White Paper

RF Channel Characterization for 4G MIMO deployment

CelPlan International, Inc.

February 2014

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Data usage in wireless network is growing at an exponential rate, while revenues are growing linearly. Operators have to maximize spectrum usage efficiency by increasing cell capacity.

OFDM and MIMO are two techniques adopted to increase network capacity. The efficient usage of these techniques brought many challenges that require a deep understanding of the RF channel characteristics along the network. The use of broadband channels (>5 MHz) exacerbated this issue.

Traditional measuring equipment provides some information about the received signal and limited or no information about the RF channel.

Many RF channel characteristics required for a proper design have to be guessed by engineers, if considered at all. This results that networks are build first and its performance evaluated after deployment and even then there are no indications on how to fix them.

The main difficulty resides in that RF parameters depend on the environment and physical antenna system configuration and vary for each network location.
Some of those additional parameters are listed below and should be measured/ predicted along the whole network:

- Multipath spread at different threshold levels
- Average frequency fading and its variance
- Average time fading and its variance
- Noise floor and Interference
- Signal to Noise Ratio along the RF frame
- RF channel response along the frame
- Correlation between antennas

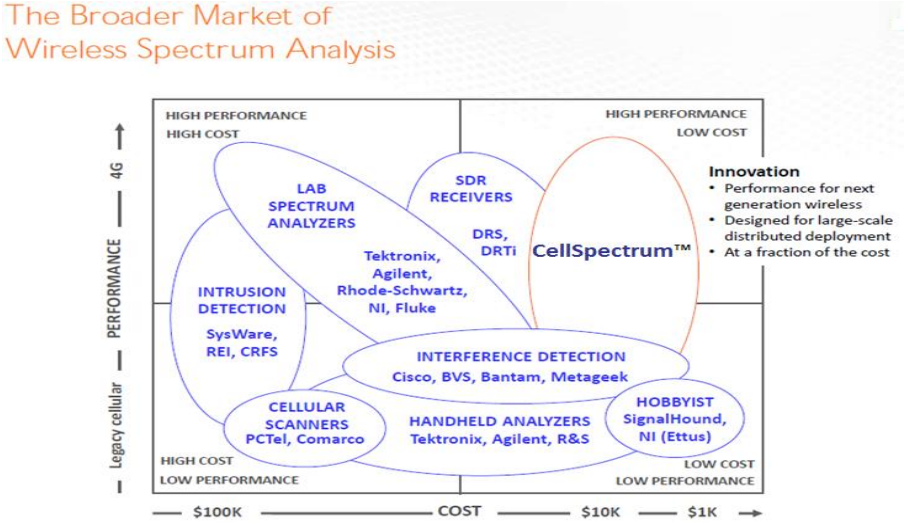
Information collected during a drive test may need to be analyzed deeply for some locations, but this only can be done with another drive test under different conditions.

Traffic volume and physical information allocation at the moment of the measurement are important data for the analysis of network issues. This becomes more important in 4G, where vendor algorithms and automatic processes, like ICIC, take over the task of avoiding interference.

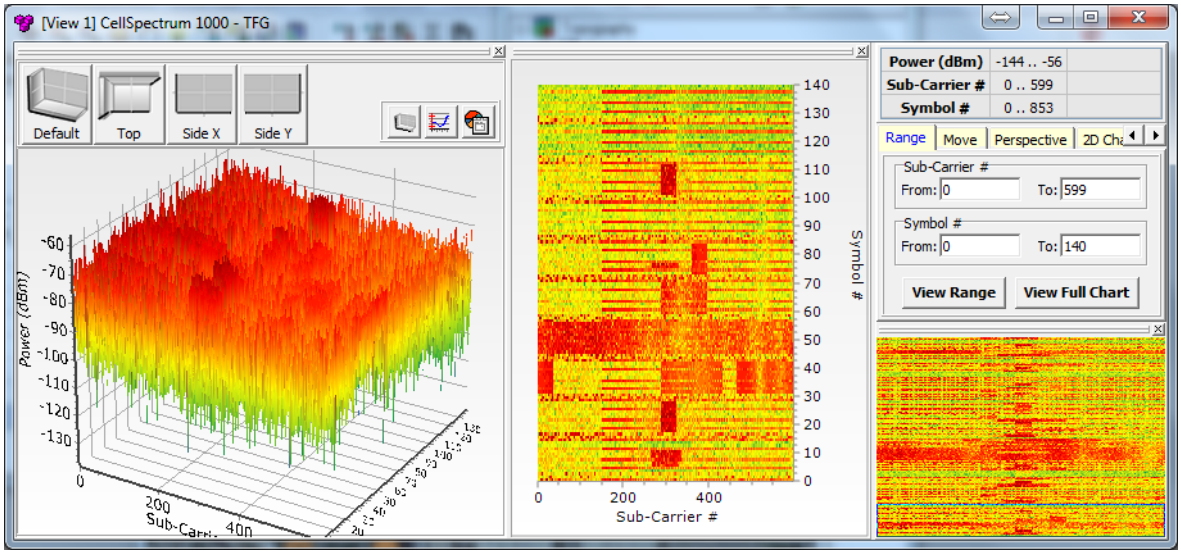
A new generation of equipment was required to perform this functionality: ***RF Spectrum and Channel Analyzers***, like CelPlan's CellSpectrum™, provide all this information, allowing the design of extremely spectrum efficient networks and consequently minimizing CAPEX and OPEX.

Framed OFDM transmitters, like WiMAX and LTE, provide an ideal platform to characterize the broadband RF channel.

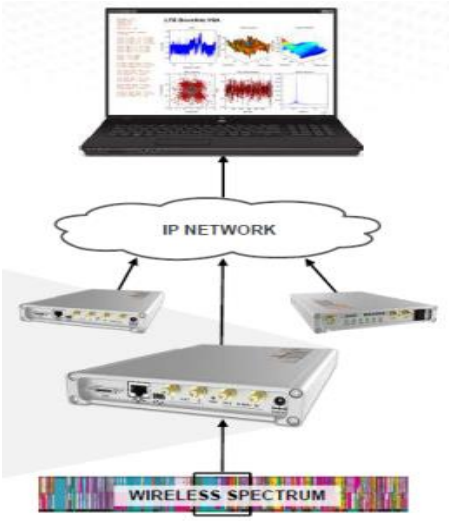
CellSpectrum™ provides valuable information for the development and specification of resource allocation algorithms, which can then be chosen according to the characteristics of each region.



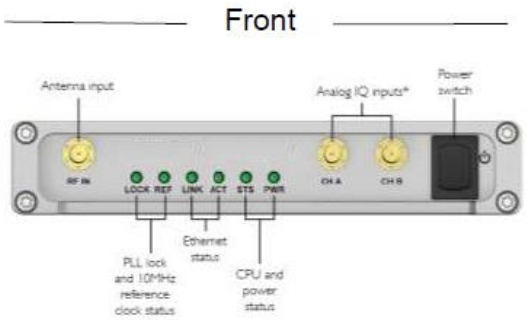
CellSpectrum™ digitizes up to 100 MHz of spectrum at a time, from 100 MHz to 18 GHz, extracting parameters as: LTE channel response per Resource Element, Multipath delay spread, Average frequency fading, Average time fading, Noise floor & interference, Signal to Noise Ratio along the RF frame, RF channel response along the frame and MIMO antenna correlation over a drive test route. It also supports time synchronized measurements, the decoding of multiple technologies and single or multiple deployments, which also makes it ideal for triangulation.

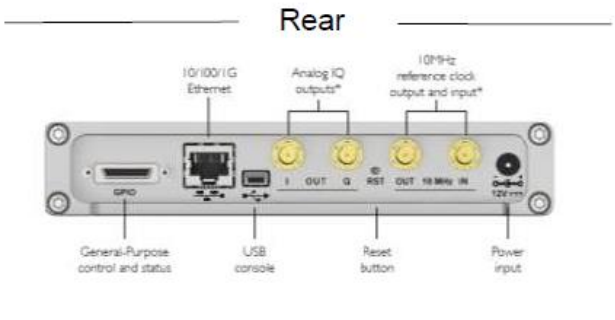


CellSpectrum™ comes in up to two hard cases, and consists of a Software Defined Receiver (SDR), a rugged outdoor multi-satellite GPS with WAAS, a Dead Reckoning unit, a universal antenna (698-960 MHz/1700-2700 MHz), a rugged Windows based PC with Solid-state drives (SSD or HDD) and cables. User should add a band pass filter for its specific band, to avoid receiver saturation. The PC is optional.



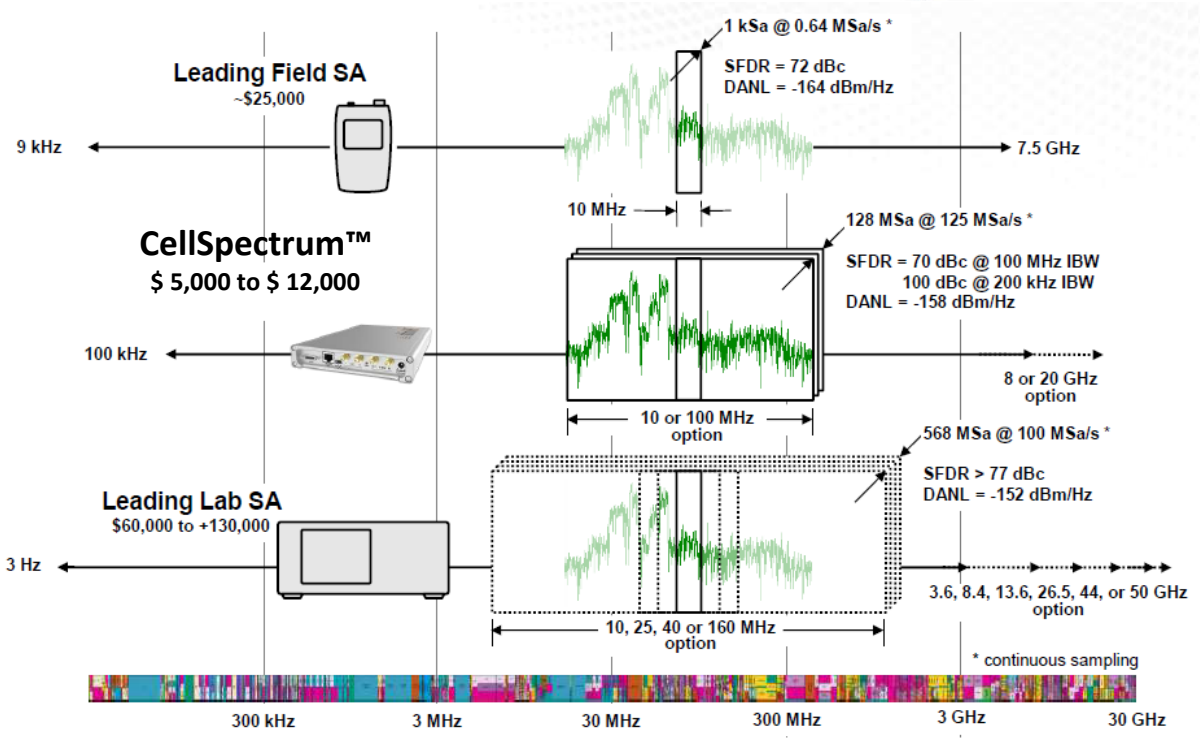
CellSpectrum™ 1000 software consisting of software capable of capturing, storing and analyzing time and location stamped spectrum data using the CellSpectrum™ 1000 hardware.
Multiple units can be synchronized to analyze simultaneous reception of multiple receive antennas (including PCB mounted ones).





CellSpectrum™ has dual functionality:

- Spectrum Analyzer: it does not compete with traditional spectrum analyzers, filling instead a gap between field spectrum analyzers and laboratory field analyzers.
- RF channel Analyzer: it is a unique instrument capable of providing detailed information about the RF channel. This is extremely valuable in setting parameters for 4 G networks, including allocation algorithms, SON and ICIC algorithms.



CellSpectrum™ is composed of 4 software modules: CellCapture™, CellSpectrum™ Analyzer, CellSearch™, CellProcess™, CellAnalyzer™.

1- CellCapture™

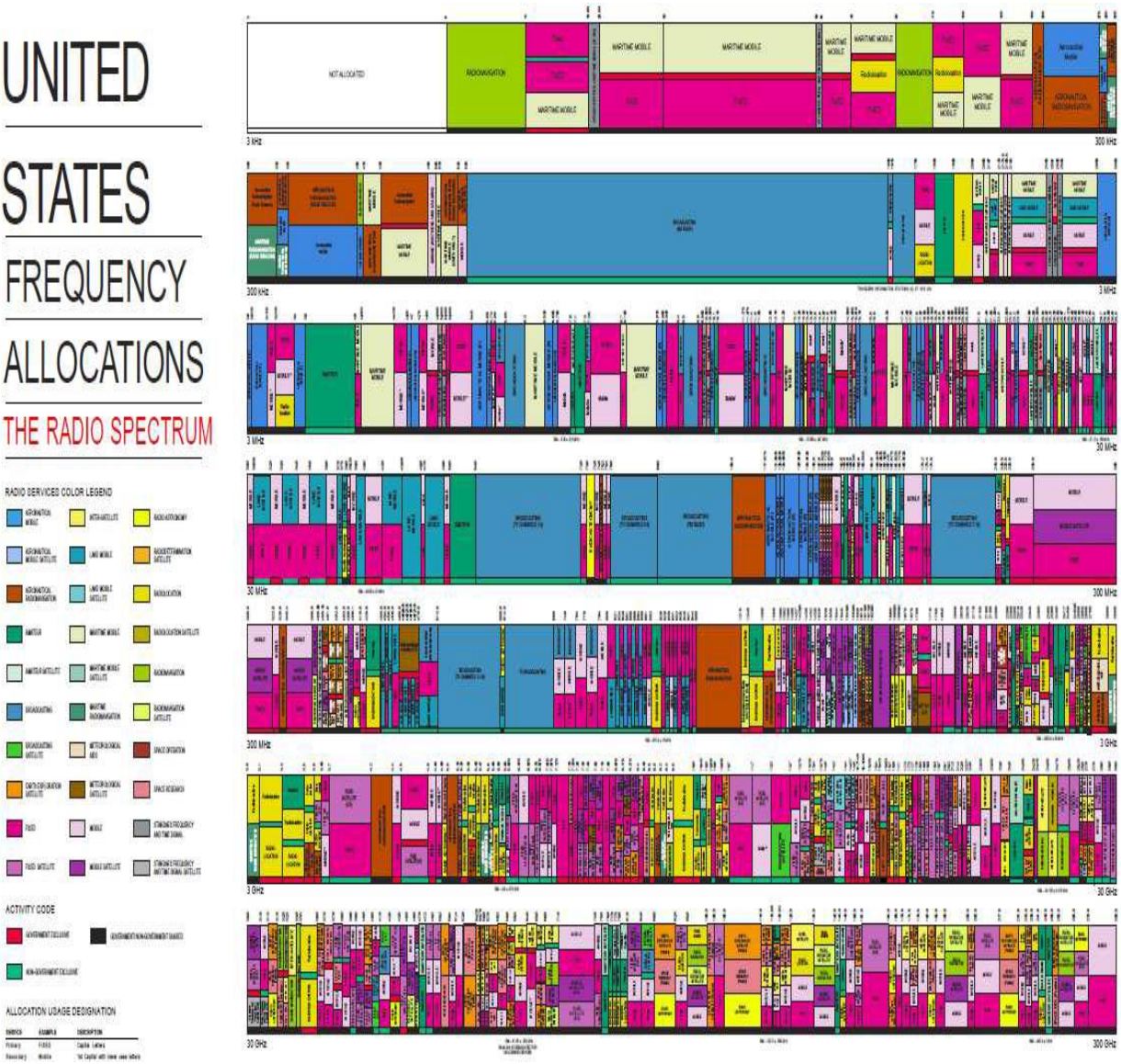
The first step in analyzing the RF channel is to capture the spectrum information in a field drive test. Any LTE equipment can be used as a source signal, so green field and existing networks can be easily characterized.

The analyzer should capture as much information as possible during the drive/walk test, so the information can be processed at a later stage and any required information can be extracted.

CellSpectrum™ has two interfaces one for the Digitizer and one for the Spectrum Analyzer.

User can specify the range of spectrum he wants to capture and store for each location. These spectrum analyzers can capture any part of the spectrum from 100 MHz to 18 GHz.

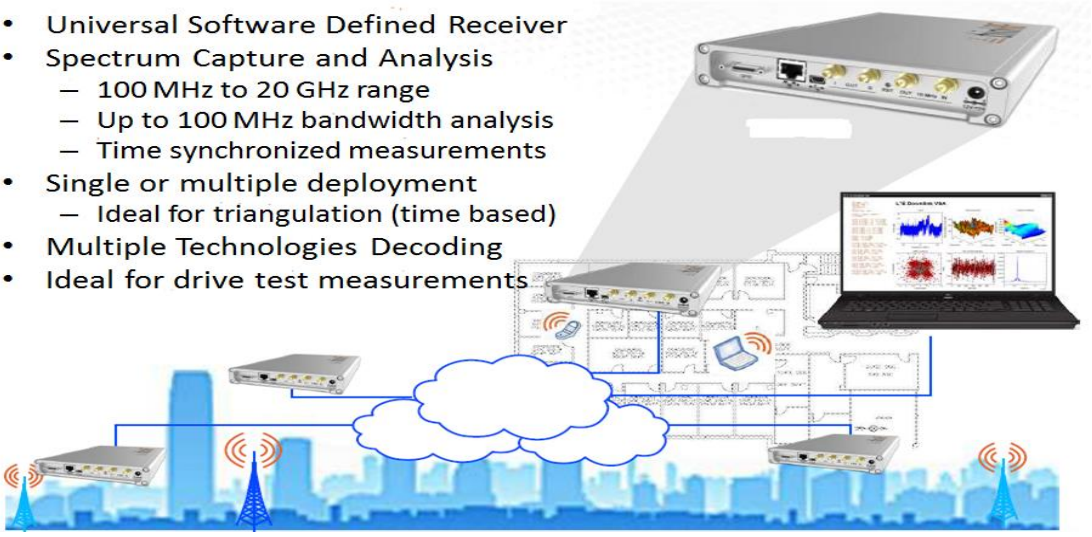
The captured spectrum is stored on a PC and can be analyzed in the field or in the office. Data can be reanalyzed at any moment to extract additional information.



CellSpectrum™ 1000 equipment captures detailed RF channel characteristics information using a process called CellCapture™, which digitizes up to 125 MHz of spectrum with a 14bit A/D converter. The information is stored in blocks of 80 ms (8 LTE frames) and contains the information of all cells providing signals above noise level at each measured location. Collection bandwidth can be adjusted for 5, 10, 20, 40, 60, 100 MHz). The equipment is capable of digitizing any 125 MHz portion of spectrum between 100 MHz and 20 GHz.

User can specify the frequency, in time or distance, with which he wants to collect data.

During collection the drive/walk test is indicated on a map and the capture signal integrity is checked and displayed, so the user can be aware that the drive/walk test is being successful. An alarm sounds each time a valid signal is not detected.



Data can be captured in a sweep or block mode. In a sweep mode a packet of data is sent for each sweep. In block mode user can specify the amount of data to be stored in each packet.

The spectrum analyzer modes support both functionalities. The RF channel analyzer works in block mode and for LTE CellSpectrum™ captures blocks of 80ms.

