Using Extreme Sensitivity GPS for In-building to Out-door Propagation Modeling

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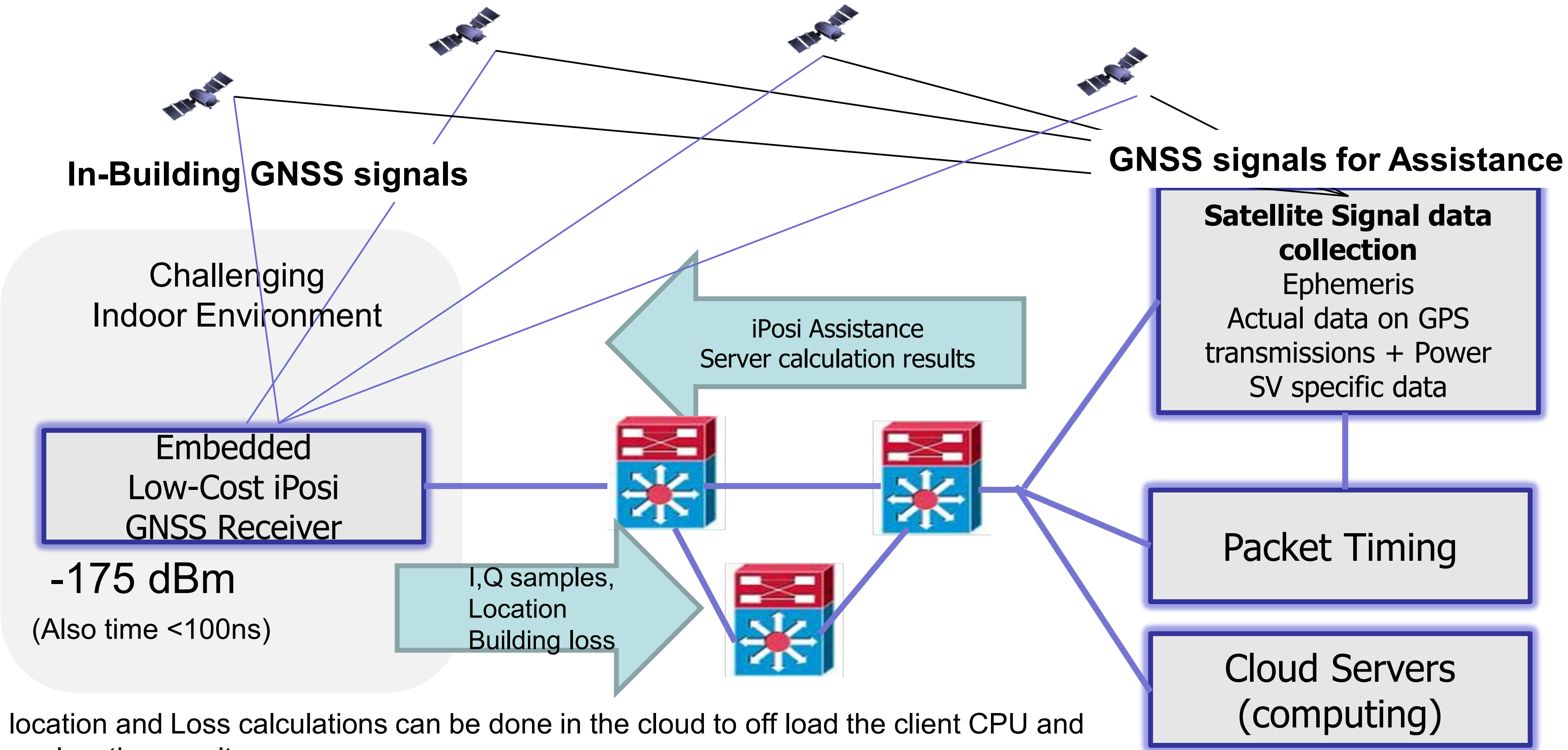
Agenda

- iPosi technology brief
- iPosi GPS measurement capability and verification
- Use of GPS measurements to protect CBRS FSS and Radar scenarios with simulation results

iPosi Internet Assisted-GNSS Service Platform



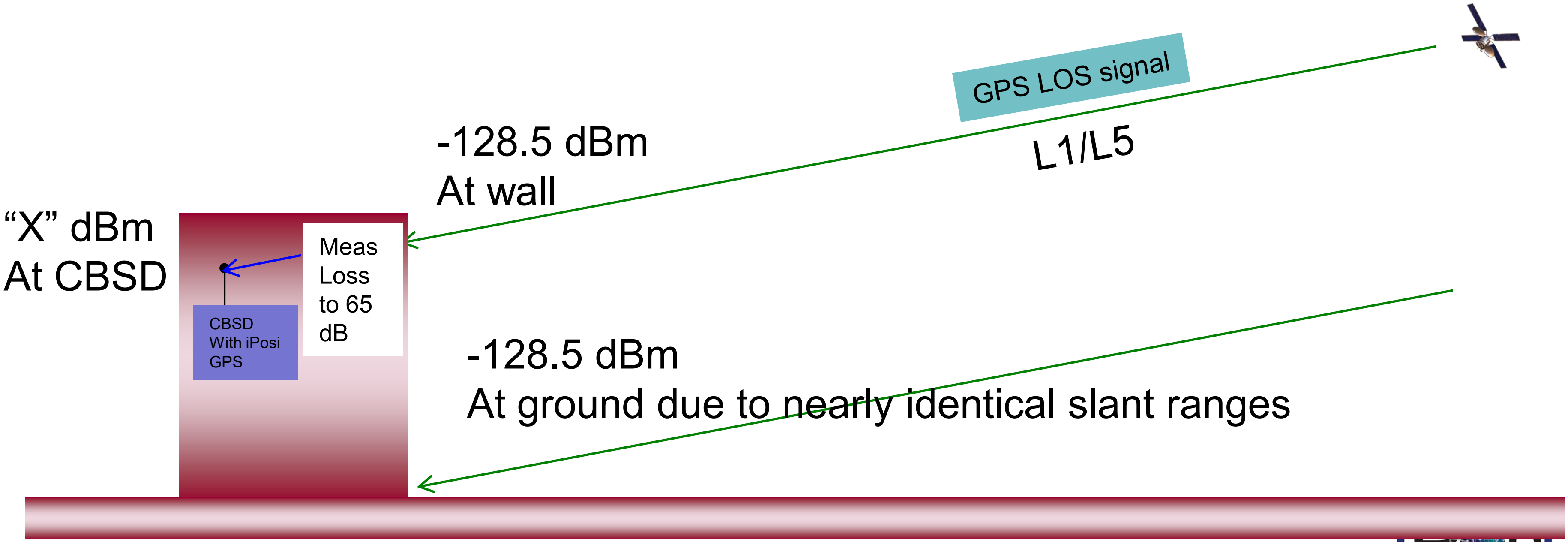
iPosi location and Loss calculations can be done in the cloud to off load the client CPU and enhance location results

iPosi Measurements

- Capability
  - Indoor location
  - Indoor sync to < 100 ns
  - Indoor loss measurements
- Dynamic range
  - GPS SV's power is >=-128.5 dBm on the ground and measured by reference stations
  - iPosi assistance and long time integration yield L1 C/A sensitivity to -175 dBm
  - Building loss measurement dynamic range is -128.5 - -175=46.5 dB plus 4 dB for higher building penetration at L1 for 50.5 dB
- L5
  - Will yield 4 dB more due to L5 higher power increasing dynamic range for a total of 54.5 dB (55 dB)
    - Penetration also increases at least 1 dB

