AeroMACS Network Reference Model Design for DFW

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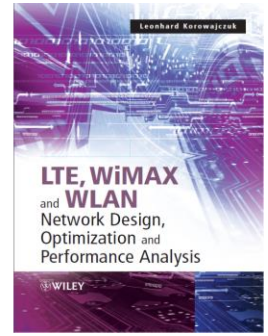
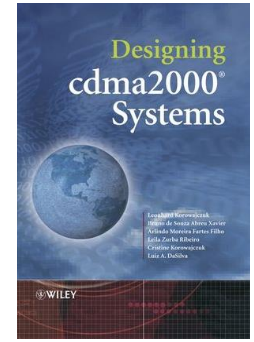
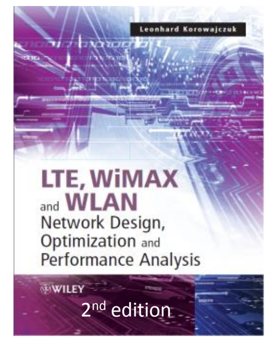
Ground to Ground Airport Communications System

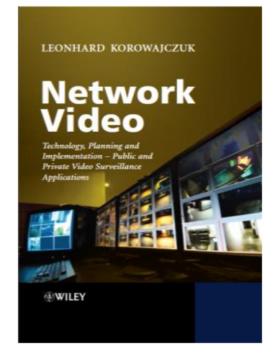
Presenter

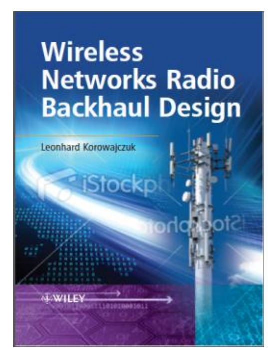
- **Leonhard Korowajczuk**
  - CEO/CTO CelPlan International
  - 45 years of experience in the telecom field (R&D, manufacturing and services areas)
  - Holds13 patents
  - Published books
    - “Designing cdma2000 Systems”
      - published by Wiley in 2006- 963 pages, available in hard cover, e-book and Kindle
    - “LTE , WiMAX and WLAN Network Design, Optimization and Performance Analysis ”
      - published by Wiley in June 2011- 750 pages, available in hard cover, e-book and Kindle
  - Books in Preparation:
    - LTE , WiMAX and WLAN Network Design, Optimization and Performance Analysis
      - second edition (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)

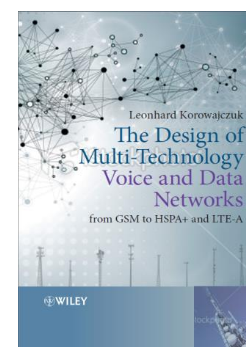












CelPlan International

- Employee owned enterprise with international presence
  - Headquarters in USA
  - 450 plus employees
  - Revenues of US$ 40M
  - 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
- 2G, 3G, 4G, 5G Technologies
- High Level Consulting
  - RFP preparation
  - Vendor interface
  - Technical Audit
  - Business Plan Preparation
  - Smart Energy, Aeronautical, …)
  - Network Managed Services
- Multi-technology / Multi-band Networks
- Backhaul, Small cells, Indoor, HetNet, Wi-Fi offloading
- Video Surveillance Systems
  - Airport perimeter
  - Video surveillance
    - Video analytics

AeroMACS Communication Scenario

- The design of an AeroMACS (Aeronautical Mobile Airport Communication System) network requires the forecast of data traffic until it reaches the stability period
  - Deploying low capacity networks would limit the applications and curb the system usefulness
- There are 2,000 takeoffs and landings daily
  - The saving in time per each transaction are at least 30 minutes in relation to the previous procedures
  - Tarmac labor is also reduced and can be directed to other activities
  - Safety is enhanced during takeoff and landing and proactive maintenance was possible
  - Security was improved during all ground operations
- What is needed is a seamless IP data link access everywhere on the ground surface
- A small investment on the communication system results in
  - Significant time savings
  - Huge operational savings
  - Increased flight safety
  - Increased security

Design Guidelines

- Seamless access to IP data links on the ground surface
- Ground Assets Location
  - Obtained through video analytics and BTS registration
    - Infrared analysis under poor visibility conditions
  - Location based group communication
  - Automatic alarms when assets leave operational area
  - Perimeter surveillance
- Ground assets control
  - Aircraft access
- Ground visibility
  - From Aircraft
- Airplane interior visibility
  - From Ground
- Aircraft data interchange (maintenance and flight data)
- Ground data interchange

Flight 101 (sometime in the future)

- Benefits brought by the AeroMACS communication system
  - Reduce taxiing time by providing a navigation map to the gate just after landing. At the moment of landing all the ground support network related to his flight would be informed and dispatched to take their positions
  - Improving taxiing safety by providing instantaneous communications to neighbor aircrafts and ground vehicles. All vehicles and personnel are informed about the arriving flight and eventual equipment in the plane path is identified by the video analytics and personnel are instructed to remove it.
  - Increasing parking safety and reducing docking time by receiving visual docking guidance with marshaling instructions. Cameras located at the gate identify the plane and provide precise guidance to perfectly park the plane.
  - The pilot can now control the jetbridge from the plane using a joystick, without the need of an operator. A camera located at the jetbridge allows for the perfect alignment.
  - Plane data is transmitted as soon as the plane reaches the gate to the different entities in priority order (some data examples are listed below)
    - ATC (Air Traffic Control): Flight data
    - AOC (Airline Operational Communications): Passenger list, Luggage, Cargo, crew data
    - Plane maintenance: Plane biometric data
    - Plane security: Cockpit and interior video during the entire turnover period. Exterior video of refueling and luggage loading areas

Flight 101 landing

- As soon as the plane lands the taxiing information is displayed in a map and turn by turn instructions are given
  - A vehicle is coming close and John presses a button in the AeroMACS terminal and broadcast his concern
  - Neighbor planes and vehicles receive the message and the vehicle moves away
- Flight 101 arrives at the gate and a map displays the sensor information giving guidance for the gate approach
  - The jetbridge had already adjusted its height and position, so it has now just to move in the direction of the door and do a final adjustment under remote command of the pilot
  - The savings in personnel and time are huge. John estimates that the new system has saved 15 minutes in relation to his best time in previous flights
  - Passengers appreciate this time saving and airline cost is reduced
- During the flight there was an incident involving an unruly passenger and at that time the internal cameras were activated
  - The issue was resolved, but the video is being downloaded
- The turnover crew enters the plane, with last moment instructions received from the airline and airport authority
- Refueling crew gets the plane data at their terminal and once done the information is sent to the proper channels
  - The advantage provided by AeroMACS is that the specialized terminals are mobile and can be placed anywhere in the tarmac

Flight 102 takeoff

- The crew of flight 102 enters the plane as soon the previous crew leaves
  - The pilot gets great reviews from John about the new system
  - Meanwhile all the fight information and updates to the manuals are loaded on board computers.
- The airline maintenance computer alerted the maintenance center about the degradation in the data provided by one of the sensors and recommends the change of one board
  - A crew was dispatched immediately with the new part
  - This issue would be normally only detected when the plane underwent regular maintenance.
- Once the technical data is downloaded, new data is loaded on the board computers
  - The pilot is impressed as all the information he needs is already in place
  - He examines the flight path and starts the check in procedure
  - He is informed how the external processes are going, including the ongoing maintenance
  - The new communication system saves another ten minutes at least.
- The security video of the turnover period indicates that the maintenance crew forgot a tool box in the plane and an alert is sent to the pilot and ground

Flight 102 takeoff

- Finally the plane is ready to leave in a record time
  - The regular one hour was reduced by 20 minutes
- Pilot initiates the take-off procedure under command of the ATC
  - He disengages the jetbridge and prepares to back up, but before this he broadcast a message to all neighbor planes and vehicles
  - The list of neighbors in the area is automatically prepared by the system, as they register to the microcells
- Mike heard that soon a new automatic pushback system will be installed and he will be able to control it from the cockpit using a joystick, after clearance from ground control
  - Additional minutes will be saved
- The taxying path is displayed in a map with turn by turn instructions
  - This is good as fog had set in and it is difficult to visually read the taxiway numbers
  - He would be probably still sitting at the gate if it was not for the AeroMACS communication system.
- On arrival at the runway Mike gets the runway environmental information and an alert is given for birds on the other side as well a sheer wind 0.5 miles upfront
  - The ground crew is informed about the birds and gives a cleared signal. Mike is alerted the moment the wind decreases and takes-off
  - AeroMACS communications are disabled

Estimating data volume per transaction

- The **runway communication cell** needs to support one aircraft at a time

Runway/ aircraft	DL	UL	Total
Duration (minutes)	1	1	1
Data (kB)	50	200	250
Voice (kB)	0	0	0
Video (kB)	0	0	0
Total (kB)	50	200	250
Average rate(kbps)	7	27	33

- The **taxiway communication cell** has to support up to 20 aircrafts at a time

Runway/ aircraft	DL	UL	Total
Duration (minutes)	8	8	8
Data (kB)	500	100	600
Voice (kB)	240	240	480
Video (kB)	0	0	0
Total (kB)	740	340	1,080
Average rate(kbps)	12	6	18

- The **gate communication** cell has to support up to 2 aircrafts a time
  - 2x 1 Mpixel (300 kbps) cameras UL
  - 1 x 1 Mpixel (300 kbps) cameras UL

Gate/ aircraft	DL	UL	Total
Duration (minutes)	45	45	45
Data (kB)	150,000	150,000	300,000
Voice (kB)	5,000	5,000	10,000
Video (kB)	101,250	202,500	303,750
Total (kB)	256,250	357,500	613,750
Average rate(kbps)	759	1,059	1,819

Who are the users? How many?

- Air Traffic Control (large airport= 2,000 employees)
  - Plane to plane
  - Plane to Ground
  - Ground to Ground
- Airport Authority (large airport = 30,000 employees)
  - Airport Management
  - Security
  - Maintenance
  - Baggage Service
  - Food
  - Emergency
- Airlines (large airport= 10,000 employees)
  - Ticket counter
  - Dispatch
  - Baggage
- AeroMACS users: estimated in 5,000 employees

What are the applications?

