Network Design Considerations and Deployment Concerns for a Ground Aircraft Communication System

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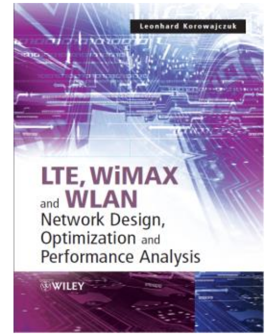
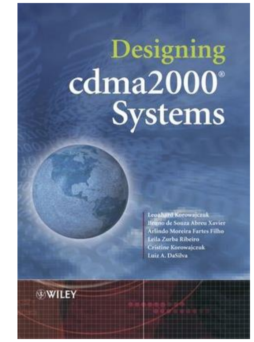
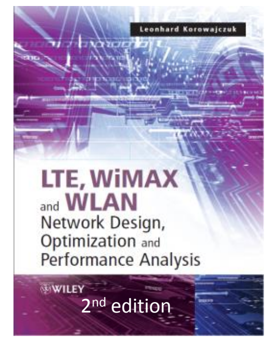
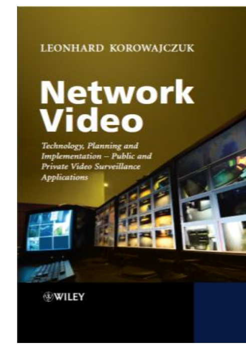
Presenter

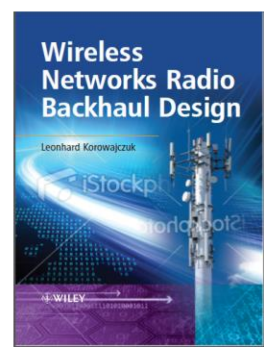
- **Leonhard Korowajczuk**
  - CEO/CTO CelPlan International
  - 45 years of experience in the telecom field (R&D, manufacturing and services areas)
  - Holds13 patents
  - Published books
    - “Designing cdma2000 Systems”
      - published by Wiley in 2006- 963 pages, available in hard cover, e-book and Kindle
    - “LTE , WiMAX and WLAN Network Design, Optimization and Performance Analysis ”
      - published by Wiley in June 2011- 750 pages, available in hard cover, e-book and Kindle
  - Books in Preparation:
    - LTE , WiMAX and WLAN Network Design, Optimization and Performance Analysis
      - second edition (2012) LTE-A and WiMAX 2.1(1,000+ pages)
    - Network Video: Private and Public Safety Applications (2013)
    - Backhaul Network Design (2013)
    - Multi-Technology Networks: from GSM to LTE (2014)
    - Smart Grids Network Design (2014)

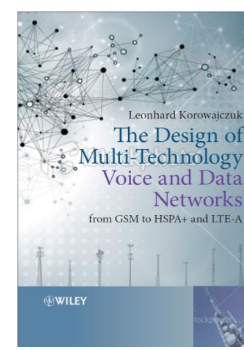












CelPlan International

- Employee owned enterprise with international presence
  - Headquarters in USA
  - 450 plus employees
  - Revenues of US$ 40M
  - Twenty (20) years in business
- Subsidiaries in 6 countries with worldwide operation
- Vendor Independent
- Network Design Software (CelPlanner Suite)
- Network Design Services
- Network Optimization Services
- Network Performance Evaluation
- Services are provided to equipment vendors, operators and consultants
- High Level Consulting
  - RFP preparation
  - Vendor interface
  - Technical Audit
  - Business Plan Preparation
  - Specialized (Smart Grids, Aeronautical, Windmill, ...)
- Network Managed Services
- 2G, 3G, 4G, 5G Technologies
- Multi-technology / Multi-band Networks
- Backhaul, Small cells, Indoor, HetNet

Network Design Considerations and Deployment Concerns for a Ground Aircraft Communication System

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Agenda

- Wireless Communications Characterization
- RF Channel Characterization
  - CelSDRx™
  - Ray Tracing

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Wireless Communications Characterization

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Wireless Communications Characterization

- We would like present a methodology we used for the NextGen Data Communication System operating at approximately 136MHz
- The same methodology can be applied for AeroMACS at 5.1 GHz
- NASA has engaged CelPlan Technologies to:
  - Collect field data
  - Analyze the propagation characteristics of that part of the spectrum
  - Provide calibrate propagation tables to be used in the CelPlanner Suite software
- A drive test campaign for two airports
  - Chicago (ORD)- busiest airport in the USA
  - Detroit (DTW)
- FAA supported the measurement efforts at both airports
- A PET-2000 transmitter was used to generate the CW frequency with approximately 5W output power
- A B1322N antenna was used (omni 2.4 dBi)

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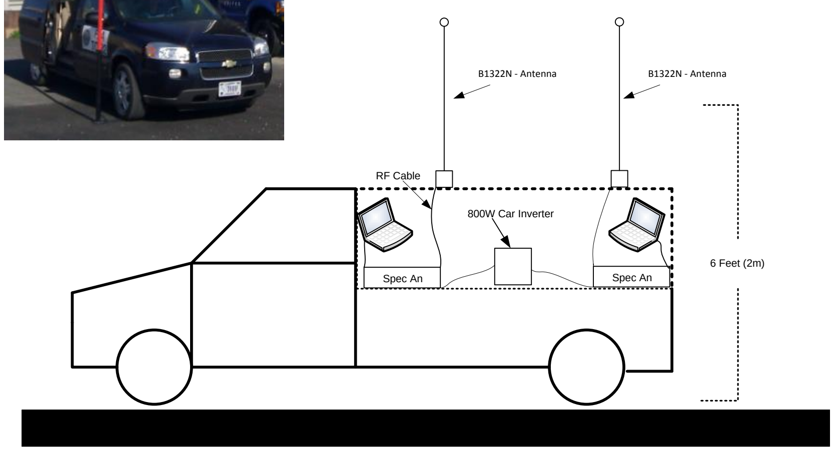
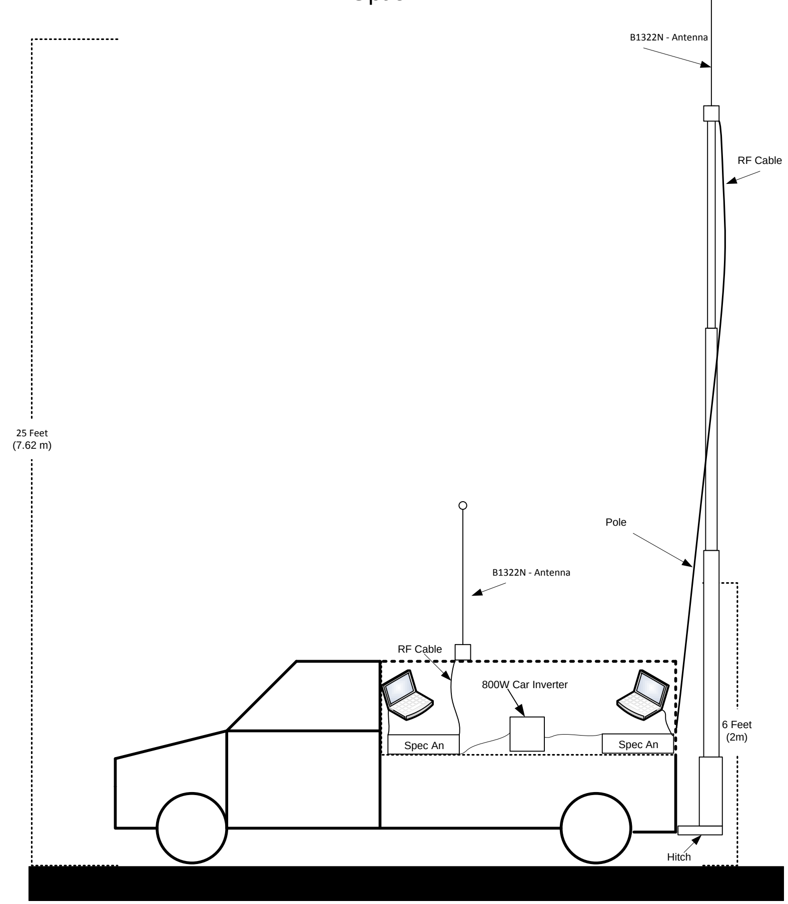
Test vehicle

- Two test vehicles were used
  - One simulated the transmitter
  - Another simulated a moving receiver

Mobile Car - RX



Static Car – RX
Option 2



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Chicago Airport (ORD)

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ORD Airport

- Airport and surroundings were modeled in 3 D
- Horizontal resolution of 1 m
- Vertical resolution of 0.5 m

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ORD Transmitter Characteristics

Characteristics	TX1	TX2	TX3
Antenna Type	Omni	Omni	Omni
Rad Center [m]	7.6	7.6	7.6
Antenna structure	mast	mast	mast
Antenna Model	B1322N	B1322N	B1322N
Azimuth [°]	N/A	N/A	N/A
Tilt [°]	0	0	0
Antenna Gain [dBd]	0.26	0.26	0.26
Latitude [dec deg]	41.97705	41.98861667	41.97447222
Longitude [dec deg]	-87.9255	-87.89038333	-87.90714722
Datum	WGS84	WGS84	WGS84
Obstruction	No	No	No
Obstruction Azimuth [°]			
Transmitter model	PET-2000	PET-2000	PET-2000
Transmit Frequency [MHz]	136.475	136.475	136.475
Signal Bandwidth [KHz]	tone	tone	tone
Warm-up duration [min]	> 15	> 15	> 15
ERP [W]	3.95	3.95	3.95
Weather	Sunny	Sunny	Sunny

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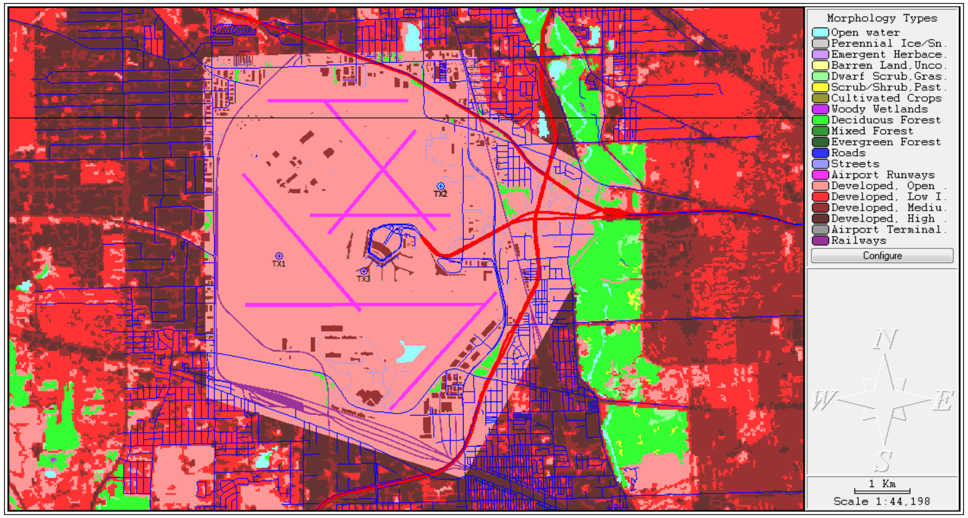
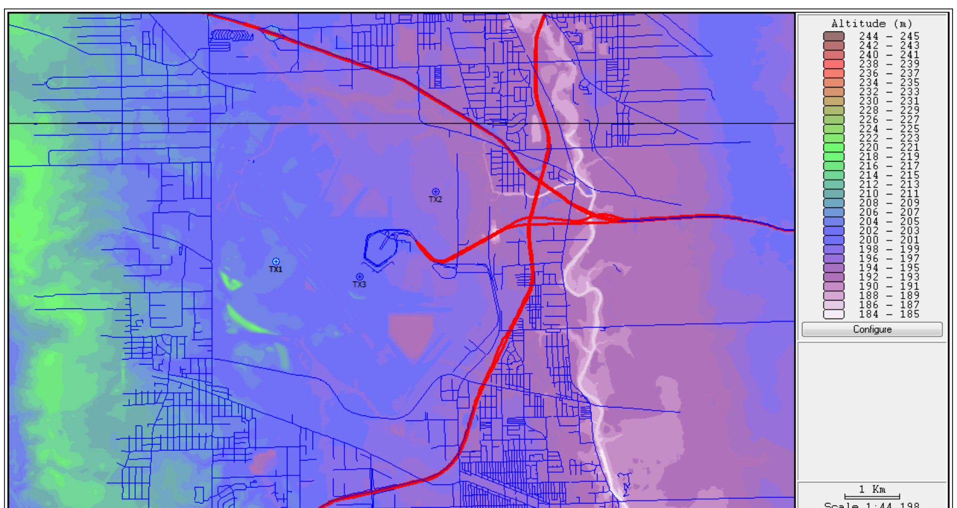
Morphology representation

