Spectrum Analysis for LTE Systems

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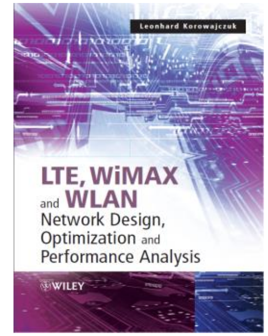
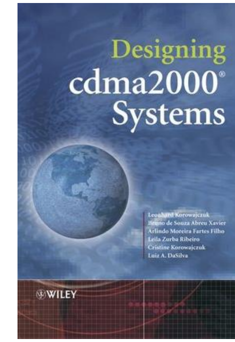
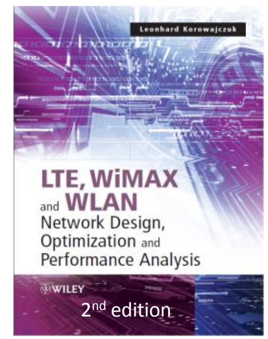
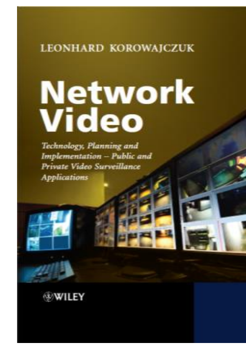
Presenter

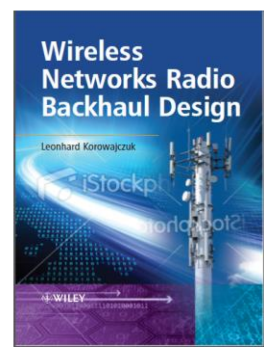
- **Leonhard Korowajczuk**
  - CEO/CTO CelPlan International
  - 45 years of experience in the telecom field (R&D, manufacturing and service areas)
  - Holds13 patents
  - Published books
    - “Designing cdma2000 Systems”
      - published by Wiley in 2006- 963 pages, available in hard cover, e-book 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 (2014) LTE-A and WiMAX 2.1(1,000+ pages)
    - Network Video: Private and Public Safety Applications (2014)
    - Backhaul Network Design (2015)
    - Multi-Technology Networks: from GSM to LTE (2015)
    - Smart Grids Network Design (2016)

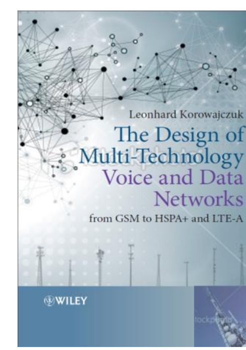












CelPlan International

- Employee owned enterprise with international presence
  - Headquarters in USA
  - 450 plus employees
  - Twenty (20) years in business
- Subsidiaries in 6 countries with worldwide operation
- Vendor Independent
- Network Design Software (CelPlanner Suite/CellDesigner)
- 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, Wi-Fi offloading

CelPlan Webinar Series

- **How to Dimension user Traffic in 4 G networks**
  - May 7th 2014
- **How to Consider Overhead in LTE Dimensioning and what is the impact**
  - June 4th 2014
- **How to Take into Account Customer Experience when Designing a Wireless Network**
  - July 9th 2014
- **LTE Measurements what they mean and how they are used?**
  - August 6th2014
- **What LTE parameters need to be Dimensioned and Optimized? Can reuse of one be used? What is the best LTE configuration?**
  - September 3rd 2014/ September 17th, 2014
- **Spectrum Analysis for LTE Systems**
  - October 1st 2014
- **MIMO: What is real, what is Wishful Thinking?**
  - November 5th 2014
- **Send suggestions and questions to: webinar@celplan.com**

Webinar 1 (May 2014)
How to Dimension User Traffic in 4G Networks

Participants from 44 countries
Youtube views: 1027

User Traffic

1. How to Dimension User Traffic in 4G Networks
2. How to Characterize Data Traffic
3. Data Speed Considerations
4. How to calculate user traffic?
5. Bearers
6. User Applications Determination
7. User Distribution

Webinar 2 (June 2014)
How to consider overhead in LTE dimensioning
and what is the impact

Participants from 49 countries

Youtube views: 545

Overhead in LTE

1. Reuse in LTE
2. LTE Refresher
    1. Frame
    2. Frame Content
    3. Transmission Modes
    4. Frame Organization
        1. Downlink Signals
        2. Uplink Signals
        3. Downlink Channels
        4. Uplink Channels
    5. Data Scheduling and Allocation
    6. Cellular Reuse
3. Dimensioning and Planning
4. Capacity Calculator

Webinar 3 (July 2014)
How to consider Customer Experience when designing a wireless network

Participants from 40 countries

Youtube views: 404

Customer Experience

1. How to evaluate Customer Experience?
2. What factors affect customer experience?
3. Parameters that affect cutomer experience
4. SINR availability and how to calculate it
5. Conclusions
6. New Products

Webinar 4 (August 6th, 2014)
LTE Measurements
What they mean?
How are they used?

Participants from 44 countries
Youtube views: 529

LTE Measurements

1. Network Measurements
   1. UE Measurements
      - RSRP
      - RSSI and its variations
      - RSRQ and its variations
      - RSTD
      - RX-TX Time Difference
   2. Cell Measurements
      - Reference Signal TX Power
      - Received Interference Power
      - Thermal Noise Power
      - RX-TX Time Difference
      - Timing Advance
      - Angle of Arrival
   3. Measurement Reporting
      - Intra-LTE
      - Inter-RAT
      - Event triggered
      - Periodic
2. Field Measurements
   1. 1D Measurements
      - RF propagation model calibration
      - Receive Signal Strength Information
      - Reference Signal Received Power
      - Reference Signal Received Quality
      - Primary Synchronization Signal power
      - Signal power
      - Noise and Interference Power
      - Fade Mean
   2. 2D Measurements
      - Primary Synchronization Signal Power Delay Profile
   3. 3D measurements
      - Received Time Frequency Resource Elements
      - Channel Frequency response
      - Channel Impulse Response
      - Transmit Antenna Correlation
      - Traffic Load
   4. Measurement based predictions

Webinar 5 (September 3rd, 2014)

What LTE parameters need to be Dimensioned and Optimized

Part 1- Downlink

Participants from 69 countries

Youtube views: 922

Webinar 5 (September 16th, 2014)

What LTE parameters need to be Dimensioned and Optimized

Part 2- Uplink

Participants from 46 countries

Youtube views: 208

Webinar 6
Spectrum Analysis for LTE Systems

October 1st 2014

Spectrum Analysis for LTE Systems

- LTE is an OFDM broadband technology, with very wide channels. Narrow band channels present similar fading characteristics in its bandwidth, with variations restricted only to time dimension. Wide band channels vary in the frequency domain also. The designer has to have a full understanding of this variations and this information is not available with traditional test gear
- Until today designers had to guess multipath and fading performance, but the deployment of wide band channels and MIMO techniques require a precise understanding of this effect geographically
  - This requires 2D and 3D analysis
- Decisions as where to deploy cells, what number of antennas to use and parameter settings, can represent huge capital (CAPEX) savings and reduce operational costs (OPEX)

- RF Parameter Characterization in Broadband Channels
- Traditional Spectrum Analysis
- LTE Performance Spectrum Analysis
- Network Characterization though Drive Test
- Drive Test Devices
  - Software Defined Receivers
  - Spectrum recording
- Visualizing Measurements in Multiple Dimensions
  - 1 Dimension
  - 2 Dimensions
  - 3 Dimensions
- Measurement Interpolation and Area Prediction
- Explaining LTE Measurement Content
  - RX Signal Strength per RE
  - Noise Filtered Channel Response for each RS
  - RF Channel Response for RS carrying OFDM symbols
  - RF Channel Response for all OFDM symbols
  - Impulse Response for each RS Carrying OFDM symbol
  - Multipath Delay Spread
  - Reference Signal Received Power
  - Receive Signal Strength Indicator: full OFDM symbols
  - Receive Signal Strength Indicator: RS RE of OFDM symbols
  - Receive Signal Strength Indicator: PBCH
  - Reference Signal Received Quality: full OFDM symbols
  - Reference Signal Received Quality: RS RE of OFDM symbols
  - Reference Signal Received Quality: PBCH
  - PSS Power Distribution Profile
  - PSS Power
  - Frequency Fade Mean
  - Frequency Fade Variance
  - Signal power
  - Noise Power
  - Signal to Noise and Interference Ratio
  - Antenna Correlation
  - LTE Frame Traffic Load

Webinar 7
MIMO
What is Real?
What is Wishful Thinking?

November 5th 2014

Registration is open

MIMO What is Real? What is Wishful Thinking?

- Antenna Ports
- Transmission Modes
- MIMO
  - Transmit Diversity
  - Cyclic Delay Diversity
  - Open Loop Spatial Multiplexing
  - Closed Loop Spatial Multiplexing
  - Beamforming
  - Multi-user MIMO
- MIMO Channel Modelling
- MIMO System Performance
- SU-MIMO vs MU-MIMO
- Antenna Correlation

LTE Technology, Network Design & Optimization Boot Camp

December 8 to 12, 2014

at University of West Indies (UWI)

St. Augustine, Trinidad

LTE Technology, Network Design & Optimization Boot Camp

- December 8 to 12, 2014
- Based on the current book and updates from the soon-to-be published 2nd edition of, "***LTE, WiMAX, and WLAN: Network Design, Optimization and Performance Analysis***", by Leonhard Korowajczuk, this -day course presents students with comprehensive information on LTE technology, projects, and deployments.
- CelPlan presents a realistic view of LTE networks, explaining what are just marketing claims and what can be achieved in real life deployments. Each module is taught by experienced 4G RF engineers who design and optimize networks around the globe.
- The materials provided are based upon this experience and by the development of industry leading planning & optimization tools, such as the CelPlanner Software Suite, which is also provided as a 30-day demo to each student
- **Module A: LTE Technology**
  - Signal Processing Applied to Wireless Communications
  - LTE Technology Overview
  - Connecting to an LTE network: an UE point of view
  - How to calculate the capacity of an LTE cell and network
  - Understanding scheduling algorithms
  - LTE measurements and what they mean
  - Understanding MIMO: Distinguishing between reality and wishful thinking
  - Analyzing 3D RF broadband drive test

LTE Technology, Network Design & Optimization Boot Camp

- **Module B: LTE Network Design**
  - Modeling the LTE Network
  - Building Network Component Libraries
  - Modeling user services and traffic
  - Creating Traffic Layers
  - RF Propagation Models and its calibration
  - Signal Level Predictions
  - LTE Predictions
  - LTE Parameters
  - LTE Resource Optimization
  - LTE Traffic Simulation
  - LTE Performance
  - Interactive Workshop (sharing experiences)
- 4G Certification (Optional)
- Additional information, Pricing & Registration available at www.celplan.com

Today's Feature Presentation

Today's Webinar

Spectrum Analysis for LTE Systems

October 1st, 2014

Spectrum Analysis for LTE Systems

1. RF Parameters Characterization in LTE
2. Spectrum Analysis
3. Channel/Technology Analysis
4. CellSpectrum Parameters
5. 3D Parameters
6. 2D Parameters
7. 1D Parameters
8. Calibration of Propagation Models
9. Comparing Predictions and Measurements
10. Generating Predictions from Measurements
11. Summary

Spectrum Analysis for LTE Systems

- 3D Parameters
  - Time Frequency Grid (TFG)
  - Channel Estimate Raw (CERAW)
  - Channel Estimate Smoothed (CESMOOTH)
  - Channel Estimate TFG (TFGCE)
  - Channel Corrected Received Signal (RXGRID)
- 2D Parameters
  - Primary Synchronisation Signal (PSS PDP)
  - Antenna Correlation
- 1D Parameters
  - RSRP
  - RSSI
  - RSRQ
  - PSS PowerSignal Power
  - Noise Power
  - Frequency Fade
  - Time Fade

1. RF Parameter Characterization in Broadband Channels (LTE)

CellSpectrum™

RF Parameter Characterization in Broadband Channels (LTE)

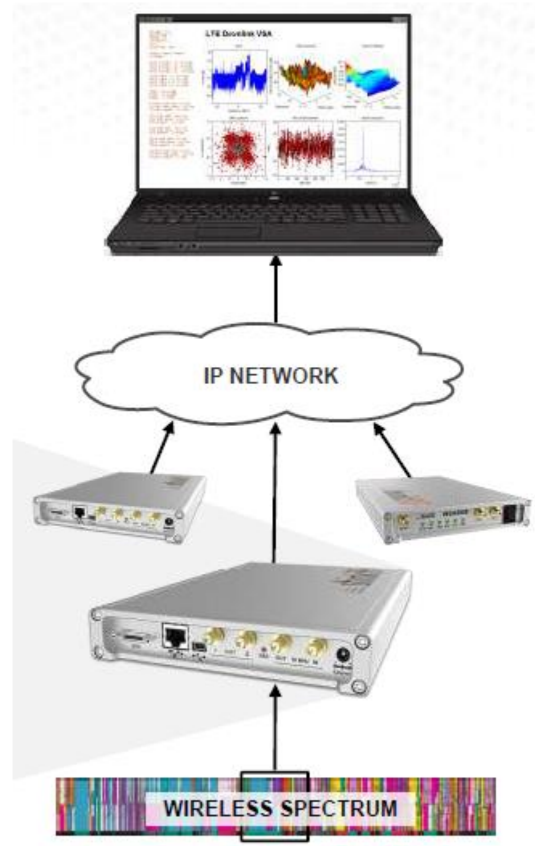
- Narrowband channels may be considered as having a uniform behavior along its bandwidth, varying only over time
  - This variation is called fading and its characterization is important to define the operating margins required for a certain performance
  - In general designers have to guess the fading distribution as it is not an easy parameter to measure, mainly as it varies from one location to another
- Broadband channels present a significant variation in frequency also and this add another dimension for the RF channel characterization
- OFDM technologies are sensitive to multipath and this is a very difficult parameter to characterize over the entire network

Requirements for a Broadband Field Spectrum and Technology Analyzer

- The industry uses primarily two main types of field drive test equipment to characterize the RF channel and network performance
  - Scanners are used to detect the RF signal and detect characteristics of the received signal
  - Technology protocol decoders are used to analyze message exchanges and are generally based on regular user devices, loaded with a special software
- Scanners perform measurements of a set of 1 dimensional parameters, like power, noise or cell IDs
- Several crucial parameters required for a proper network design are not analyzed due to its complexity, as they require 2 and 3 dimensional analysis
  - A three dimensional analysis will capture information in frequency, time and energy domains
- Commercial scanners capture some 1D parameters but if any additional analysis is required it can be not done, requiring another drive test
- CelPlan felt this limitation and decide to develop a product that would cover the main shortcomings of existing tools
- The specification for the new field test equipment were then specified:
  - It should capture the entire spectrum under observation
  - It should be able to analyze the spectrum in 3 D
  - It should provide answers at least to the following questions:
    - What is the multipath delay spread in every part of the network?
    - What is the expected time and frequency fading?
    - What is the actual correlation between transmit antennas in the field?
    - What is the average path loss?
    - How are the best servers distributed along the network?
    - How is traffic distributed in an LTE frame?

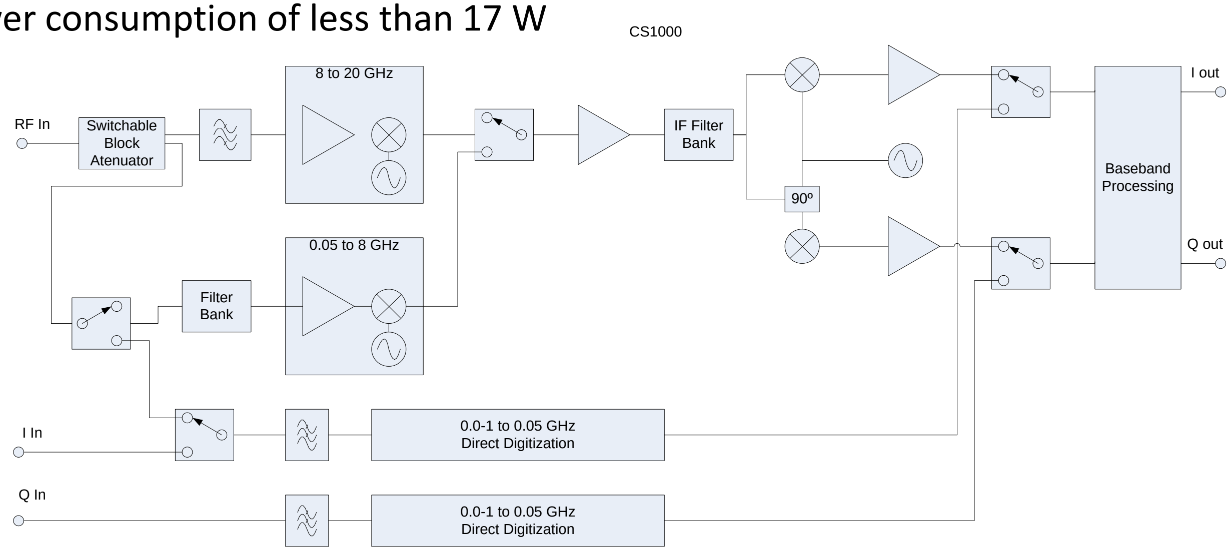
CellSpectrum™

- It is an RF Spectrum and Channel Analyzer based on a universal software-defined receiver that enables capturing, digitizing, storing and analyzing detailed RF & technology characteristics needed for the proper design of wireless networks
- It digitizes and stores up to 100 MHz of spectrum at a time, from 100 MHz to 18 GHz, extracting parameters as:
  - LTE channel response per Resource Element
  - Multipath delay spread
  - Average frequency fading
  - Average time fading
  - Noise floor
  - Interference
  - Traffic Distribution
  - 3D visualization capability
- Additionally, allocation and traffic information can be derived, providing valuable information about the allocation used for Inter Cell Interference Coordination (ICIC). Framed OFDM transmitters, like WiMAX and LTE, provide ideal platforms to characterize the RF channel



CS1000 ™ Hardware

- CS1000 has a versatile signal analysis platform which offers the best features of super heterodyne and direct conversion receiver architectures
- Designed to provide a wide 100 MHz instantaneous bandwidth with the flexibility to switch into an 'offset-free' super-heterodyne mode of operation
- Frequency range: The standard units are calibrated up to 8 GHz
- Dynamic range: in excess of 100 dB
- Providing the ability to test baseband signals and also to interface with very wideband (> 100 MS/s) digitizers and data recording systems
- Spectrum scan rate of 200 GHz/s
- Small form factor and low power consumption
  - The dimensions of CS1000 are 9.5" x 6.5" x 1.2"
  - DC power consumption of less than 17 W



CellSpectrum™ 1000 Software

- CellSpectrum ™ 1000 software collects and processes the data produced by the CellSpectrum 1000 hardware
- CellSpectrum ™ 1000 uses a powerful multi-screen visualization platform, with many unique features as:
  - Multiple Views
  - Integrated Google Maps and Google Earth images, including Street View
  - View synchronization in terms of display area
  - Simultaneous mouse display in all views
  - Synchronization between 2D graphs and geographic maps
  - Display of 3D graphs
  - Statistic Data analysis display
- CellSpectrum ™ 1000 provides access to the following features:
  - A full-fledged Spectrum Analyzer
  - A Technology Analyzer
  - A set of assorted spectrum analyzers, scanners and radios
  - A CelPlanner project that can be displayed with the measurements

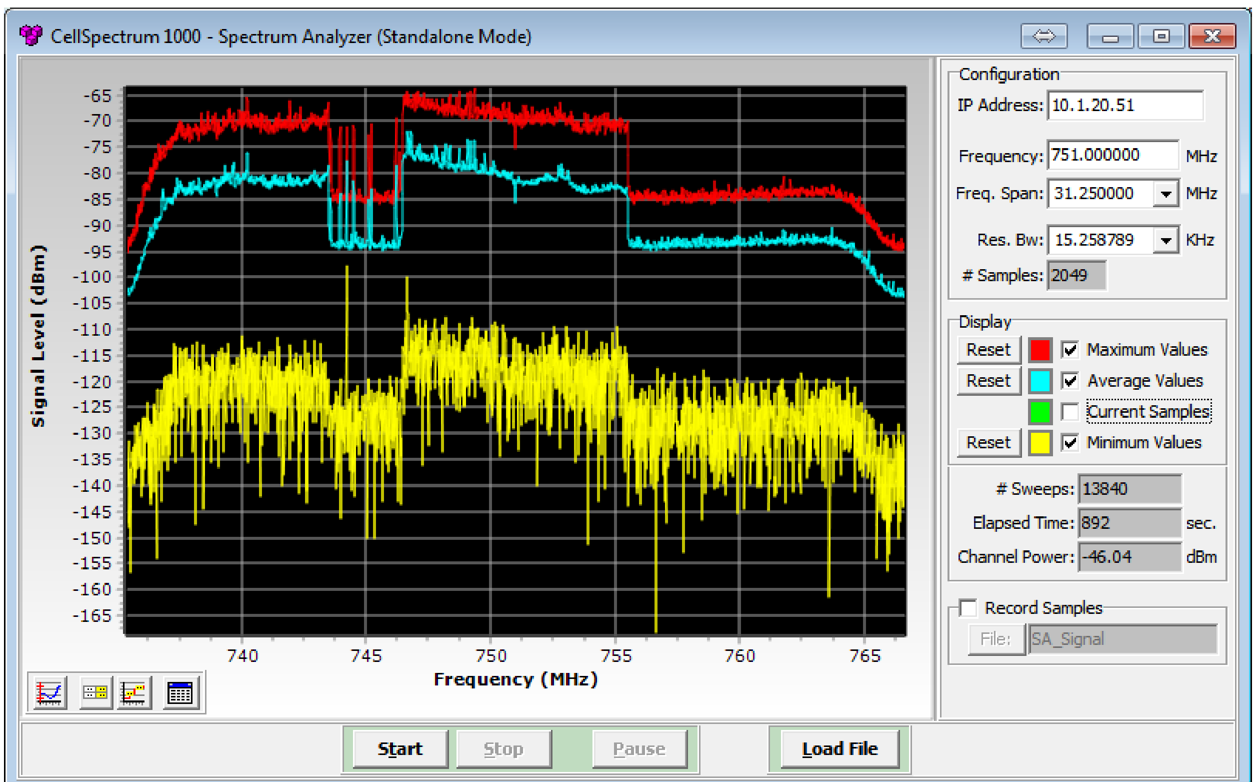
2. Spectrum Analysis

CellSpectrum ™ 1000

Spectrum Analyzer (Stand Alone)

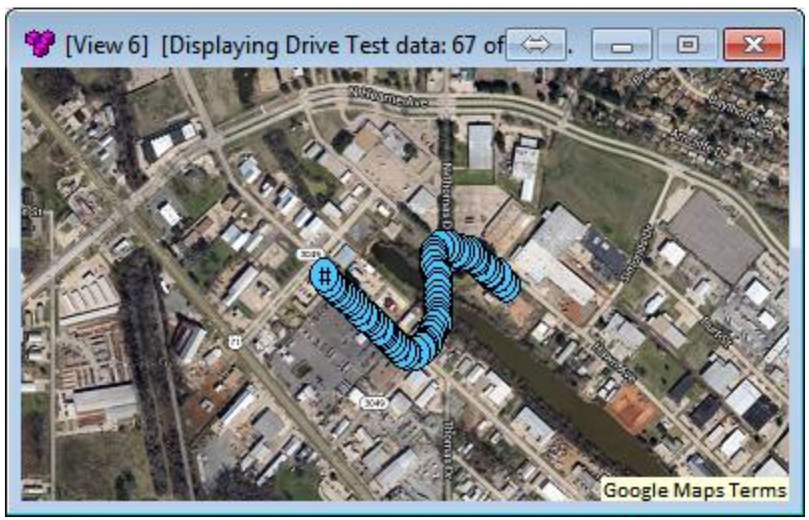
CelPlan Wireless Solutions & Consulting

- User can capture live data or load data from a file
- User can use automatic display signal level range or define it manually
- Spectrum samples can be recorded in a file with a sampling rate of approximately 1 second.
- The entire displayed bandwidth is calculated, as well the power within two markers defined by the user
- Measured power can be recorded to a file
- User can access the hardware remotely

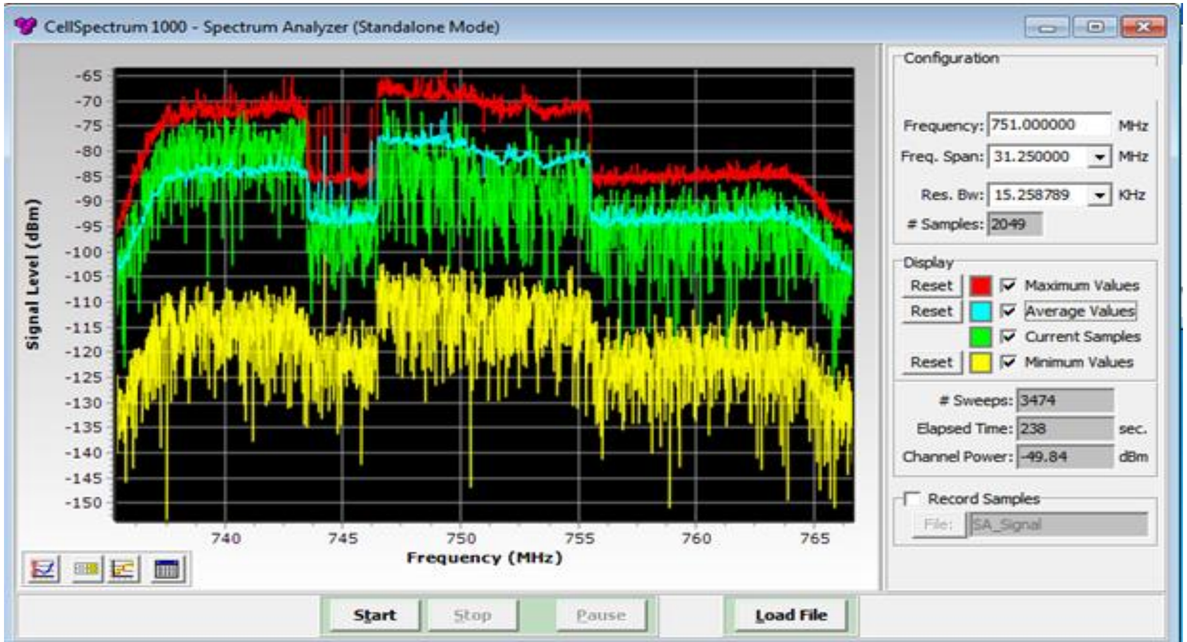


Spectrum Analyzer (Drive/Walk Test)

- Mode: Defines if the measurement is indoor or outdoor. Indoor measurement points are defined on a map when performing the walk test. Outdoor measurements use a GPS, with an optional dead reckoning system.
- GPS: Allows the configuration of the GPS collection
- Log File: Allows the configuration and management of the file where measurements will be logged.
- Display: Allows the management of what should be displayed
- Base Station: Allows the configuration of Base Stations
- Events: Allows the display of events during drive test



Spectrum Analyzer (Drive/Walk Test)

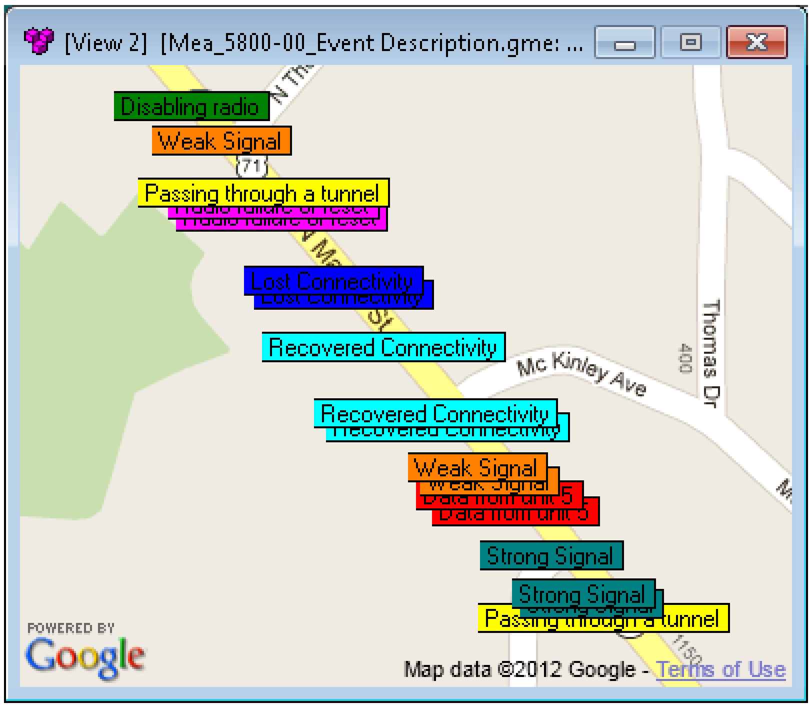


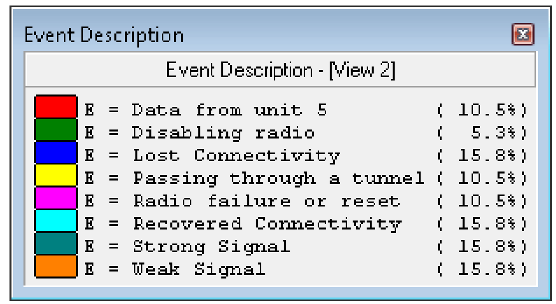
Log Data

Rec#	UTC	Time	Lat	Lon	Speed	nSat	AntHeight	BS_Dist	Mode	Ch.Pw.	ManualEventId (Event Descript
160	00:00:00	13:04:39.509	32.534683	-93.764817	72.00	3	10.0	-	Outdoor	#	(Location Event)
161	00:00:00	13:04:40.523	32.534714	-93.764864	72.00	3	10.0	-	Outdoor	#	(Location Event)
162	00:00:00	13:04:41.537	32.534797	-93.764964	72.00	3	10.0	-	Outdoor	#	(Location Event)
163	00:00:00	13:04:42.551	32.534881	-93.765064	72.00	3	10.0	-	Outdoor	#	(Location Event)
164	00:00:00	13:04:43.566	32.534933	-93.765131	72.00	3	10.0	-	Outdoor	#	(Location Event)
165	00:00:00	13:04:44.580	32.534964	-93.765200	72.00	3	10.0	-	Outdoor	#	(Location Event)
166	00:00:00	13:04:45.594	32.535064	-93.765314	72.00	3	10.0	-	Outdoor	#	(Location Event)
167	00:00:00	13:04:46.608	32.535164	-93.765414	72.00	3	10.0	-	Outdoor	#	(Location Event)
168	00:00:00	13:04:46.665	32.535233	-93.765497	72.00	3	10.0	-	Outdoor	0	(Tunnel)
169	00:00:00	13:04:47.622	32.535233	-93.765497	72.00	3	10.0	-	Outdoor	#	(Location Event)
170	00:00:00	13:04:48.636	32.535283	-93.765581	72.00	3	10.0	-	Outdoor	#	(Location Event)
171	00:00:00	13:04:49.010	32.535347	-93.765667	72.00	3	10.0	-	Outdoor	1	(Overpass)
172	00:00:00	13:04:49.650	32.535347	-93.765667	72.00	3	10.0	-	Outdoor	#	(Location Event)
173	00:00:00	13:04:50.664	32.535400	-93.765750	72.00	3	10.0	-	Outdoor	#	(Location Event)
174	00:00:00	13:04:51.678	32.535467	-93.765817	72.00	3	10.0	-	Outdoor	#	(Location Event)
175	00:00:00	13:04:52.692	32.535514	-93.765881	72.00	3	10.0	-	Outdoor	#	(Location Event)
176	00:00:00	13:04:53.162	32.535567	-93.765947	72.00	3	10.0	-	Outdoor	2	(Near cell site)
177	00:00:00	13:04:53.707	32.535567	-93.765947	72.00	3	10.0	-	Outdoor	#	(Location Event)
178	00:00:00	13:04:54.721	32.535667	-93.766064	72.00	3	10.0	-	Outdoor	#	(Location Event)

Spectrum Analyzer (Drive/Walk Test)

- Event Recording





3. Channel/Technology Analyzer

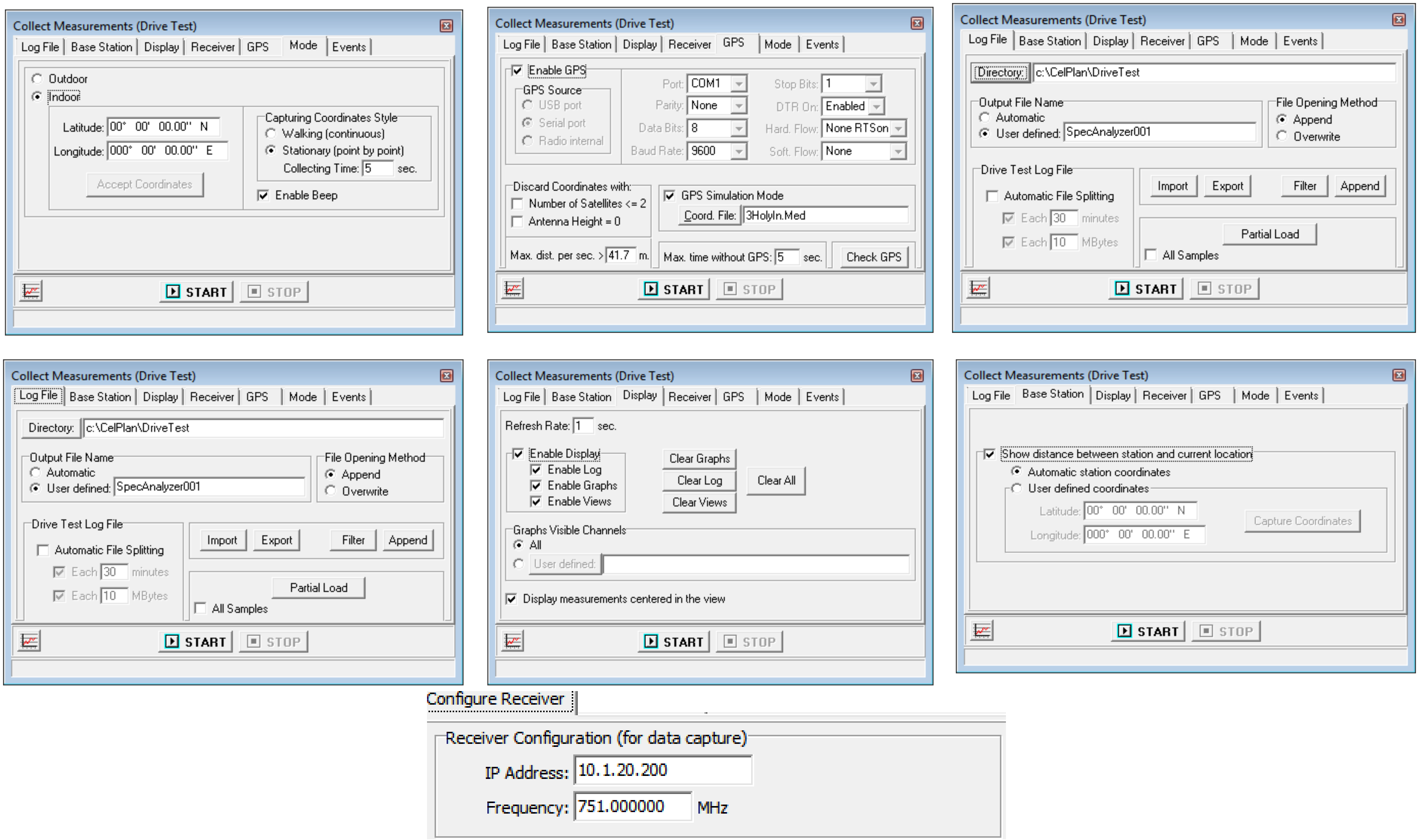
CellSpectrum 1000™

Channel/ Technology Analyzer

- Configuration
- Collection
- Post Processing
- Visualization

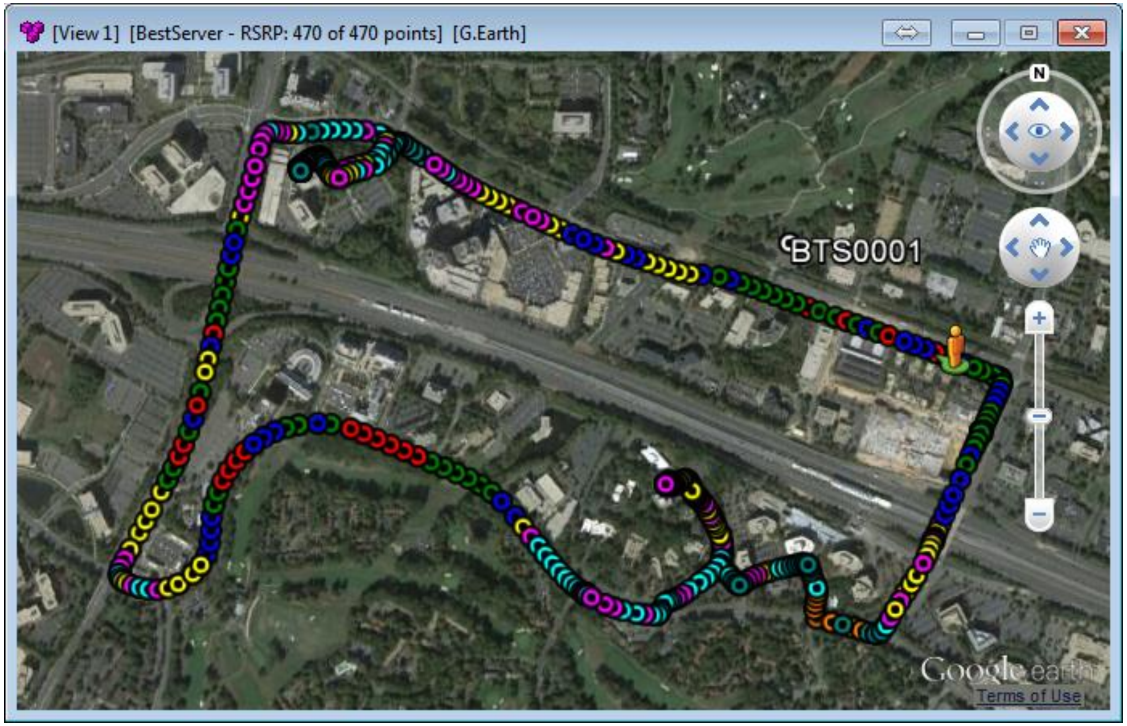
Equipment Configuration

- Configuration



Collection

- During collection the following infromation is displayed
  - Number of detected PCIs (MIB was succesfully decoded)
  - Lat Long
  - Speed
  - GPS reported height
- Collection can be done:
  - Outdoor: GPS /Dead Reckoning
  - Indoor: floor plant taps
- Events can be added
- Collection took 16 minutes
- 100 MHz of spectrum were captured around 2.5 GB in the Reston (VA) area



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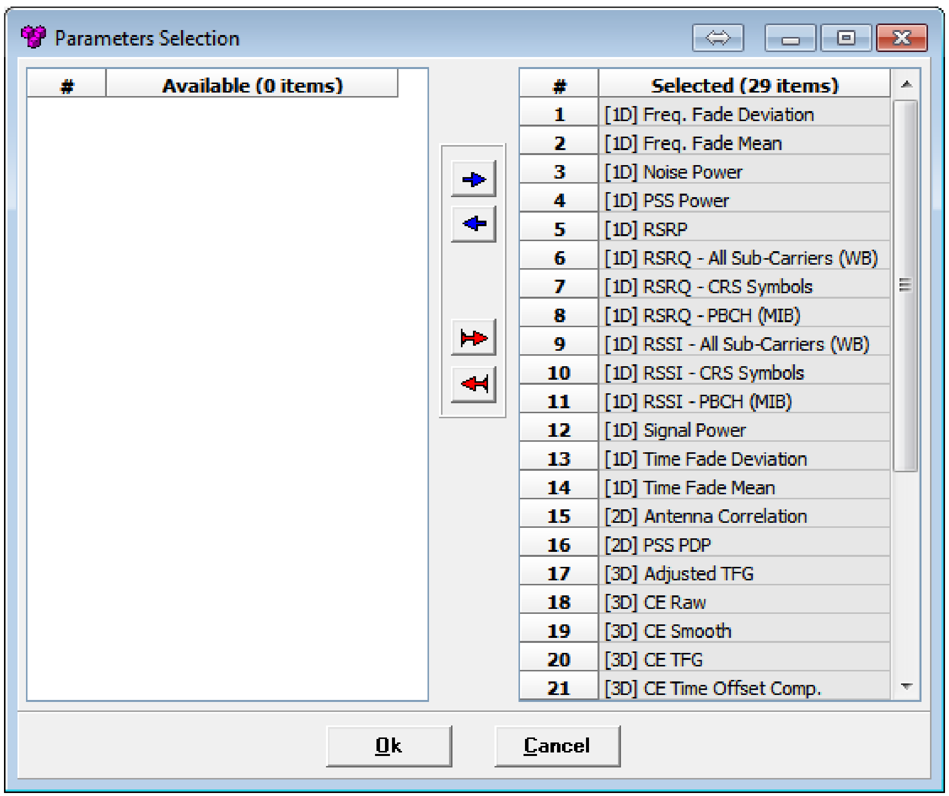
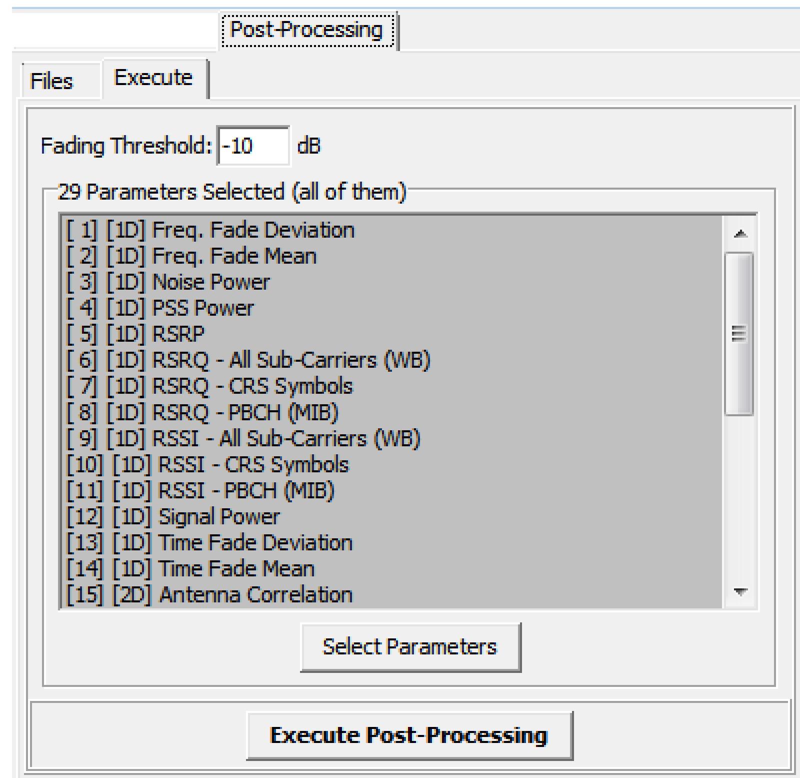
Post Processing

- Twenty Nine Parameters were selected to be extracted from the collected 100 MHz of spectrum
- Post processing took 30 minutes



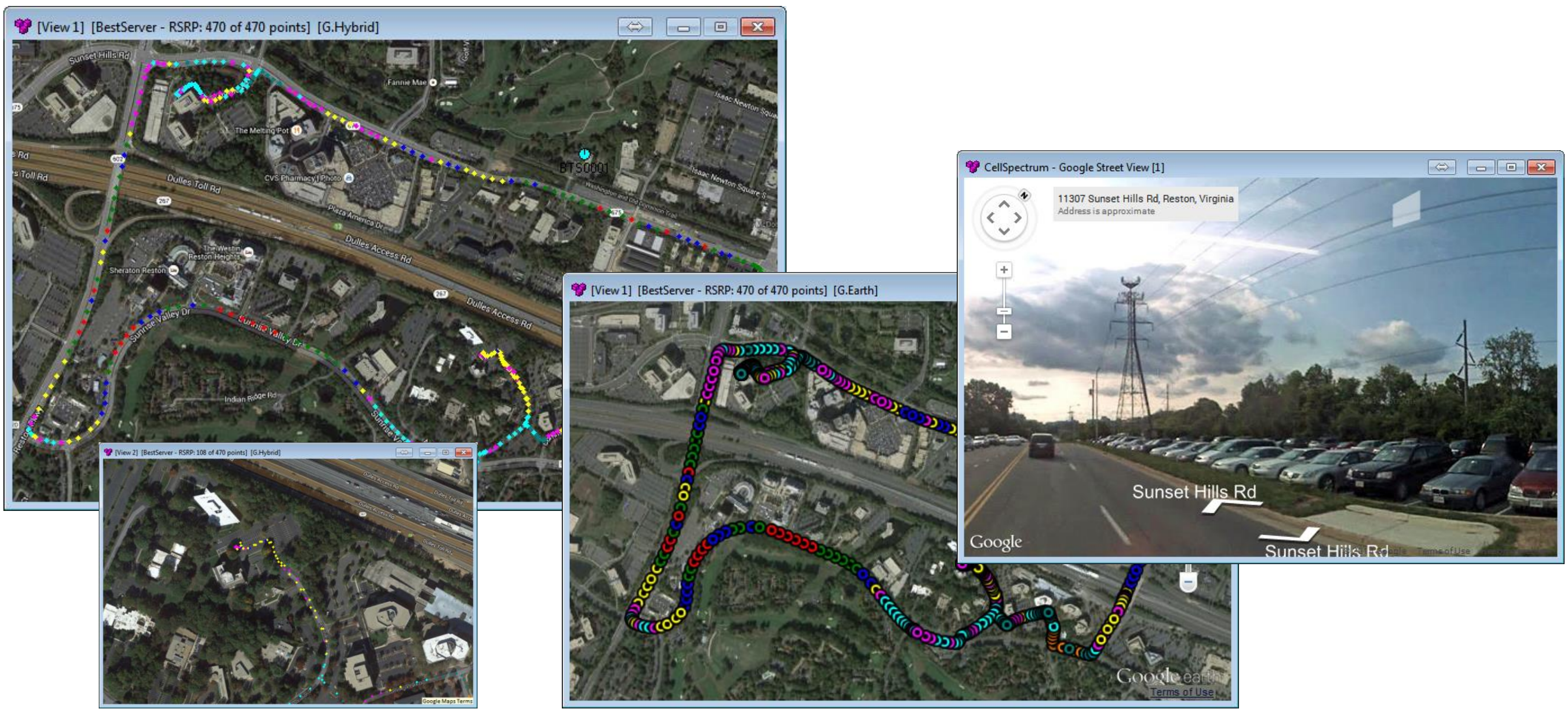


Visualization/ Analysis

- CelView power visualization engine is used to visualize geographically the measurements
- CellSearch algorithm is used to detect the cells PCIs at each measured point
- CellVisualize algorithm is used to display the different parameters in 1D, 2D and 3D

CelView ™

- Multiple Views can be open
- Views and pointer are synchronized
- Google Maps and Google Earth can be used as background
  - Street View can be displayed from within the tool
- Measurements can be displayed and exported to be used by CelPlanner Suite

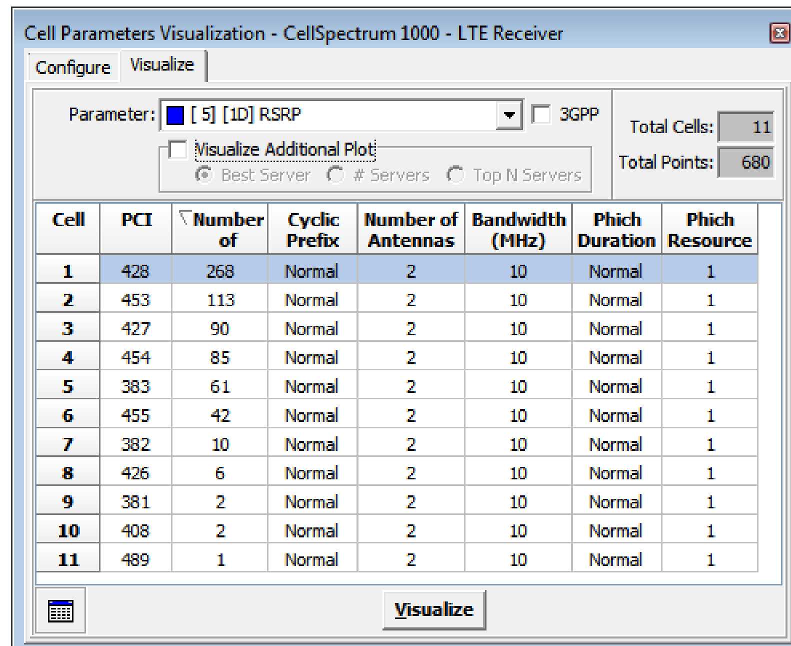


CellSearch ™

- CellSearch scans the spectrum looking for the three PSS (Primary Synchronization Symbol) values in the 62 central LTE sub-carriers. It identifies the largest peaks and decodes the PSS value for each one. Each peak is then processed by:
  - Detecting its center in time domain
  - Detecting its center in frequency domain
  - Obtaining symbol, slot and subframe synchronization
- The two occurrences of the 168 SSS (Secondary Synchronization Signal) codes are detected, defining:
  - Cell PCI (0 to 503)
  - Cyclic Prefix (0, 1)
  - Start of Frame
  - PCI Multipath location
- Next the PBCH is detected over the 72 central subcarriers, slot 0, Symbols 3 to 6, defining:
  - Cell Bandwidth (1.4, 3.0, 5.0, 10.0, 15.0, 20.0 MHz)
  - PHICH Configuration (duration and scaling factor)
    - H-ARQ position (normal=0, extended=1)
    - H-ARQ scaling factor (1/6, 1/2, 1, 2)
  - System Frame Number (SFN): The 8MSBs are explicit in the MIB the 2 LSB are obtained by analyzing the MIB repletion frames. The first repetition happens in a frame with 00 as its least significant bits.
- Number of antennas: A 16 bit CRC (Cyclic Redundancy Check) is applied on the MIB information bits. The CRC is then scrambled by three patterns each related to the number of physical antennas used (1, 2 or 4). The tree combinations have to be tried (blind detection) to find out the number of antennas used.