2- CelSpectrum™ Analyzer

CellSpectrum™ 1000 can be used as a regular spectrum analyzer, as illustrated below. It can be configured to display up to three traces. The main specifications are:

Range: 100 MHz to 18 GHz

Bandwidth: 125 MHz (IBW: 100 MHz)

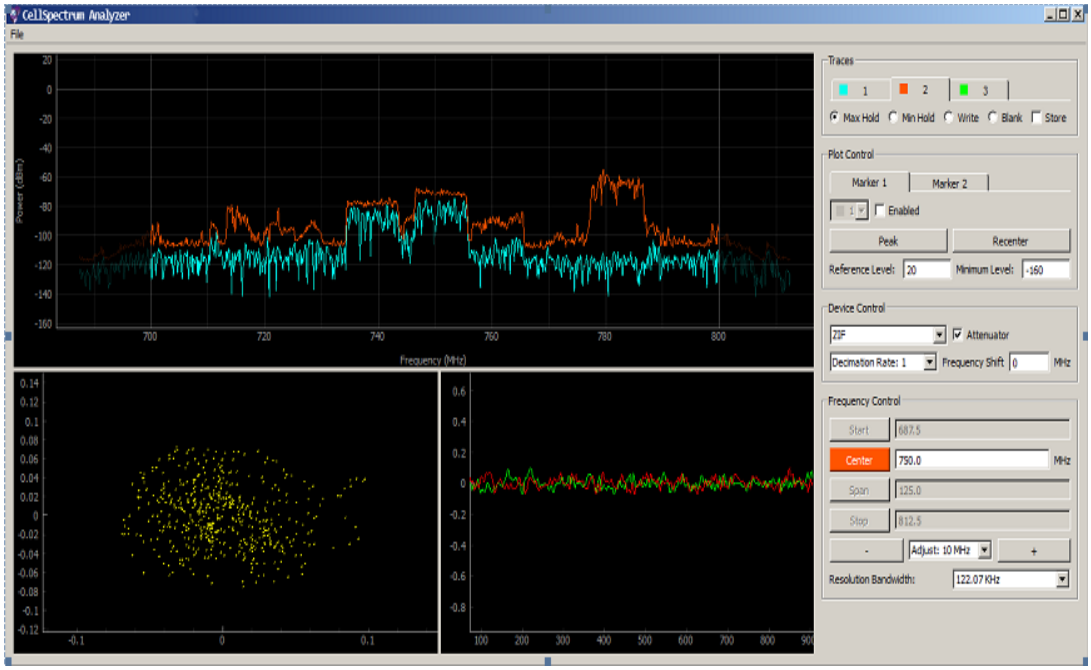
Decimation: 1, 4, 8, 16, 32, 64, 128, 256, 512, 1024

Resolution Bandwidth: 976.562 KHz, 488.281 KHz, 244.1141 KHz, 122.07 kHz, 61.035 kHz, 30.518 kHz, 15.259 kHz, 7.62939 kHz, 3.815 kHz

Display: Max hold, Min hold, Write, Blank

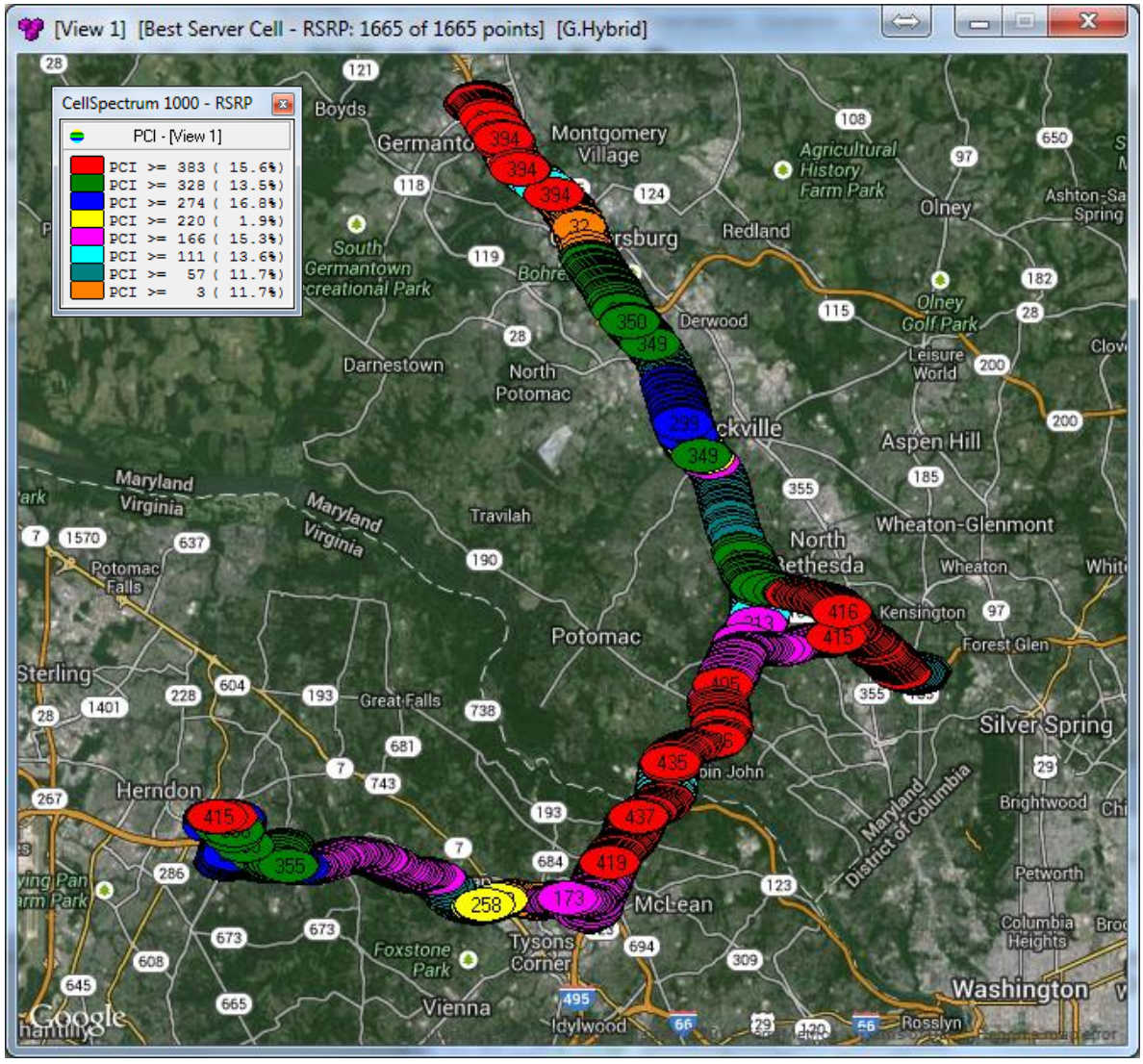
Capture modes:

- Once the GUI receives the Data, CellSpectrum™ Analyzer computes the FFT on each data packet, combine each packet and plots (note each packet contains 100MHz of IBW in 125MHz, so the 100MHz is extracted, and combined with the rest of the FFTs).
- **ZIF (Zero-IF Receiver)** is our default mode of operation, tuning range is 50MHz- 20GHz. The data received is 14-bit IQ (placed in 16-bits in the VRT packet), and the IBW is 100MHz (note total BW is 125MHz). It uses block capture mode. Uses block mode.
- **SH (Super-Heterodyne Receiver)** will send 14-bit I data, tuning range is 50MHz- 20GHz. The IBW for SH mode is 30MHz (note total BW is 62.5MHz, and we are working on increasing the IBW to 40MHz). It uses block capture mode. Uses block mode.
- **HDR (High Dynamic Range)** will send 24-bit I data (placed in 32-bits in the VRT packet), tuning range is 50MHz-20GHz. The IBW for HDR mode is 100 KHz. It uses block capture mode. Uses block mode.
- **Sweep-ZIF** uses the ZIF receiver mode, with the sweep capture mode. The GUI would set up a sweep entry with a start, step, and a stop frequency in the WSA. When sweep mode is initiated, the WSA tunes to each frequency (start, start + step, start + (2 X step),..., stop), captures data for each frequency, and sends the data to the GUI.
- **Sweep-ZIF** Left uses the same concept as above, but instead of taking the full 100MHz from the FFT, it will only take the left sided 50MHz (this is to avoid having a DC offset in the middle of the FFT).



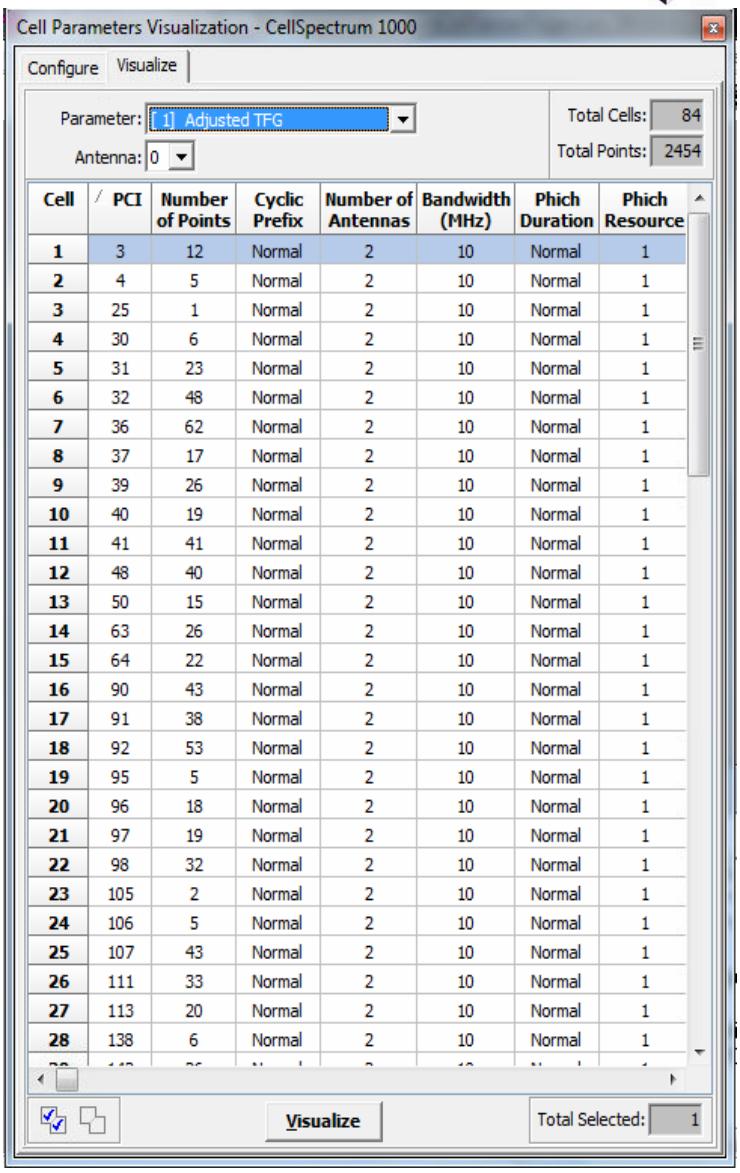
3- CellSearch™

Once data is collected a cell search process is initiated, using CellSearch™ module. The digitized spectrum is analyzed at each measured point and all detected PCIs are listed. User can then visualize the locations where each PCI was detected and the cell broadcasted characteristics.



CellSpectrum™ displays the following information for each detected PCI, as illustrated below.

- Primary Cell Identity (PCI): 0 to 503
- Number of measured points
- Cyclic Prefix (CP) used (normal or extended)
- Number of TX antennas: 1, 2 or 4
- Bandwidth (BW): 1.4, 3.0, 5.0, 10, 15 or 20 MHz
- PHICH Resource: Normal or Extended
- PHICH Duration: 1/6, ½, 1, 2



Cell	PCI	Number of Points	Cyclic Prefix	Number of Antennas	Bandwidth (MHz)	Phich Duration	Phich Resource
1	3	12	Normal	2	10	Normal	1
2	4	5	Normal	2	10	Normal	1
3	25	1	Normal	2	10	Normal	1
4	30	6	Normal	2	10	Normal	1
5	31	23	Normal	2	10	Normal	1
6	32	48	Normal	2	10	Normal	1
7	36	62	Normal	2	10	Normal	1
8	37	17	Normal	2	10	Normal	1
9	39	26	Normal	2	10	Normal	1
10	40	19	Normal	2	10	Normal	1
11	41	41	Normal	2	10	Normal	1
12	48	40	Normal	2	10	Normal	1
13	50	15	Normal	2	10	Normal	1
14	63	26	Normal	2	10	Normal	1
15	64	22	Normal	2	10	Normal	1
16	90	43	Normal	2	10	Normal	1
17	91	38	Normal	2	10	Normal	1
18	92	53	Normal	2	10	Normal	1
19	95	5	Normal	2	10	Normal	1
20	96	18	Normal	2	10	Normal	1
21	97	19	Normal	2	10	Normal	1
22	98	32	Normal	2	10	Normal	1
23	105	2	Normal	2	10	Normal	1
24	106	5	Normal	2	10	Normal	1
25	107	43	Normal	2	10	Normal	1
26	111	33	Normal	2	10	Normal	1
27	113	20	Normal	2	10	Normal	1
28	138	6	Normal	2	10	Normal	1

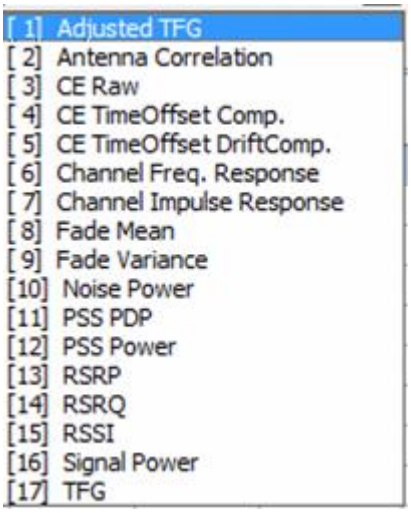
4- CellProcess™

Every detected PCI (Primary Cell Identity) corresponds to one radio and one cell. CellProcess™ extracts each cell data and allows the user to visualize it along the drive test route, using the powerful CelView™ interface. Measurement locations are displayed along the route, through markers. Those markers can be visualized on CellDesigner™ maps, Google maps (street map, hybrid and physical), Google Earth (including Street View). Data can be visualized in 1D (dimension), 2D or 3D. User can open multiple views simultaneously and open more than one instance of CellProcess™.

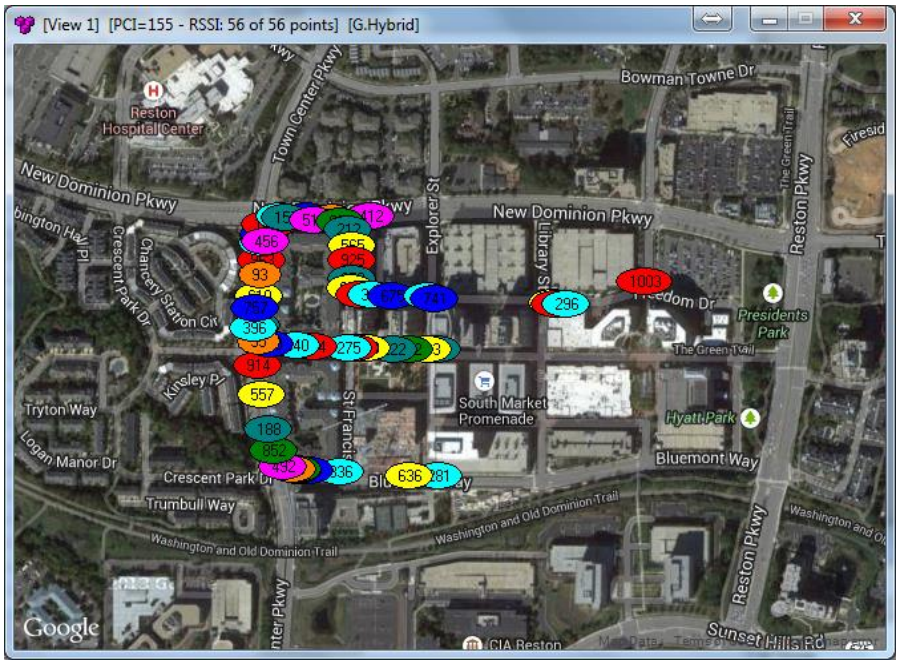
One D data visualization applies to data that can be represented by a single value. This value is shown directly on the marker identifying the capture. Two D data visualization applies to data that is represented by a two variables matrix. It is visualized by a 2D graph that is displayed by clicking on the respective marker. Three D data visualization applies to data that is represented by a three variables matrix. It is visualized on a bird view, on which the user can zoom. Each capture has 6.1 LTE frames and is represented in the bird view. The top view of the zoom area is shown in a separate screen, as well as a 3D view. User can manipulate the 3D view to see it from different angles. All views can be resized and adjusted as desired by the user.

Additional cell information can then be displayed for each measured point, to characterize the RF channel. Some of the data applies to the whole channel, while other is specific to each transmit antenna. The options are listed below and displayed in the dialogue drop box.

	MEASUREMENTS
1	RF Signal Strength per RE
2	RF Channel Response for each RS
3	Noise Filtered RF Channel Response for each RS
4	RF Channel Response for RS carrying OFDM symbols
5	RF Channel Response for all OFDM symbols
6	Impulse Response for each RS carrying OFDM symbol
7	Multipath delay Spread
8	Reference Signal Received Power
9	Receive Signal Strength Indicator- full OFDM symbols
10	Receive Signal Strength Indicator- RS RE of OFDM symbol
11	Receive Signal Strength Indicator- PBCH
12	Reference Signal Received Quality- full OFDM symbols
13	Reference Signal Received Quality- RS RE of OFDM symbol
14	Reference Signal Received Quality- PBCH
15	PSS Power Distribution Profile
16	PSS Power
17	Frequency Fade Mean
18	Frequency Fade Deviation
19	Frequency Time Mean
20	Frequency Time Variance
21	Signal Power
22	Noise Power
23	Signal to Noise/Interference Power
24	Antenna Correlation
25	Traffic Load Grid (Hot, Mild, Cold)
26	Traffic Load

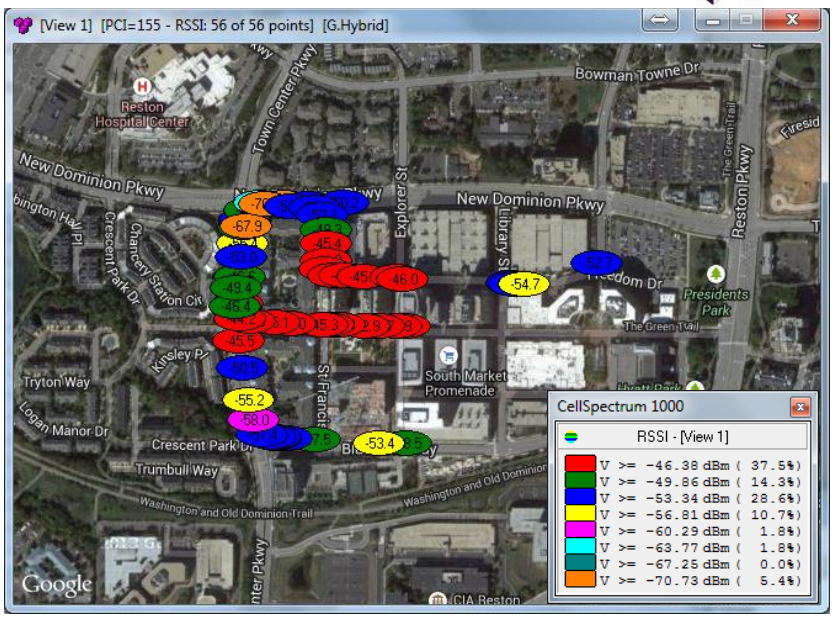


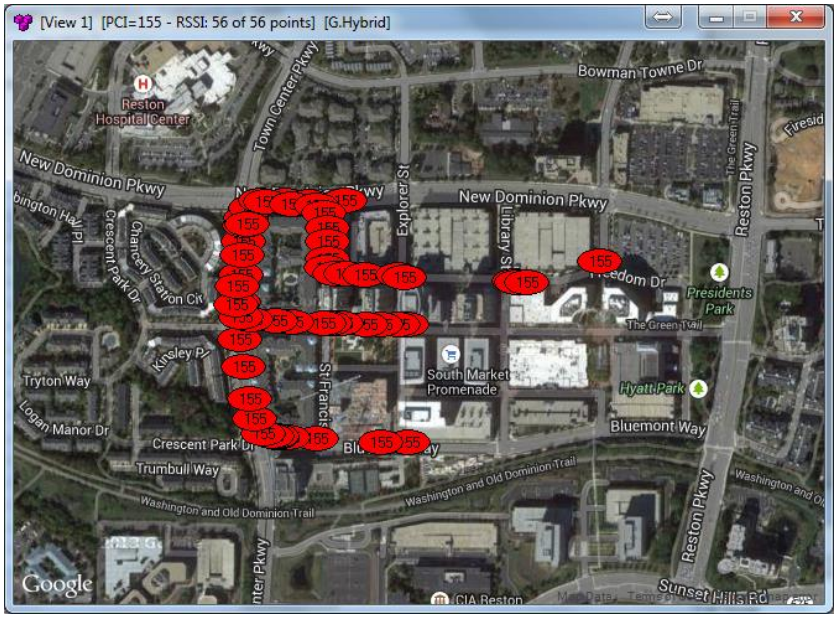
- **System Frame Number (SFN):** The initial frame number of the capture at each measured point is displayed. This is important to verify synchronization between receivers.



- **Time Stamp (TS):** The time at which each measurement was done is displayed.