- Today's applications are:
  - File Transfer (FTP)
  - Telemetry
  - Device control
  - Text messages
  - Video
  - E-mail
  - Web access (Internet)
  - Voice applications (Skype)
  - Remote desktop
  - Meeting applications (WebEx)
  - Proprietary
- New applications will appear as soon as the network is available
- Network design and traffic considerations should be such to accommodate an increase 5 fold in traffic

Where the service has to be provided and to whom?

- Apron areas
- Taxiways
- Runways
- Gates
- Maintenance areas
- Security areas
- Fire and health safety areas

- Airframes
- Pilots
- Vehicles
- Managers
- Personnel

What is the cell capacity?

- AeroMACS spectrum is: 5.091 GHz to 5.150 GHz
  - 11 channels of 5 MHz
- Additional possible spectrum: 5.0 to 5.030 GHz
  - 6 channels of 5 MHz
- Assuming a spectral efficiency of 0.5 bps/Hz, a channel could have a capacity of 2.5 Mbps
- The 11 channels should be enough to provide the required cellular reuse, redundancy and peak management
  - Channels should be divided in two groups:
    - Runway and taxiways
    - Gates and apron
- Segmentation can be used for additional interference control
- Zoning can be used to isolate traffic categories

What is the traffic demand?

Runway/ aircraft	DL	UL	Total
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What is the cell capacity?

- Gate cell should operate with aircraft using 64 QAM 5/6
- Remaining ground communication may use lower modulation schemes
- Design cell average goodput efficiency is:
  - Gate: 0.8 bit/s/Hz
  - Taxiway: 0.2 bit/s/Hz
  - Runway: 0.05 bit/s/Hz
- The cell capacity (goodput) becomes then:
  - Gate: 4 Mbps (14 GB per hour)
  - Taxiway: 50 kbps (0.9 GB per hour)
  - Runway: 1 Mbps (3.6 GB per hour)

Overall AeroMACS Market

- 2014 market estimate

Cells	
US	12,120
EU	12,296
Subtotal	24,416
Rest of World	12,000
Total	36,416

Ground Vehicles	
US	235,705
EU	94,893
Subtotal	330,598
Rest of World	47,447
Total	378,044

Airframes	
US	6,000
EU	5,000
Subtotal	11,000
GAA aiframes	200,000
Rest of World	2,500
Total	213,500

What are the required network technical capabilities?

- The network should be overdesigned for capacity, so it can handle local traffic peaks
- The network should be redundant
  - Two sets of hardware should provide service in each location
- Network should be secure
  - WiMAX provides a layer of security by itself, not being in use by the general public
  - Encryption should be strong
- Services and users should have priority levels
- Services and users should be categorized in exclusive zones
- Zone overflow should be possible for certain categories

What devices will be used?

- Aircraft devices should be standardized by ICAO
  - Our initial calculations indicate that there is no need to perforate the airframe to install the antennas
  - In principal the antennas can be placed inside the plane, to be confirmed by measurements
- Ground devices could be of the following types, pending standardization
  - Smartphones
  - Tablets
  - Modems
  - USB dongles
  - Consoles
  - Embedded

What are the deployment options?

- Each entity can deploy its own network
  - Spectrum will have to be split or frequency coordination will have to be enforced
  - The total investment will be higher
- A single entity can be in charge of deploying and operating the network for all entities
  - Spectrum usage issue is resolved
  - Investment is minimized
  - Resource splitting becomes the issue
- A mixed solution, with a dedicated network for critical operations and another one for logistics

DFW AeroMACS Design

Ground to Ground Airport Communications System

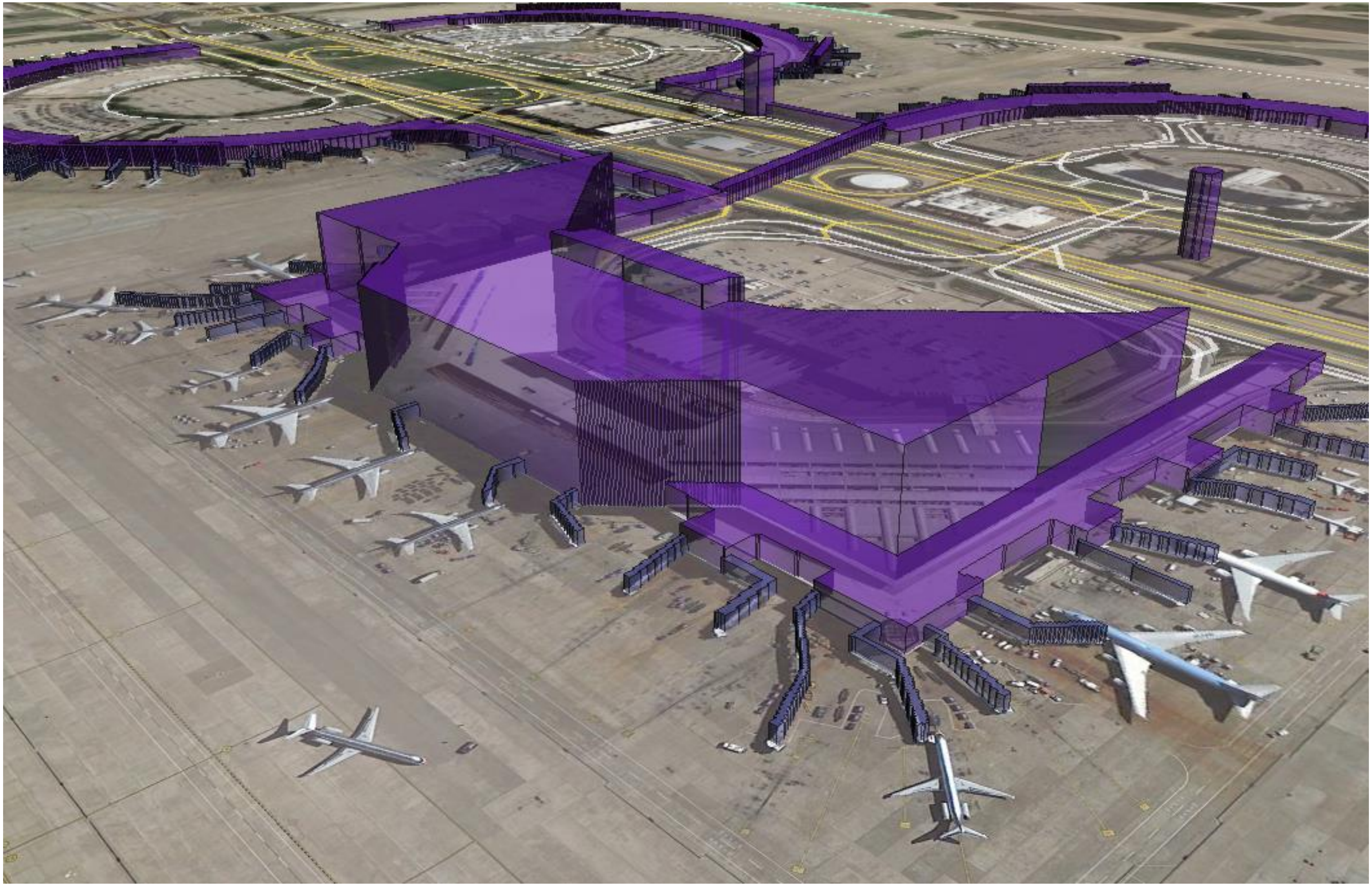
What is the required network capacity?

- DFW has 5 terminals 196 gates
  - Terminal A: 31 gates
  - Terminal B: 49 gates
  - Terminal C: 31 gates
  - Terminal D:30 gates
  - Terminal E: 35 gates
  - Terminal F: future
- DFW has an average of 1,800 takeoff and landings (TL) per day
  - Peak can reach 156 TL per hour
  - Minimum permanence in a gate is 45 minutes
  - Maximum supported tonnage per gate: 300 MB
  - Gate coverage needs to be redundant
- DFW will require approximately:
  - 83 gate cells (microcell)
  - 8 runway/taxiways cells