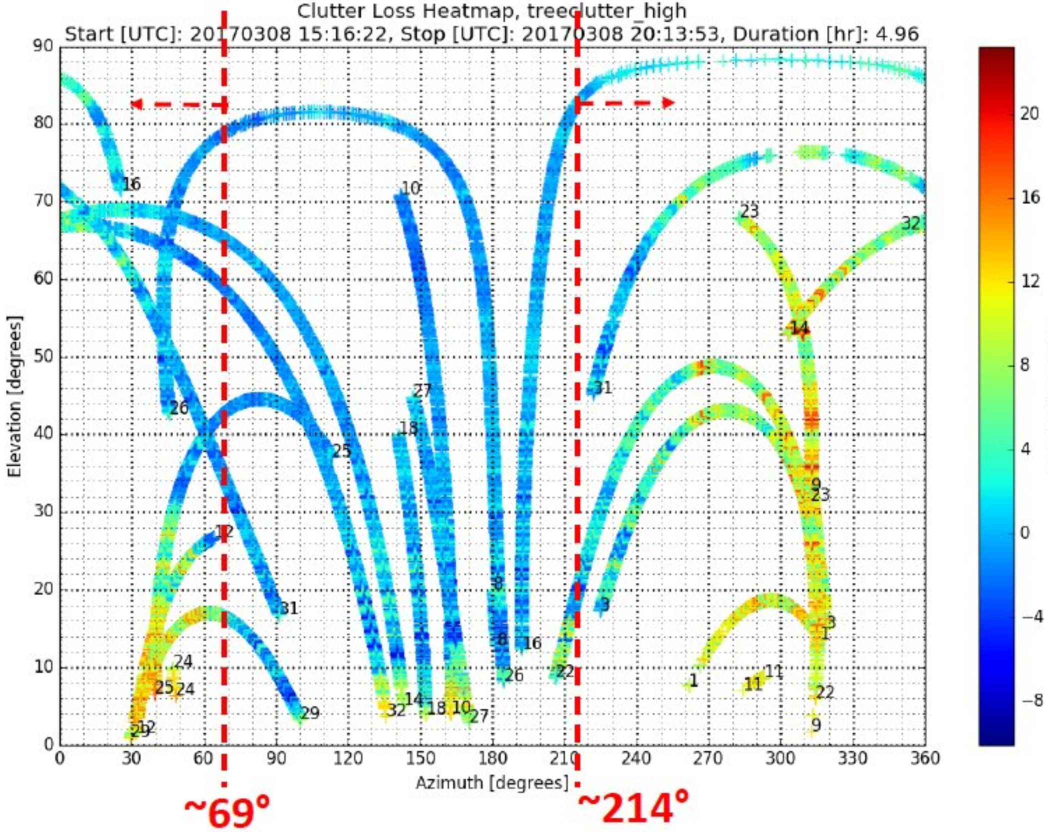
GPS Measurements On Indoor CBSDs

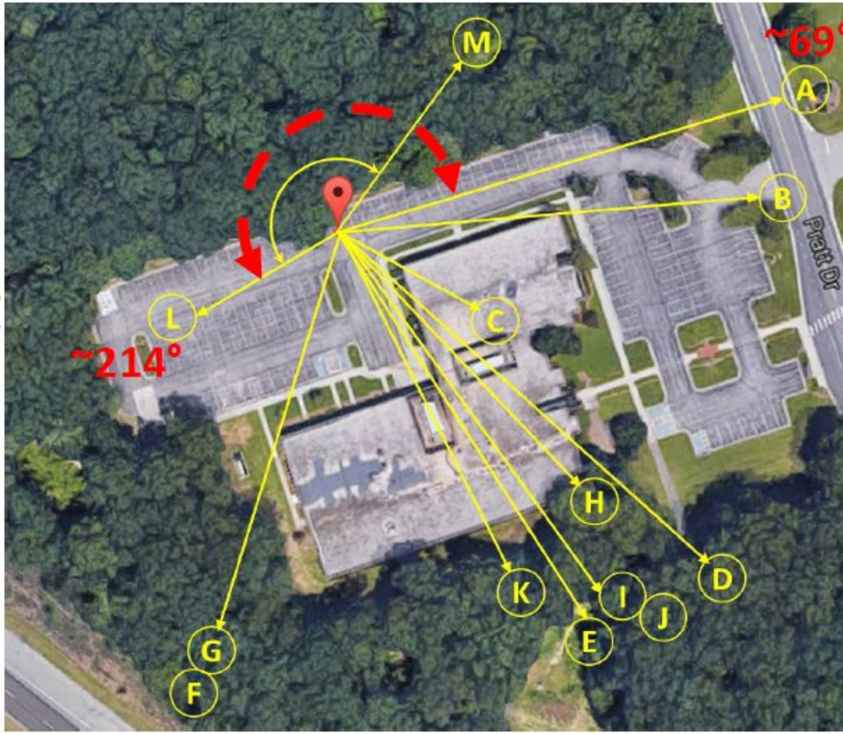
- Extreme sensitivity GPS receiver measures loss indoors with GPS L1/L5 (and other systems)
  - Can also be used outdoors to measure clutter



Sample Outdoor Data Set by VT

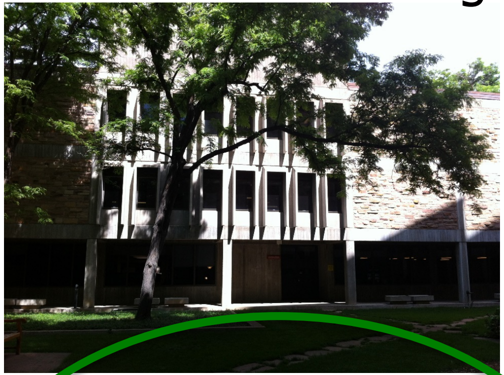
Successful Measurement Campaign of Clutter Loss Vs. Az. And El.