- **Receive Signal Strength Information (RSSI):** this is the signal strength of the Reference Signals of an OFDM symbol, averaged over all OFDM symbols that carry Reference Signals. This measurement is done before the extraction of the Reference Signal, so it includes the interference from adjacent cells. The 3gpp specification is not clear and it leads to a conclusion that the traffic carrying REs should be considered in the power sum. RSSI value varies with the presence of traffic. This gives variable results with time and measured frame locations, making this measurement of little use. CellSpectrum™ measures the RSSI in three different ways.
    - Full OFDM Symbols as specified by 3gpp
    - Only RE carrying RS in an OFDM symbol
    - Measured over the PBCH symbols (which should be fully loaded in principle)


[View 1] [PCI=155 - RSSI: 56 of 56 points] [G.Hybrid]
Reston Hospital Center
Bowman Towne Dr
New Dominion Pkwy
Town Center Pkwy
Explorer St
Library St
Reston Pkwy
Freedom Dr
Presidents Park
The Green Trail
Chancery Station Cir
Crescent Park Dr
Kinsley Pl
Tryton Way
Logan Manor Dr
Trumbull Way
St Francis
South Market Promenade
Washington and Old Dominion Trail
CIA Reston
Google
CellSpectrum 1000
RSSI - [View 1]
V >= -46.38 dBm (37.5%)
V >= -49.86 dBm (14.3%)
V >= -53.34 dBm (28.6%)
V >= -56.81 dBm (10.7%)
V >= -60.29 dBm (1.8%)
V >= -63.77 dBm (1.8%)
V >= -67.25 dBm (0.0%)
V >= -70.73 dBm (5.4%)


[View 1] [PCI=155 - RSSI: 56 of 56 points] [G.Hybrid]
Reston Hospital Center
Bowman Towne Dr
New Dominion Pkwy
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Reston Pkwy
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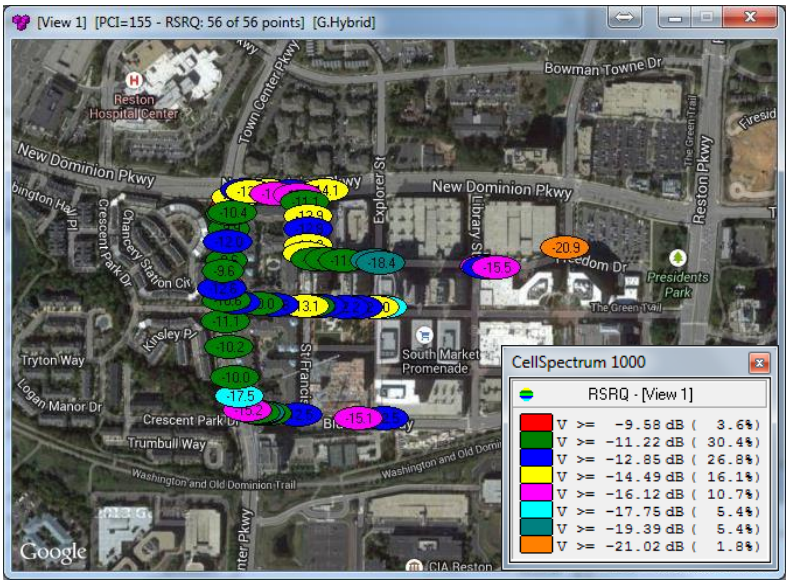
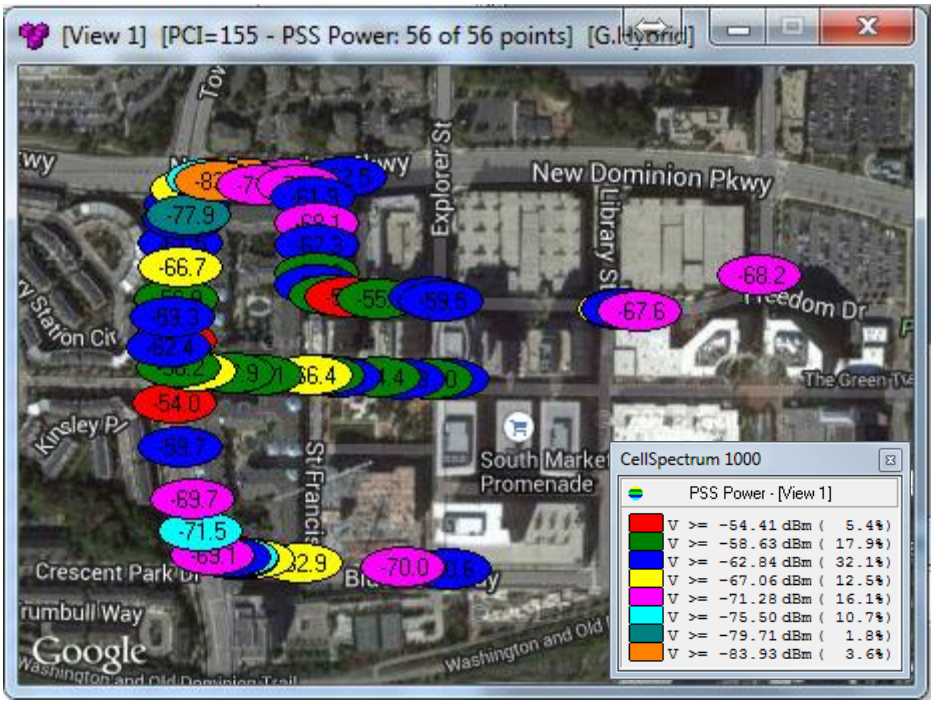
Presidents Park
The Green Trail
Chancery Station Cir
Crescent Park Dr
Kinsley Pl
Tryton Way
Logan Manor Dr
Trumbull Way
St Francis
South Market Promenade
Hyatt Park
Bluemont Way
Crescent Park Dr
Washington and Old Dominion Trail
CIA Reston
Sunset Hills Rd
Google

- **Reference Signal Received Power (RSRP):** it is the signal strength of a single Reference Signal resulting from the average of all received Reference Signals on a frame or a set of frames. This measurement is done after the Reference Signal is extracted using the respective Gold code for each antenna port. The average is done over all antenna ports. CellSpectrum does the average over 6 frames.

- **Reference Signal Received Quality (RSRQ):** it is an attempt to express the quality of the received signal, but its value should be taken with a grain of salt, as it expresses the ratio of the average extracted Reference Signal and the average of two sub-carriers that carry Reference Signals. It does include neighbor cell interference. CellSpectrum™ calculates the RSRQ in three different ways.
    - Full OFDM Symbols as specified by 3gpp
    - Only RE carrying RS in an OFDM symbol
    - Measured over the PBCH symbols (which should be fully loaded in principle)

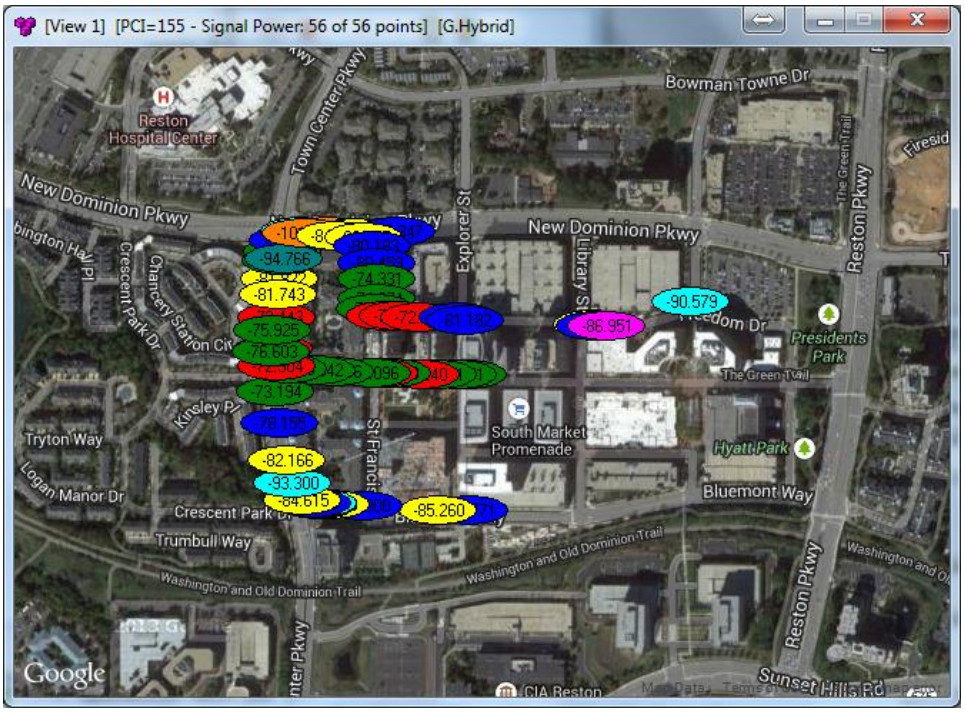


- **Primary Synchronization Signal (PSS) Power**: this parameter expresses the peak power of the PSS signal. Value is expressed per RE.

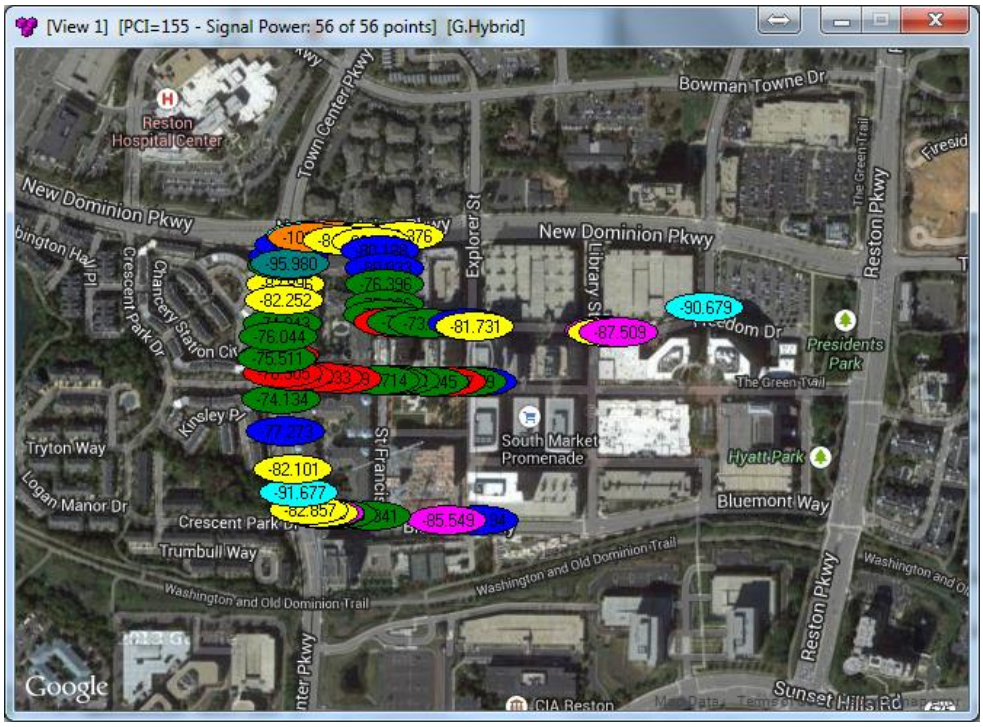


- **Signal Power (SP)**: The signal power is calculated over the REs carrying Reference Signals, after filtering. Figures below show values for antenna port 0 and 1, respectively.

Signal power for port 0

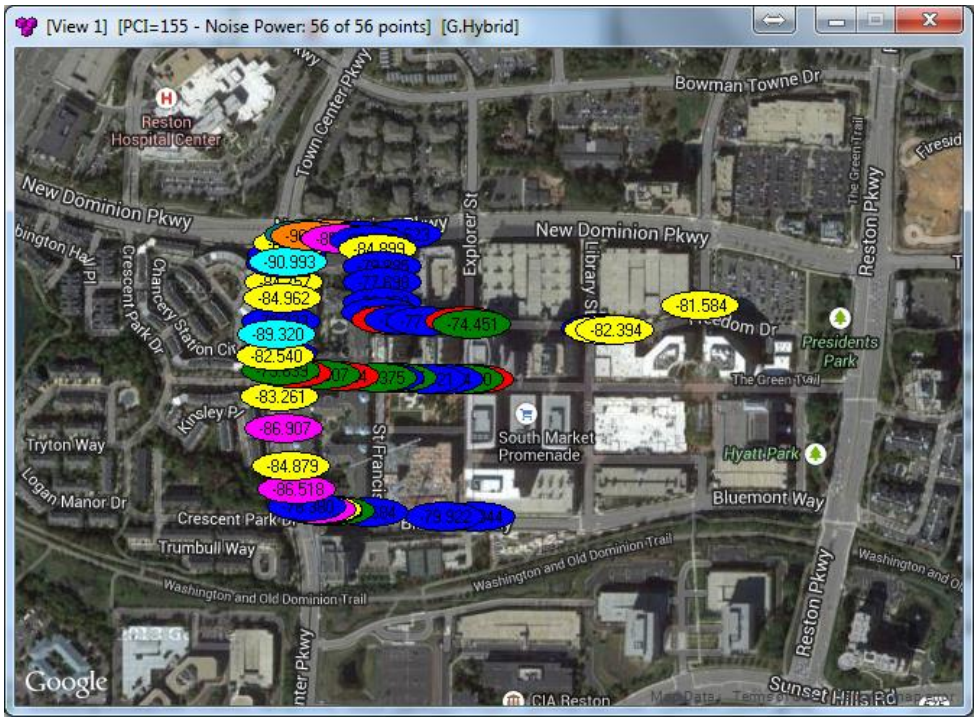


Signal power for port 1

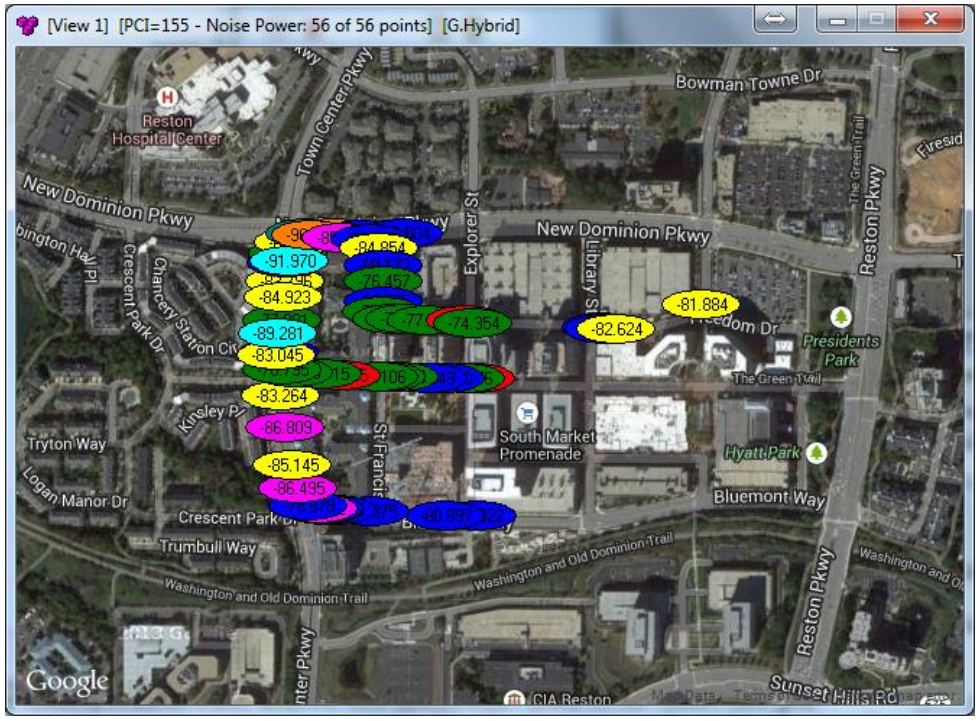


- **Noise and Interference Power (NIP):** The signal power is calculated over the REs carrying Reference Signals before filtering and then the filtered signal is subtracted. The noise power is the result. Figures below show values for antenna port 0 and 1, respectively.

Noise and Interference Power for port 0

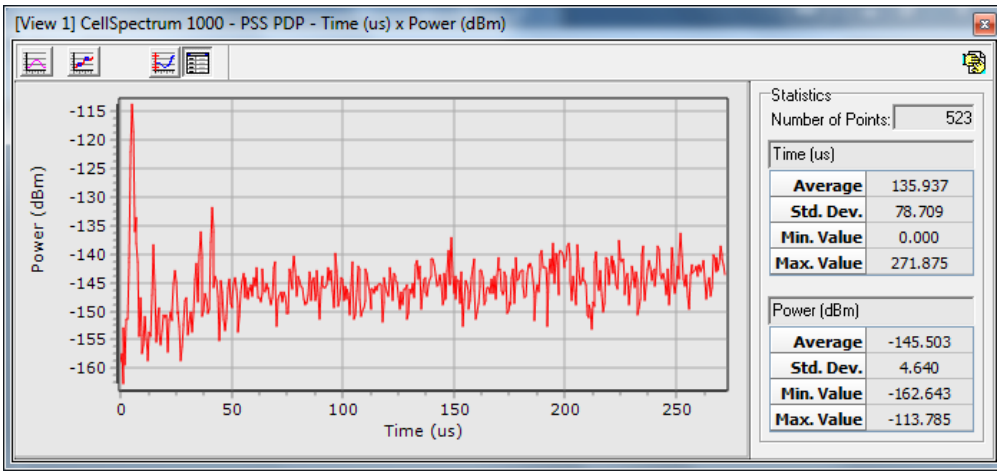


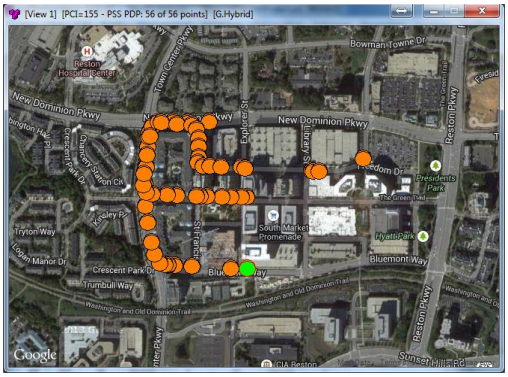
Noise and Interference Power for port 1



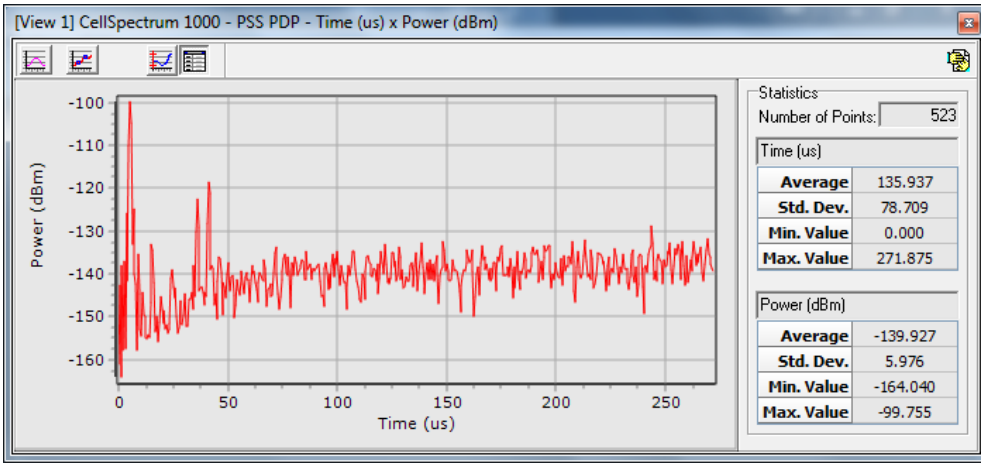
- **Primary Synchronization Signal Power Delay Profile (PSS PDP)**: this parameter expresses the multipath spread for a threshold specified by the user. Figures below show values three different points in the network. This parameter can be used to specify the Cyclic Prefix (CP).

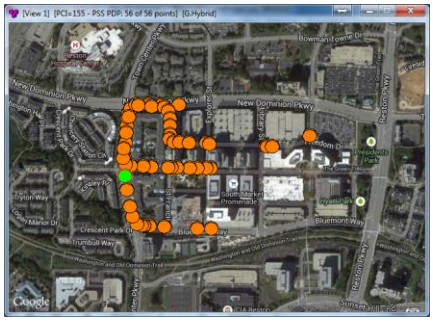
Primary Synchronization Signal Power Delay Profile point 1



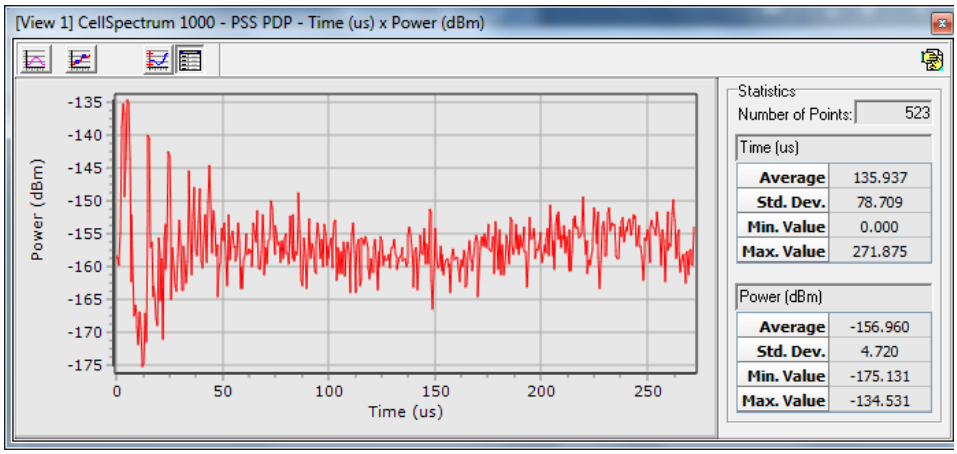


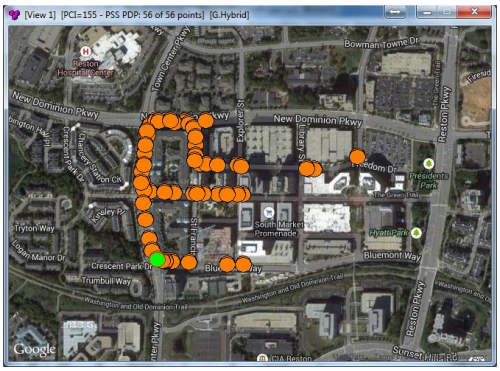
Primary Synchronization Signal Power Delay Profile point 2