CellSearch ™

- Eleven PCIs were detected during the drive test
  - PCI 428 had the largest ocurrence (268 points)
- All PCIs used:
  - Normal Cyclic Prefix
  - Two antennas
  - 10 MHz bandwidth channel
  - Normal PHICH duration
  - PHICH Resources =1

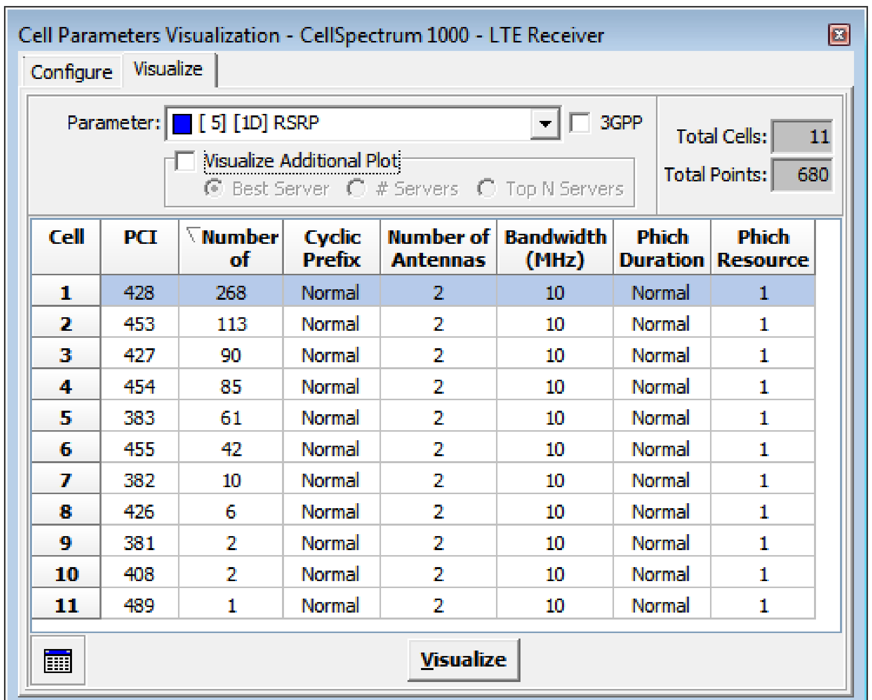


Cell	PCI	Number of	Cyclic Prefix	Number of Antennas	Bandwidth (MHz)	Phich Duration	Phich Resource
1	428	268	Normal	2	10	Normal	1
2	453	113	Normal	2	10	Normal	1
3	427	90	Normal	2	10	Normal	1
4	454	85	Normal	2	10	Normal	1
5	383	61	Normal	2	10	Normal	1
6	455	42	Normal	2	10	Normal	1
7	382	10	Normal	2	10	Normal	1
8	426	6	Normal	2	10	Normal	1
9	381	2	Normal	2	10	Normal	1
10	408	2	Normal	2	10	Normal	1
11	489	1	Normal	2	10	Normal	1

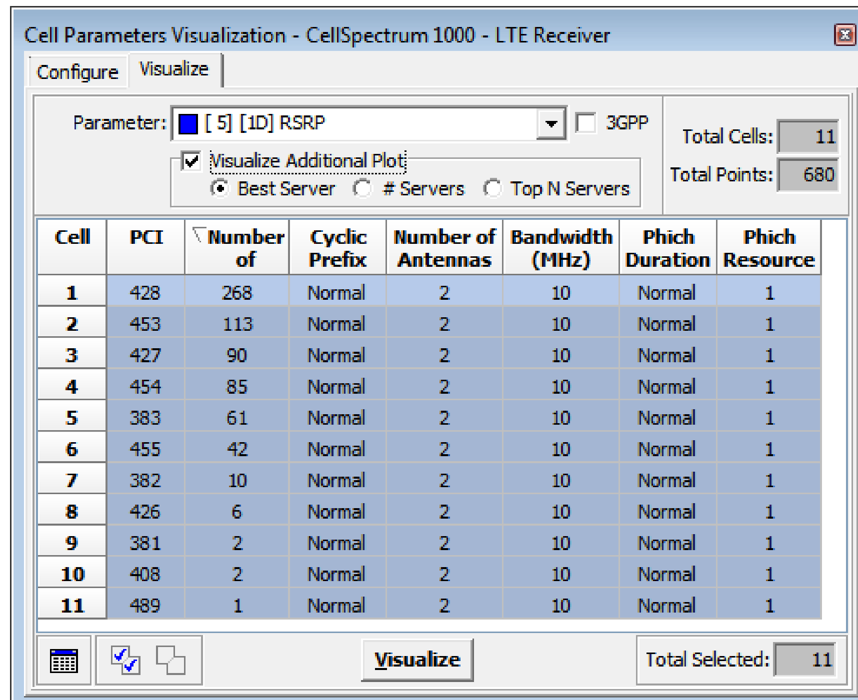
CellVisualize™

- CellVisualize can be configured to display:
  - Best Server
  - Number of Servers
  - Each of top N servers
  - Individual PCI

- Measurements can be configured to display
  - Measurement value in power, time or frequency
  - Measurement value using 3GPP notation
  - PCI
  - Time
  - SFN



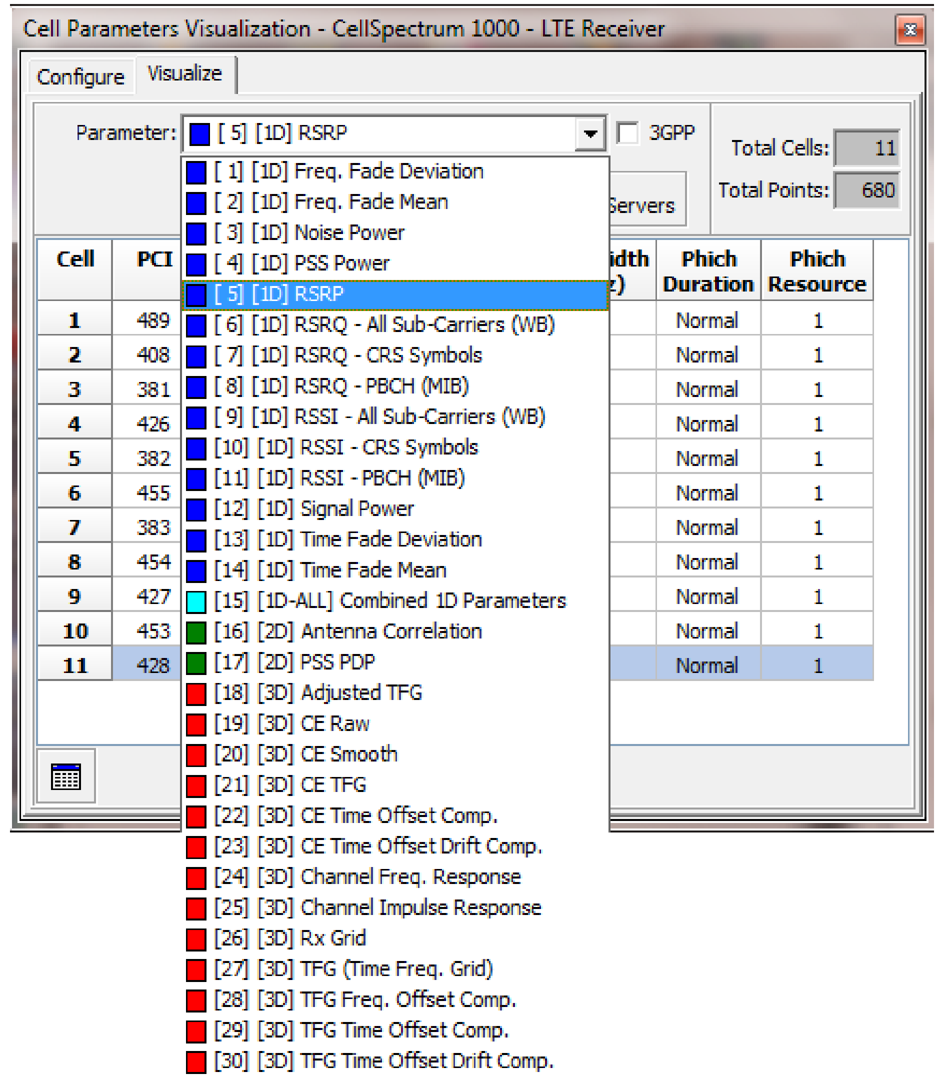
Cell	PCI	Number of	Cyclic Prefix	Number of Antennas	Bandwidth (MHz)	Phich Duration	Phich Resource
1	428	268	Normal	2	10	Normal	1
2	453	113	Normal	2	10	Normal	1
3	427	90	Normal	2	10	Normal	1
4	454	85	Normal	2	10	Normal	1
5	383	61	Normal	2	10	Normal	1
6	455	42	Normal	2	10	Normal	1
7	382	10	Normal	2	10	Normal	1
8	426	6	Normal	2	10	Normal	1
9	381	2	Normal	2	10	Normal	1
10	408	2	Normal	2	10	Normal	1
11	489	1	Normal	2	10	Normal	1



Cell	PCI	Number of	Cyclic Prefix	Number of Antennas	Bandwidth (MHz)	Phich Duration	Phich Resource
1	428	268	Normal	2	10	Normal	1
2	453	113	Normal	2	10	Normal	1
3	427	90	Normal	2	10	Normal	1
4	454	85	Normal	2	10	Normal	1
5	383	61	Normal	2	10	Normal	1
6	455	42	Normal	2	10	Normal	1
7	382	10	Normal	2	10	Normal	1
8	426	6	Normal	2	10	Normal	1
9	381	2	Normal	2	10	Normal	1
10	408	2	Normal	2	10	Normal	1
11	489	1	Normal	2	10	Normal	1

CellVisualize ™

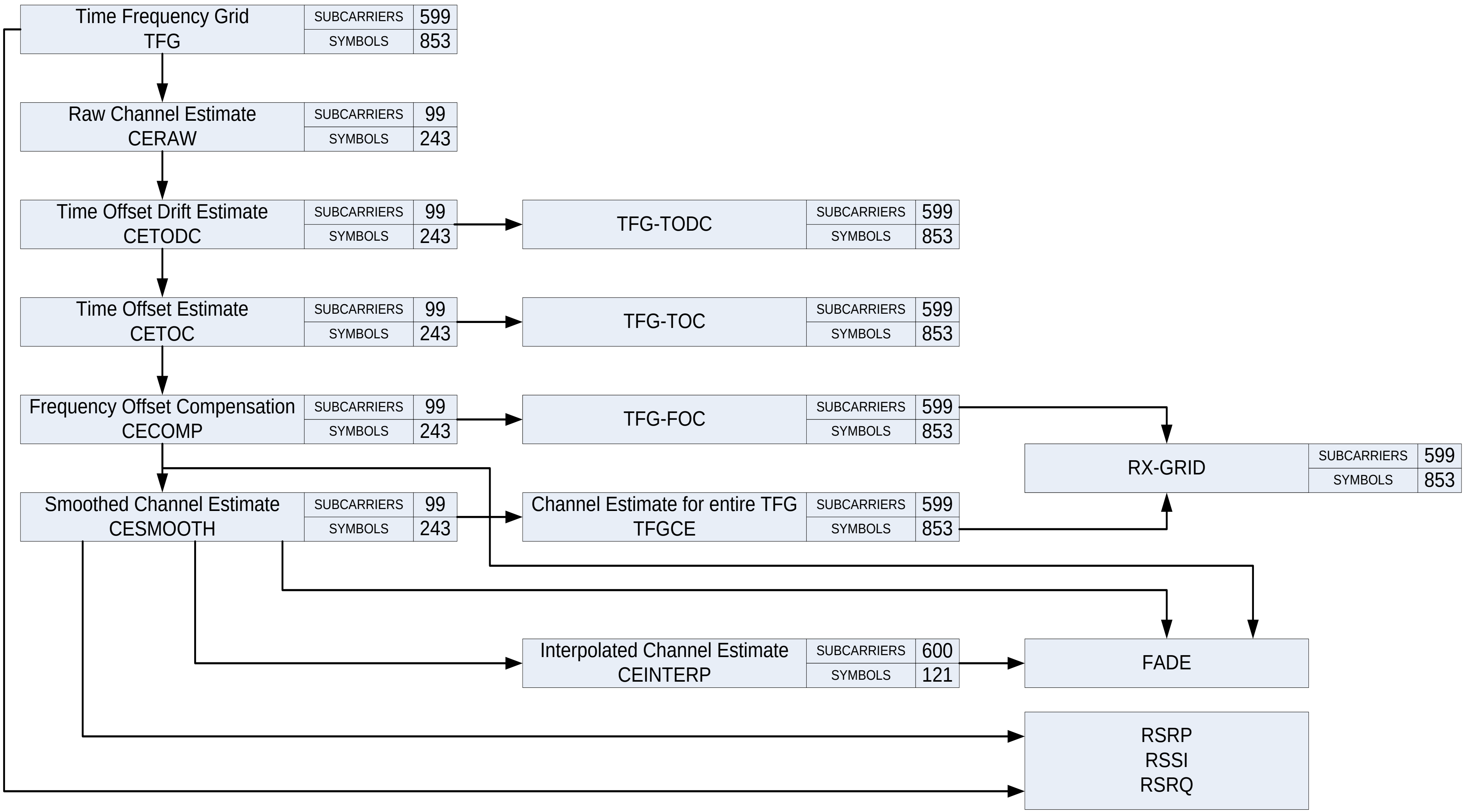
- CellVisualize displays:
  - A window with the drive test route view
  - The window legend
  - A view presentation dialogue that allows the configuration of how and what parameter characteristic is displayed
  - A window with the representation of the measured value by sampling sequence (only for 1D parameters)



4. CellSpectrum™ Parameters

CellSpectrum 3D Matrixes

- Several matrixes are obtained from the digitized data



CellSpectrum 3 D Matrixes

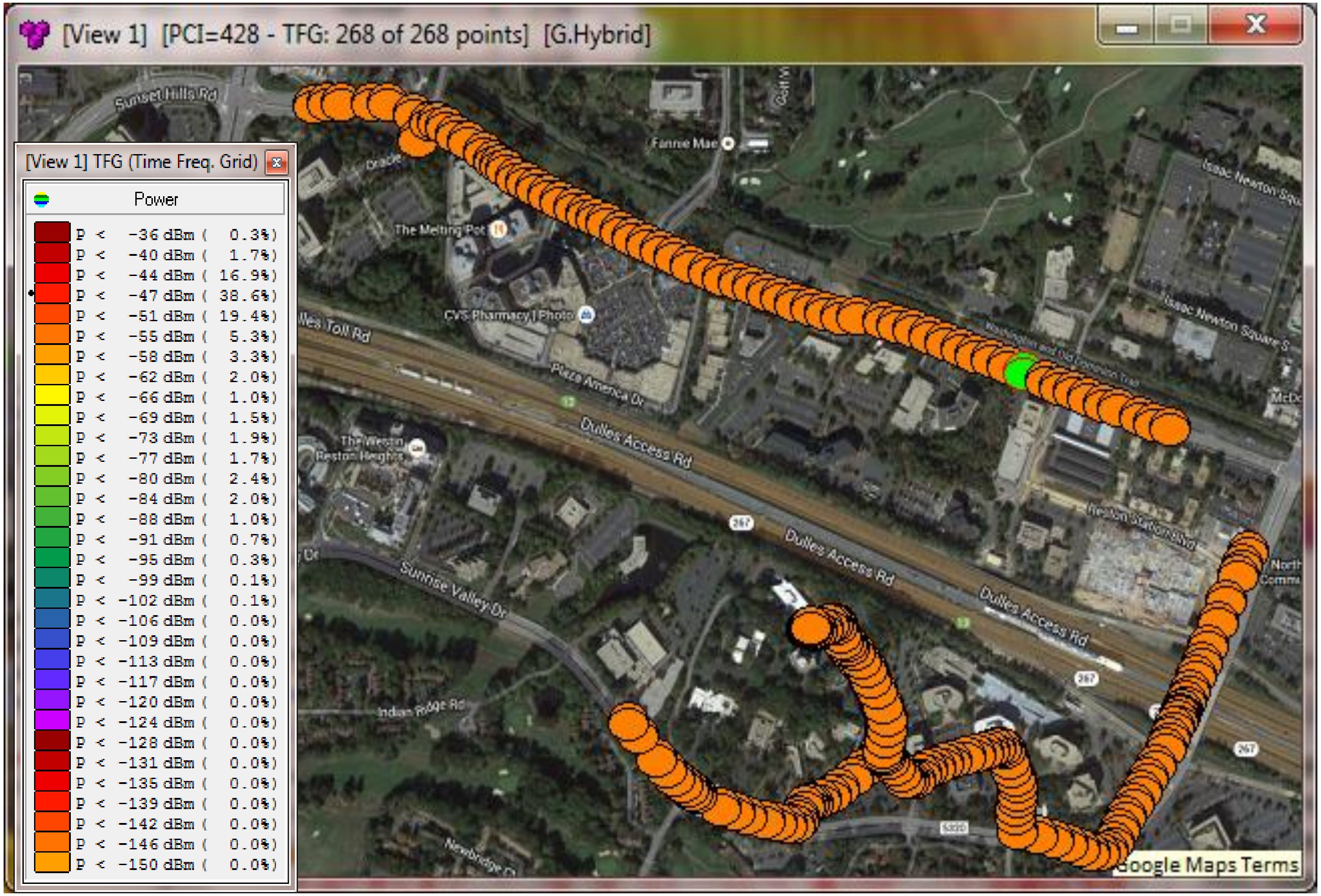
- TFG: Represents tha actual received power for each Resource Element (RE) of 6.1 frames
- CERAW: Represents the Channel response Estimate (CE) fro REs containing Reference Signals (RS)
- CETODC: Corrects for Time Offset Drift in the Channel Estimate (CE)
- CETOC: Corrects the overall time shift (phase shift in frequency domain) in the Channel Estimate
- CECOMP: Corrects the frequency shift betweent ransmitter and receiver
- CESMOOTH: Averages Reference Signals with its neighbor Reference Signals to reduce fading effects
- TFGCE: Interpolates the CE between Reference Signals calculating the CE for the remaining REs
  - It represents the vlaues of TFG corrected by the channel estimates
- RXGRID: Estimates data values based on the previous matrixes

5. 3D Parameters

CellSpectrum™

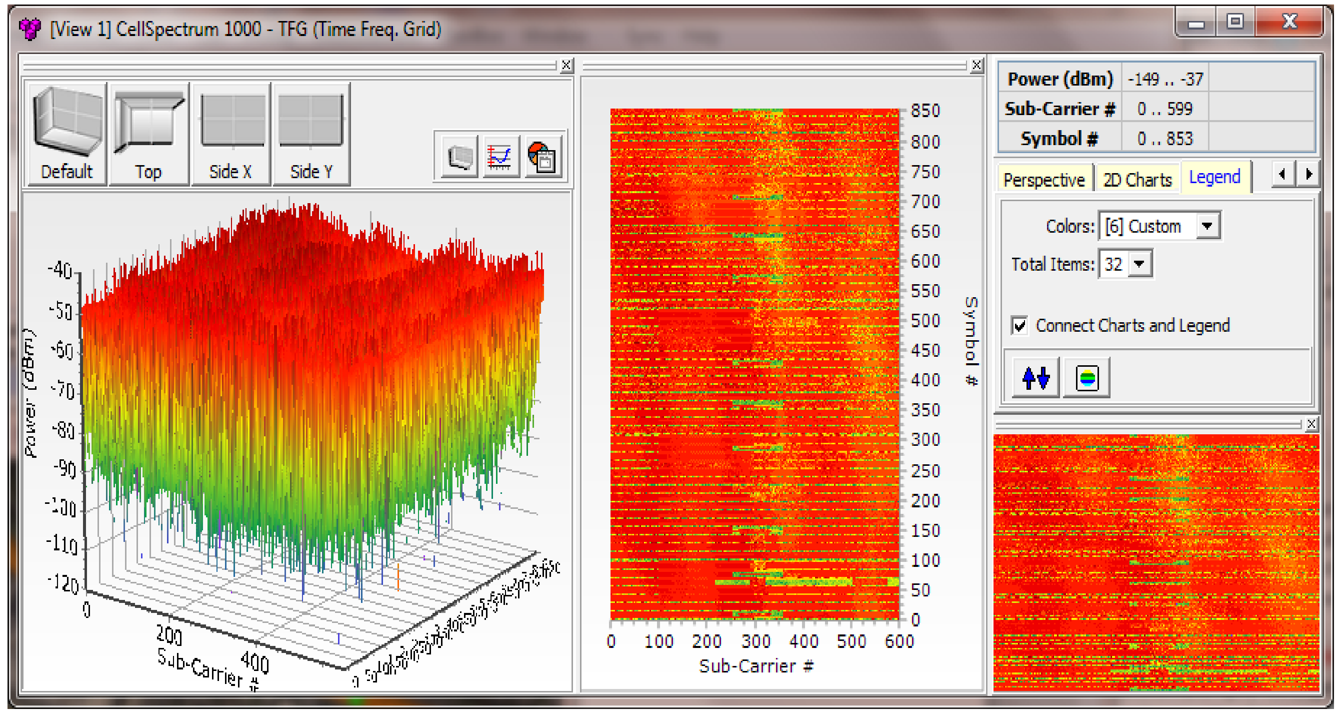
TFG

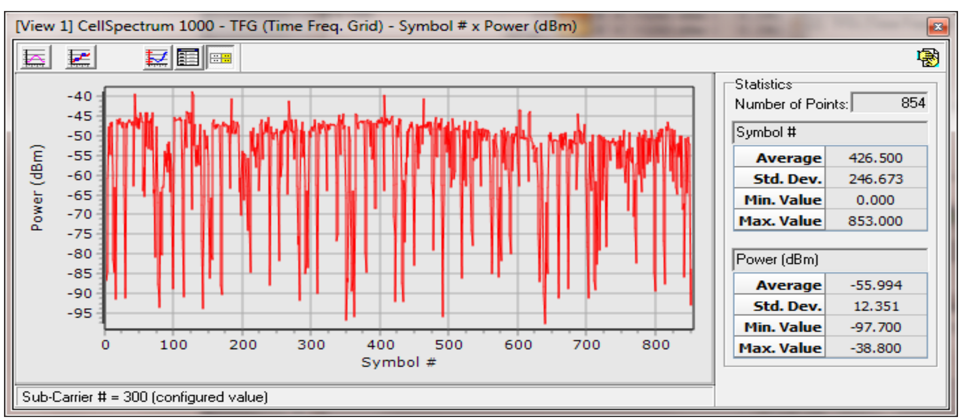
- LOS signal

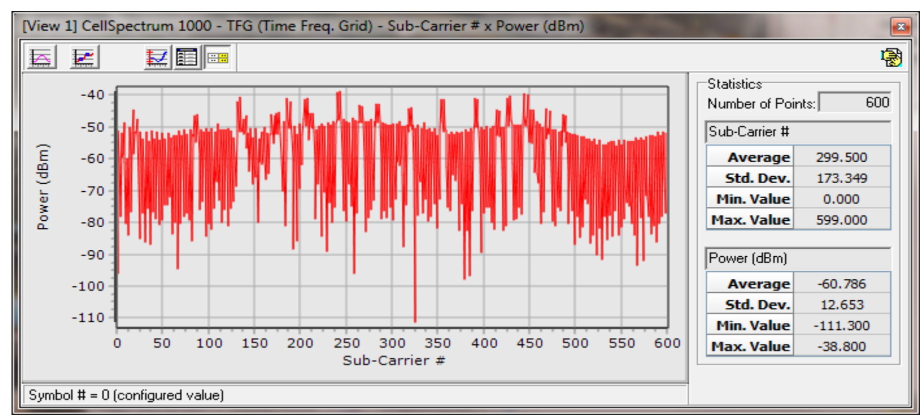


TFG

- 3 D view
  - 600 subcarriers
  - 863 symbols
- 2 D view
  - Subcarrier 300
- 2D view
  - Symbol 0

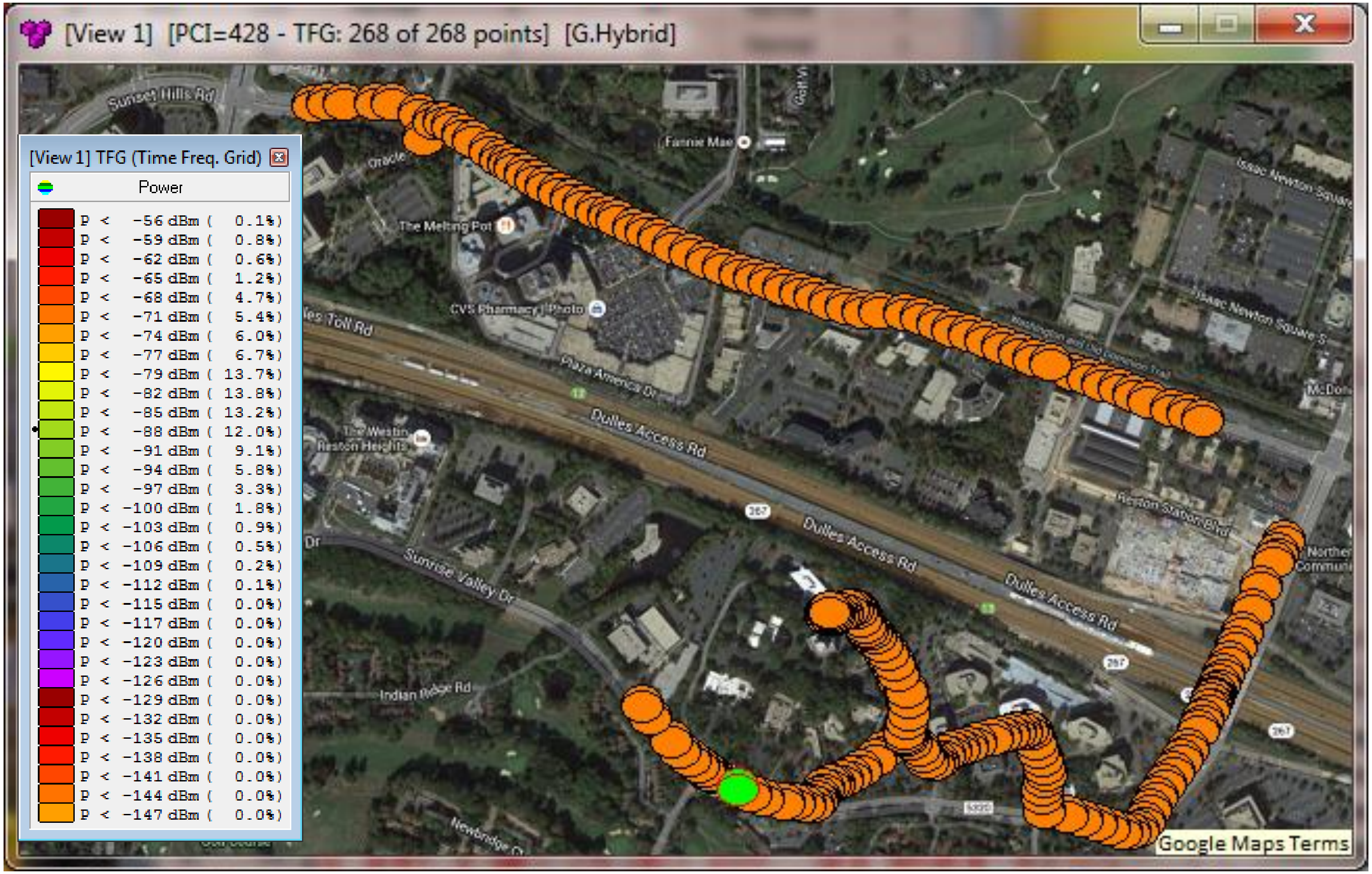






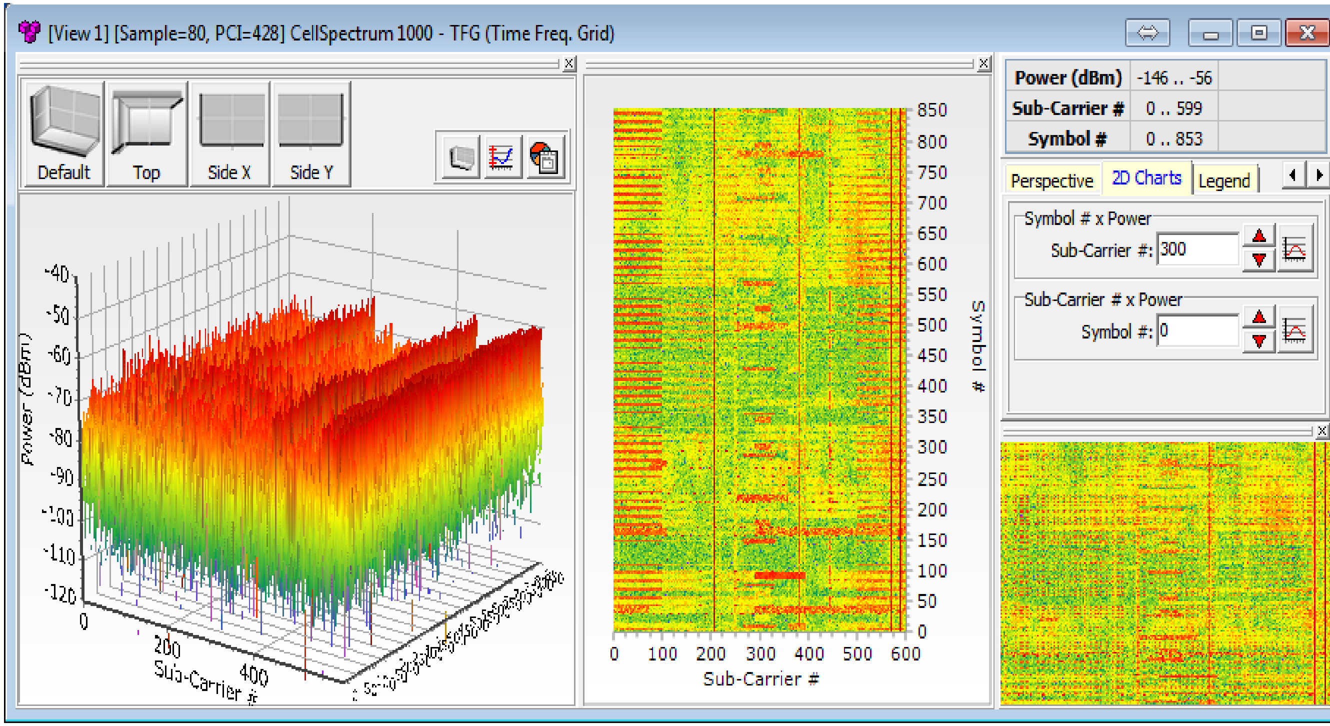
TFG

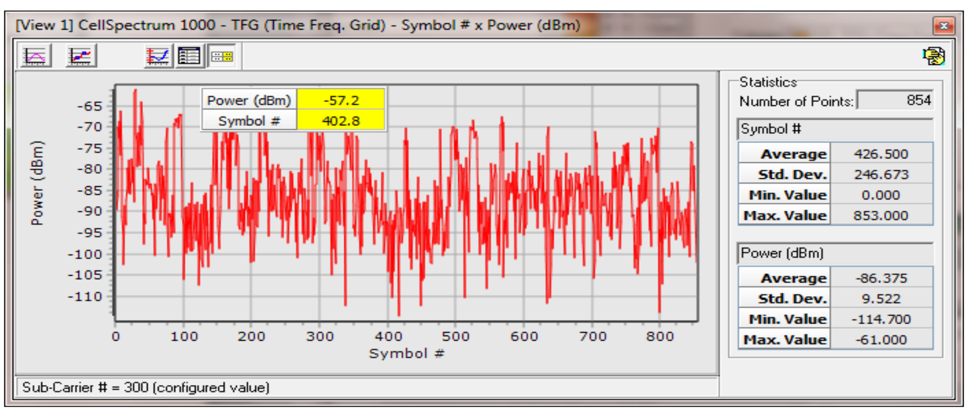
- NLOS Signal

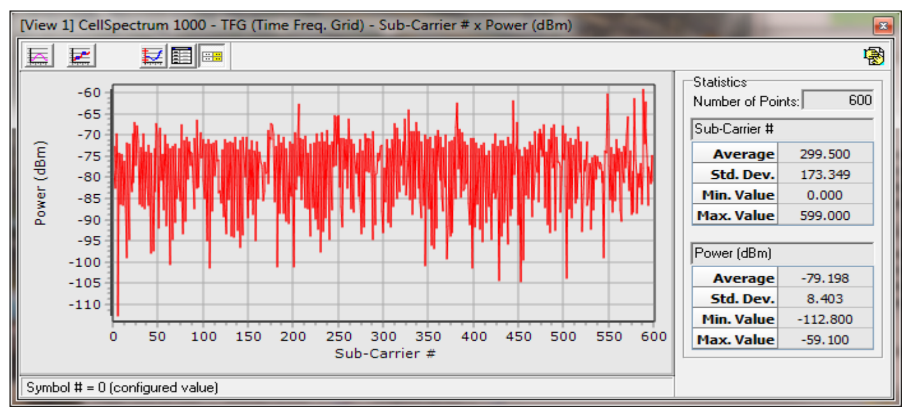


TFG

- 3 D view
  - 600 subcarriers
  - 863 symbols
- 2 D view
  - Subcarrier 300
- 2D view
  - Symbol 0

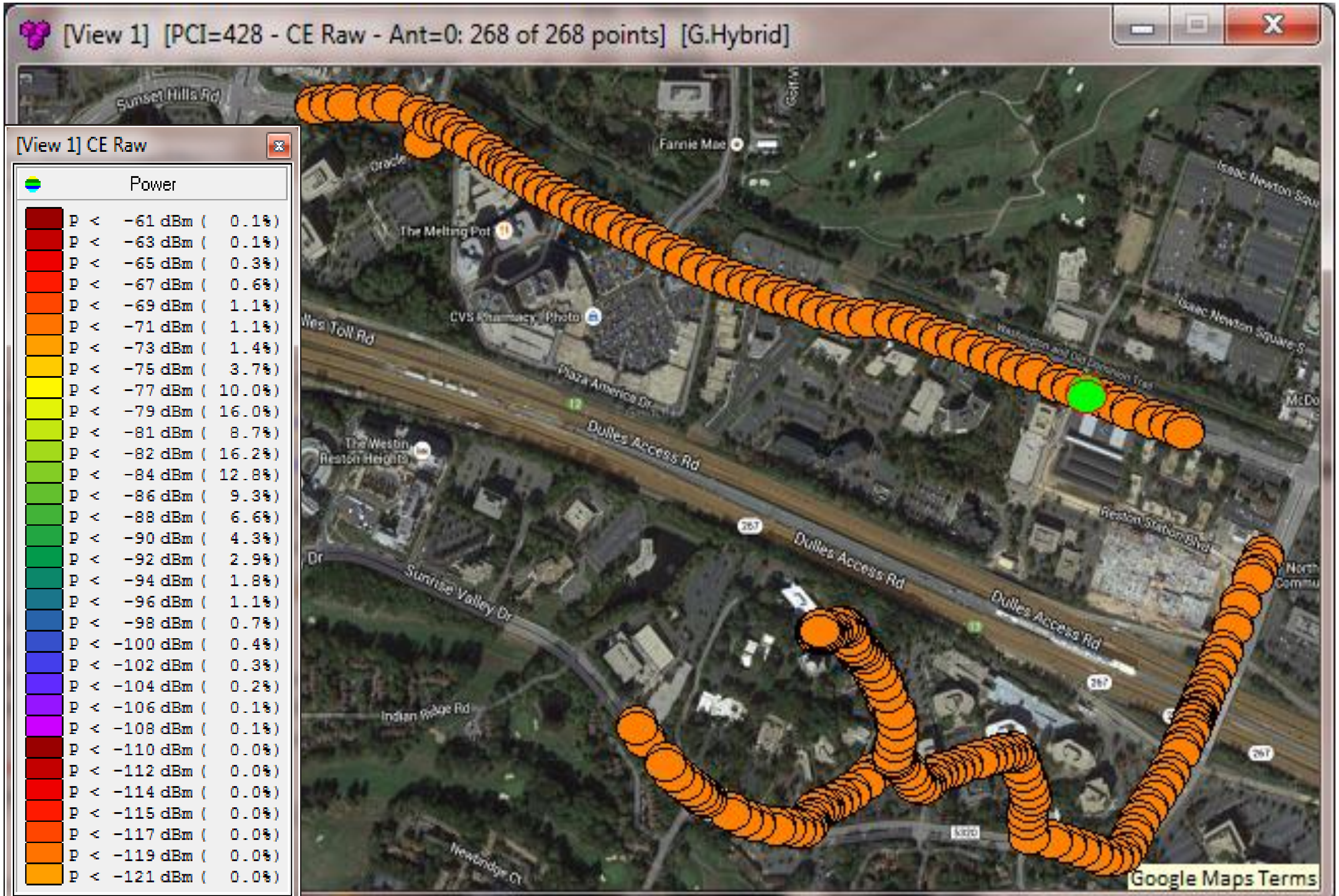






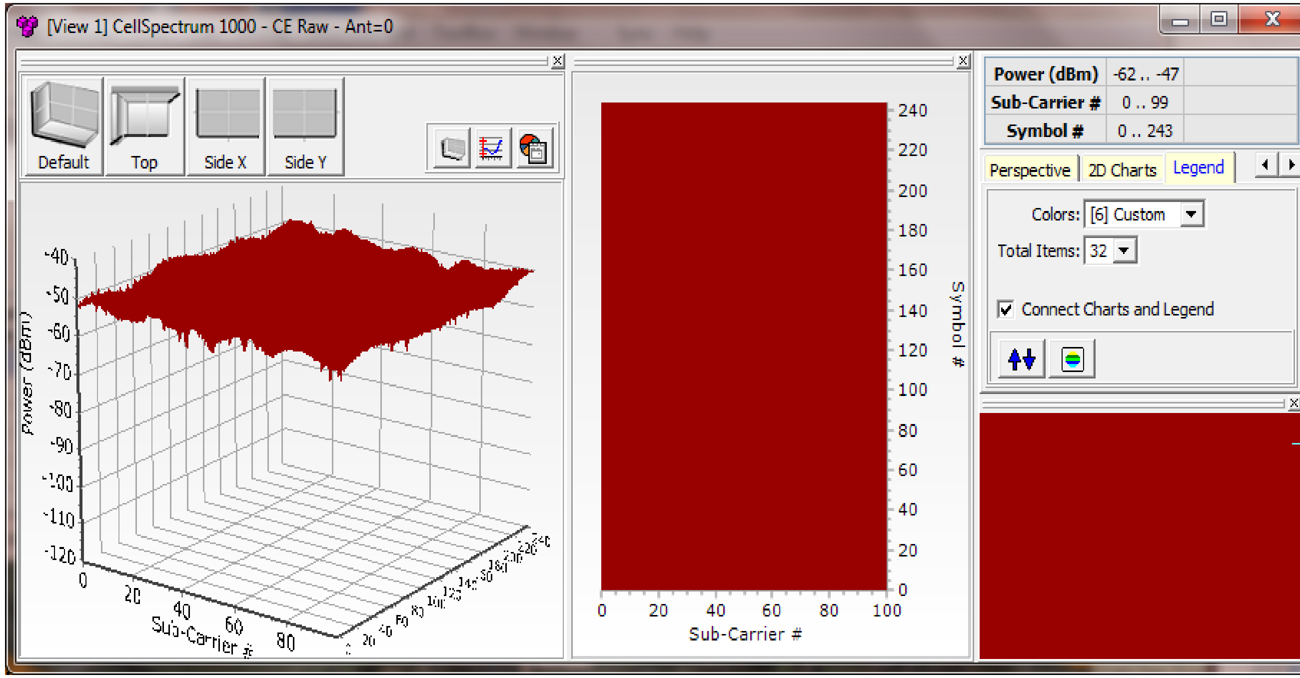
CERAW

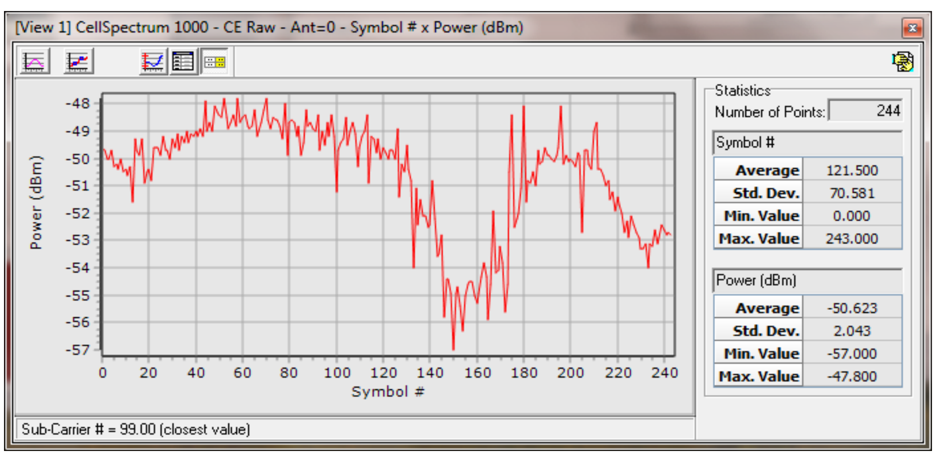
- LOS Signal

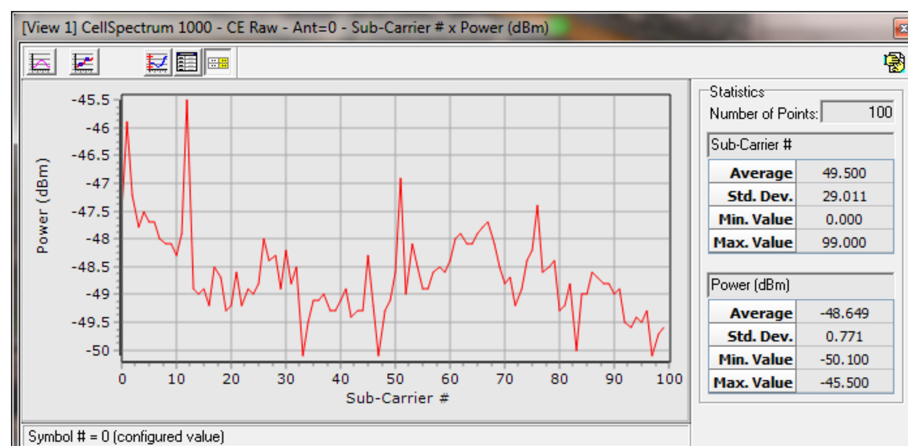


CERAW

- 3 D view
  - 100 subcarriers
  - 243 symbols
- 2 D view
  - Subcarrier 50
- 2D view
  - Symbol 0