iPosi Measured Building loss with GPS-Example

CU EECE Building

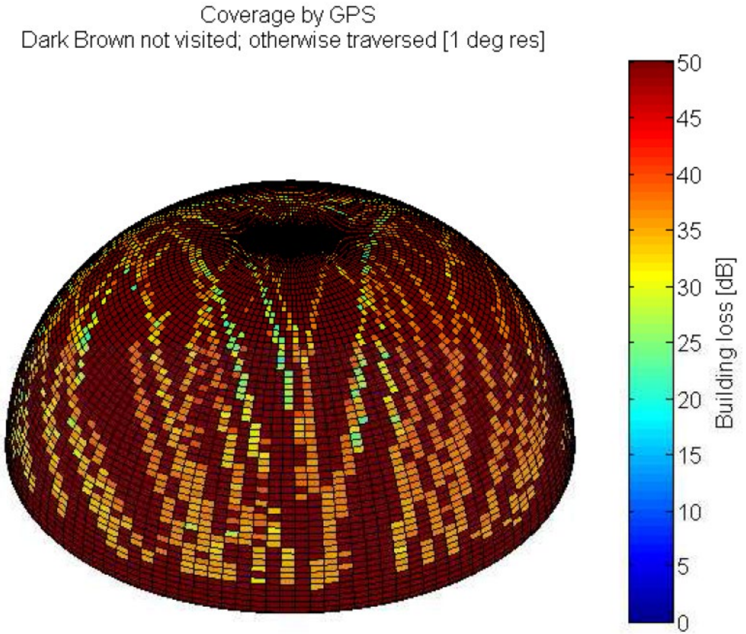


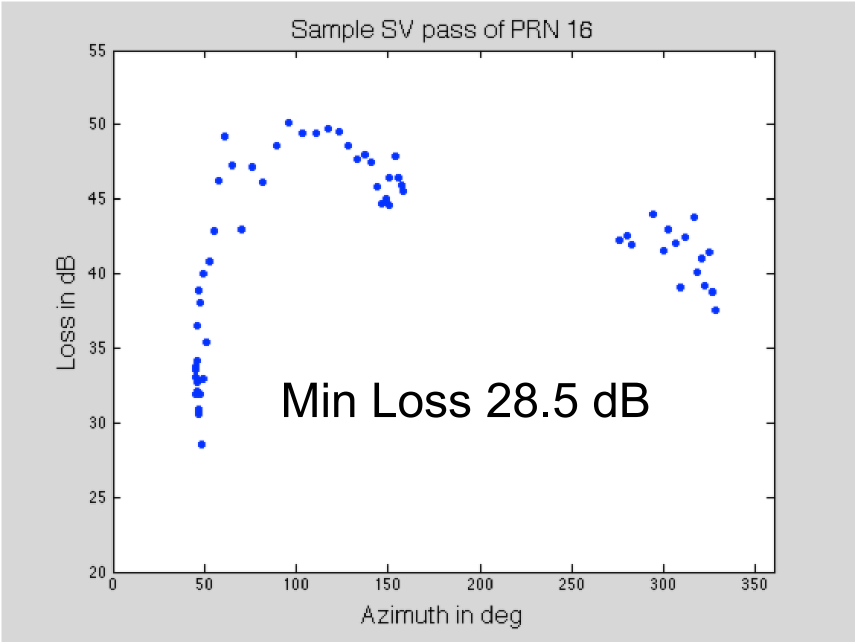
iPosi Facility

Suburban House

Data for basement next page

University Of Colorado Engineering Building Basement

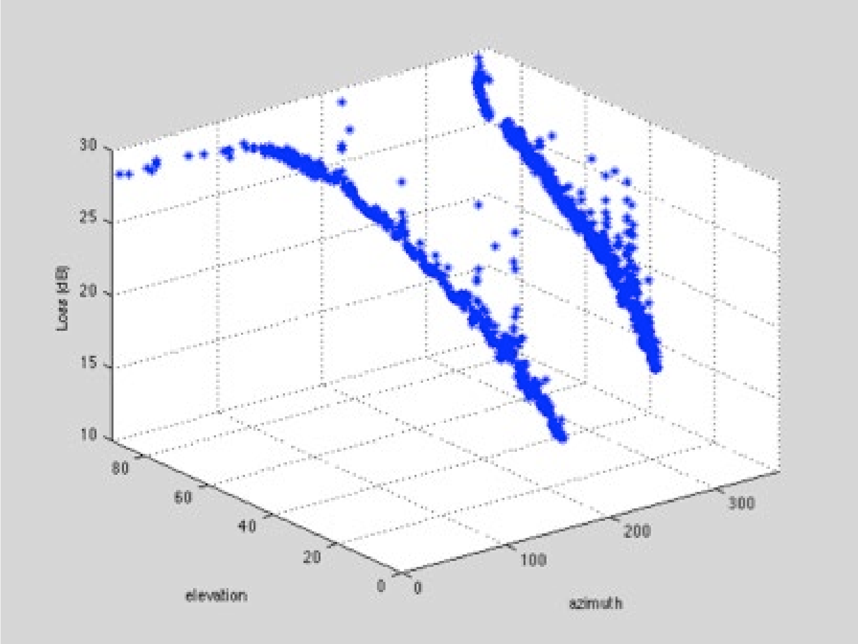




- Brown pixels have not been visited by GPS in the short time the measurements were made
- Losses by inspection range from ~20 dB to 50 dB

House Loss

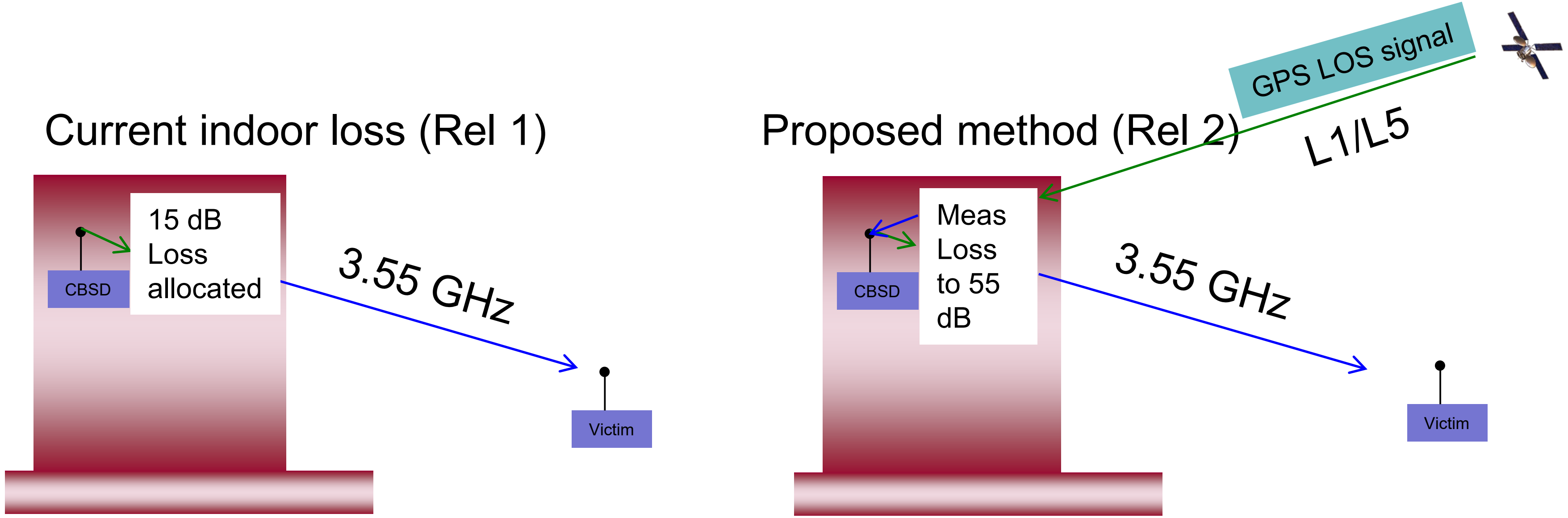
Losses generally increase monotonically with SV elevation angle and indicate true building loss over all elevation angles



Minimum loss < 15 dB

Indoor CBSD loss factors from Winnforum for Victim

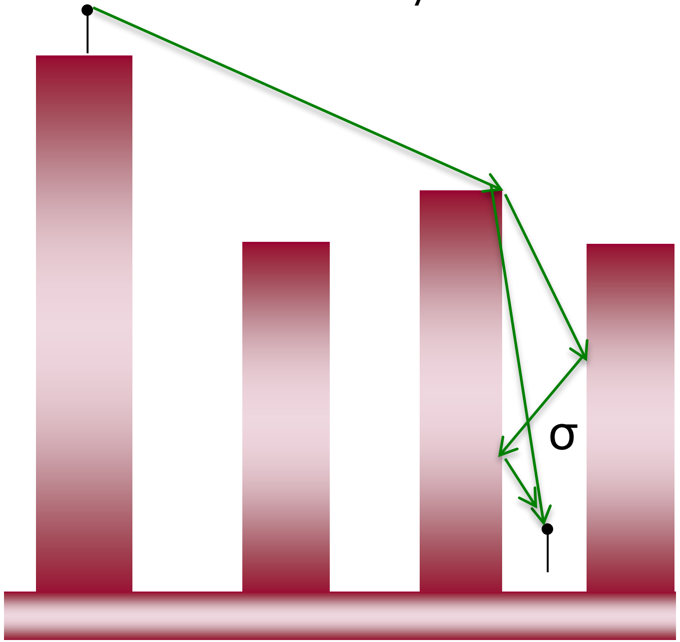
- Losses measured at L1/L5 and are Reciprocal
- Losses at 3.55 GHz are typically much greater than L1/L5 (see supplemental material)
  - iPosi recommends a minimum of 4 dB be added to L1, 5 dB to L5



Antenna Height Issue

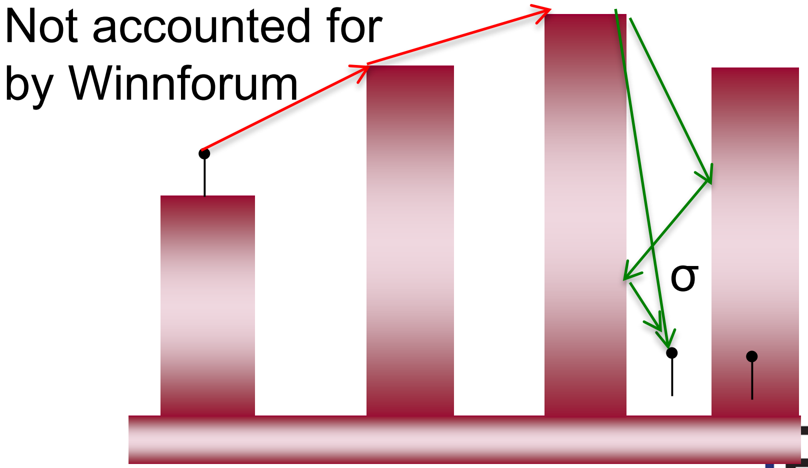
Okumura/eHata conditions

- One antenna must be above all buildings
- eHata clutter currently accounted for by σ



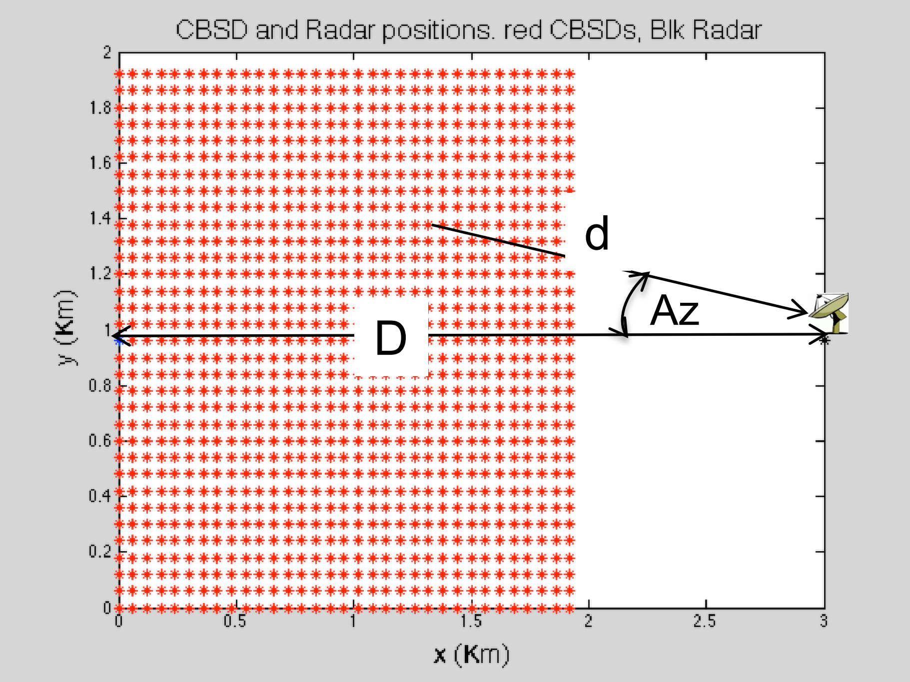
CBRS Indoor typical conditions

- Antennas are below clutter and not considered by WinnForum prop model
- Also antennas are indoors
- Below the roof line and indoor losses *are measured by GPS*