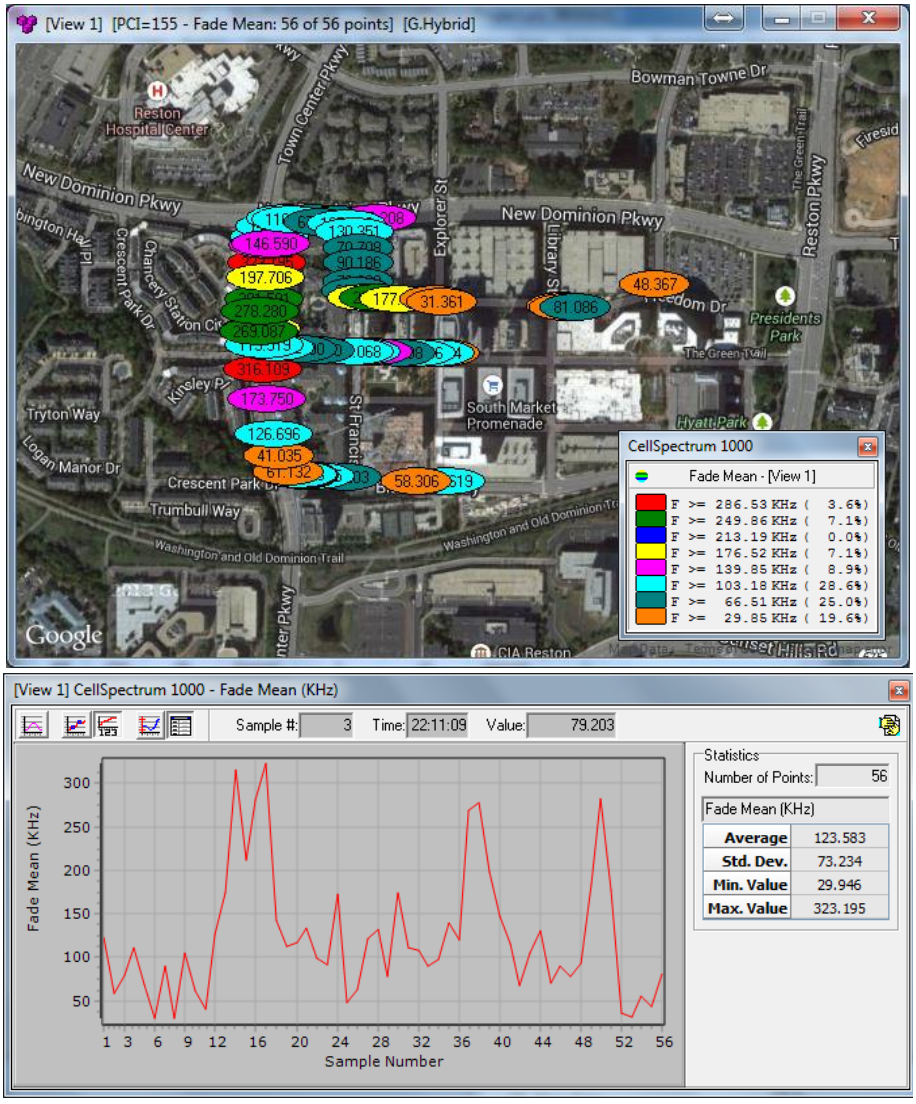
Primary Synchronization Signal Power Delay Profile point 3



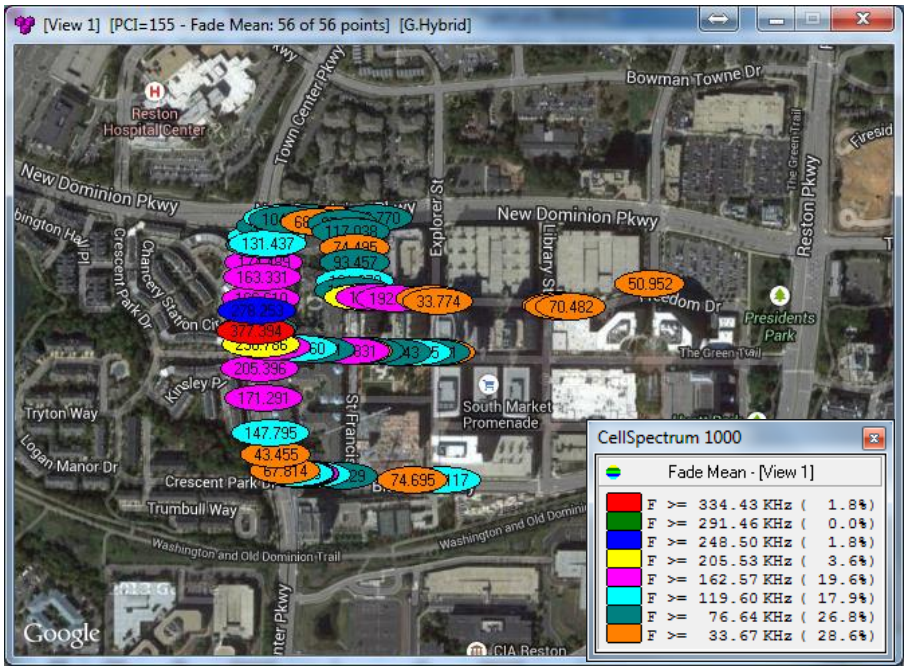


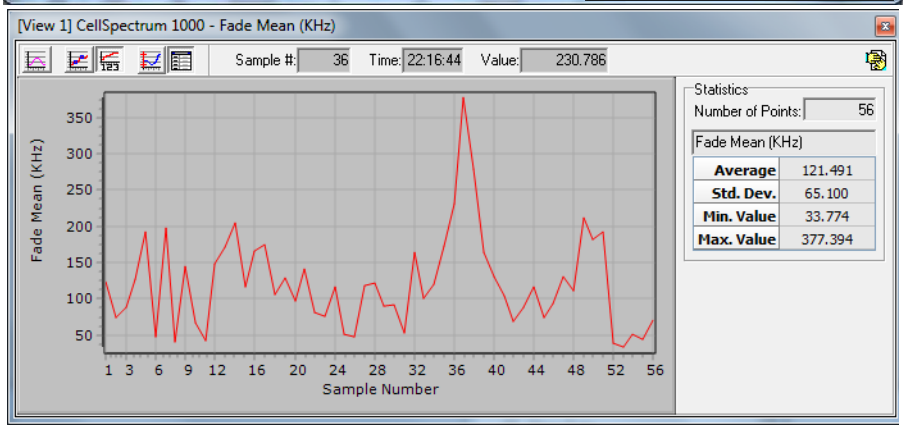
- **Fade Mean:** this parameter expresses the mean frequency fading duration in kHz. . Figures below show values for antenna port 0 and 1, respectively.
- **Fade deviation**: this parameter expresses the standard deviation of the fade.

Fade Mean port 0



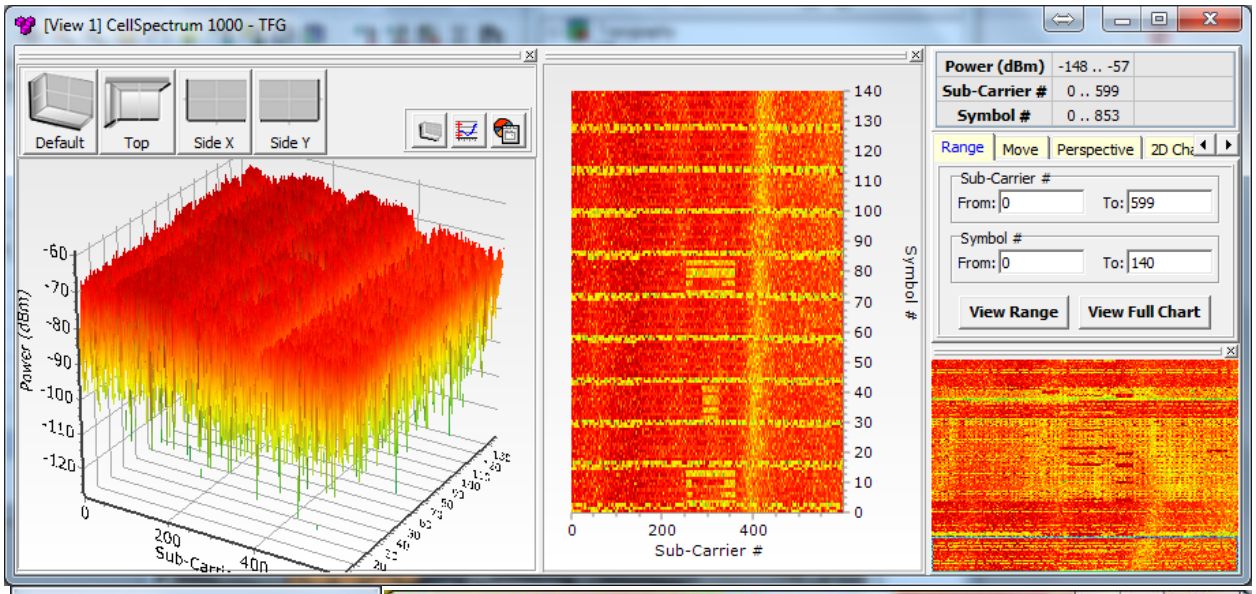
Fade Mean port 1

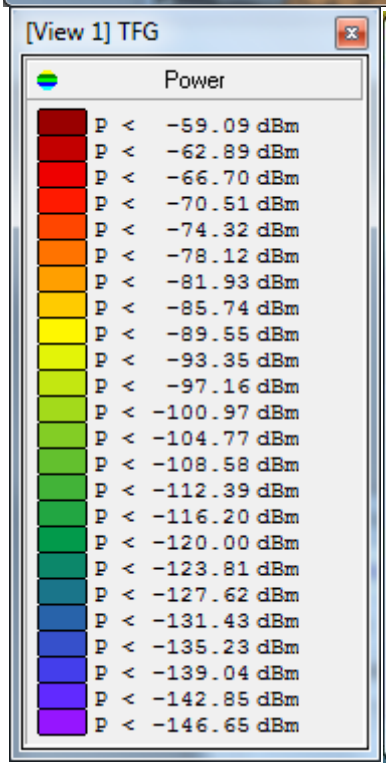


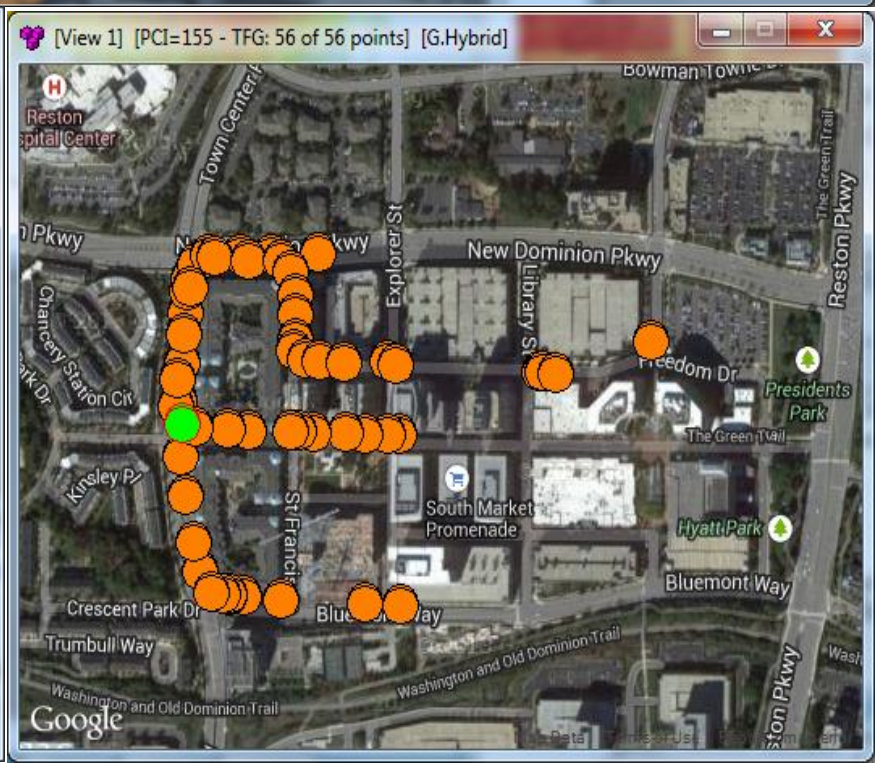


- **Received Time Frequency Grid (TFG):** Matrix with the power of all Resource Elements (RE) of a frame as received.

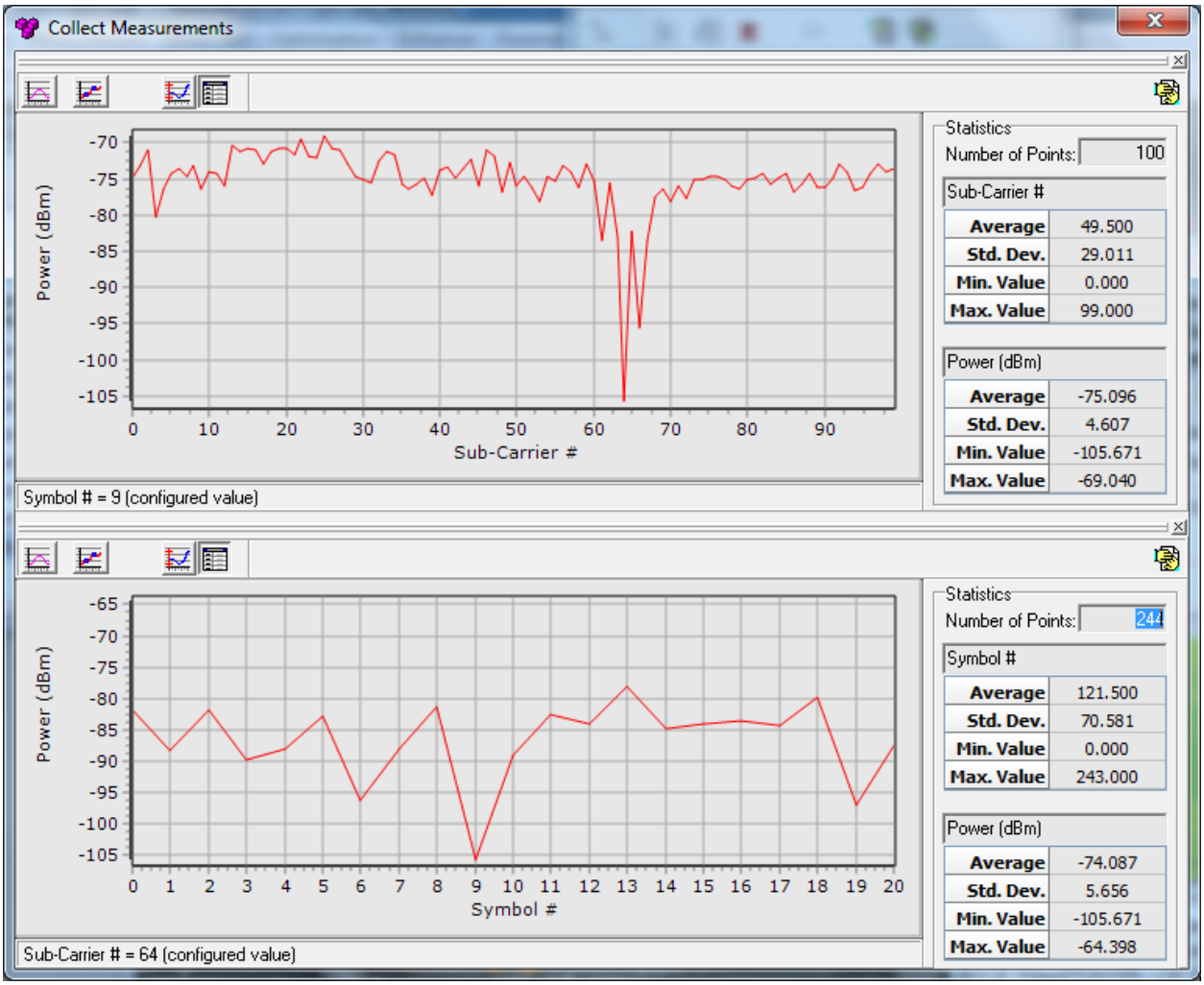
Received Time Frequency Grid point 1



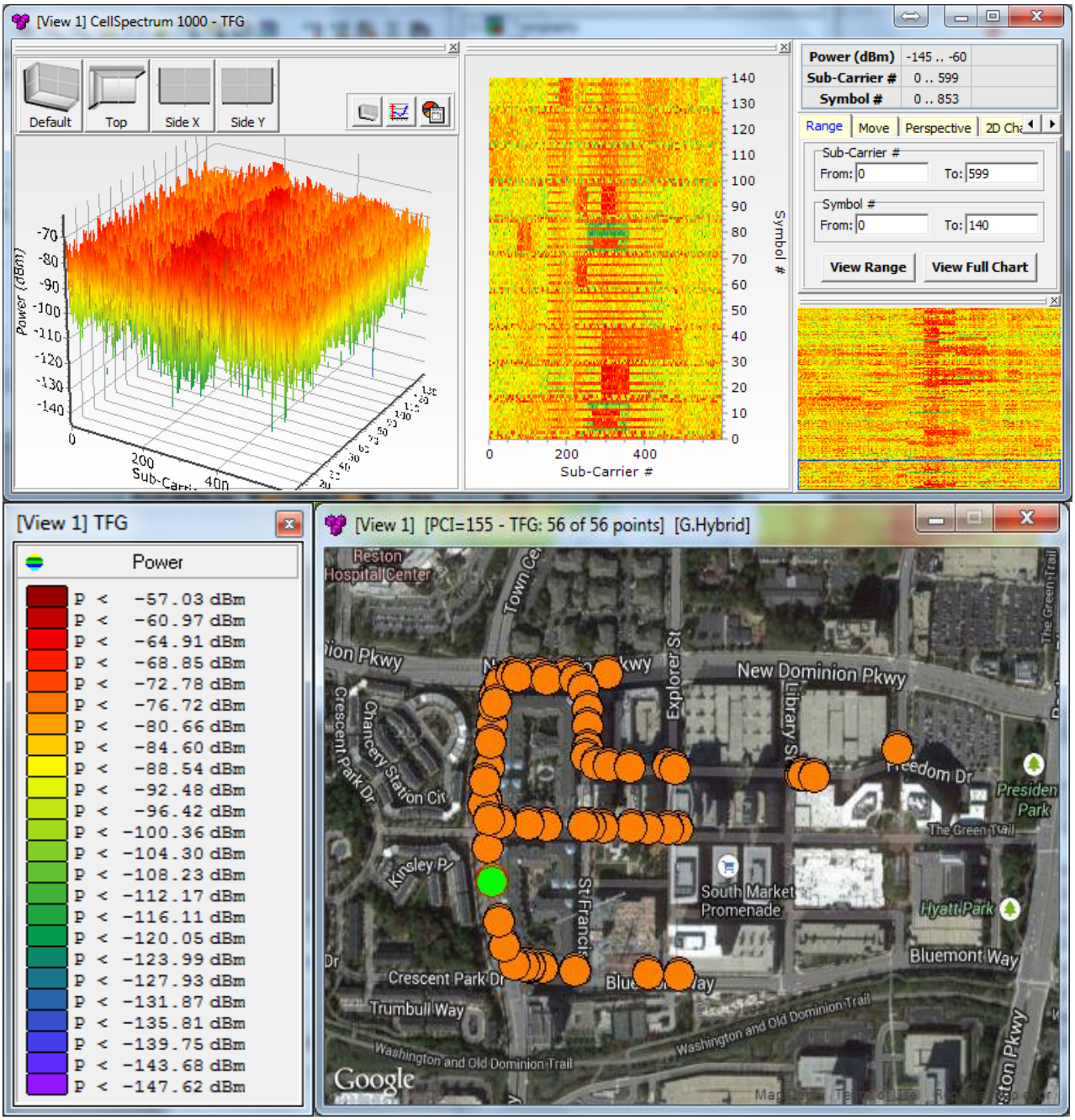




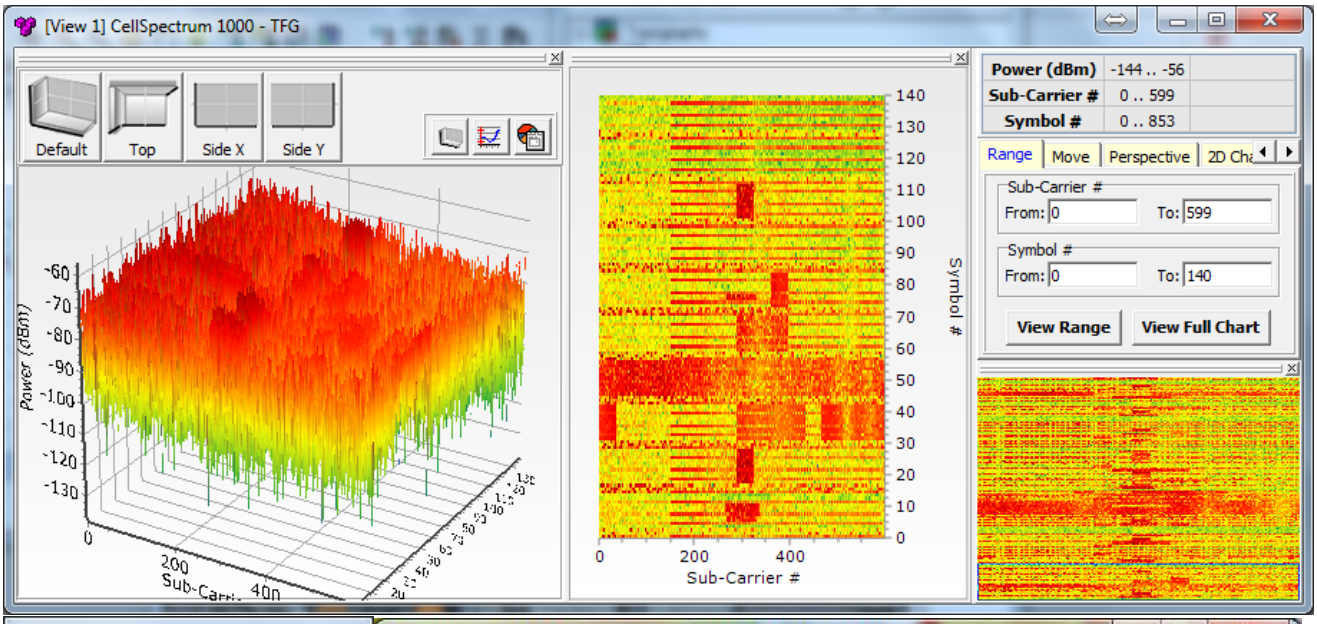
2D cut at symbol 9 and sub-carrier 64, respectively

