802.11n Channel Model Validation

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Outline

- Overview of 802.11n channel models
- Intel's validation
  - Office environment
  - Delay spread
  - Channel capacity
  - Ricean K factor
- Zyray's validation
  - Hot spot, large office, and open space
  - Ricean K factor
  - Channel capacity
- Metalink's validation
  - Office environment
  - Time variation
  - Channel capacity
- Conclusion

802.11n Channel Models

- Extended from Medbo’s SISO models for HIPERLAN/2

Medbo’s SISO model

⇓ Cluster decomposition and angle assignment

Angular power delay profile for all taps

⇓ Integration over all angles for each tap

Correlation matrixes seen from Rx and Tx for each tap

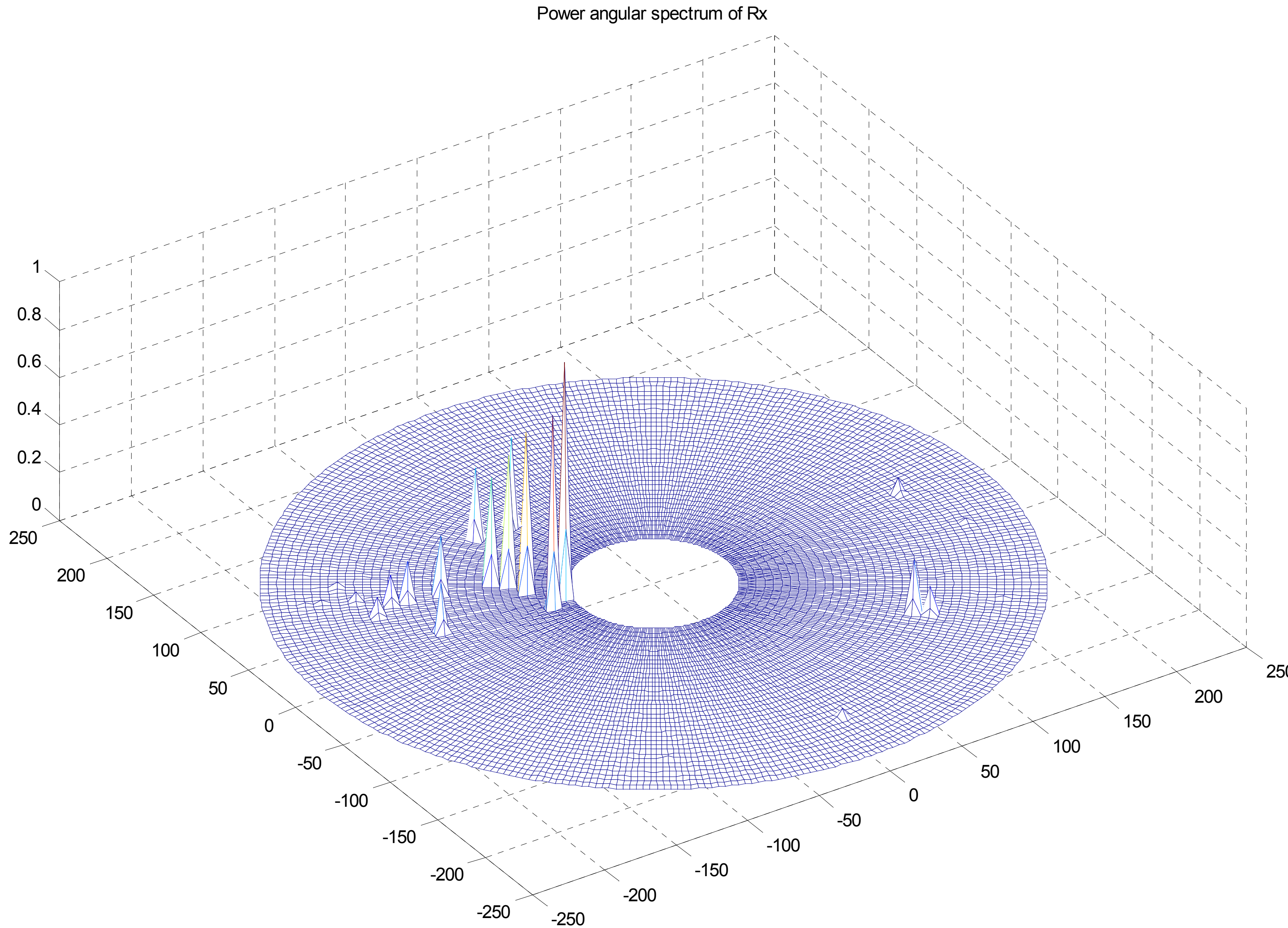
⇓ Kronecker product of Rx and Tx correlation matrixes