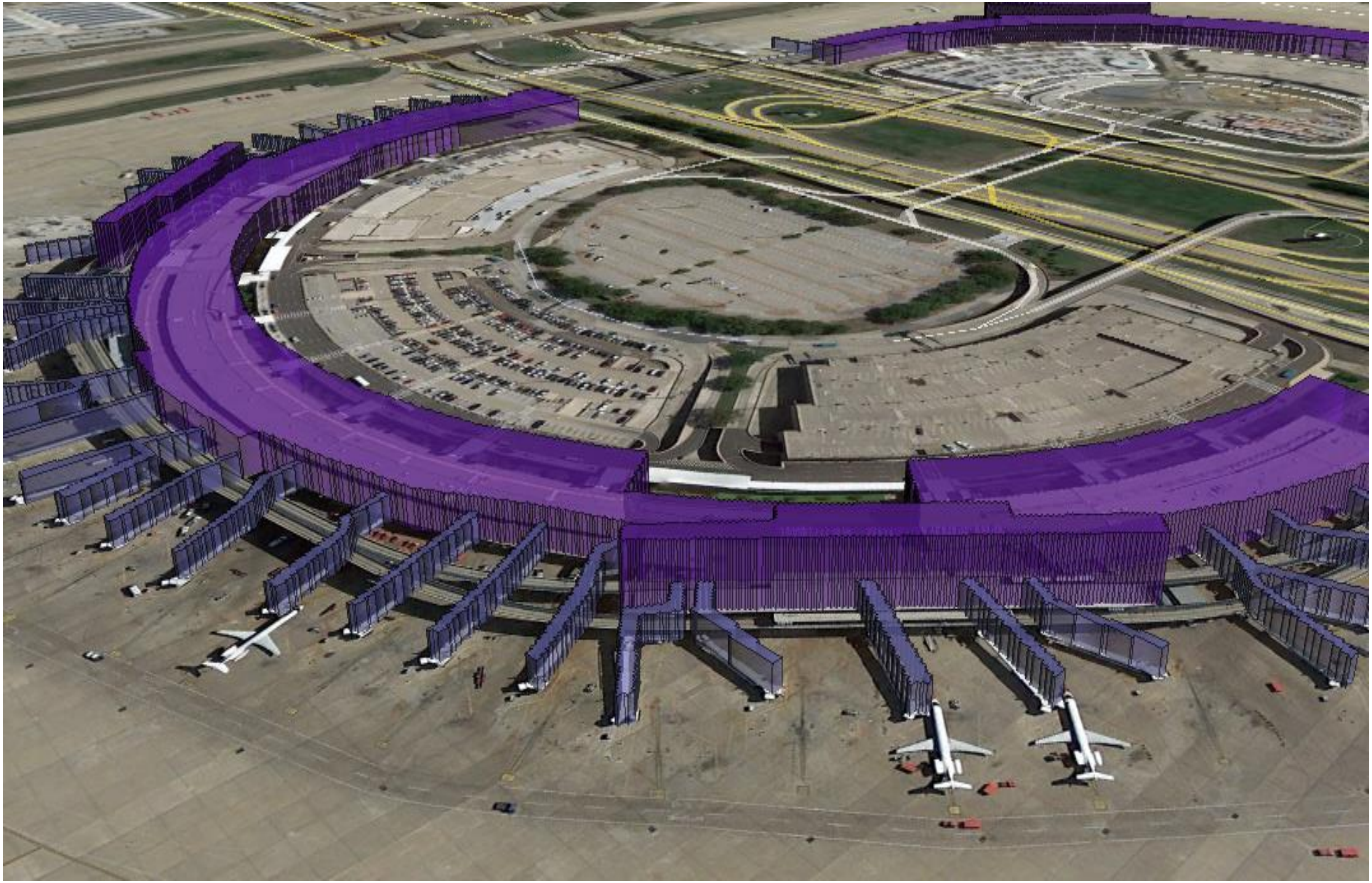
DFW Terminals

DFW Terminals

Terminal D

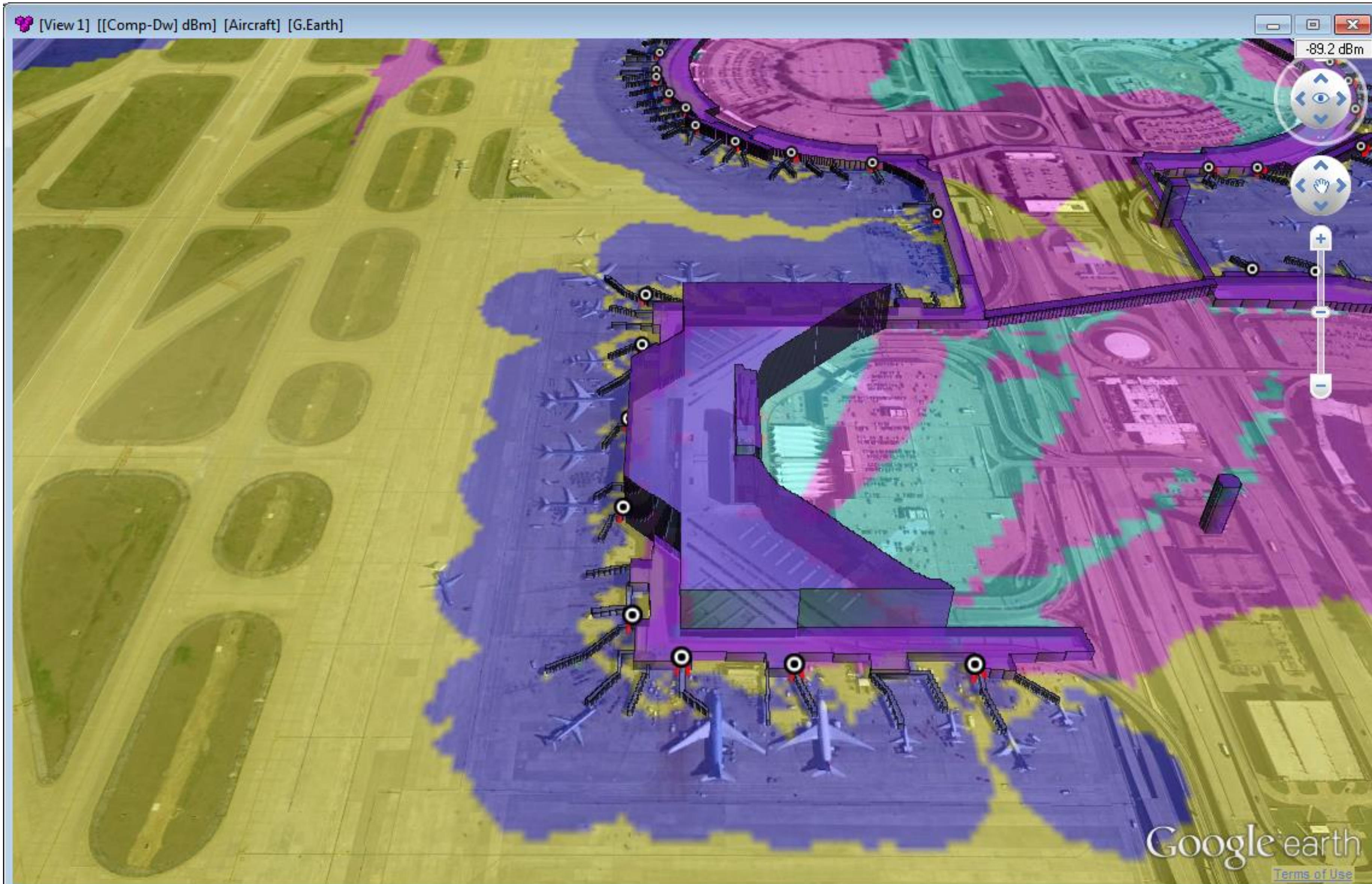


Terminal B

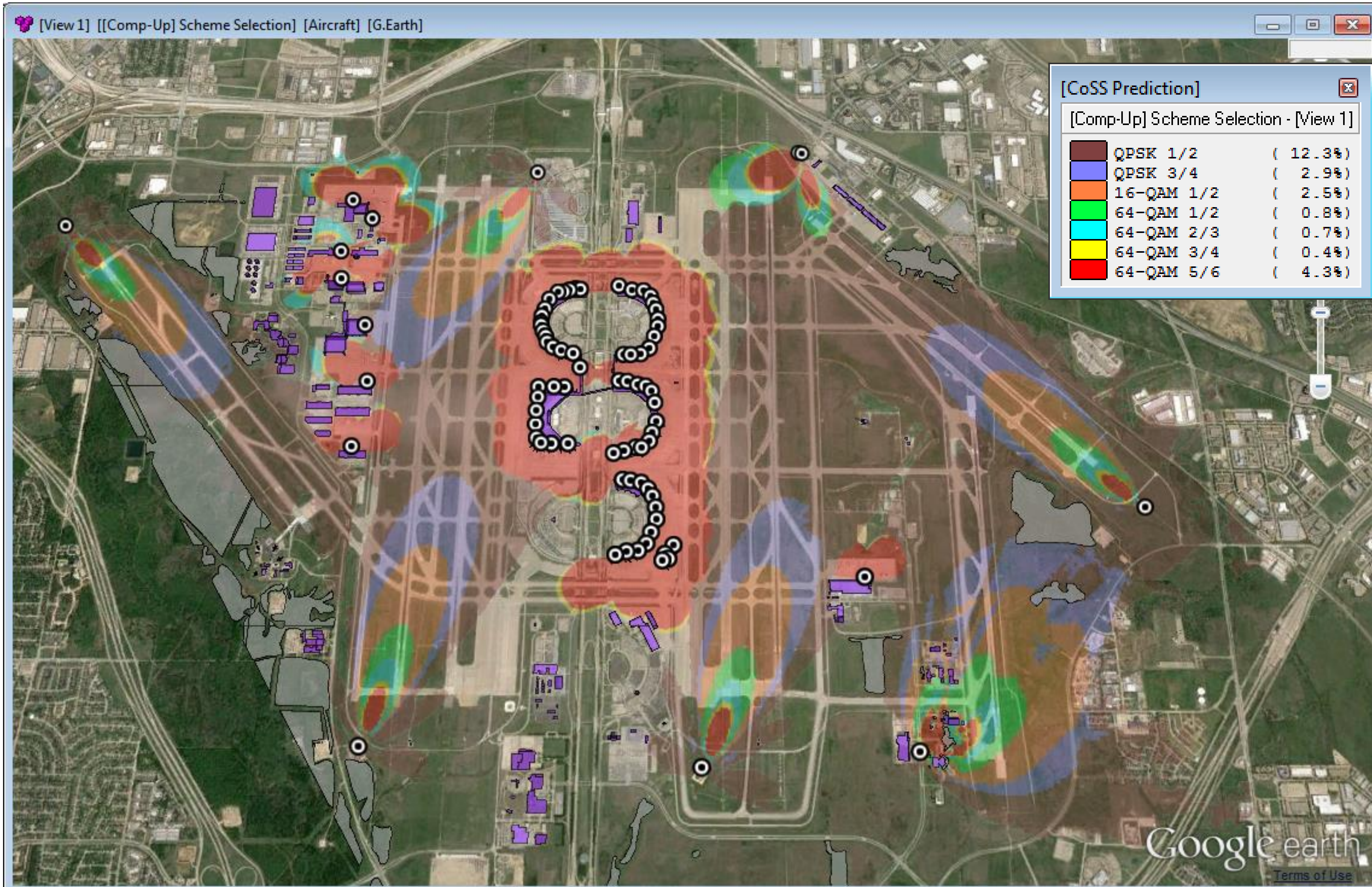


Signal level DL (dBm)

Signal Level (dBm)