FSS Interference Simulation Model Parameters

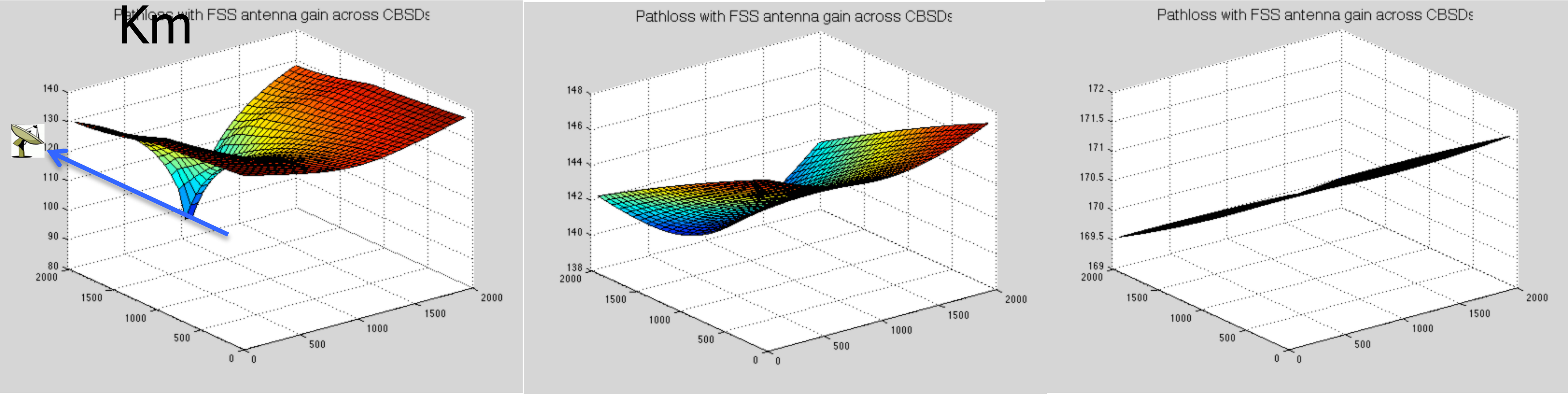
- **FSS parameters**
  - Noise Power =-105 dBm/30 MHz [1]
  - Interference target I/N <= -12 dB
- 1089 small cell sites, all indoors
- **Each Site has 3 small cells each site each with 10 MHz BW adjacent channels**
- **30 dBm EIRP**
- Buildings 60 m center to center
- CBSD's are 30 m haat FSS at 10 m
- Ehata model suburban propagation model suburban homogeneous
- Use FCC FSS antenna gain model for Elevation at 20 degrees and calculated Azimuth
- Calculate interference power at 15 dB building loss and uniform random variable of 15 to 55 dB
- D is the distance from far edge of cluster to FSS



[1] Intelsat ExParte; "C-Band / 5G Coexistence FCC Debrief Presented by Intelsat & SES " 4/19/2018

Pathloss + FSS antenna gain

- D= 2 Km D=5 Km D=22.3 Km



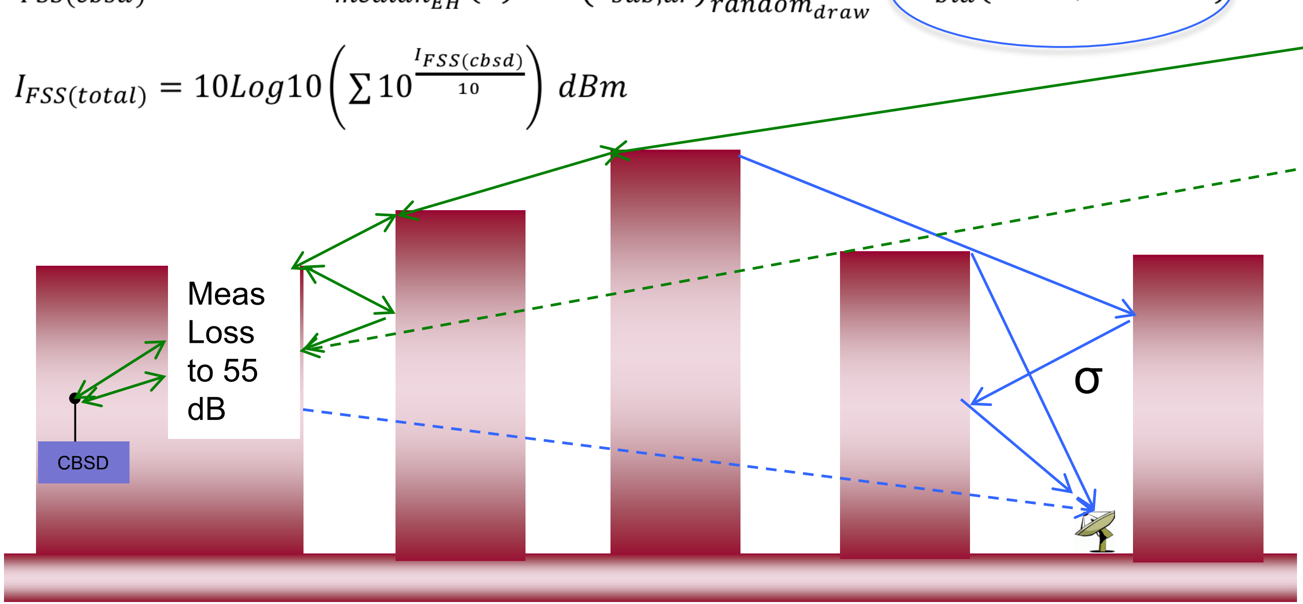
- At high distances D>5 Km G+PL about constant
- CBSDs that need to be adjusted are nearly uniformly distributed across the CBSD footprint at higher D

Simulation Models For Indoor CBSD Interference to FSS

- Loss is reciprocal at the same frequency (shown as solid green traces, dashed are direct but high loss paths)
- Measured GPS loss (simulated here) will *include below* the roof line clutter loss
- Fixed 15 dB building loss will typically under estimate the loss
  - In some cases 15 dB building loss may *under estimate the the total path loss and allow interference*