Correlation matrix for channel matrix entries and for each tap

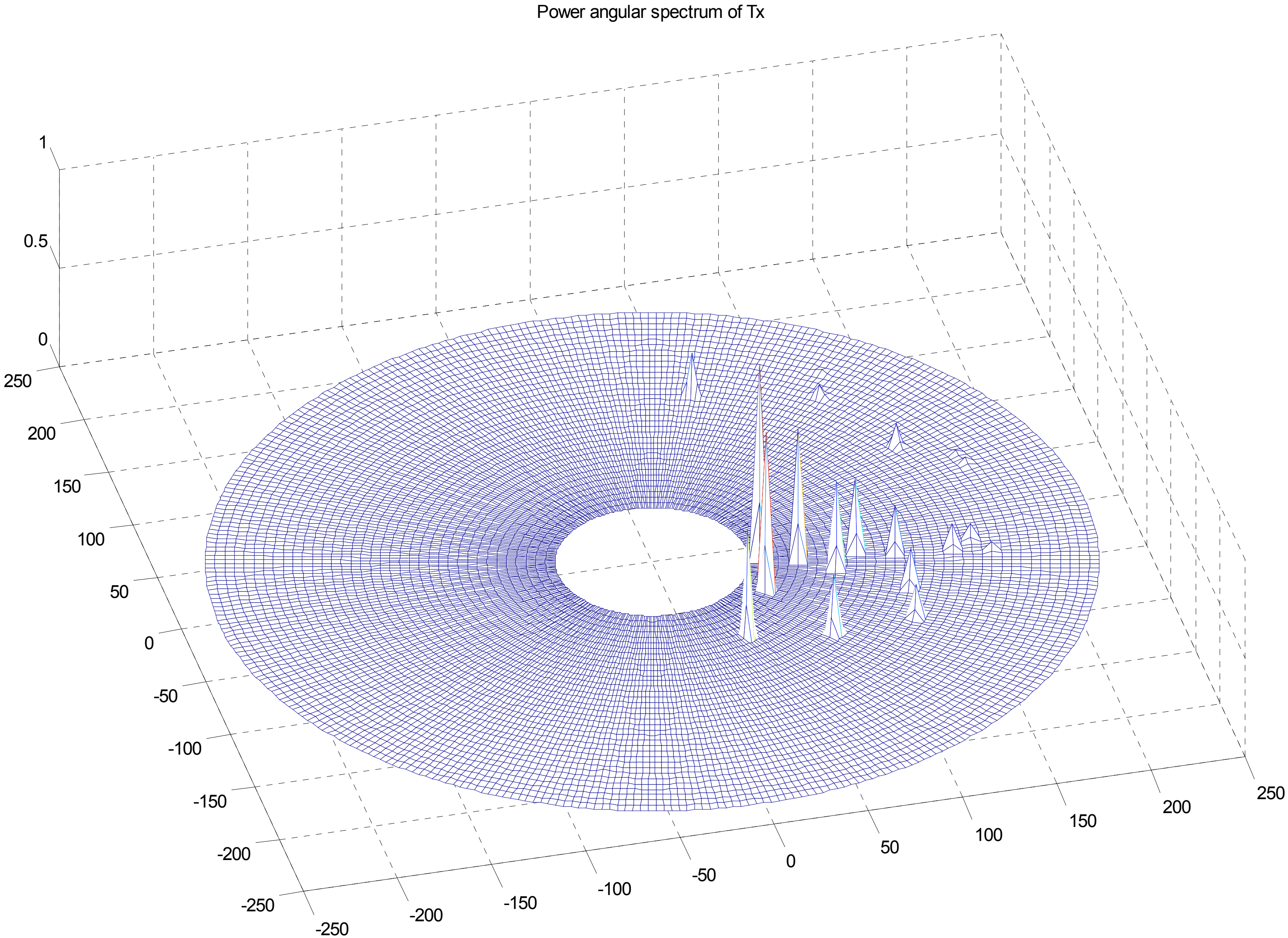
⇓ Cholesky decomposition

Generate channel matrix from i.i.d. Gaussian random variables for each tap

Multipath profile seen from receiver



Multipath profile seen from transmitter



Correlation Matrix on Transmit (Receive) Side

- For 2x2 MIMO channel, transmit (receive) correlation matrix

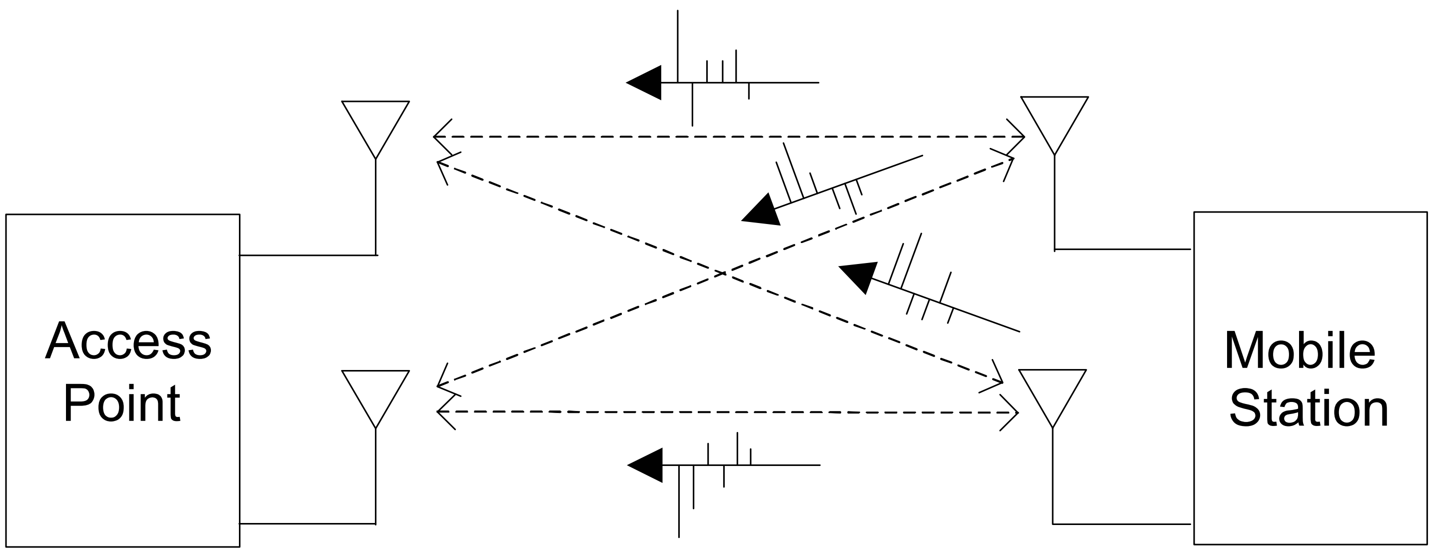
$$\mathbf{R}_{tx} = \begin{bmatrix} 1 & \rho^*_{tx12} \\ \rho_{tx21} & 1 \end{bmatrix} \qquad \mathbf{R}_{rx} = \begin{bmatrix} 1 & \rho^*_{rx12} \\ \rho_{rx21} & 1 \end{bmatrix}$$

- Channel matrix **H** for the *i*th tap

$$\mathbf{H}(i) = [\mathbf{R}_{rx}(i)]^{1/2}\,[\mathbf{H}_{iid}][\mathbf{R}_{tx}(i)]^{1/2}$$

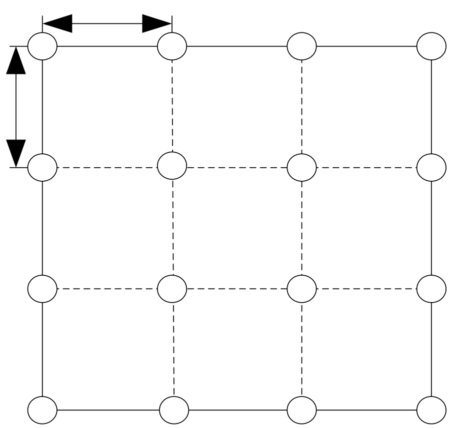
User Interface

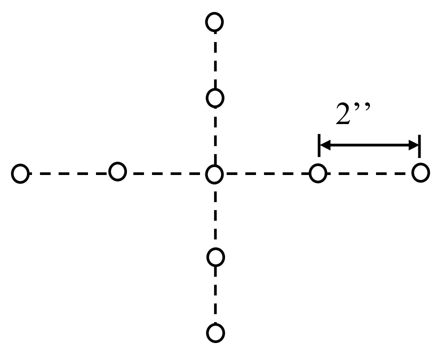
- Simple user interface: No. of antennas, spacing, 2.4/5.2 GHz, channel type
- The model delivers time domain channel impulse response for each Tx/Rx antenna pair.



