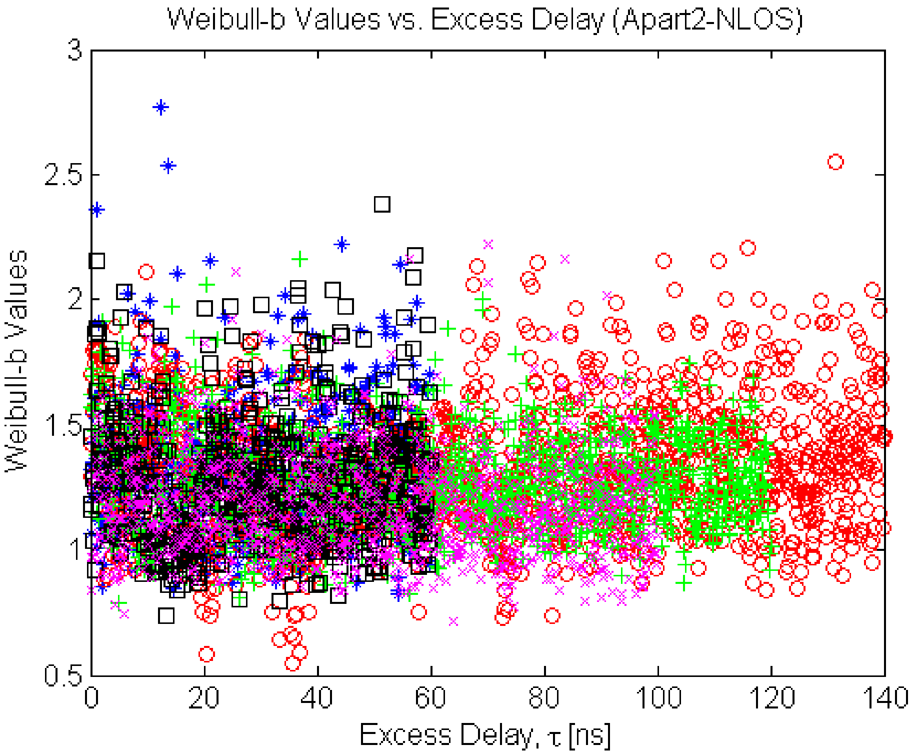
Variations of Weibull-*b* with Delay – LOS





Variations of Weibull-*b* with Delay – NLOS





Small-Scale Amplitude Statistics Parameters

Location	σ-Lognormal Parameter		*m*-Nakagami Parameter		*b*-Weibull Parameter	
	μ_{σ_L}	σ_{σ_L}	μ_{m_N}	σ_{m_N}	μ_{b_W}	σ_{b_W}
LOS (3-Bedroom Apart.)	0.022	0.23	0.68	0.28	0.24	0.19
NLOS (3-Bedroom Apart.)	0.036	0.27	0.68	0.35	0.24	0.23
LOS (4-Bedroom Apart.)	0.021	0.25	0.66	0.28	0.25	0.19
NLOS (4-Bedroom Apart.)	0.049	0.27	0.69	0.28	0.23	0.18

Conclusion

- Frequency domain technique UWB measurement campaign has been carried out in indoor residential environment (high-rise apartments) covering frequencies from 3-10 GHz.
- Measurement covered both LOS & NLOS scenarios.
- Channel measurement results which characterize both the large-scale and small-scale parameters of the channel are reported.

Reference

1. B. Kannan *et. al.*, “Characterization of UWB Channels: Small-Scale Parameters for Indoor and Outdoor Office Environment,” IEEE 802.15-04-0385-00-04a, July 2004.