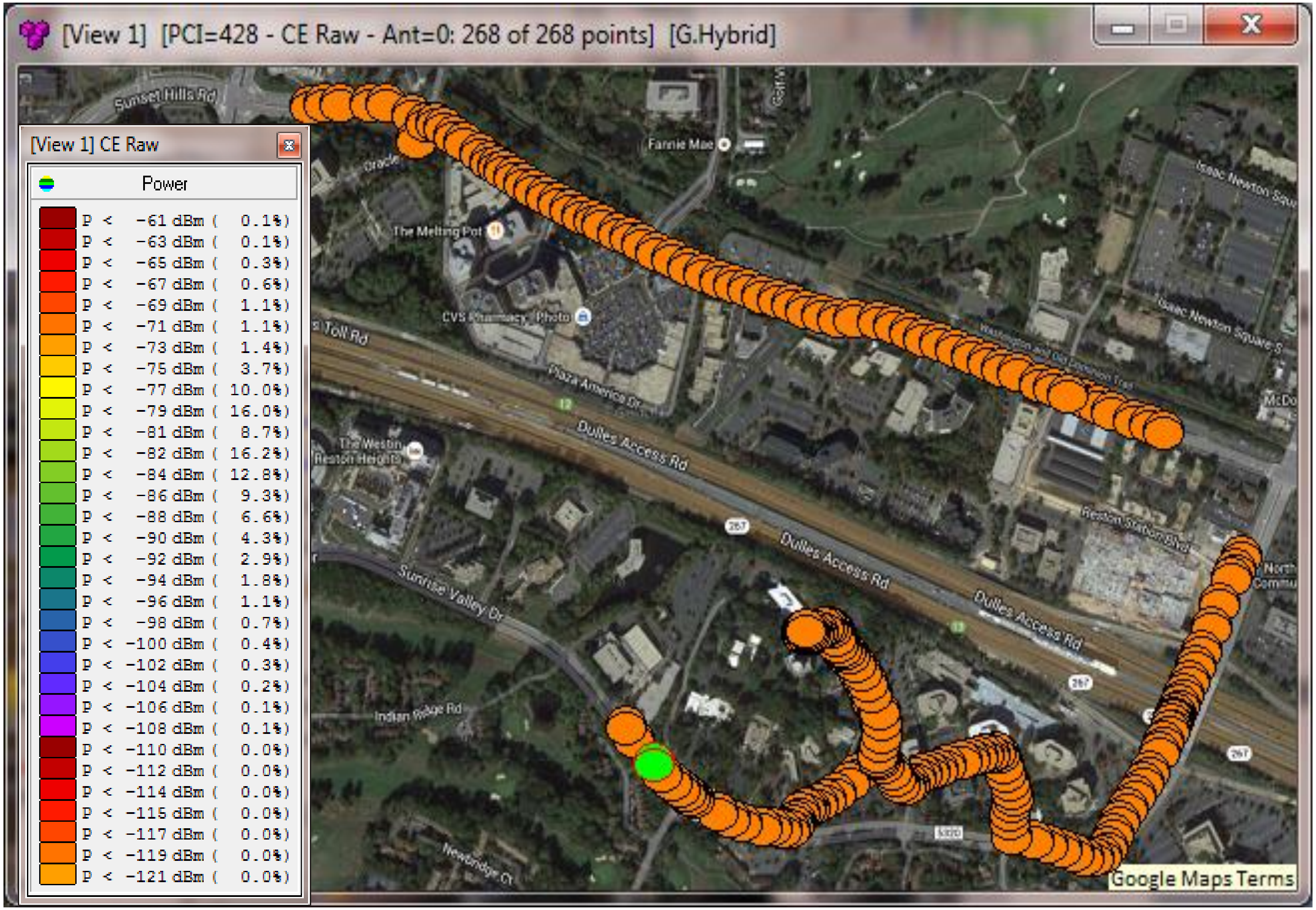






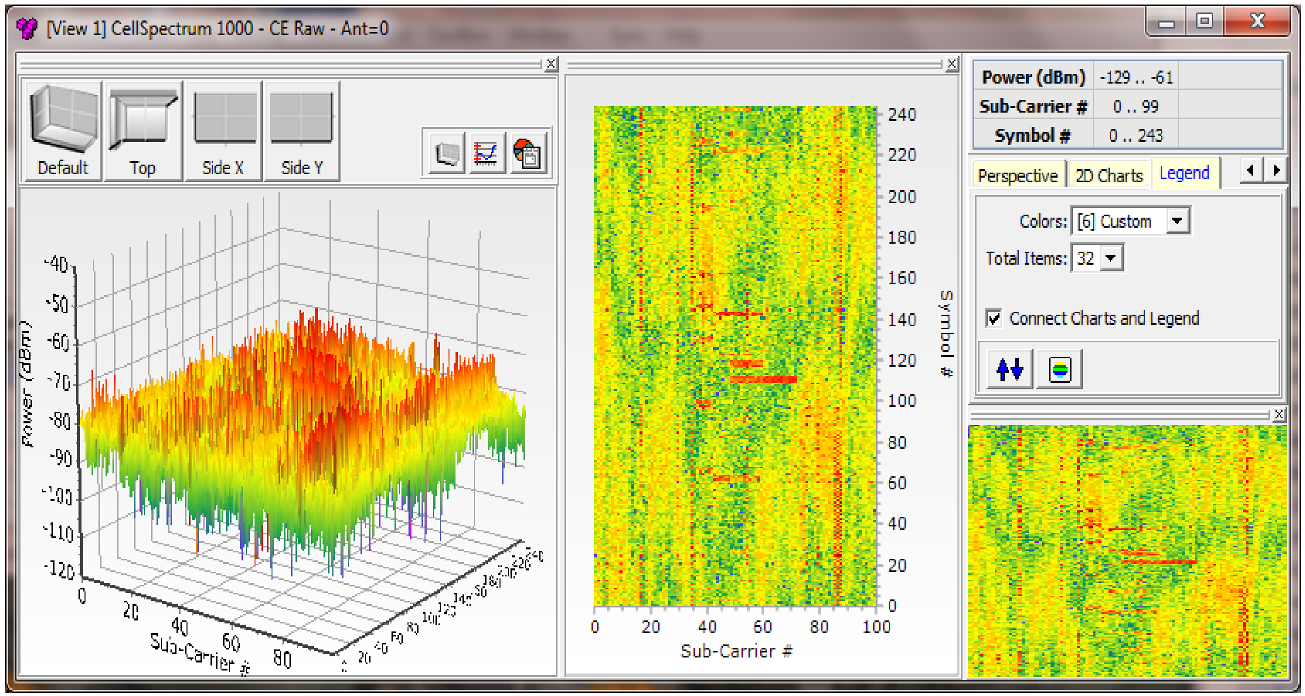
CERAW

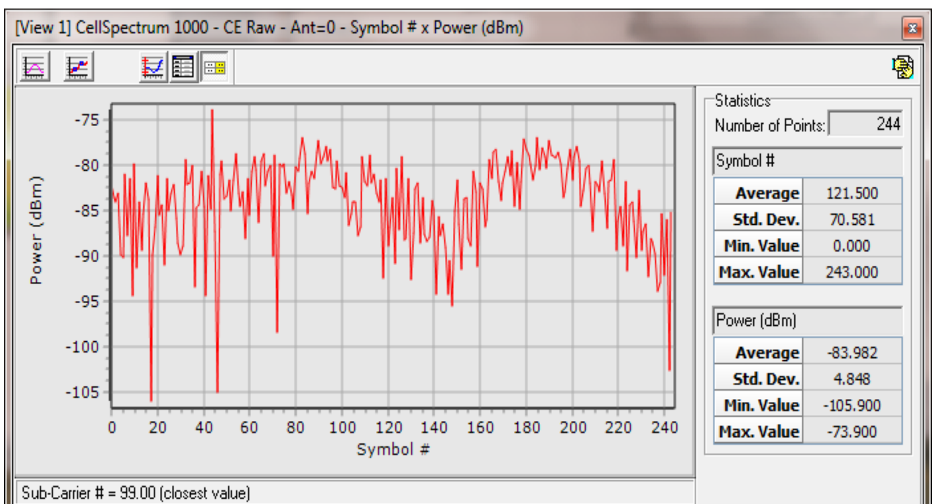
- NLOS signal

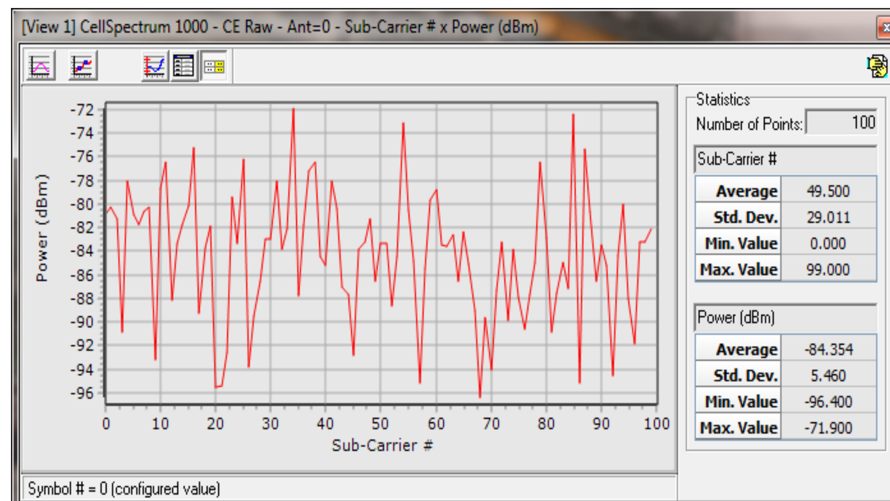


CERAW

- 3 D view
  - 100 subcarriers
  - 243 symbols
- 2 D view
  - Subcarrier 50
- 2D view
  - Symbol 0

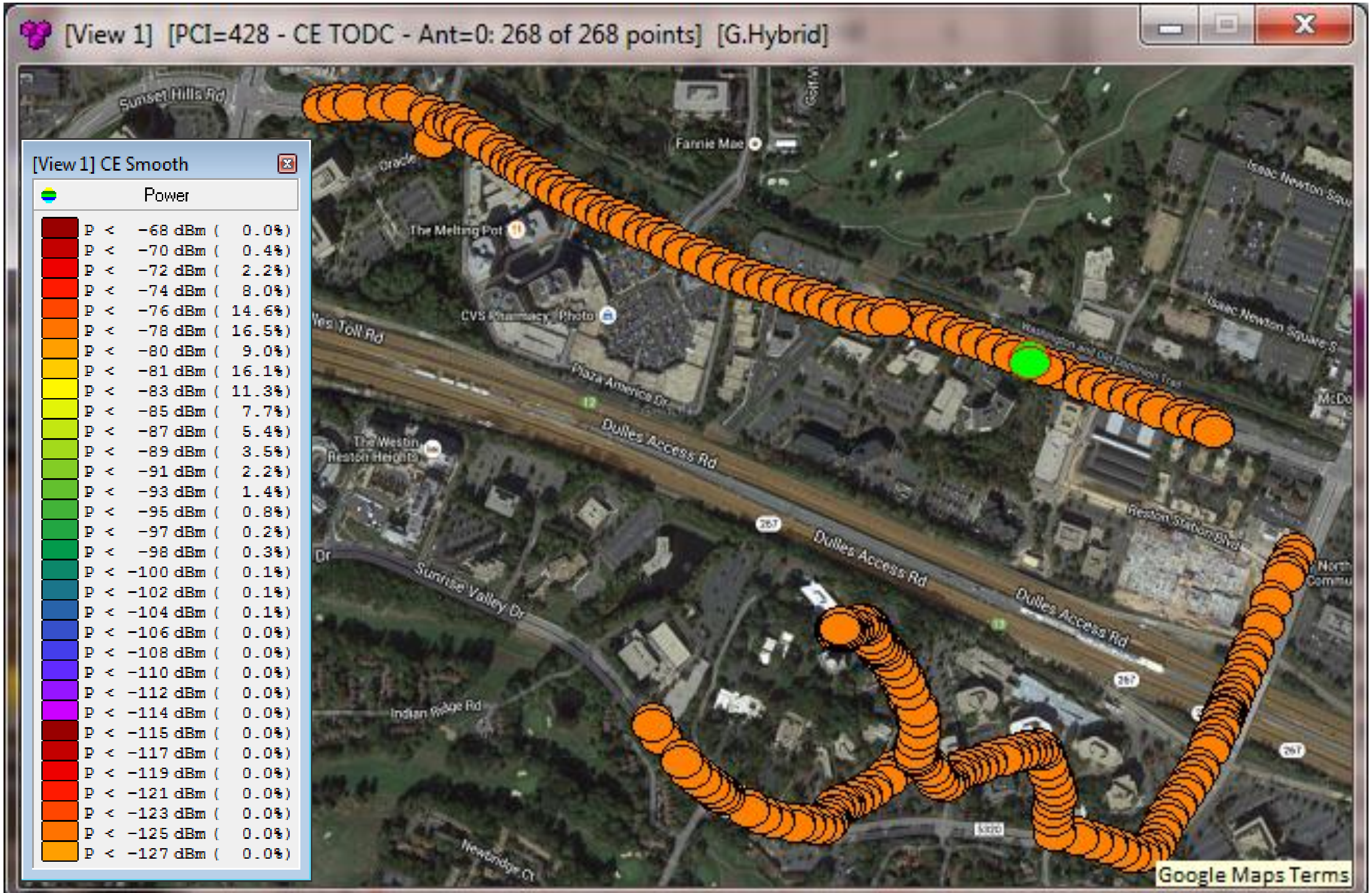






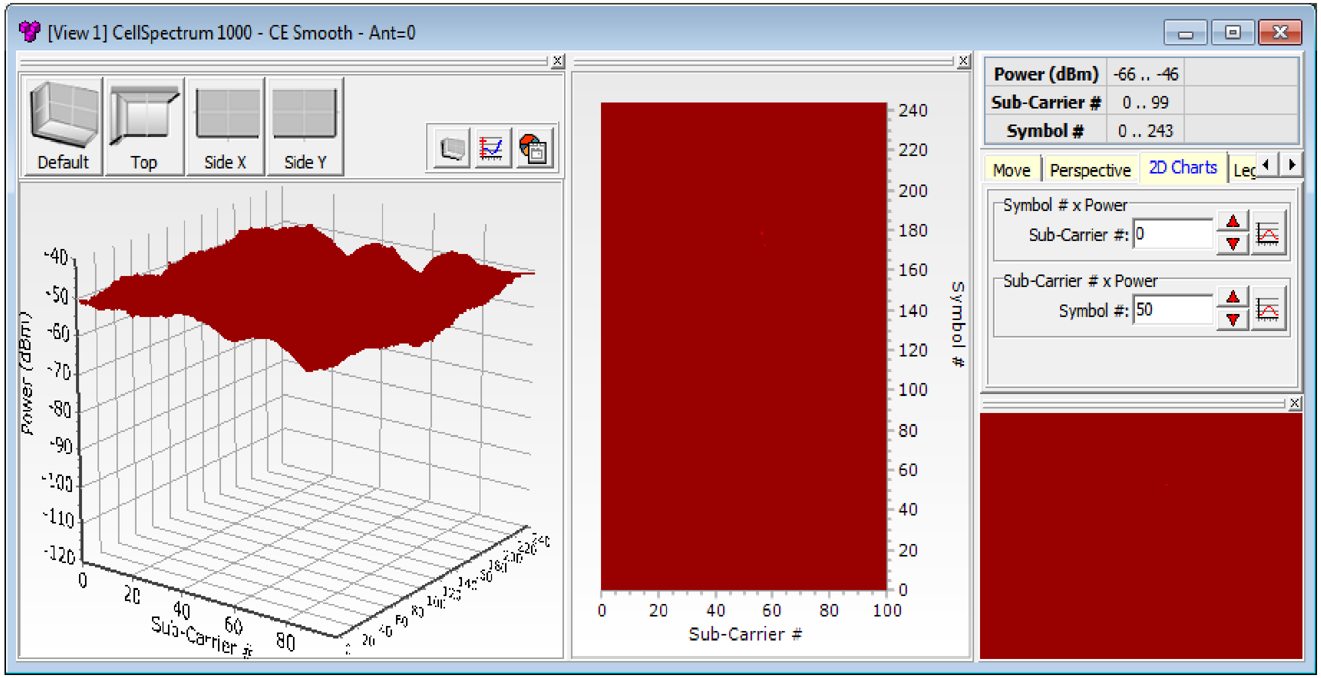
CESMOOTH

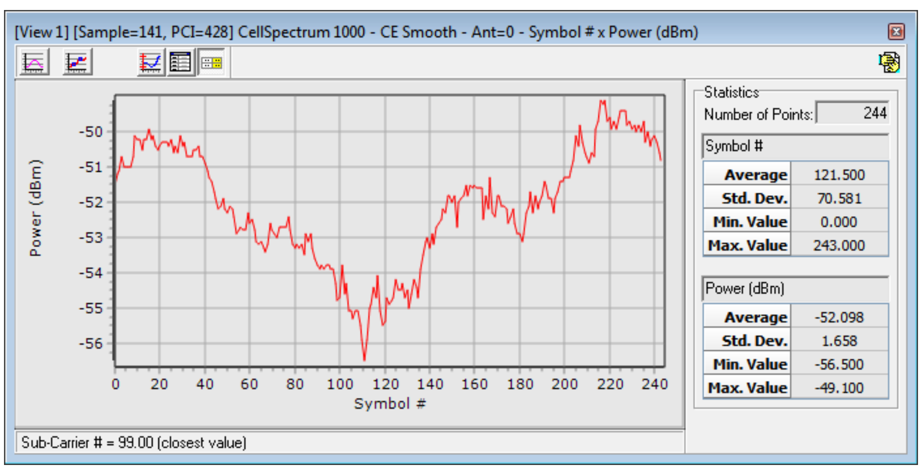
- LOS signal

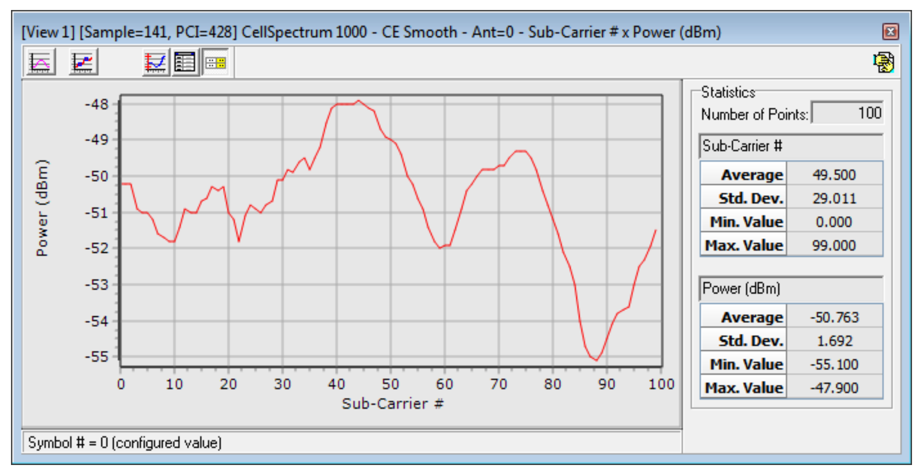


CESMOOTH

- 3 D view
  - 100 subcarriers
  - 243 symbols
- 2 D view
  - Subcarrier 50
- 2D view
  - Symbol 0

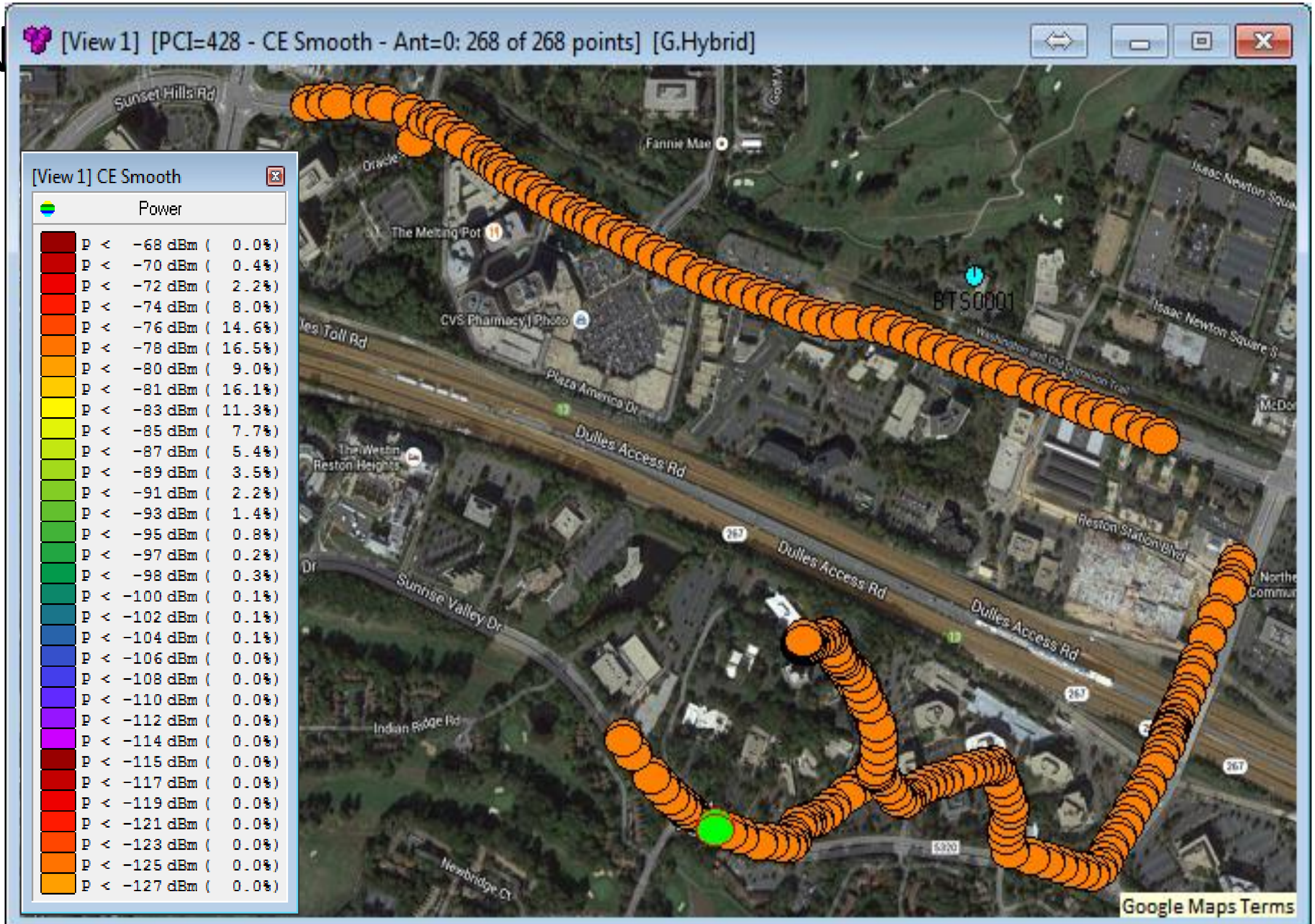






CESMOOTH

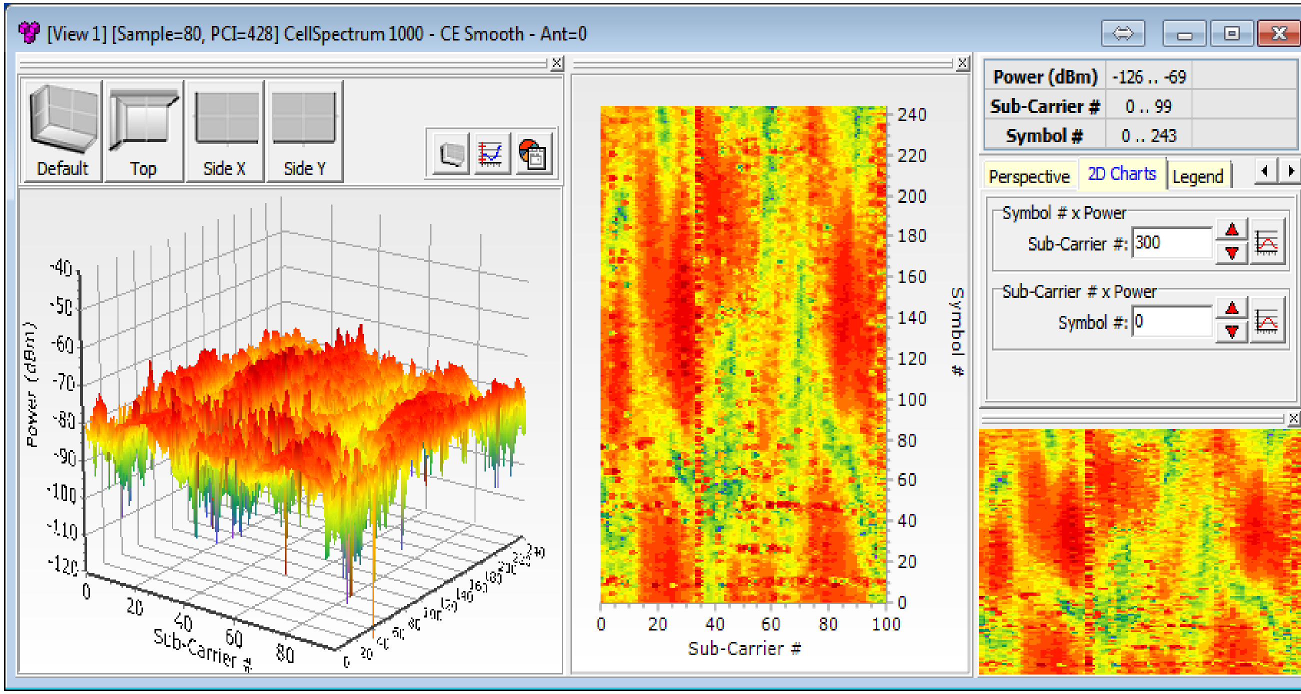
- N

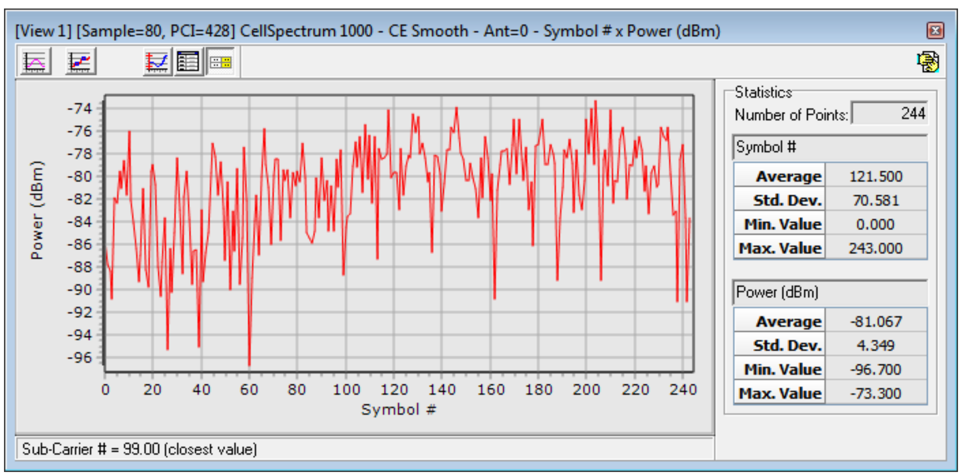


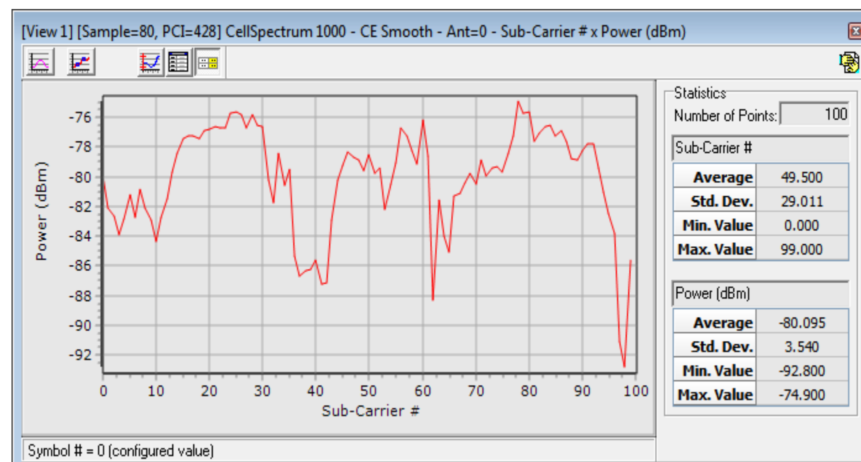
[View 1] [PCI=428 - CE Smooth - Ant=0: 268 of 268 points] [G.Hybrid]
[View 1] CE Smooth
Power
P < -68 dBm (0.0%)
P < -70 dBm (0.4%)
P < -72 dBm (2.2%)
P < -74 dBm (8.0%)
P < -76 dBm (14.6%)
P < -78 dBm (16.5%)
P < -80 dBm (9.0%)
P < -81 dBm (16.1%)
P < -83 dBm (11.3%)
P < -85 dBm (7.7%)
P < -87 dBm (5.4%)
P < -89 dBm (3.5%)
P < -91 dBm (2.2%)
P < -93 dBm (1.4%)
P < -95 dBm (0.8%)
P < -97 dBm (0.2%)
P < -98 dBm (0.3%)
P < -100 dBm (0.1%)
P < -102 dBm (0.1%)
P < -104 dBm (0.1%)
P < -106 dBm (0.0%)
P < -108 dBm (0.0%)
P < -110 dBm (0.0%)
P < -112 dBm (0.0%)
P < -114 dBm (0.0%)
P < -115 dBm (0.0%)
P < -117 dBm (0.0%)
P < -119 dBm (0.0%)
P < -121 dBm (0.0%)
P < -123 dBm (0.0%)
P < -125 dBm (0.0%)
P < -127 dBm (0.0%)
Sunset Hills Rd
Fannie Mae
The Melting Pot
CVS Pharmacy | Photo
BTS0001
Plaza America Dr
Dulles Access Rd
Dulles Access Rd
Dulles Access Rd
The Westin Reston Heights
Sunrise Valley Dr
Indian Ridge Rd
Newbridge Ct
Reston Station Blvd
Isaac Newton Square S
Google Maps Terms

CESMOOTH

- 3 D view
  - 100 subcarriers
  - 243 symbols
- 2 D view
  - Subcarrier 50
- 2D view
  - Symbol 0

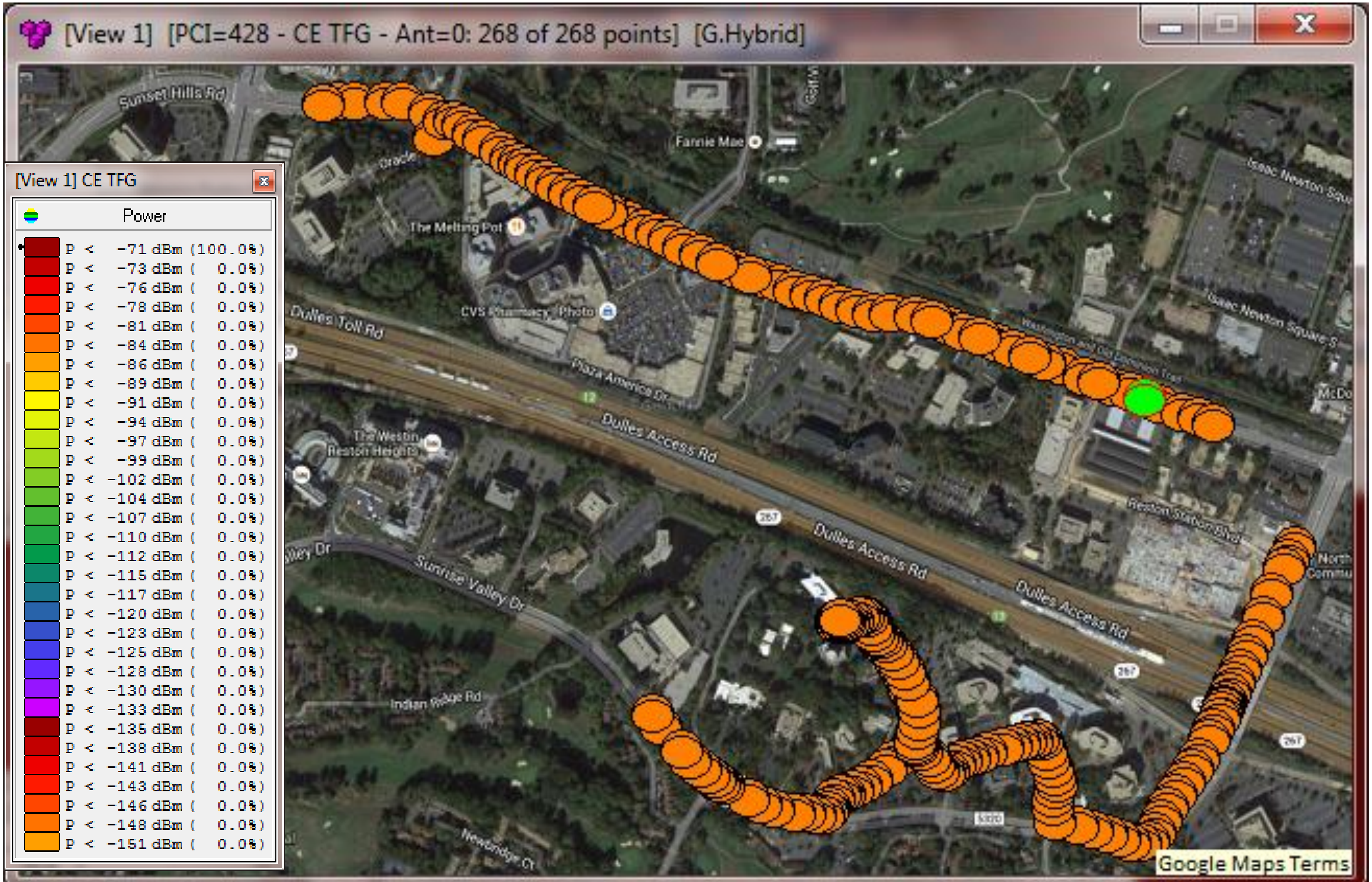






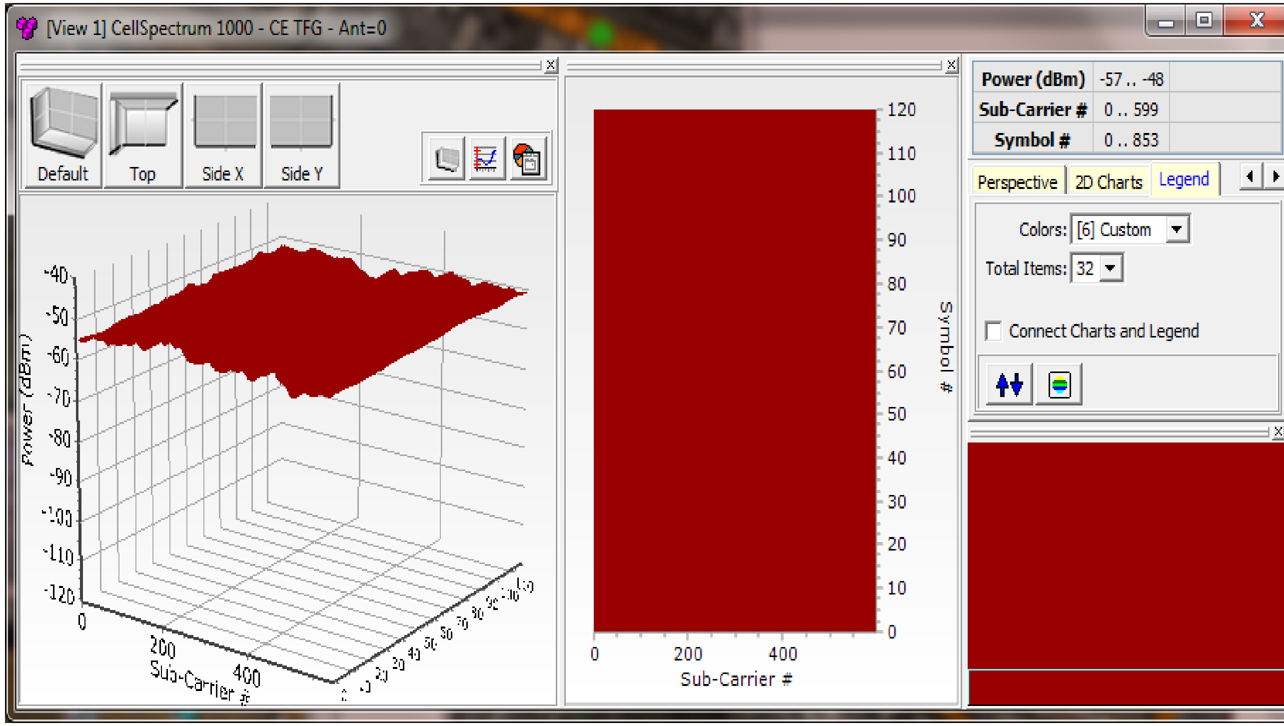
TFGCE

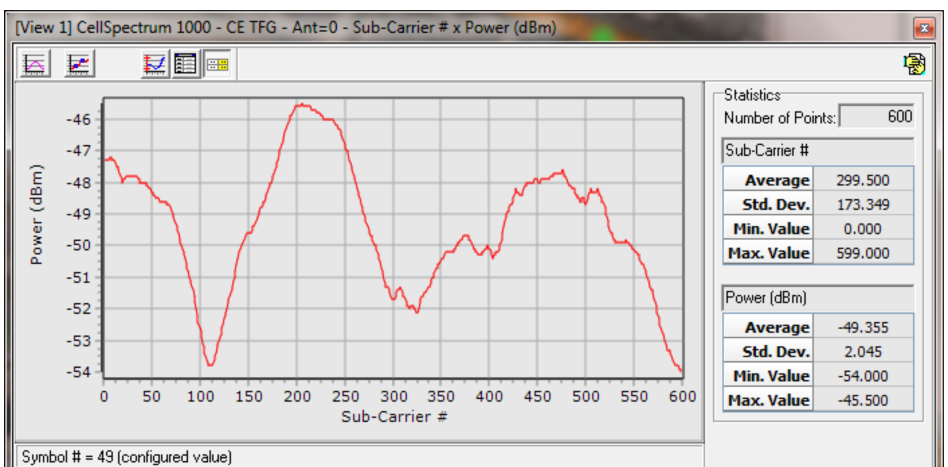
- LOS Signal

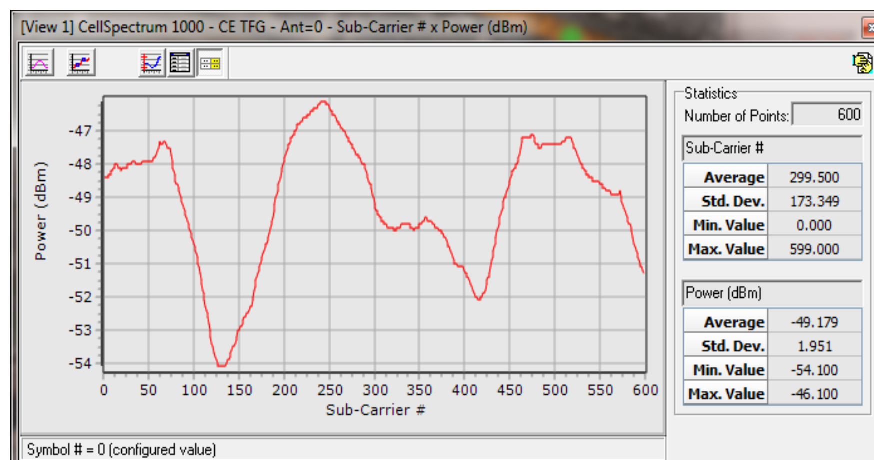


TFGCE antenna 0

- 3 D view
  - 600 subcarriers
  - 853 symbols
- 2 D view
  - Subcarrier 300
- 2D view
  - Symbol 0

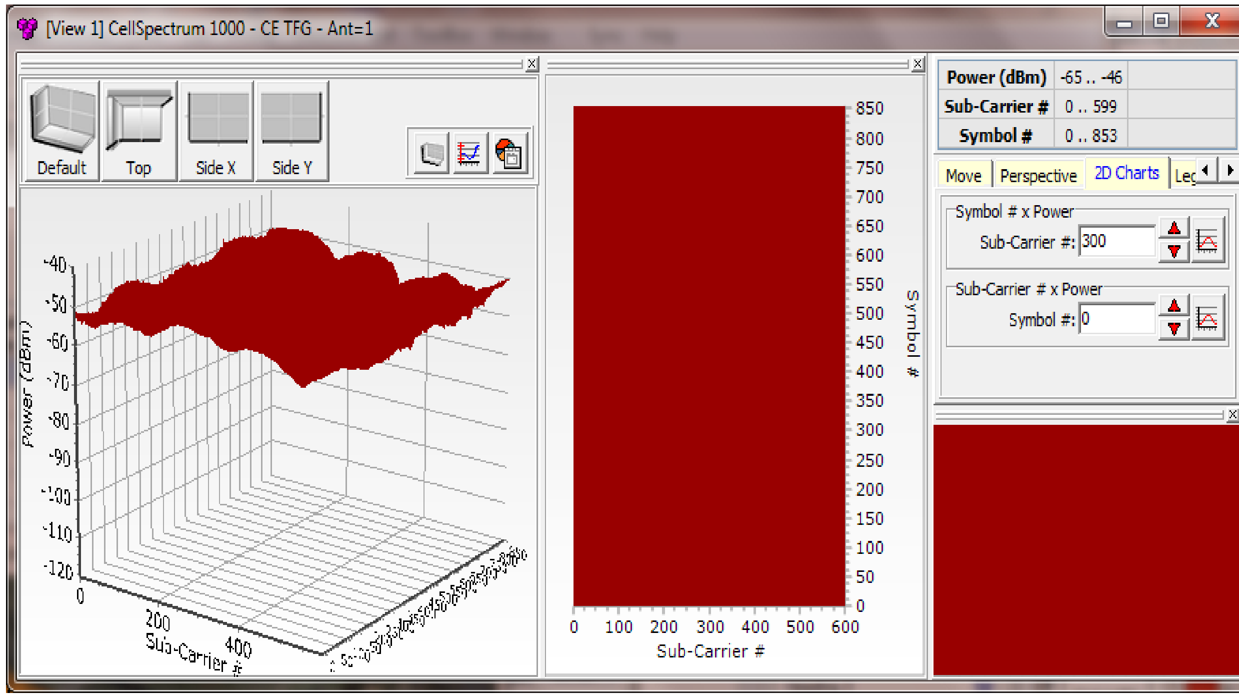


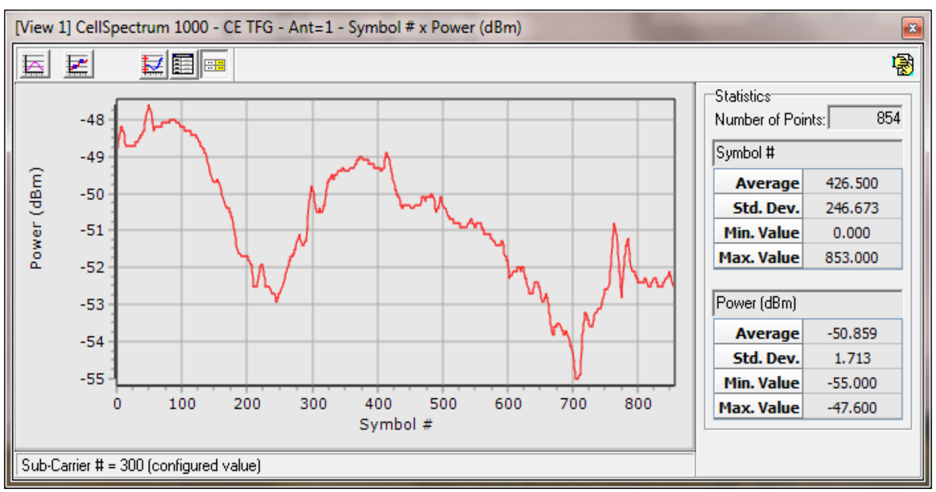


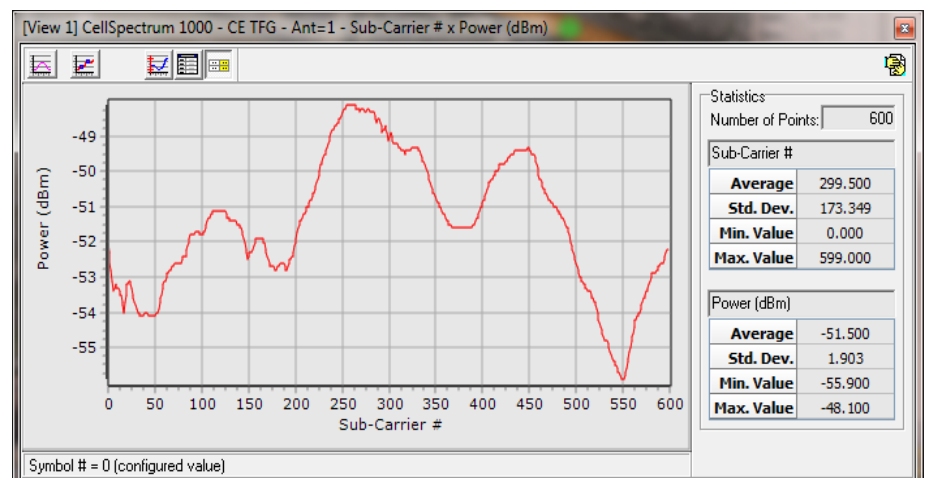


TFGCE antenna 1

- 3 D view
  - 600 subcarriers
  - 854 symbols
- 2 D view
  - Subcarrier 300
- 2D view
  - Symbol 0