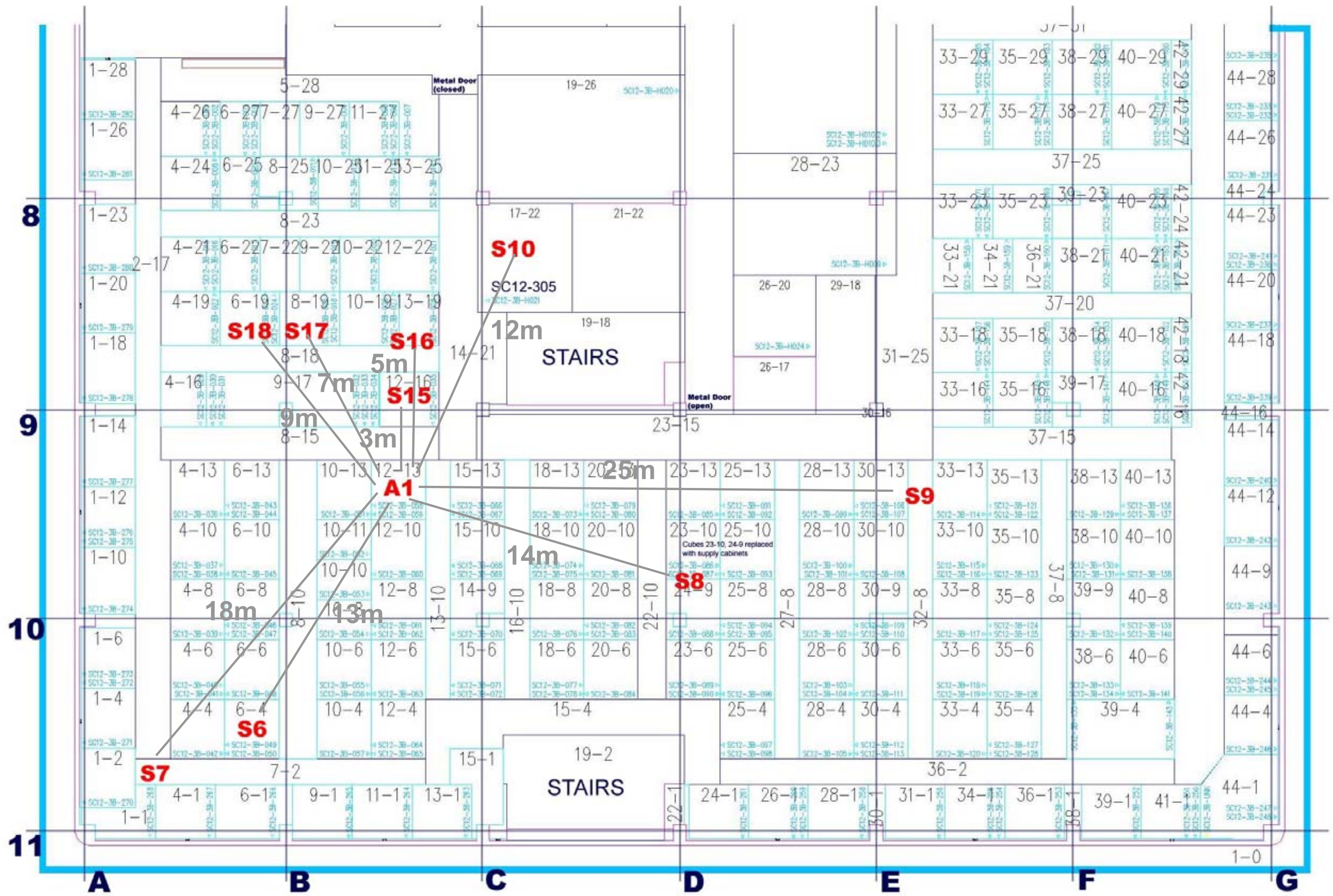
Intel’s Measurements

- One (typical) office environment
- Distance 5-25 m and RMS delay 23-79 ns
- 2.4 GHz and 5.2 GHz
- 2 inch and 4 inch antenna spacing
- 20,000 measured 4x4 channels and 9 locations.





Measurement Locations



RMS Delay Spread

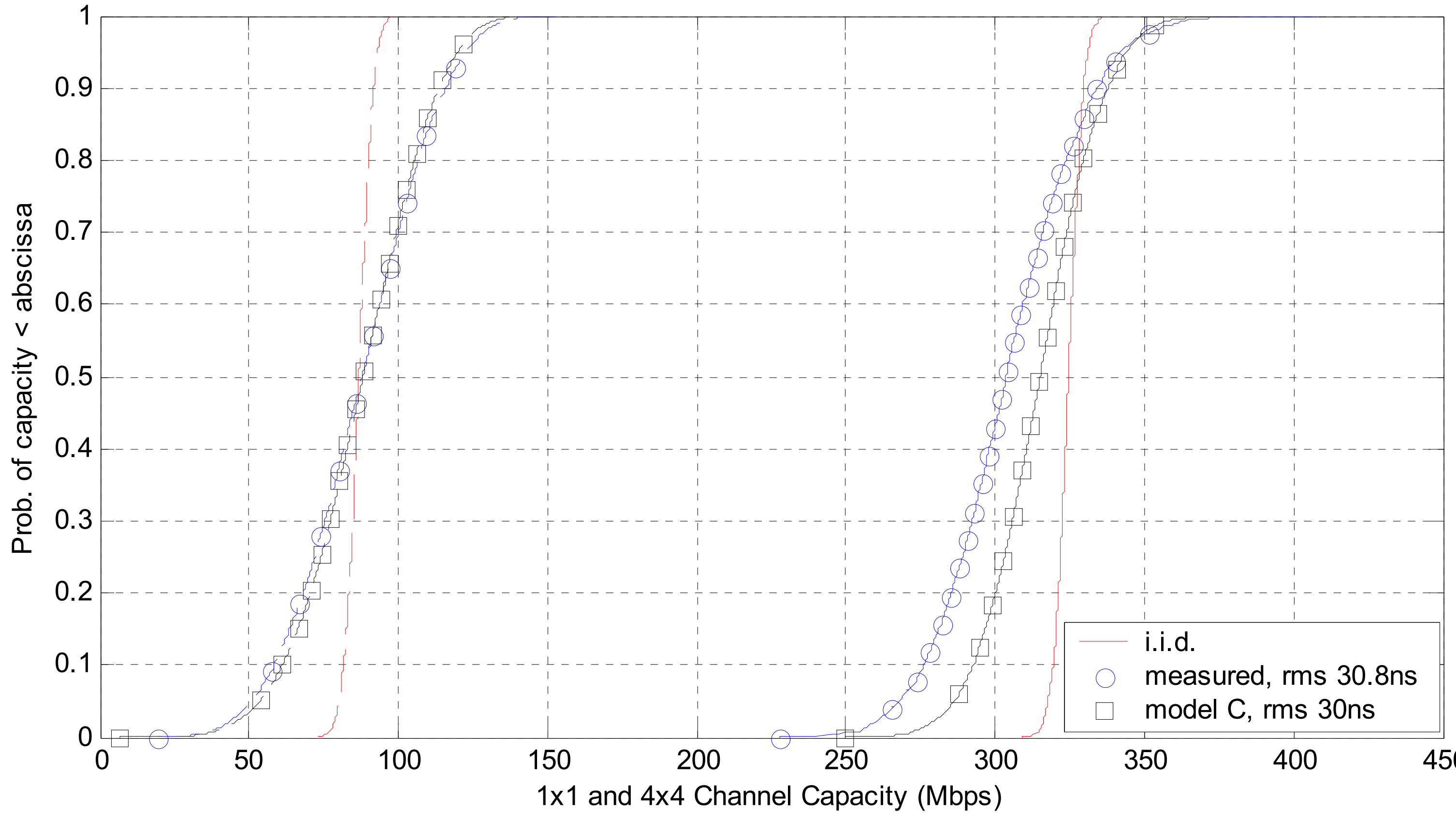
- Mean and standard deviation of RMS delay spreads in measurements

	S16—seq. 30	S15—seq. 29	S17—seq. 31	S18—seq. 32	S6—seq. 15	S8—seq. 20	S10—seq. 22	S7—seq. 19	S9—seq. 21
τ_{rms} Mean (ns)	23.6	27.4	34.1	38.5	56.5	63.4	67.3	68.2	79.2
τ_{rms} STD (ns)	5.5	4.9	6.1	6.2	5.6	6.4	8.0	6.2	9.1

- RMS delay spreads in the models
  - Model C: 30 ns small office
  - Model D: 50 ns typical office
  - Model E: 100 ns large office

1x1 and 4x4 Channel Capacity

- SNR 15 dB; 5.2 GHz band; 20 MHz bandwidth; 4'' spacing
- CDF of 1x1 and 4x4 capacity



Capacity of 4x4 Channels in 5.2 GHz Band

- 4x4 channel with 20 MHz bandwidth and 4’’ spacing
- SNR 15dB
- Model error is less than 5%

	Model Capacity (Mbps)	Measured Capacity (Mbps)	Difference (%)
Model C	315	305	3.4
Model D	324	312	3.9
Model E	311	299	4.1
IID Channel	325		

Capacity of 4x4 Channels in 2.4 GHz Band

- 4x4 channel with 20 MHz bandwidth and 2’’ spacing
- SNR 15dB
- Model error is less than 15%

	Model Capacity (Mbps)	Measured Capacity (Mbps)	Difference (%)
Model C	245	288	14.9
Model D	285	290	1.6
IID Channel	325		

MIMO Multiplier in 5.2 GHz Band

- 1x1 and 4x4 channels with 20 MHz bandwidth
- SNR 15dB
- MIMO multiplier is about 3.6
- Models match measurements for both 1x1 and 4x4 channels