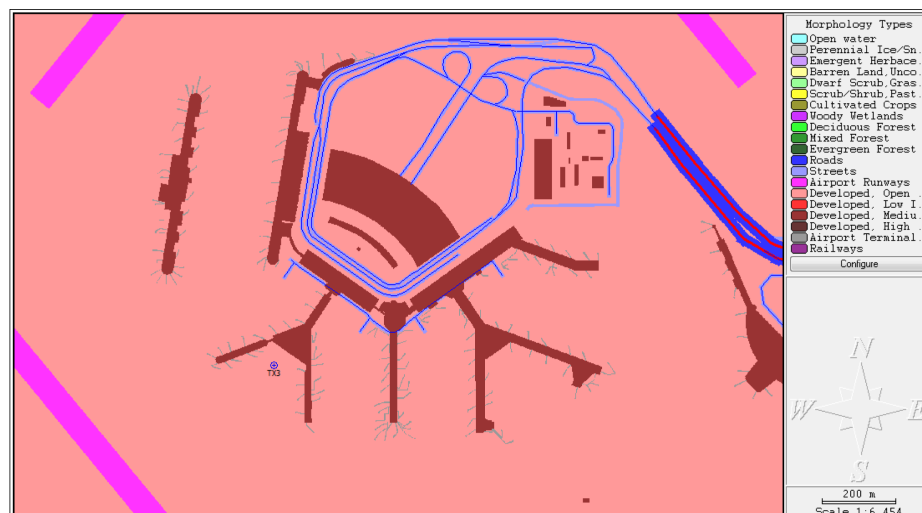


Topography

Surroundings Morphology

Buildings Morphology





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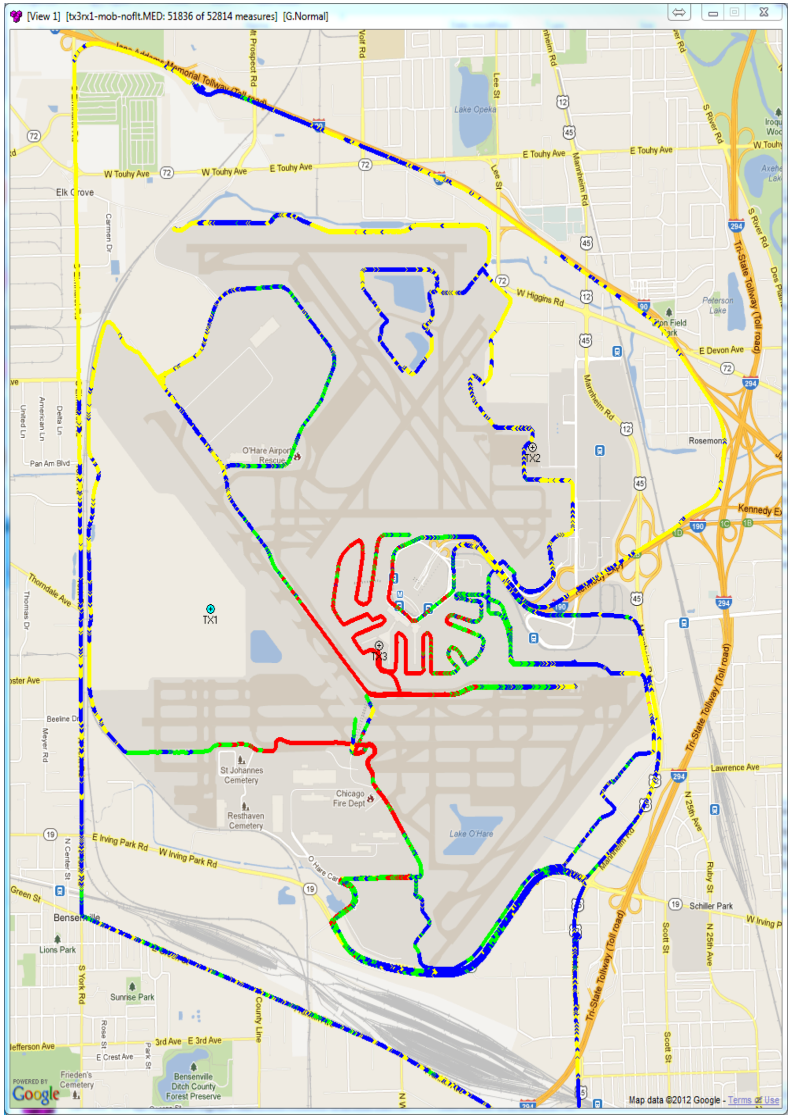
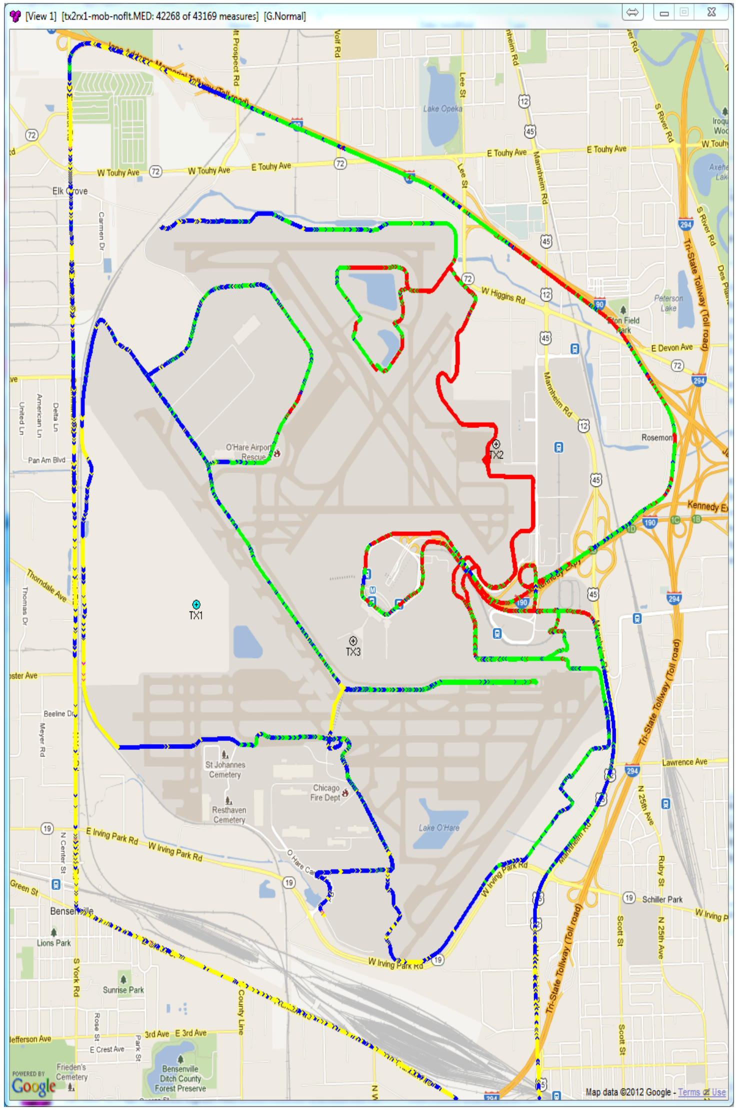
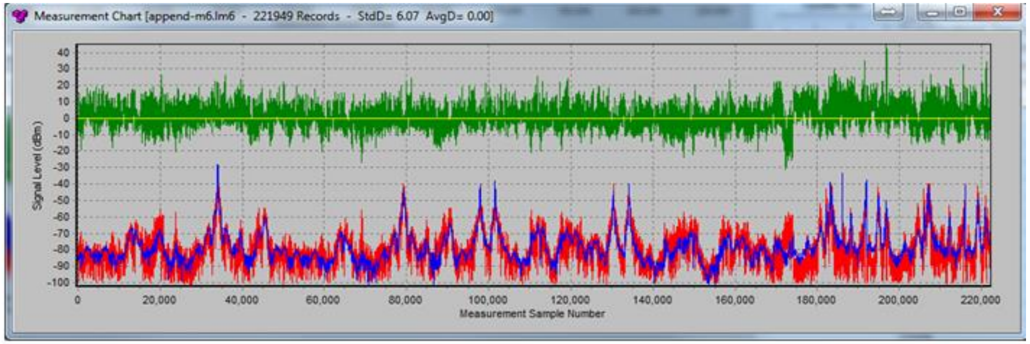
Drive Test Measurements

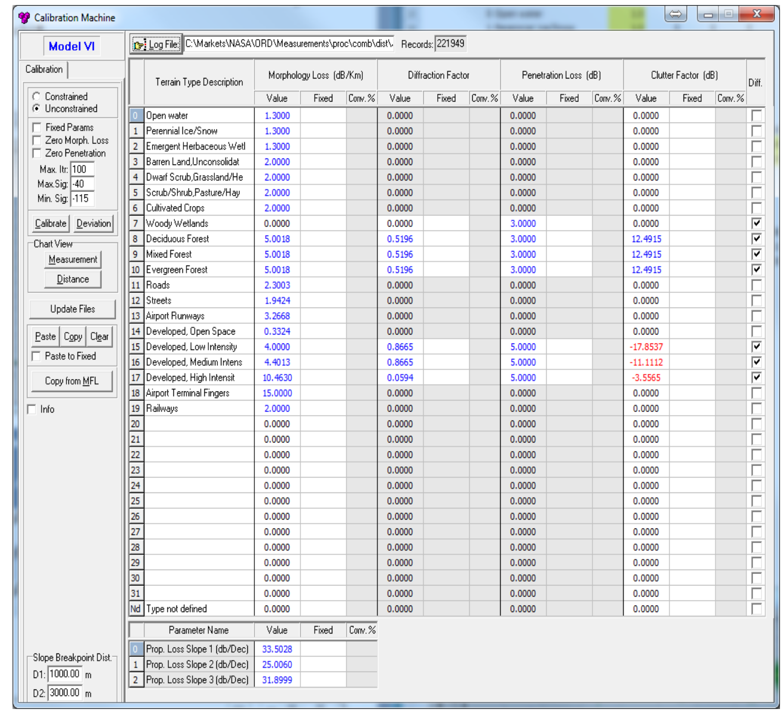


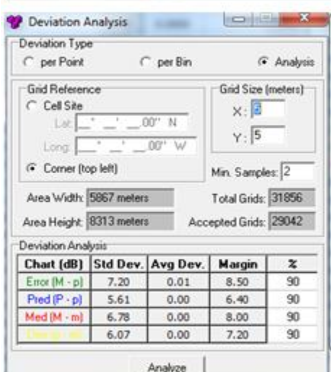


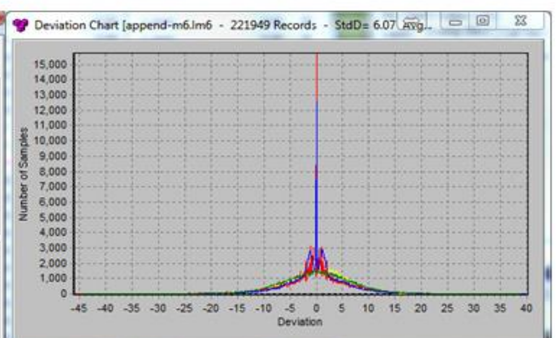
Measurement x Predictions

- Prediction model used was: Korowajczuk 3D









	Unconstrained Calibration Set		
	Standard Deviation [dB]	Average Deviation [dB]	RMS [dB]
Model II - 2D Korowajczuk	6.16	0.04	6.16
Model III - Microcell	6.96	0	6.96
Model VI - 3D Korowajczuk	6.07	0	6.07