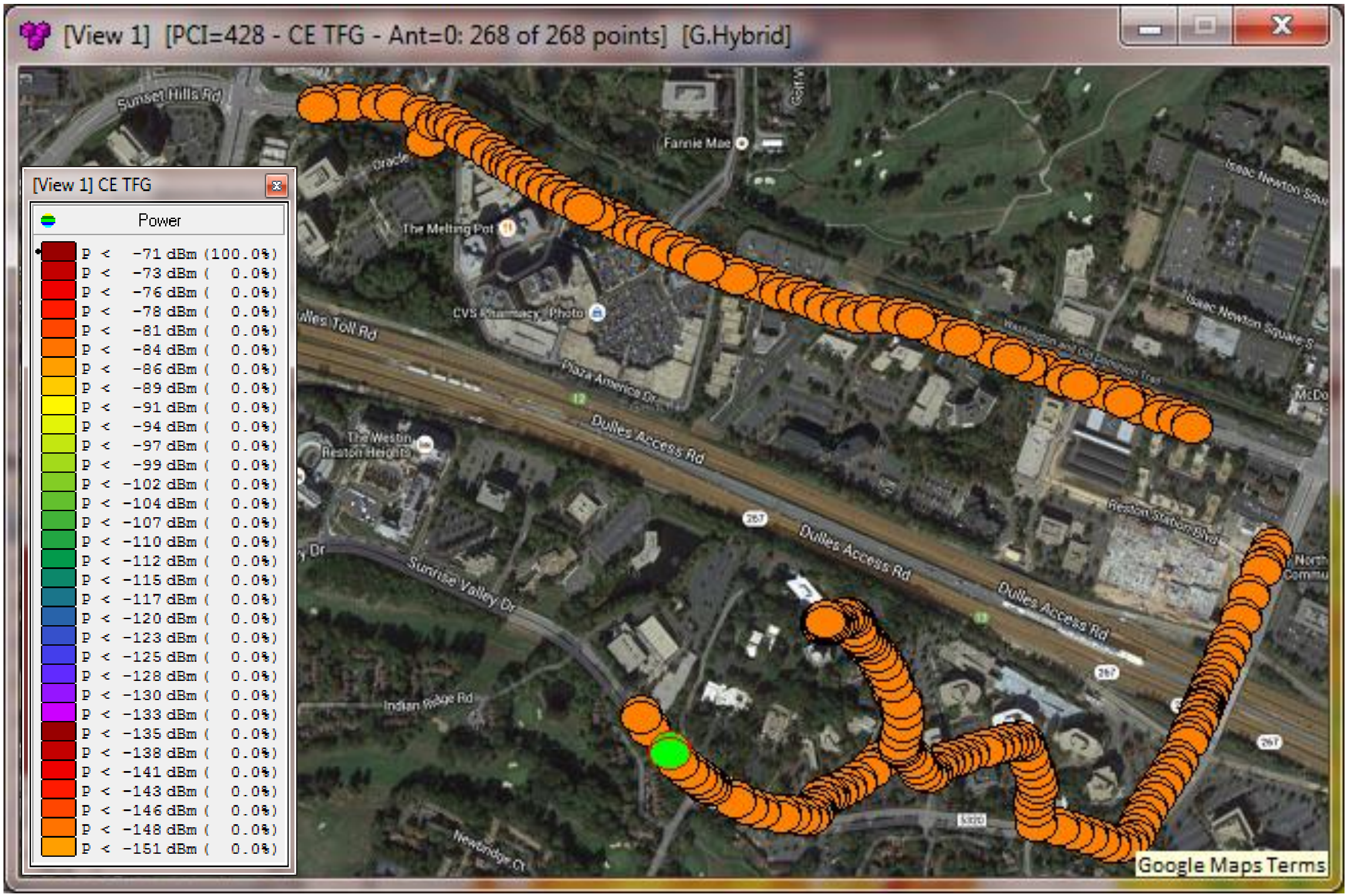






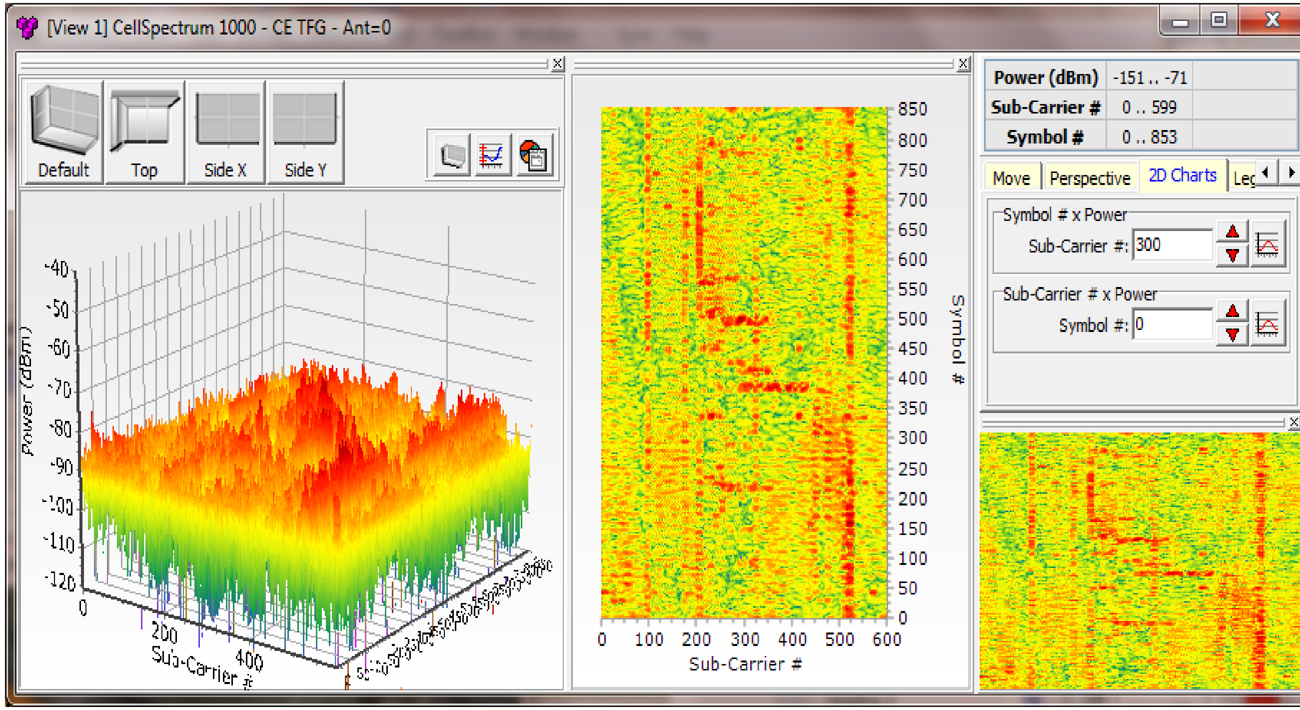
TGFCE

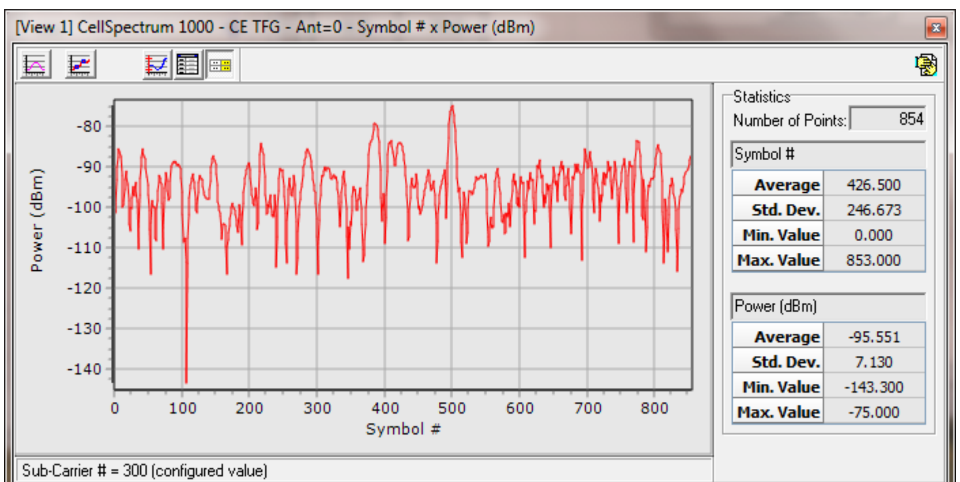
- NLOS

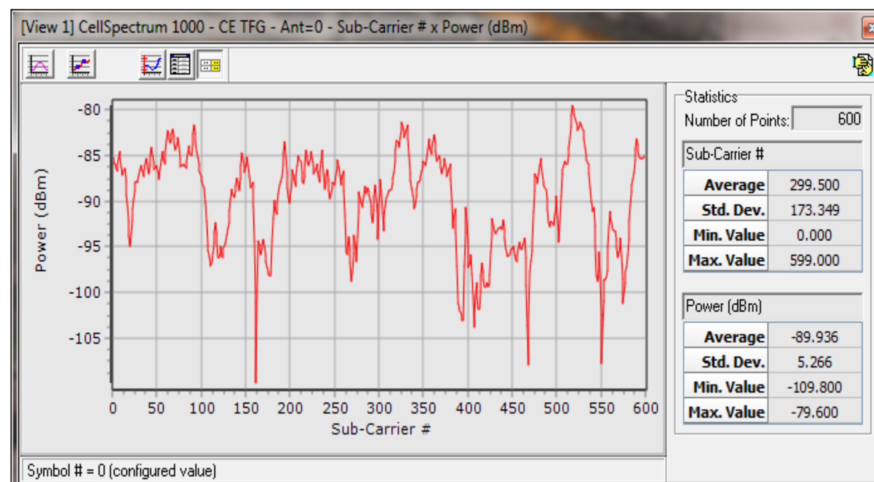

[View 1] [PCI=428 - CE TFG - Ant=0: 268 of 268 points] [G.Hybrid]
[View 1] CE TFG
Power
P < -71 dBm (100.0%)
P < -73 dBm (0.0%)
P < -76 dBm (0.0%)
P < -78 dBm (0.0%)
P < -81 dBm (0.0%)
P < -84 dBm (0.0%)
P < -86 dBm (0.0%)
P < -89 dBm (0.0%)
P < -91 dBm (0.0%)
P < -94 dBm (0.0%)
P < -97 dBm (0.0%)
P < -99 dBm (0.0%)
P < -102 dBm (0.0%)
P < -104 dBm (0.0%)
P < -107 dBm (0.0%)
P < -110 dBm (0.0%)
P < -112 dBm (0.0%)
P < -115 dBm (0.0%)
P < -117 dBm (0.0%)
P < -120 dBm (0.0%)
P < -123 dBm (0.0%)
P < -125 dBm (0.0%)
P < -128 dBm (0.0%)
P < -130 dBm (0.0%)
P < -133 dBm (0.0%)
P < -135 dBm (0.0%)
P < -138 dBm (0.0%)
P < -141 dBm (0.0%)
P < -143 dBm (0.0%)
P < -146 dBm (0.0%)
P < -148 dBm (0.0%)
P < -151 dBm (0.0%)
Sunset Hills Rd
Fannie Mae
The Melting Pot
CVS Pharmacy Photo
Plaza America Dr
Dulles Access Rd
The Westin Reston Heights
Sunrise Valley Dr
Indian Ridge Rd
Reston Station Blvd
Isaac Newton Square
Google Maps Terms

TFGCE antenna 0

- 3 D view
  - 600 subcarriers
  - 853 symbols
- 2 D view
  - Subcarrier 300
- 2D view
  - Symbol 0

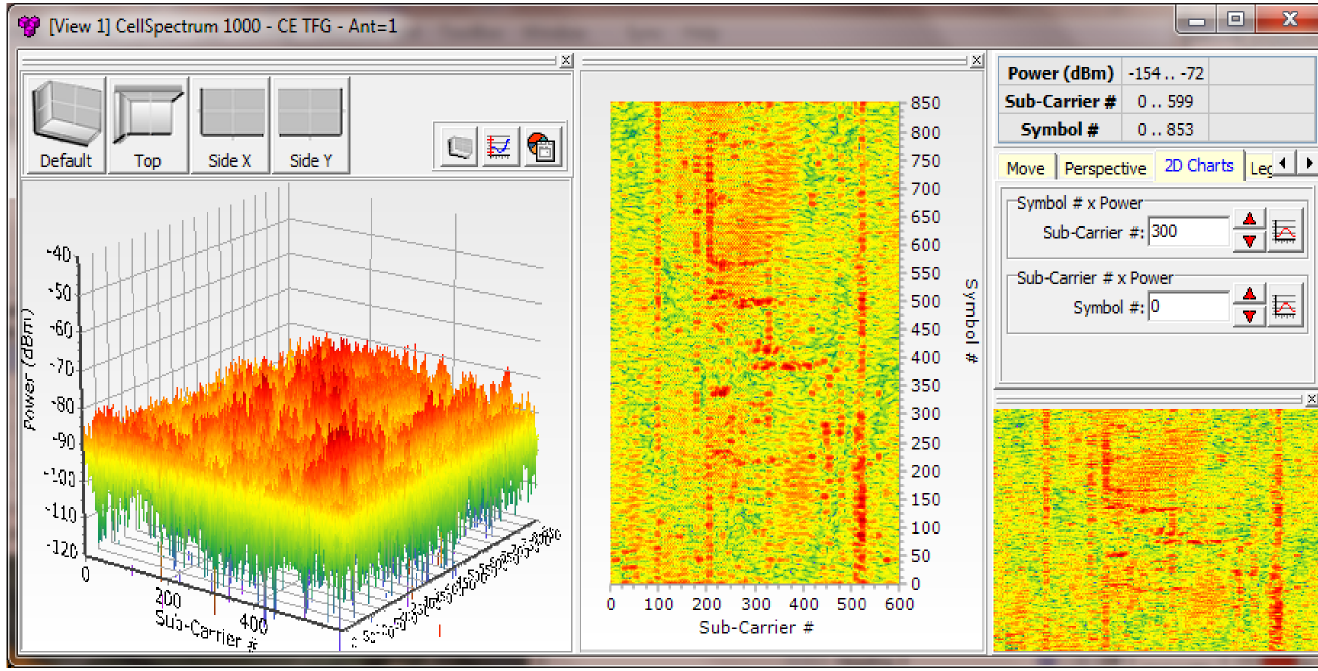


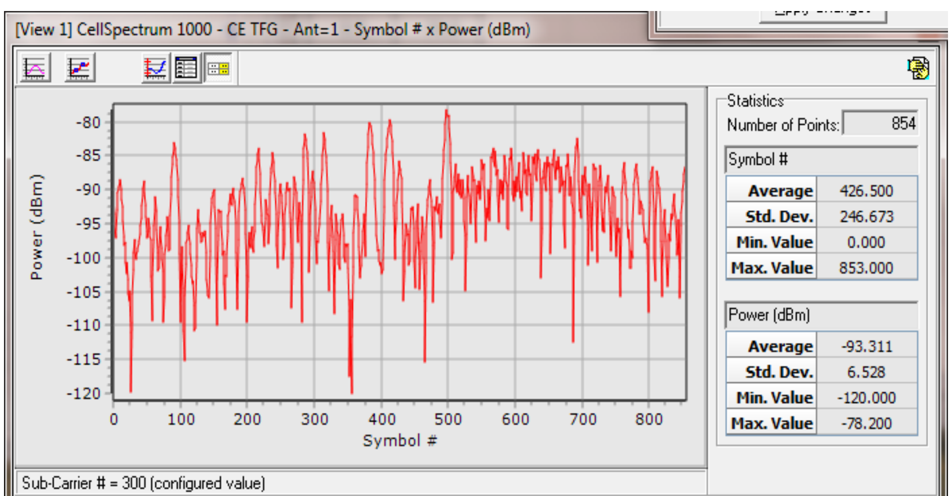


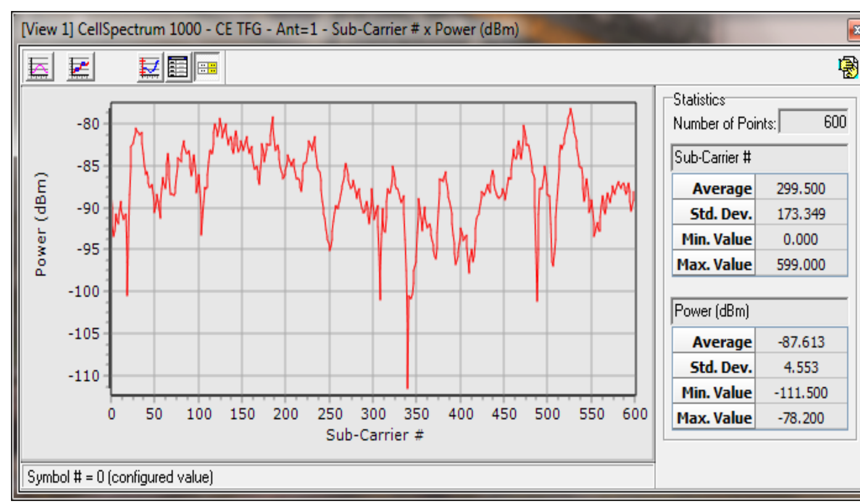


TFGCE antenna 1

- 3 D view
  - 600 subcarriers
  - 854 symbols
- 2 D view
  - Subcarrier 300
- 2D view
  - Symbol 0

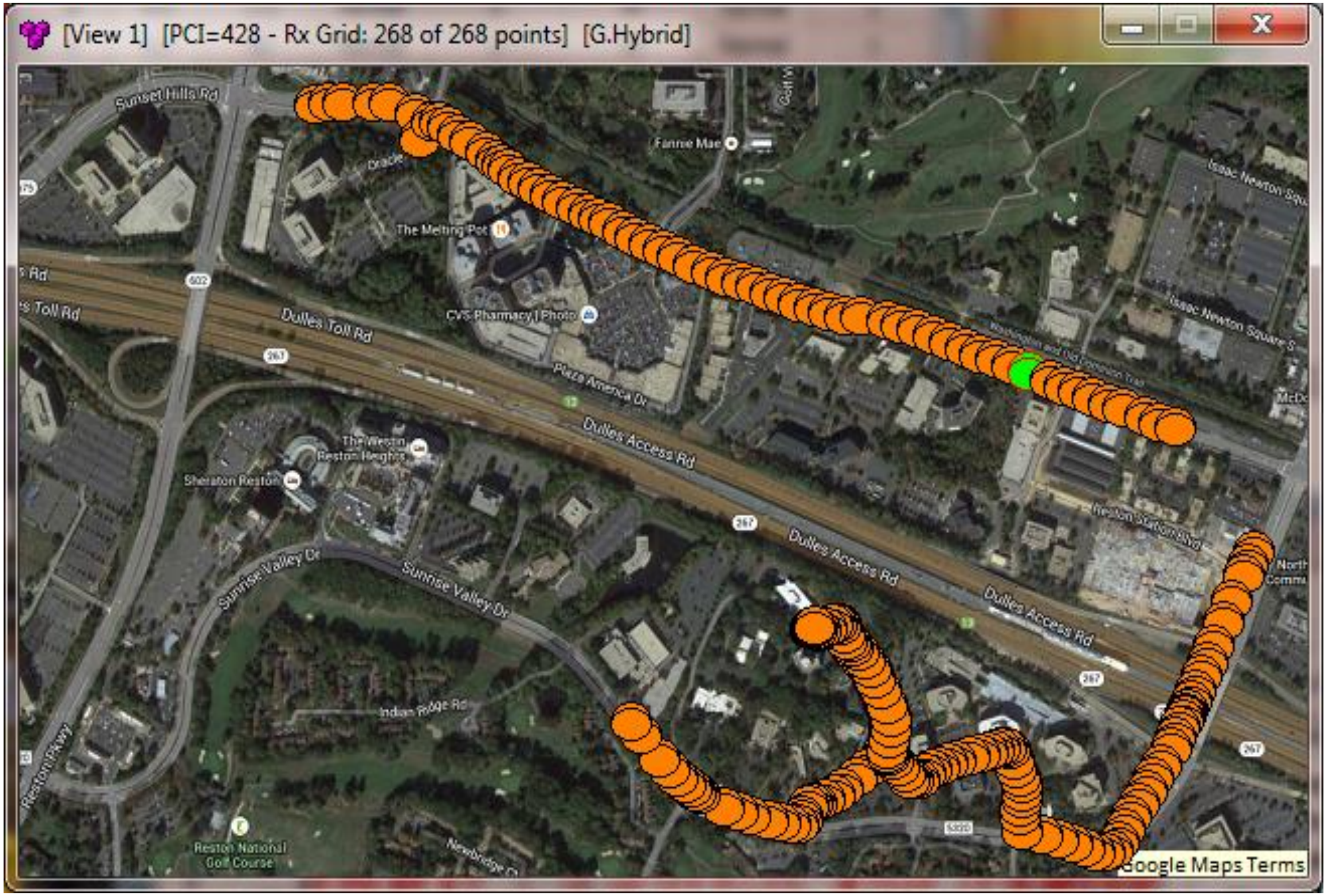






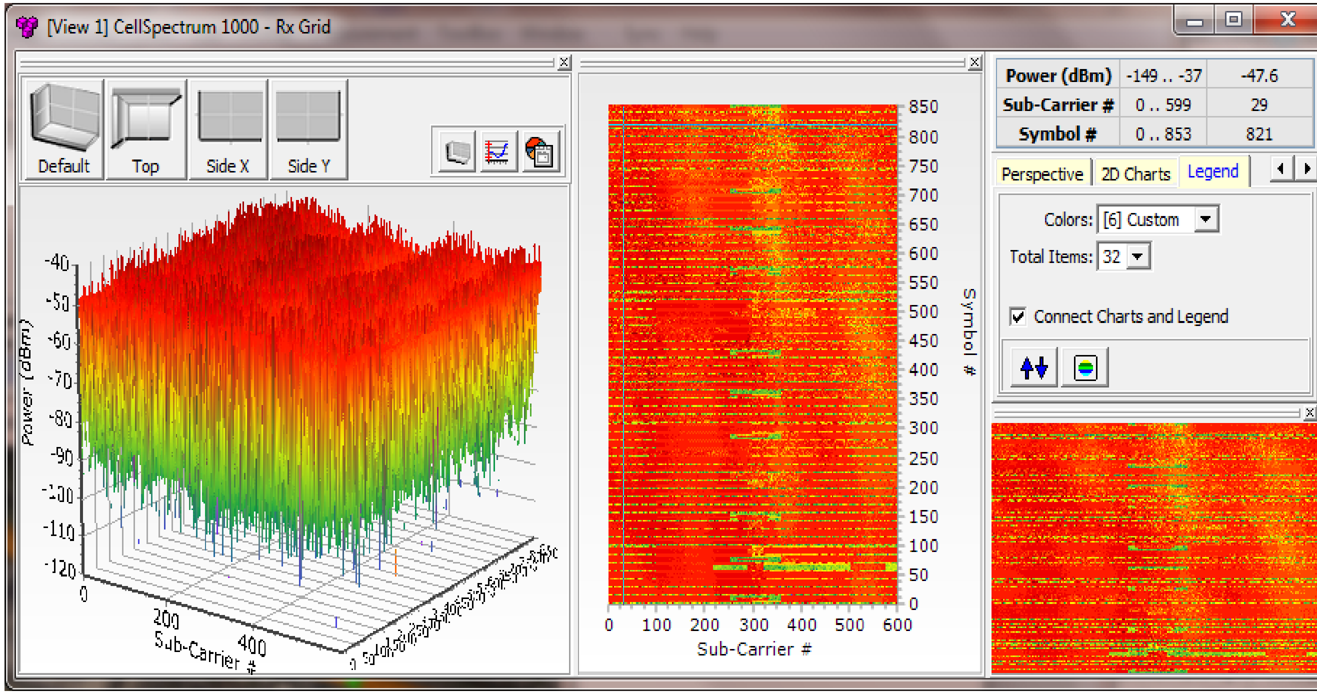
RXGRID

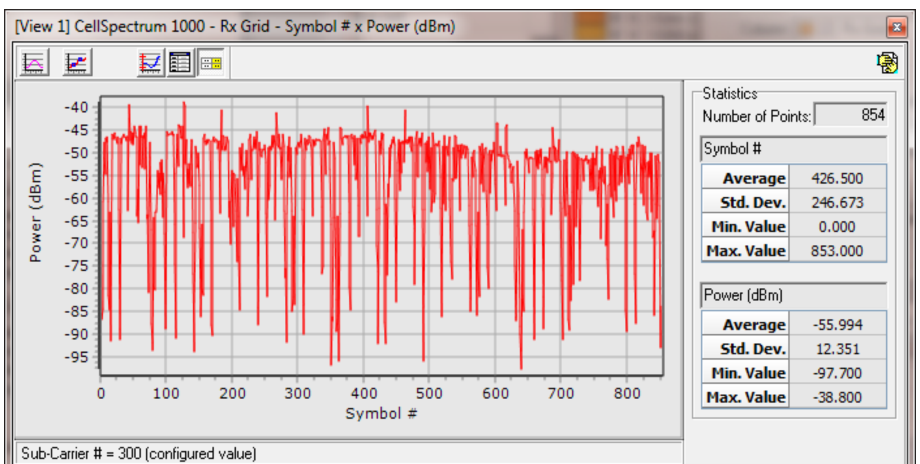
- LOS

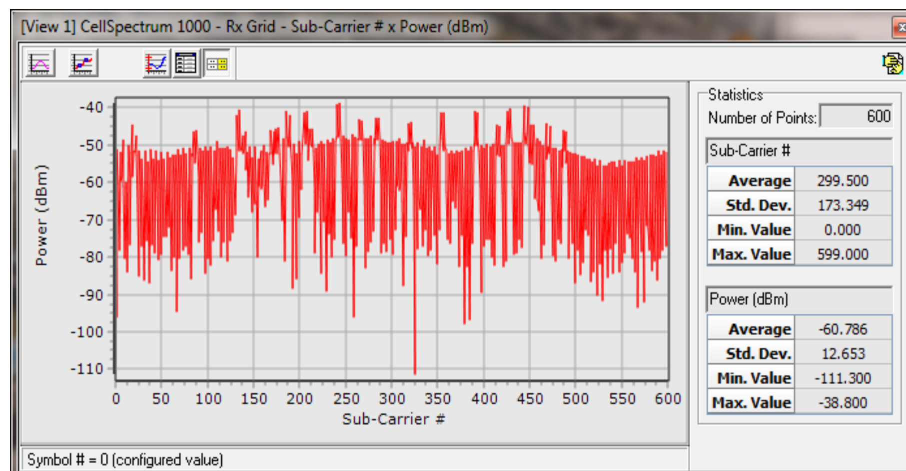

[View 1] [PCI=428 - Rx Grid: 268 of 268 points] [G.Hybrid]
Sunset Hills Rd
Fannie Mae
Isaac Newton Squ
The Melting Pot
Dulles Toll Rd
CVS Pharmacy | Photo
Isaac Newton Square S
Plaza America Dr
Dulles Access Rd
The Westin Reston Heights
Sheraton Reston
Reston Station Blvd
Sunrise Valley Dr
Dulles Access Rd
Indian Ridge Rd
Reston Pkwy
Reston National Golf Course
Newbridge Ct
Google Maps Terms

RXGRID

- 3 D view
  - 600 subcarriers
  - 854 symbols
- 2 D view
  - Subcarrier 300
- 2D view
  - Symbol 0

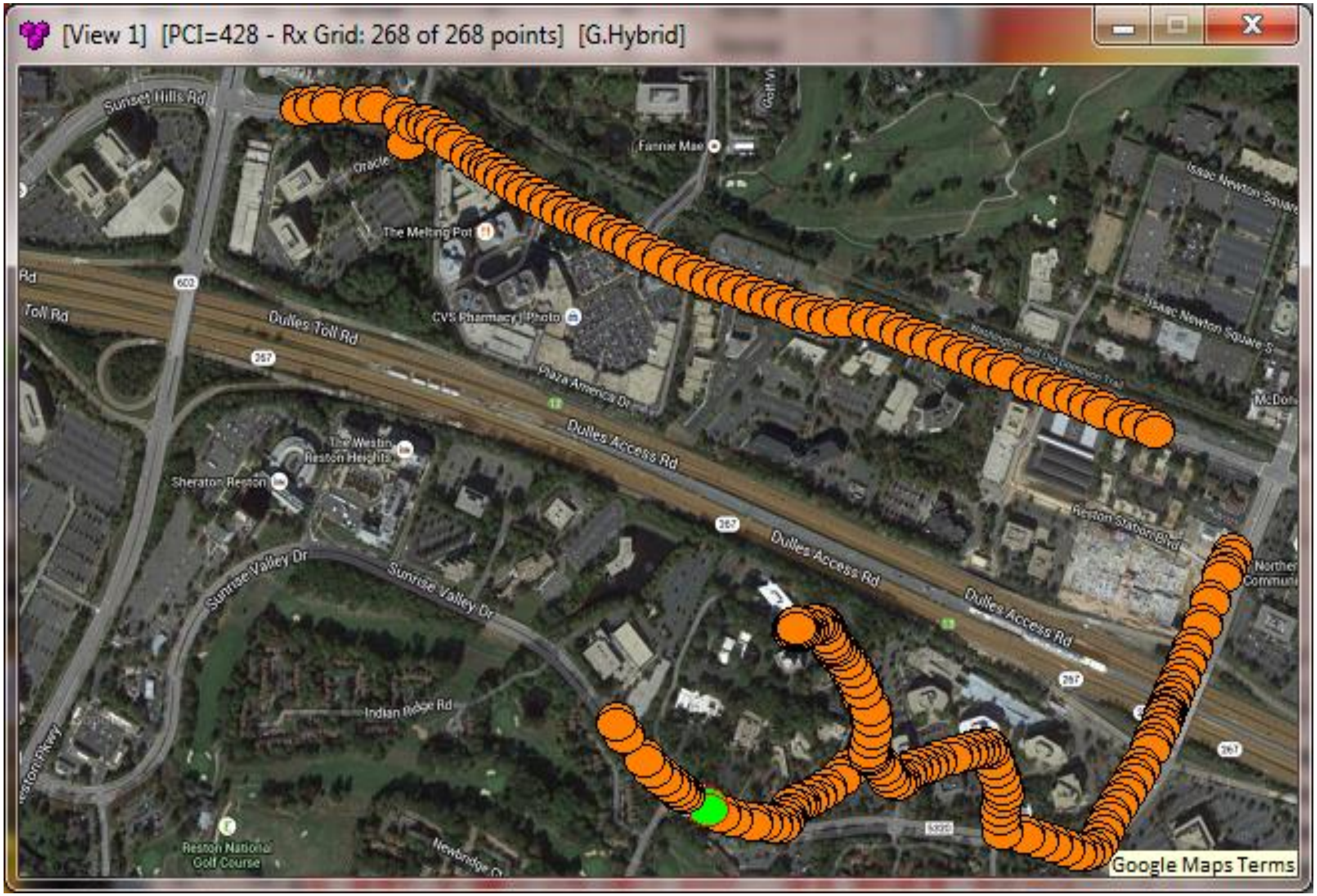






RXGRID

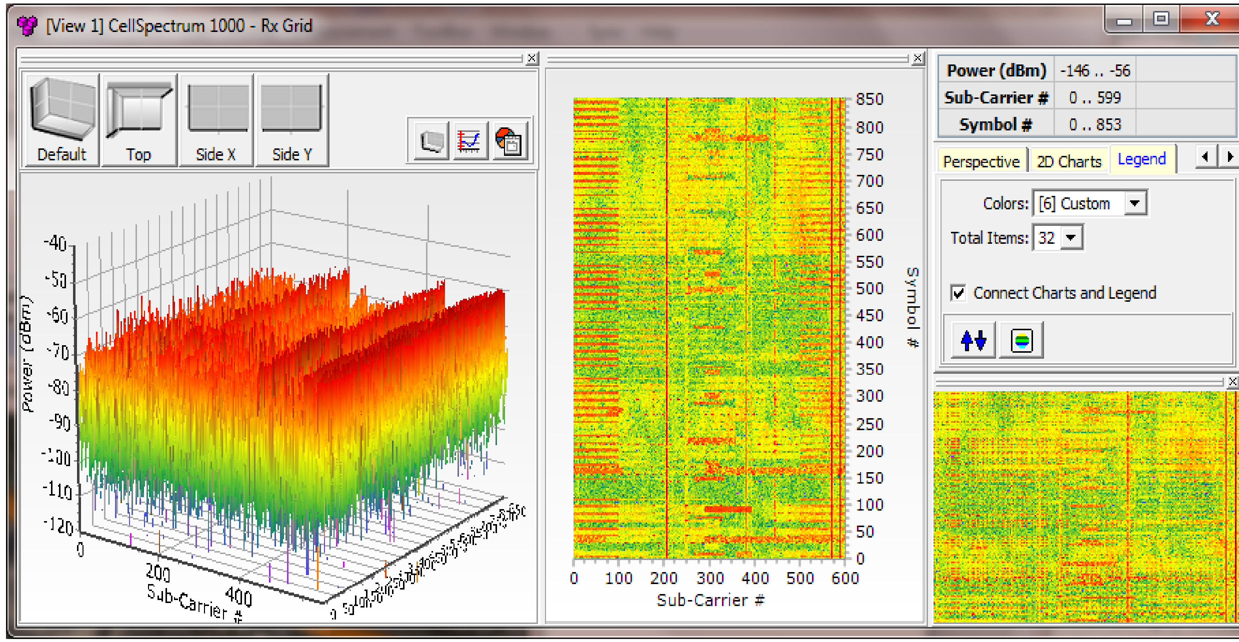
- NLOS

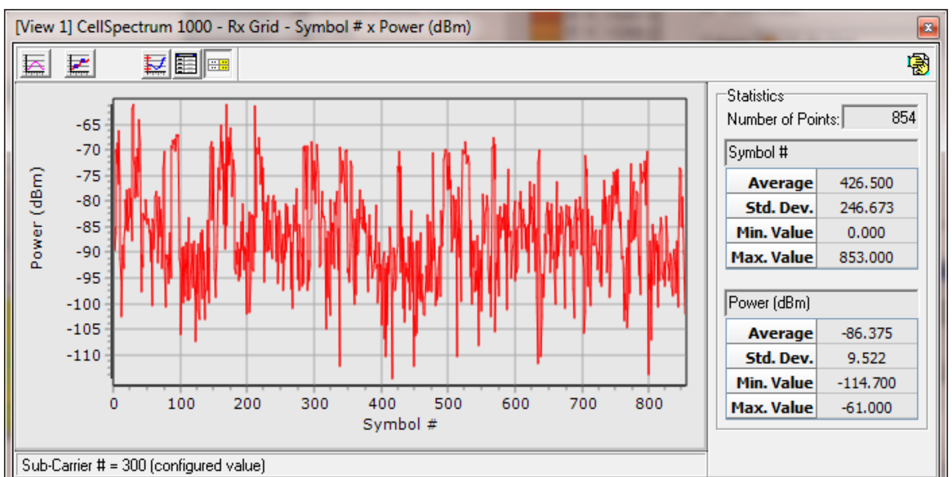


[View 1] [PCI=428 - Rx Grid: 268 of 268 points] [G.Hybrid]
Sunset Hills Rd
Fannie Mae
Oracle
The Melting Pot
Issac Newton Square
Isaac Newton Square S
CVS Pharmacy | Photo
Dulles Toll Rd
Toll Rd
Plaza America Dr
Dulles Access Rd
The Westin Reston Heights
Sheraton Reston
Reston Station Blvd
Sunrise Valley Dr
Indian Ridge Rd
Reston National Golf Course
Newbridge Ct
Google Maps Terms

RXGRID

- 3 D view
  - 600 subcarriers
  - 854 symbols
- 2 D view
  - Subcarrier 300
- 2D view
  - Symbol 0





6. 2D Parameters

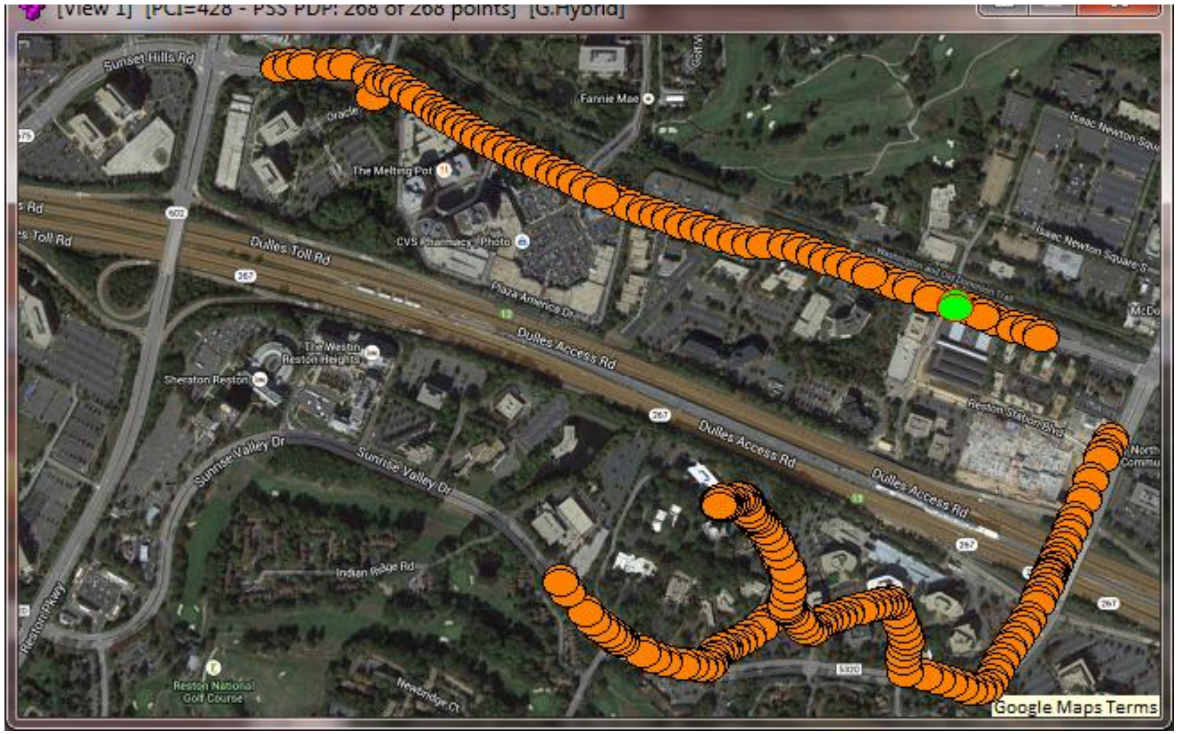
CellSpectrum™

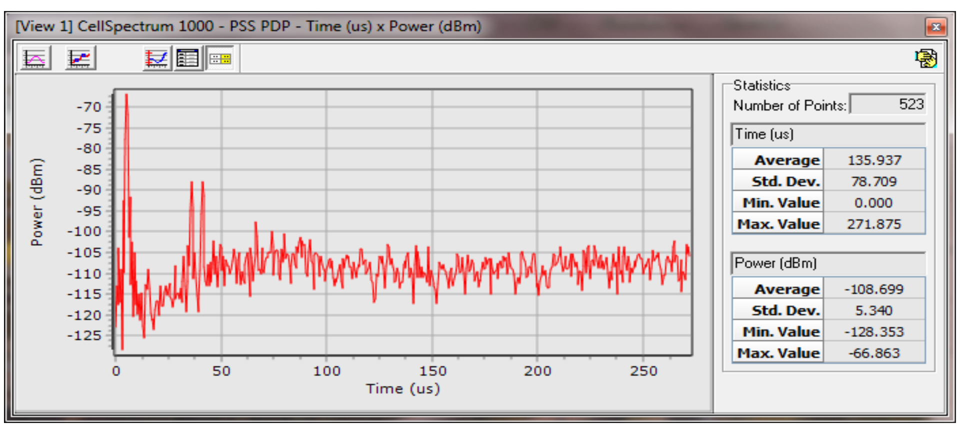
PSS PDP

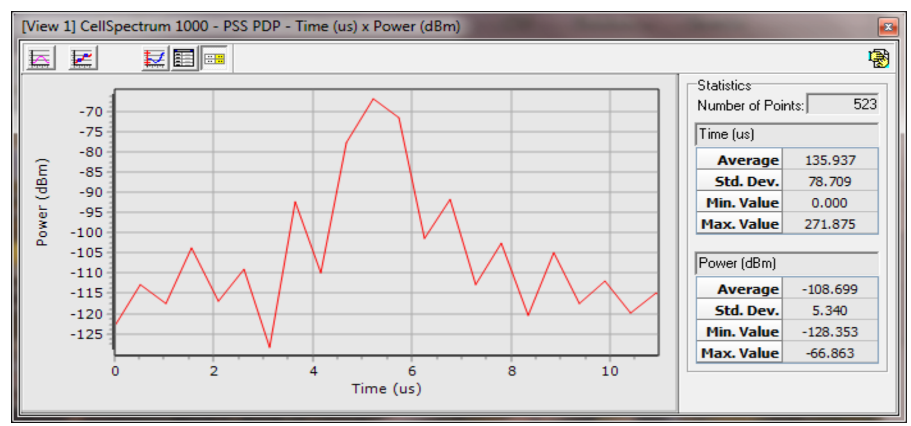
- Primary Synchronization Signal Power Distribution Profile can be used to characterize mutlipath in the environment
- PSS sequence is orthogonal to its shifts
- Detecting PSS sequence ocurrences allows the detection fo multipaths
- PSS PDP can be used to define the cell Cyclic Prefix

PSS PDP

- LOS

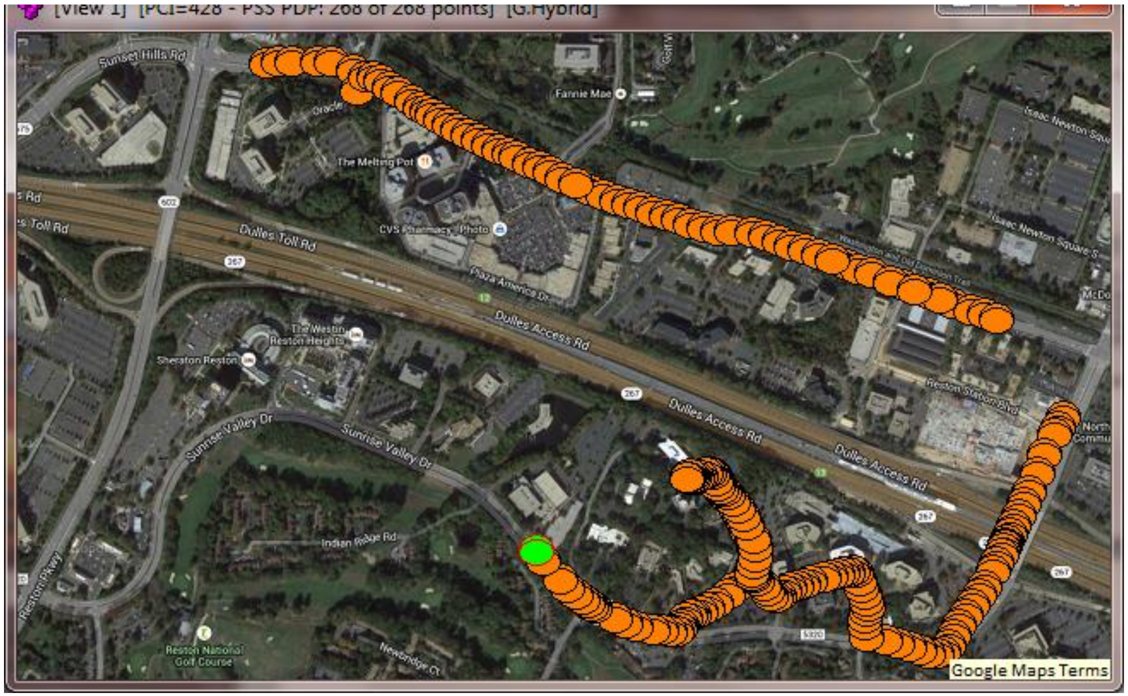

[View 1] [PCI=428 - PSS PDP: 268 of 268 points] [G.Hybrid]
Sunset Hills Rd
Fannie Mae
Oracle
The Melting Pot
Isaac Newton Sq
Isaac Newton Square S
Dulles Toll Rd
CVS Pharmacy - Photo
Plaza America Dr
Dulles Access Rd
The Westin Reston Heights
Sheraton Reston
Reston Station Blvd
Sunrise Valley Dr
Indian Ridge Rd
Reston Pkwy
Reston National Golf Course
Newbridge Ct
Google Maps Terms

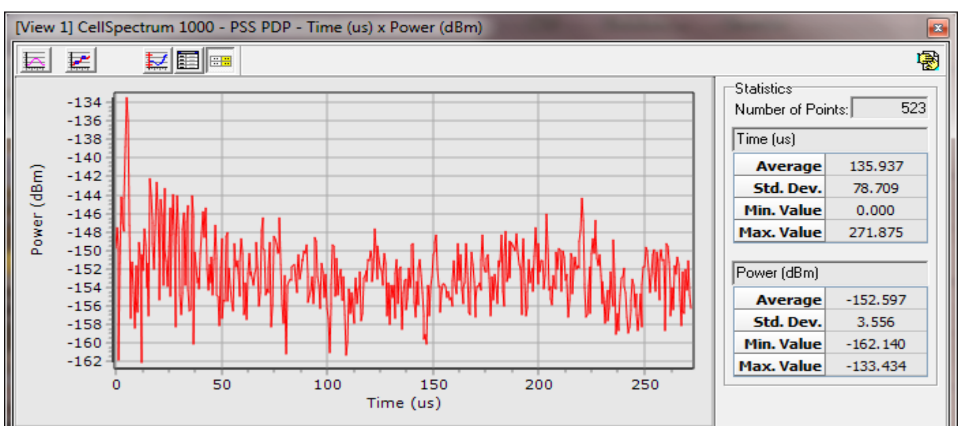

[View 1] CellSpectrum 1000 - PSS PDP - Time (us) x Power (dBm)
Power (dBm)
-70
-75
-80
-85
-90
-95
-100
-105
-110
-115
-120
-125
0
50
100
150
200
250
Time (us)
Statistics
Number of Points: 523
Time (us)
Average 135.937
Std. Dev. 78.709
Min. Value 0.000
Max. Value 271.875
Power (dBm)
Average -108.699
Std. Dev. 5.340
Min. Value -128.353
Max. Value -66.863

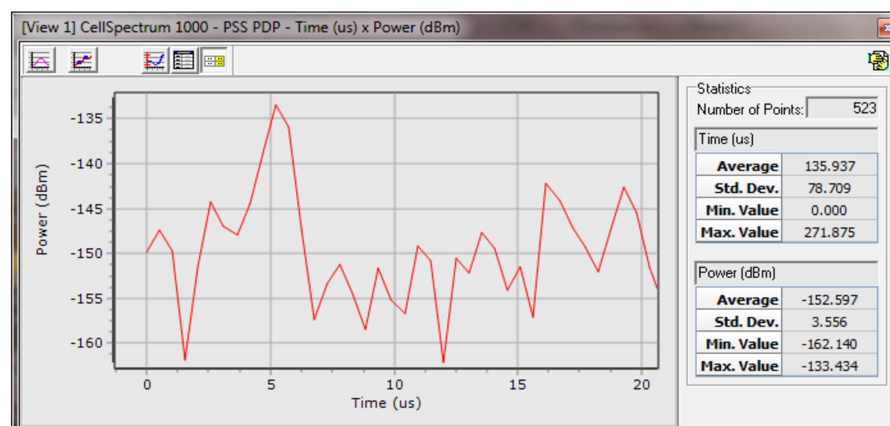

[View 1] CellSpectrum 1000 - PSS PDP - Time (us) x Power (dBm)
Power (dBm)
-70
-75
-80
-85
-90
-95
-100
-105
-110
-115
-120
-125
0
2
4
6
8
10
Time (us)
Statistics
Number of Points: 523
Time (us)
Average 135.937
Std. Dev. 78.709
Min. Value 0.000
Max. Value 271.875
Power (dBm)
Average -108.699
Std. Dev. 5.340
Min. Value -128.353
Max. Value -66.863

PSS PDP

- NLOS


[View 1] [PCI=428 - PSS PDP: 268 of 268 points] [G.Hybrid]
Sunset Hills Rd
Fannie Mae
Isaac Newton Squ
Isaac Newton Square S
The Melting Pot
CVS Pharmacy
Photo
Dulles Toll Rd
Plaza America Dr
Dulles Access Rd
The Westin Reston Heights
Sheraton Reston
Sunrise Valley Dr
Reston Station Blvd
Indian Ridge Rd
Reston Pkwy
Reston National Golf Course
Newbridge Ct
Google Maps Terms


[View 1] CellSpectrum 1000 - PSS PDP - Time (us) x Power (dBm)
Power (dBm)
-134
-136
-138
-140
-142
-144
-146
-148
-150
-152
-154
-156
-158
-160
-162
0
50
100
150
200
250
Time (us)
Statistics
Number of Points: 523
Time (us)
Average 135.937
Std. Dev. 78.709
Min. Value 0.000
Max. Value 271.875
Power (dBm)
Average -152.597
Std. Dev. 3.556
Min. Value -162.140
Max. Value -133.434

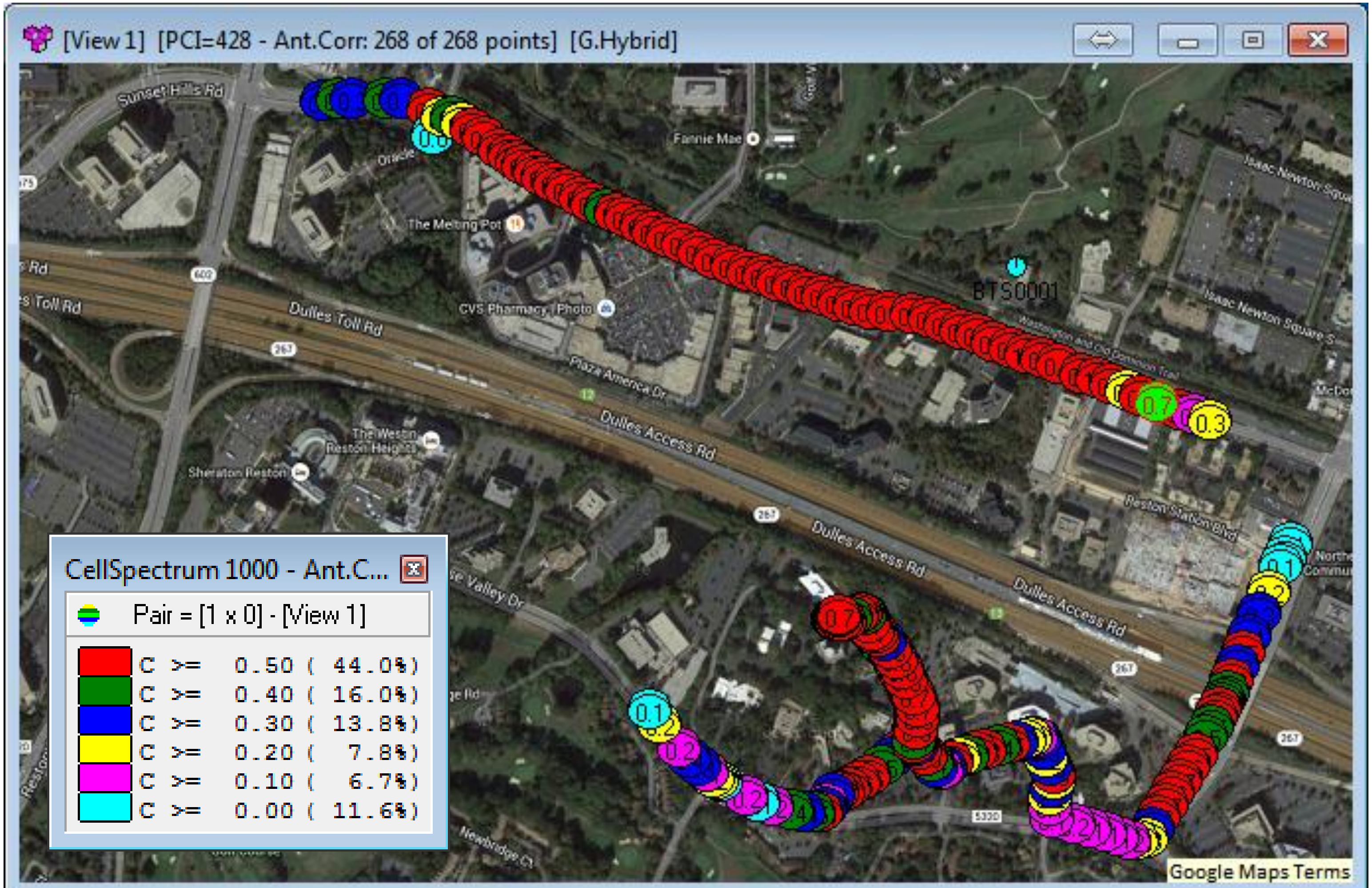

[View 1] CellSpectrum 1000 - PSS PDP - Time (us) x Power (dBm)
Power (dBm)
-135
-140
-145
-150
-155
-160
0
5
10
15
20
Time (us)
Statistics
Number of Points: 523
Time (us)
Average 135.937
Std. Dev. 78.709
Min. Value 0.000
Max. Value 271.875
Power (dBm)
Average -152.597
Std. Dev. 3.556
Min. Value -162.140
Max. Value -133.434