	1x1 Capacity (mbps) Model, Measured	4x4 Capacity (mbps) Model, Measured	4x4 Cap. / 1x1 Cap. Model, Measured
Model C	88, 87	315, 305	3.5, 3.6
Model D	86, 87	324, 312	3.6, 3.7
Model E	87, 86	311, 299	3.5, 3.6
IID Channel Model	87	325	3.7

MIMO Multiplier in 2.4 GHz Band

- 1x1 and 4x4 channels with 20 MHz bandwidth
- SNR 15dB
- MIMO multiplier is about 3.3
- Models match measurements for 1x1 and 4x4 channels
- Model C slightly underestimates 4x4 capacity

	1x1 Capacity (mbps) Model, Measured	4x4 Capacity (mbps) Model, Measured	4x4 Cap. / 1x1 Cap. Model, Measured
Model C	88, 88	245, 288	2.8, 3.3
Model D	87, 87	285, 290	3.3, 3.3
IID Channel Model	87	325	3.7

Measured K Factors

- K factor is less than 0 dB in measured channels
- LOS component is not dominant

Set #	Perspective	STA Location	Distance (m)	LOS/ NLOS	K factor (dB)
1	AP	S1	3	LOS	-3.56
1	STA	S1	3	LOS	-6.24
2	STA	S2	19	NLOS	$-\infty$
3	AP	S4	11	NLOS	-3.86
4	AP	S5	13	NLOS	$-\infty$
5	AP	S12	13	NLOS	$-\infty$
5	STA	S12	13	NLOS	-4.18
6	AP	S13	12	NLOS	-1.11
6	STA, conf.	S13	12	NLOS	$-\infty$
7	AP	S20	8.5	NLOS	-2.23
7	STA	S20	8.5	NLOS	-5.71

- D. Cheung, C. Prettie, Q. Li, and J. Lung, “Ricean K factor in office cubicle environment” IEEE doc: 802.11-03/xxxr0, Nov. 2003.

Summary of Intel's Validation

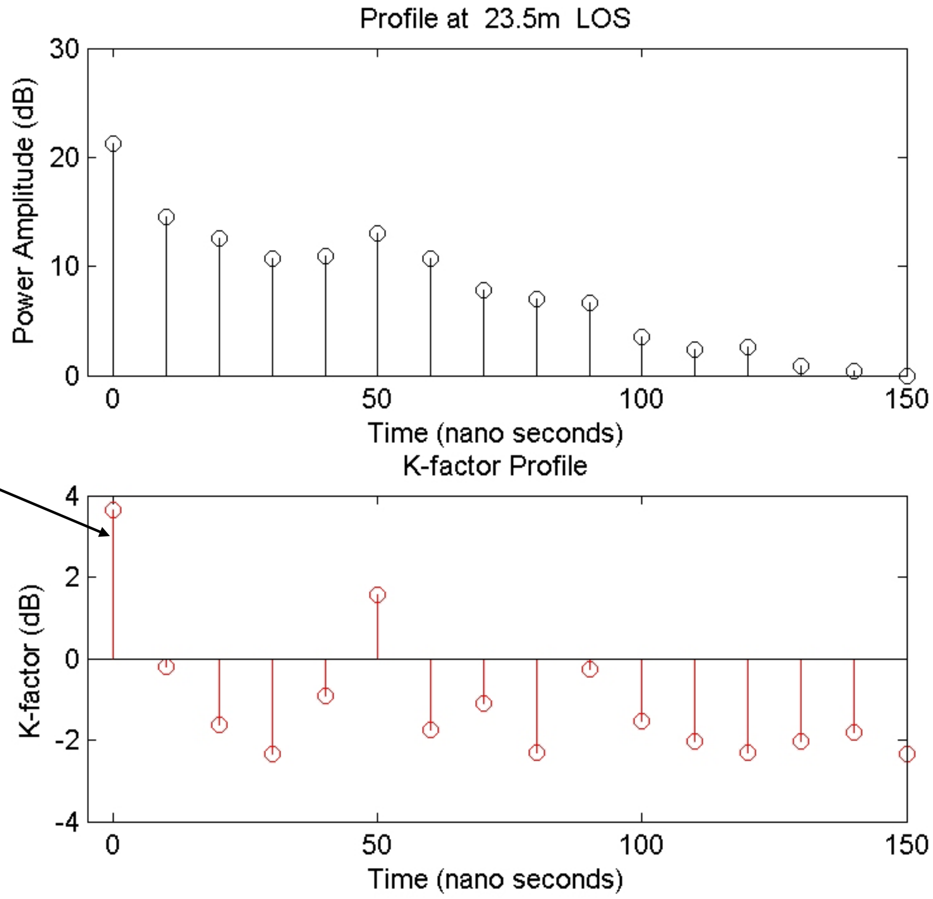
- Channel capacities of three office models (C,D,E) match measurements for 2.4 GHz band, 5.2 GHz band, and 2 antenna spacings
- Measured delay spreads match measurements
- 4x4 capacity is 3.6 and 3.3 times of 1x1 capacity for 2λ and $\lambda/2$ spacing respectively
- K factor is small in the office environment

Zyray's Measurements

- Large indoor environments (office, cafeteria) - Mainly Models D and E equivalent, partially F (only LOS).
- 5.25 GHz frequency
- 4x4 MIMO measurements
- Dipole antennas
- Antenna spacing: $\lambda/2$
- LOS and NLOS conditions, 1 – 50 m
- 500 MIMO channel snapshots at each location over 2.5 m distance (10 sec. measurement), 40 locations

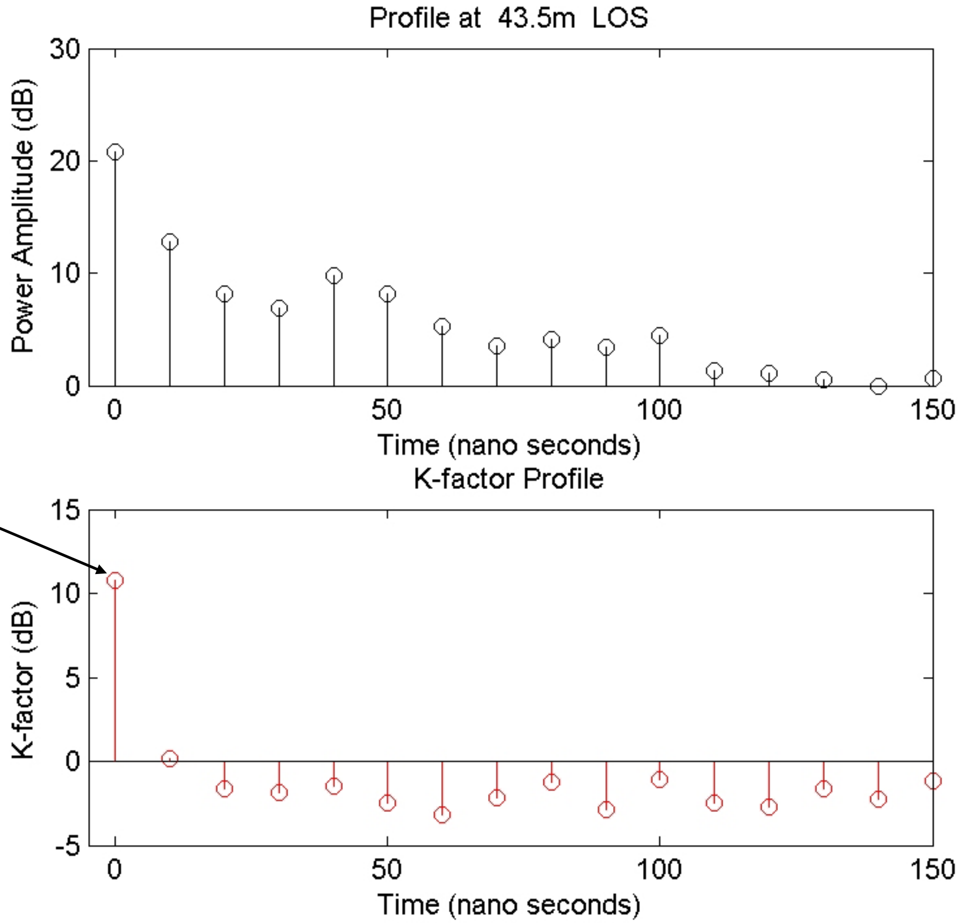
K-factor Experimental Data Results
LOS, d=23.5m