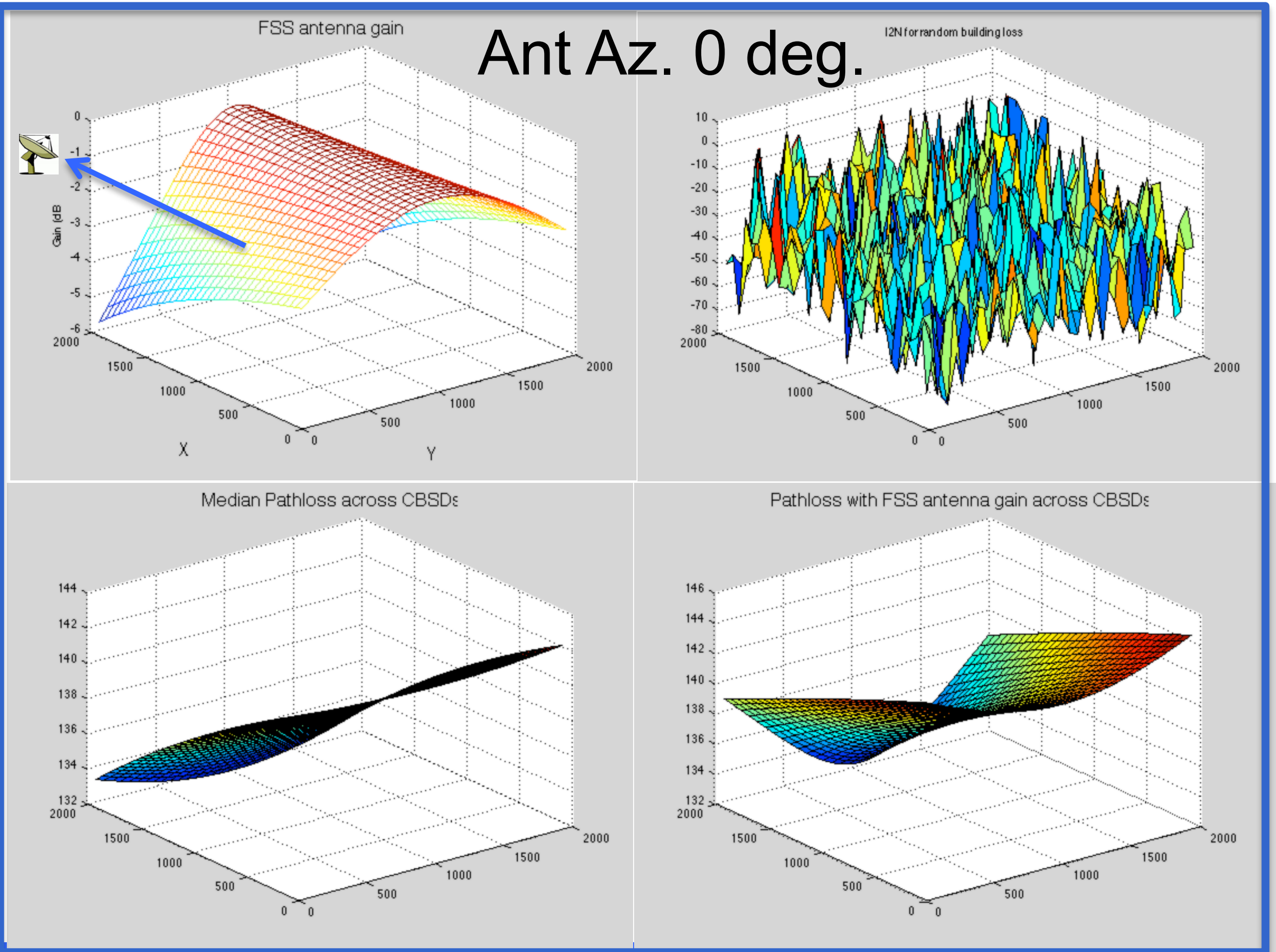
$$I_{FSS(cbsd)} = EIRP - L_{median_{EH}}(d) - L(\sigma_{sub,ur})_{random_{draw}} - L_{bld}(15dB, random) - G(diff_{elv}, diff_{Az})\ dBm$$

$$I_{FSS(total)} = 10Log10\left(\sum 10^{\frac{I_{FSS(cbsd)}}{10}}\right)\ dBm$$

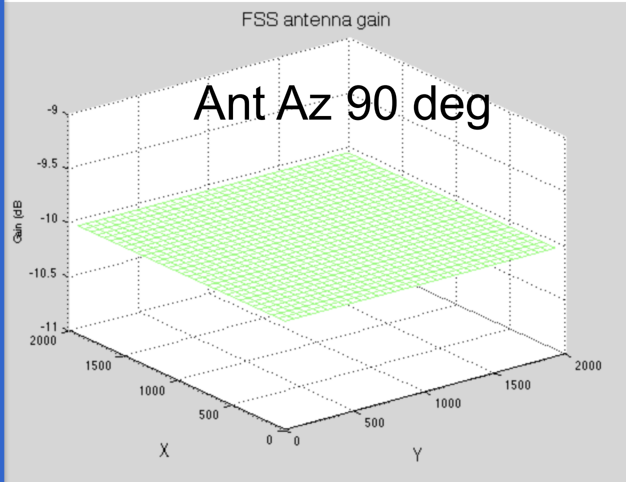


- Use lowest elevation angle measured data available at correct azimuth
- Using GPS measures all Tx propagation factors

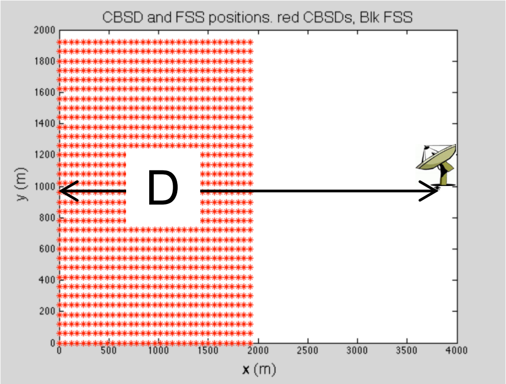
FSS Antenna Gain and Path Loss with D=4 Km



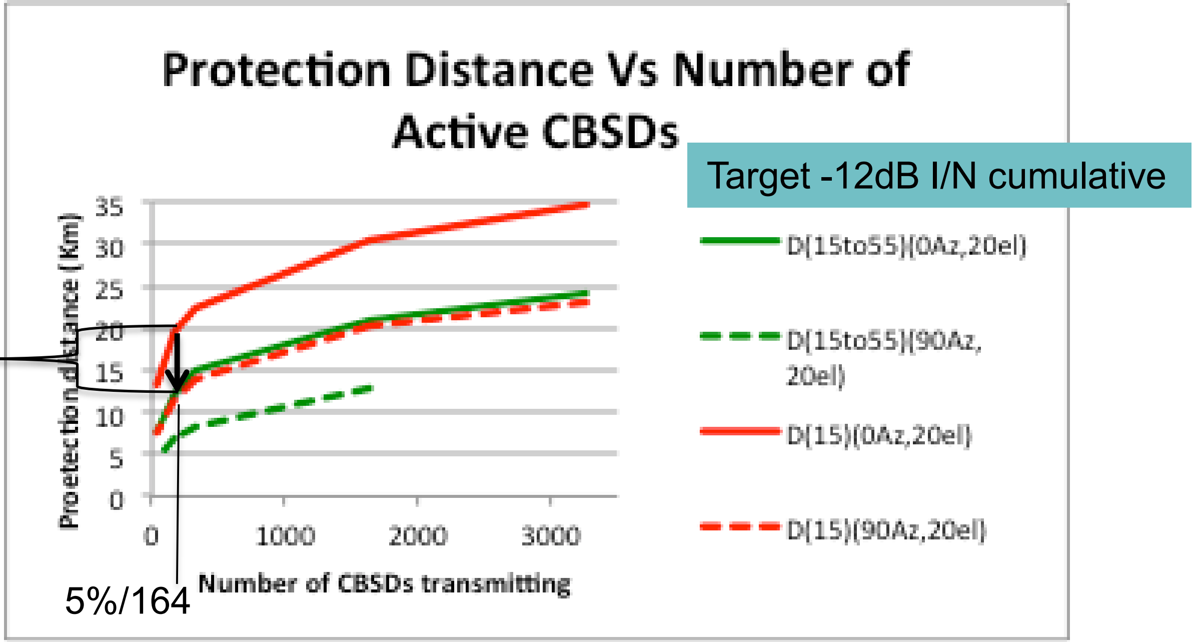
- Patterns provide some insight
- Narrow beam width of FSS antenna is missed with elevation angle of 20 degrees



Protection Distance for Co-Channel Interference into a 30 MHz FSS with Fixed 15 dB and Uniform Distribution of 15 to 55 dB Building Loss(El =20deg, Az=0 deg)



19.5 Km reduced to to 12 Km
With Uniform loss model



- Select 5% usage at any instant with 12 Km Vs 19.5 Km protection distance on bore sight of FSS
- Drops to 6.7 Km at 90 deg. from bore sight
- Depends on actual loss distribution->next slide

