Analytical Estimation of VDL Mode 2 in a Dynamic Environment

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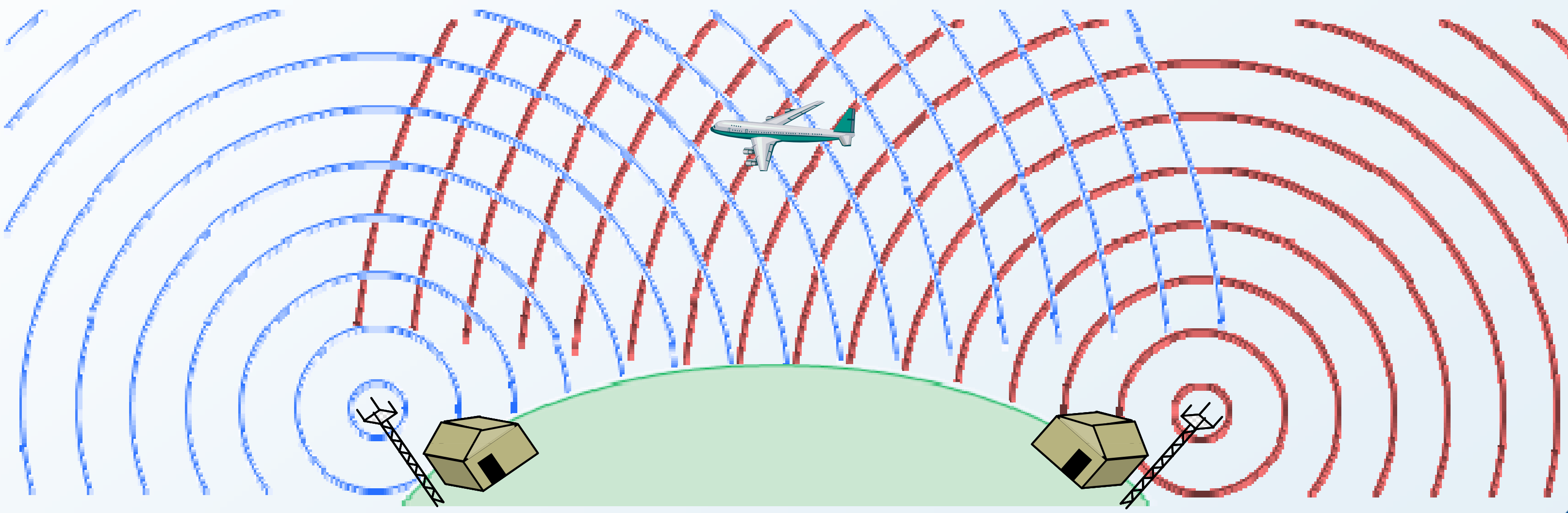
Background

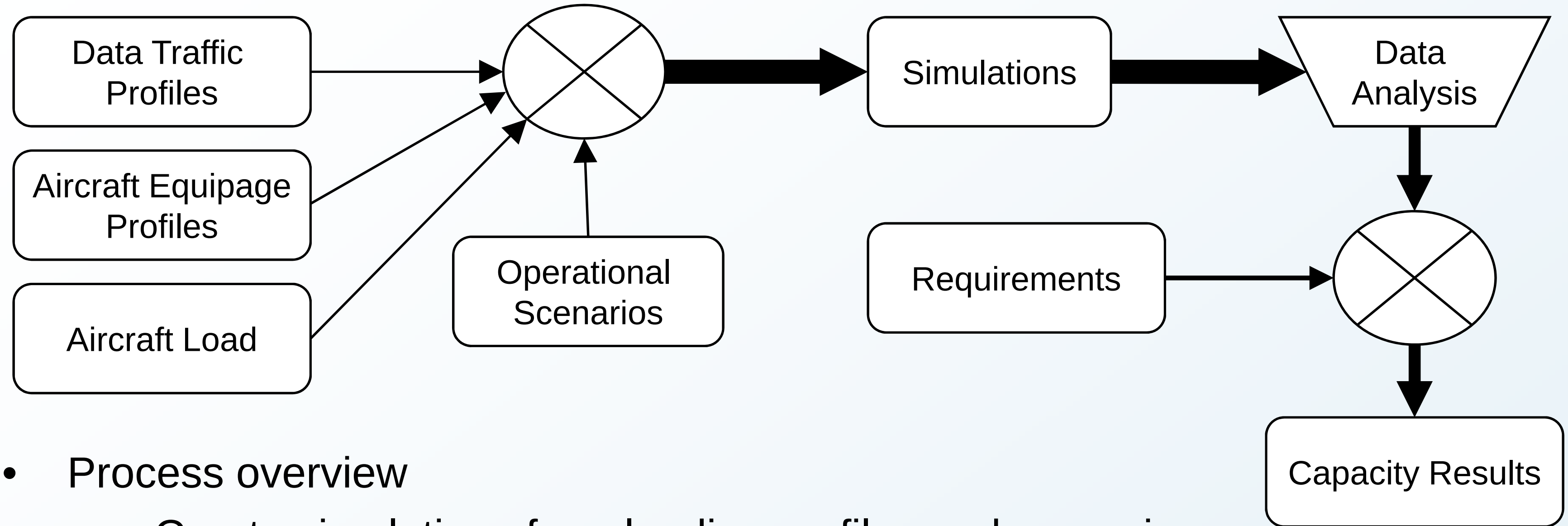
- NASA Glenn Research Center / Cleveland State University are using simulations to support an FAA analysis study on VDL Mode 2
  - Utilize custom simulation models for VDL Mode 2
  - Determine channel capacity based on requirements
- Studies are based on the Communications Operating Concepts and Requirements (COCR) document
  - Traffic profiles
  - Domain definitions
  - Delay requirements
  - http://nas-architecture.faa.gov/nas/downloads/cocr/COCR_v200.pdf