High K-factor on
the first tap



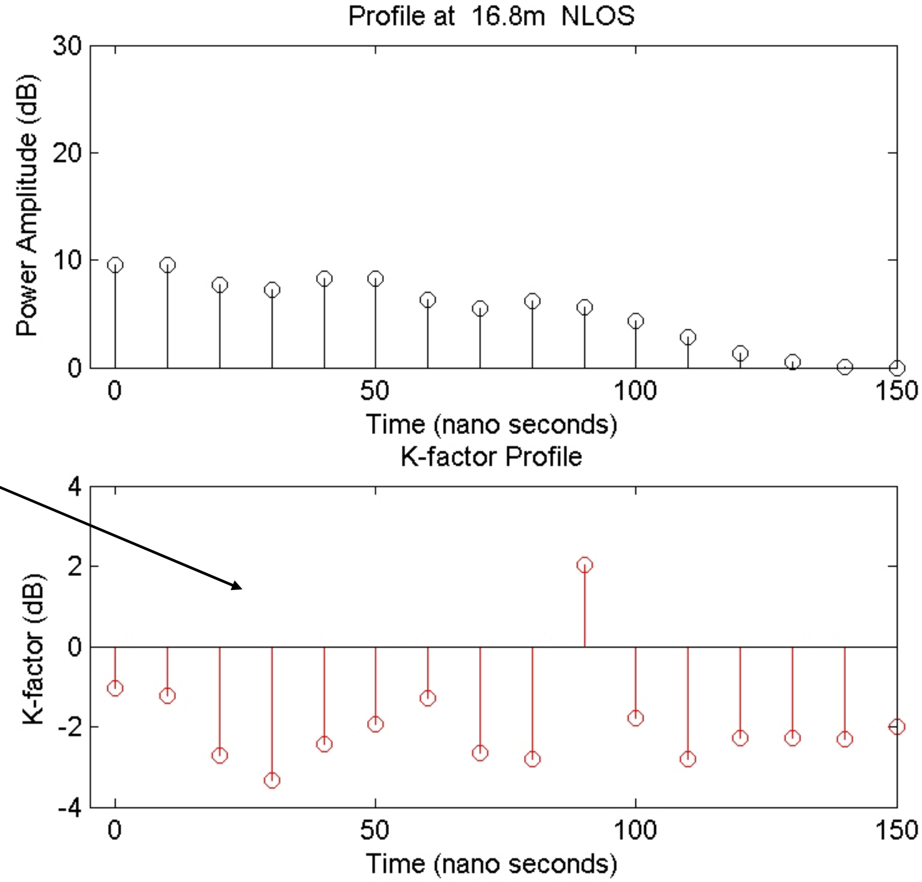
K-factor Experimental Data Results
LOS, d=43.5m