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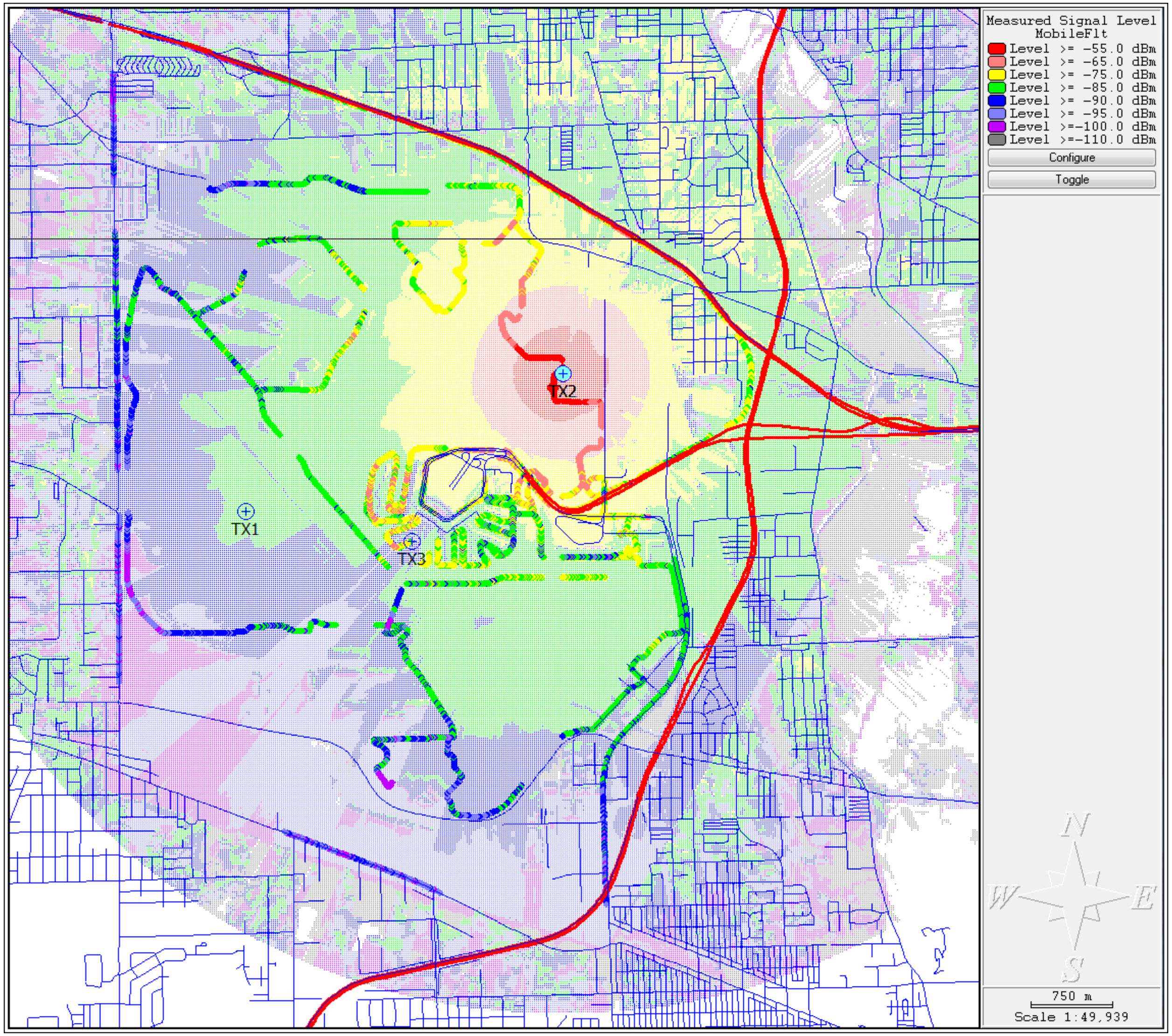
Predictions x Measurements



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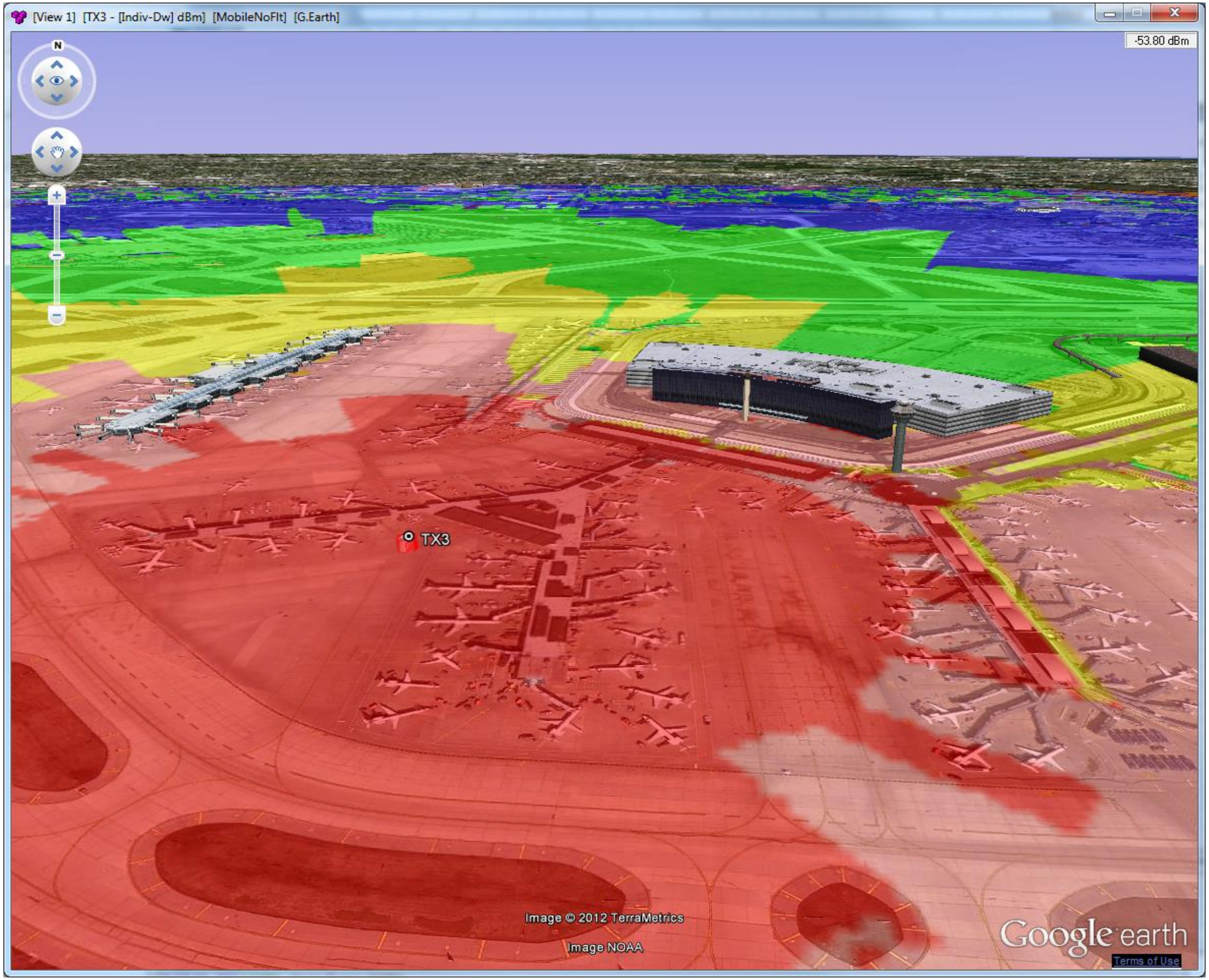
Airport 3 D Coverage view



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Detroit Airport (DTW)

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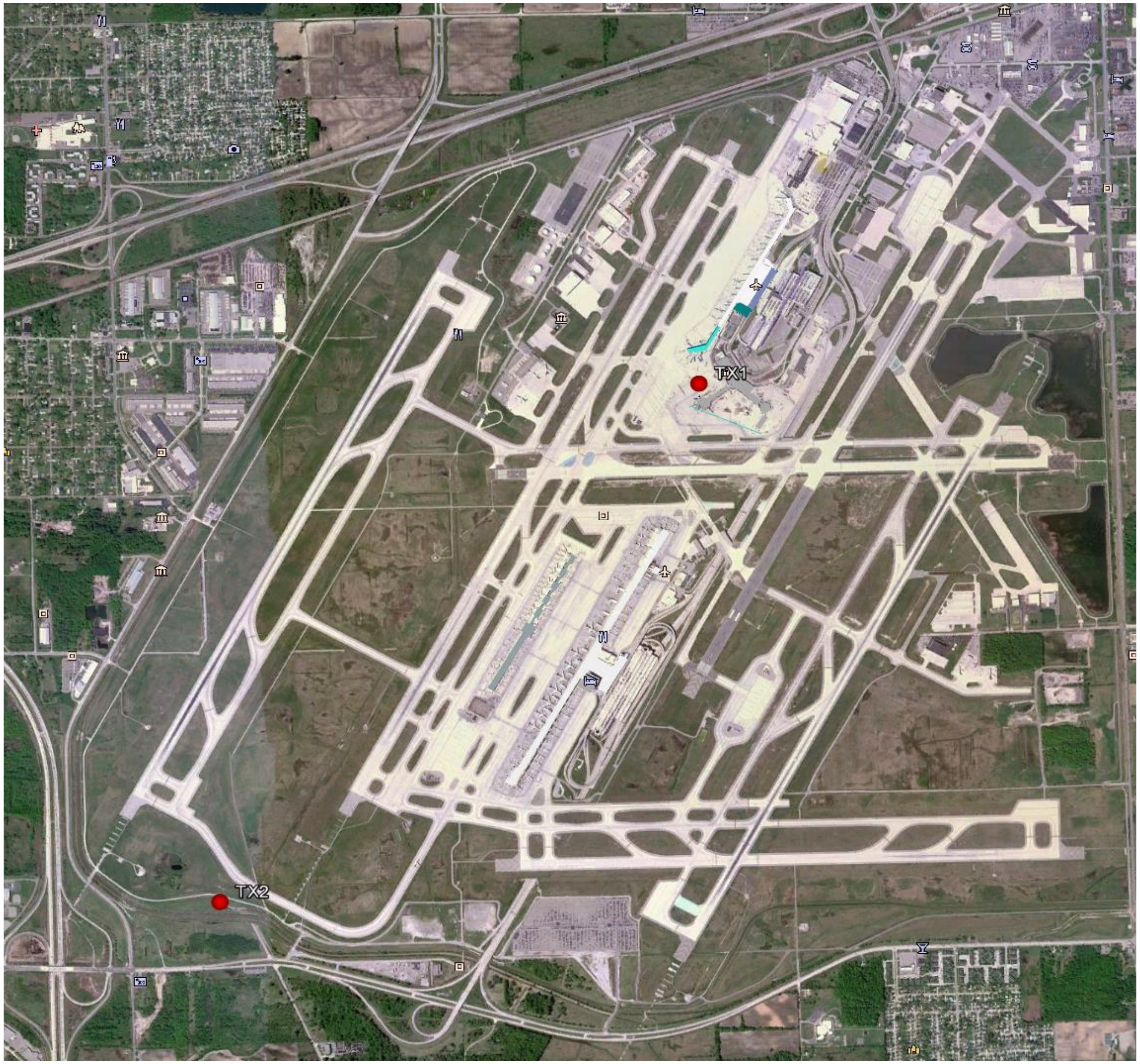
DTW Airport



- Airport and surroundings were modeled in 3 D
- Horizontal resolution of 1 m
- Vertical resolution of 0.5 m

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DTW Transmitter Characteristics

Characteristics	TX1	TX2
Antenna Type	Omni	Omni
Rad Center [m]	7.6	7.6
Antenna structure	mast	mast
Antenna Model	B1322N	B1322N
Azimuth [°]	N/A	N/A
Tilt [°]	0	0
Antenna Gain [dBd]	0.26	0.26
Latitude [dec deg]	42.22115833	42.19732222
Longitude [dec deg]	-83.35130833	-83.37918611
Datum	WGS84	WGS84
Obstruction	No	No
Obstruction Azimuth [°]		
Transmitter model	PET-2000	PET-2000
Transmit Frequency [MHz]	136.425	136.425
Signal Bandwidth [KHz]	tone	tone
Warm-up duration [min]	> 15	> 15
EiRP [W]	3.76	3.76
Weather	Sunny	Sunny

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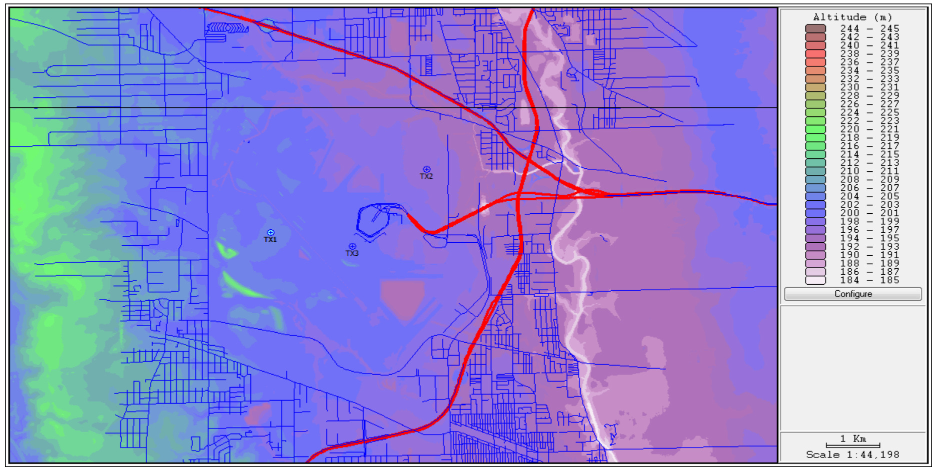
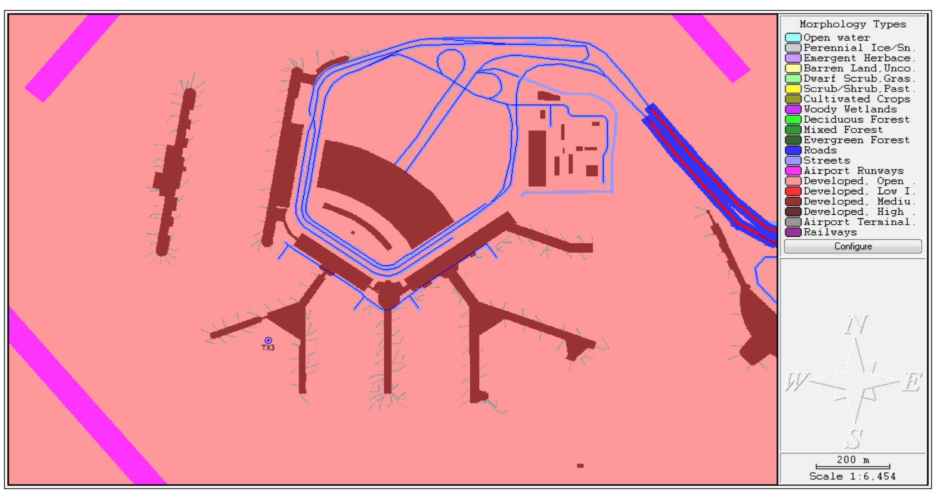
Morphology representation