Modulation Scheme



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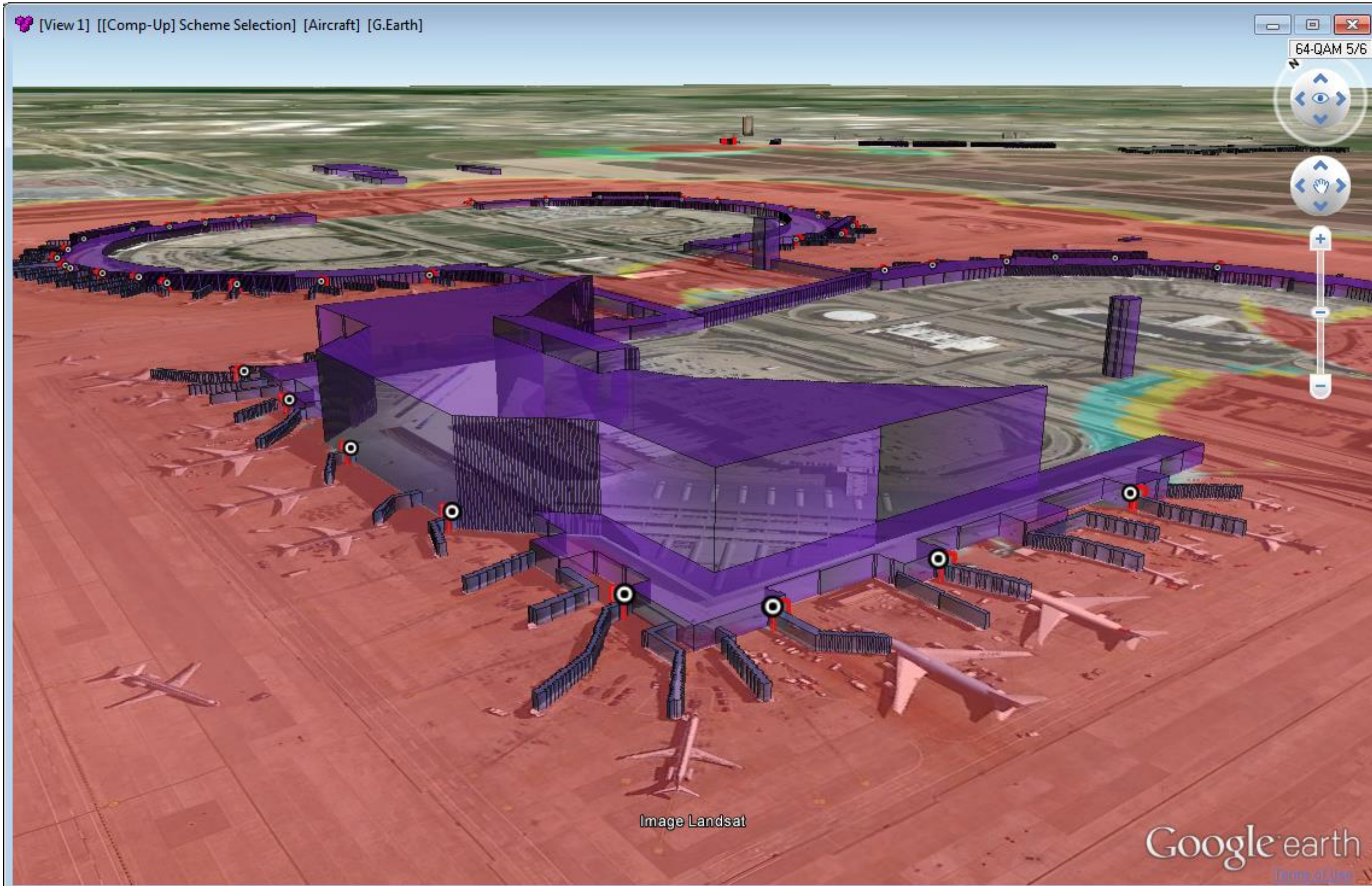
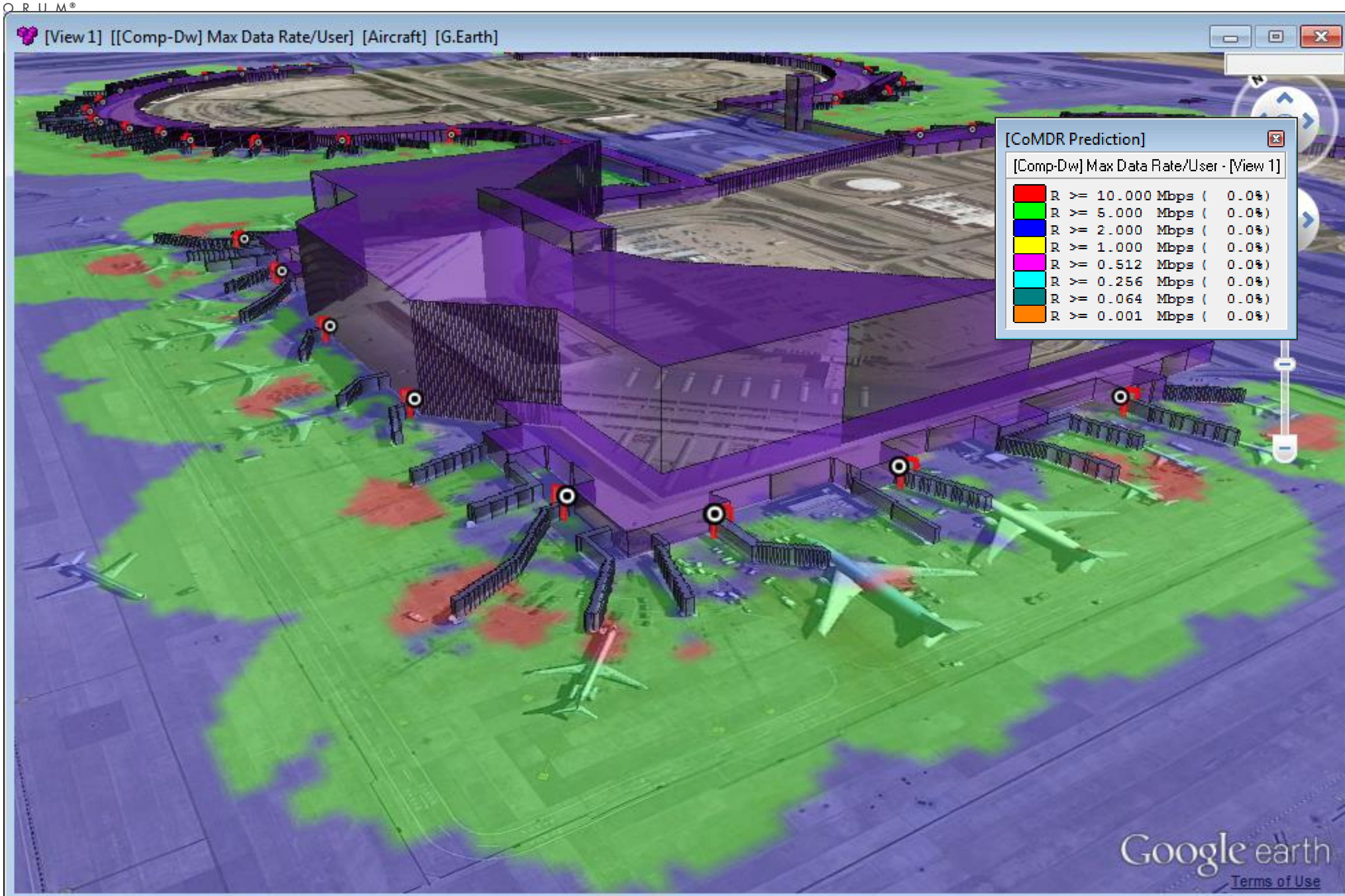