High K-factor on the first tap

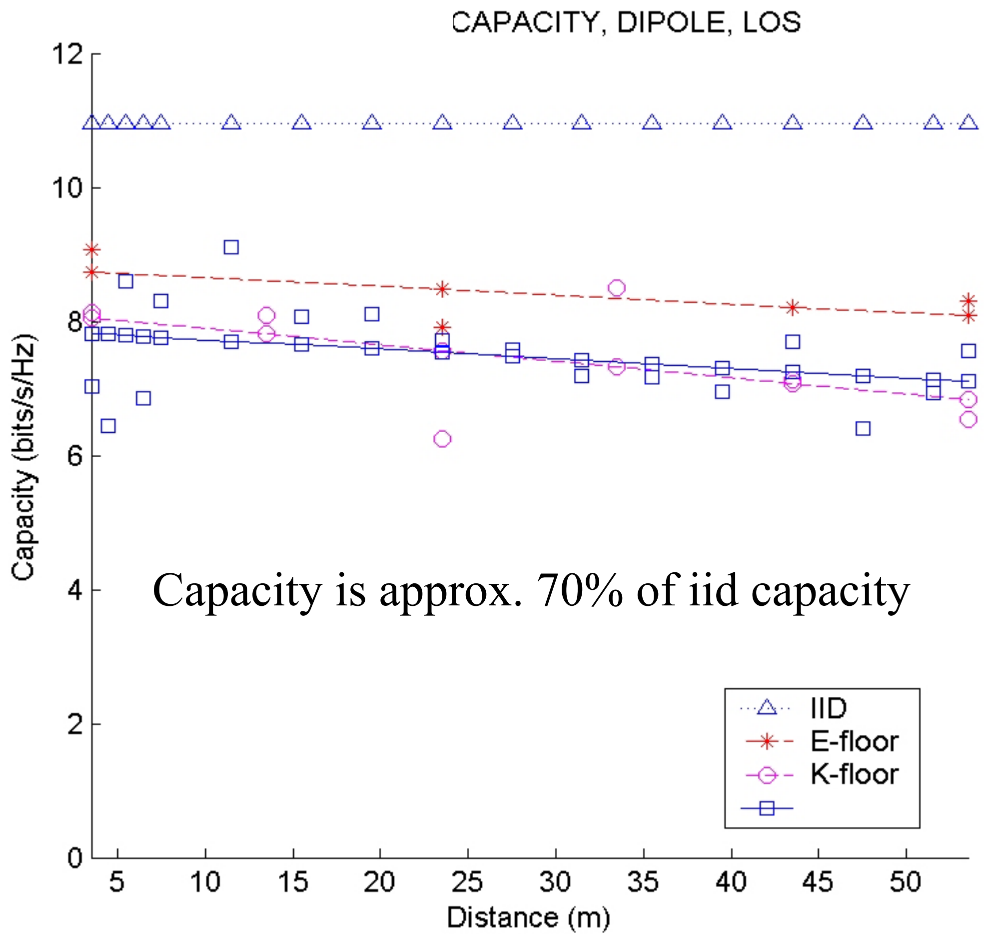


K-factor Experimental Data Results
NLOS, d=16.8m

Generally no high K-factors



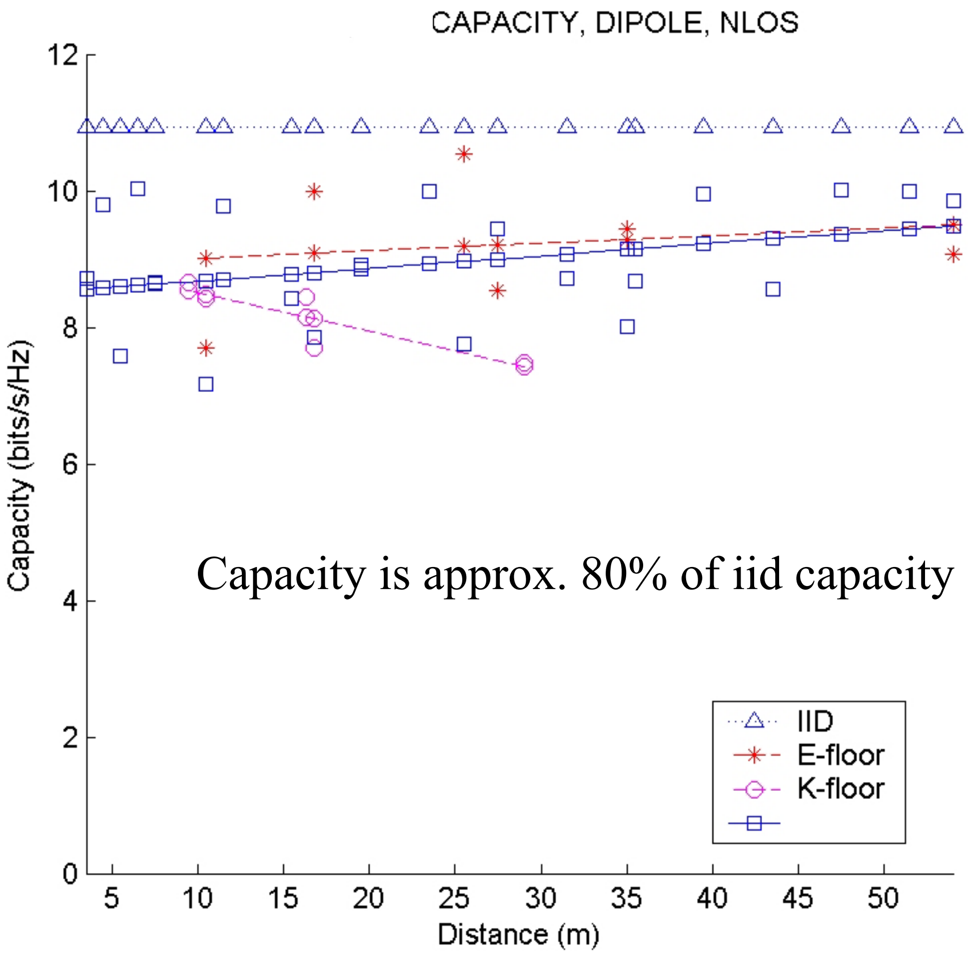
4 x 4 MIMO Capacity Results
LOS



Capacity is approx. 70% of iid capacity

Parameters:
SNR = 10 dB
Antennas: Dipole
Antenna spacing: λ/2

4 x 4 MIMO Capacity Results NLOS



Parameters:
SNR = 10 dB
Antennas: Dipole
Antenna spacing: λ/2

Summary of Zyray’s Validation

For the Models D and E and partially F (only LOS) equivalent environments following was found from the experimental data:

- LOS K-factor is in the range 2-10 dB
- NLOS K-factor is < - 2 dB in most cases
- LOS 4x4 MIMO capacity is approx. 70% of iid
- NLOS 4x4 MIMO capacity is approx. 80% of iid

The results match proposed models well.

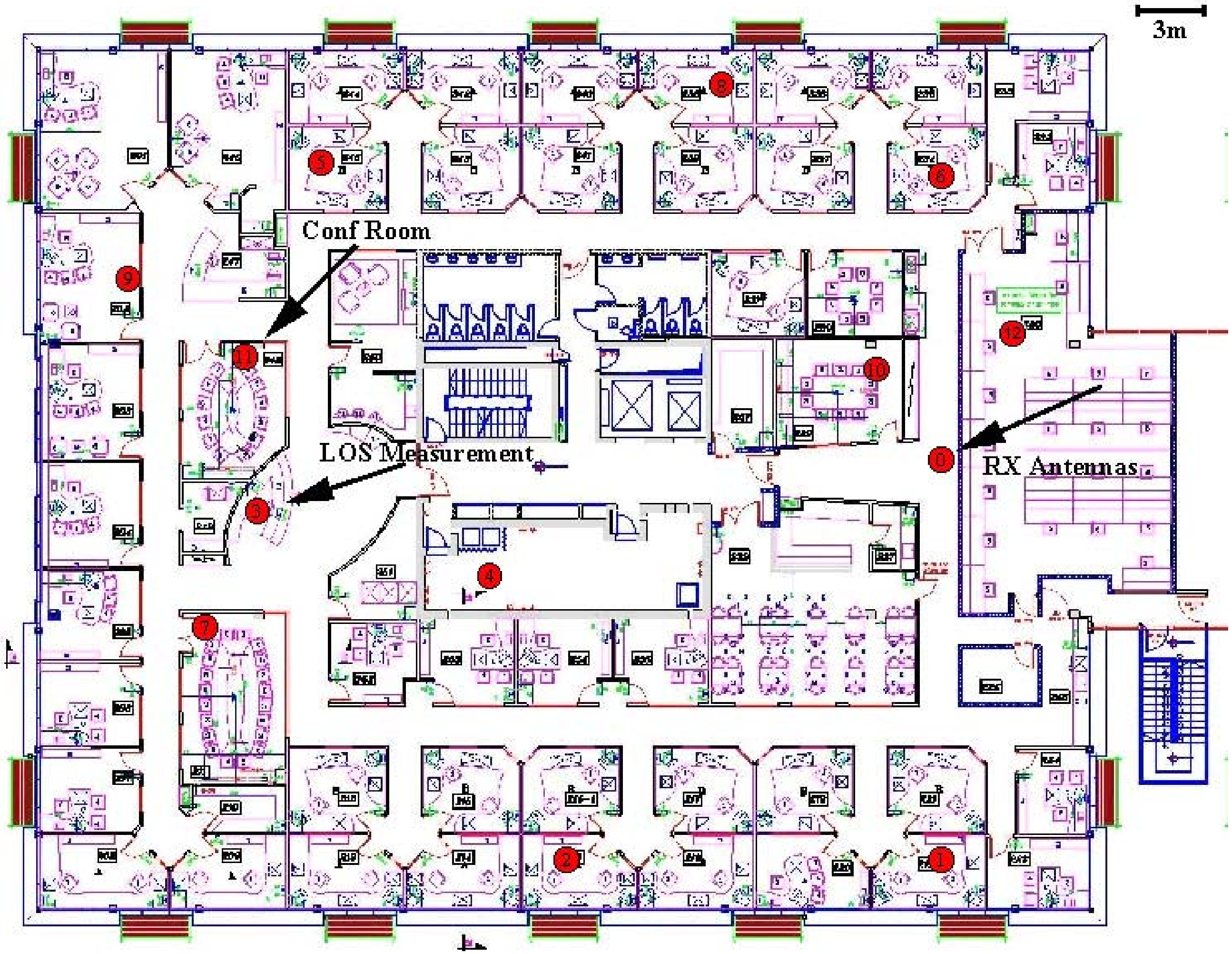
Metalink's Measurements

- About 500,000 measurements taken at various locations and scenartios within the company.
- Measurements were taken at the lower UNII band (~5.2 GHz)
- Receive antennas fixed at a height of ~2m (e.g. AP position)
- TX setup moves between measurement positions