Topography



Surroundings Morphology



Buildings Morphology

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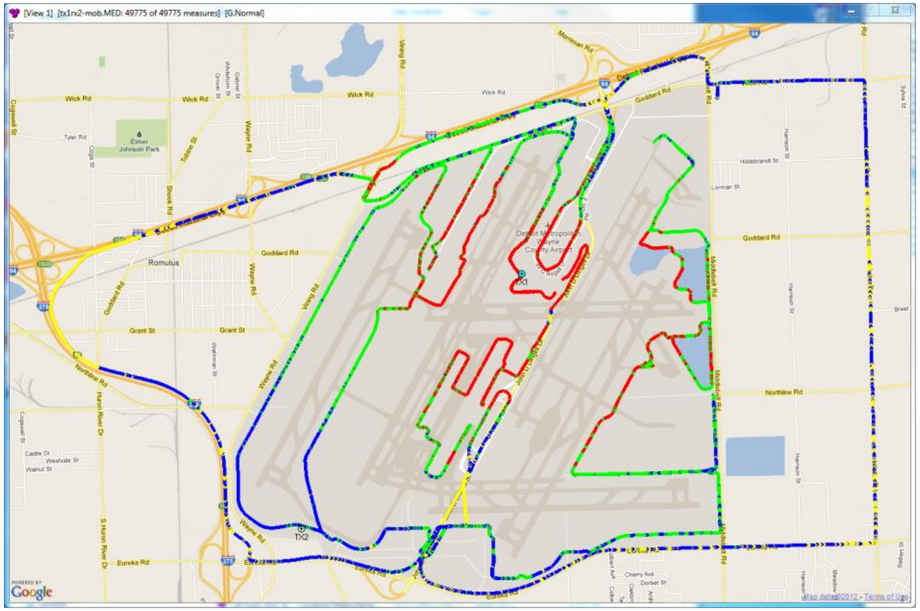
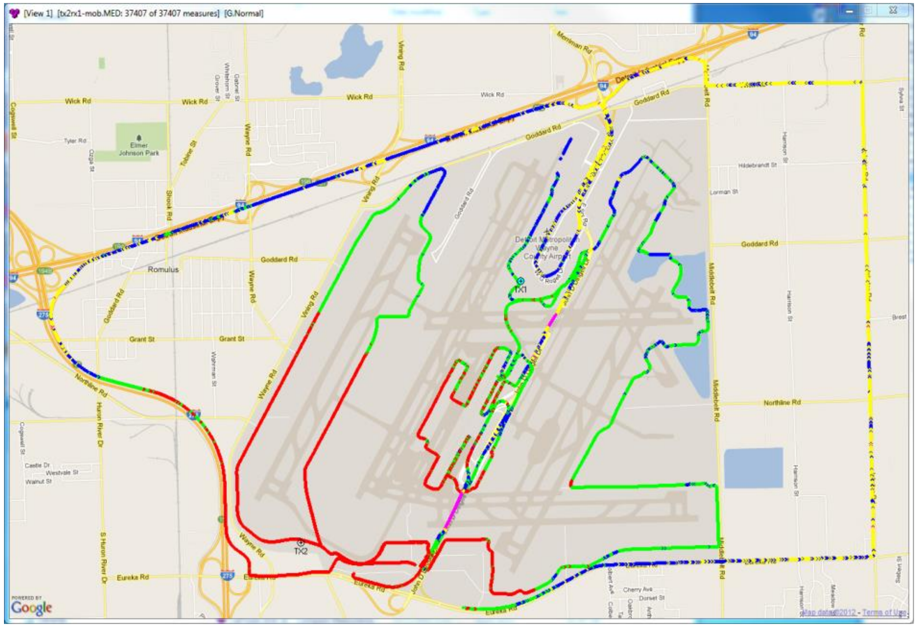
Drive Test Measurements





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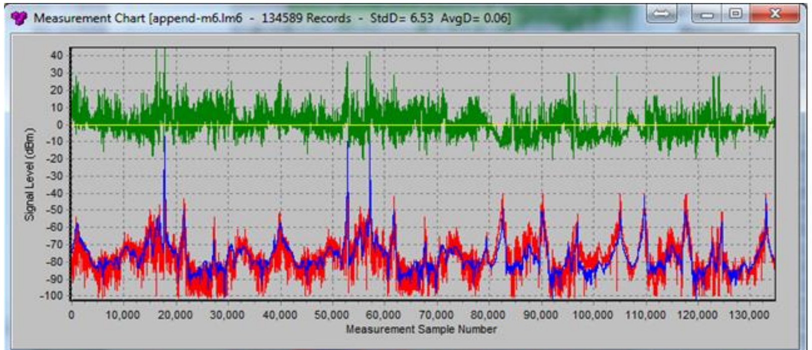
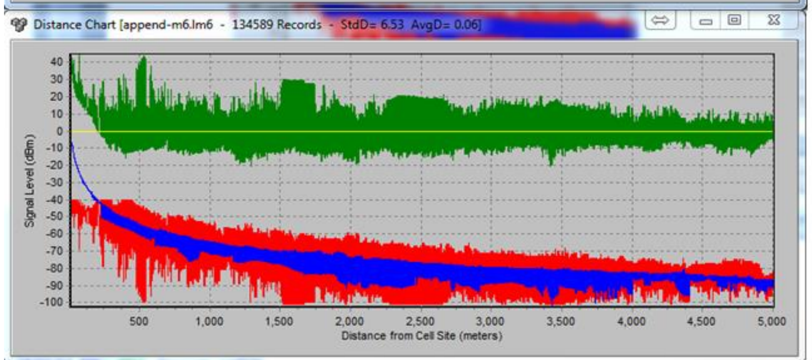
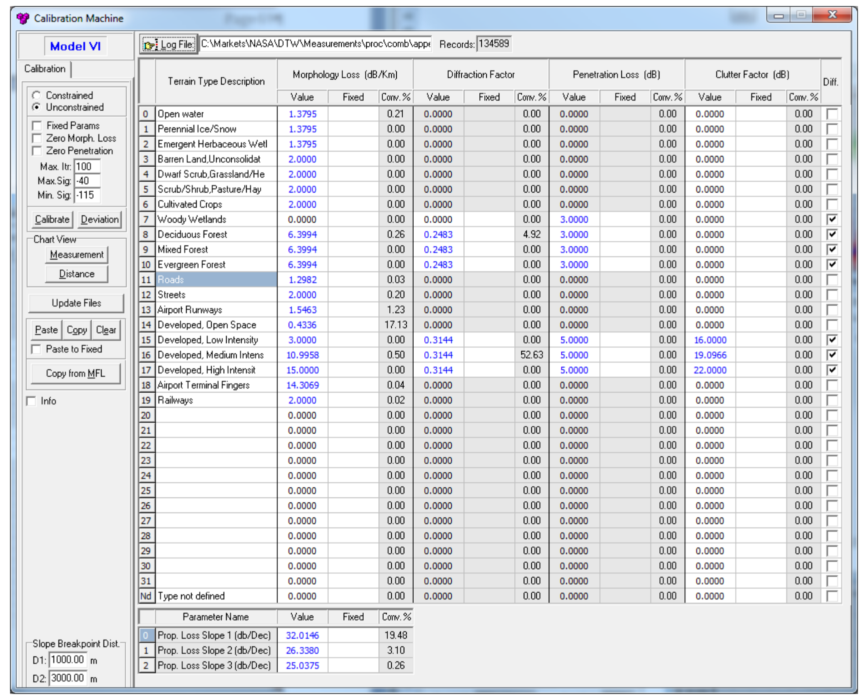
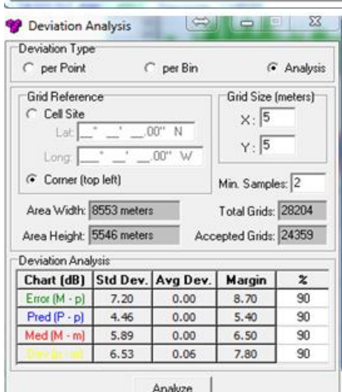
Measurement x Predictions

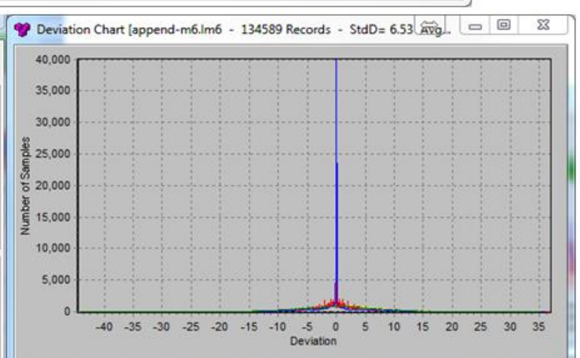


	Unconstrained Calibration Set		
	Standard Deviation [dB]	Average Deviation [dB]	RMS [dB]
Model II - 2D Korowajczuk	6.52	0.09	6.52
Model III - Microcell	6.13	0	6.13
Model VI - 3D Korowajczuk	6.53	0.06	6.53









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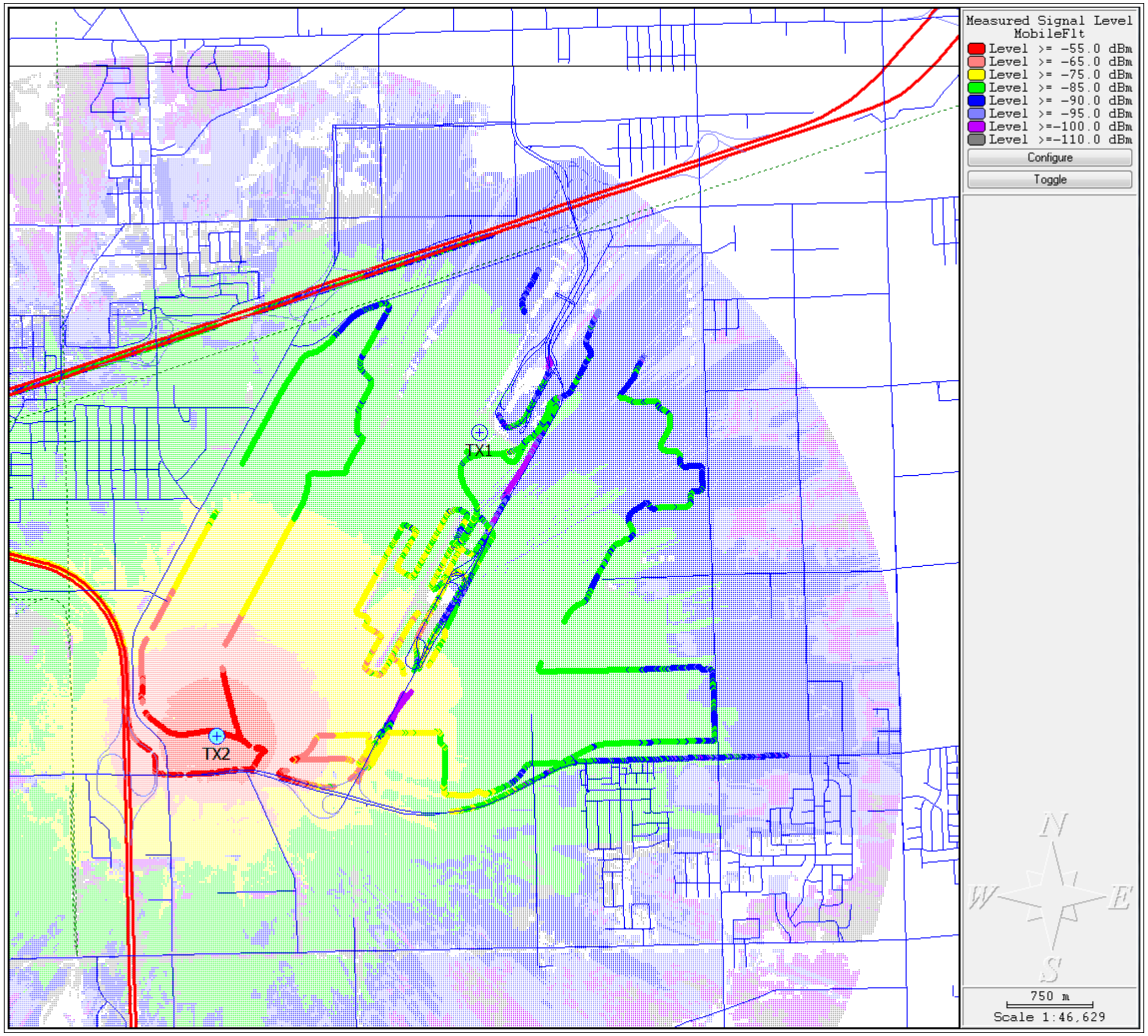
Measurement x Predictions