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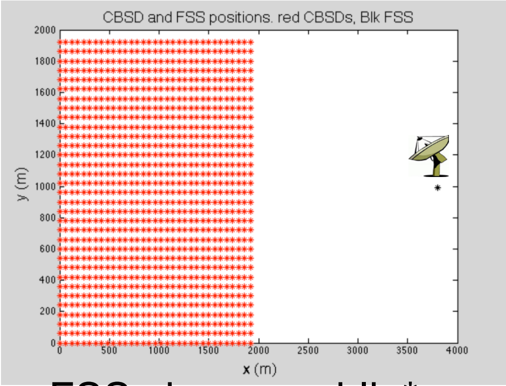
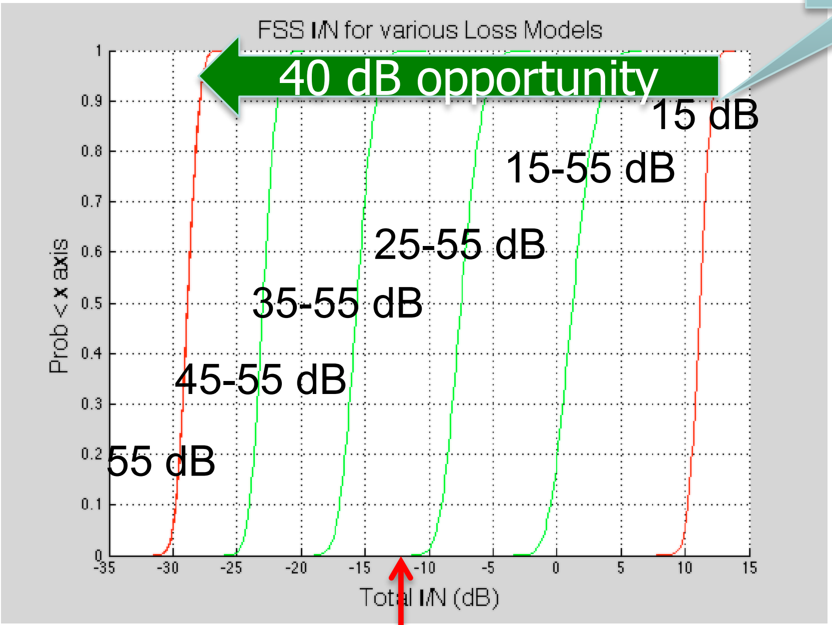
Comparison of Co-Channel Interference into a 30 MHz FSS With Various Building Loss Models for 3*1089 CBSDs



FSS shown as blk *

20 deg elevation
Towards the
CBSDs
All CBSDs at 30
dBm

WinnForum R1
allocation



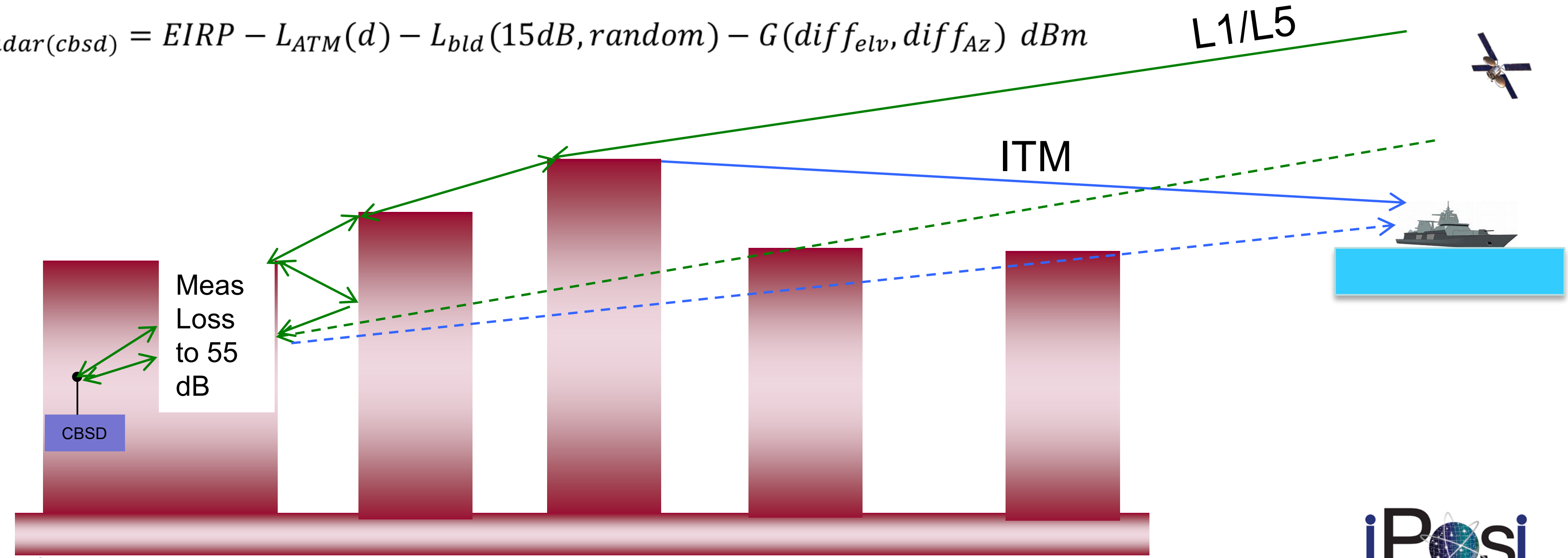
Objective -12 dB (I=-132 dBm/MHz)

- Building loss measurements provide up to 40 dB interference protection opportunity over a fixed 15 dB assumption
- > 100x capacity increase opportunity

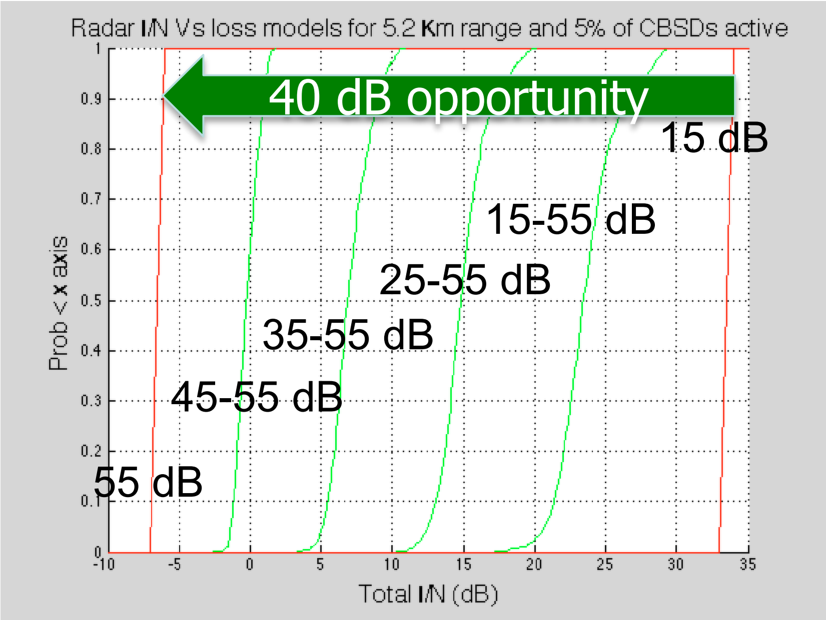
Simulation Model for Indoor CBSD Interference to Radar

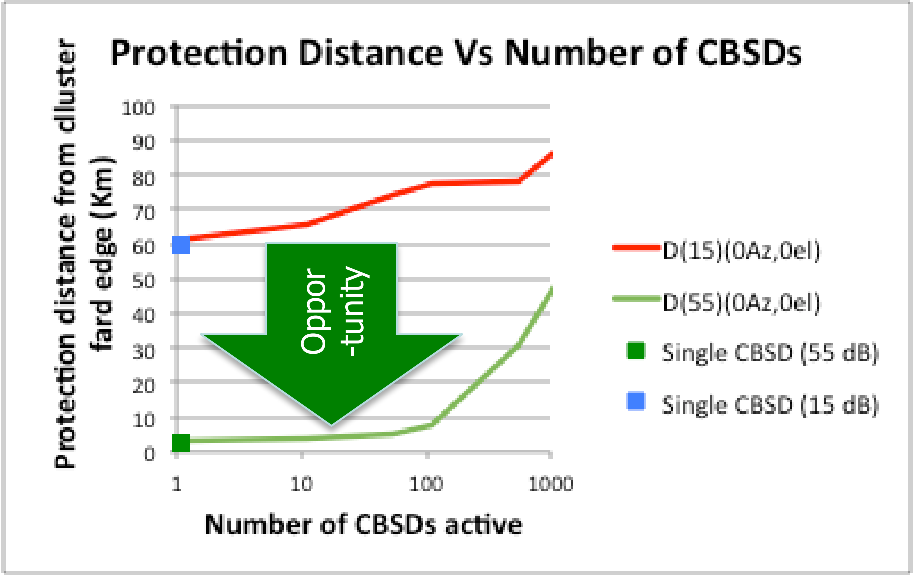
- Measured GPS loss (simulated here) will *include below* the roof line clutter loss
- Loss is reciprocal at the same frequency (shown as solid green traces, dashed are direct but high loss paths)
- No clutter at radar end

$$I_{Radar(cbsd)} = EIRP - L_{ATM}(d) - L_{bld}(15dB, random) - G(diff_{elv}, diff_{Az})\ dBm$$