Antenna Correlation

- **Variance** is a measure of the variability or spread in a set of data.
  - $Var\ (X) = \sum_{i=0}^{N} (X_i - X)^2/N = \sum_{i=0}^{N} {x_i^2}/{N}$
    - N is the number of scores in a set of scores
      X is the mean of the N scores.
      X_i is the *i*th raw score in the set of scores
      x_i is the *i*th deviation score in the set of scores
      Var(X) is the variance of all the scores in the set
- **Covariance** is a measure of the extent to which corresponding elements from two sets of ordered data move in the same direction
  - $Var\ (X) = \sum_{i=0}^{N} (X_i - X)(Y_i - Y)/N = \sum_{i=0}^{N} {x_i y_i}/{N}$
    - N is the number of scores in each set of data
      X is the mean of the N scores in the first data set
      X_i is the *i*the raw score in the first set of scores
      x_i is the *i*th deviation score in the first set of scores
      Y is the mean of the N scores in the second data set
      Y_i is the *i*the raw score in the second set of scores
      y_i is the *i*th deviation score in the second set of scores
      Cov(X, Y) is the covariance of corresponding scores in the two sets of data
- Variance and covariance are often displayed together in a variance-covariance matrix, (aka, a covariance matrix). Variances appear along the diagonal and covariance appears in the off-diagonal elements, as shown below.
  - $\boldsymbol{V} = \begin{bmatrix} \sum_{i=0}^{N} x_i^2/N & \sum_{i=0}^{N} x_i y_i/N \\ \sum_{i=0}^{N} y_i x/N & \sum_{i=0}^{N} y_i^2/N \end{bmatrix}$
    - **V** is a *c* x *c* variance-covariance matrix
      N is the number of scores in each of the *c* data sets
      x_i is a deviation score from the *ith* data set
      $\Sigma\ x_i^2$ / N is the variance of elements from the *i*th data set
      $\Sigma\ x_i\ x_j$ / N is the covariance for elements from the *i*th and *j*th data sets

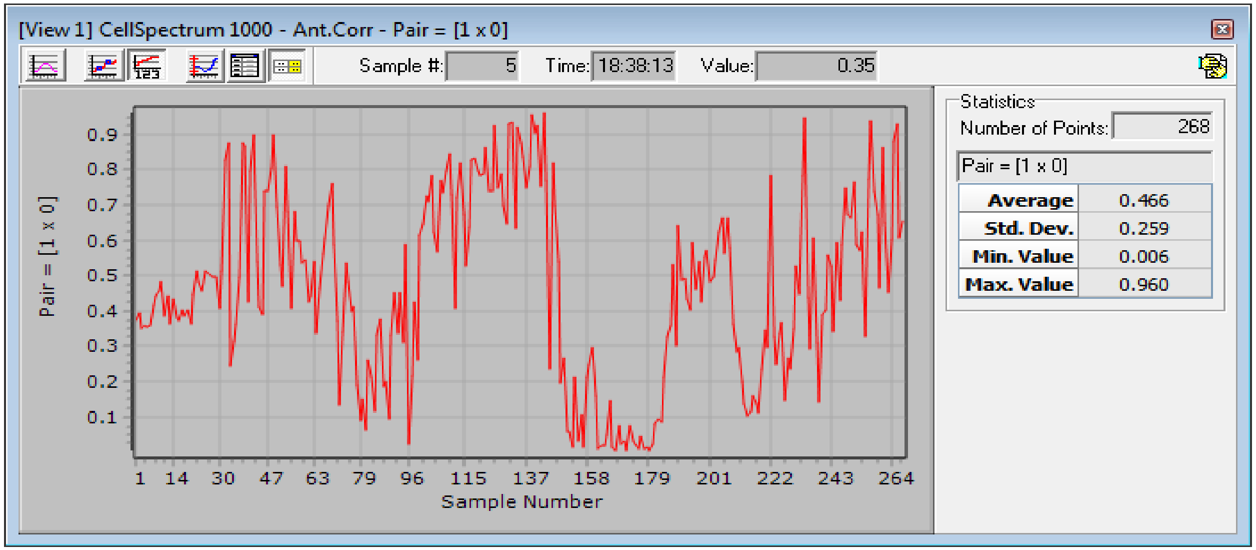
Antenna Correlation

- Covariance



Antenna Correlation

- Values above 0.5 have little chance of benefiting from MIMO
- Values close to zero can benefit from MIMO



[View 1] Antenna Correlation Matrix [2 x 2]

	0	1
0	0.529	0.701
1	0.701	1.000

Statistics	
Average	0.733
Std. Dev.	0.196
Min. Value	0.529
Max. Value	1.000

7. 1D Parameters

CellSpectrum™

Reference Signal Received Power (RSRP)

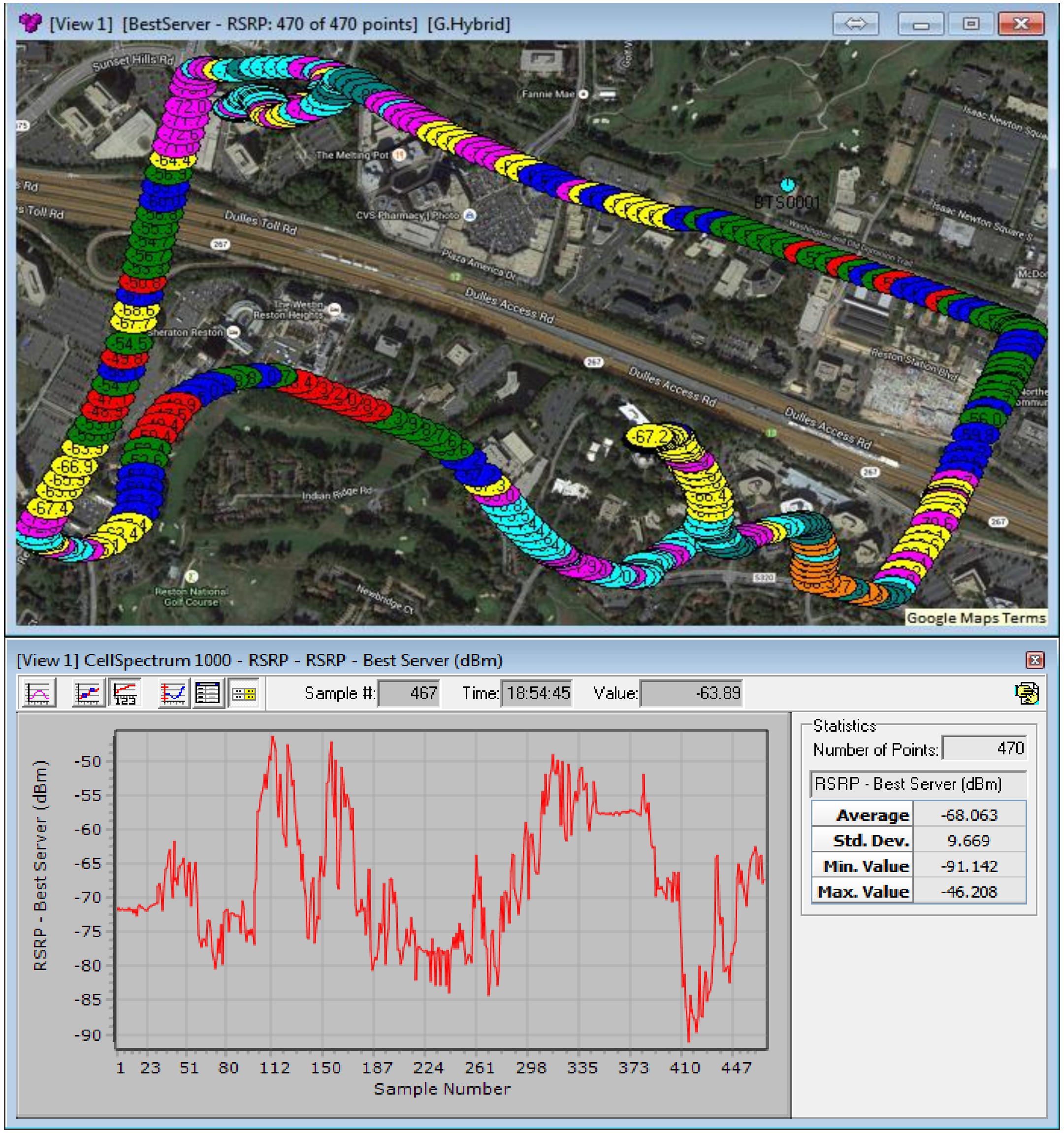
- This signal is measured by averaging the power of Resource Elements that carry Reference Signals
- The 3GPP is not specific about how many symbols should be considered
- CellSpectrum averages all the CRS in each capture
- This averaging is done by multiplying the measured patterns by the expected pattern, filtering some of the noise and interference
- The maximum reportable RSRP considers:
  - Maximum level that an UE can receive: -25 dBm
  - Bandwidth of 1.4 MHz bandwidth: 72 REs
    - $\log(72)$=*-44 dBm*
- The minimum reportable RSRP considers:
  - Maximum path loss of 152 dB
  - Transmit power of 43 dBm
  - Bandwidth of 20 MHz: 1200 REs
    - 43-152-10log(1200)= -139.72
    - This value is below the noise floor, which is -132.3 dBm)
- The absolute RSRP measurement accuracy specified by 3GPP is: ± 8 dB
  - Between two intra-frequency measurements is ± 3 dB
  - Between two inter-frequency measurements is ± 6 dB
- RSRP measurements are mapped onto integer values for reporting purposes.
- RSRP parameter represents a strong indication of the received signal strength, as the influence of interference is minimized. Higher the reported value, stronger is the signal.
- It can be used additionally to:
  - Calibrate the propagation model
  - Analyze the precision of the signal coverage predictions
  - Locate areas with low received signal strength
  - Analyze the best server and its transition along the route

Value Reported	Actual (dBm)
0	RSRP<-140
1	-140 ≤ RSRP ≤ -139
2	-139 ≤ RSRP ≤ -138
3	-138 ≤ RSRP ≤ -137
4	-137 ≤ RSRP ≤ -136
....	....
n	n-139 ≤ RSRP ≤ n-140
....	....
87	-54 ≤ RSRP ≤ -53
88	-53 ≤ RSRP ≤ -52
89	-52 ≤ RSRP ≤ -51
90	-51 ≤ RSRP ≤ -50
91	-50 ≤ RSRP ≤ -49
92	-49 ≤ RSRP ≤ -48
93	-48 ≤ RSRP ≤ -47
94	-47 ≤ RSRP ≤ -46
95	-46 ≤ RSRP ≤ -45
96	-45 ≤ RSRP ≤ -44
97	-44 ≤ RSRP

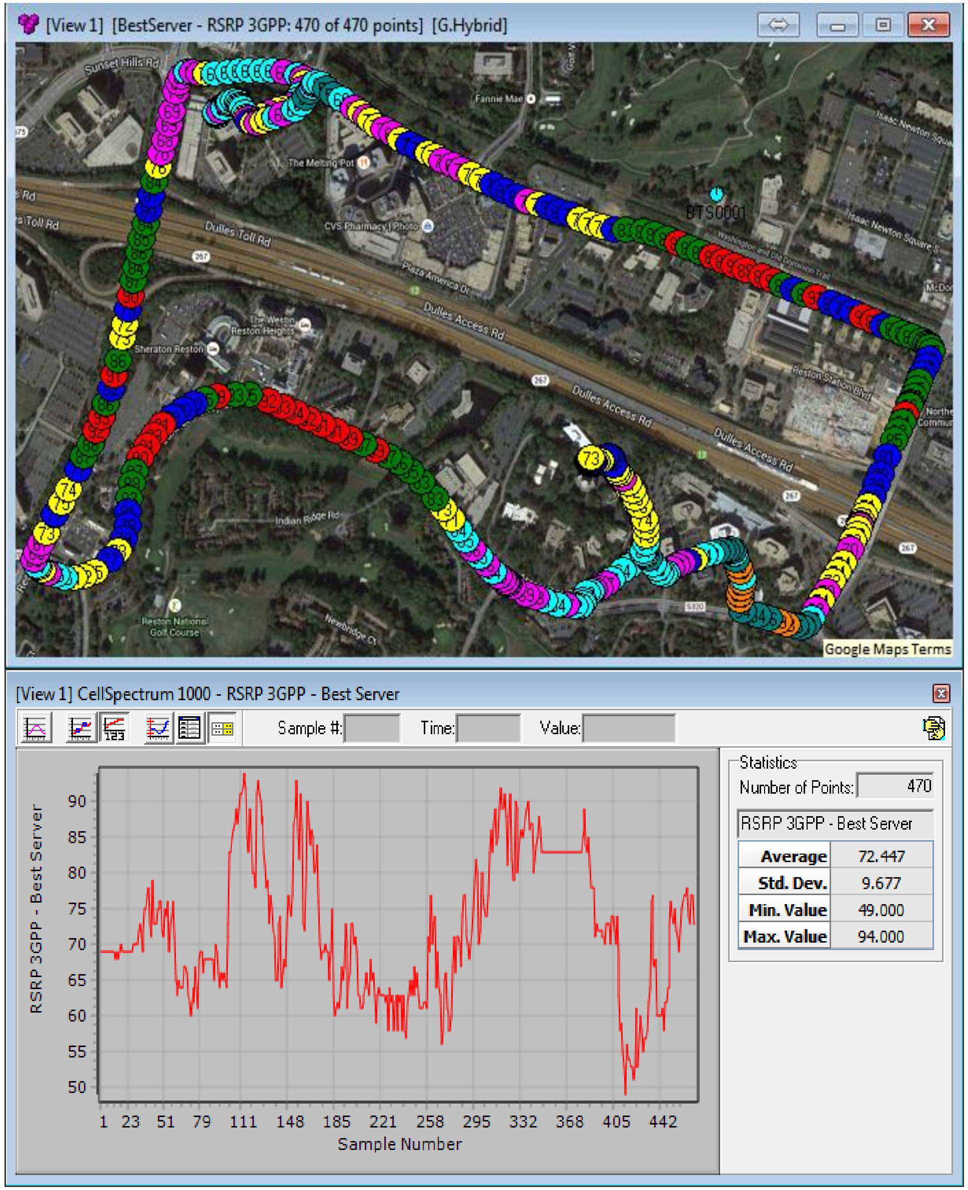
RSRP

- The first set of screens shows the best server signal (in dBm) along the drive test route geographically (map) and in sampling order (graph).
- The second set shows the 3GPP RSRP value.
- The third set shows the best server PCI (Physical Cell Identity).
- The fourth set shows the SFN (System Frame Number).
- The fifth set shows the measurement timing.
- The sixth set shows the Number of Servers. (Why the high numbers?)
- The seventh set shows the First Server at each point and the respective PCI (Why it is different from the best server?)
- The eight set shows the second server at each point and the respective PCI.
- The ninth set shows the third server at each point and the respective PCI.
- The tenth set of screens shows RSRP parameter for PCI 428

Best Server Signal Level (dBm)

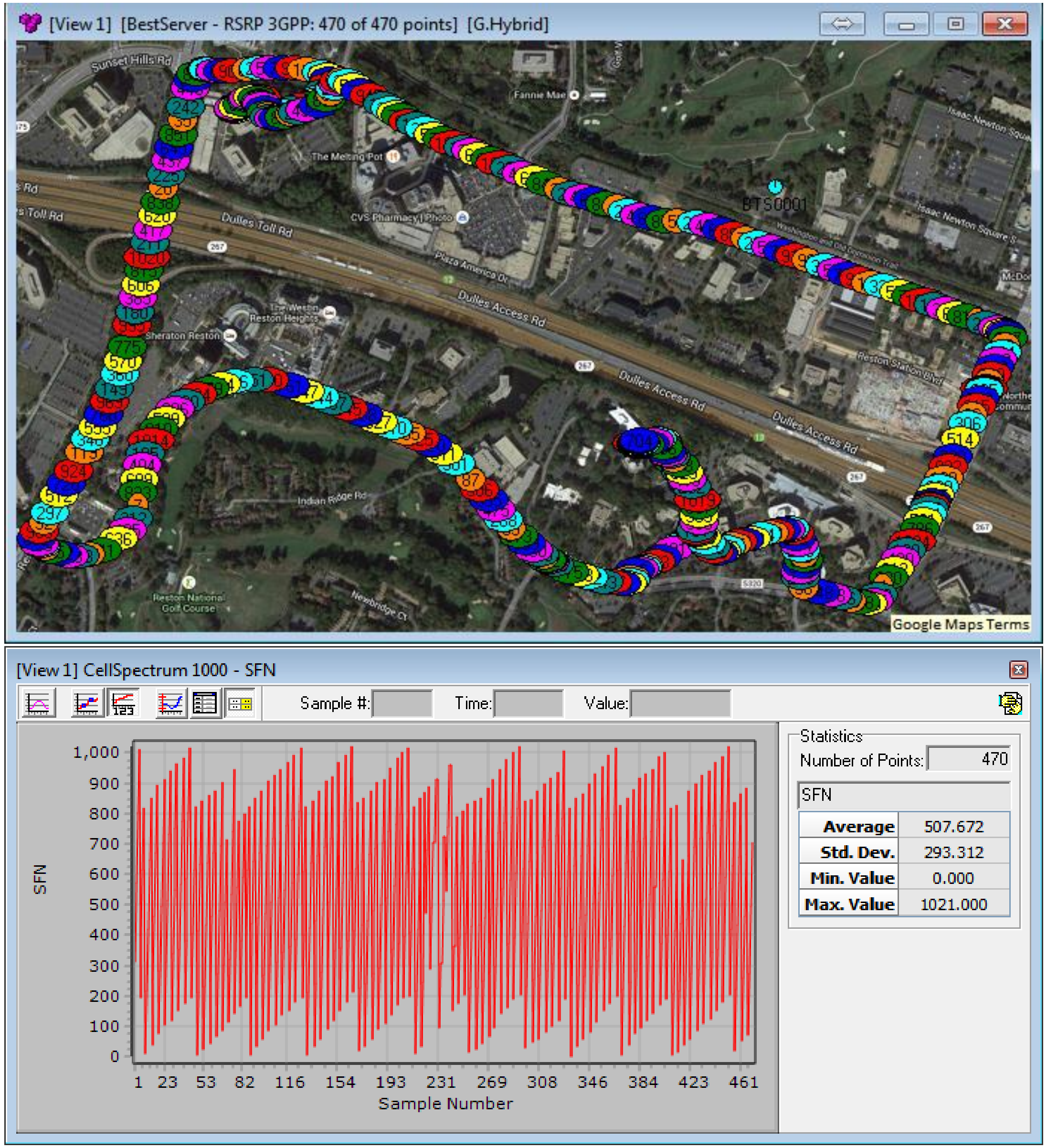


Best Server signal level using 3GPP units



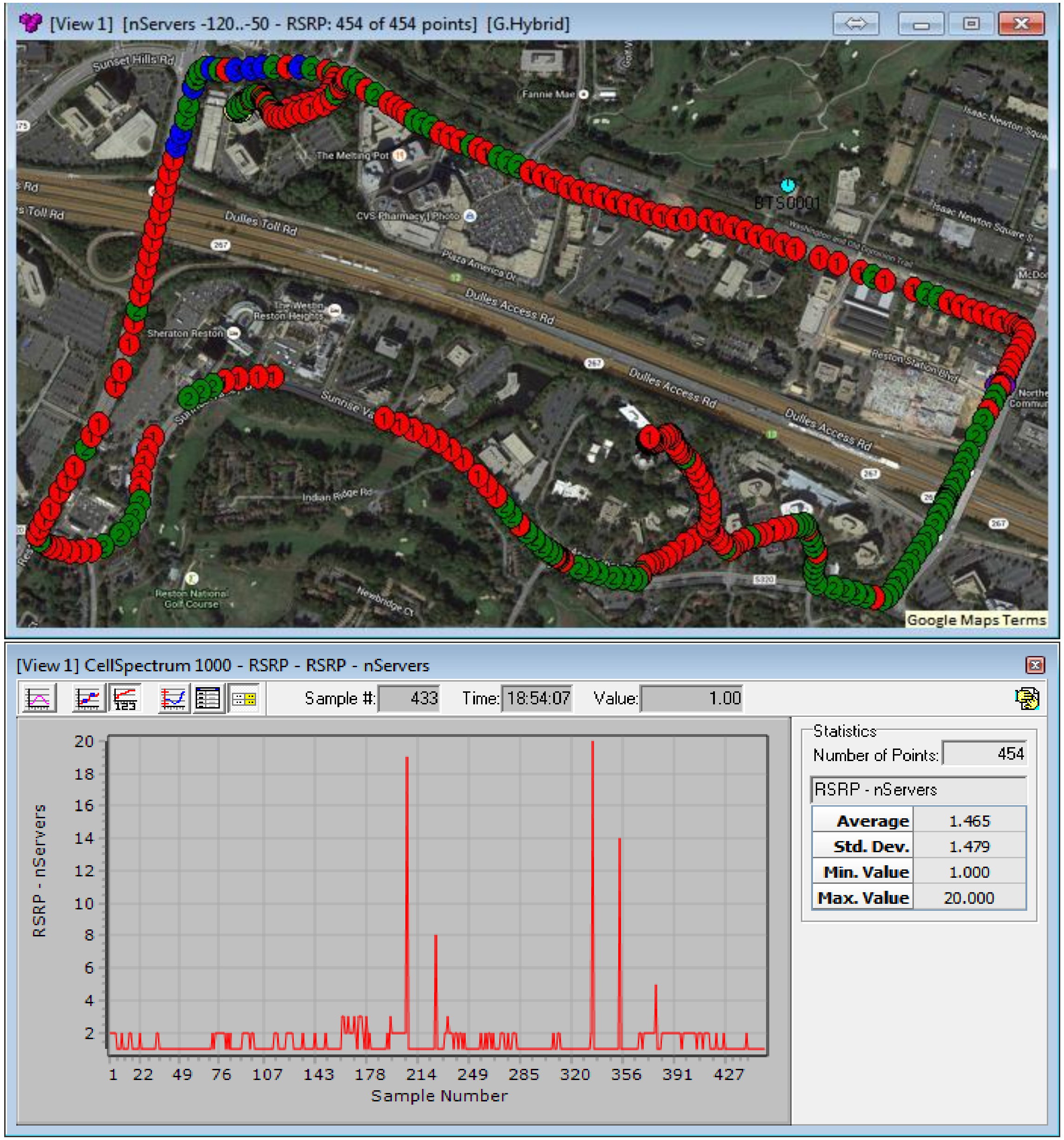
Best Server PCI

Best Server SFN

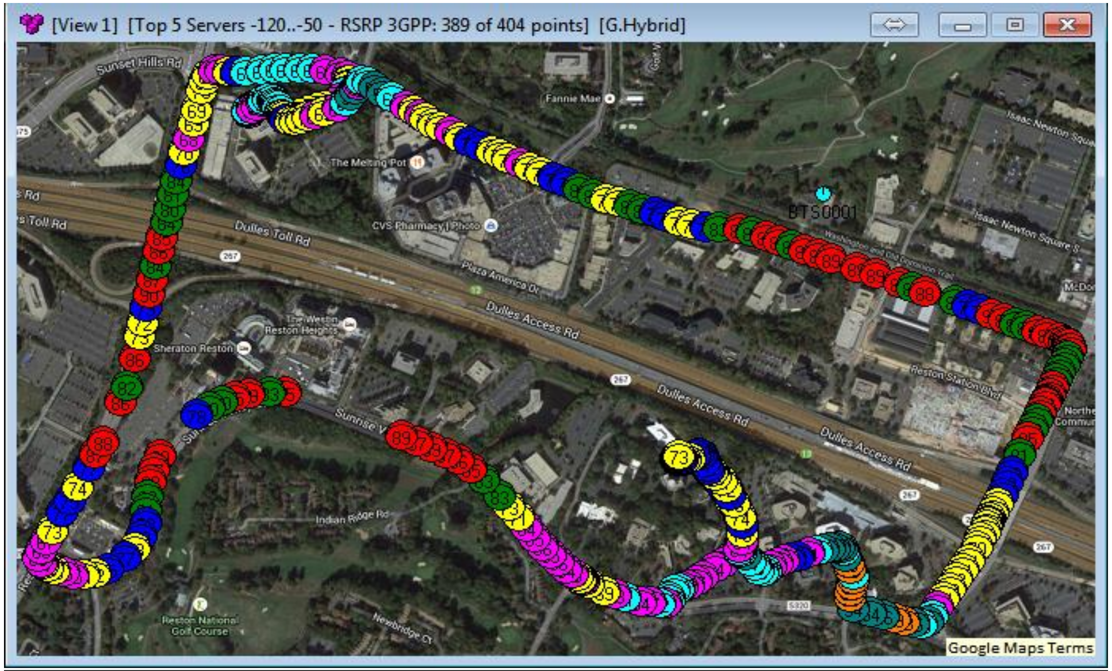


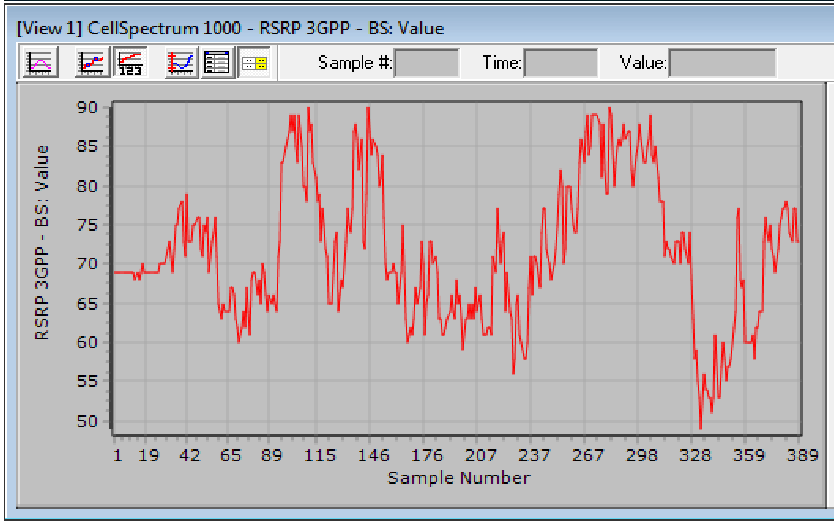
Best Server Measurement Time

Number of Servers



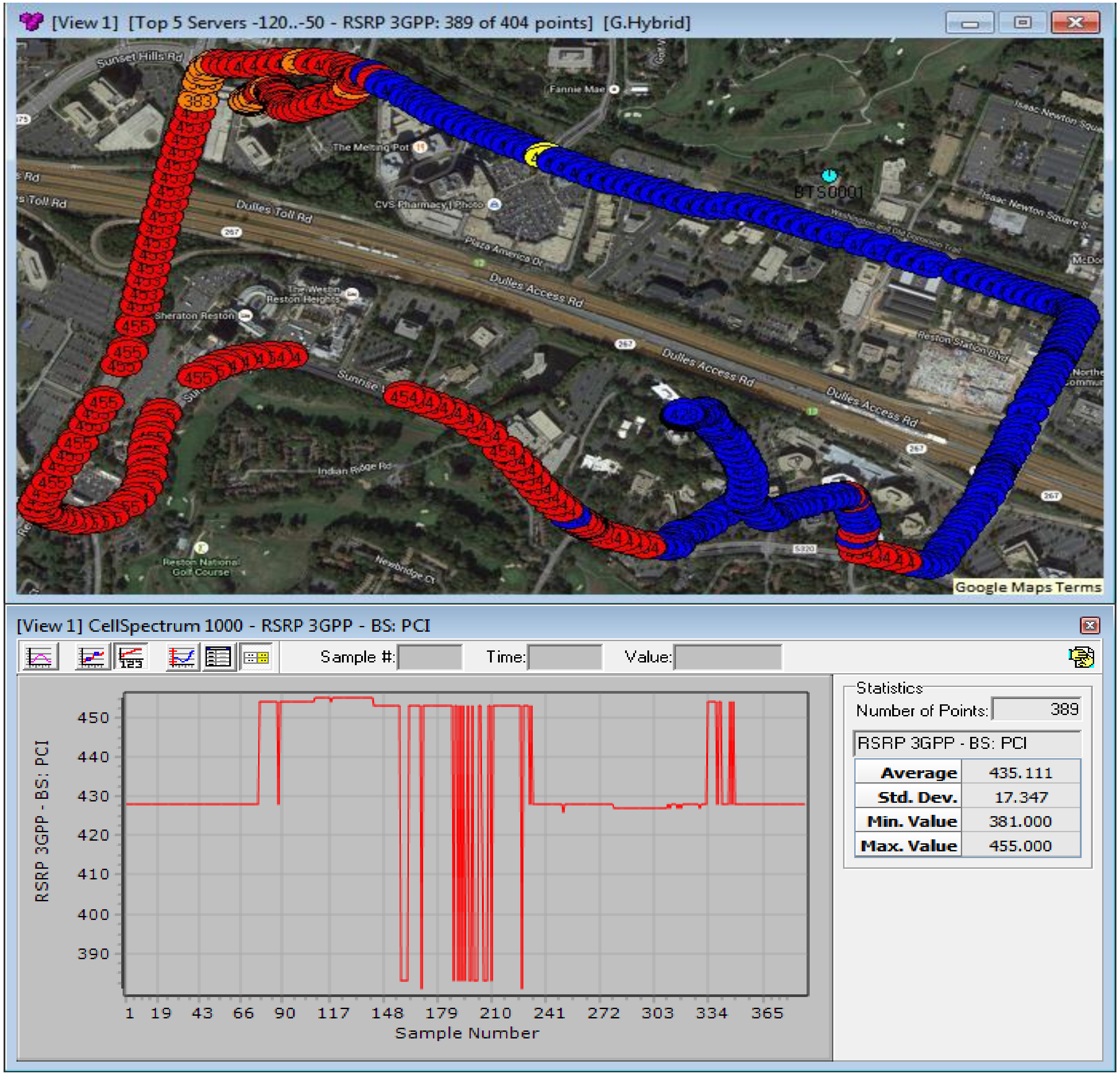
First Server Signal Level



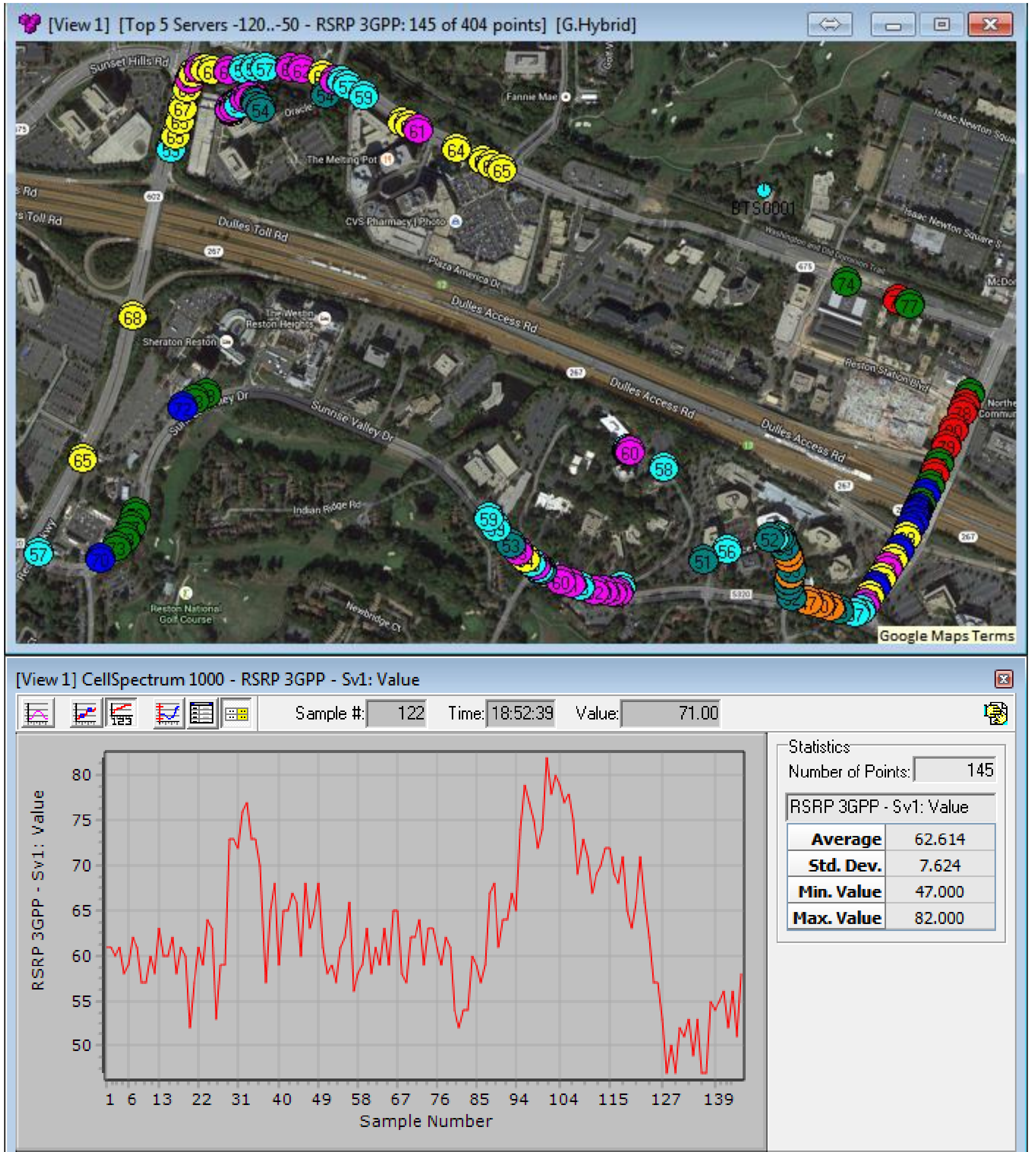


Average	71.553
Std. Dev.	8.928
Min. Value	49.000
Max. Value	90.000

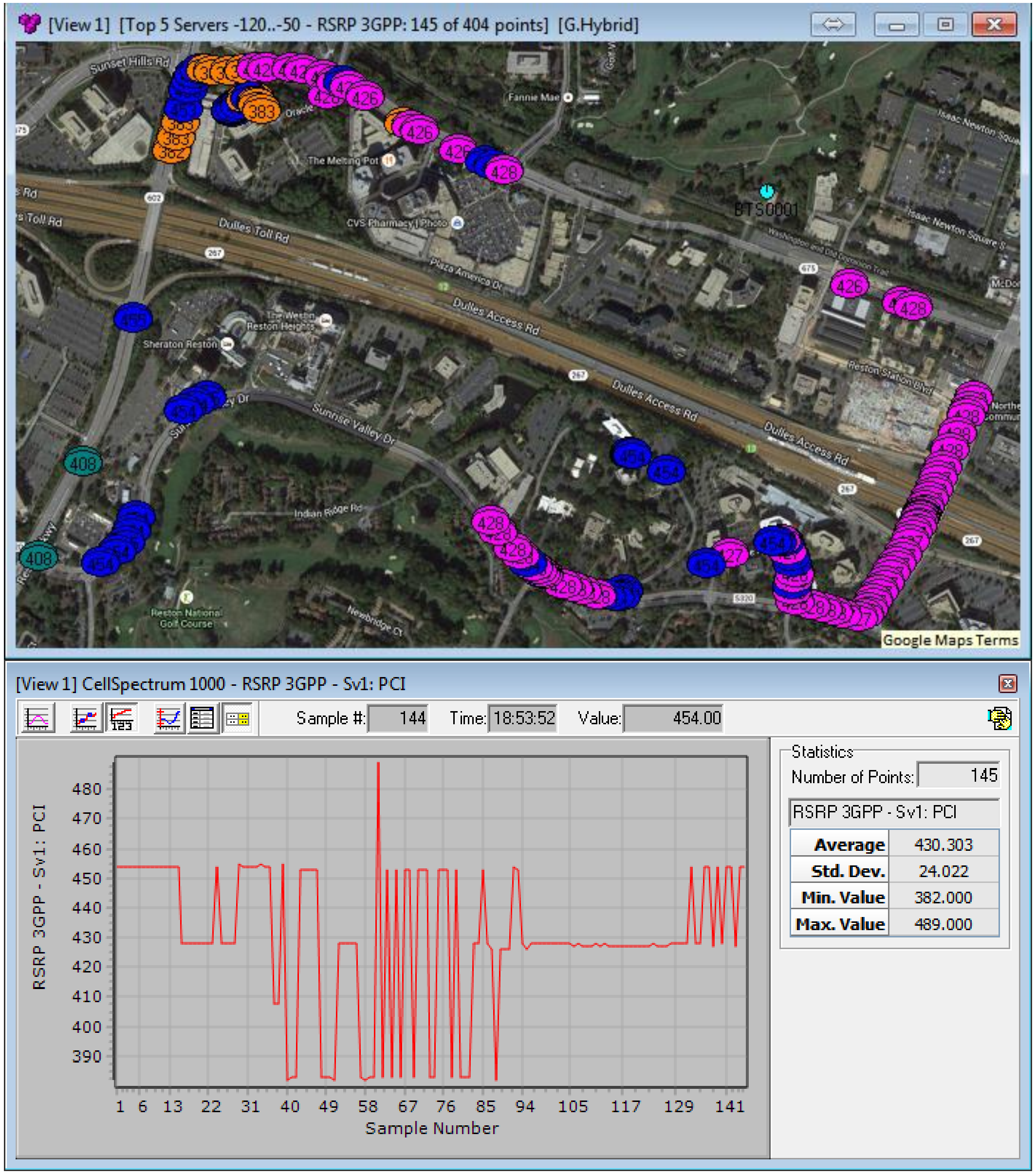
First Server PCI



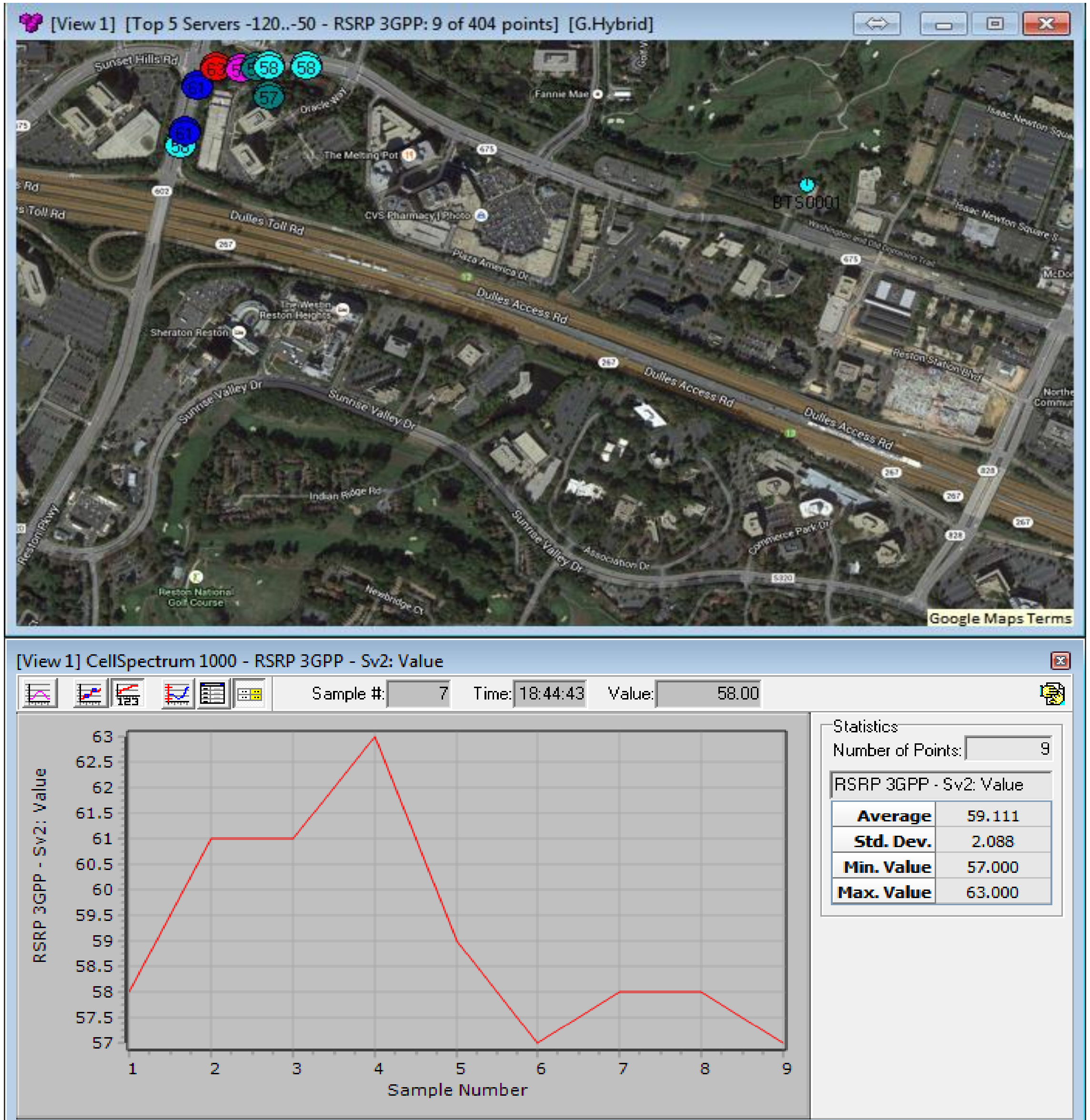
Second Server Signal Level



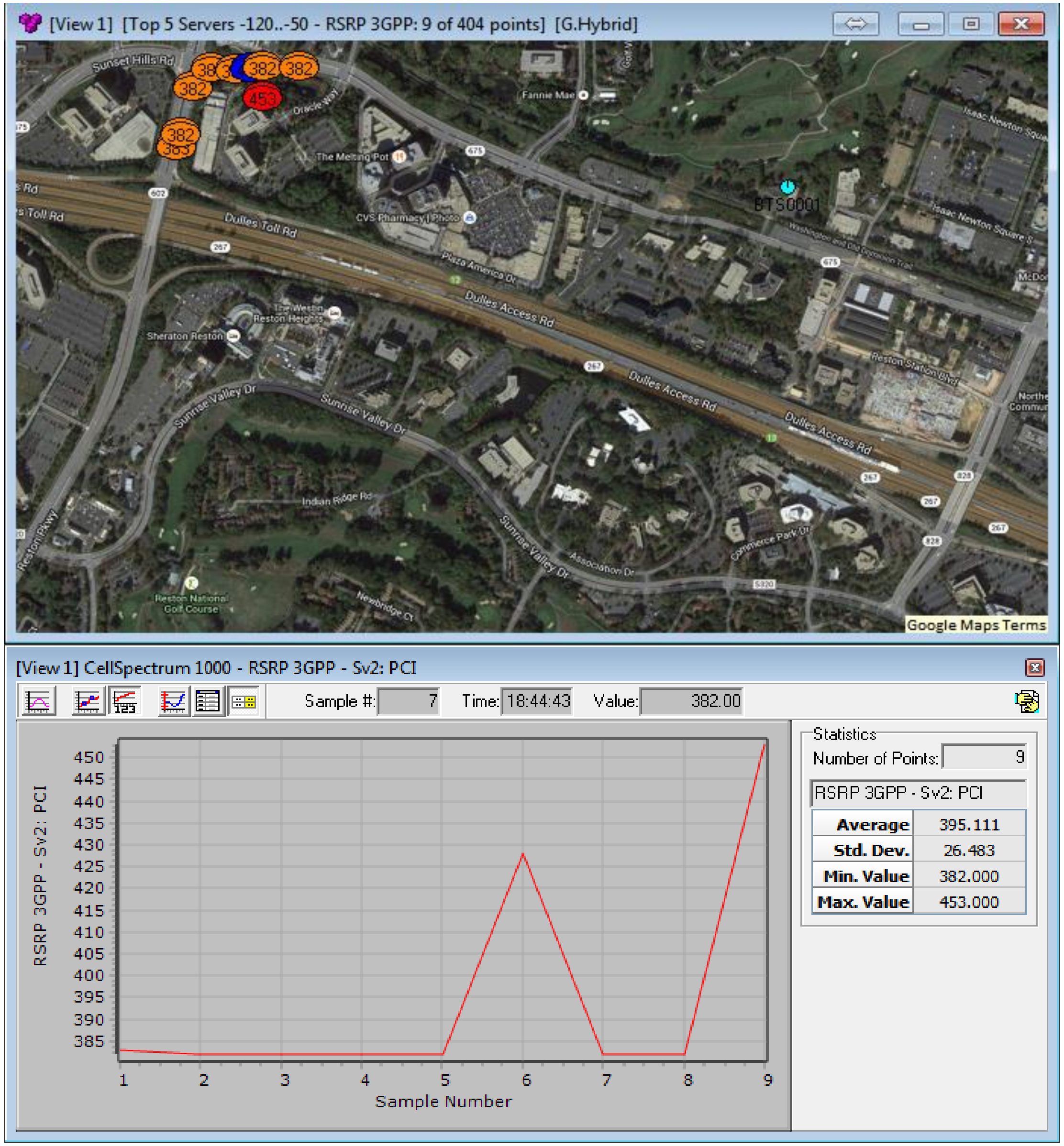
Second Server PCI



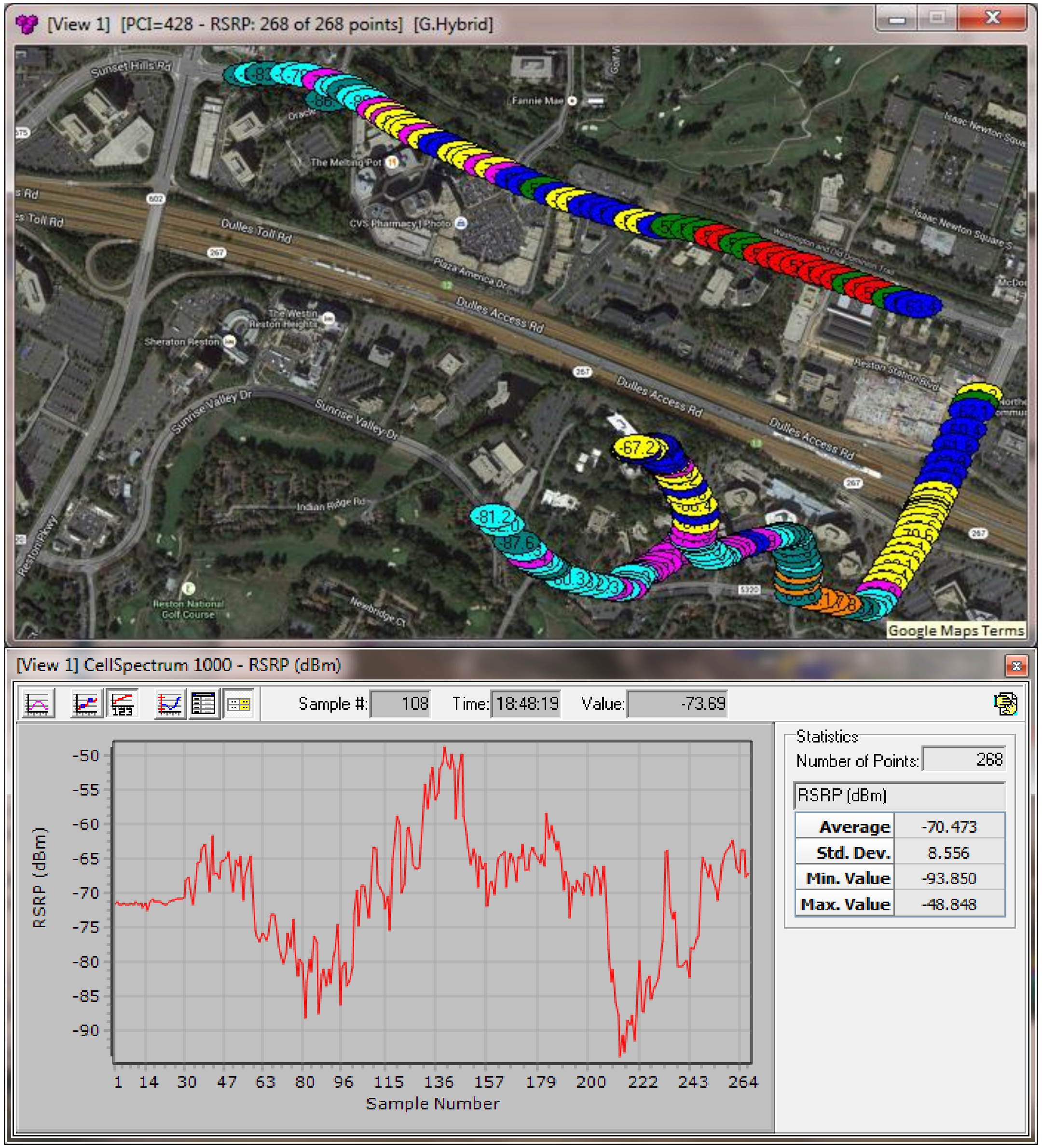
Third Server Signal Level



Third Server PCI



RSRP Signal Strength (dBm) for PCI 428



Received Signal Strength Indicator (RSSI)