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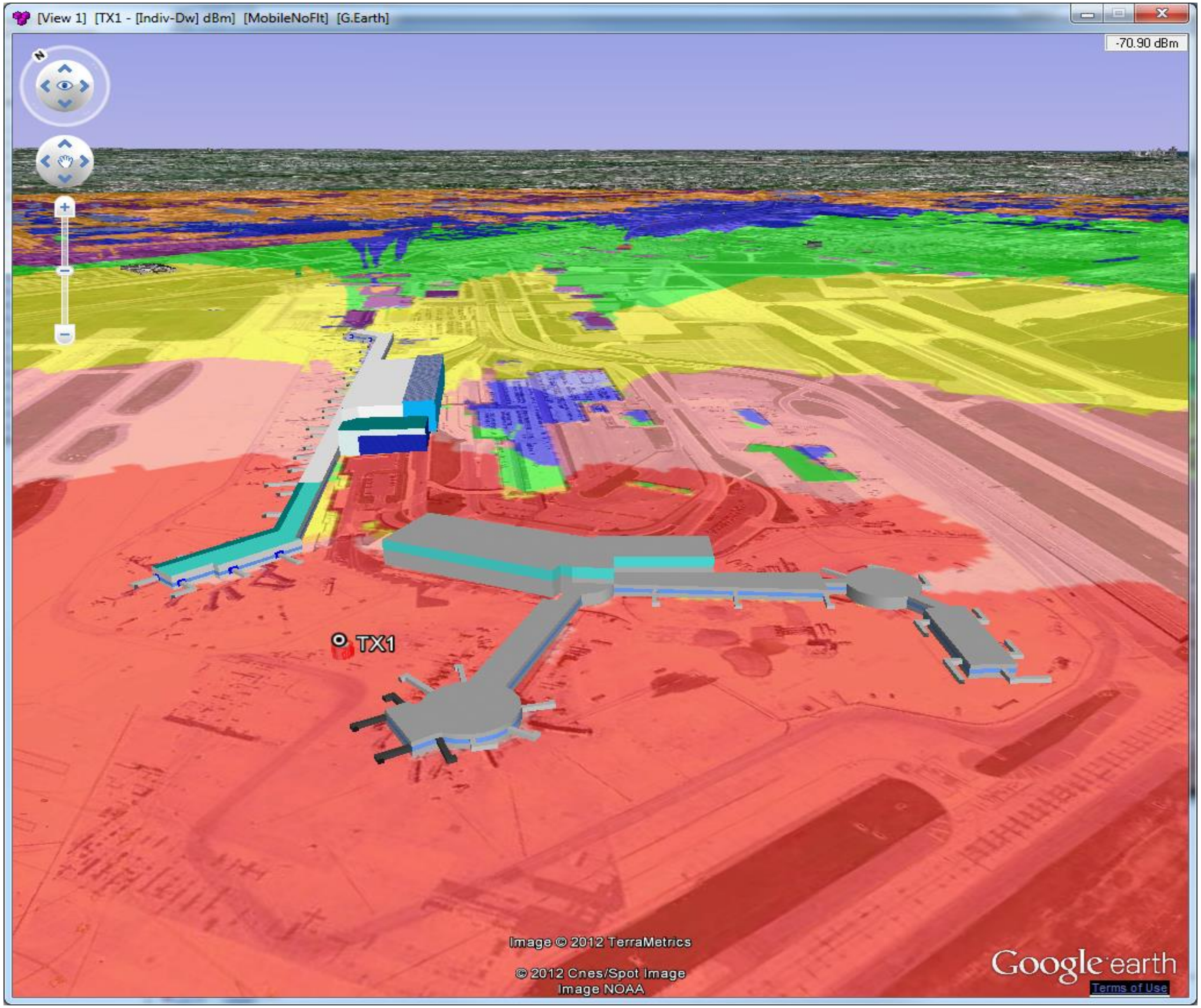
Airport 3 D Coverage view



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Ray Tracing Predictions

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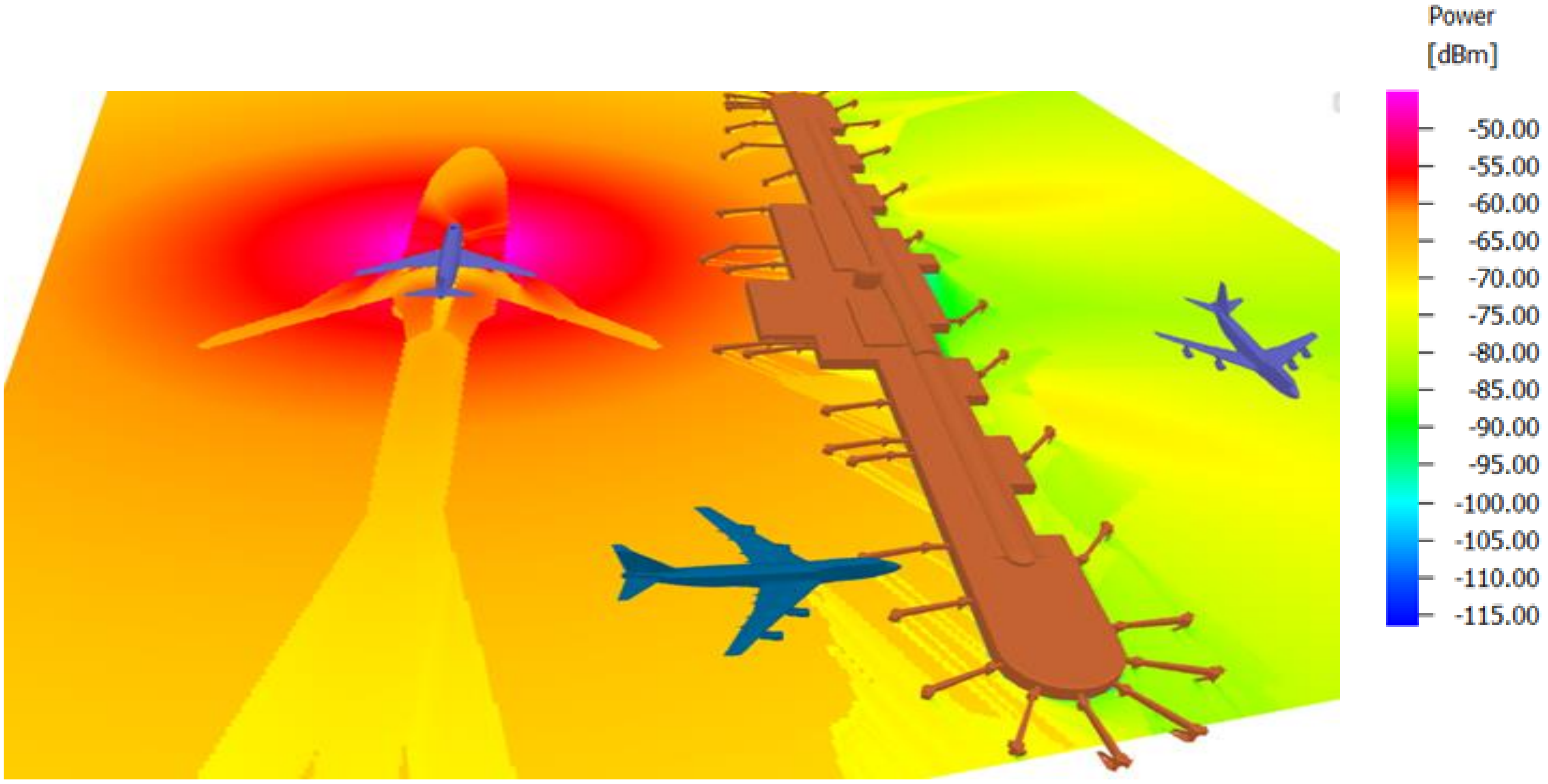
Ray Tracing Prediction

- Ray Tracing requires extremely precise data bases to provide similar results as empirical models
- Processing time is very high when compared to empirical models
- Ray Tracing has a unique property of providing multipath delay predictions



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RF Channel Characterization

Multipath Analysis

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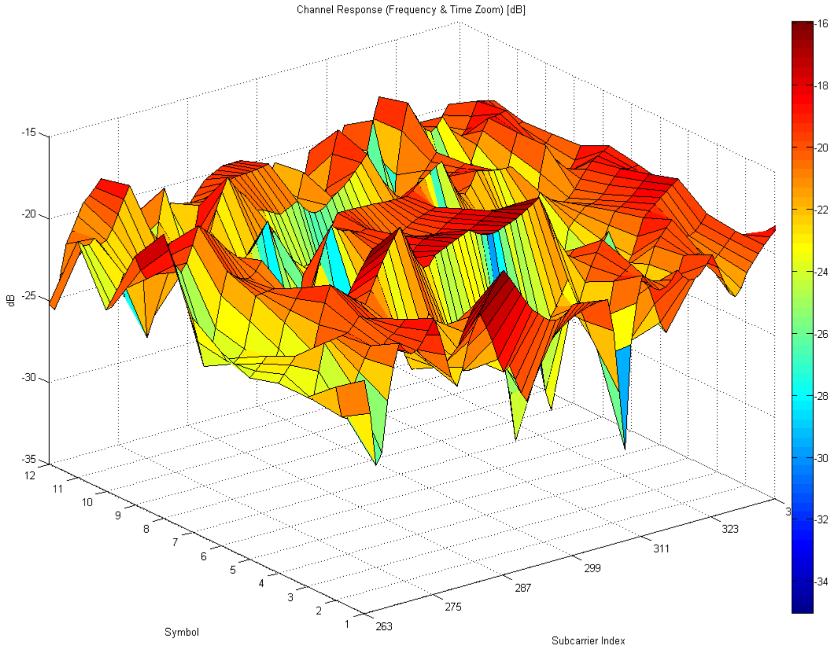
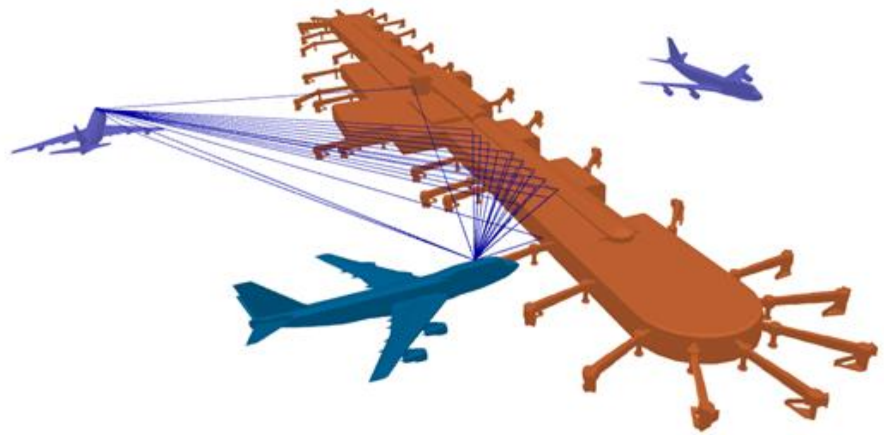
Multipath fading

- Multipath is a major impairment in wireless communications and should be properly characterized
- Characterization can be done using:
  - Channel response per OFDM sub-carrier
  - Ray Tracing





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Channel Response

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CelSDRx™

- Universal Software Defined Receiver (SDRx)
- Captures up to 100 MHz of spectrum from 100 MHz to 18 GHz
- Digitizes signal at 125 Msps and provides I and Q components
- Digitally extracts information for any digital technology: LTE, WiMAX, HSPA, UMTS, GSM
- Performs
  - Symbol synchronization
  - Frame Synchronization
  - Sub-Channel Equalization
  - Bandwidth and frame number determination
- Detects
  - RF Channel Response in time and frequency
    - Displays fading amplitude, band and duration
  - Channel Traffic load
  - Received signal coherence from different antennas
  - Received signal coherence to different antennas
- GPS data geo-referencing, allowing drive tests
- Ideal to plan network parameters
- Ideal to scan competitive networks
- Patents applied