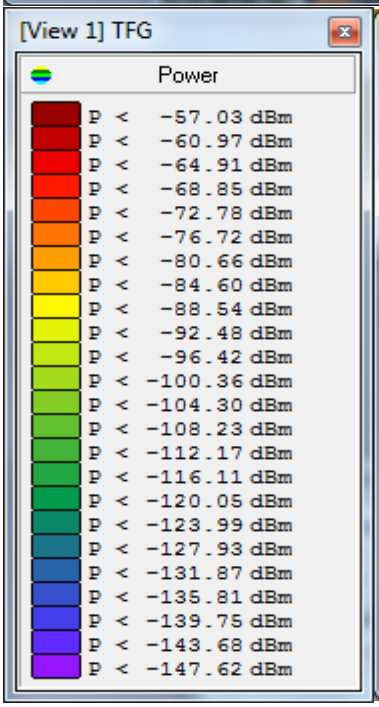


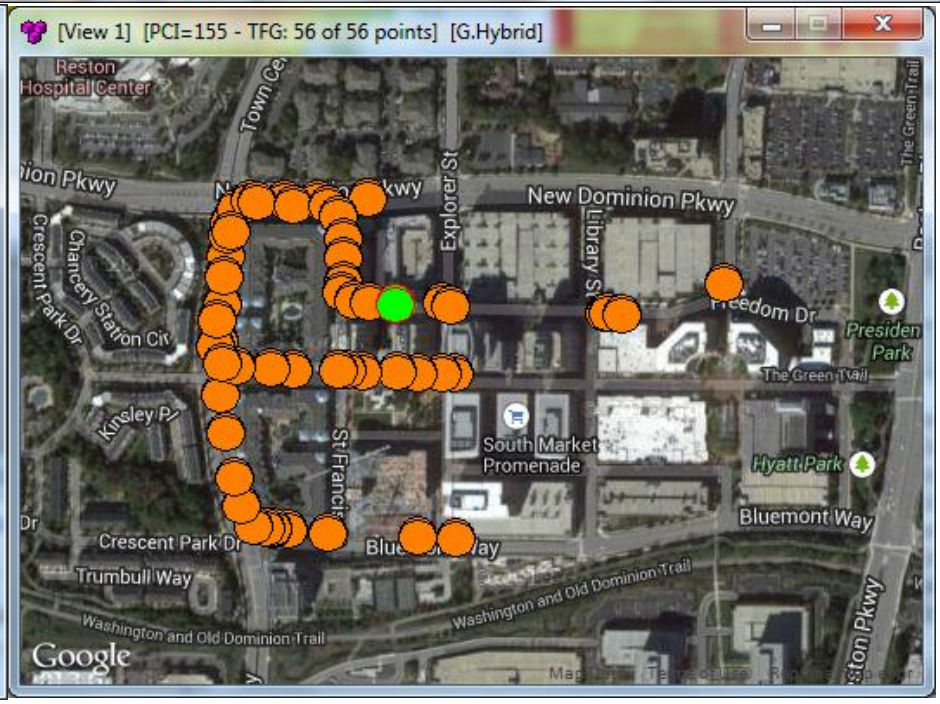
Antenna port 0, point 2



Antenna port 0, point 3

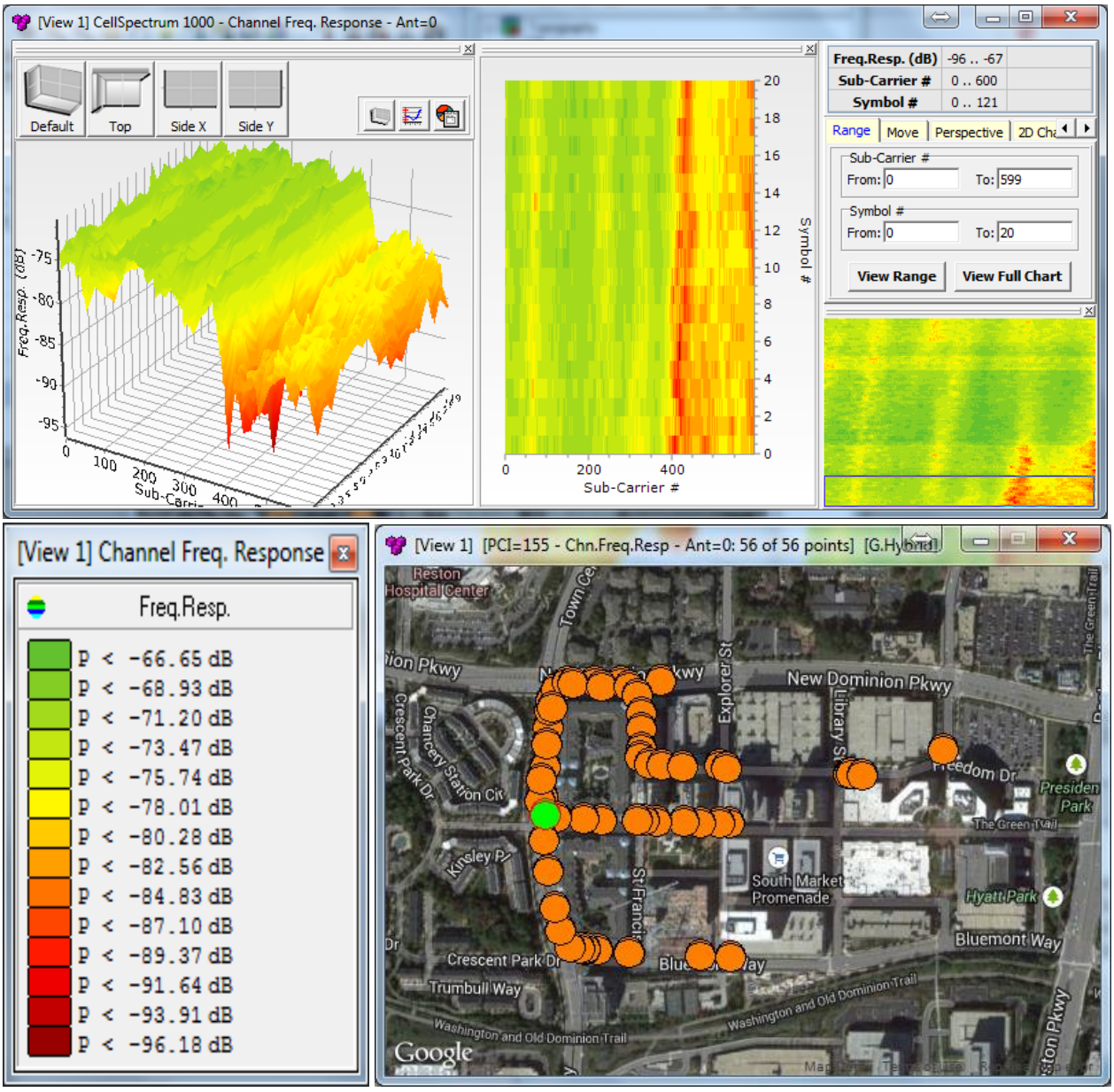




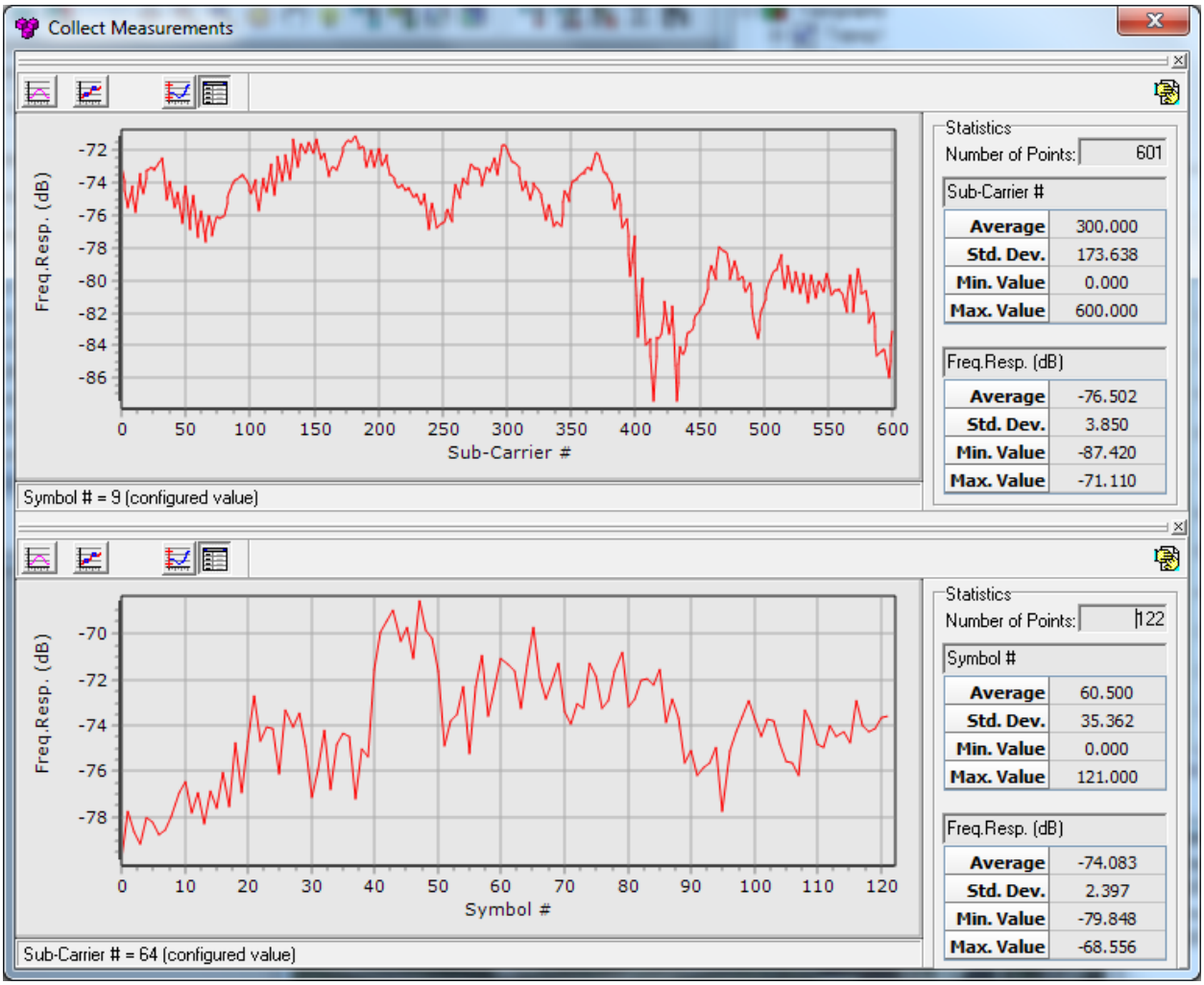


- **Channel Frequency Response (CFR)**: Matrix with the power corrections to be applied to all Resource Elements (RE) of a frame. This matrix is calculated for the Resource Elements carrying Reference Signals. It is shown for 3 measured points for the two antennas, respectively.

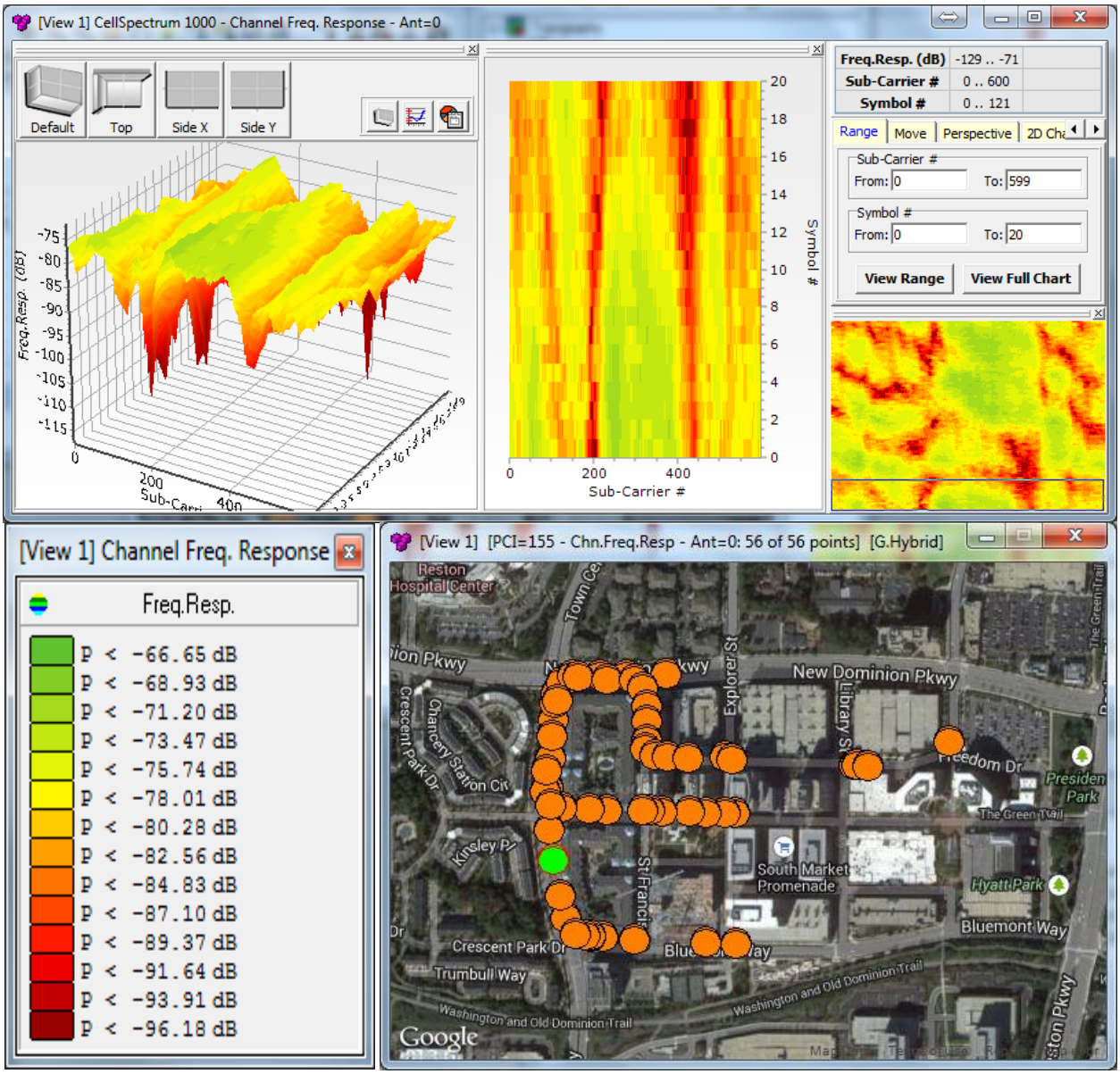
Antenna port 0, point 1



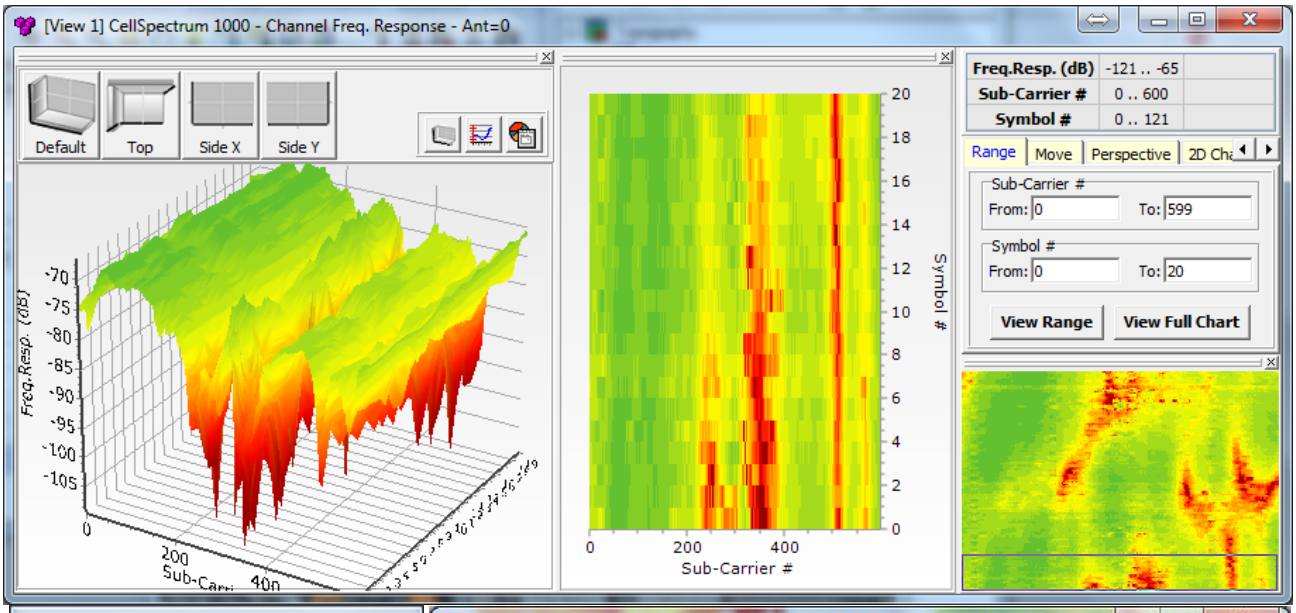
2D cut at symbol 9 and sub-carrier 64, respectively