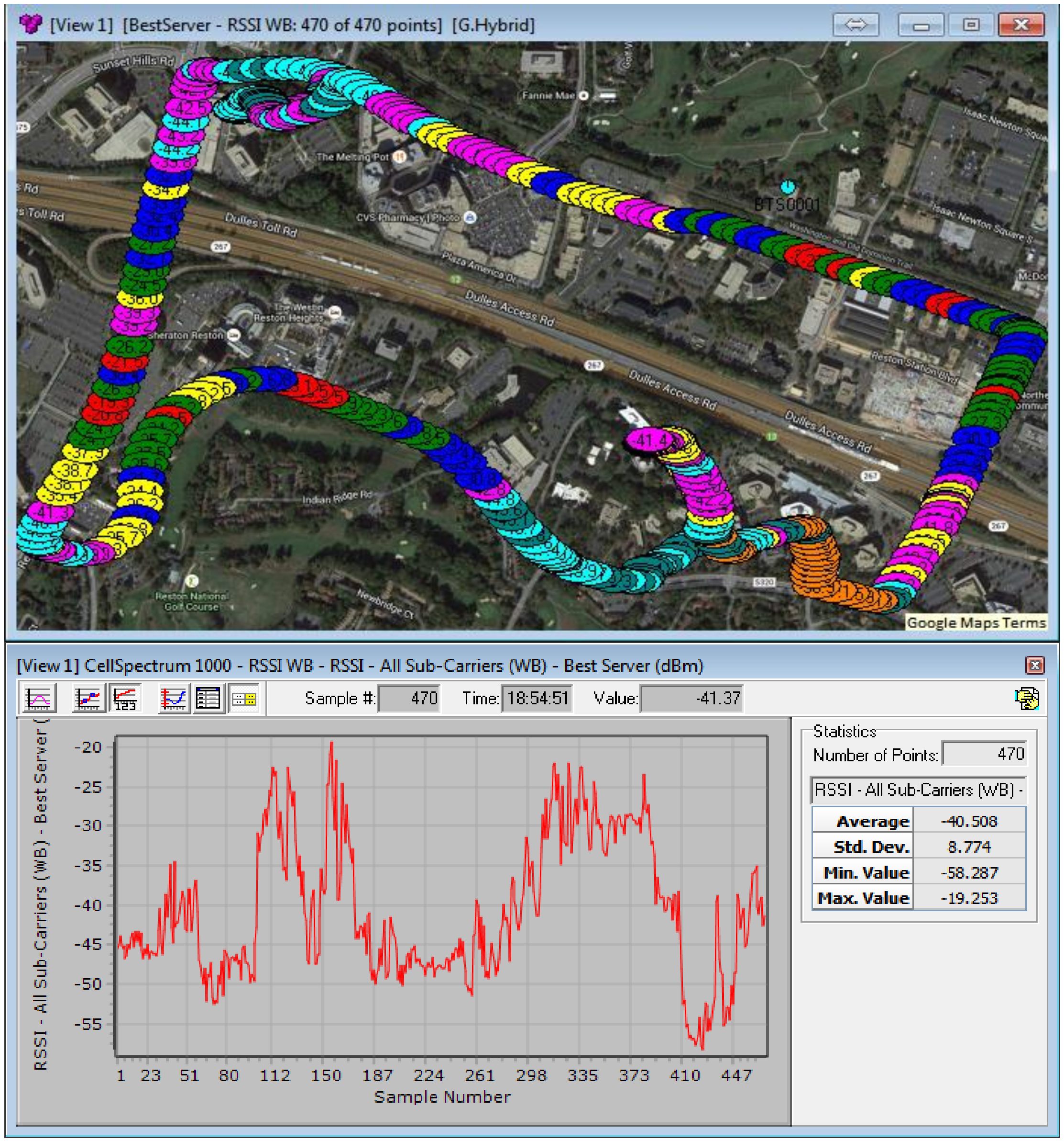
- OFDM systems are made of many subcarriers which are combined into a single temporal signal.
- The transmitted power is adjusted to provide a pre-defined power level for the CRS (Cell Reference Signal)
- This pre-defined level is called EPRE-RS (Energy Per Resource Element for the Reference Signal) and is broadcasted in SIB2 (System Information Block 2)
- An additional parameter Power Boost (P_B) is specified in SIB2, which gives the ratio between the PDSCH and CRS
  - This parameter range varies between 0 and 3 dB.
- RSSI is a measurement of the total power received and that is how it is specified by 3GPP
  - In OFDM the power is adjusted based on the CRS and the Power Boost figure. The power amplifier has to accommodate all sub-carriers.
- The table below calculates the EPRE for different bandwidth, targeting a power of 10 W at 10 MHz, assuming a Power Boost of 0 dB
  - The resulting EPRE is 12 dBm
- This power is the average power value and the Power Amplifier should be dimensioned to accommodate PAPR (Peak to Average Power Ratio) peaks
  - Generally a margin of about 10 dB is required

Bandwidth (MHz)	1.4	3	5	10	15	20
Resource Blocks (RB)	6	15	25	50	75	100
Number of Sub-Carriers	72	180	300	600	900	1200
EPRE (dBm)	12	12	12	12	12	12
Transmit power (dBm)	30.6	34.6	36.8	39.8	41.5	42.8

Received Signal Strength Indicator (RSSI)

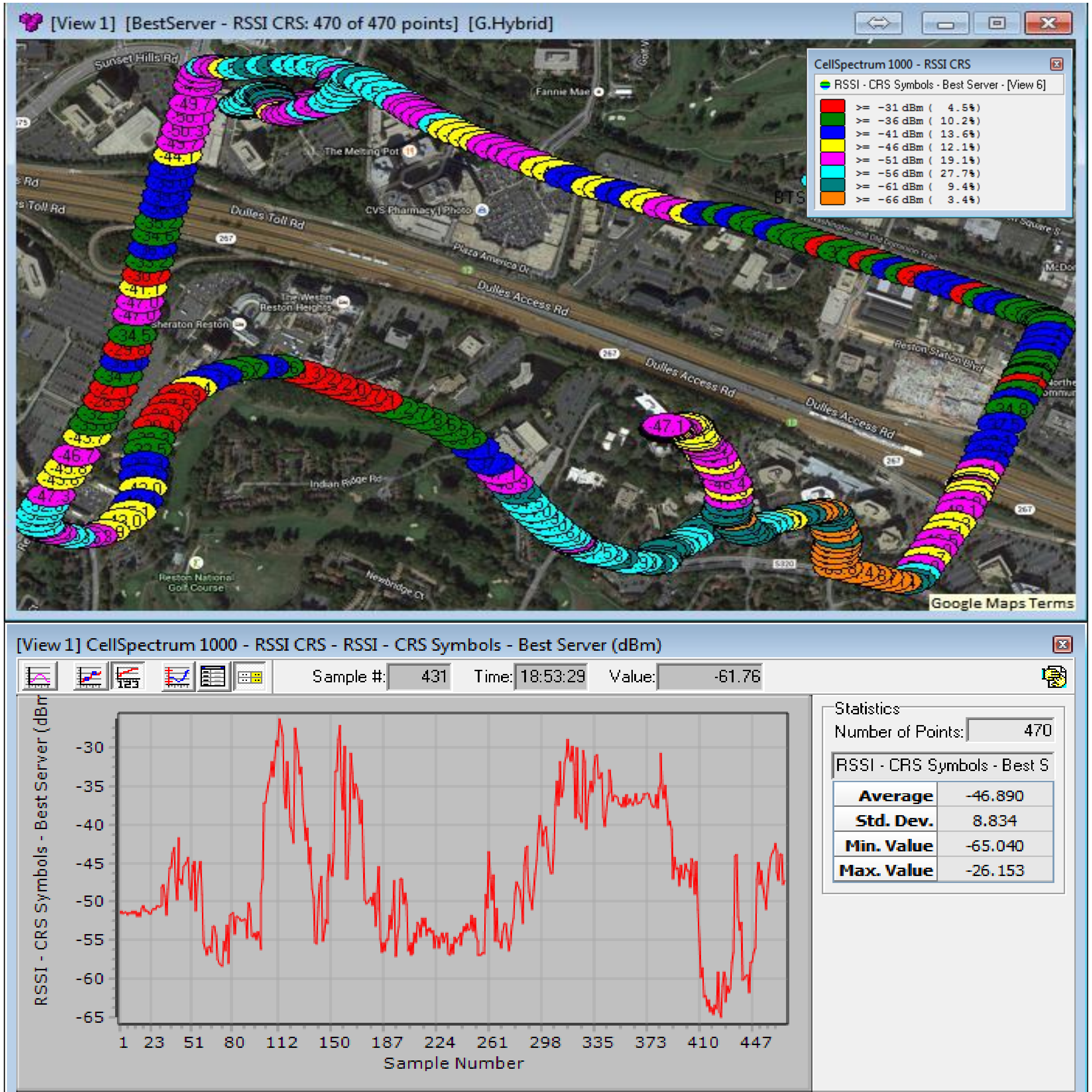
- The received signal will be attenuated by the path loss, and this will be the RSSI value
- The above calculated EPRE allows for power to all sub-carriers
  - In an OFDM system subcarriers use is traffic dependent and some subcarriers will not be transmitting power
  - So the RSSI value will vary with traffic
- According to 3GPP RSSI should be measured over all subcarriers of OFDM symbols carrying CRS at port 0, and averaged by the number of OFDM symbols measured
- The 3GPP specification implies that the RSSI measurement varies with traffic
  - The RSSI ratio with and without traffic for a single antenna system is 10.8 dB and for a two antenna system is 7.8 dB
- The 3GPP measurement is represented in CellSpectrum as a wide band measurement
  - Two other measurements are done, which are independent of traffic
  - One is measured only on RE containing RS. The difference with the RSRP measurement is that the data is not filtered by the RS pattern, so interference is also measured
  - The other measurement is done on the MIB area, as the information is always present and uses QPSK modulation

RSSI WB

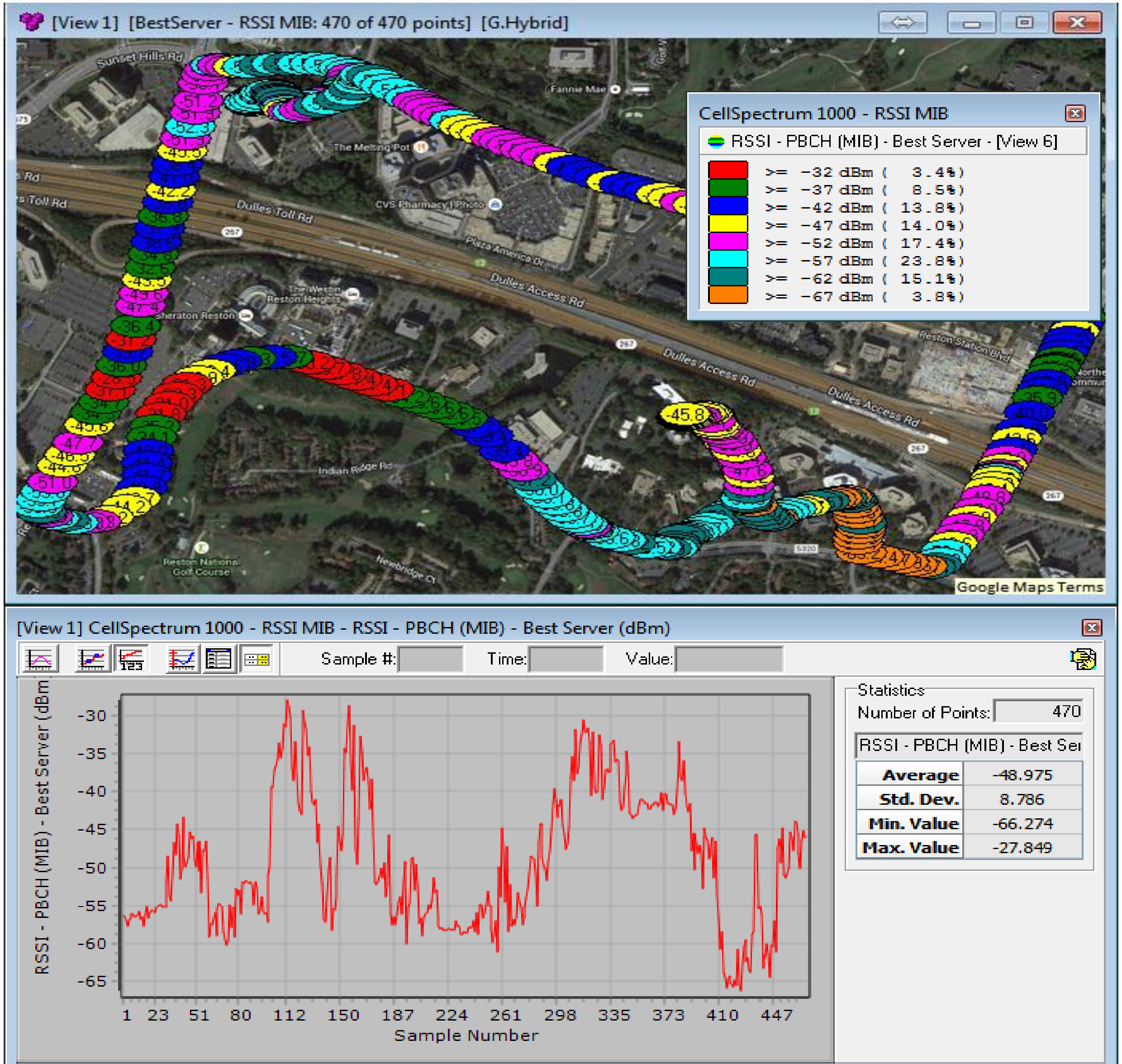


[View 1] [BestServer - RSSI WB: 470 of 470 points] [G.Hybrid]
BTS0001
Google Maps Terms
[View 1] CellSpectrum 1000 - RSSI WB - RSSI - All Sub-Carriers (WB) - Best Server (dBm)
Sample #: 470
Time: 18:54:51
Value: -41.37
RSSI - All Sub-Carriers (WB) - Best Server (
Sample Number
Statistics
Number of Points: 470
RSSI - All Sub-Carriers (WB) -
Average -40.508
Std. Dev. 8.774
Min. Value -58.287
Max. Value -19.253

RSSI CRS


[View 1] [BestServer - RSSI CRS: 470 of 470 points] [G.Hybrid]
CellSpectrum 1000 - RSSI CRS
RSSI - CRS Symbols - Best Server - [View 6]
>= -31 dBm (4.5%)
>= -36 dBm (10.2%)
>= -41 dBm (13.6%)
>= -46 dBm (12.1%)
>= -51 dBm (19.1%)
>= -56 dBm (27.7%)
>= -61 dBm (9.4%)
>= -66 dBm (3.4%)
BTS
Sunset Hills Rd
Dulles Toll Rd
Dulles Access Rd
Plaza America Dr
Indian Ridge Rd
Reston National Golf Course
Newbridge Ct
Reston Station Blvd
Google Maps Terms
[View 1] CellSpectrum 1000 - RSSI CRS - RSSI - CRS Symbols - Best Server (dBm)
Sample #: 431
Time: 18:53:29
Value: -61.76
RSSI - CRS Symbols - Best Server (dBm)
-30
-35
-40
-45
-50
-55
-60
-65
1 23 51 80 112 150 187 224 261 298 335 373 410 447
Sample Number
Statistics
Number of Points: 470
RSSI - CRS Symbols - Best S
Average -46.890
Std. Dev. 8.834
Min. Value -65.040
Max. Value -26.153

RSSI PBCH (MIB)

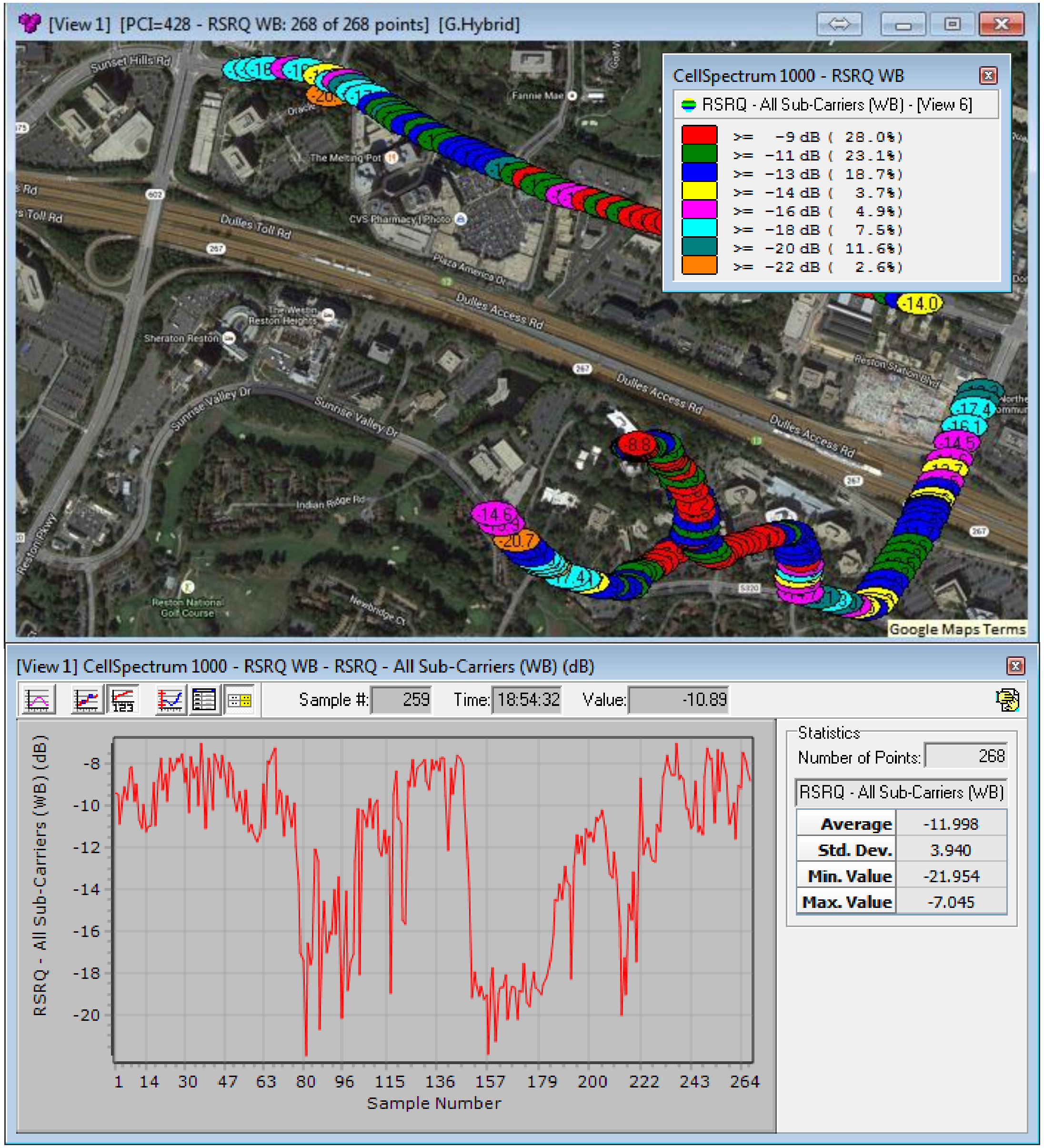


Reference Signal Received Quality (RSRQ)

- This is a 3GPP specified parameter
  - $RSRQ = Number\ of\ RB * RSRP/RSSI$
- The most common interpretation of the standard is to use wideband RSSI, although RSSI-CRS would make more sense to express RSRQ
- The maximum reportable RSRQ considers for two antennas:
  - No Traffic being transferred, only RS
  - $RSRQ = N * RSRP/2 * N * RSRP = 0.5 = -3dB$
- The minimum reportable RSRQ considers:
  - All symbols carrying traffic
  - An SNIR (Signal to Noise and Interference Ratio) of -9 dB
  - $RSRQ = N * RSRP/N * 12 * RSRP/8 = 1/96 = -19.82\ dB$
- The absolute RSRQ measurement accuracy specified by 3GPP for intra frequency is: ± 3.5 dB
- The absolute RSRQ measurement accuracy specified by 3GPP for measurements between intra and inter frequency is: ± 4 dB
- RSRP measurements are mapped onto integer values for reporting purposes. Higher the reported RSRQ value better is the signal
- UE vendors may use any different criteria to show better performance of its units
- CellSpectrum calculates three values of RSRQ, one for each type RSSI measurement

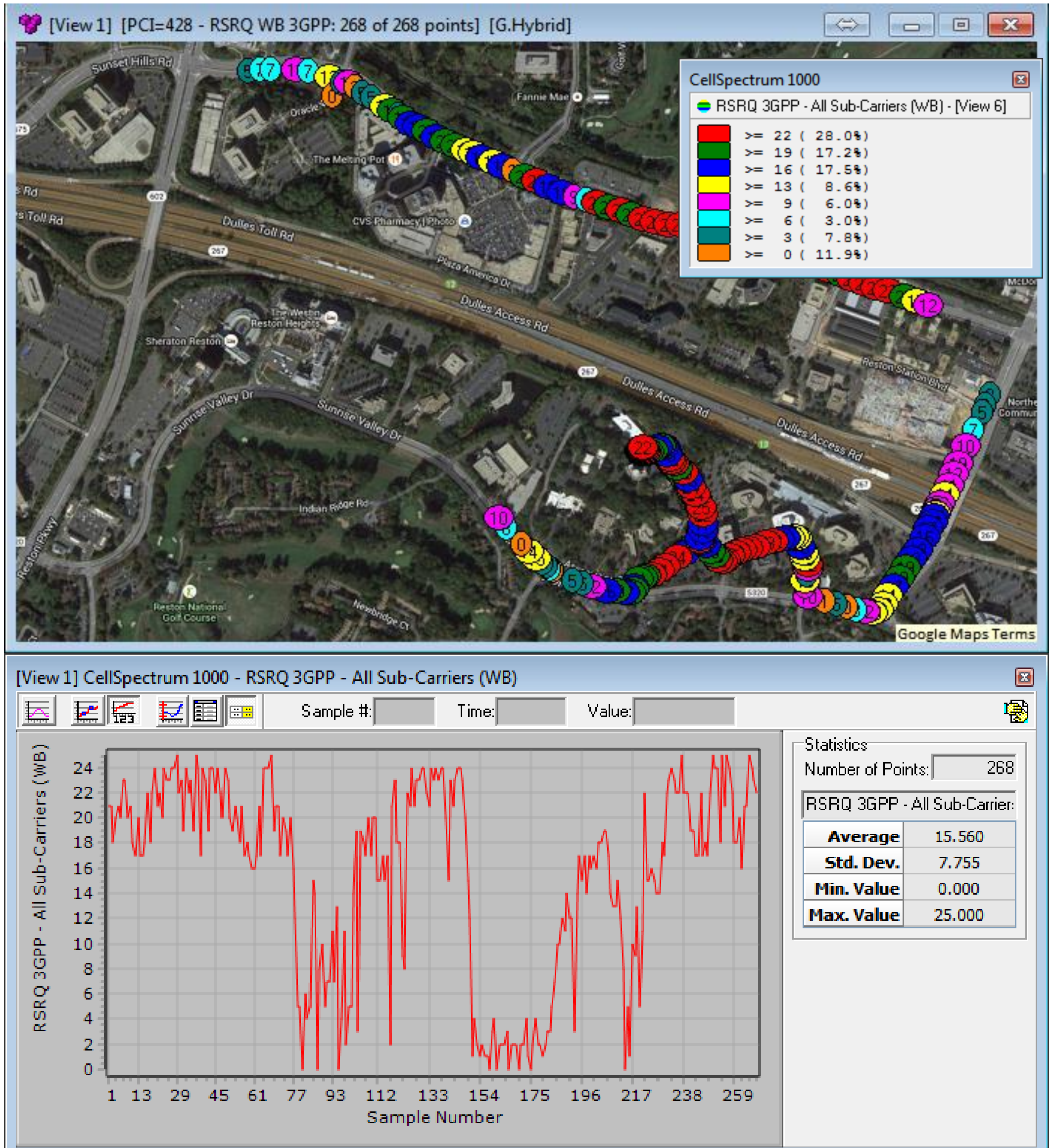
Value Reported	RSRQ (dB)
0	RSRQ ≤ -19.5
1	-19.5 ≤ RSRQ ≤ -19
2	-19 ≤ RSRQ ≤ -18.5
3	-18.5 ≤ RSRQ ≤ -18
4	-18 ≤ RSRQ ≤ -17.5
5	-17.5 ≤ RSRQ ≤ -17
6	-17 ≤ RSRQ ≤ -16.5
7	-16.5 ≤ RSRQ ≤ -16
8	-16 ≤ RSRQ ≤ -15.5
9	-15.5 ≤ RSRQ ≤ -15
10	-15 ≤ RSRQ ≤ -14.5
11	-14.5 ≤ RSRQ ≤ -14
12	-14 ≤ RSRQ ≤ -13.5
13	-13.5 ≤ RSRQ ≤ -13
14	-13 ≤ RSRQ ≤ -12.5
15	-12.5 ≤ RSRQ ≤ -12
16	-12 ≤ RSRQ ≤ -11.5
17	-11.5 ≤ RSRQ ≤ -11
18	-11 ≤ RSRQ ≤ -10.5
19	-10.5 ≤ RSRQ ≤ -10
20	-10 ≤ RSRQ ≤ -9.5
21	-9.5 ≤ RSRQ ≤ -9
22	-9 ≤ RSRQ ≤ -8.5
23	-8.5 ≤ RSRQ ≤ -8
24	-8 ≤ RSRQ ≤ -7.5
25	-7.5 ≤ RSRQ ≤ -7
26	-7 ≤ RSRQ ≤ -6.5
27	-6.5 ≤ RSRQ ≤ -6
28	-6 ≤ RSRQ ≤ -5.5
29	-5.5 ≤ RSRQ ≤ -5
30	-5 ≤ RSRQ ≤ -4.5
31	-4.5 ≤ RSRQ ≤ -4
32	-4 ≤ RSRQ ≤ -3.5
33	-3.5 ≤ RSRQ ≤ -3
34	-3 ≤ RSRQ

RSRQ WB

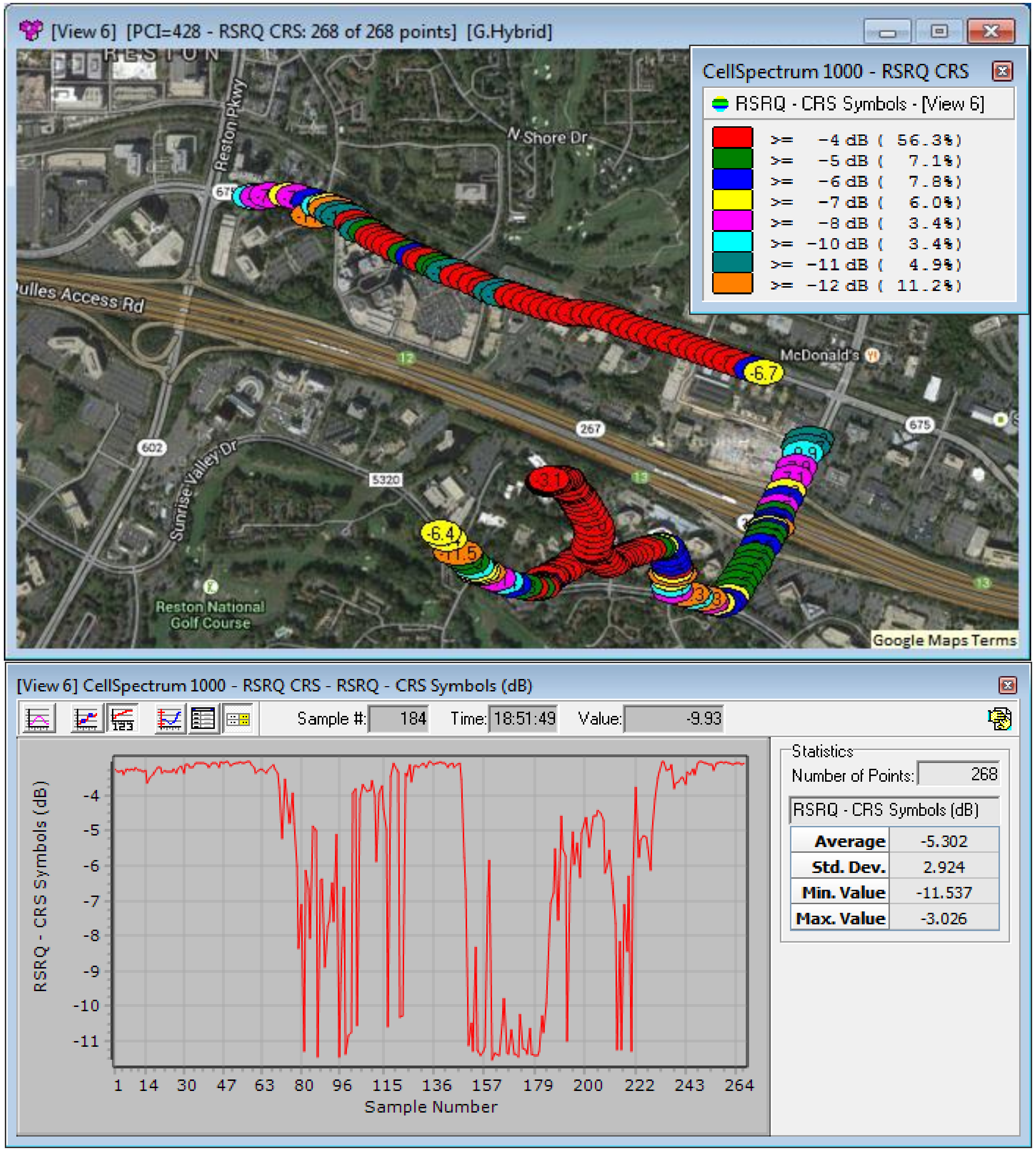


[View 1] [PCI=428 - RSRQ WB: 268 of 268 points] [G.Hybrid]
CellSpectrum 1000 - RSRQ WB
RSRQ - All Sub-Carriers (WB) - [View 6]
>= -9 dB (28.0%)
>= -11 dB (23.1%)
>= -13 dB (18.7%)
>= -14 dB (3.7%)
>= -16 dB (4.9%)
>= -18 dB (7.5%)
>= -20 dB (11.6%)
>= -22 dB (2.6%)
Dulles Toll Rd
Dulles Access Rd
Sunrise Valley Dr
Google Maps Terms
[View 1] CellSpectrum 1000 - RSRQ WB - RSRQ - All Sub-Carriers (WB) (dB)
Sample #: 259
Time: 18:54:32
Value: -10.89
RSRQ - All Sub-Carriers (WB) (dB)
-8
-10
-12
-14
-16
-18
-20
1 14 30 47 63 80 96 115 136 157 179 200 222 243 264
Sample Number
Statistics
Number of Points: 268
RSRQ - All Sub-Carriers (WB)
Average -11.998
Std. Dev. 3.940
Min. Value -21.954
Max. Value -7.045

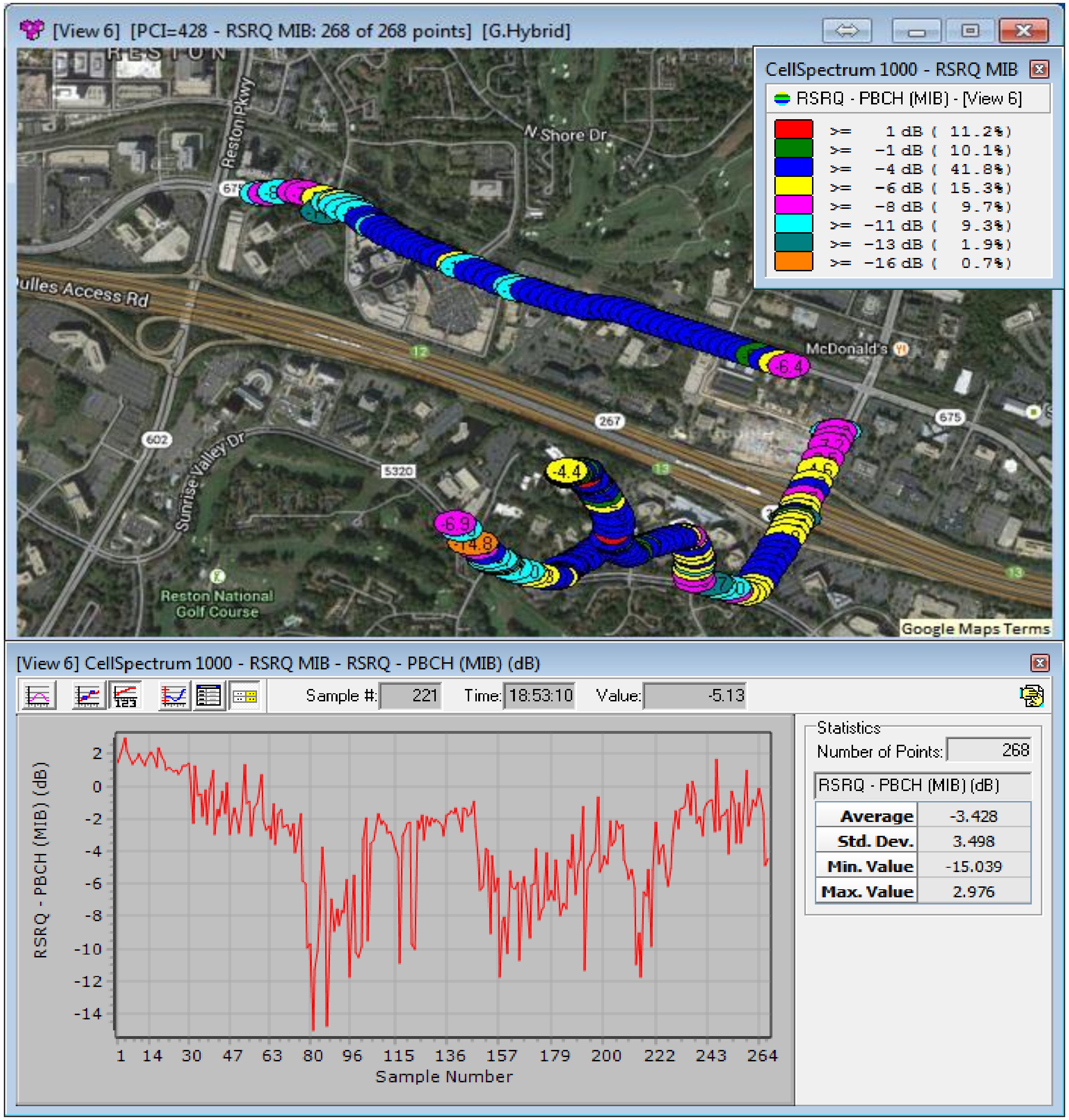
RSRQ WB 3GPP


[View 1] [PCI=428 - RSRQ WB 3GPP: 268 of 268 points] [G.Hybrid]
CellSpectrum 1000
RSRQ 3GPP - All Sub-Carriers (WB) - [View 6]
>= 22 (28.0%)
>= 19 (17.2%)
>= 16 (17.5%)
>= 13 (8.6%)
>= 9 (6.0%)
>= 6 (3.0%)
>= 3 (7.8%)
>= 0 (11.9%)
Dulles Toll Rd
Dulles Access Rd
Sunrise Valley Dr
Google Maps Terms
[View 1] CellSpectrum 1000 - RSRQ 3GPP - All Sub-Carriers (WB)
Sample #:
Time:
Value:
RSRQ 3GPP - All Sub-Carriers (WB)
Sample Number
Statistics
Number of Points: 268
RSRQ 3GPP - All Sub-Carrier
Average 15.560
Std. Dev. 7.755
Min. Value 0.000
Max. Value 25.000

RSRQ CRS


[View 6] [PCI=428 - RSRQ CRS: 268 of 268 points] [G.Hybrid]
CellSpectrum 1000 - RSRQ CRS
RSRQ - CRS Symbols - [View 6]
>= -4 dB (56.3%)
>= -5 dB (7.1%)
>= -6 dB (7.8%)
>= -7 dB (6.0%)
>= -8 dB (3.4%)
>= -10 dB (3.4%)
>= -11 dB (4.9%)
>= -12 dB (11.2%)
Reston Pkwy
N Shore Dr
Dulles Access Rd
McDonald's
Sunrise Valley Dr
Reston National Golf Course
Google Maps Terms
[View 6] CellSpectrum 1000 - RSRQ CRS - RSRQ - CRS Symbols (dB)
Sample #: 184
Time: 18:51:49
Value: -9.93
Statistics
Number of Points: 268
RSRQ - CRS Symbols (dB)
Average -5.302
Std. Dev. 2.924
Min. Value -11.537
Max. Value -3.026
RSRQ - CRS Symbols (dB)
Sample Number

RSRQ MIB



[View 6] [PCI=428 - RSRQ MIB: 268 of 268 points] [G.Hybrid]
CellSpectrum 1000 - RSRQ MIB
RSRQ - PBCH (MIB) - [View 6]
>= 1 dB (11.2%)
>= -1 dB (10.1%)
>= -4 dB (41.8%)
>= -6 dB (15.3%)
>= -8 dB (9.7%)
>= -11 dB (9.3%)
>= -13 dB (1.9%)
>= -16 dB (0.7%)
[View 6] CellSpectrum 1000 - RSRQ MIB - RSRQ - PBCH (MIB) (dB)
Sample #: 221
Time: 18:53:10
Value: -5.13
RSRQ - PBCH (MIB) (dB)
Sample Number
Statistics
Number of Points: 268
RSRQ - PBCH (MIB) (dB)
Average -3.428
Std. Dev. 3.498
Min. Value -15.039
Max. Value 2.976

Comparing RSRP, RSSI and RSRQ

- The next table compares the results for the best servers of the drive test route
- RSRP and RSSI values are normalized for an average EPRE (Energy Per Resource Element)

	Average (dBm)	Std. (dB)	3GPP	3GPP Std.	Subcarriers	EPRE
RSRP	-68.1	9.7	72.5	9.7	1	-68.1
RSSI WB	-40.5	8.7	15.56	7.75	600	-68.3
RSSI CRS	-46.9	8.8			100	-66.9
RSSI MIB	-48.9	8.7			72	-67.5

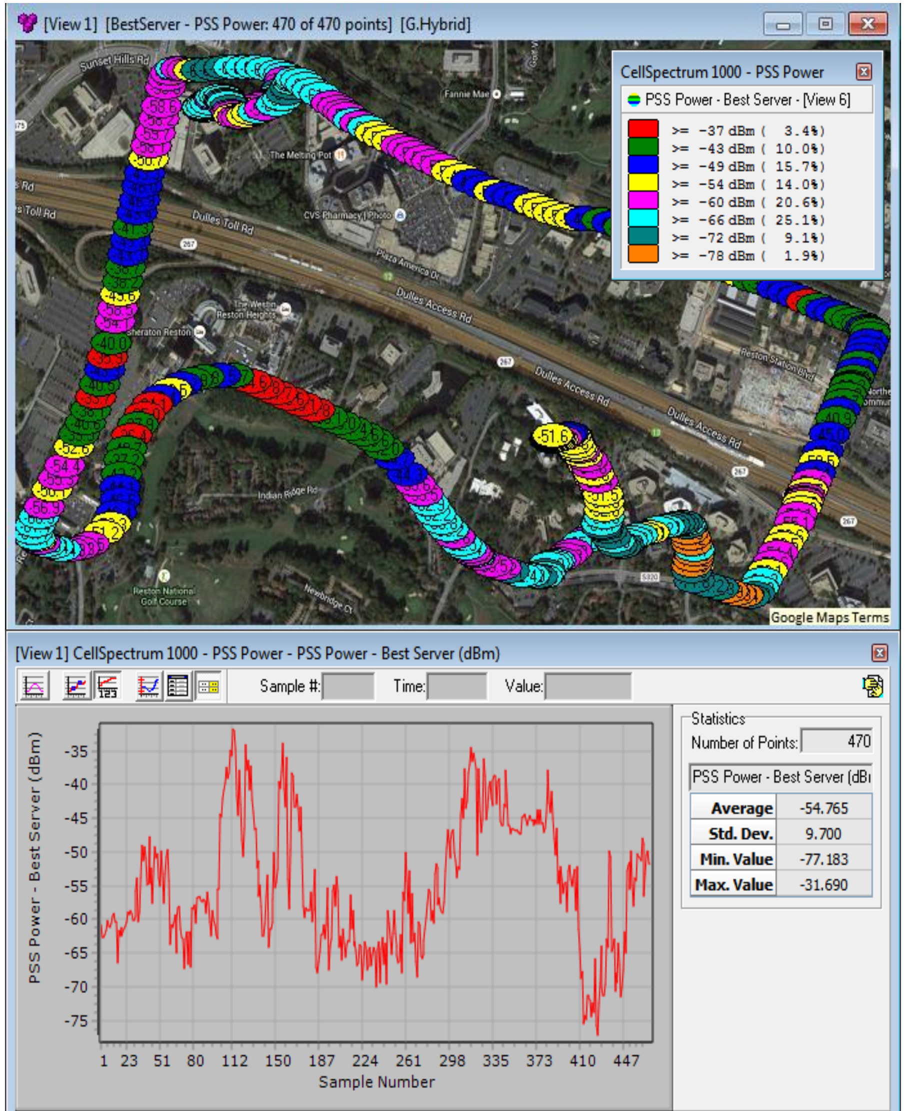
- Comparing RSRP and RSSI CRS we get a deterioration of 1.2 dB. This means that there is an average noise rise due to interference of 1.2 dB.
- RSSI MIB shows a noise rise of 0.6 dB, indicating less interference on the MIB.
- RSSI WB has lower EPRE, as some subcarriers were not transmitting traffic, so it is a measurement of low value.
- RSRQ values vary much depending on the RSSI criteria. The most consistent criteria is to use RSRQ CRS or RSRQ MIB. The table below shows the average values over the drive test route for the best server.