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CelSDRx ™ Specifications

- Frequency coverage: 100 MHz to 18 GHz
- Instantaneous Bandwidth: 100 MHz
- Displayed Average Noise Level:
    - -115 dBm @ 10 MHz
    - -110 dBm @ 1500 MHz
    - -110 dBm @ 2500 MHz
- Maximum RF input: +10 dBm
- Non-input related spurs: < -100 dBm
- Maximum RF gain: 20 dB
- IF gain: -10 to +30 dB in 1 dB steps
- Power Supply +12 VDC

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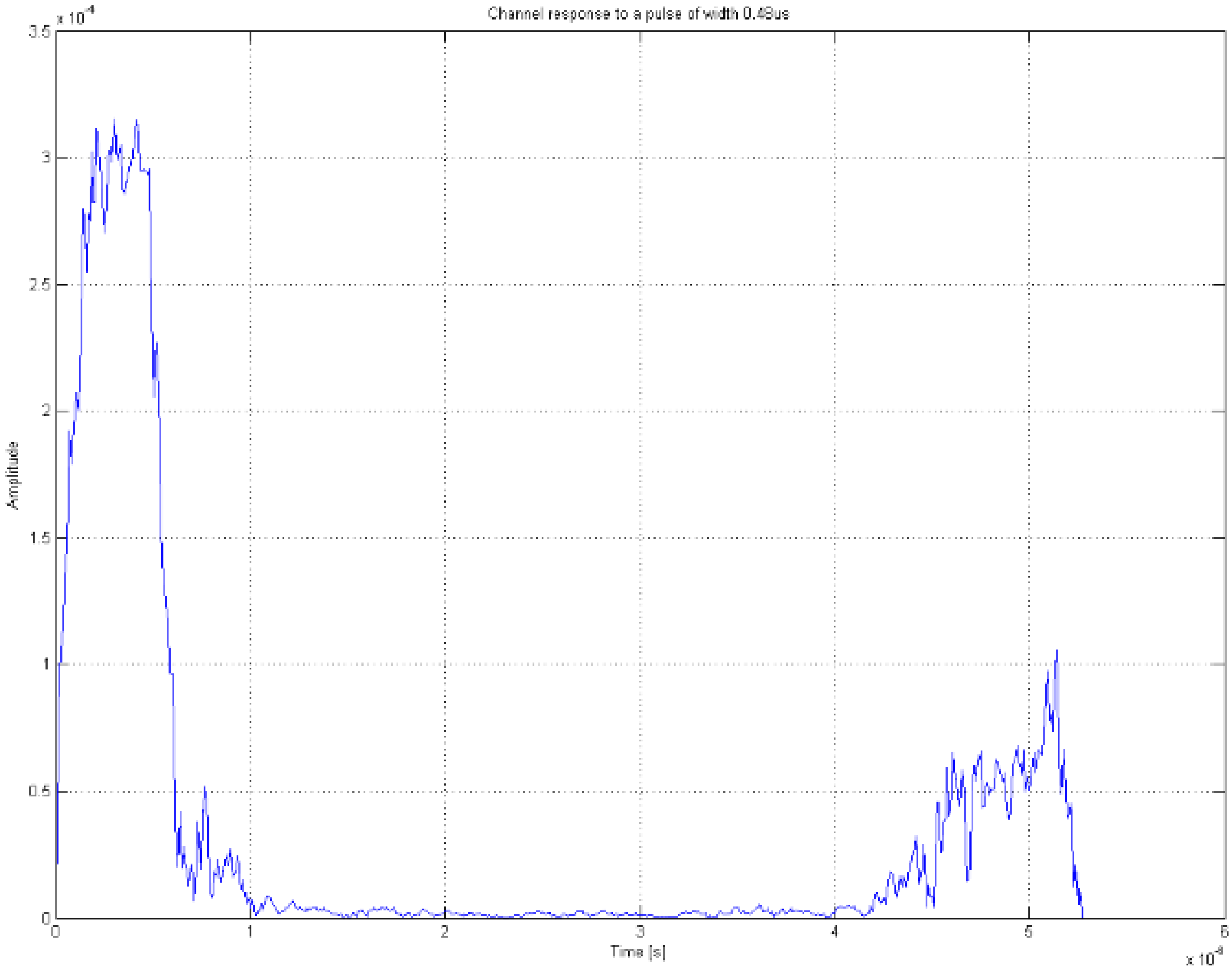
Impulse Response



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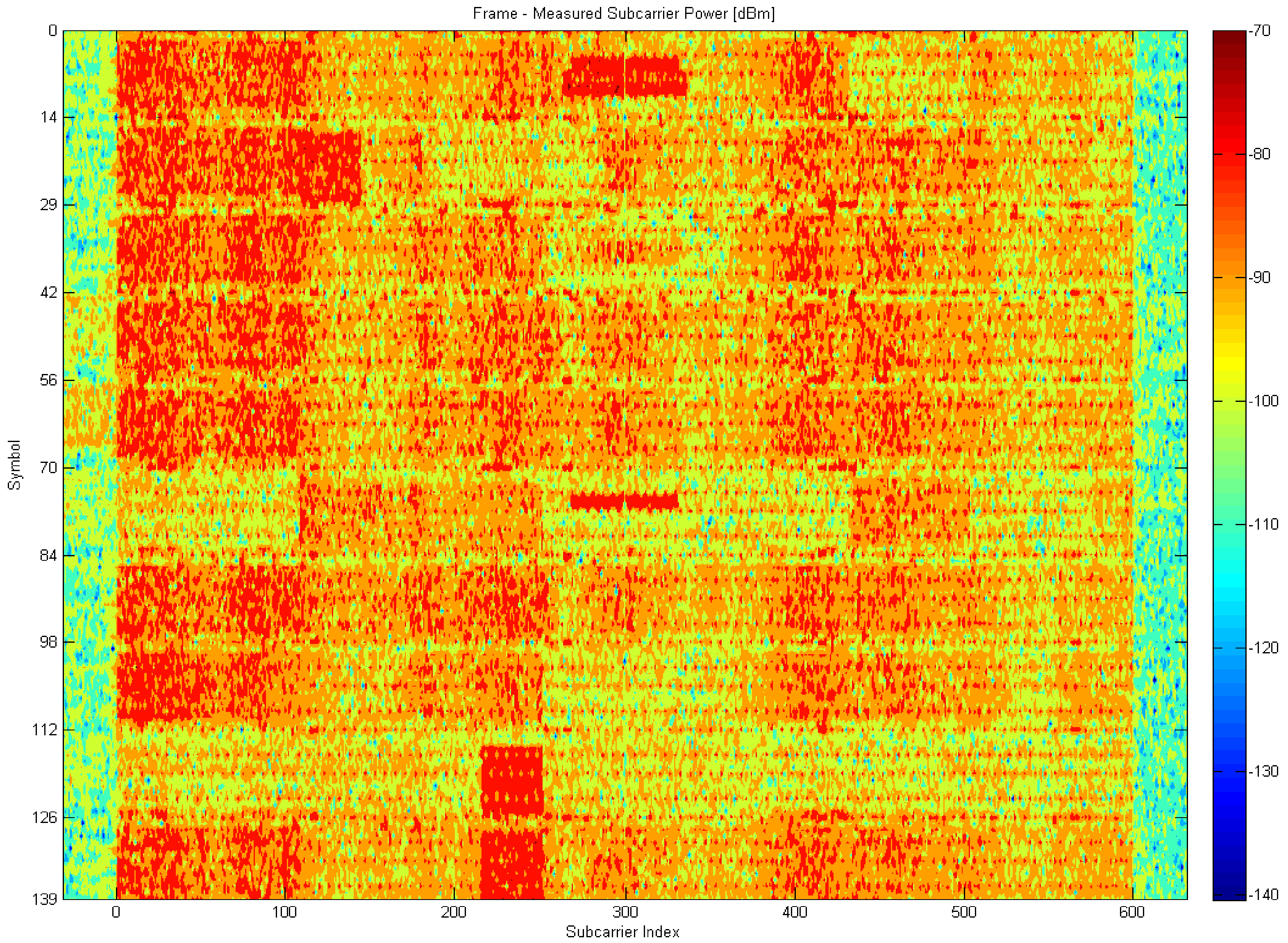
Measured Power per Resource Element (dBm)



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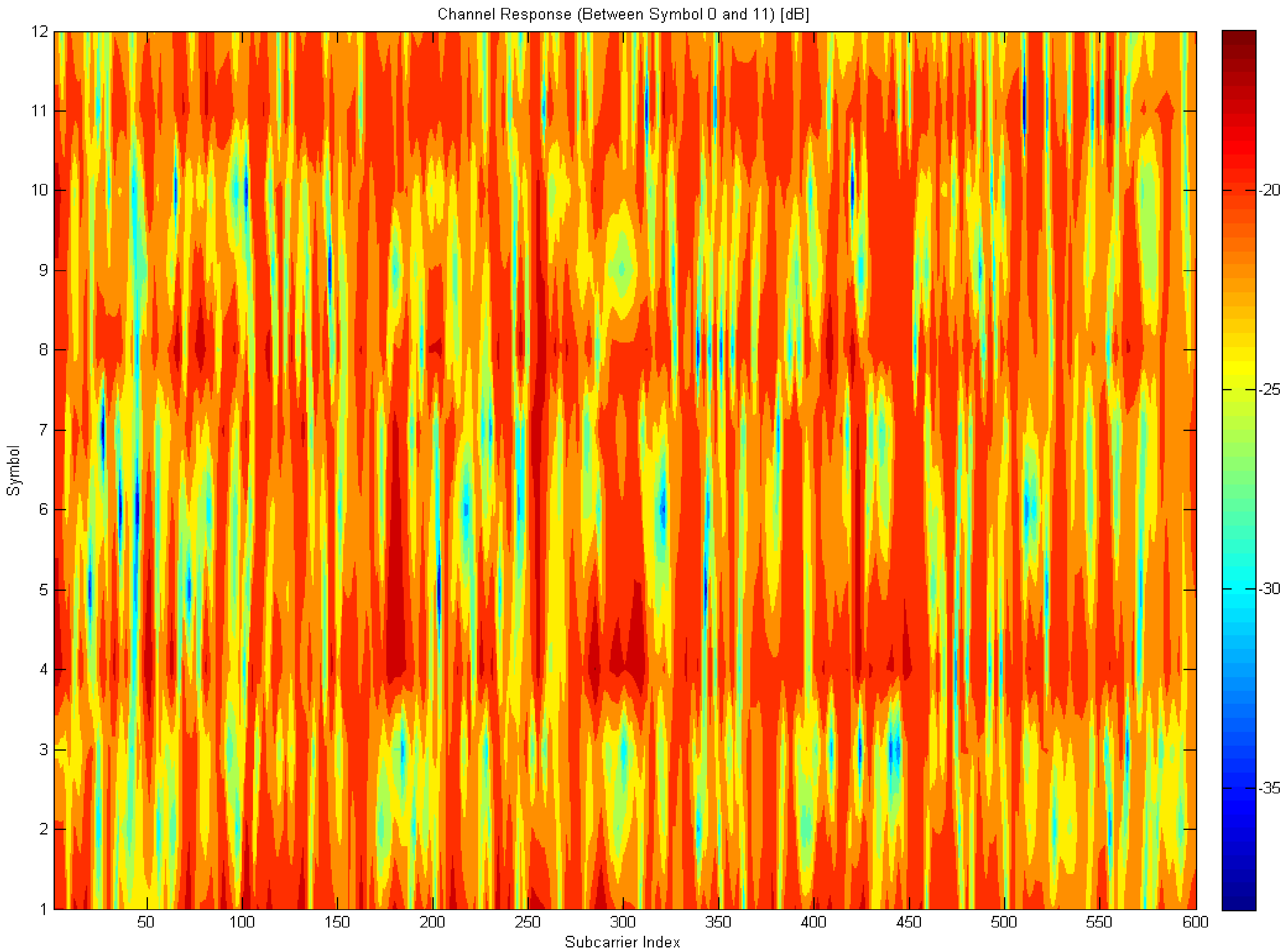
RF Channel Response (time zoom)