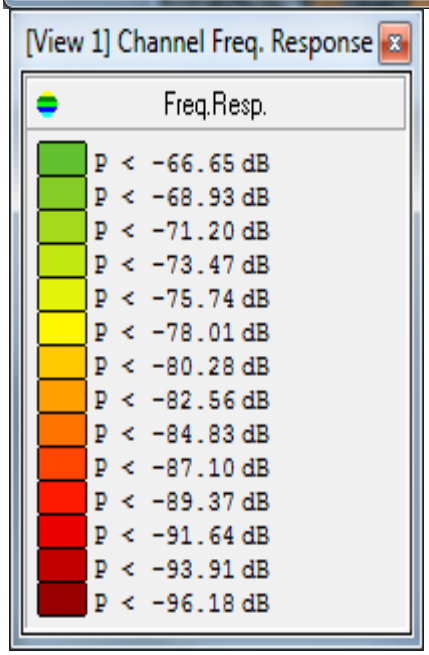


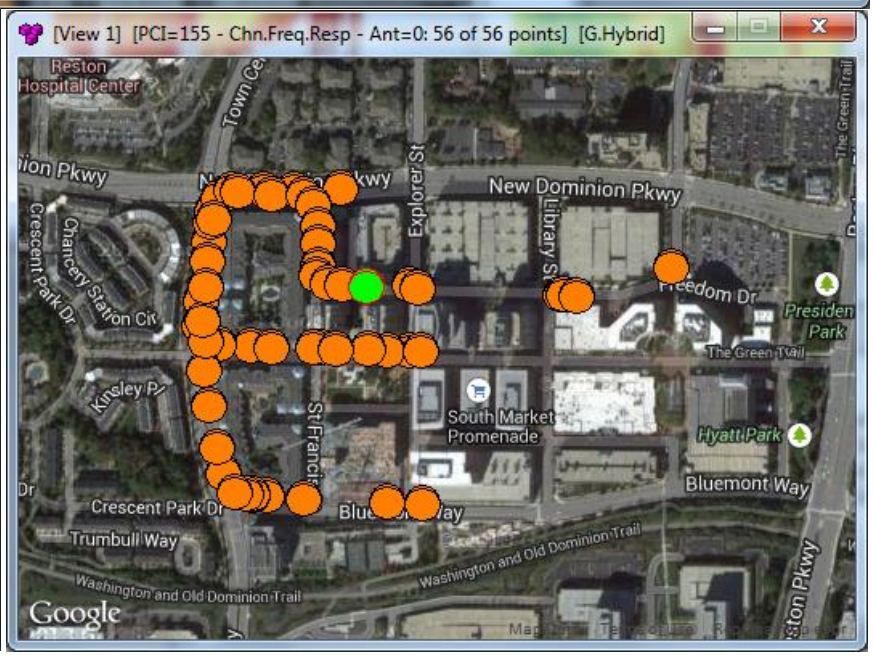
Antenna port 0, point 2



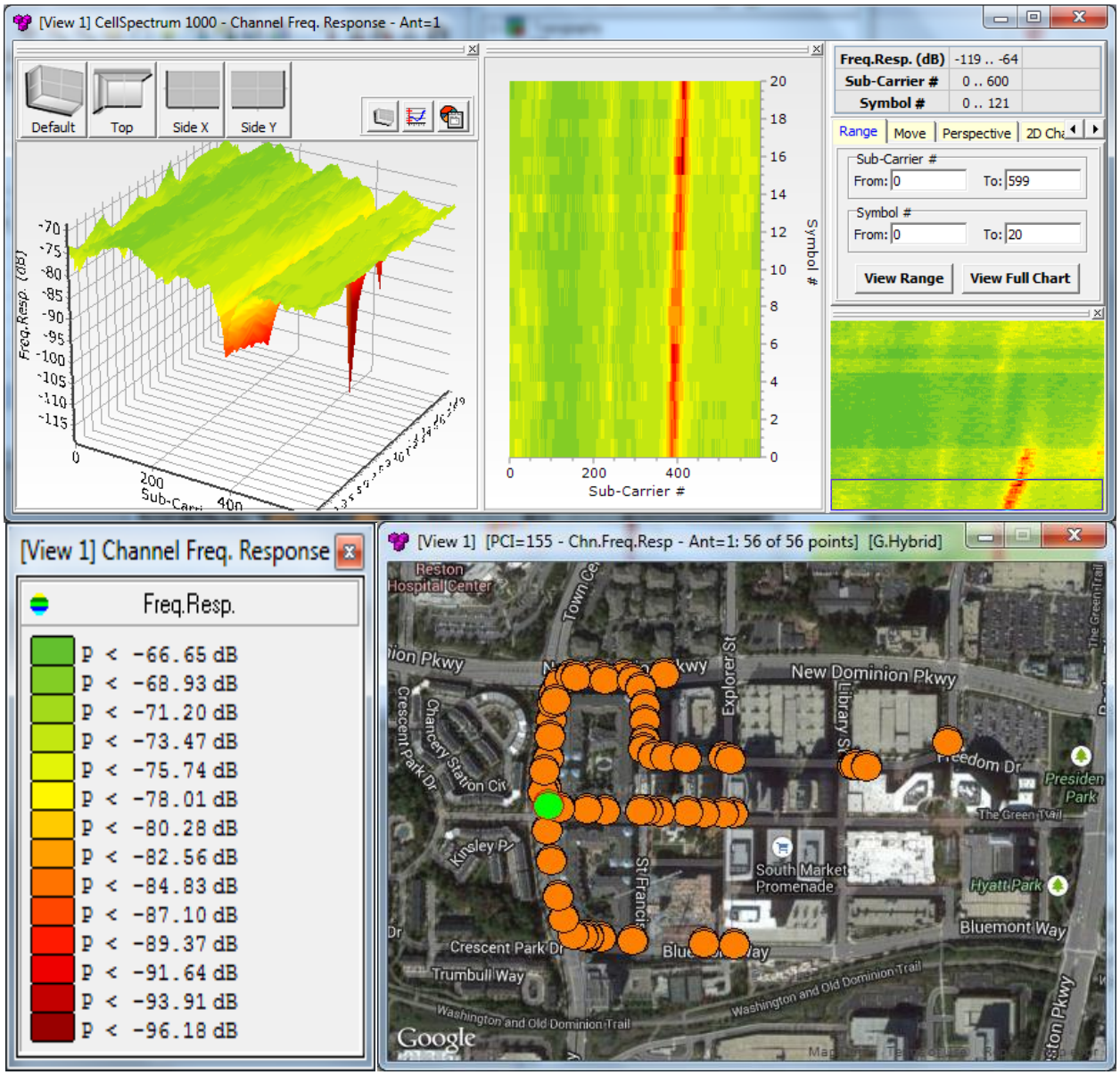
Antenna port 0, point 3



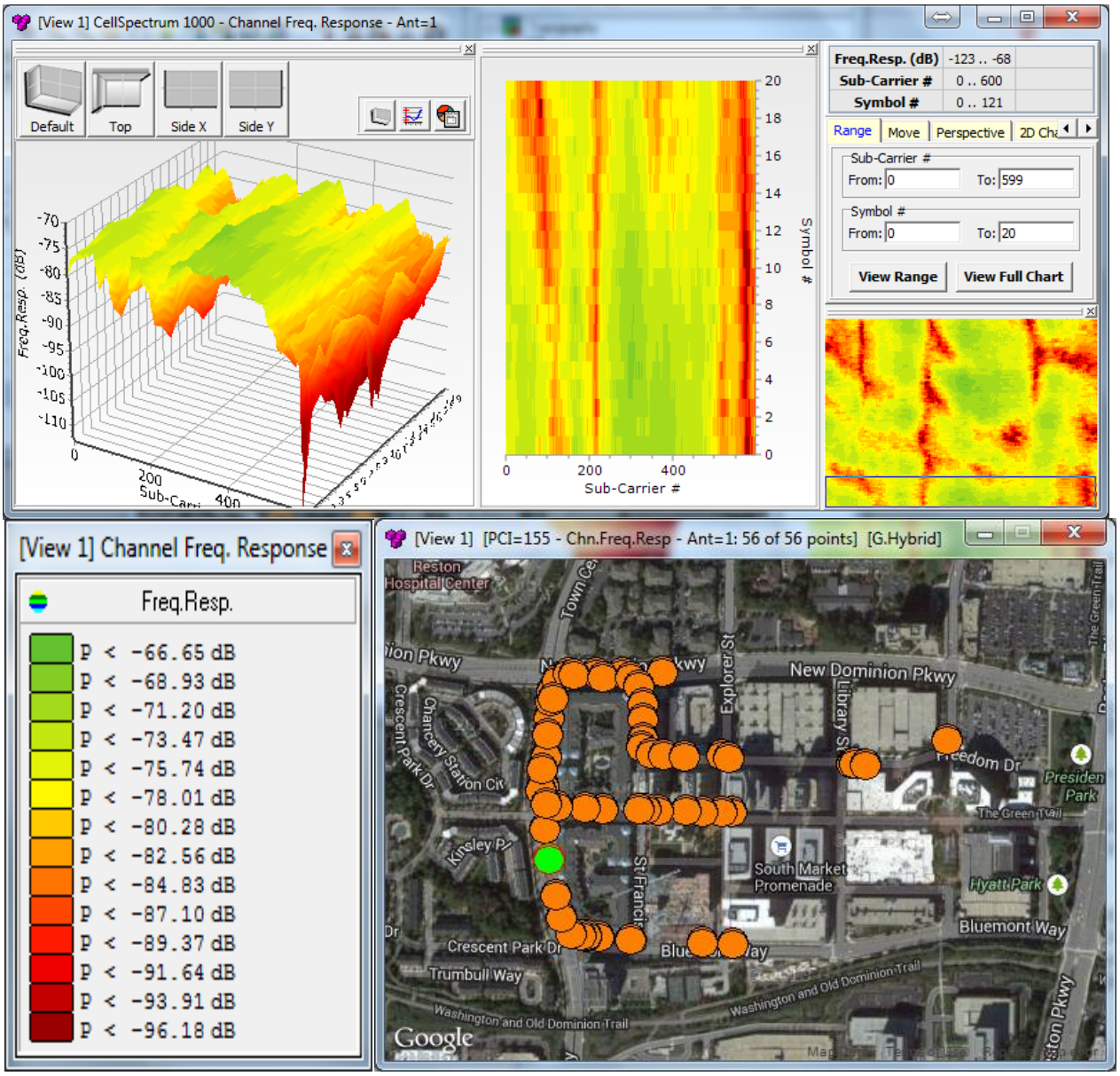




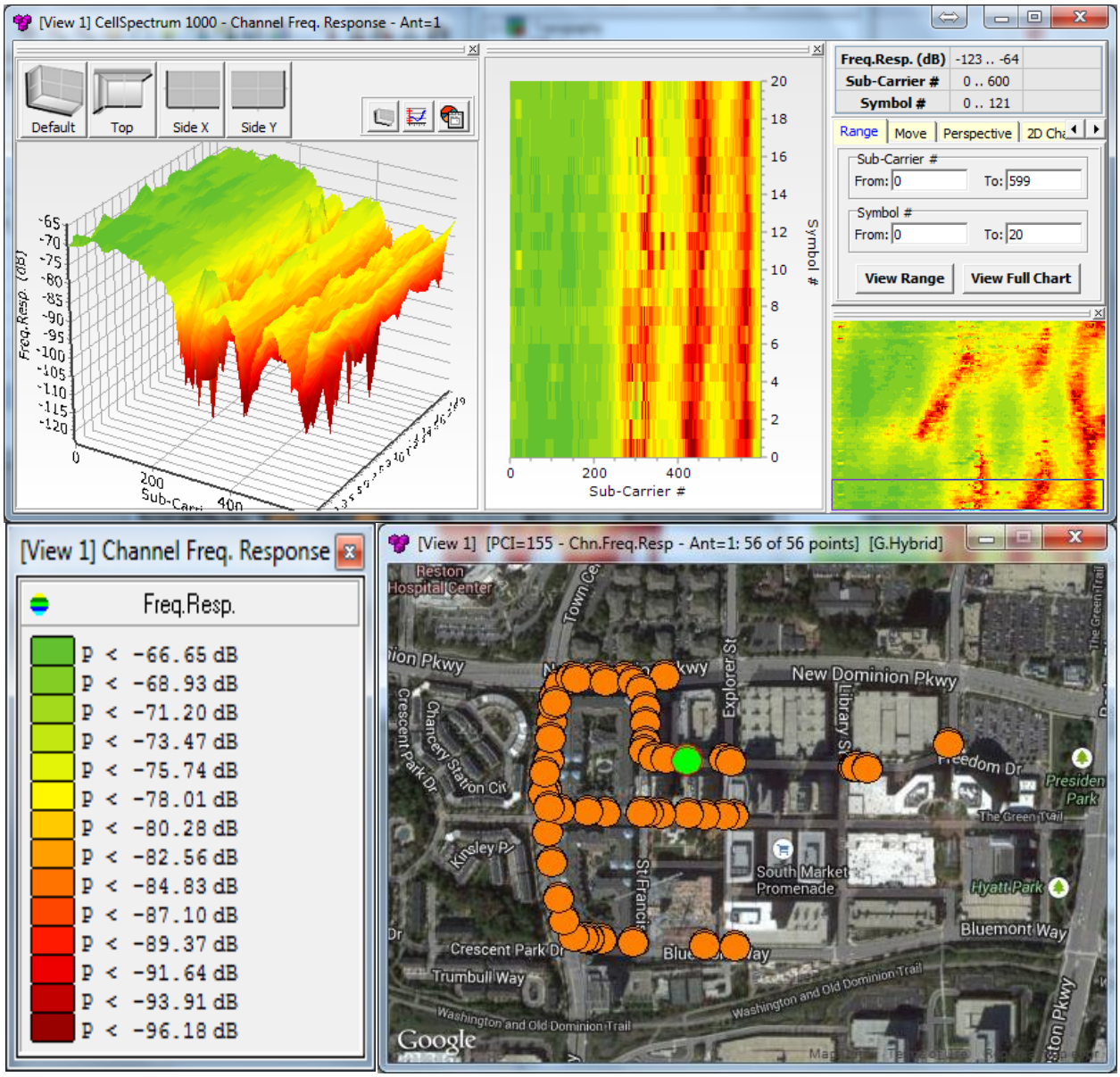
Antenna port 1, point 1



Antenna port 1, point 2

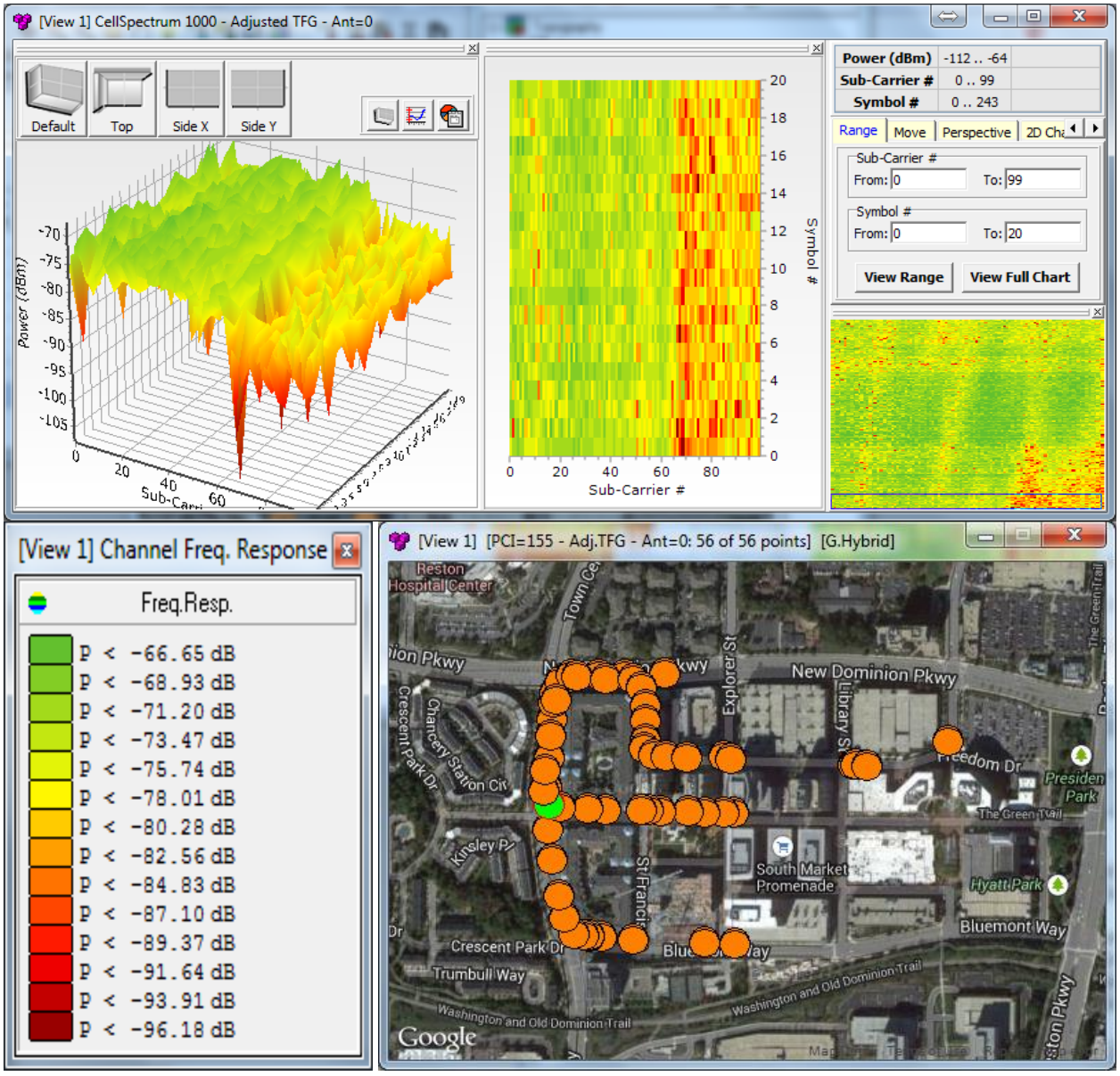


Antenna port 1, point 3

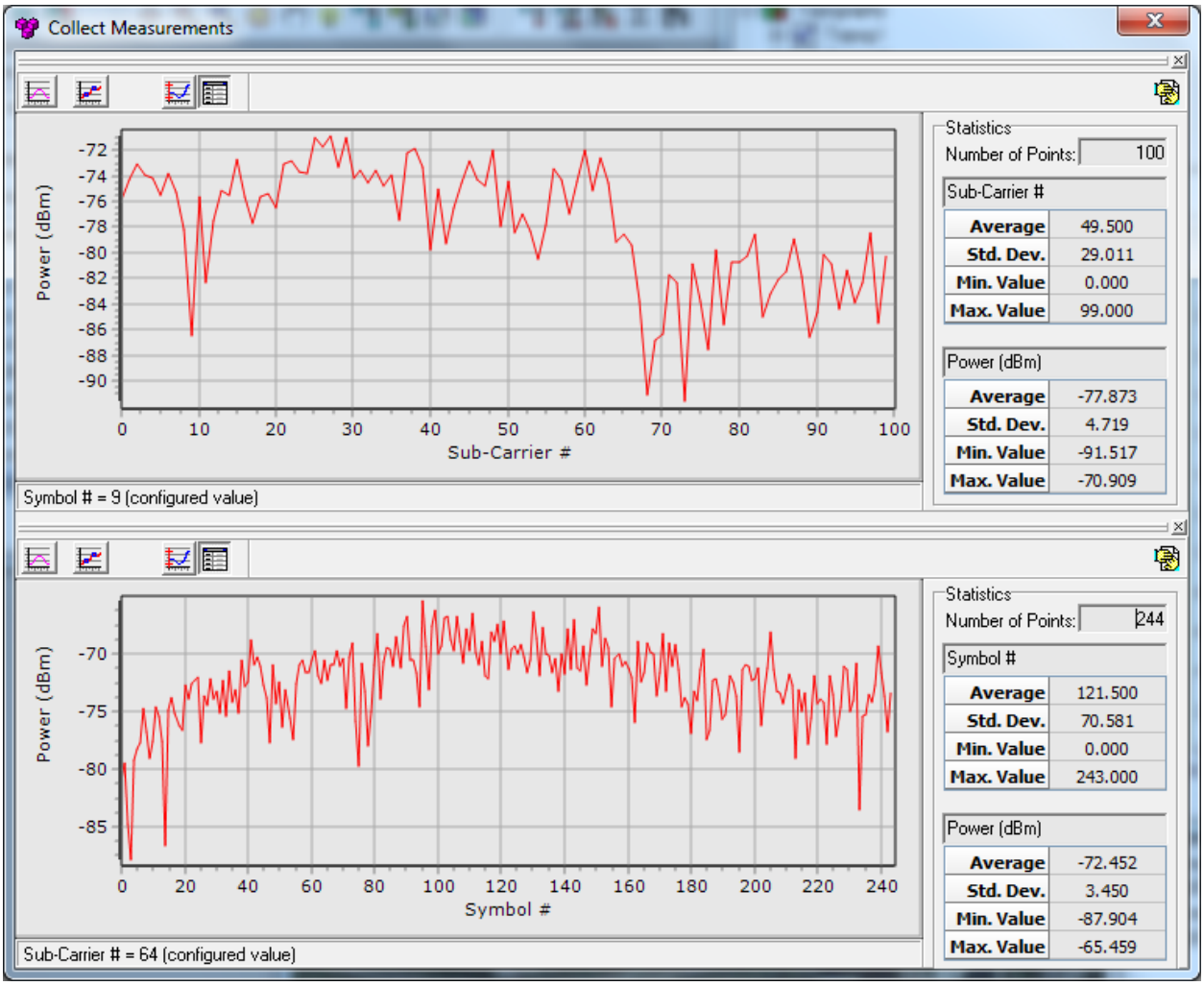


- **Adjusted Time Frequency Grid (ATFG):** Matrix with the power of all Resource Elements (RE) of a frame after equalization with the Reference Signals