I/N to Radar 1 Vs Indoor Loss Model and ITM

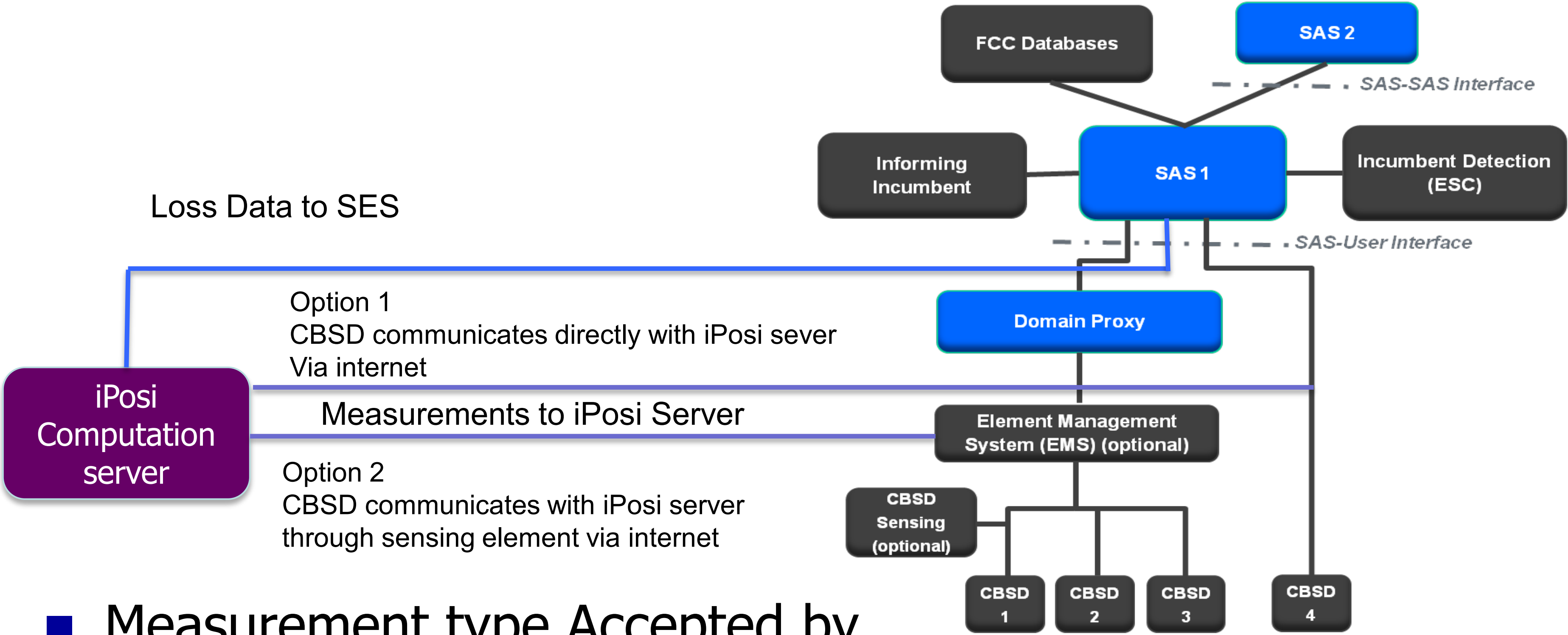




- Up to 40 dB less interference using measured data over 15 dB fixed loss
- Up to 57 Km less protection range

LossCalc 10 LTE to radar

3.55 to 3.7 GHz Architecture with SAS



- Measurement type Accepted by Winnforum WG3

Conclusion

- Extreme sensitivity GPS/GNSS can be used to measure indoor to outdoor losses and it can be applied to existing propagation models
- Measured loss is far superior to fixed 15 dB loss models due to the inclusion of building loss and below the roof line loss effects
- Measured loss avoids problem that 15 dB assumption may be excessive
- It can greatly improved CBRS utilization and capacity for protection of FSS, Naval radar/DPA, PAL to PAL GAA to PAL
- Extendable to CBSD to CBSD protection and to other Shared systems

Supplemental

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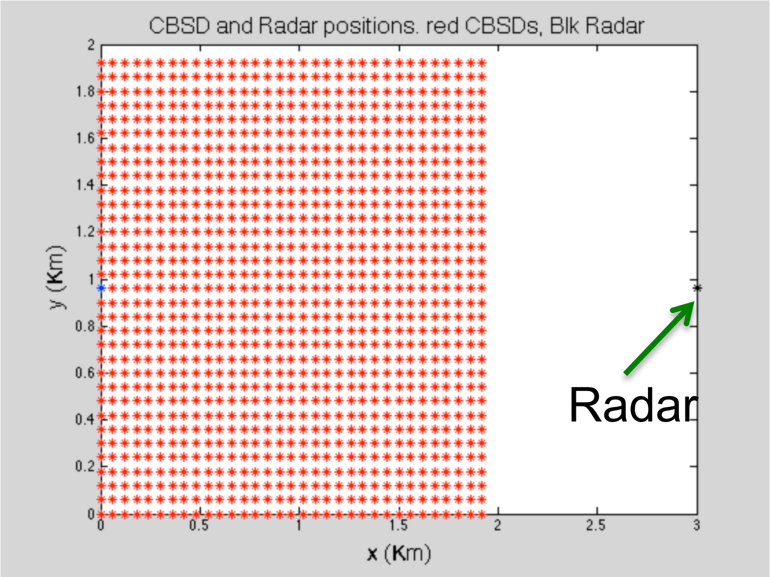
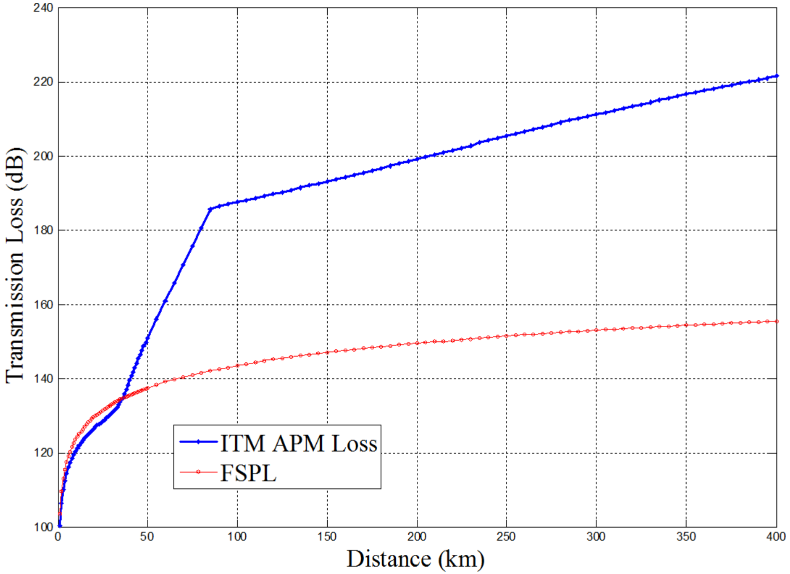
CBSD Radar Protection System for Analysis

60m CBSD spacing, 2 Km by 2 Km
1089 CBSDS



ITM model [2]
H_Radar=50 m
H_CBSD=25 m



[2] "Radar in-Band Interference Effects on Macrocell LTE Uplink Deployments in the U.S. 3.5 GHz Band"
2015 International Conference on Computing, Networking and Communications (ICNC), Workshop on Computing, Networking and Communications (CNC)
Mo Ghorbanzadeh, Eugene Visotsky, Prakash Moorut, Weidong Yang