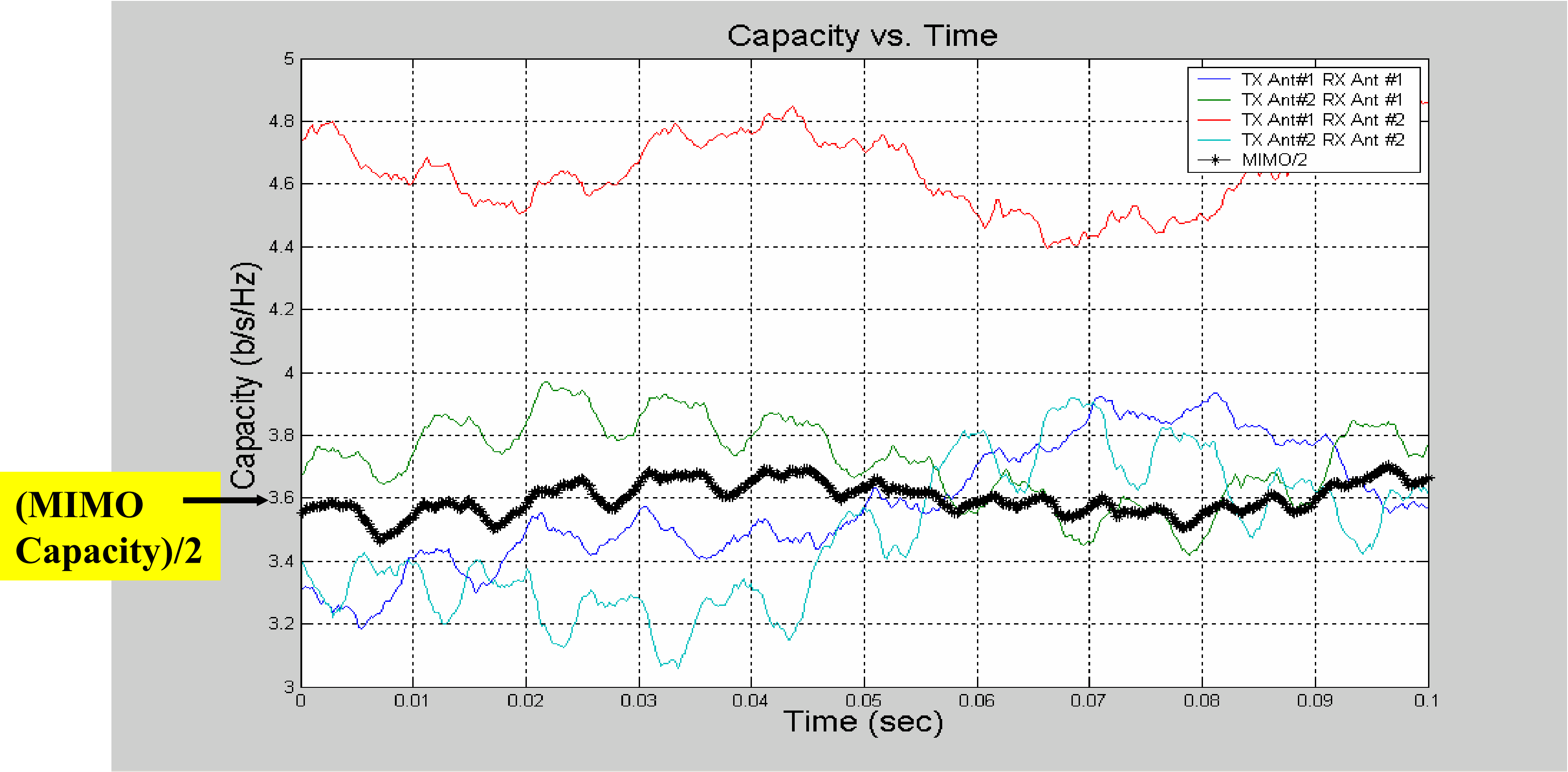
Measurement Set Up

- Philosophy:
  - Full simultaneous MIMO measurements
  - Relatively slow sampling rate (46MHz)– long sampling period (100msec)
  - Store all samples and post-process offline
  - Use wideband transmission signals (>20MHz)
  - Omni reception and transmission antennas with ~λ/2 spacing