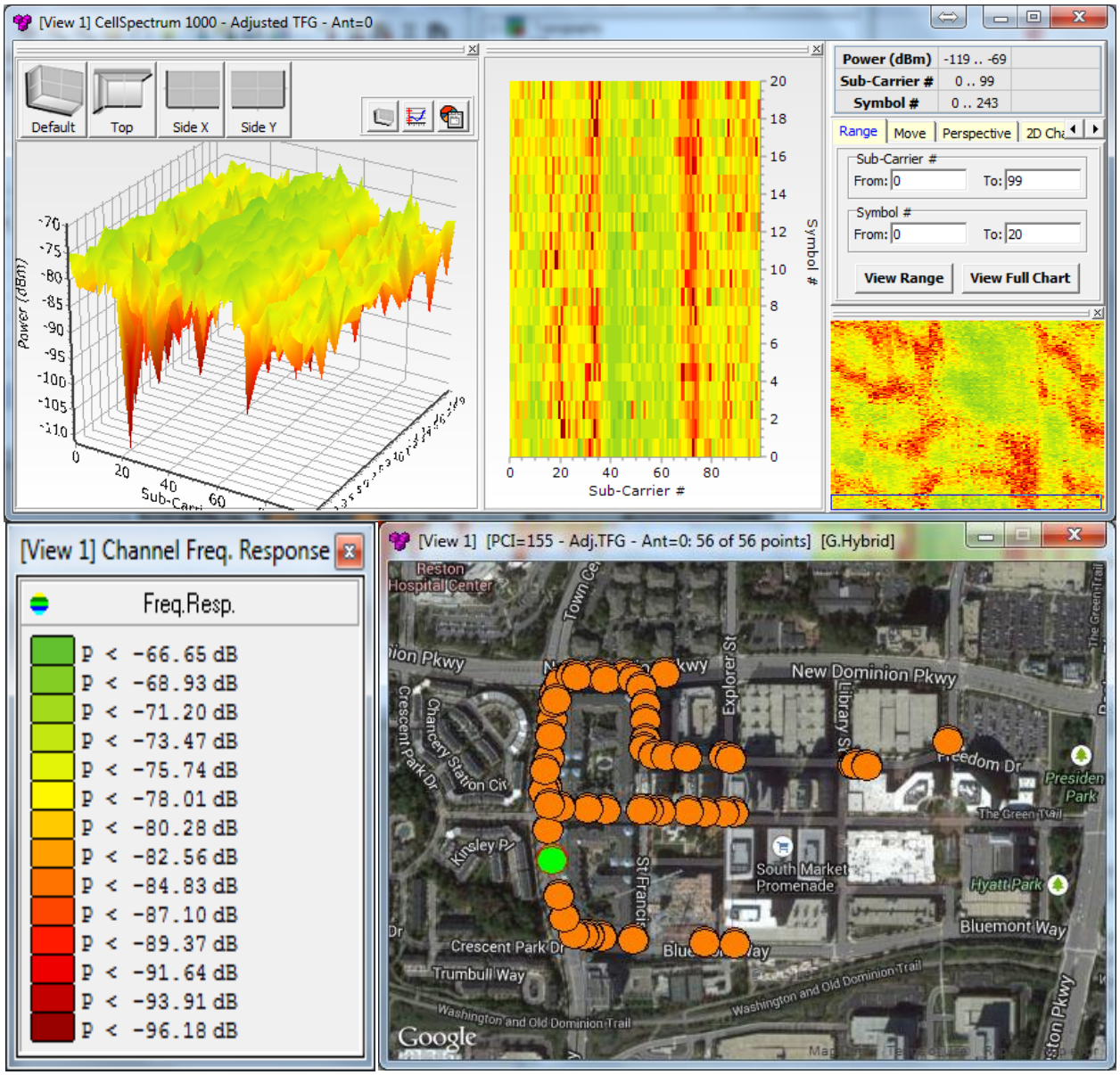
Adjusted Time Frequency port 0, point1



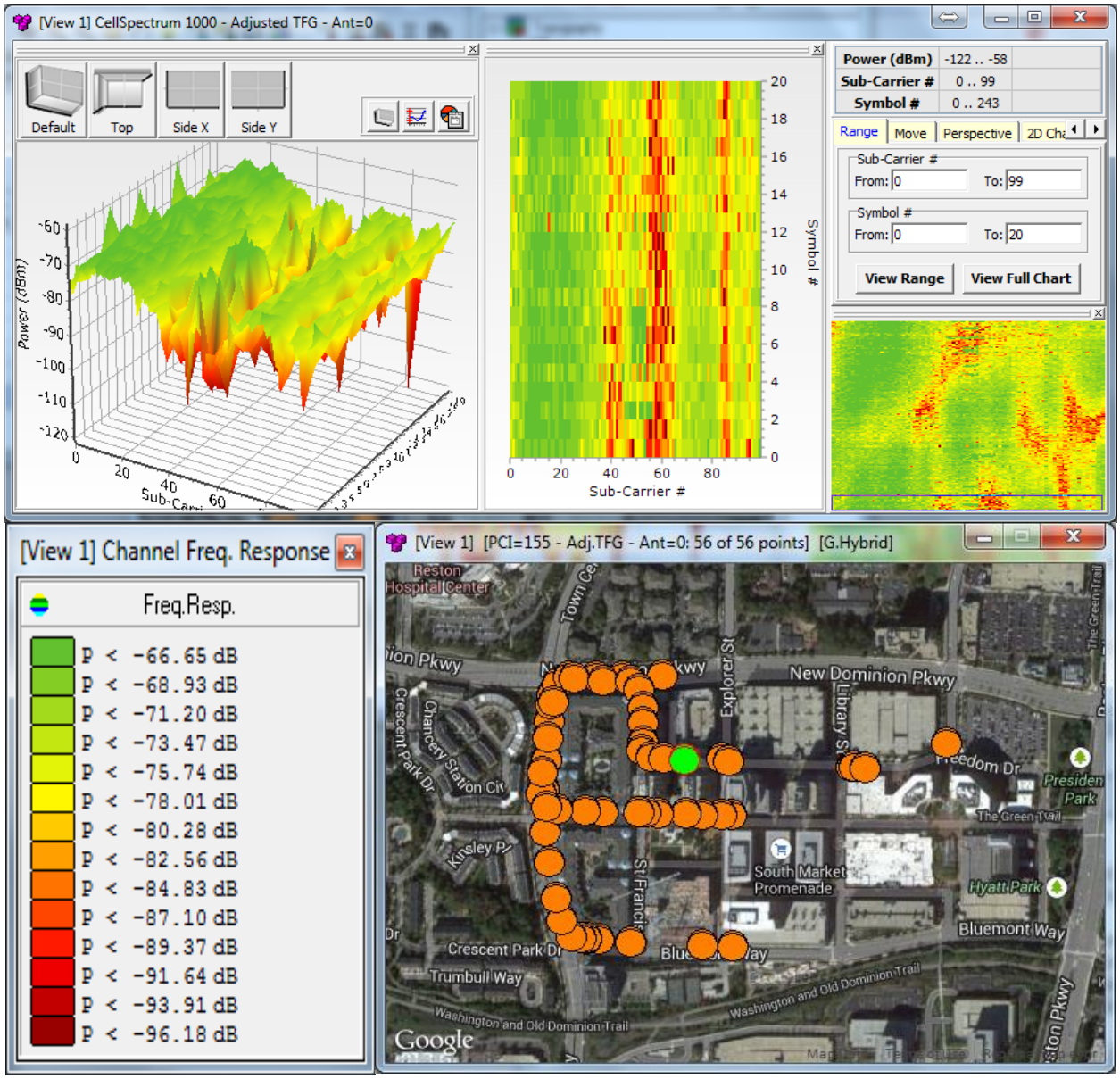
2D cut at symbol 9 and sub-carrier 64, respectively