Maximum Data Rate per user



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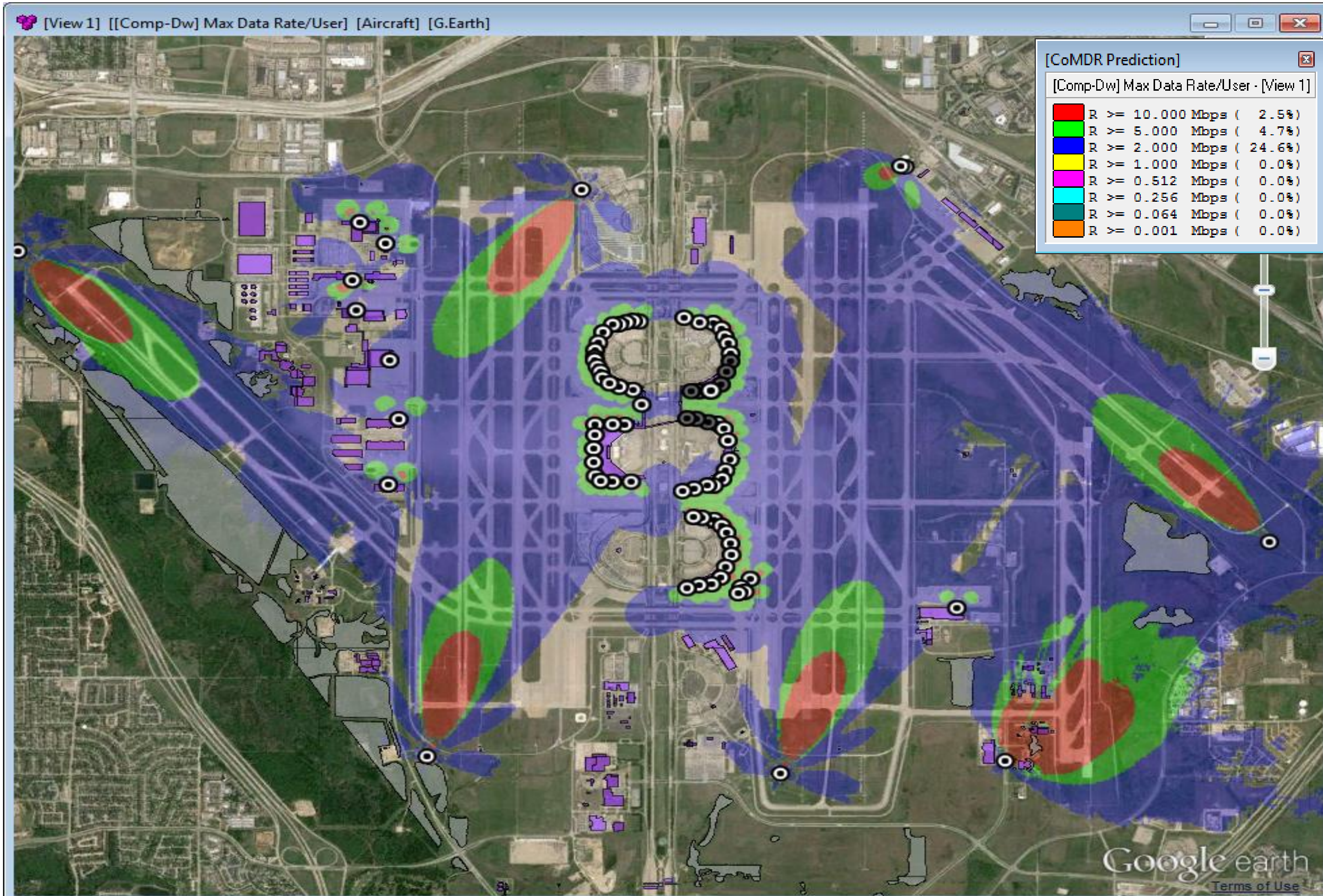
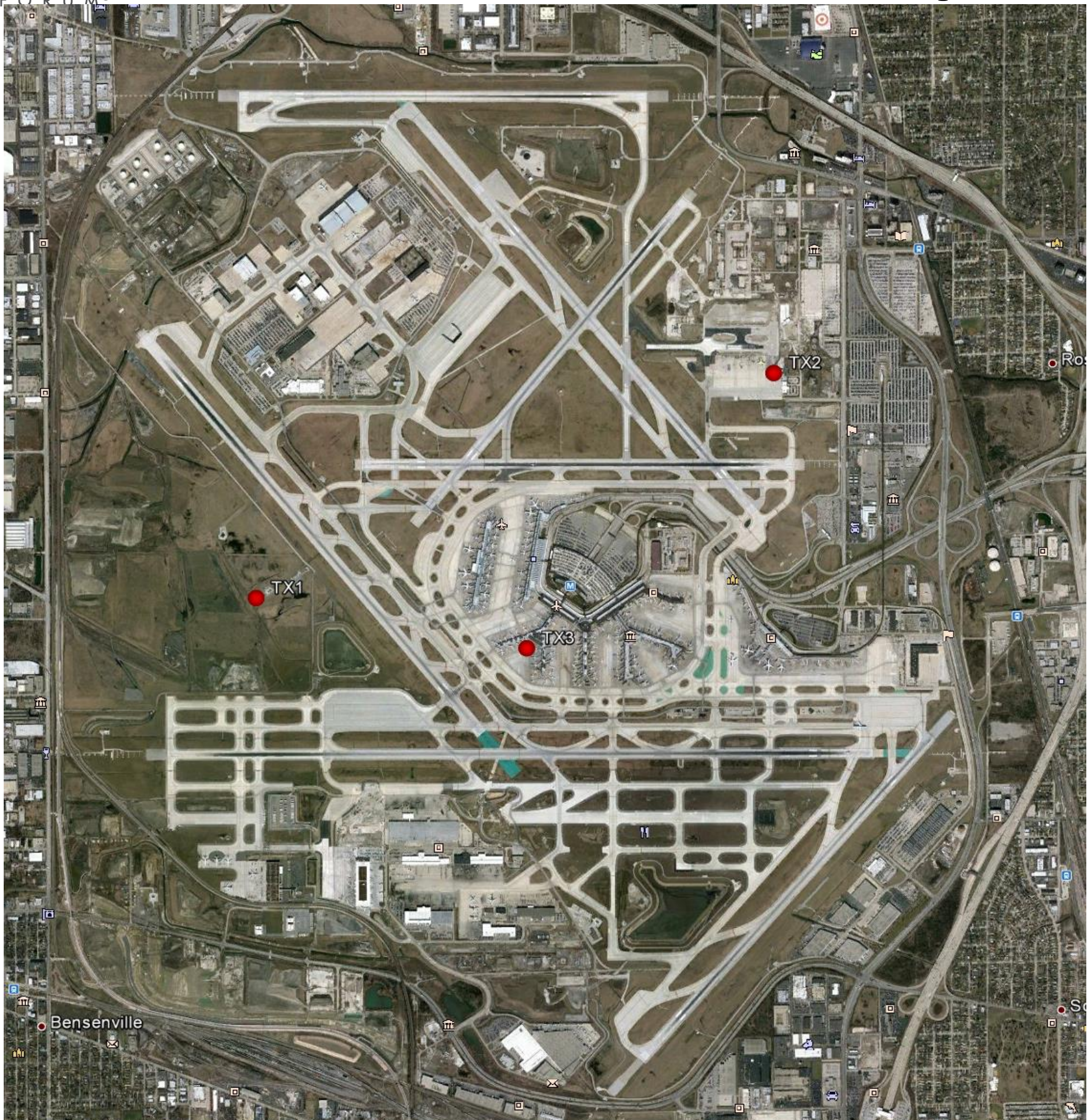


Wireless Communications Characterization

Wireless Propagation

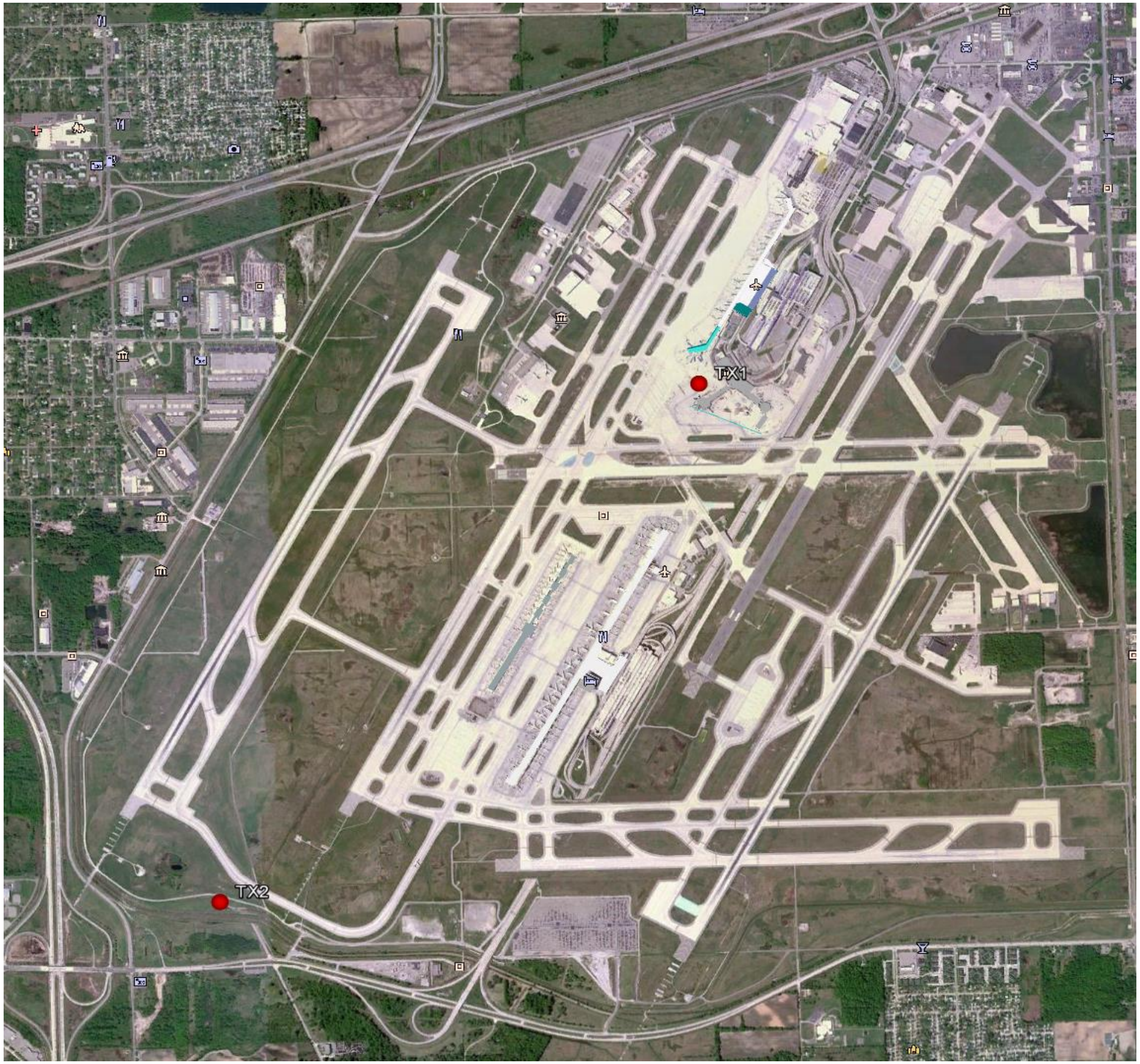
- CelPlan have done propagation measurements at Chicago (ORD) and Detroit (DTW) airports for the NextGen Communication System, and the same can be done for AeroMACS
- CelPlan has developed 3D models of airports including moving airframes
- CelPlan has the K3D model that is recognized as the best in the industry
- CelPlan has developed a 3D scanner that characterizes the performance of OFDM in 3 dimensions

ORD Airport



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

DTW Airport

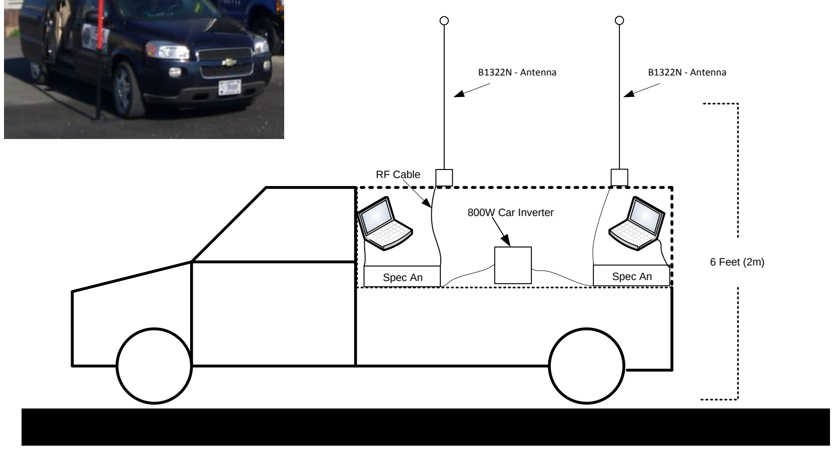


- Airport and surroundings were modeled in 3 D
- Horizontal resolution of 1 m
- Vertical resolution of 0.5 m