	Average (dBm)	Std. (dB)	3GPP	3GPP Std.
RSRQ WB	-12.0	3.9	15.6	7.7
RSRQ CRS	-5.3	2.9	28.8	5.7
RSRQ MIB	-3.4	3.5	30.6	5.1

- The above analysis can be done on a cell by cell basis

PSS Power

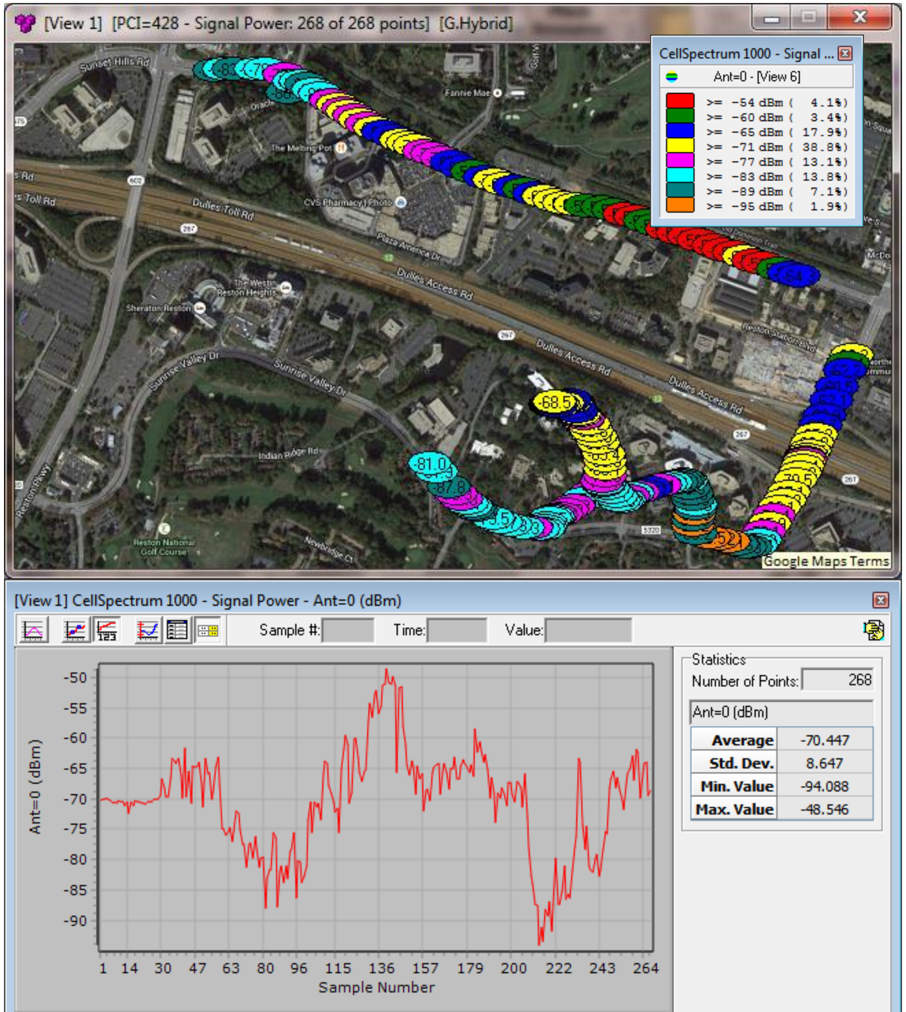
- This measurement indicated the peak of the PSS power
- This signal is measured over the PSS 62 symbols

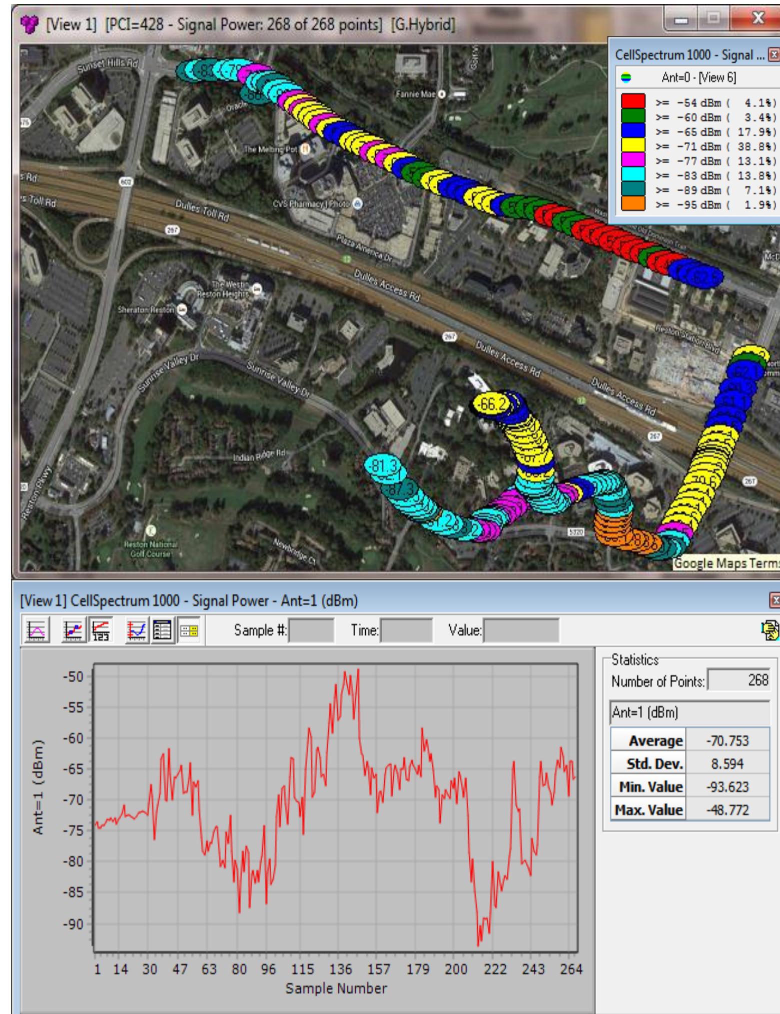


Signal Power

CelPlan
Wireless Solutions & Consulting

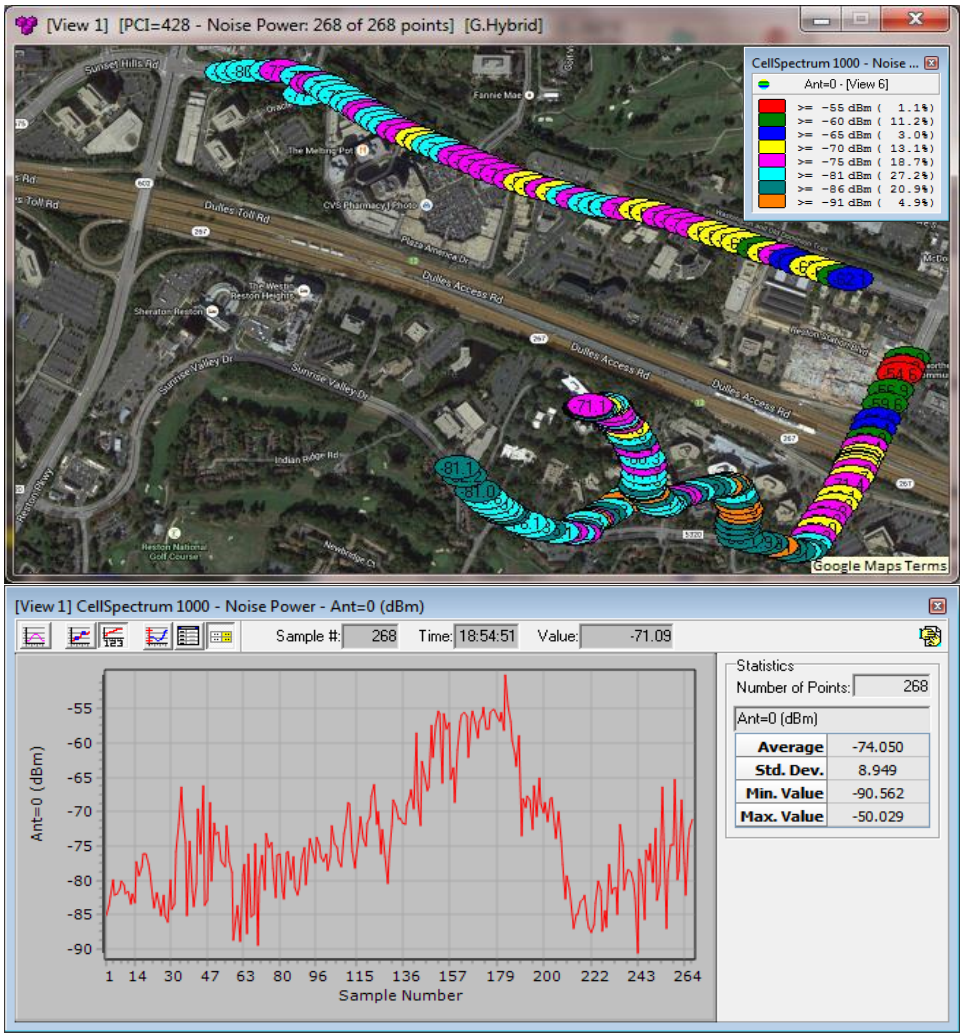
- Signal power is measured over Reference Signals, averaged by their neighbors (Channel Estimate Smooth- CESMOOTH)
- A measurement is made for each antenna
- Signal power is given per EPRE

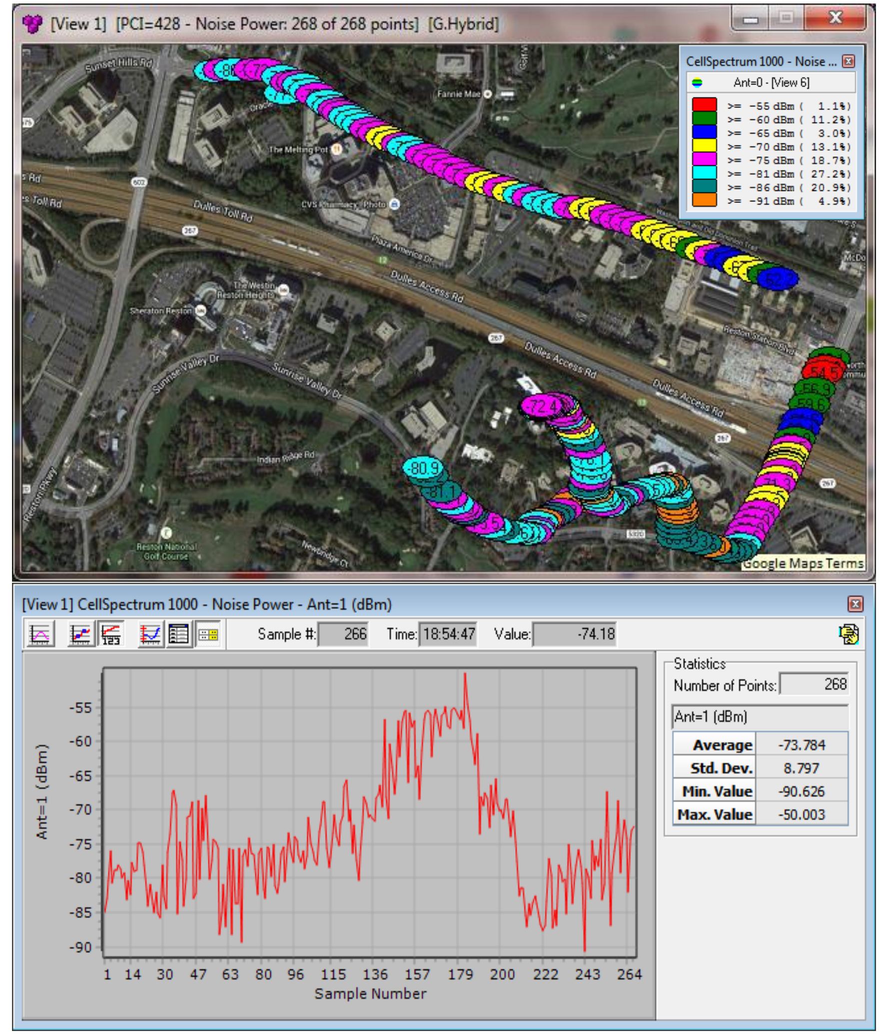




Noise Power

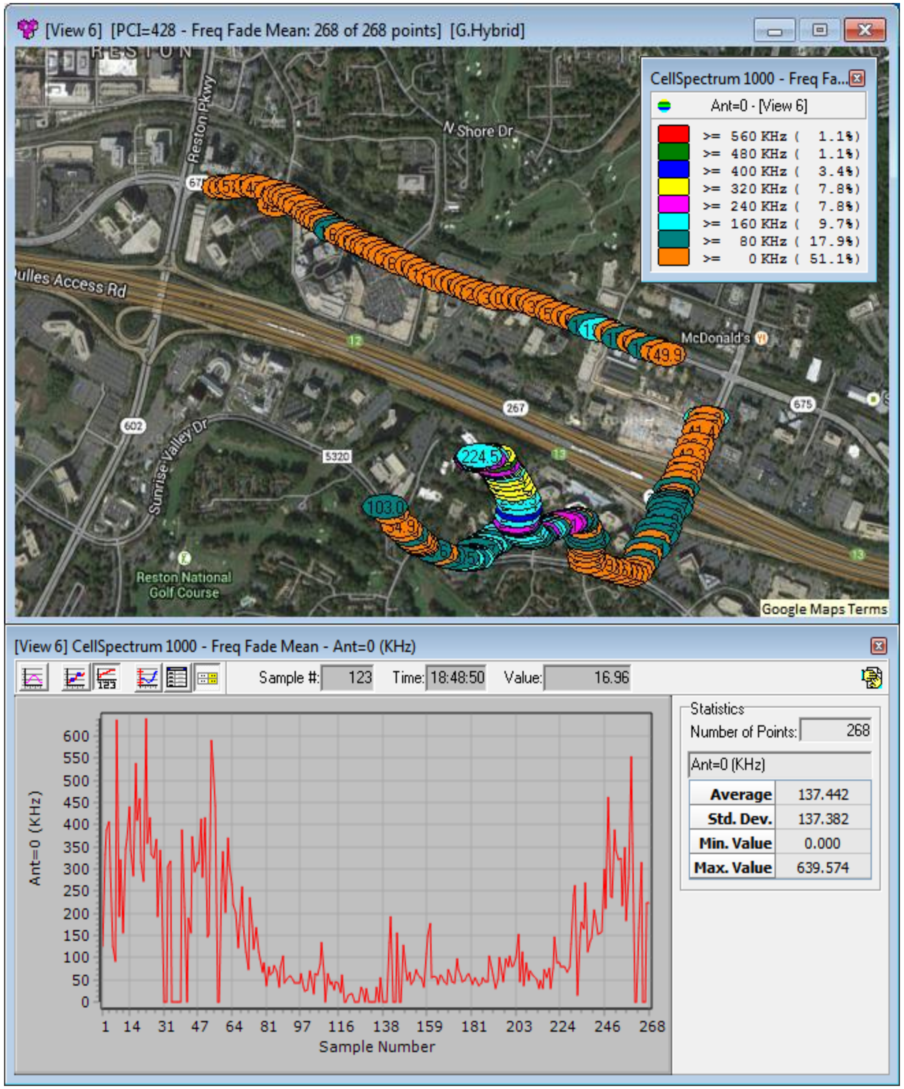
- Noise Power is calculated over CE Comp
- Noise power is given per EPRE

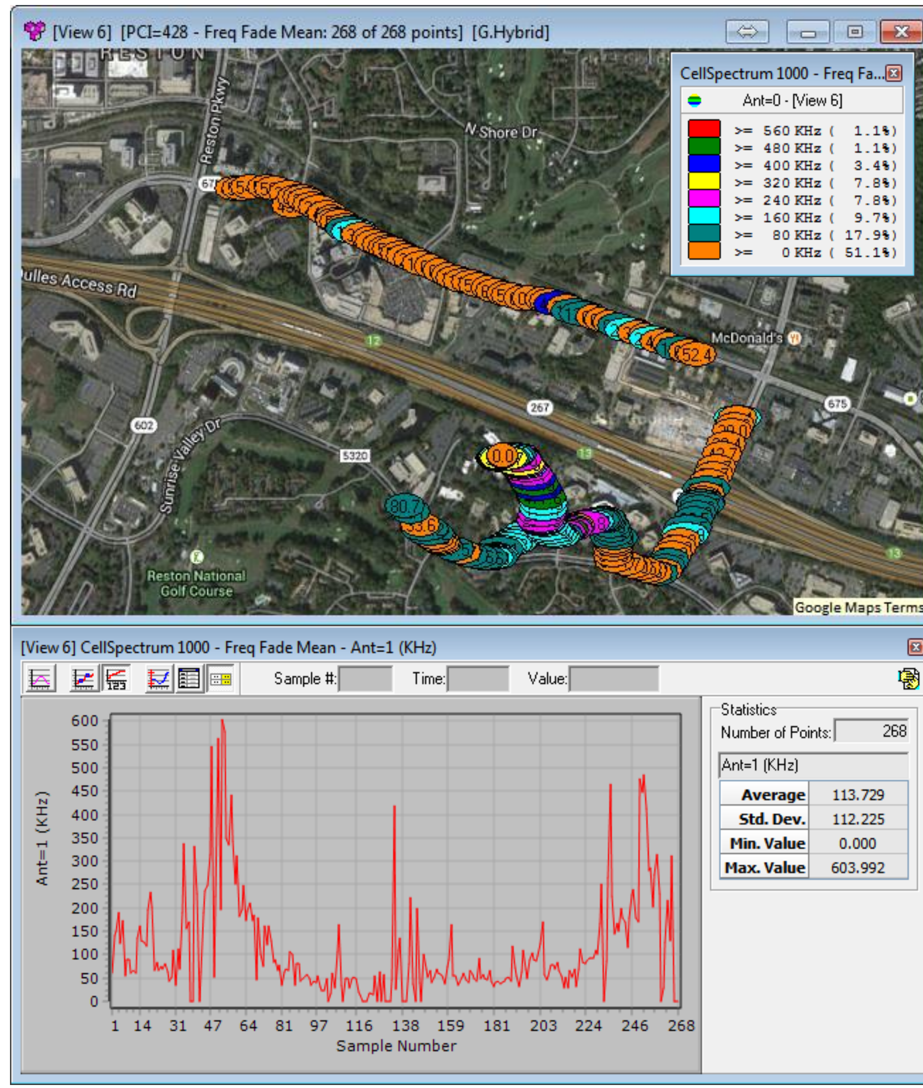




Frequency Fade

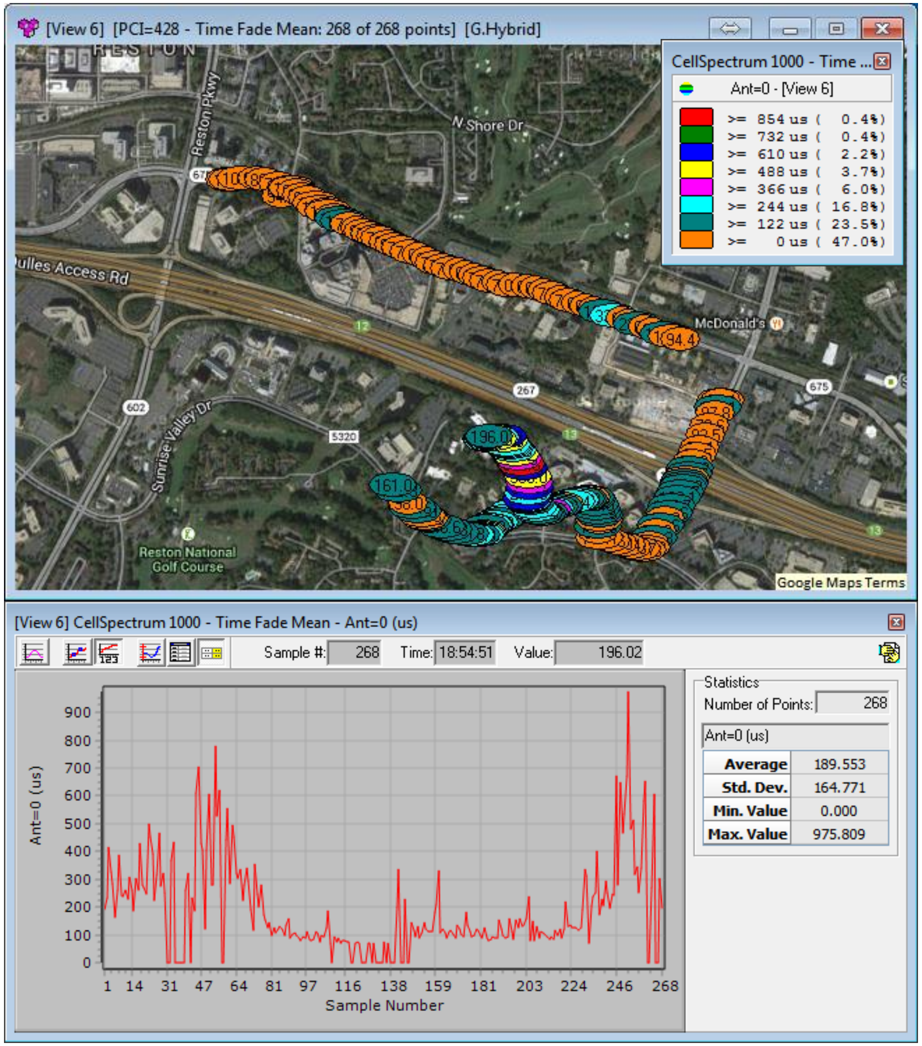
- This parameter indicates what the frequency fading characteristics along the cell area are

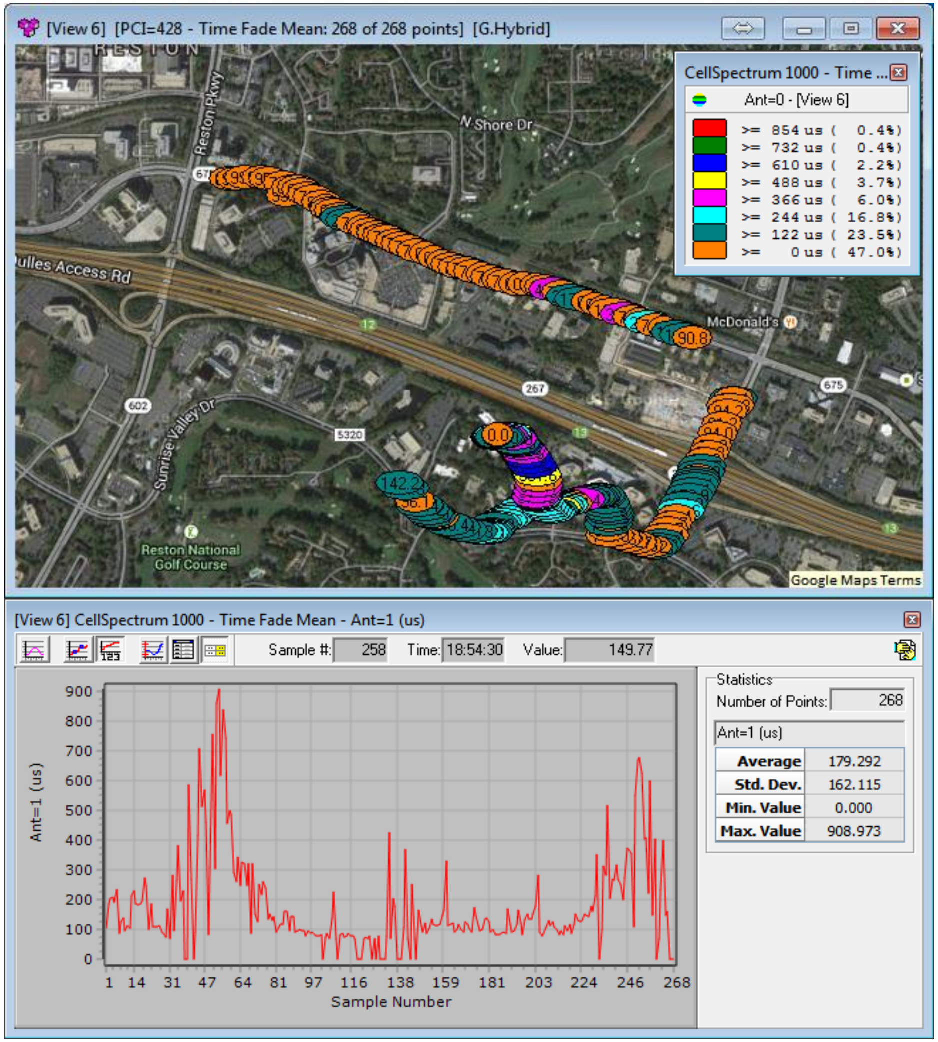




Time Fade

- This parameter indicates what the time fading characteristics along the cell area are



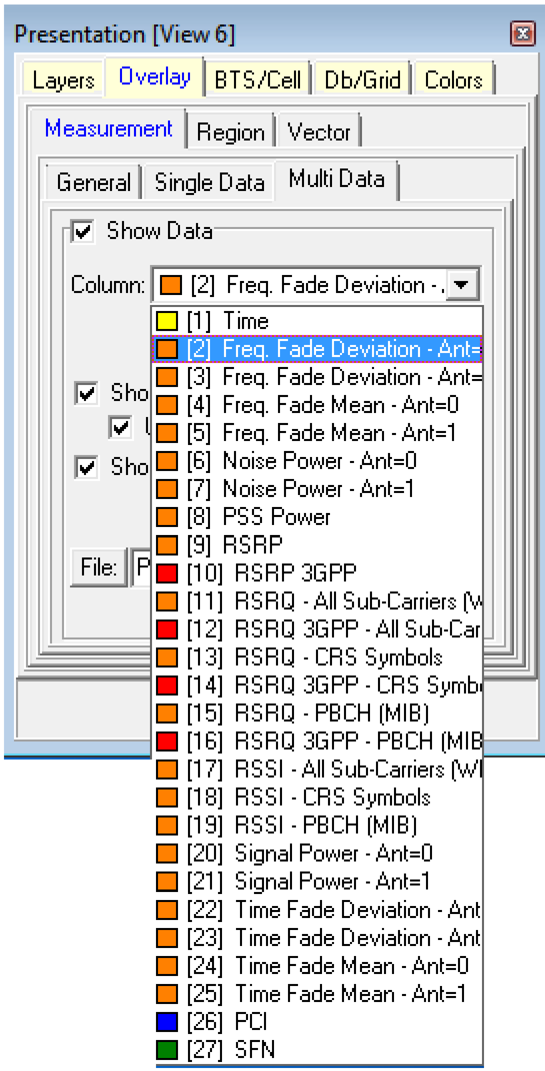


Combine all 1 D Parameters

- A summary of all 1D parameters can be displayed or exported to a table

[CellSpectrum Multi-Data Measurements v1.0-00]												
nRecords	236											
Rec #	Time	Lat	Long	Freq. Fade Deviation - Ant=0 (KHz)	Freq. Fade Deviation - Ant=1 (KHz)	Freq. Fade Mean - Ant=0 (KHz)	Freq. Fade Mean - Ant=1 (KHz)	Noise Power - Ant=0 (dBm)	Noise Power - Ant=1 (dBm)	PSS Power (dBm)	RSRP (dBm)	RSRP 3GPP
1	18:52:47	38.944887	-77.339473	58.6	81.2	61.2	84.4	-79.4	-81.4	-69.4	-81.2	59
2	18:52:50	38.944913	-77.339645	50.4	60.1	57.2	67.7	-81.1	-81.5	-75.4	-85.9	55
3	18:52:45	38.944939	-77.339321	71.4	70	71.4	70.7	-82.7	-82.5	-70	-83	58
4	18:52:52	38.944962	-77.33984	46.4	46.9	52.9	53.6	-84.9	-85.4	-74.3	-87.8	53
5	18:52:54	38.945017	-77.340068	23.3	23.5	30.6	29.5	-87.1	-87	-79.3	-93.8	47
6	18:52:43	38.945058	-77.33921	45.2	101.3	49.9	79.4	-77.6	-77.6	-64.6	-78.3	62
7	18:52:56	38.945071	-77.340327	42	43	48.8	52	-84.9	-83.6	-78.8	-90.7	50
8	18:52:58	38.945119	-77.340607	23.8	26	29.9	29.7	-84.9	-85.3	-76	-93.1	47
9	18:53:02	38.945192	-77.340992	62.3	57.5	72.6	65.1	-83.1	-83.4	-74.3	-88.6	52
10	18:52:41	38.945216	-77.339102	96	97.4	89	78.6	-74.3	-74.6	-62.2	-72.8	68
11	18:40:42	38.945281	-77.34527	130.2	176.7	118.3	162.3	-75.2	-76.4	-66.7	-78.1	62

RSRQ - All Sub-Carriers (WB) (dB)	RSRQ 3GPP - All Sub-Carriers (WB)	RSRQ - CRS Symbols (dB)	RSRQ 3GPP - CRS Symbols	RSRQ - PBCH (MIB) (dB)	RSRQ 3GPP - PBCH (MIB)	RSSI - All Sub-Carriers (WB) (dBm)	RSSI - CRS Symbols (dBm)	RSSI - PBCH (MIB) (dBm)	Signal Power - Ant=0 (dBm)	Signal Power - Ant=1 (dBm)	Time Fade Deviation - Ant=0 (us)	Time Fade Deviation - Ant=1 (us)	Time Fade Mean - Ant=0 (us)	Time Fade Mean - Ant=1 (us)	PCI	SFN
-12.2	15	-5.5	28	-5.8	28	-52	-58.6	-58.4	-84.1	-79.5	72.9	103.5	106.6	126.8	428	619
-13.5	12	-6.5	27	-5.1	29	-55.3	-62.4	-63.7	-87.3	-84.7	60.2	81.5	100.7	110.2	428	828
-13.5	13	-5.9	28	-5.1	29	-52.5	-60.1	-60.8	-82.7	-83.2	82.5	93.7	112.9	115.2	428	415
-15.7	8	-7.6	24	-6.3	27	-55.1	-63.2	-64.6	-87.6	-88	50.4	61.3	94.8	98.5	428	13
-20	0	-11.3	17	-11	18	-56.9	-65.6	-65.9	-94.1	-93.6	32.8	30.8	83.4	82.7	428	216
-13.3	13	-6.2	27	-4.5	30	-48	-55.1	-56.8	-78.2	-78.4	45.7	128.6	88.7	129	428	210
-17.3	5	-8.2	23	-9	21	-56.5	-65.6	-64.7	-91.2	-90.3	49.1	49.2	93	96.2	428	438
-19.1	1	-11.3	17	-11.7	16	-57.1	-64.9	-64.4	-93.5	-92.8	32.4	35	83.6	84.6	428	648
-14.7	10	-7.1	25	-6.5	27	-56.9	-64.5	-65.2	-88.2	-89.1	79.3	76.2	117.1	113	428	38
-12.6	14	-4.7	30	-2.4	34	-43.2	-51.1	-53.4	-73.1	-72.5	104.8	81.6	130.3	110.4	428	4



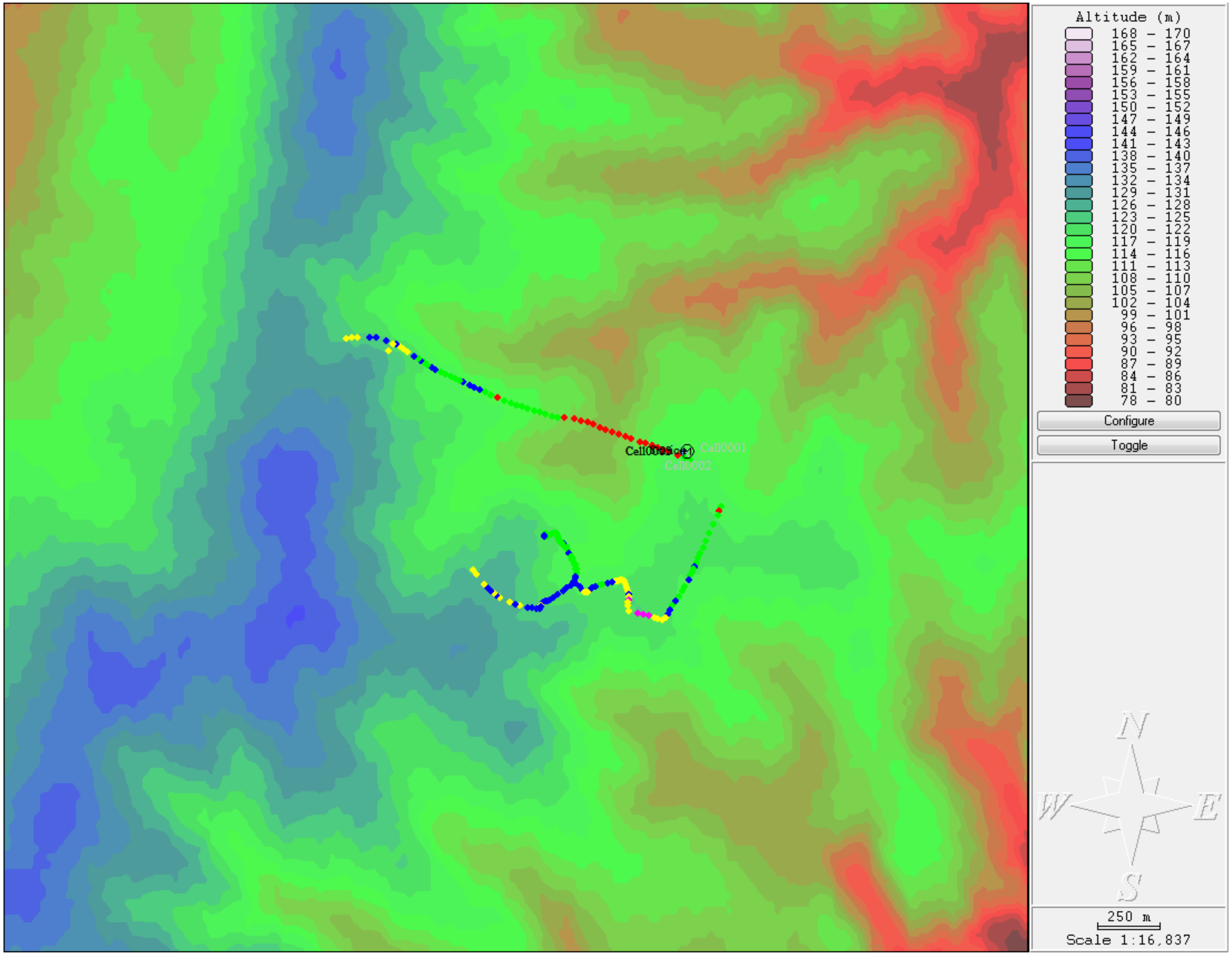
Combine all 1 D Parameters

Parameter	Average (dBm)	Std. (dB)	EPRE (dBm)
PSS power	-54.7	9.7	-72.6
Signal power ant 0	-70.4	8.6	-70.4
Signal power ant 1	-70.7	8.6	-70.7
Noise Power ant 0	-74.0	8.9	-74.0
Noise Power ant 1	-73.7	8.7	-73.7
	Average (Hz)	Std. (Hz)	
Frequency Fade mean ant 0	137.0	137.0	
Frequency Fade mean ant 1	113.7	112.2	
Frequency Std. ant 0	137.0	128.0	
Frequency Std. ant 1	108.0	109.0	
	Average (µs)	Std. (µs	
Time fade mean ant 0	189.0	164.0	
Time fade mean ant 1	179.0	162.0	
Time fade deviation ant 0	222.0	239.0	
Time fade deviation ant 1	183.0	209.0	

8. Calibrating Propagation Model

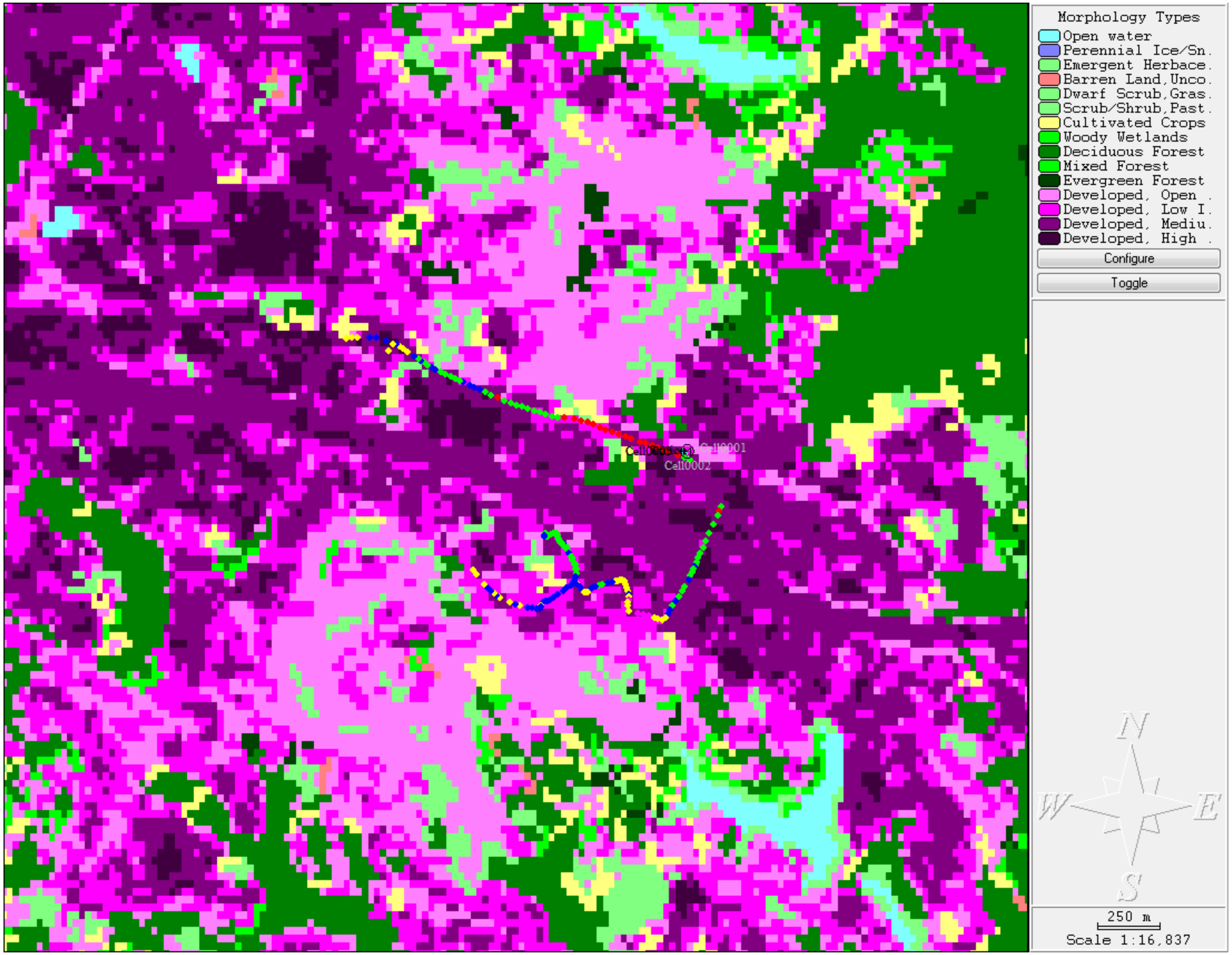
Topography Data Base

- The topography data base used had a resolution of 30 m

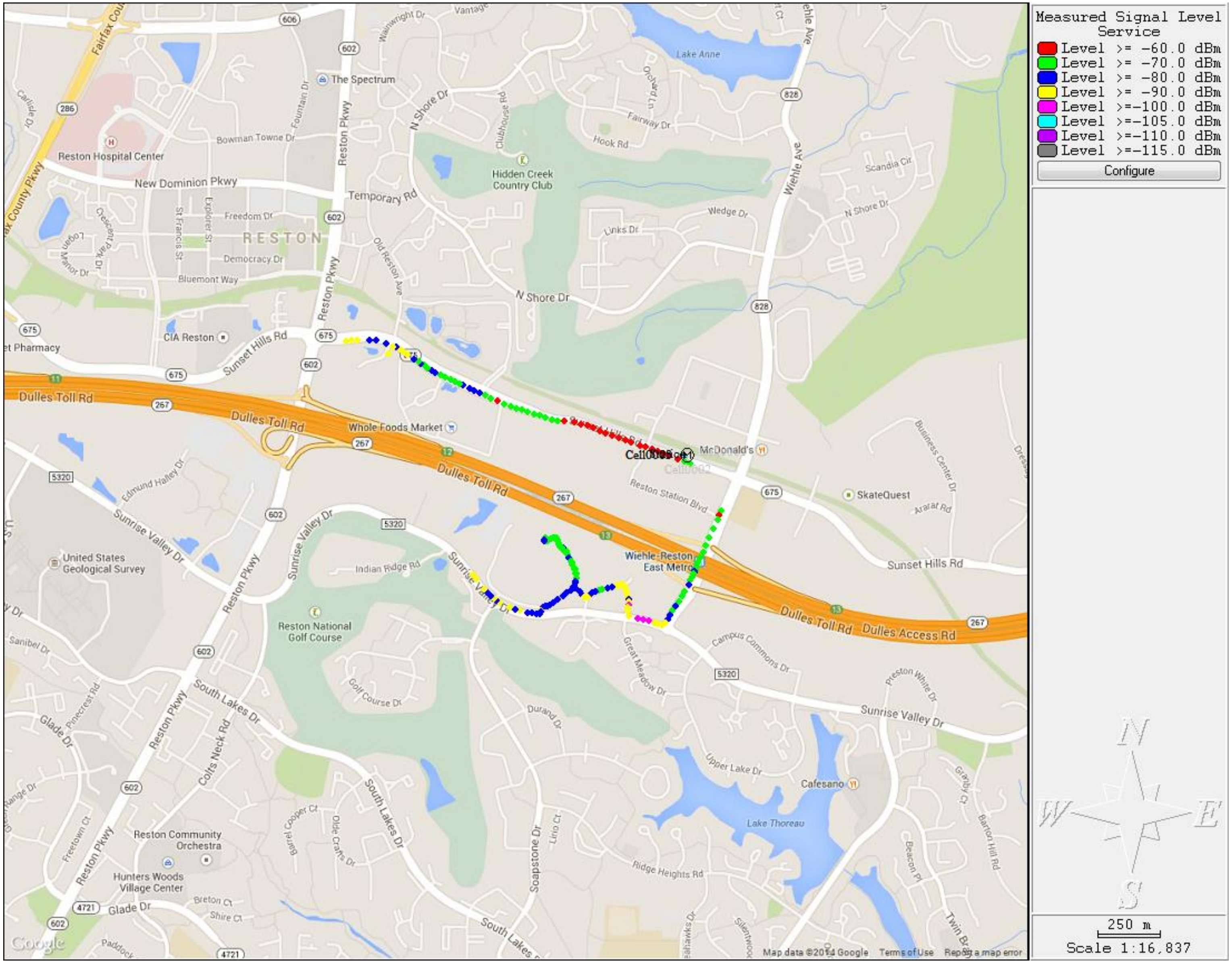


Morphology Data Base

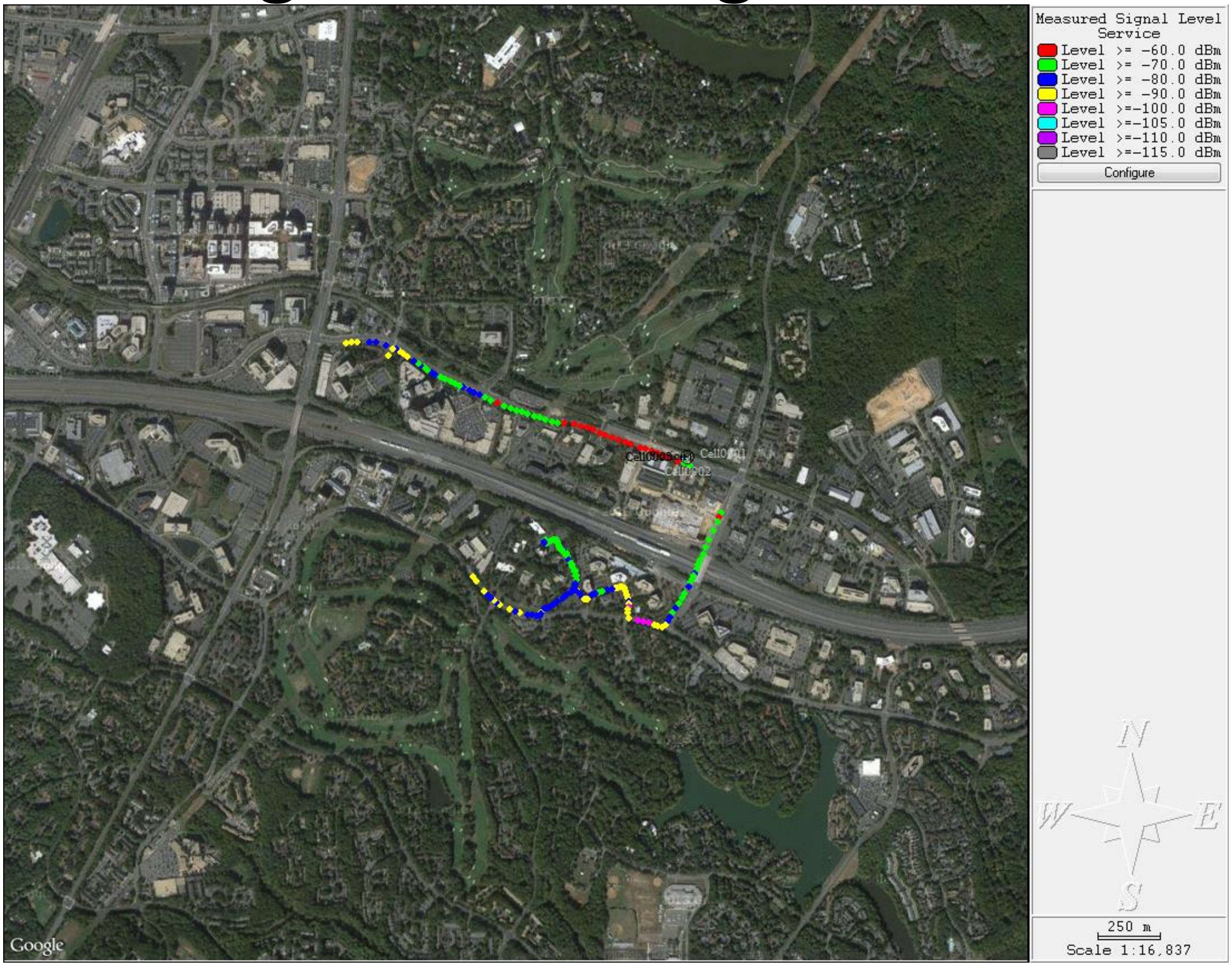
• The morphology data base used had a resolution of 30 m



Map image

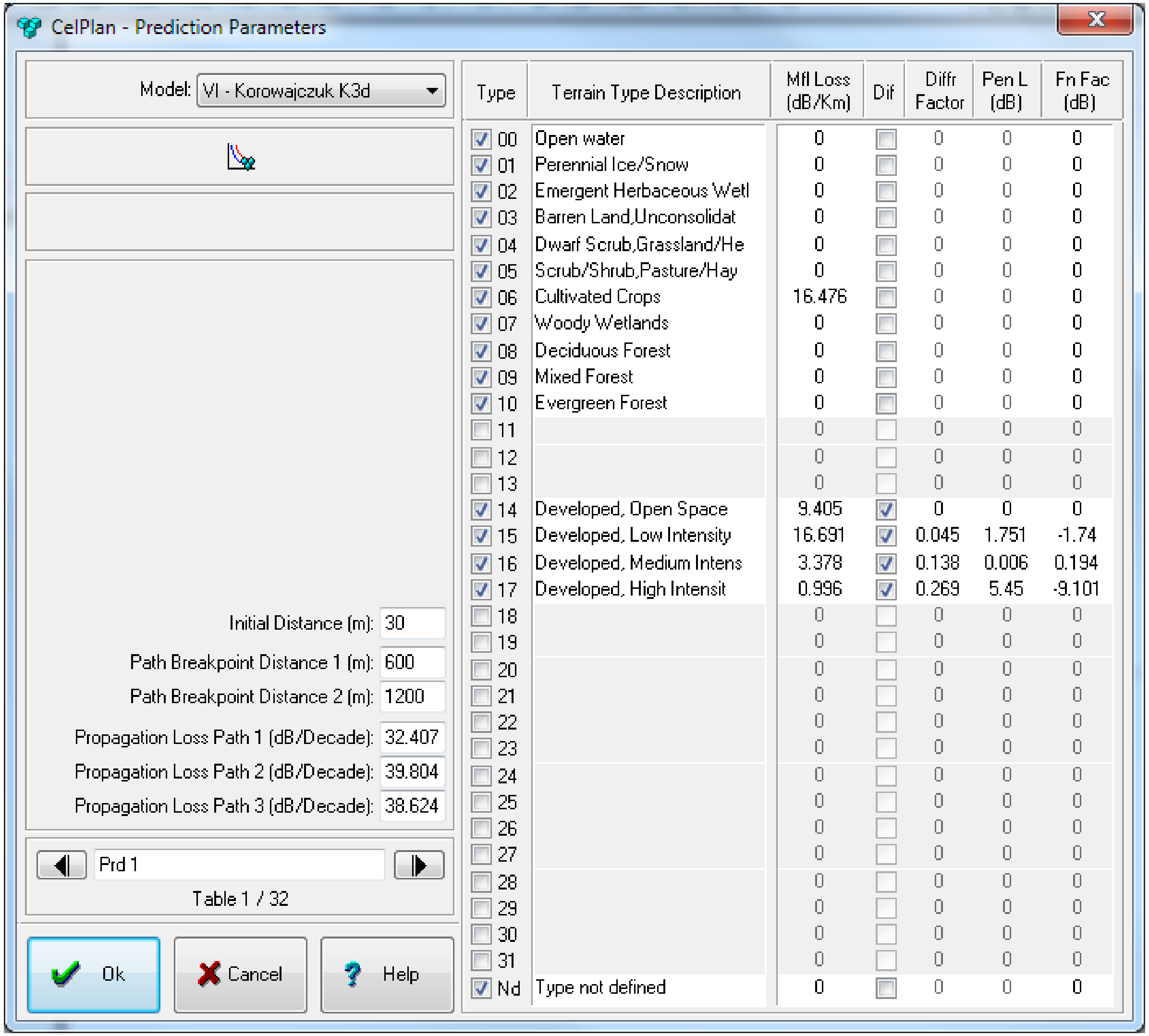

Measured Signal Level
Service
Level >= -60.0 dBm
Level >= -70.0 dBm
Level >= -80.0 dBm
Level >= -90.0 dBm
Level >=-100.0 dBm
Level >=-105.0 dBm
Level >=-110.0 dBm
Level >=-115.0 dBm
Configure
N
W
E
S
250 m
Scale 1:16,837
Reston Hospital Center
New Dominion Pkwy
RESTON
Hidden Creek Country Club
Lake Anne
Dulles Toll Rd
Whole Foods Market
McDonald's
Reston Station Blvd
SkateQuest
Sunset Hills Rd
Wiehle-Reston East Metro
Dulles Access Rd
United States Geological Survey
Reston National Golf Course
Sunrise Valley Dr
Lake Thoreau
Cafesano
Reston Community Orchestra
Hunters Woods Village Center
Map data ©2014 Google