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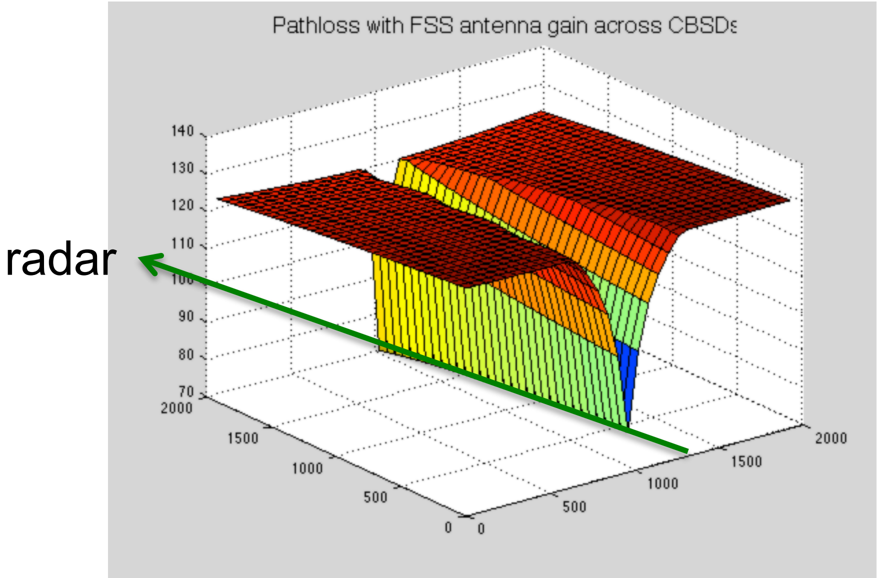
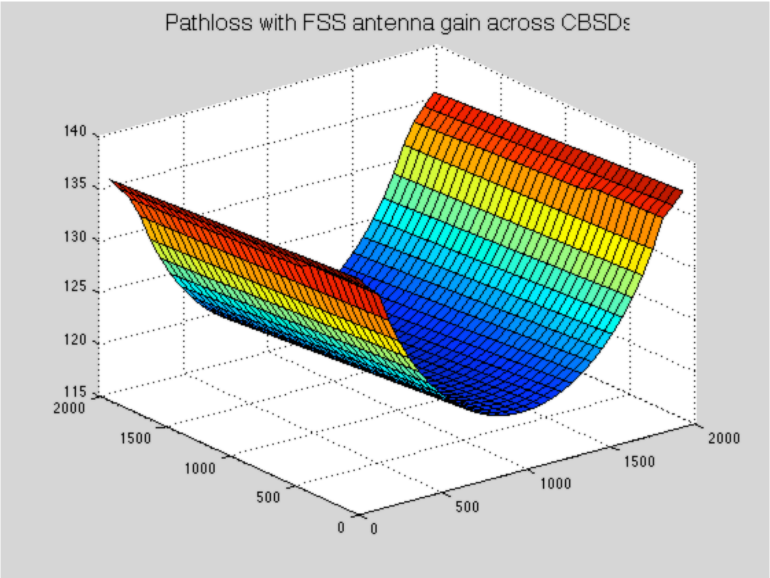
Radar Antenna Pattern over CBSD Cluster

3 Km



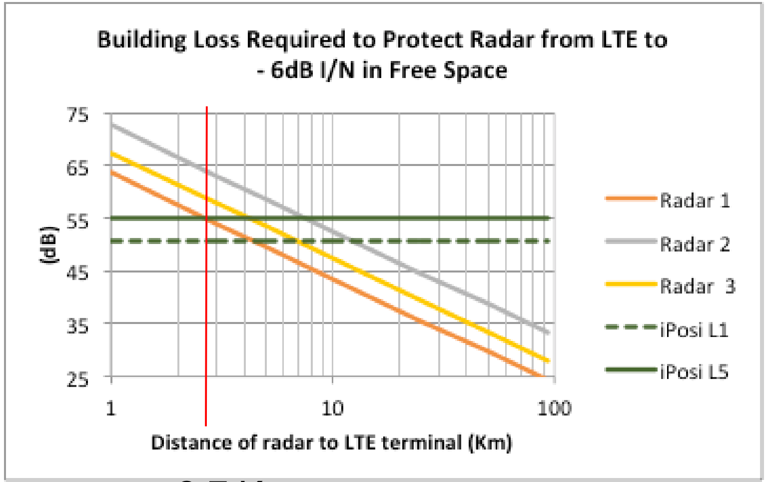
60 Km



- Demonstrates impact of antenna gain and propagation

Worst case Protection of Ship-borne Radar from single in-building LTE CBSD with Free Space

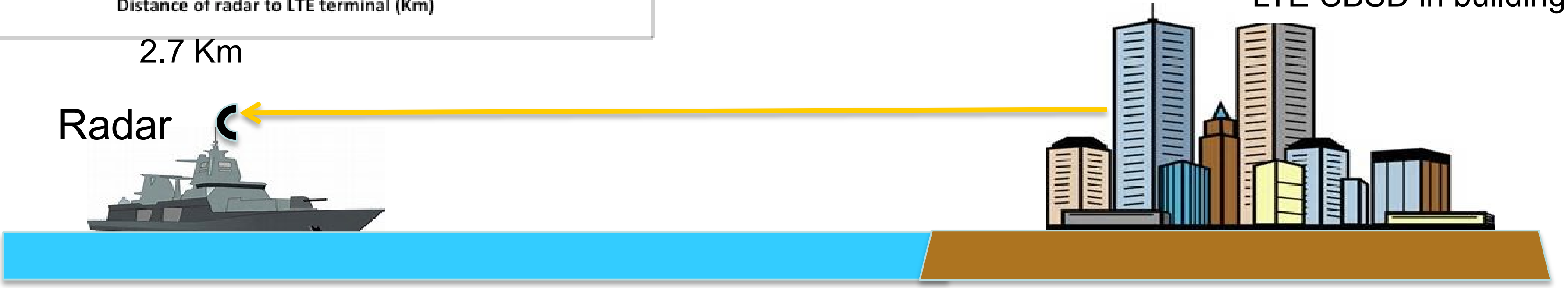
Radar at 50 m above sea level
LTE terminal also 50 m above sea level but in building



2.7 Km

Example: Building containment loss can determine if there is sufficient building loss as close as 2.7 Kms from Naval radar #1 in the main beam

Uses NTIA Radar parameters



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Selected loss from NISTIR 6055

- 3.5 GHz signals have a minimum of 4 dB more loss with the average at 11 dB
- Implies losses measured by iPosi at 1.5 GHz actually indicate 4 dB more loss at 3.5 GHz

Building Material Loss-Rappaport

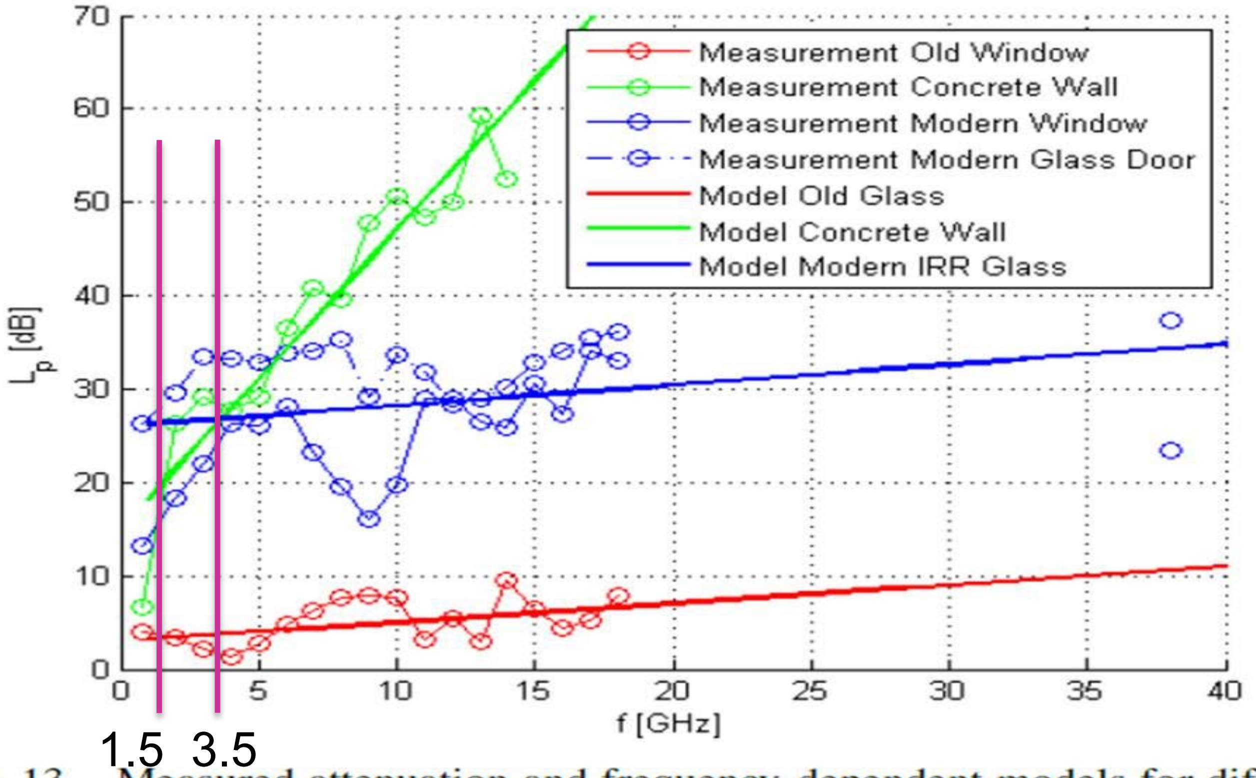

Fig. 13. Measured attenuation and frequency-dependent models for different facade elements.

- Losses mostly dramatically higher at 3.5 Vs 1.5 GHz
- Exception for old glass

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