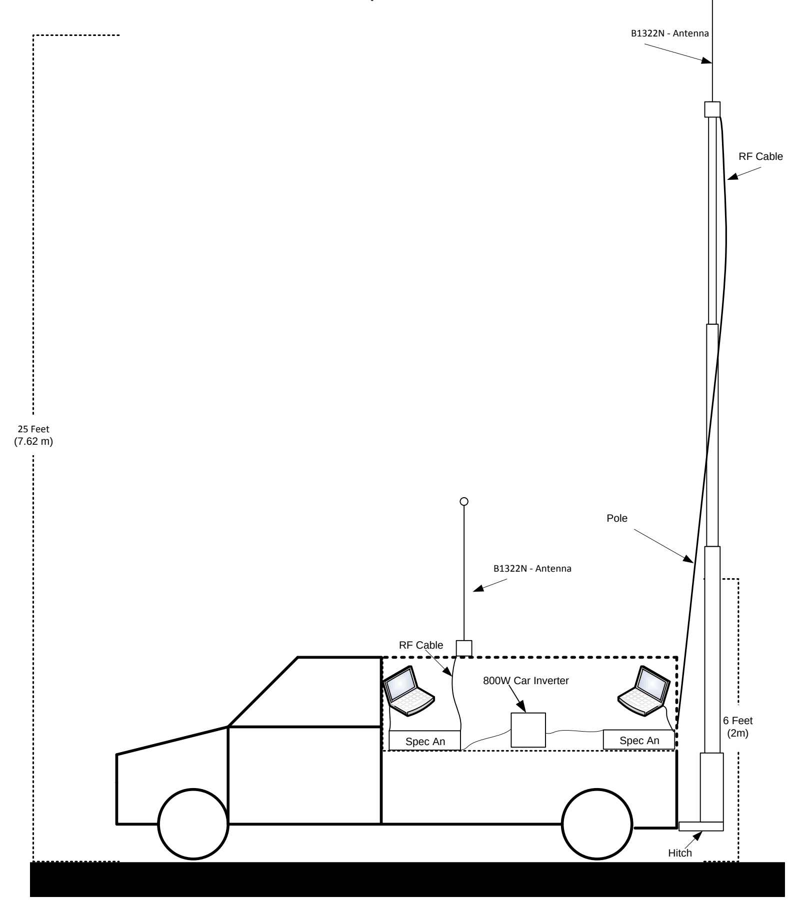
Test vehicle

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

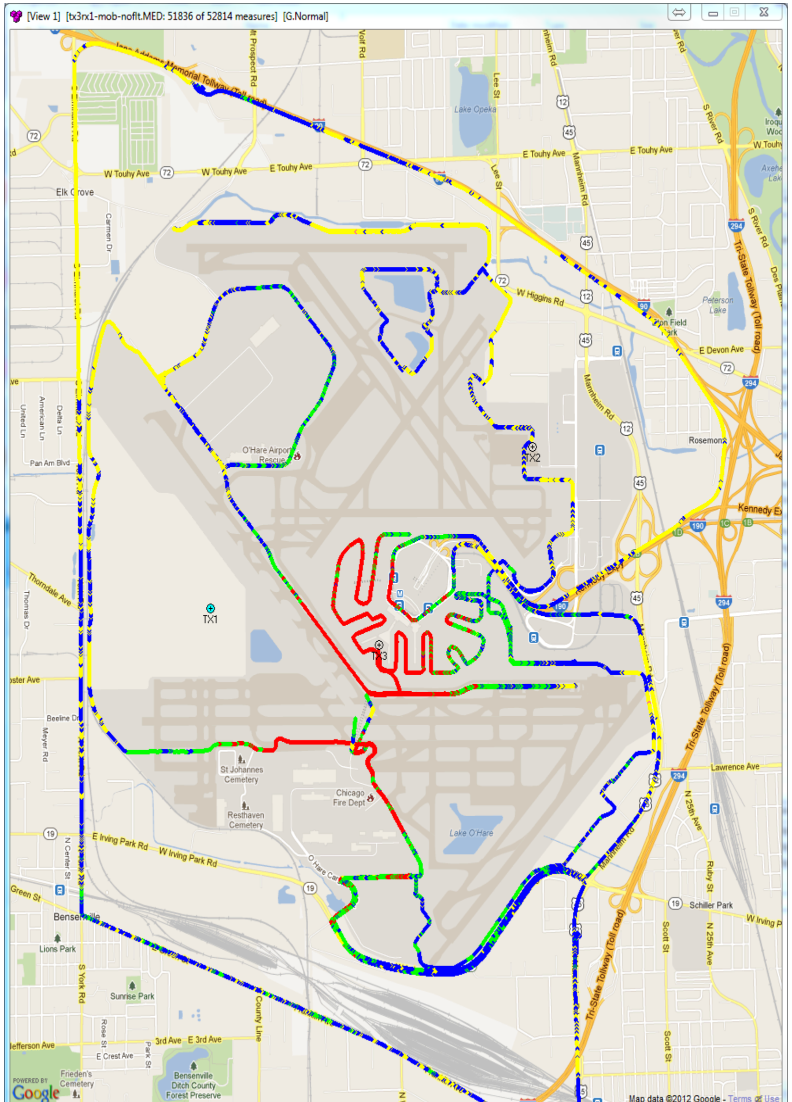
Mobile Car - RX

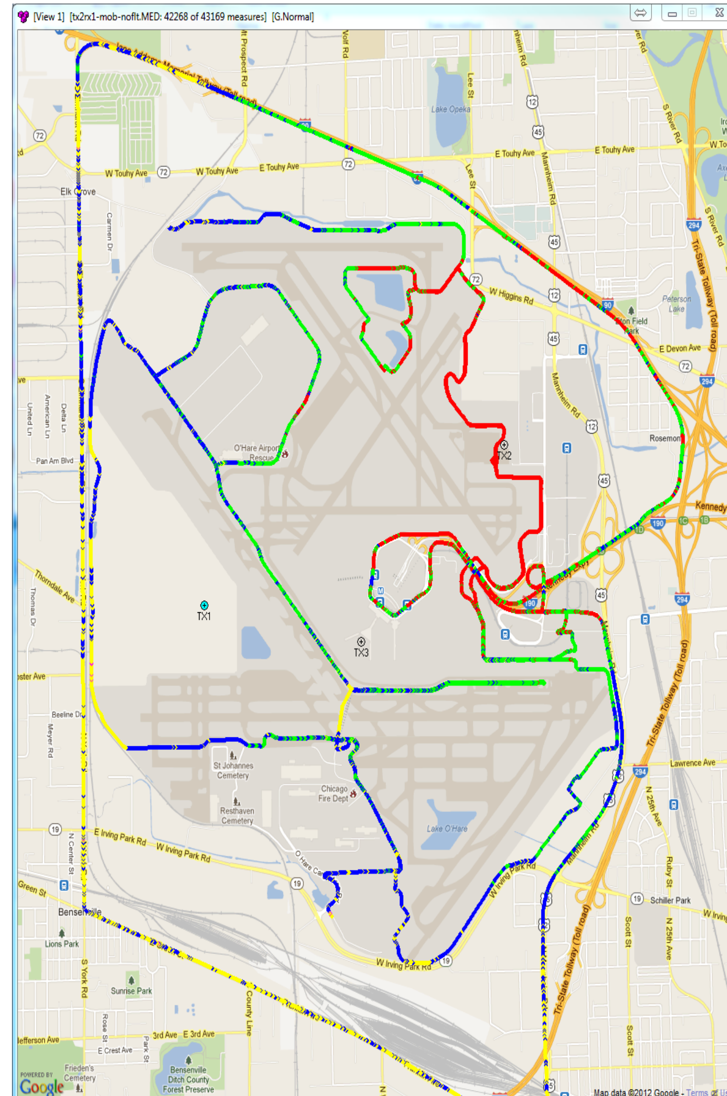


Static Car – RX
Option 2



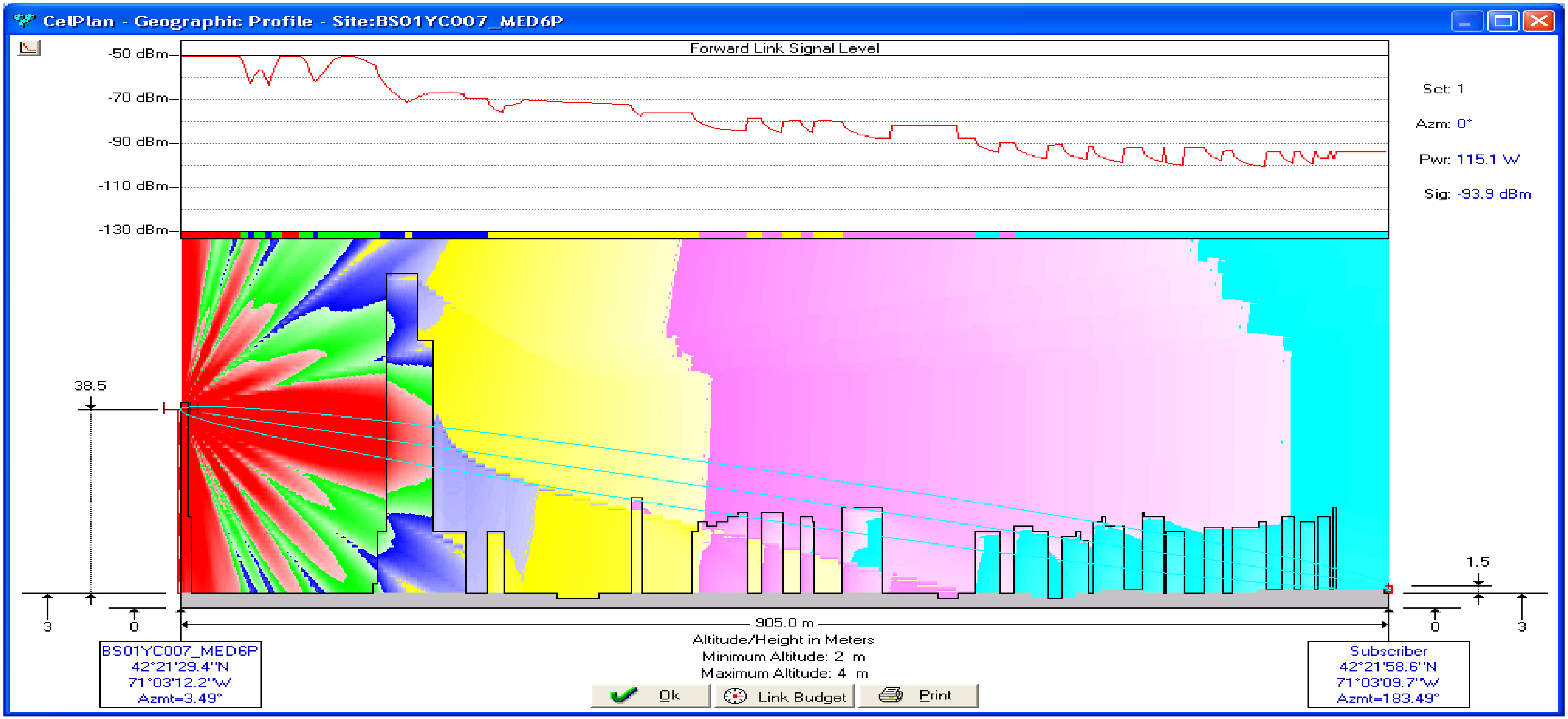
Drive Test Measurements





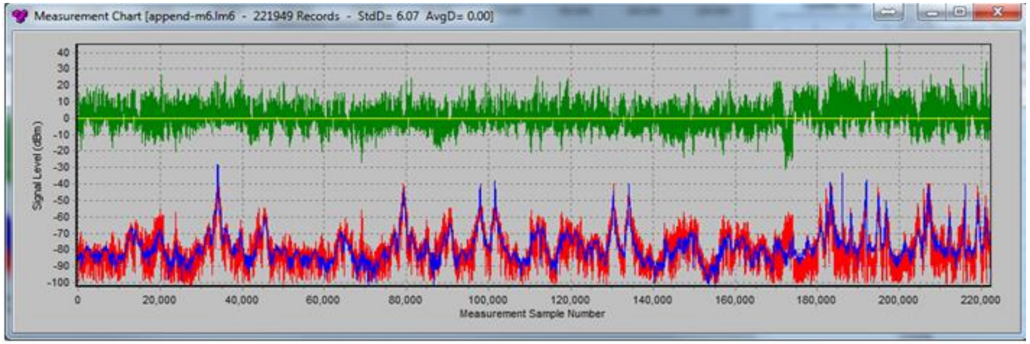
K3D Propagation Model

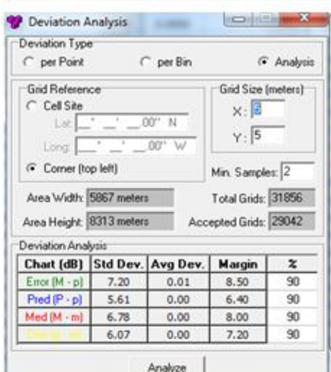
- The K3D model considers propagation in 3D and uses fractional morphology
- The model predicts outdoor and indoor coverage