Google Earth Image



Propagation Model Calibration

- The Propagation Model used was the Korowajczuk 3D (K3D)
- The calibrated parameters are shown in the table
- A better terrain date base will render better results



Type	Terrain Type Description	Mfl Loss (dB/Km)	Dif	Diffr Factor	Pen L (dB)	Fn Fac (dB)
☑ 00	Open water	0	☐	0	0	0
☑ 01	Perennial Ice/Snow	0	☐	0	0	0
☑ 02	Emergent Herbaceous Wetl	0	☐	0	0	0
☑ 03	Barren Land,Unconsolidat	0	☐	0	0	0
☑ 04	Dwarf Scrub,Grassland/He	0	☐	0	0	0
☑ 05	Scrub/Shrub,Pasture/Hay	0	☐	0	0	0
☑ 06	Cultivated Crops	16.476	☐	0	0	0
☑ 07	Woody Wetlands	0	☐	0	0	0
☑ 08	Deciduous Forest	0	☐	0	0	0
☑ 09	Mixed Forest	0	☐	0	0	0
☑ 10	Evergreen Forest	0	☐	0	0	0
☐ 11		0	☐	0	0	0
☐ 12		0	☐	0	0	0
☐ 13		0	☐	0	0	0
☑ 14	Developed, Open Space	9.405	☑	0	0	0
☑ 15	Developed, Low Intensity	16.691	☑	0.045	1.751	-1.74
☑ 16	Developed, Medium Intens	3.378	☑	0.138	0.006	0.194
☑ 17	Developed, High Intensit	0.996	☑	0.269	5.45	-9.101
☐ 18		0	☐	0	0	0
☐ 19		0	☐	0	0	0
☐ 20		0	☐	0	0	0
☐ 21		0	☐	0	0	0
☐ 22		0	☐	0	0	0
☐ 23		0	☐	0	0	0
☐ 24		0	☐	0	0	0
☐ 25		0	☐	0	0	0
☐ 26		0	☐	0	0	0
☐ 27		0	☐	0	0	0
☐ 28		0	☐	0	0	0
☐ 29		0	☐	0	0	0
☐ 30		0	☐	0	0	0
☐ 31		0	☐	0	0	0
☑ Nd	Type not defined	0	☐	0	0	0

Propagation Model Calibration

- Average Deviation: 0.01 dB
- Standard Deviation : 6.16 dB

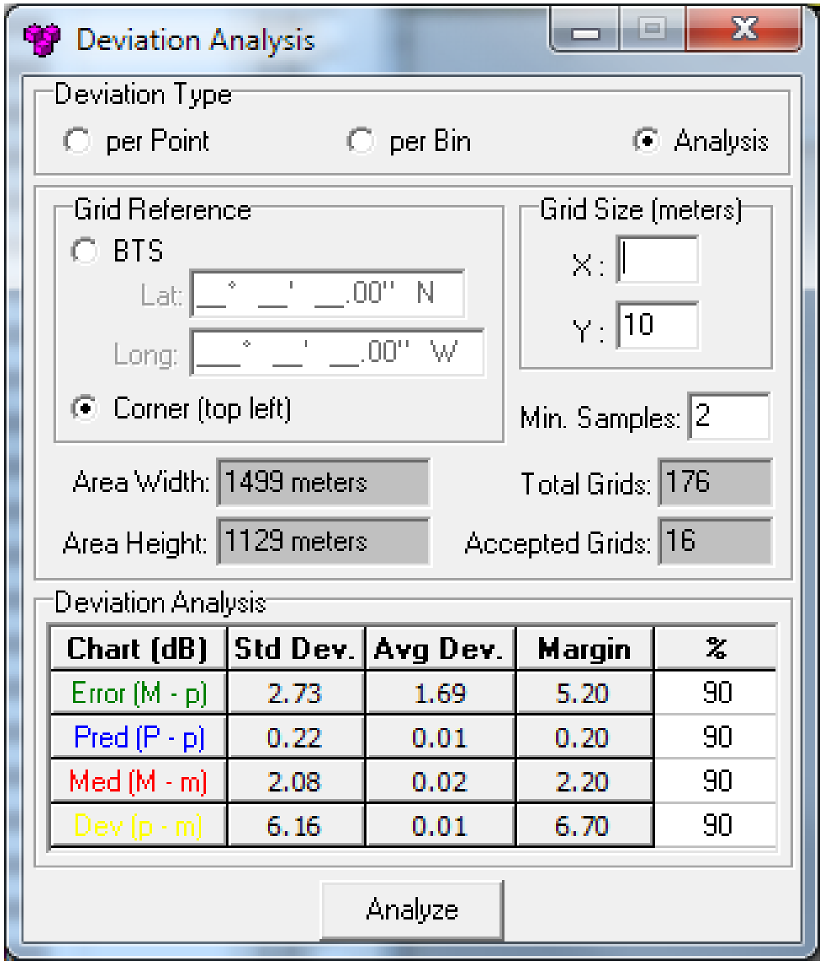
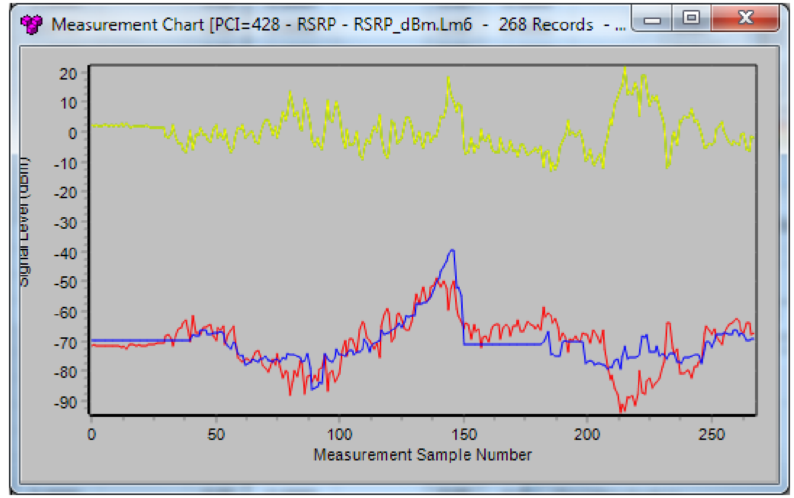
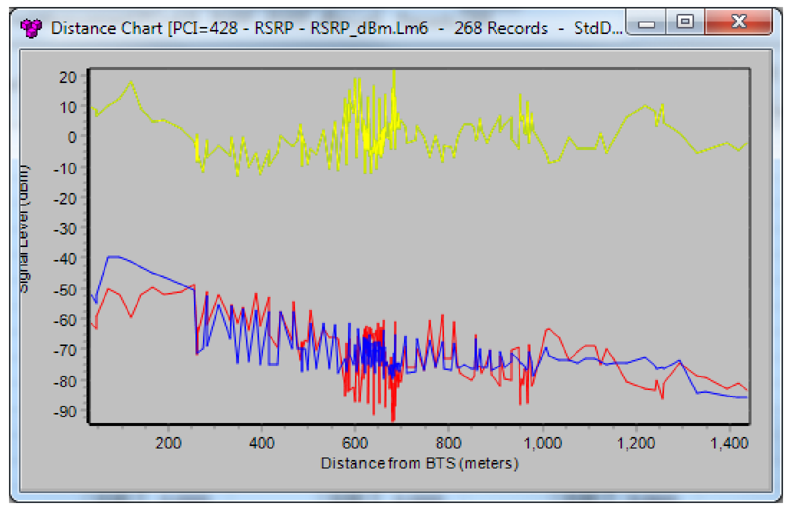


Chart (dB)	Std Dev.	Avg Dev.	Margin	%
Error (M - p)	2.73	1.69	5.20	90
Pred (P - p)	0.22	0.01	0.20	90
Med (M - m)	2.08	0.02	2.20	90
Dev (p - m)	6.16	0.01	6.70	90



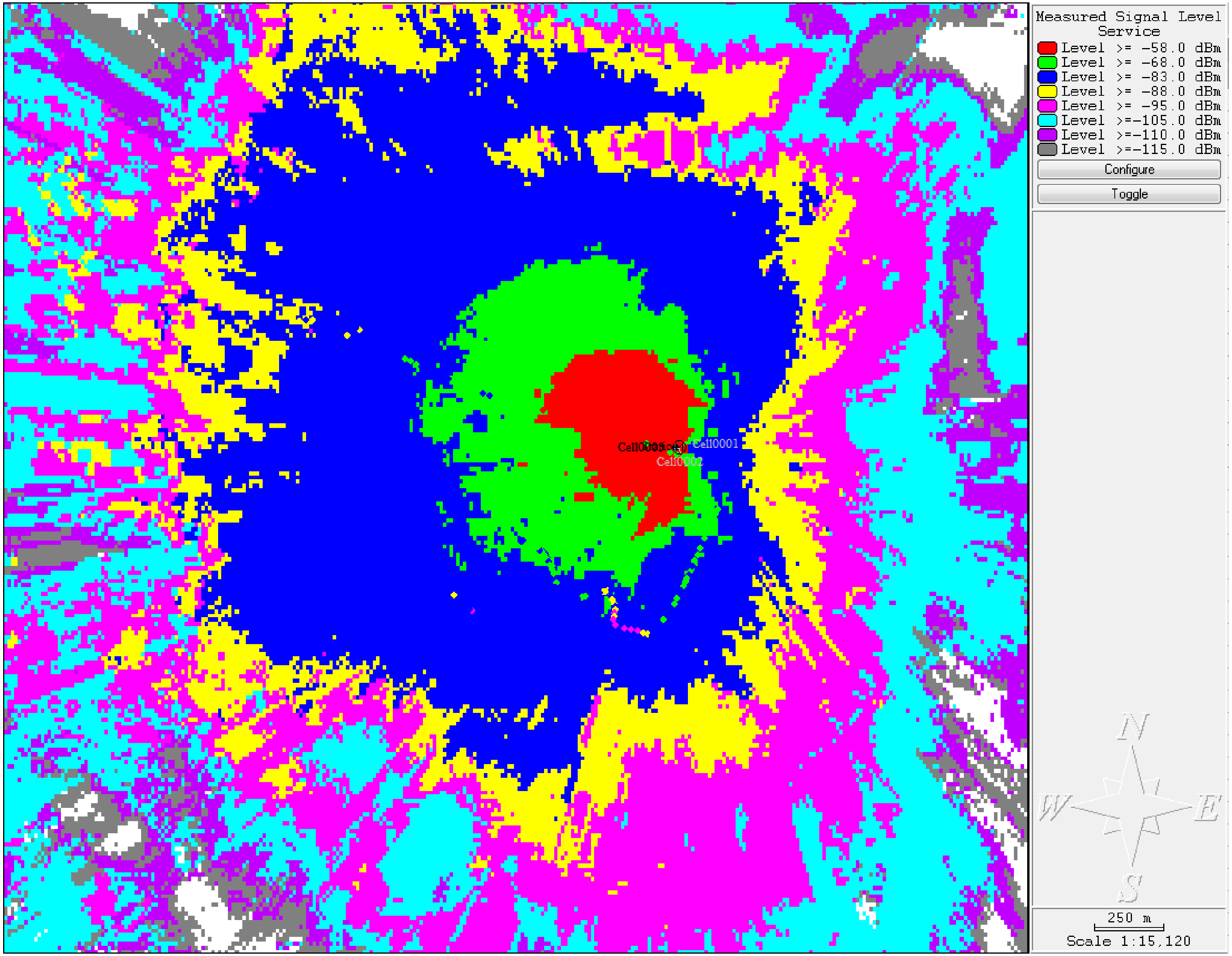


9. Comparing Predictions and Measurements

CelPlanner Predictions

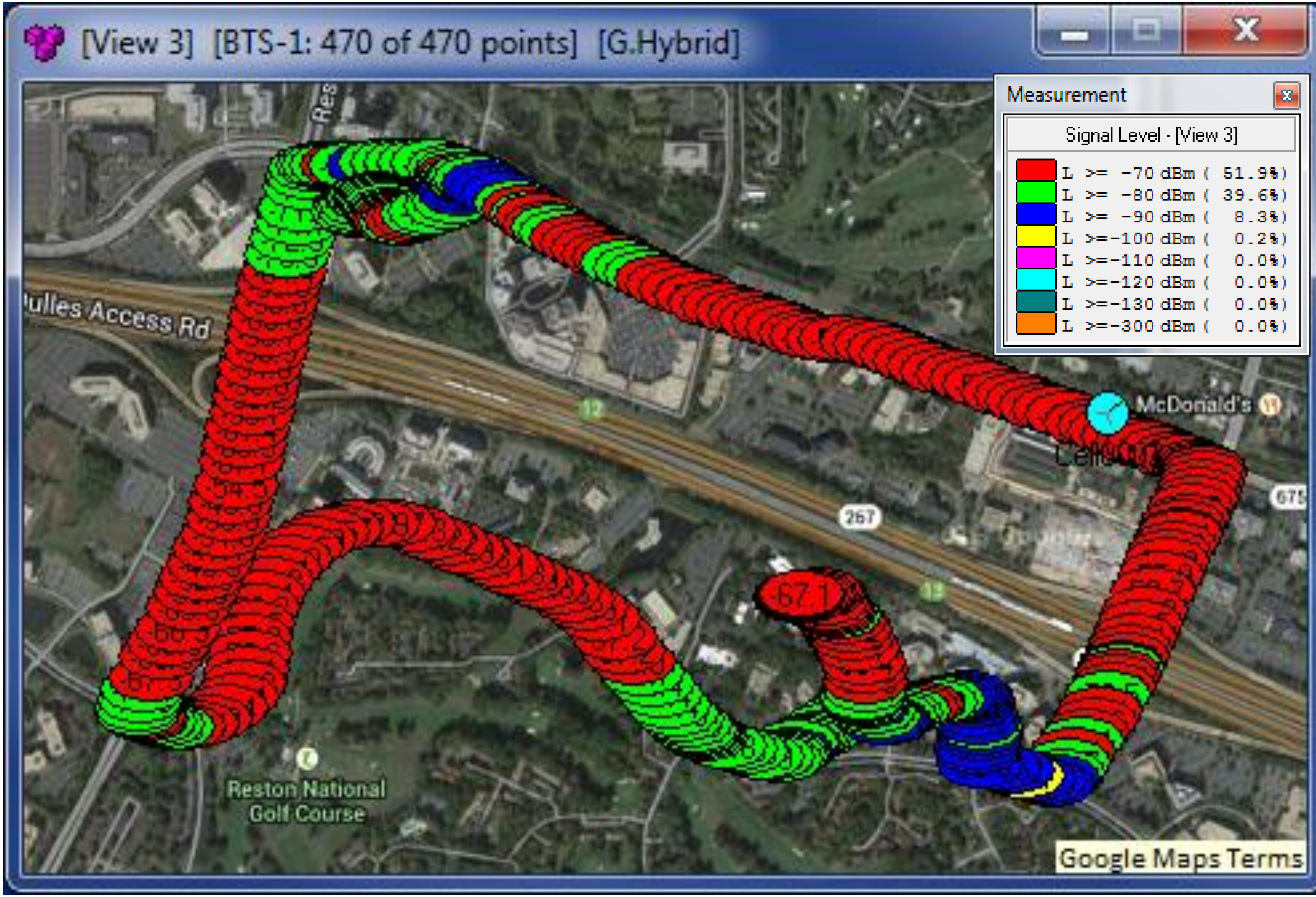
- We decided to model in CelPlanner the cell with PCI 428
- The site characteristics were not known
- The site characteristics were then based on information gathered using Street View inside CelPlanner and the most common parameters used in our projects
  - Location, Antenna height, Antenna Azimuth, Antenna Gain/Pattern and Transmit Power were assumed
- The propagation model was calibrated using the K3D model
- The predictions and overlayed measurements are shown next

Prediction x Measurement

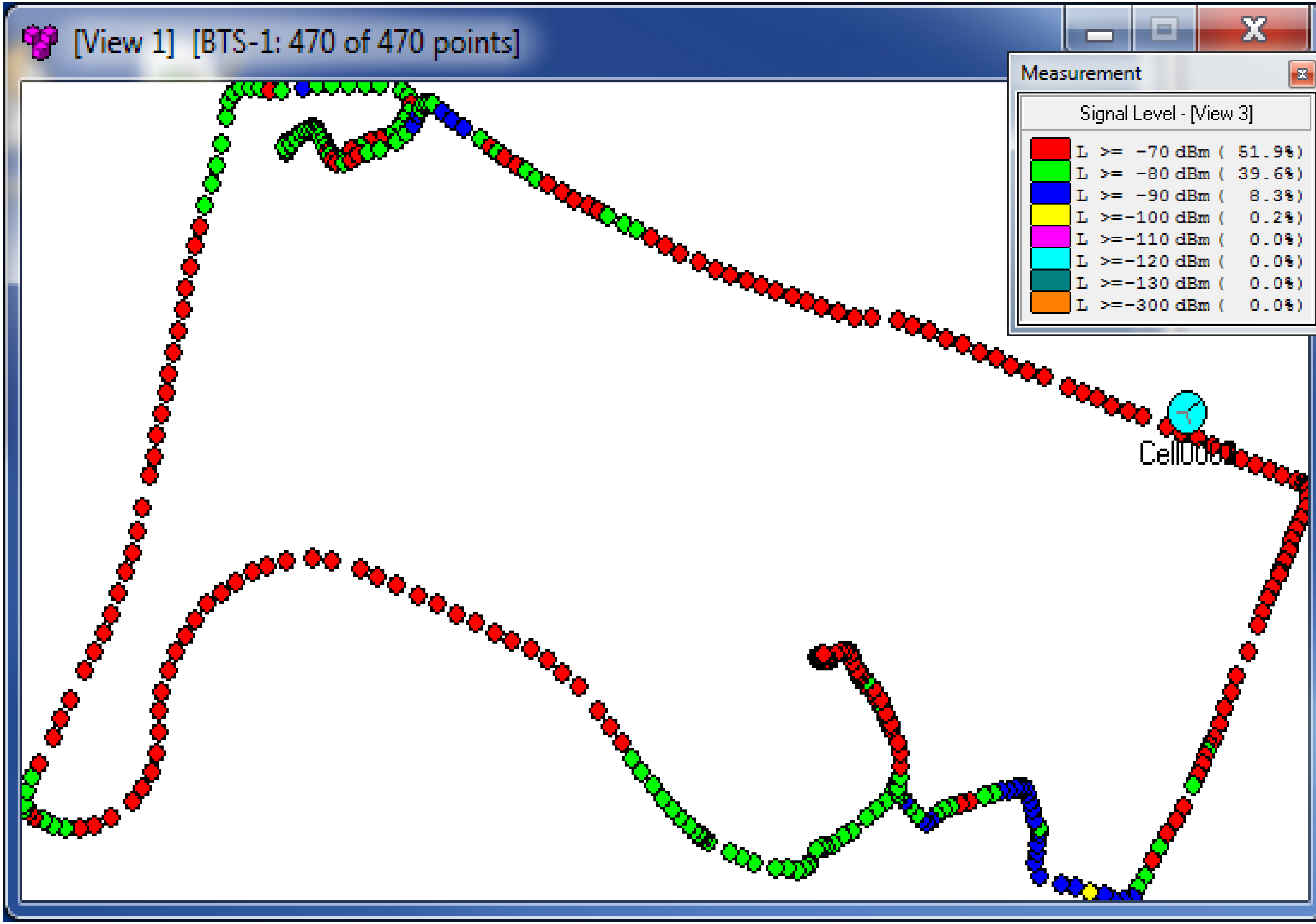


10. Generating Predictions from Measurements

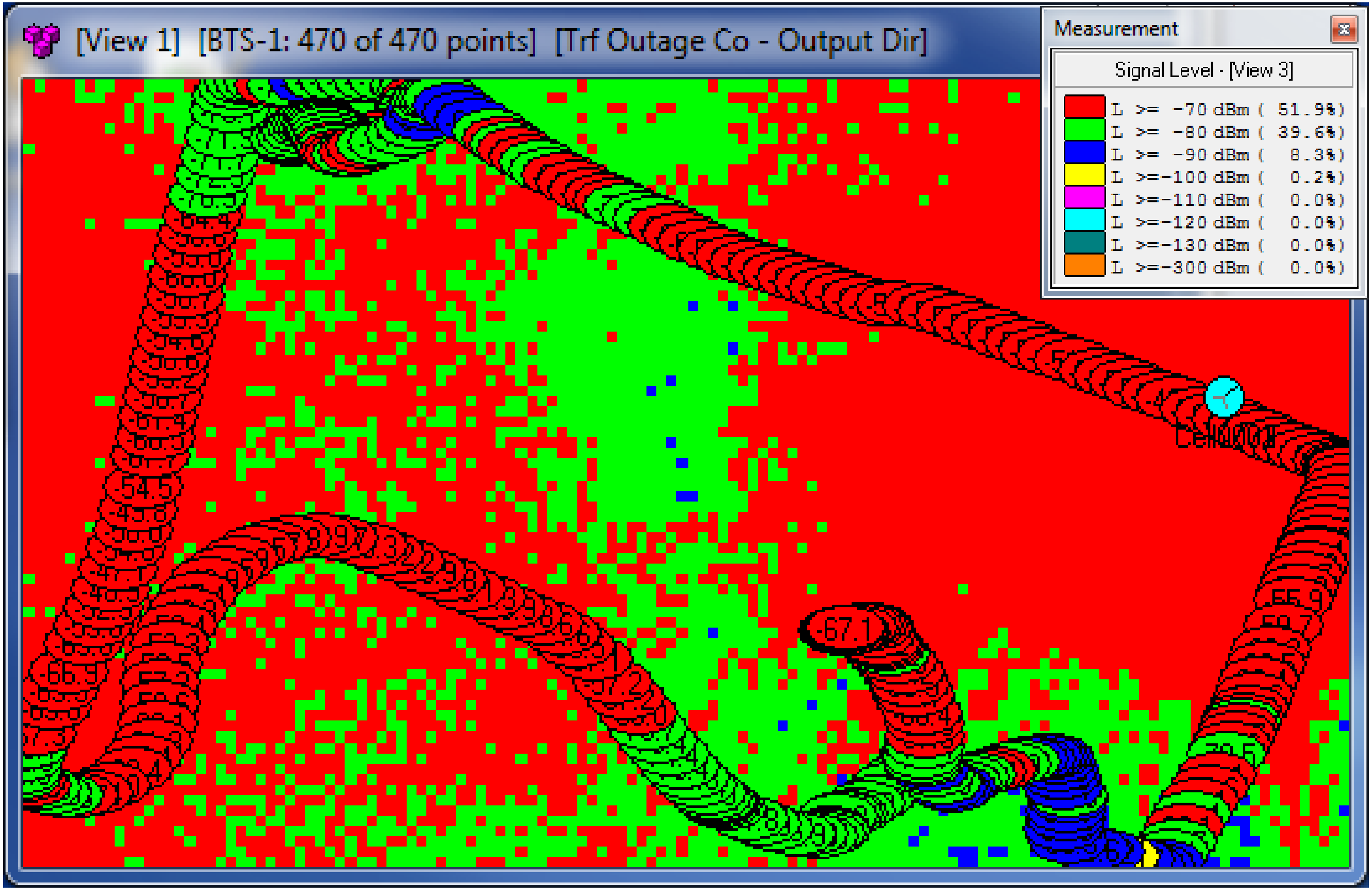
RSRP Measurements



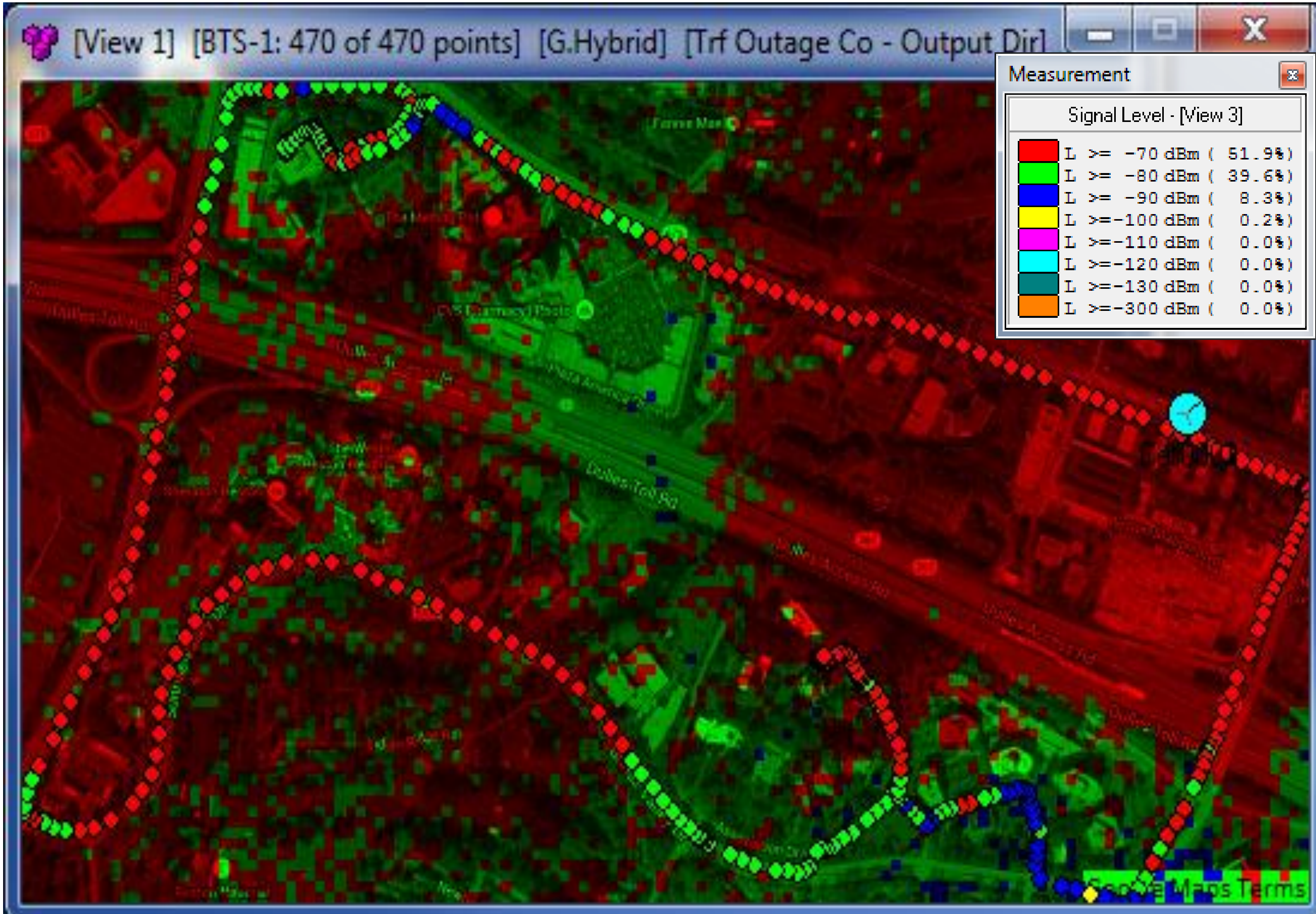
RSRP Measurements extracted



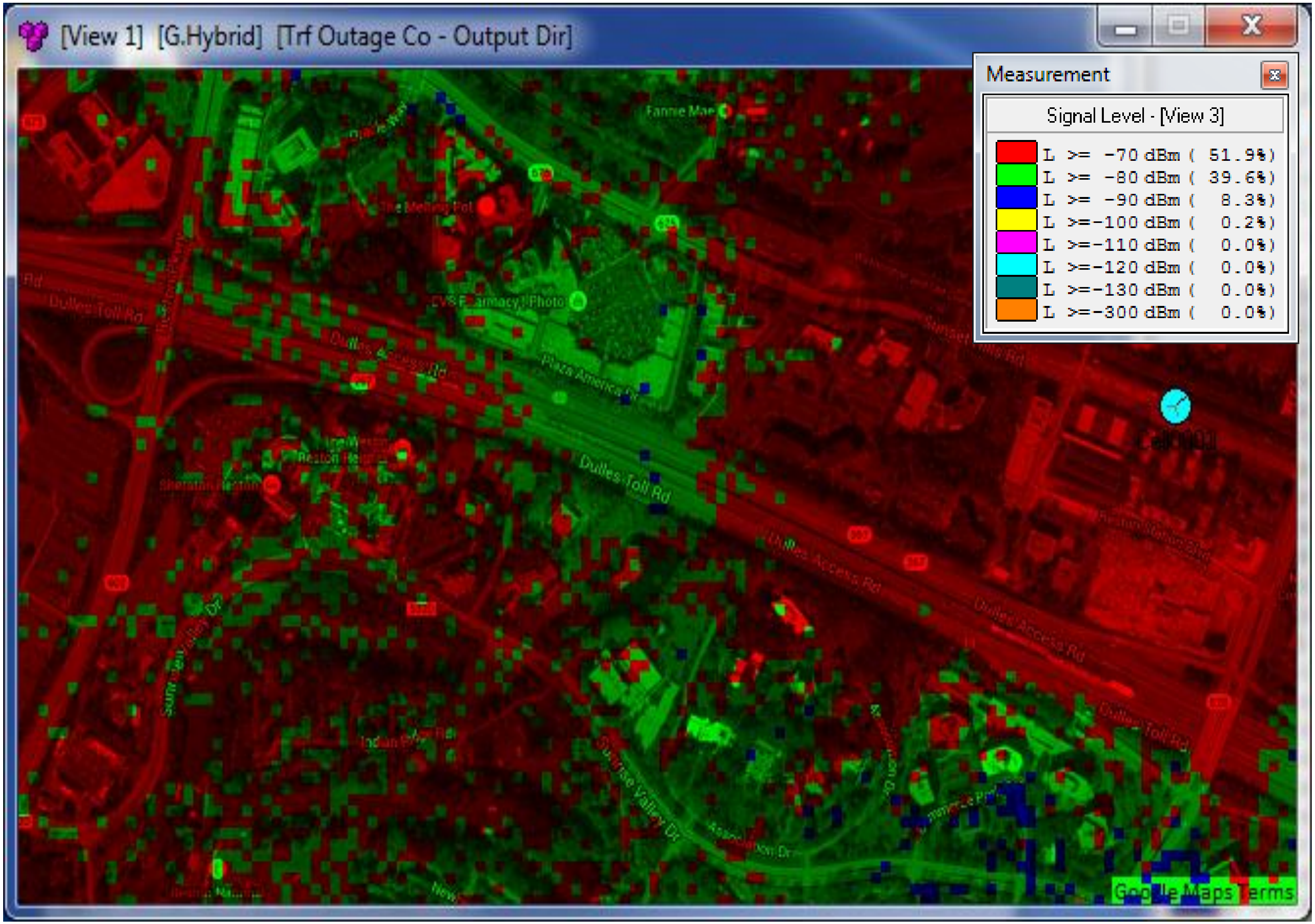
3 D Interpoalated Measurements x RSRP



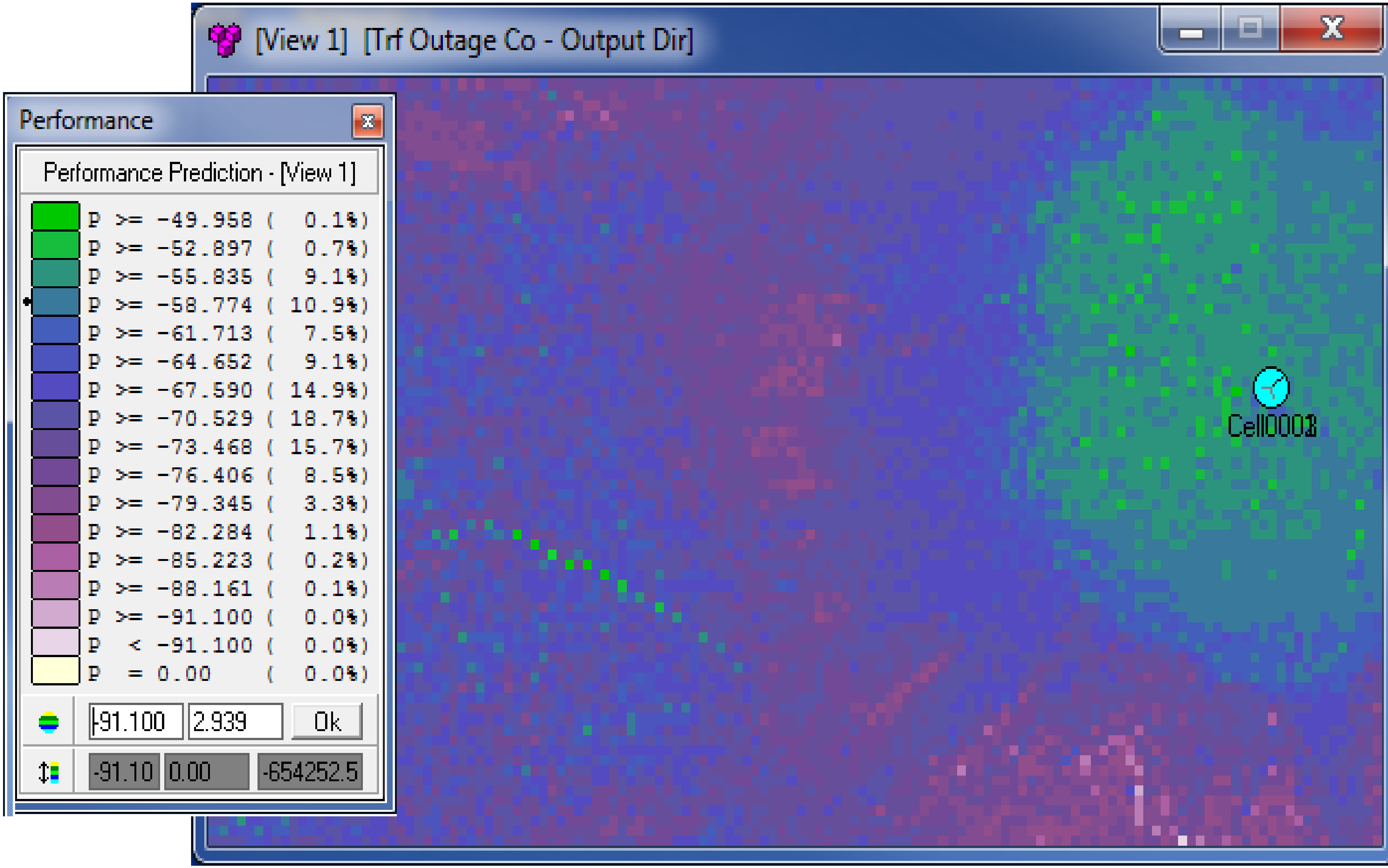
3 D Interpoalated Measurements x RSRP



3 D Interpoalated Measurements



3D Interpolation Granularity



11. Summary

Summary

- A broadband channel is very complex and requires an extensive analysis
- An LTE network requires an in depth understanding of the RF channel behavior to be properly configured
  - Multipath spread
  - Time fading
  - Frequency fading
  - Antenna Correlation
  - Intereference
  - Noise Rise
- Significant CAPEX and OPEX savings can be obtained by understanding the channel behavior
  - Deploy multiple antennas only it makes sense
  - Reduce “chasing its own tail” by understanding the cause of the issues and not relying just on the simptoms

12. CelPlan New Products

CellSpectrum

CellDesigner

CellDesigner

A new Generation of Planning Tools

A collaborative work with operators

Your input is valuable

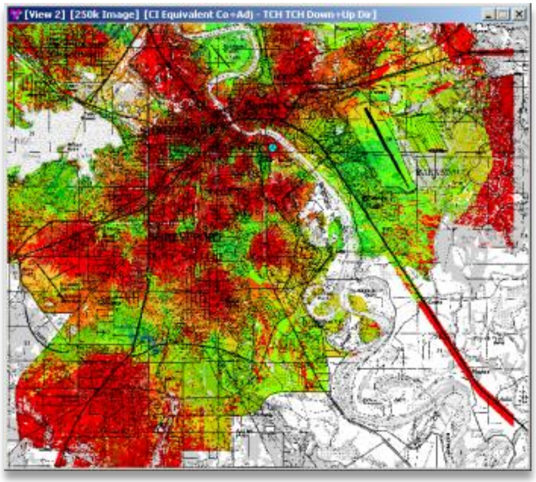
CellDesigner

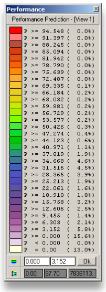
- CellDesigner is the new generation of Planning and Optimization tools
- Wireless networks became so complex that it requires a new generation of tools, capable of:
  - Documenting the physical deployments
  - Documenting network parameters for each technology
  - Flexible data traffic modelling (new services, new UE types)
  - Traffic allocation to different technologies
  - Fractional Resouce Planning
  - Performance evaluation
  - Integrated backhaul

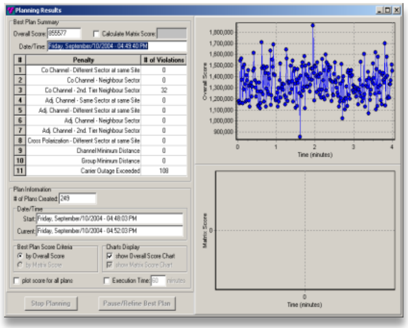
CellDesigner™

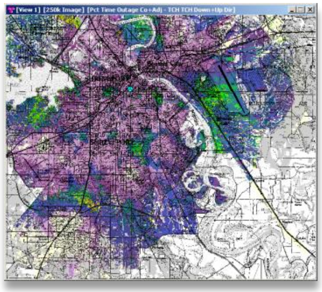
Simultaneous Multi-Technology Support

- Supports all wireless technology standards:
  - LTE–A (TDD and FDD), WiMAX, WI-FI, WCDMA (UMTS), HSPA, HSPA+, IS2000 (1xRTT, EVDO), GSM (including Frequency Hoping), GPRS, EDGE, EDGE-E, CDMA One, PMR/LMR (Tetra and P25), MMDS/LMDS, DVB-T/H, and Wireless Backhaul
- Full network representation
  - Site, Tower, Antenna Housing, Antenna System, Sector, Cell, Radio
  - Full network parameter integration
  - KPI integration
- Full implementation of the Korowajczuk 3D model, capable of performing simultaneously outdoor and indoor multi-floor predictions
- Multi-technology dynamic traffic simulation









CelPlan
Wireless Solutions & Consulting

CellDesigner™

Automatic Resource Planning (ARP)

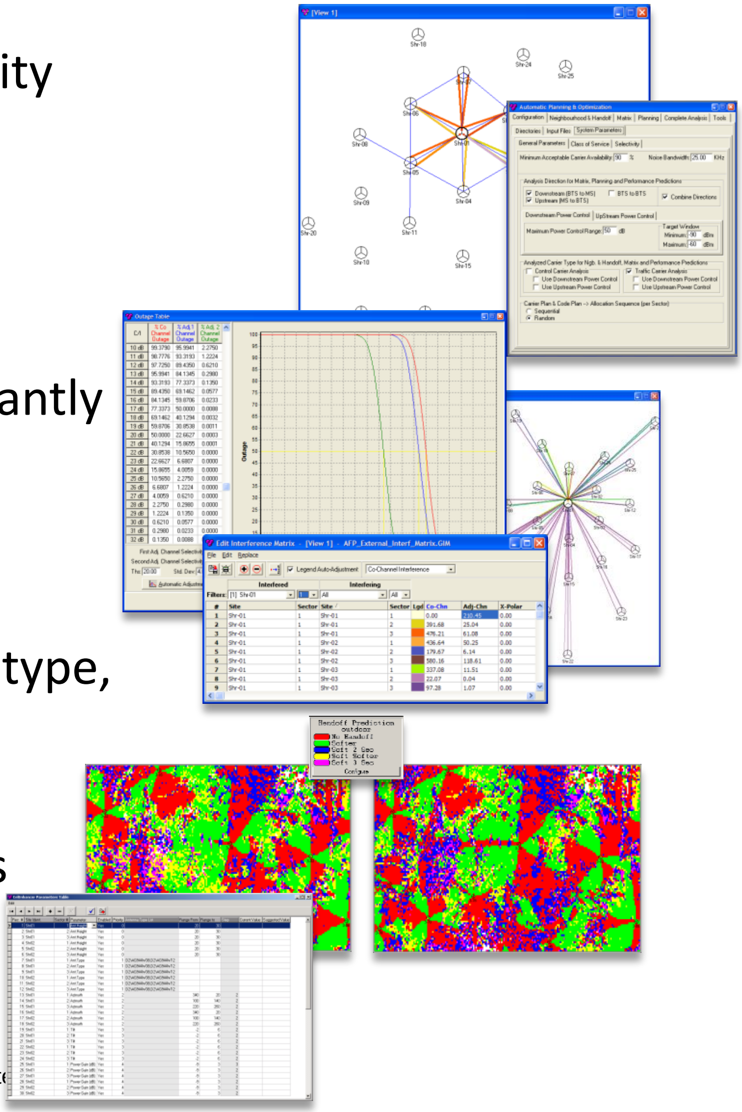
- Enables the dramatic increase of network capacity and performance
- Handover, Frequency and Code Optimization
- Automatically and efficiently optimizes handoff thresholds, neighbor lists, and frequency plans
- Patent-pending methodology capable of significantly increasing cell capacity (SON & ICIC)

Automatic Cell Planning (ACP)

- Footprint and interference enhancement
- Allows optimization of radiated power, antenna type, tilt, azimuth, and height

Performance Predictions

- Overall performance prediction per service class (bearer)



CellDesigner™

Google Earth Integration

- Capable of presenting predictions and measurements live in Google Earth's 3D environment

Network Master Plan (NMP)

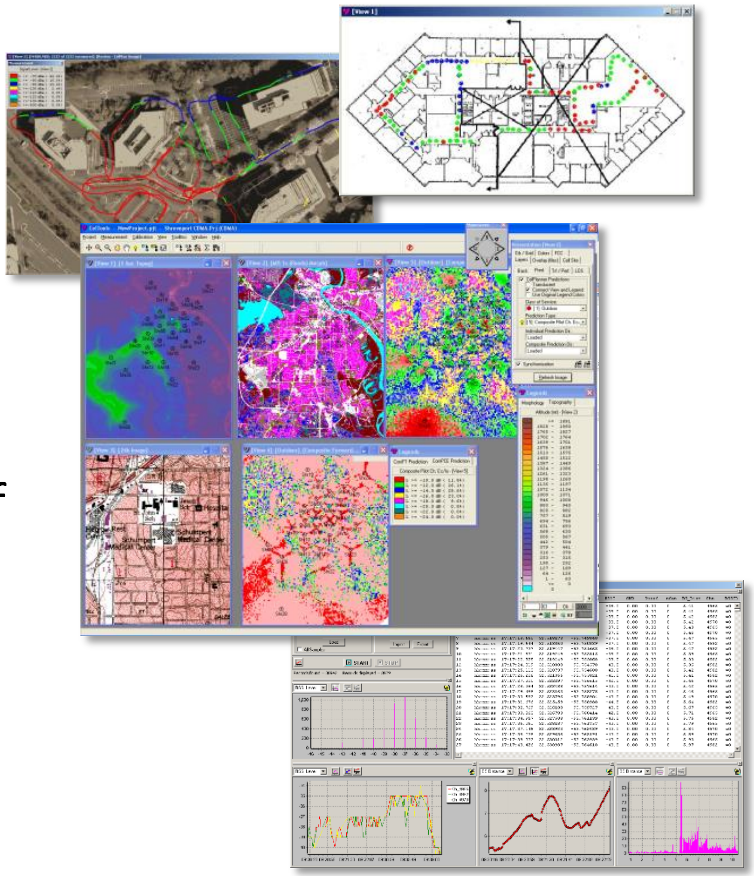
- Patent-pending methodology that simplifies SON and ICIC

Integration of Field Measurement Data

- Collection of data from virtually any type of measurement equipment and any format
- Automatic extraction of propagation parameters

Integration of KPIs

- Comparison reports between reported and calculated KPIS



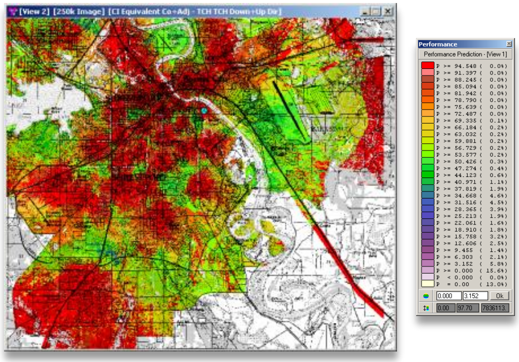
CellDesigner™

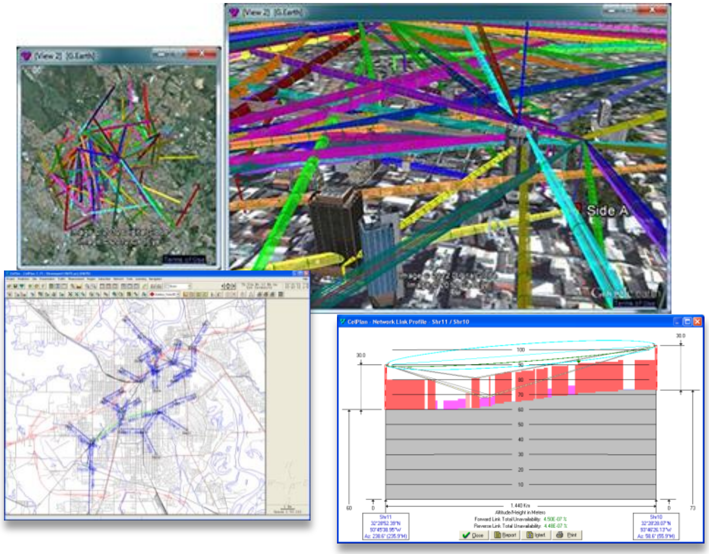
GIS Database Editor

- Allows the editing and processing of geographical databases

Backhaul Planning

- Calculates network interconnections, interference analysis & reporting for point-to-point, microwave transmission links
- Can display obstruction in Fresnel zones as well as the path loss
- Calculates attenuation caused by diffraction.
- Calculates rain attenuation for each link
- Provides link performance and compares against the requirements established by ITU-R





Thank You!

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Questions?