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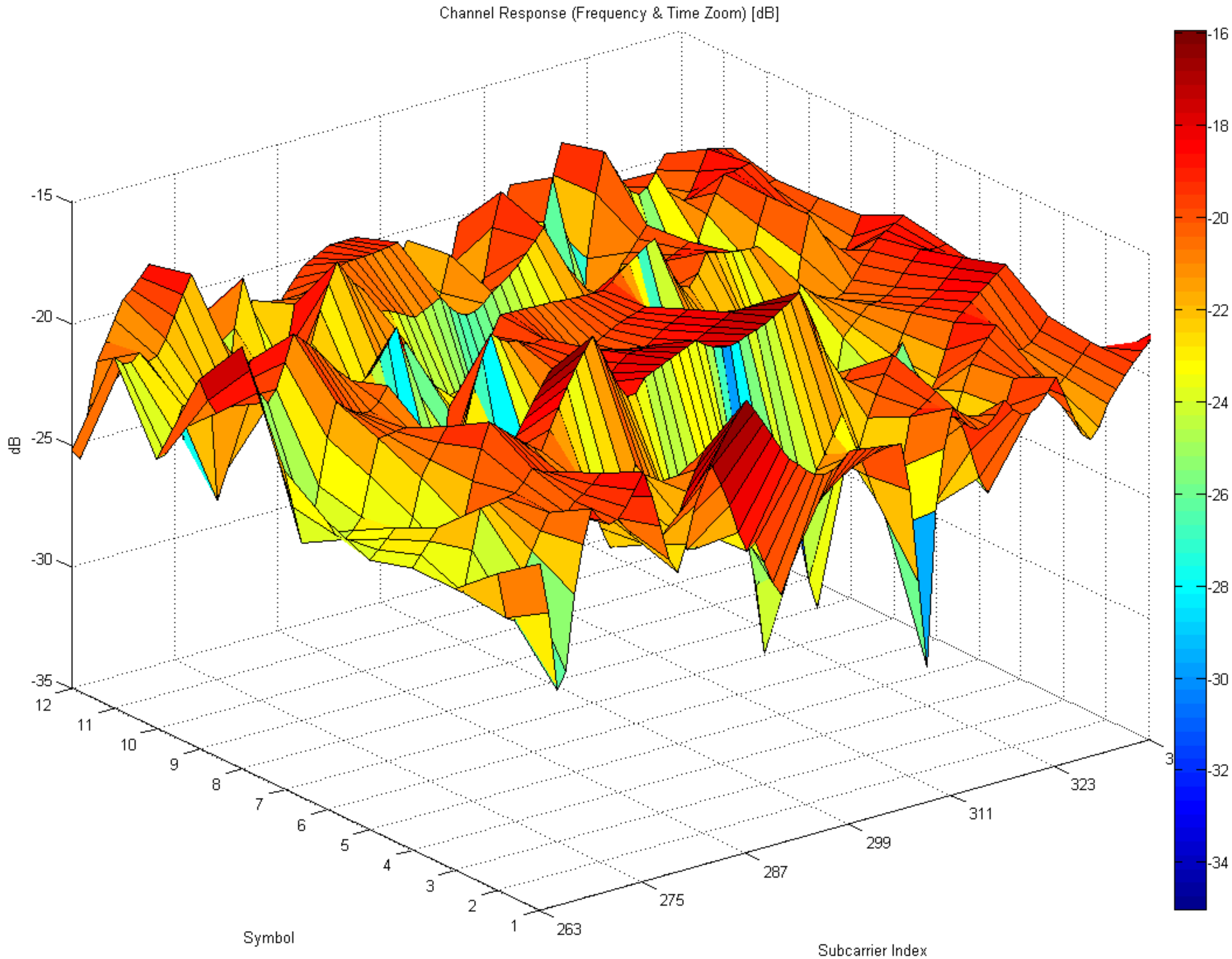
RF Channel Response (3D detail)



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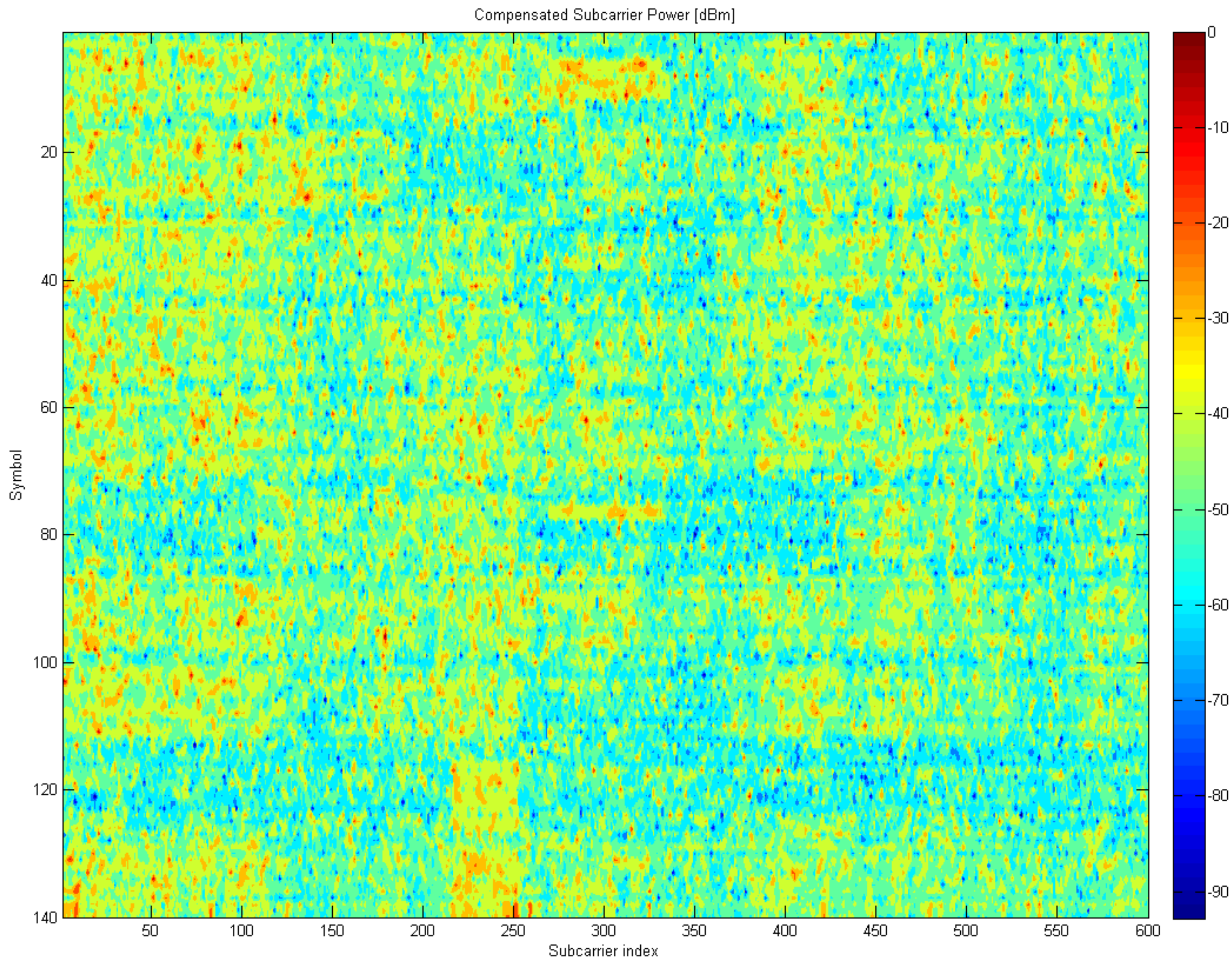
Adjusted Power per Resource Element (dBm)



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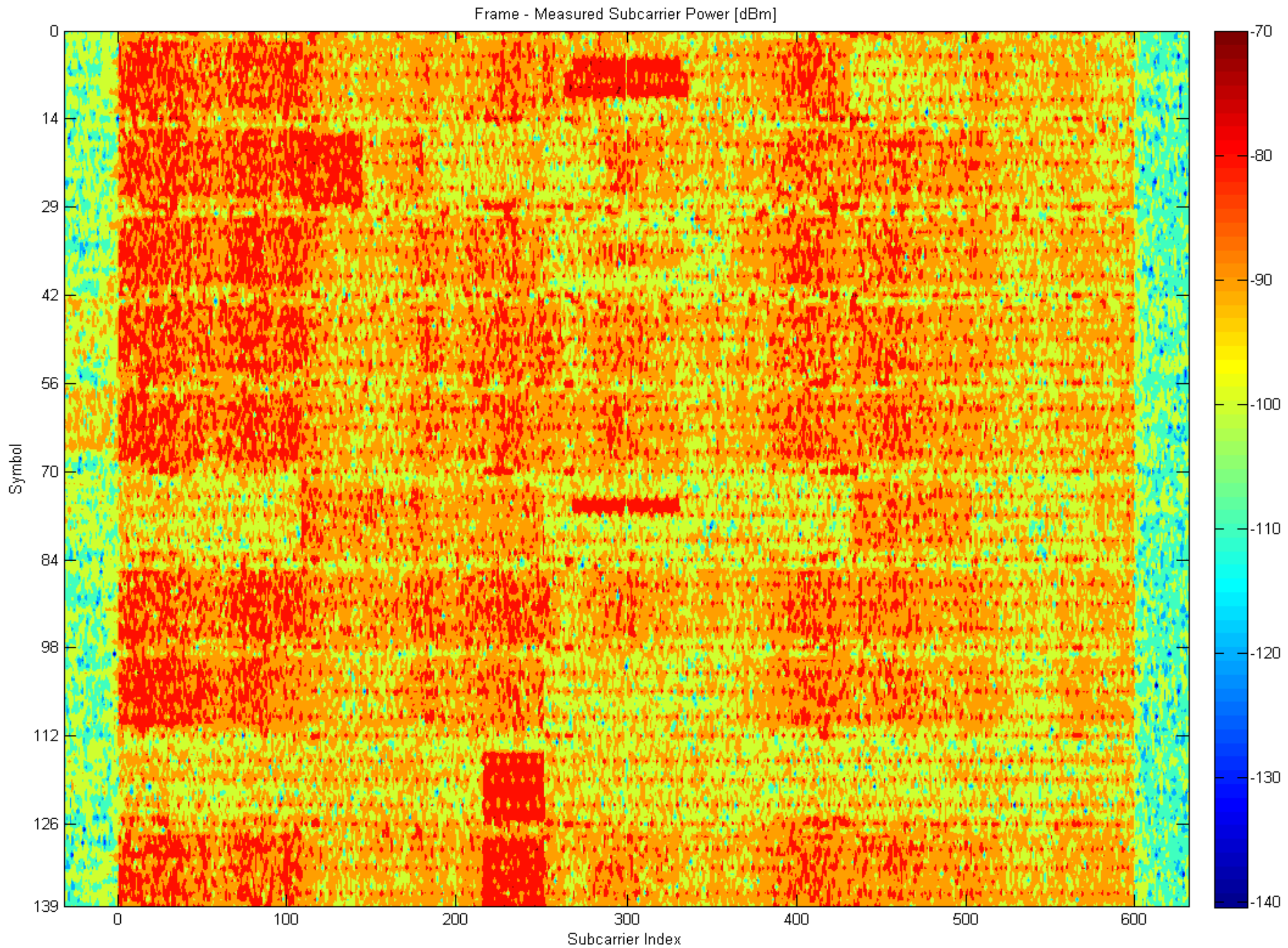
Traffic view

- Traffic allocation can be visualized per frame



Correlation

- Correlation is considered as the sympathetic movement of two or more variables
- Pearson's Product-Moment Correlation Coefficient

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}},$$

  - The correlation coefficient varies between +1 and -1
    - Positive Correlation: movement is in the same direction
    - Negative Correlation: movement is in the opposite direction
- Reference signals transmitted by two antennas can be used to establish the channel response
- The correlation coefficient for the two channel responses can then be calculated