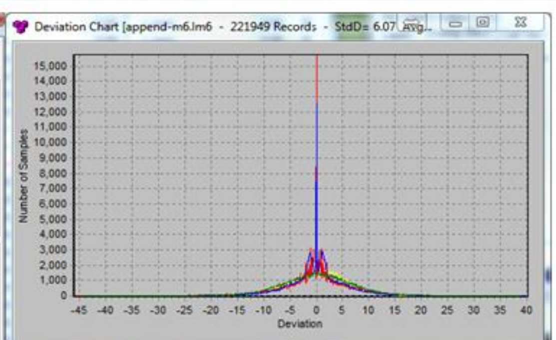


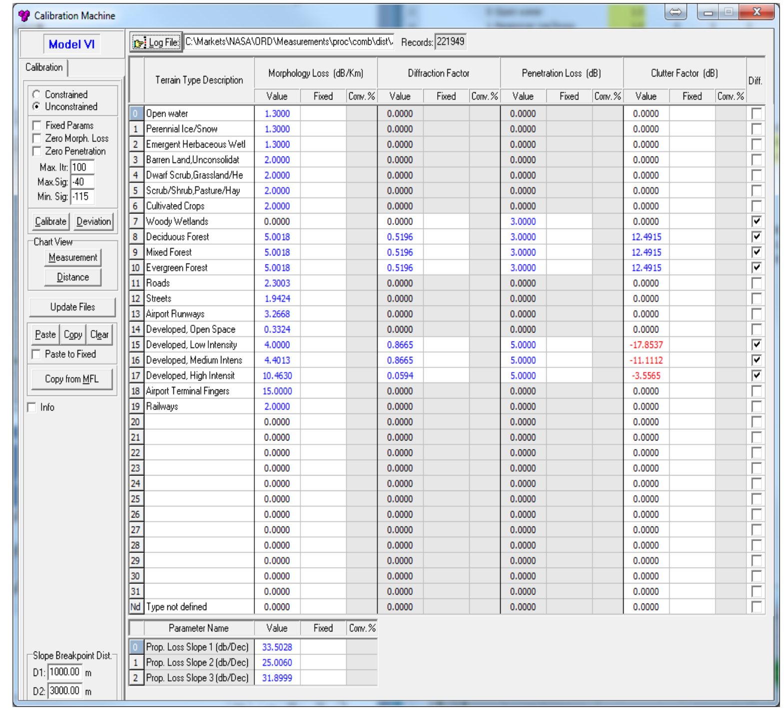
Measurement x Predictions

- Prediction model used was: Korowajczuk 3D



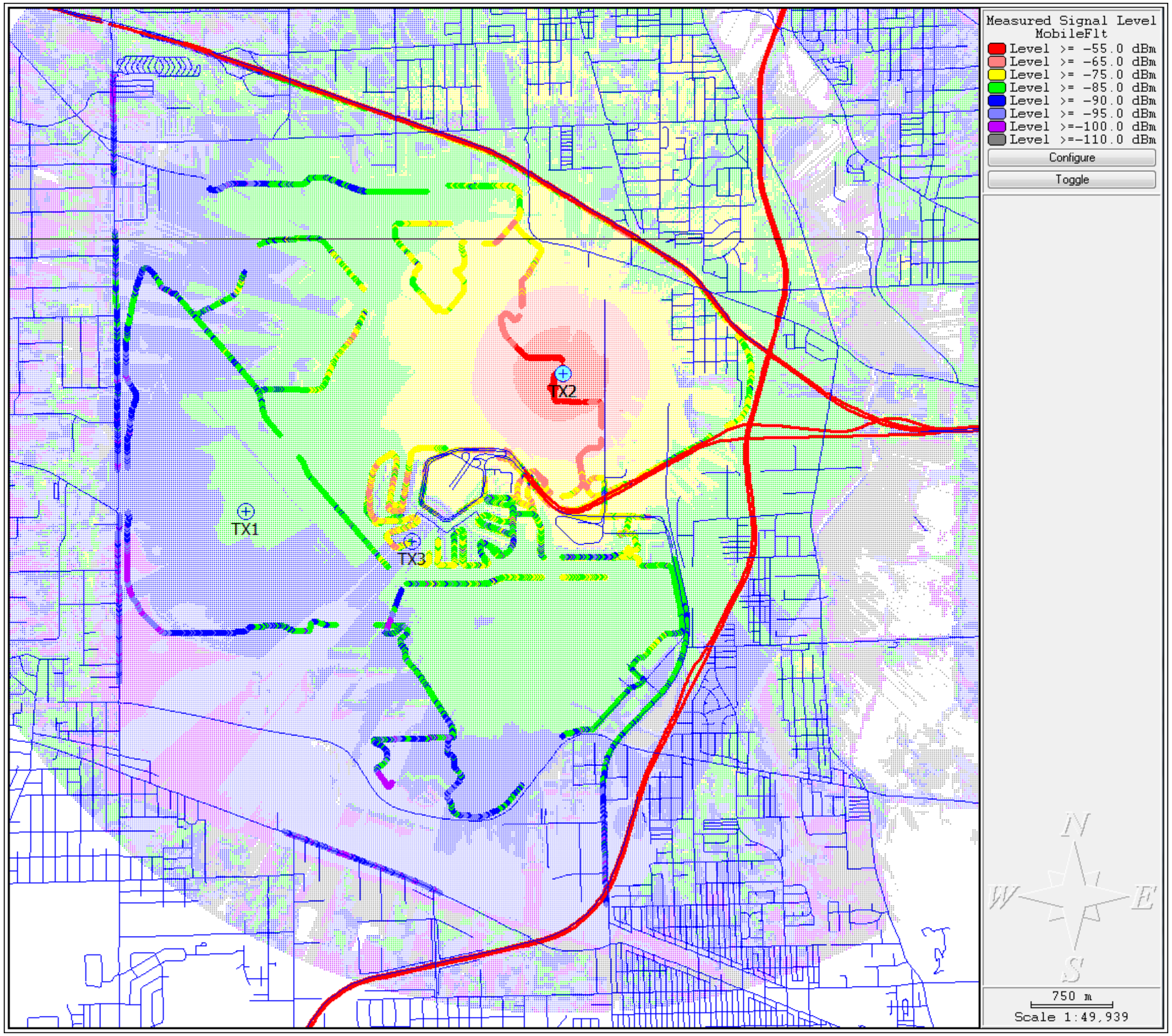




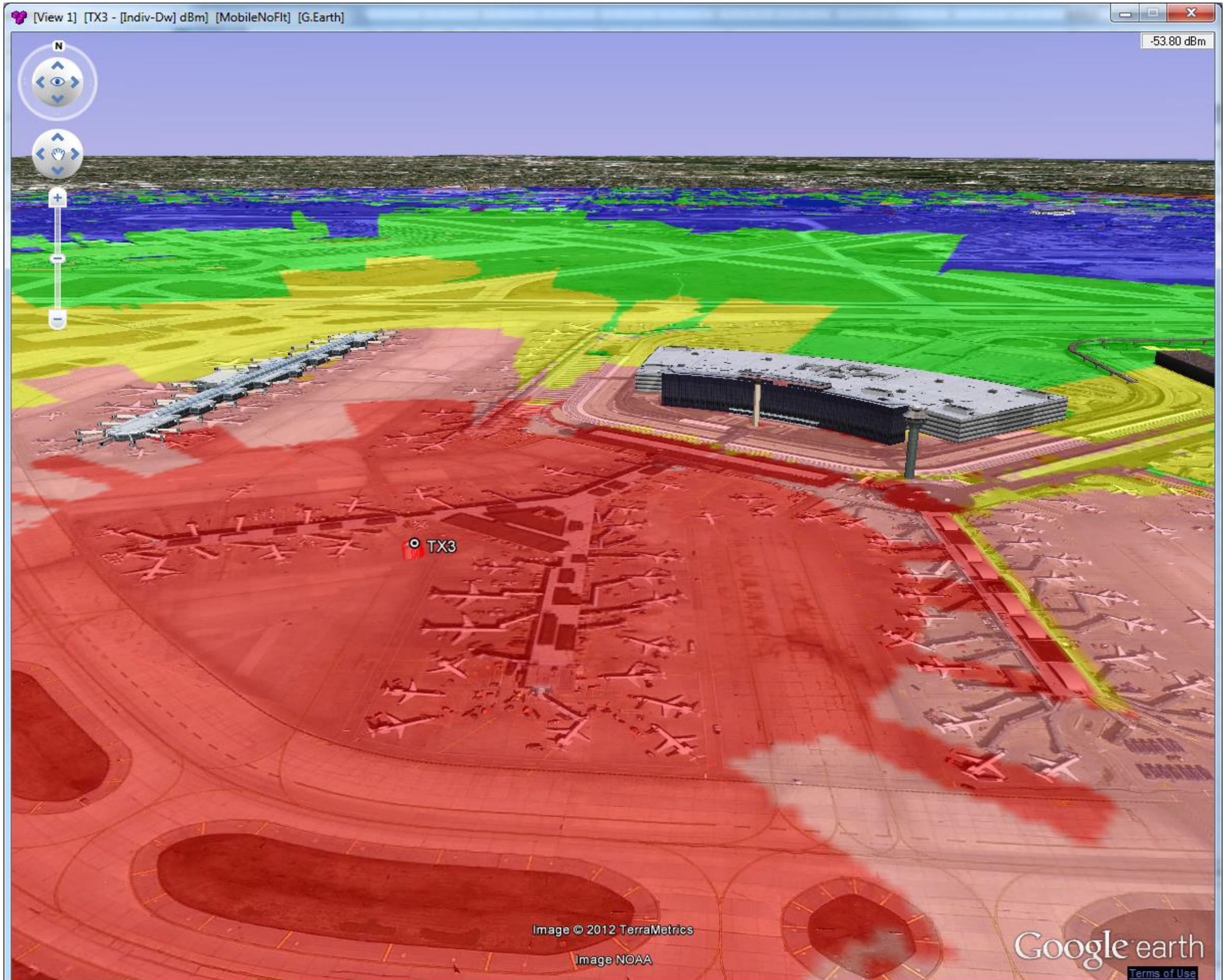


	Unconstrained Calibration Set		
	Standard Deviation [dB]	Average Deviation [dB]	RMS [dB]
Model II - 2D Korowajczuk	6.16	0.04	6.16
Model III - Microcell	6.96	0	6.96
Model VI - 3D Korowajczuk	6.07	0	6.07

Predictions x Measurements

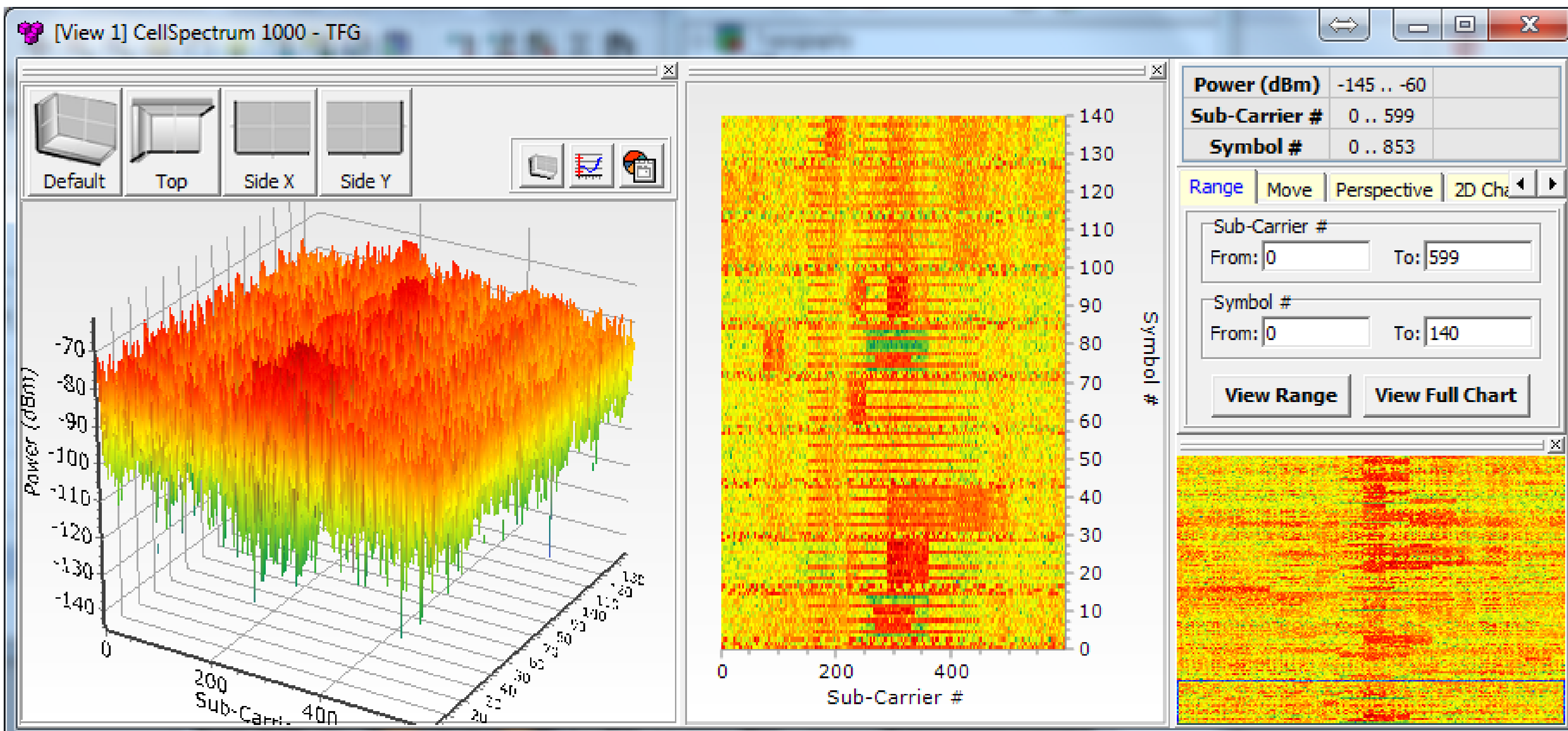


Airport 3 D Coverage view



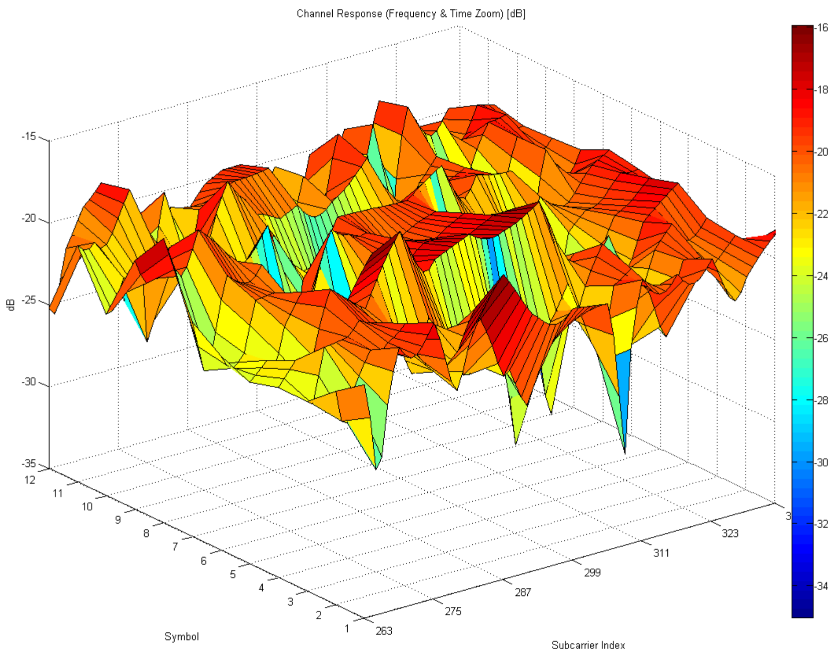
CellSpectrum

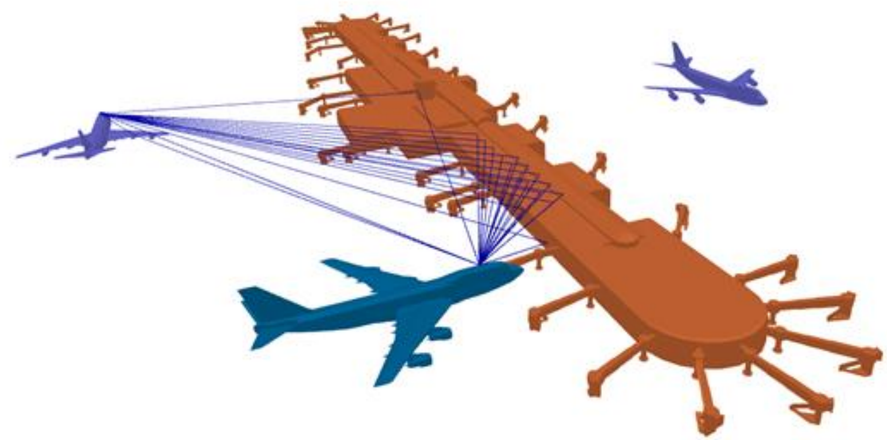
- CelPlan developed CellSpectrum that characterizes the RF channel in 3D
- An entire OFDM frame can be analyzed on a symbol basis



Multipath fading

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





Conclusions

- AeroMACS network design is a complex task and requires the analysis of several scenarios
- Research should be done to dimension user requirements at different airport sizes and locations
- RF propagation characterization should be done, a propagation model chosen and propagation parameters calibrated
- Preliminary network designs should be perform for different scenarios and capacities

Thank You!

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Questions?