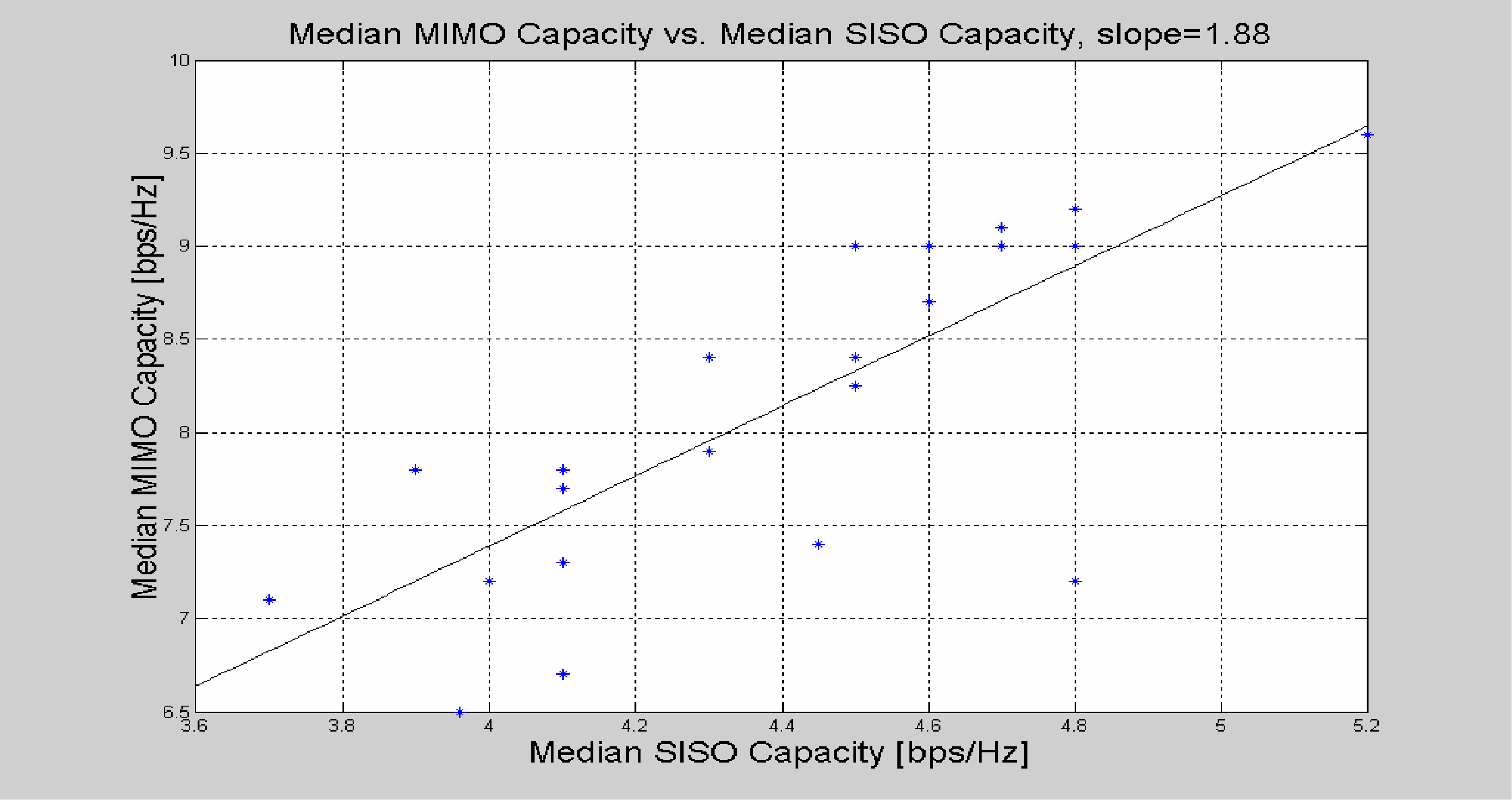
Indoor Measurement Locations



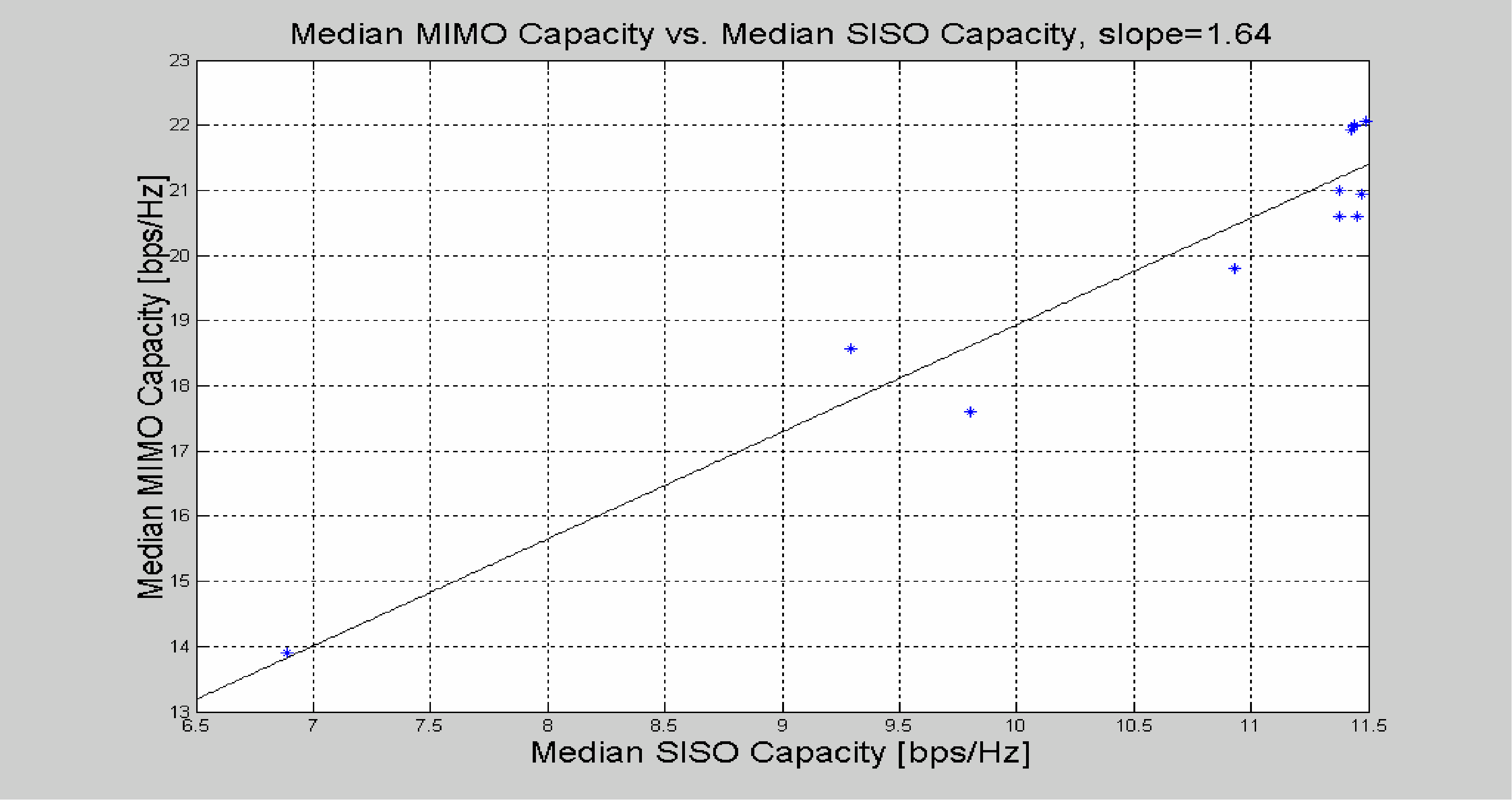
Real-Environment Calculated Capacity
(M11-14)



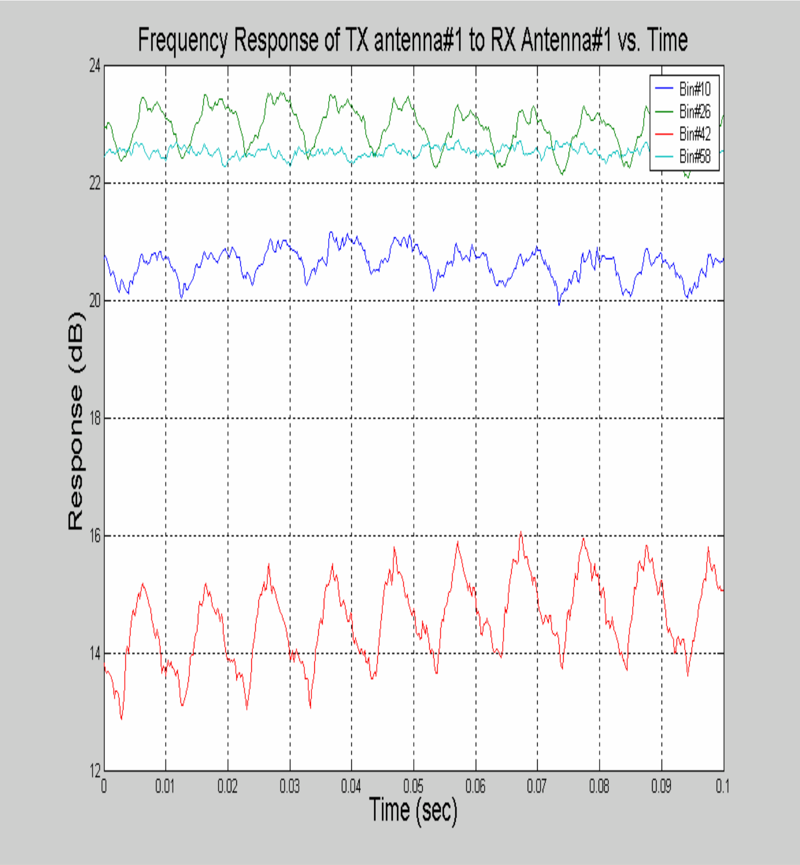
MIMO Capacity Enhancement-NLOS, Dist= 25.6m (M11-XX)



MIMO Capacity Enhancement- LOS, Dist=25m (M11-XX)



Periodic Modulation



- In nearly all tests, a strong AM-like periodicity is clearly seen.
- The period of this modulation was tested to be exactly 100Hz

The Fluorescent Effect

- Fluorescent lights become conductive twice every AC power cycle.
- During that period, the electromagnetic environment (reflections) are changed.
- The channels in such environment exhibit strong AM modulation in all parameters (frequency response, RMS delay spread, capacity, etc.)
- The Fluorescent effect has been incorporated into the channel model

Summary of Metalink's Validation [6]

- In typical enterprise scenario 2 antenna MIMO enhances the median capacity by 1.5-2x (NLOS and LOS)
- Channels exhibits "slow" variability changes over 100ms (f<10Hz)
- In the vicinity of fluorescence lights the channel is modulated by a 100/120Hz AM modulation
- These results are already integrated into the channel models

Conclusion

- Validation covers model C, D, E, and F
- 1x1, 2x2, and 4x4 channel capacity match measurements on both 2.4 and 5.2 GHz
- Model K factors match measurements
- Time variation due to fluorescent lights are included in the models
- MIMO multipliers are about 1.8 and 3.5 for 2x2 and 4x4 channels respectively

References

- [1] V. Erceg, et al, “Indoor MIMO WLAN Channel Models,” IEEE Doc. No. 802.11-03/161r2, Sept. 2003.
- [2] N. Tal, “Time Variable HT MIMO Channel Measurements,” IEEE 802.11-03/515r0, July 2003.
- [3] A. Jagannatham, V. Erceg, “Indoor MIMO Wireless Channel Measurements and Modeling at 5.25 GHz,” Document in preparation, Sept. 2003.
- [4] D. Cheung, C. Prettie, Q. Li, and J. Lung, “Ricean K factor in office cubicle environment” IEEE doc: 802.11-03/xxxr0, Nov. 2003.
- [5] – Branka Vucetic, “Space-Time Coding”, Wiley& Sons, 2003
- [6] – Tal, et. al, “Fluorescent light bulb interaction with electromagnetic signals”, IEEE 11-03-718-04-000n.