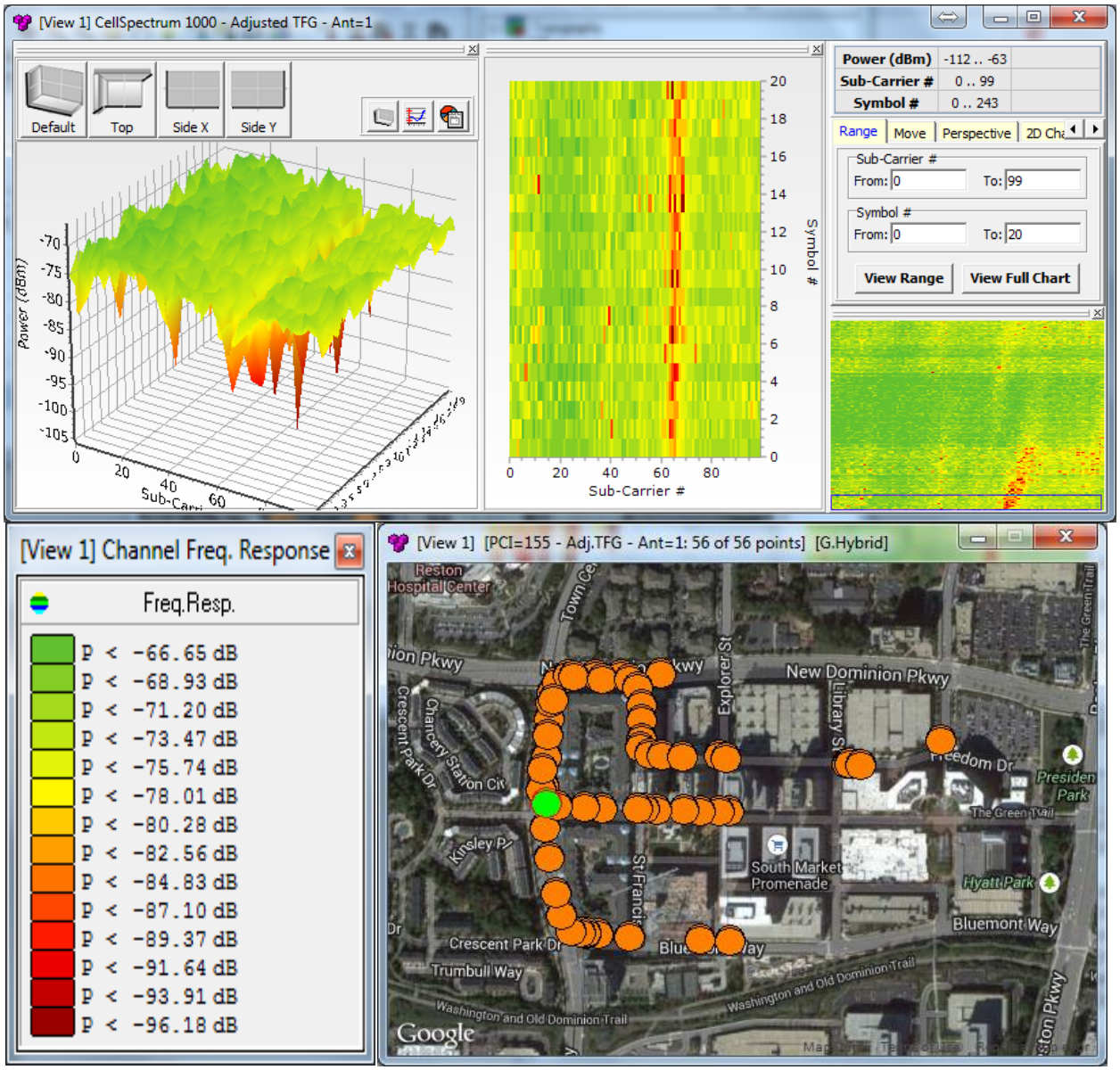
Adjusted Time Frequency port 0, point2



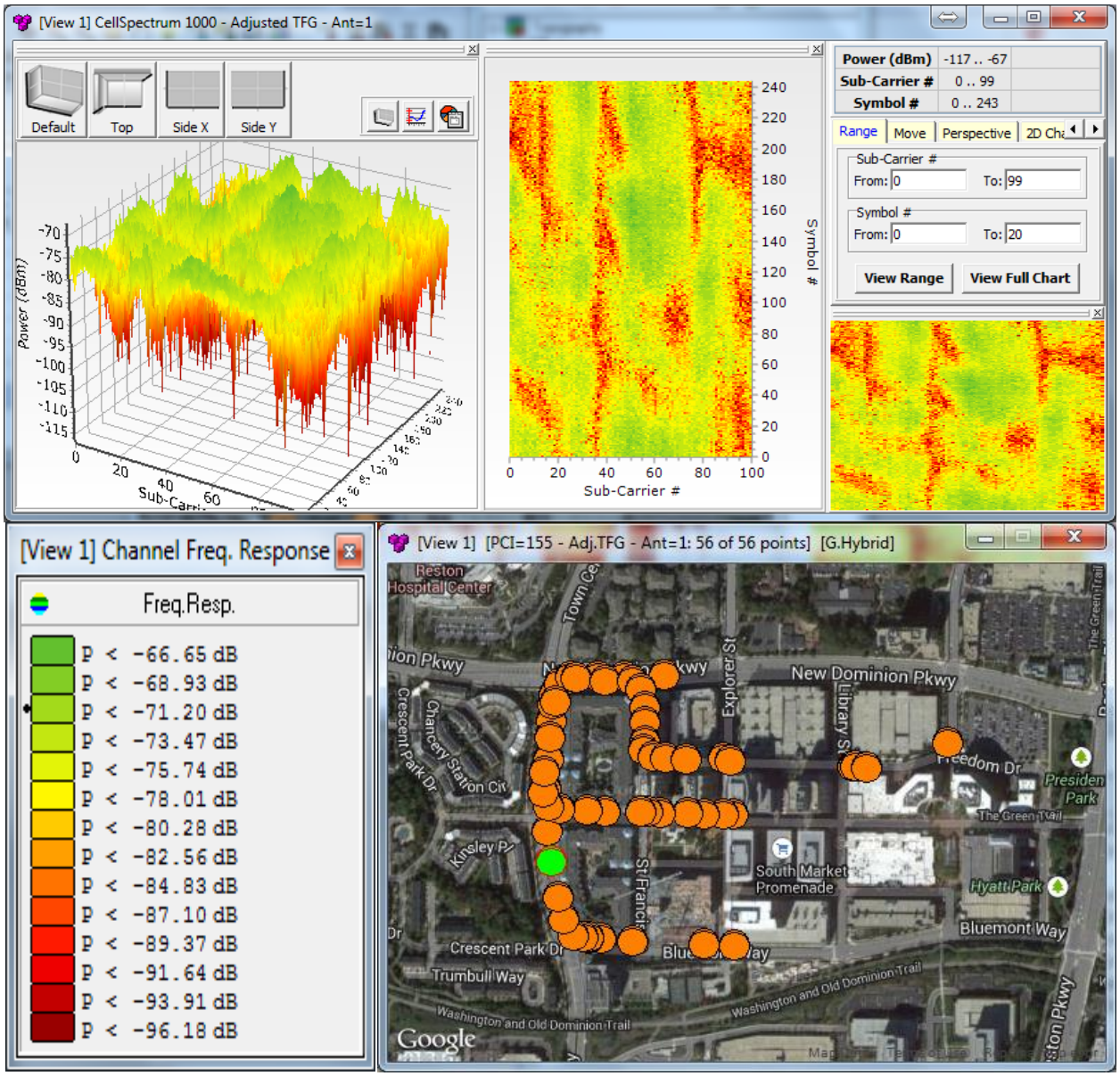
Adjusted Time Frequency port 0, point 3



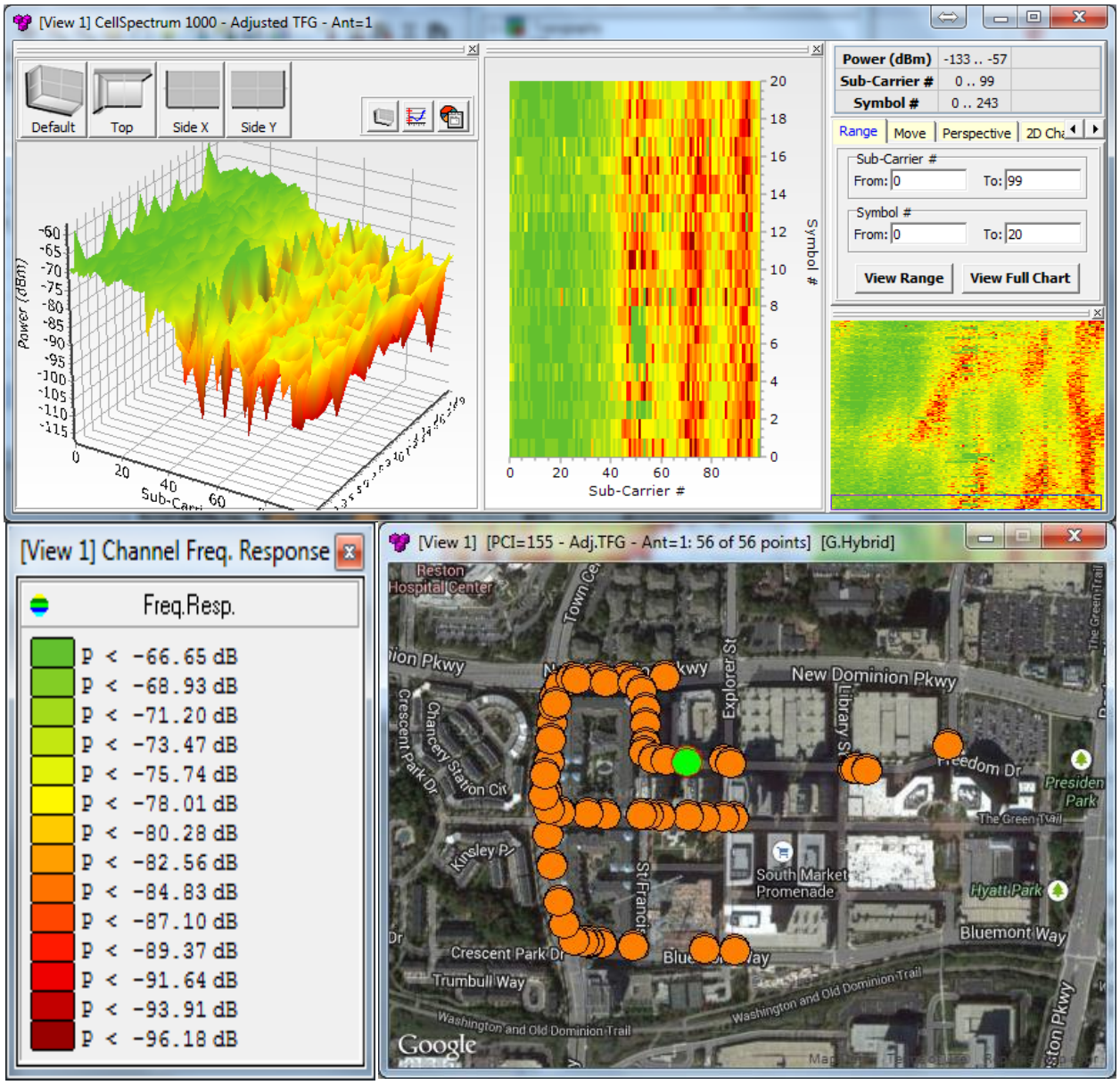
Adjusted Time Frequency port 1, point1



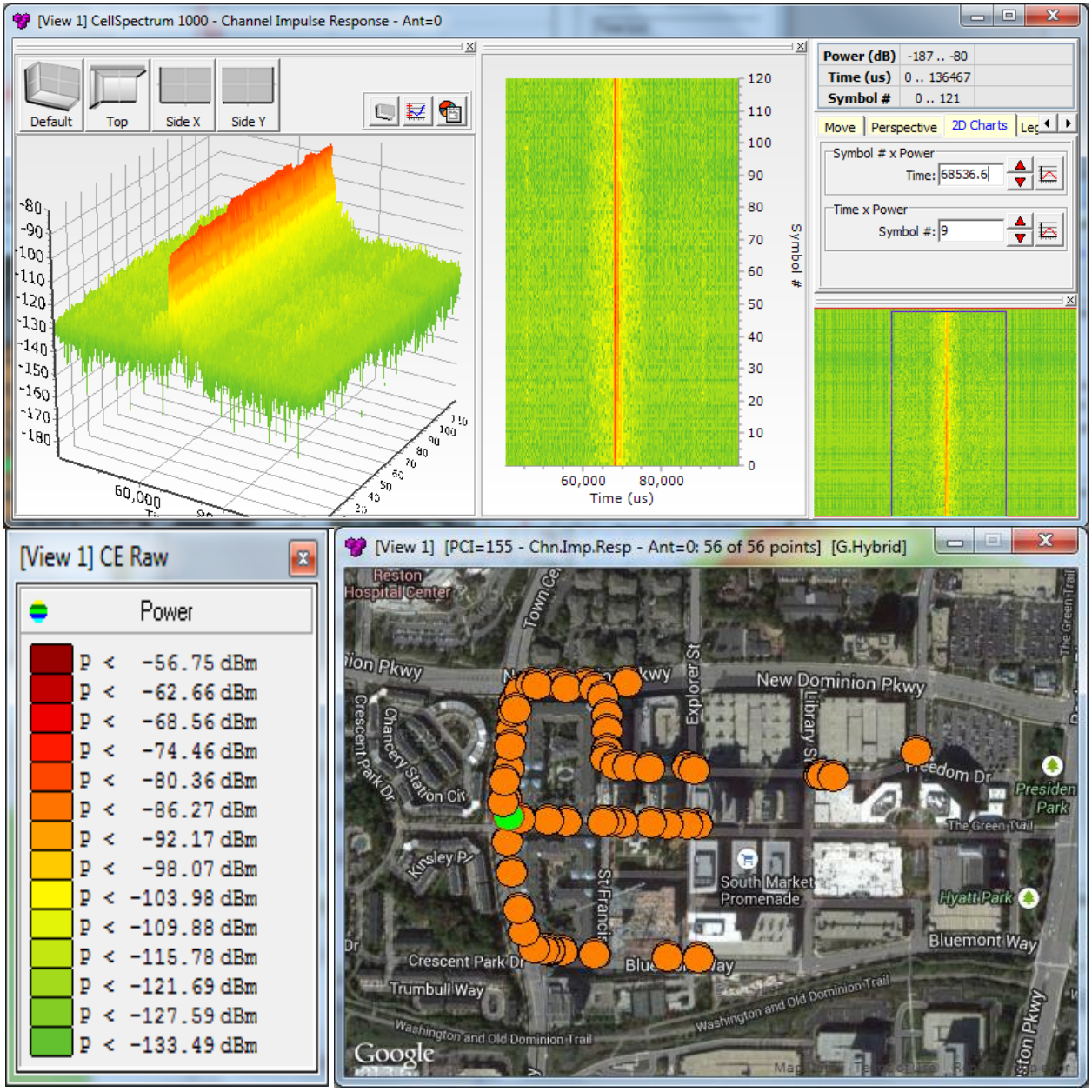
Adjusted Time Frequency port 0, point2



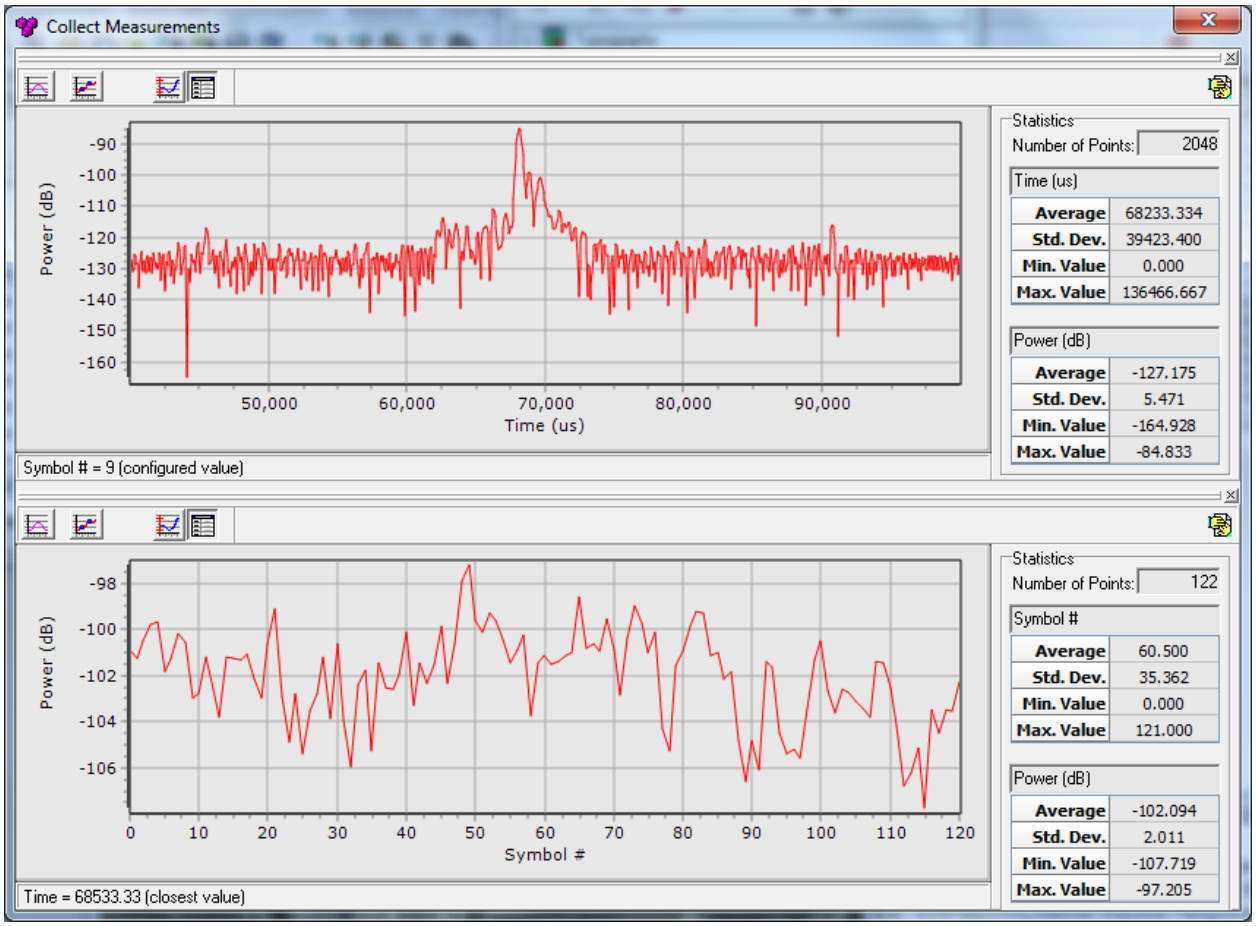
Adjusted Time Frequency port 0, point 3



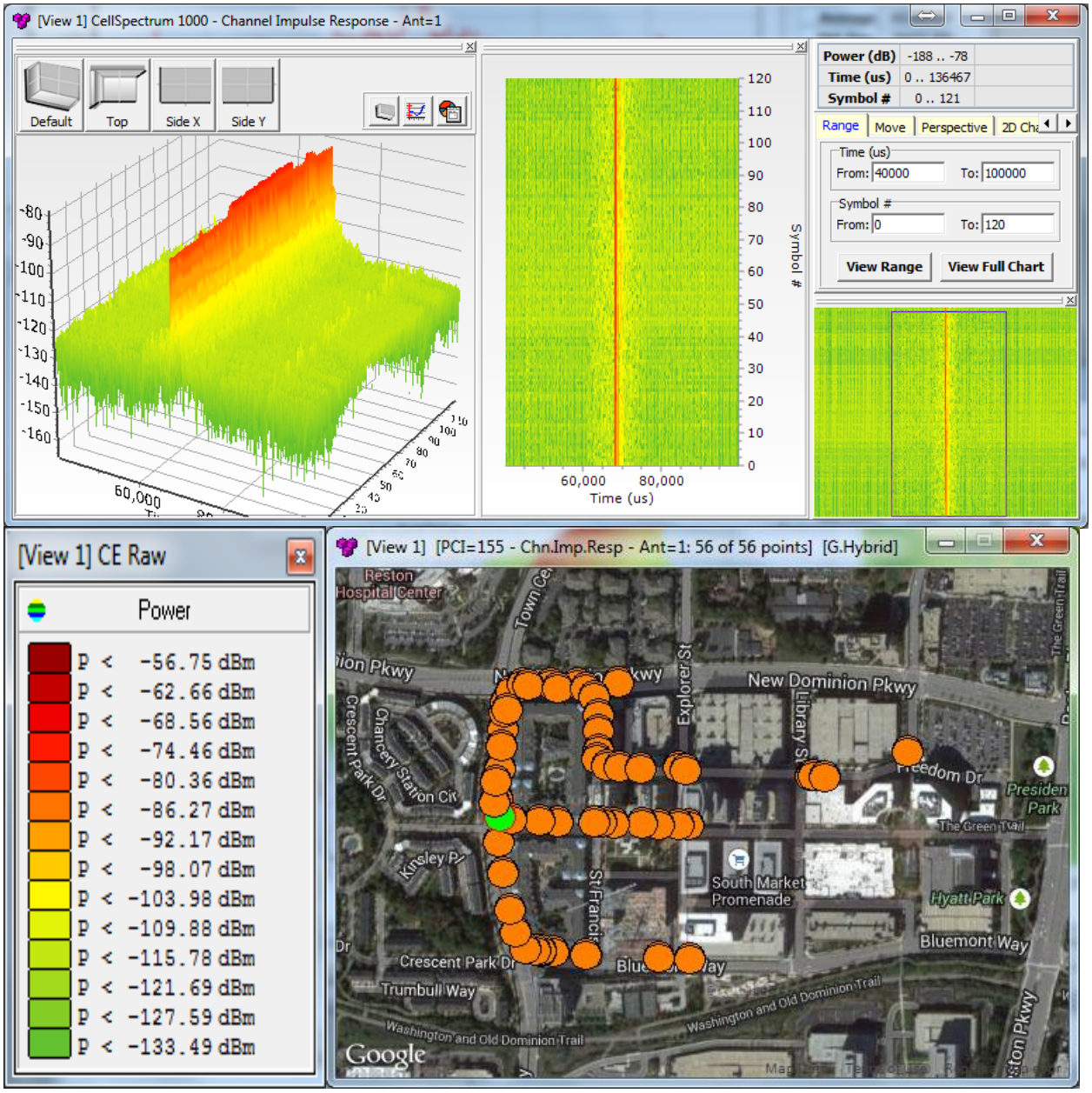
- **Channel Impulse Response (IR):** Matrix with the impulse response per frame Resource Element Antenna port 0



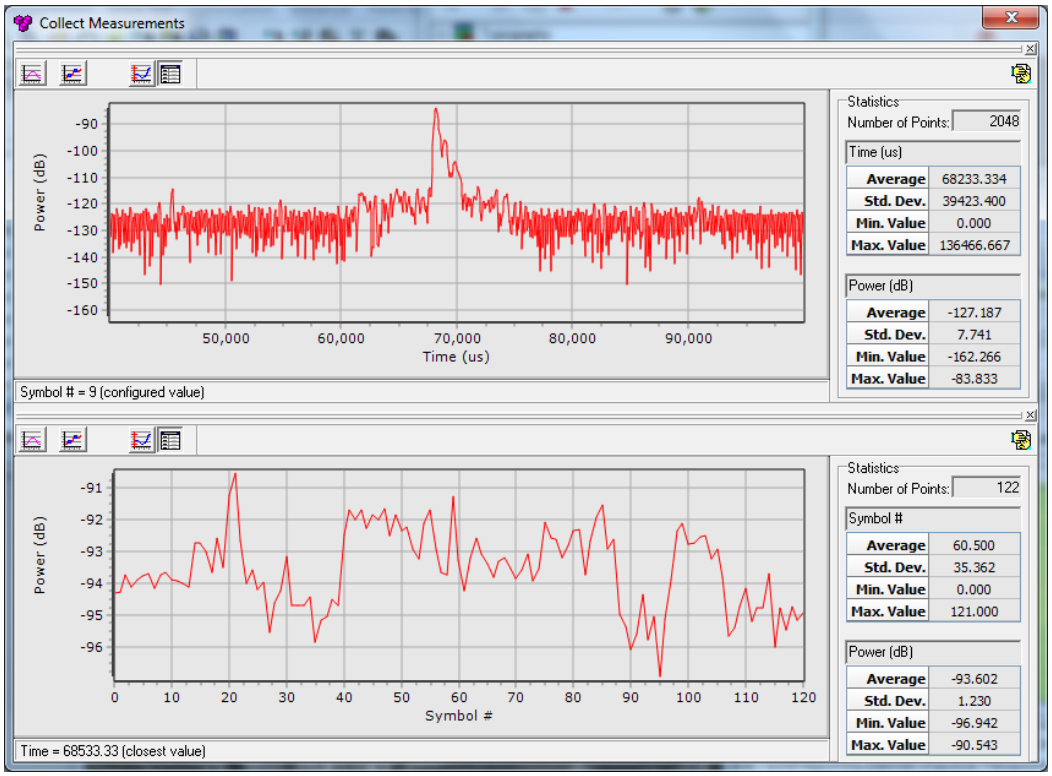
2D cut at symbol 9 and sub-carrier 64, respectively



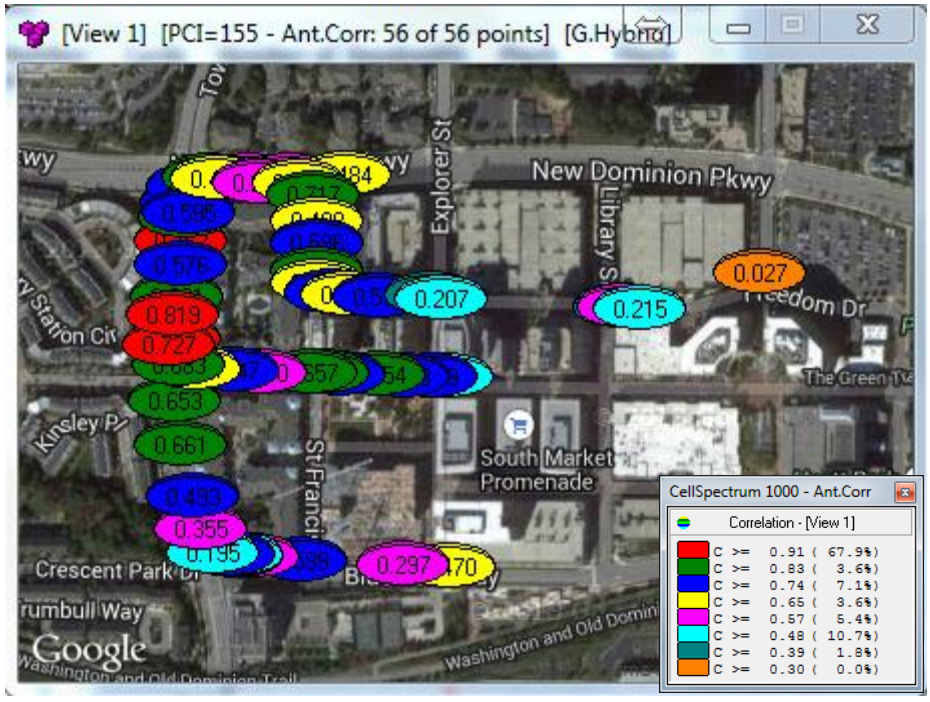
Antenna Port 1

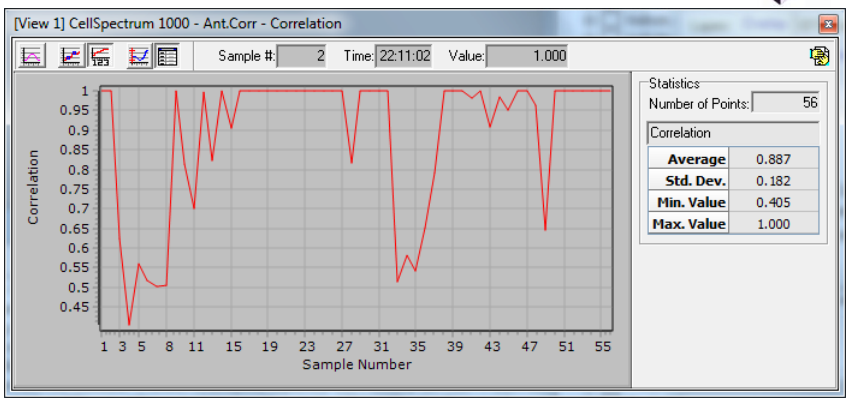


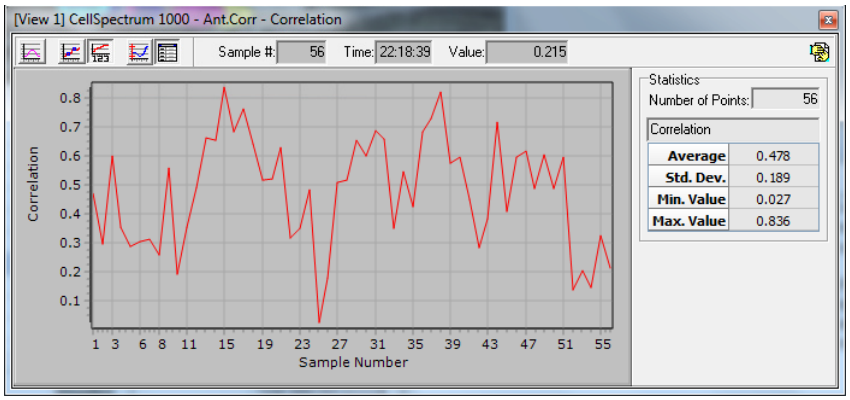
2D cut at symbol 9 and sub-carrier 64, respectively

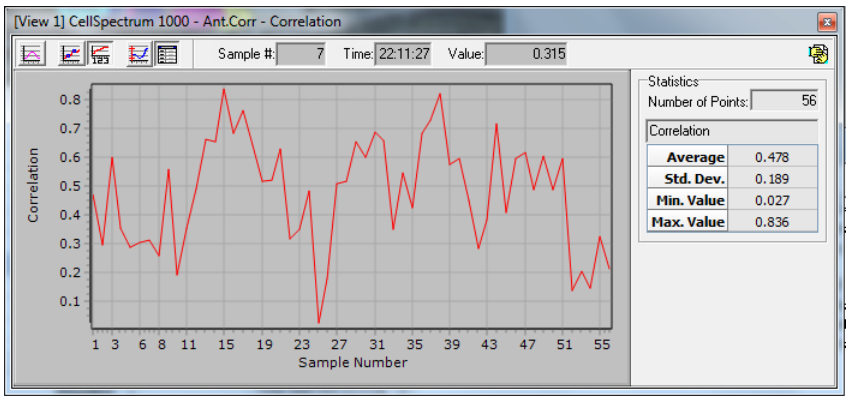


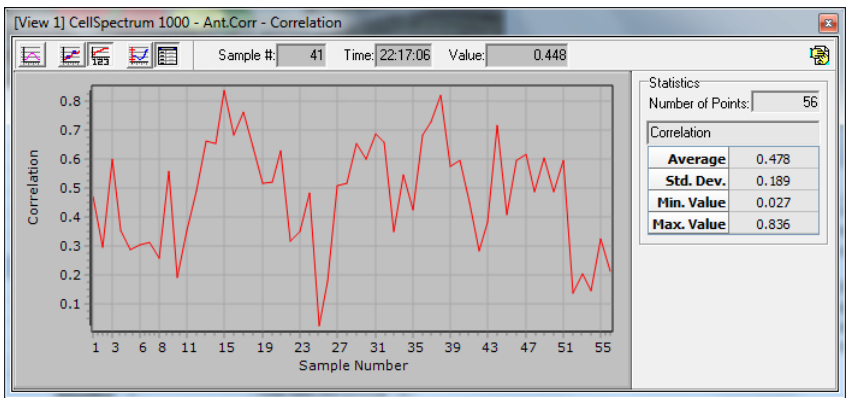
- **Transmit Antenna Correlation (TxAC):** The correlations between the transmit antennas are calculated for the I, Q and magnitude signals. Additionally a second receive antenna can be measured using a second CellSpectrum™




[View 1] CellSpectrum 1000 - Ant.Corr - Correlation
Sample #: 2 Time: 22:11:02 Value: 1.000
Statistics
Number of Points: 56
Correlation
Average 0.887
Std. Dev. 0.182
Min. Value 0.405
Max. Value 1.000
Correlation
Sample Number


[View 1] CellSpectrum 1000 - Ant.Corr - Correlation
Sample #: 56 Time: 22:18:39 Value: 0.215
Statistics
Number of Points: 56
Correlation
Average 0.478
Std. Dev. 0.189
Min. Value 0.027
Max. Value 0.836
Correlation
Sample Number


[View 1] CellSpectrum 1000 - Ant.Corr - Correlation
Sample #: 7 Time: 22:11:27 Value: 0.315
Statistics
Number of Points: 56
Correlation
Average 0.478
Std. Dev. 0.189
Min. Value 0.027
Max. Value 0.836
Correlation
Sample Number


[View 1] CellSpectrum 1000 - Ant.Corr - Correlation
Sample #: 41 Time: 22:17:06 Value: 0.448
Statistics
Number of Points: 56
Correlation
Average 0.478
Std. Dev. 0.189
Min. Value 0.027
Max. Value 0.836
Correlation
Sample Number

- **Traffic Load Grid (Hot, Mild, Cold) (TLG):** 3D representation of frame indicating the RE that are carrying traffic. RE elements are classified in a hot category when the presence of traffic can be clearly identified, mild category when the signal detected can be either traffic or interference and cold when no traffic presence is detected. This prediction will be ready in the next release.

- **Used symbols/Empty symbols ratio (UER)**: Expresses the amount of traffic being carried. Can be used to evaluate traffic load. This prediction will be ready in the next release.

- **Condition Number for N by N MIMO (CN):** this feature allows the usage of multiple receive antennas. Each antenna is connected to a CellSpectrum™ unit and both capture the received spectrum. A printed board dual antenna circuit can be used to simulate the antennas of a smart phone. This prediction will be ready in the next release.

Several other measurements are available to verify the decoding process. They are:

- Channel Estimation Raw
- Channel Estimation Time Offset Compensation
- Channel Estimation Time Offset Drift Compensation

Additional predictions can be developed under user request.

CellSpectrum™ provides a unique visualization of the network behavior and allows the prediction of key parameters over the whole network. It can be done for outdoor and indoor multi-level signals. Developers can tailor their allocation algorithms and operators can choose the best algorithms for each location.

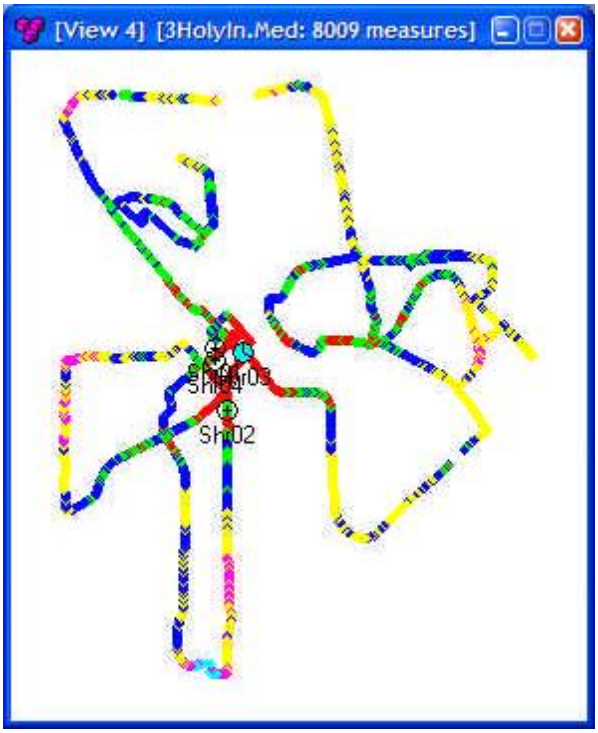
5- CellAnalyzer™

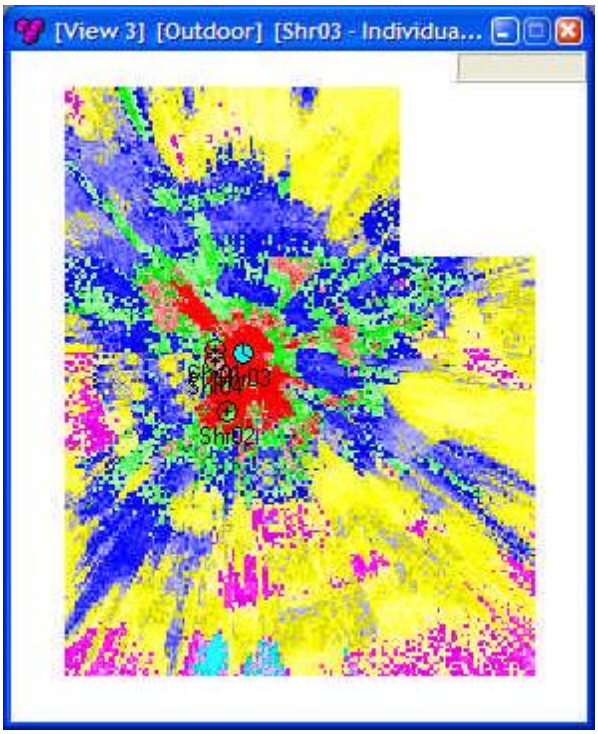
CellSpectrum™ will provide analysis features that will check the collected data and compare it to cell settings or recommend cell settings. This feature is in development and customer inputs are welcomed.

6- CellPrediction™

CellPrediction computes area coverage predictions from drive test measurement, as illustrated below. Any of the above parameters can be used to generate predictions. Those predictions can then be used to enhance more complex predictions that depend on these specific parameters.

As an example, cell capacity is dependent of which MIMO algorithm can be deployed in a location. A prediction generated from the antenna correlation parameter can provide the required information for the capacity prediction tool.





CellSpectrum™ is a must to have equipment to all that intend to deploy 4G MIMO networks. It provides a unique view into the RF channel.