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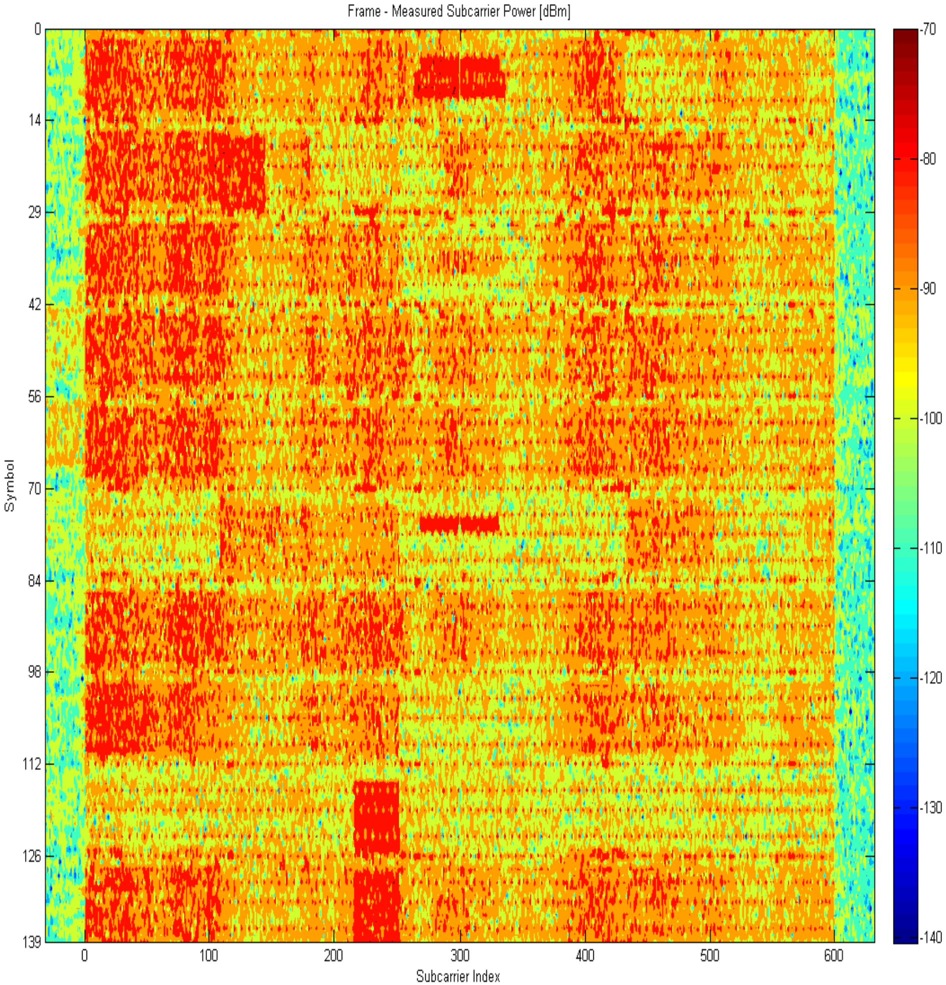
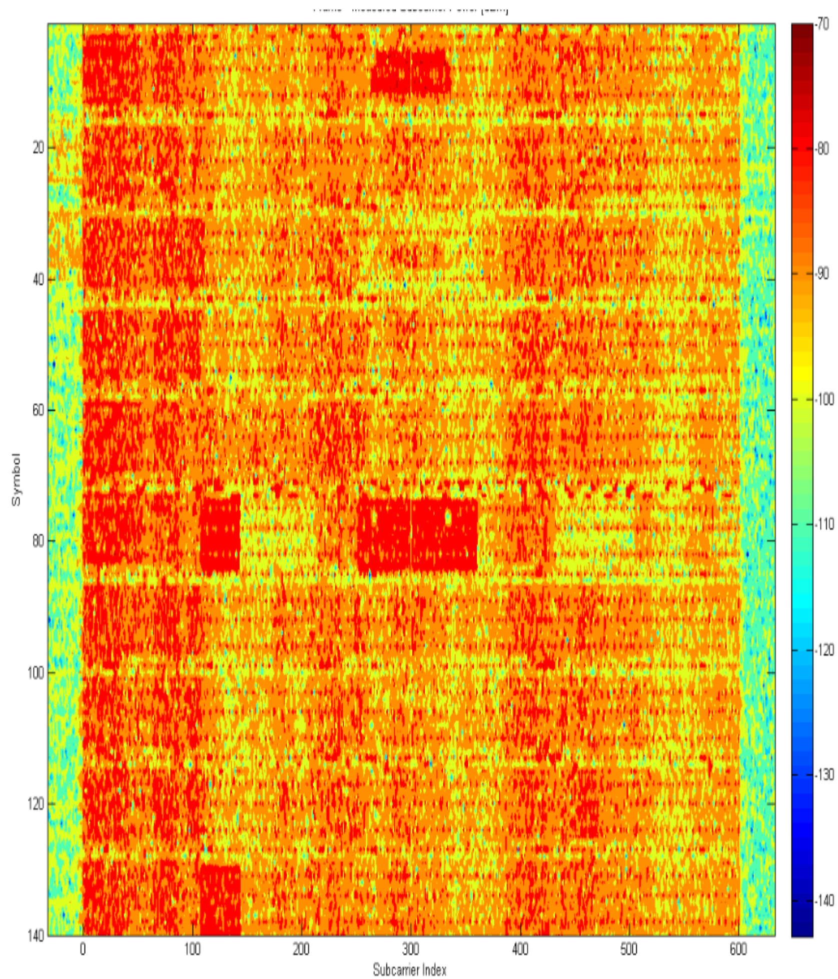
Correlation between antennas

- Correlation index between two antennas

  CI=0.42





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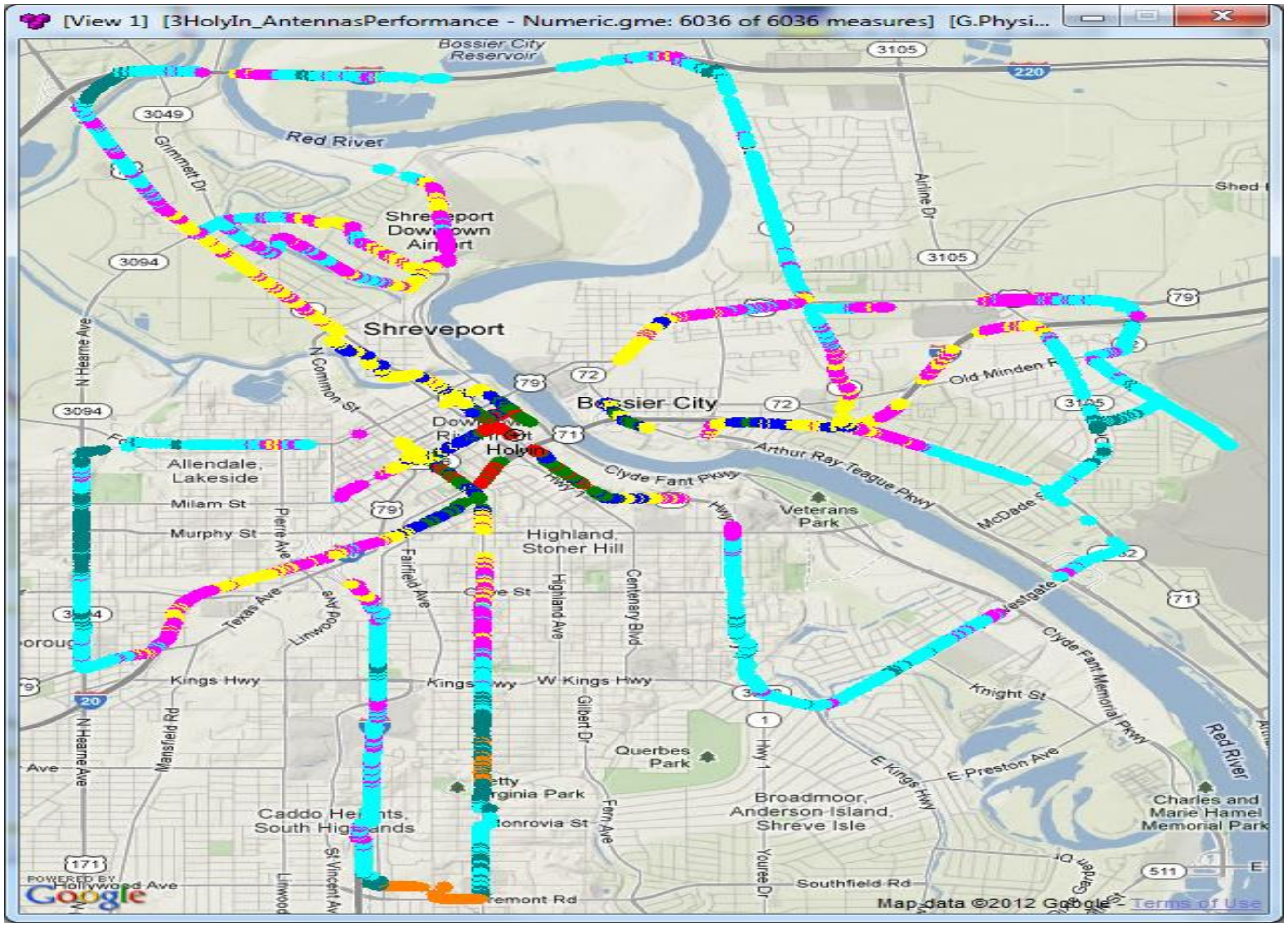
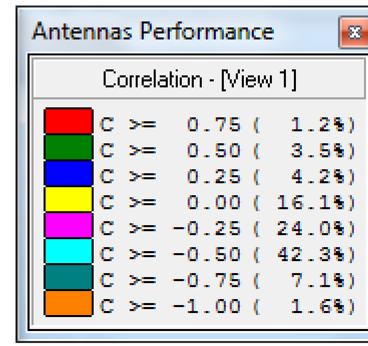
Antenna Correlation Drive

- Antenna correlation variation





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Multipath using Ray Tracing

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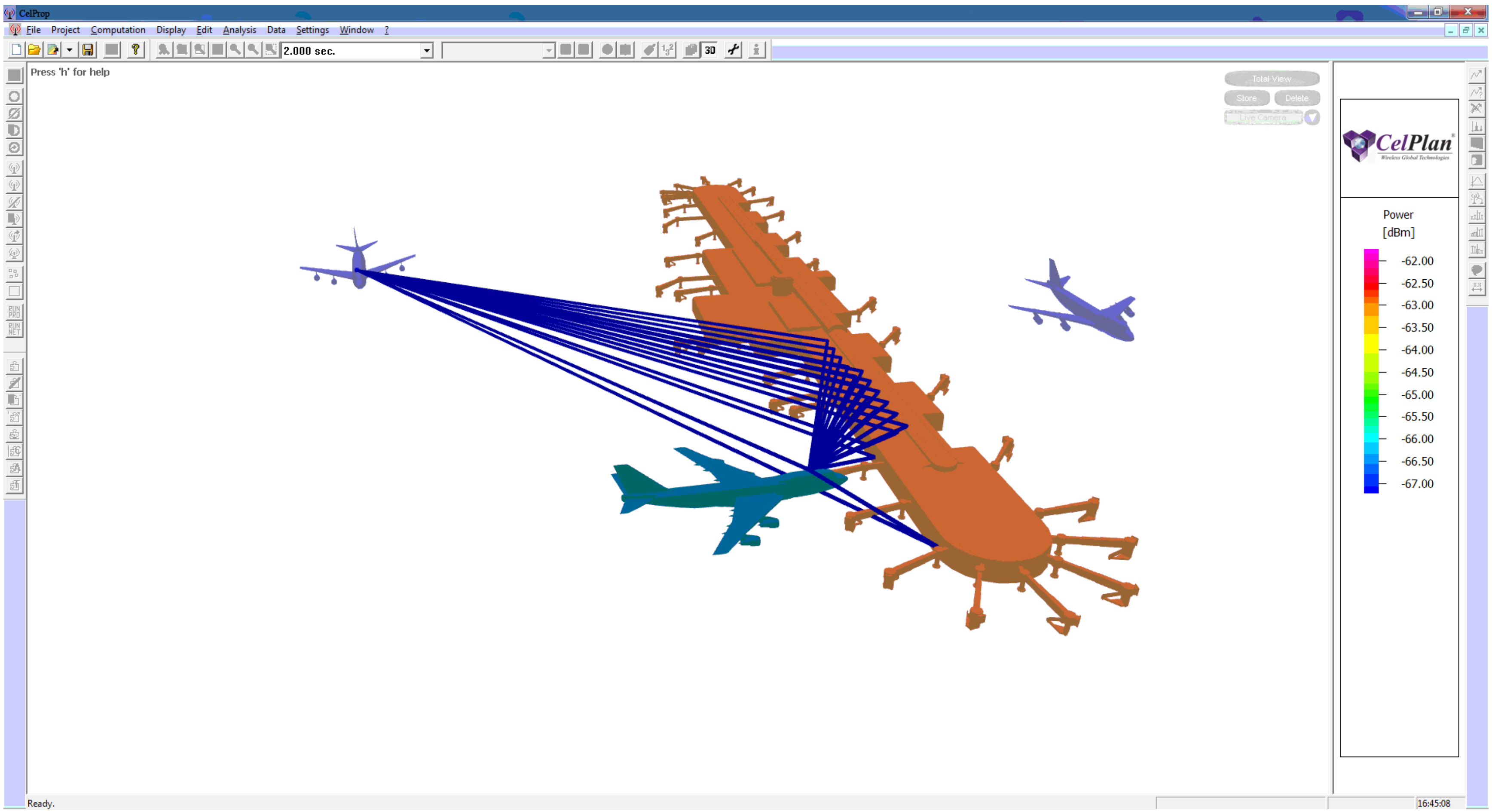
Multipath between moving airplanes



Conclusions

- Propagation characteristics were calculated for two airports
- Parameter reusability showed a good agreement for similar size airports
- Parameters will vary for smaller airports, with less obstructions
- Shadows and interference can be calculated for different transmitter locations
- The propagation parameters were then applied to the CelPlanner prediction software
- A special interface (API) was developed that allows the CelPlanner SW to provide data to other simulation tools
- The same methodology can be applied to other bands, like AeroMACS (5091 to 5150 MHz)
- Ray tracing can be used to perform predictions
- CelPlan can uniquely characterize multipath through
  - Channel Response determination
  - Ray tracing
- CelPlan can be your partner for a reliable design of AeroMACS

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Questions?

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