CSMA and Hidden Terminals

- VDL Mode 2 uses a Carrier Sense Multiple Access (CSMA) protocol
  - Uses a simple ‘listen-before-transmit’ approach to reduce on-channel collisions
- CSMA is susceptible to hidden terminals
  - The hidden terminal problem arises when not all radios have the same view of the network



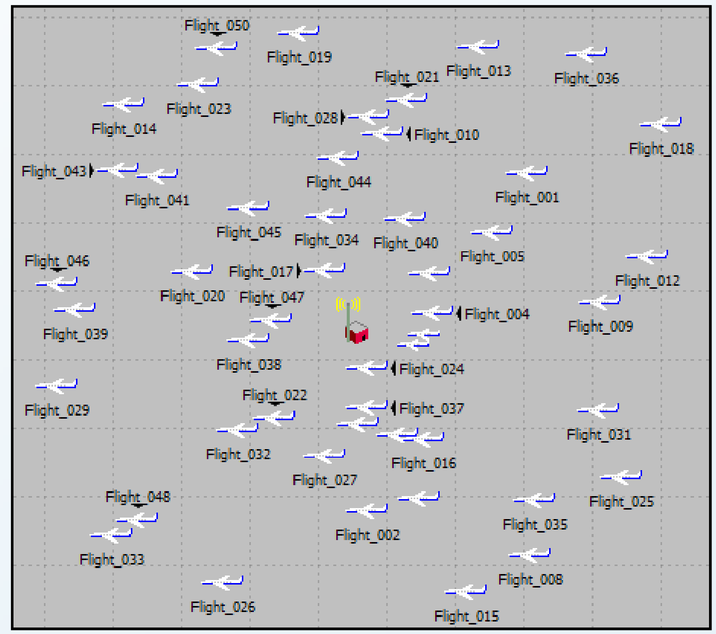
Capacity Determination Process



- Process overview
  - Create simulations from loading profiles and scenarios
  - Run simulations and collect and analyze the data
  - Compare the results to requirements to determine capacity
    - Main requirement is 95th percentile subnetwork delay
- Notes
  - Changes in profile assumptions lead to re-simulation
  - Simulations may take a considerable amount of time to run
    - Anywhere from several minutes to a few hours apiece

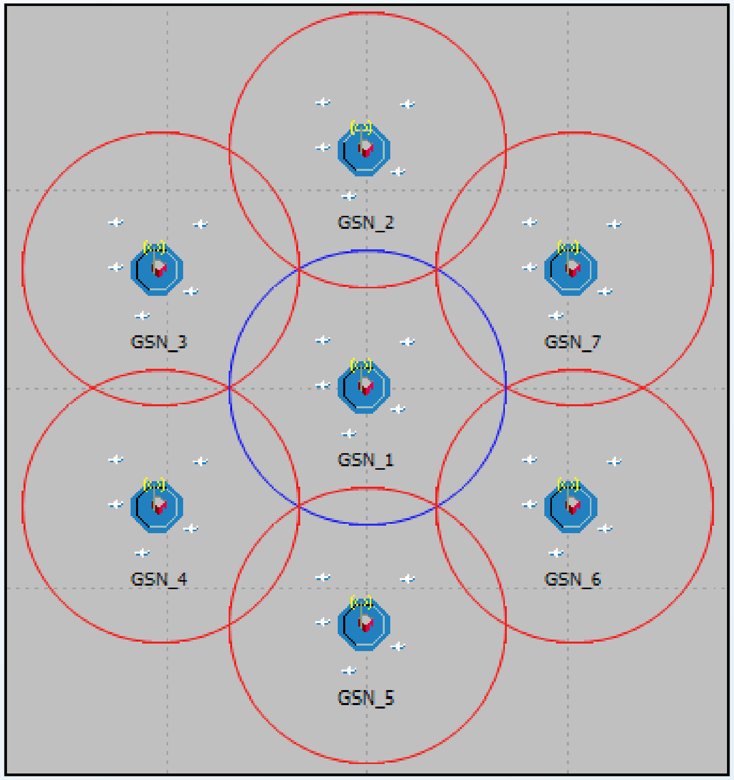
Simulation Process

- Scenario design
  - Number of aircraft
  - Distance from ground station (based on domain)
  - Altitude (based on domain)
- Assign a traffic profile
  - Based on domain and segment
- Run the simulation
  - Set run length based on sample size
  - Use multiple runs with varying seed values
- Analyze the overall results
  - Capacity determined as maximum number of aircraft that met requirements



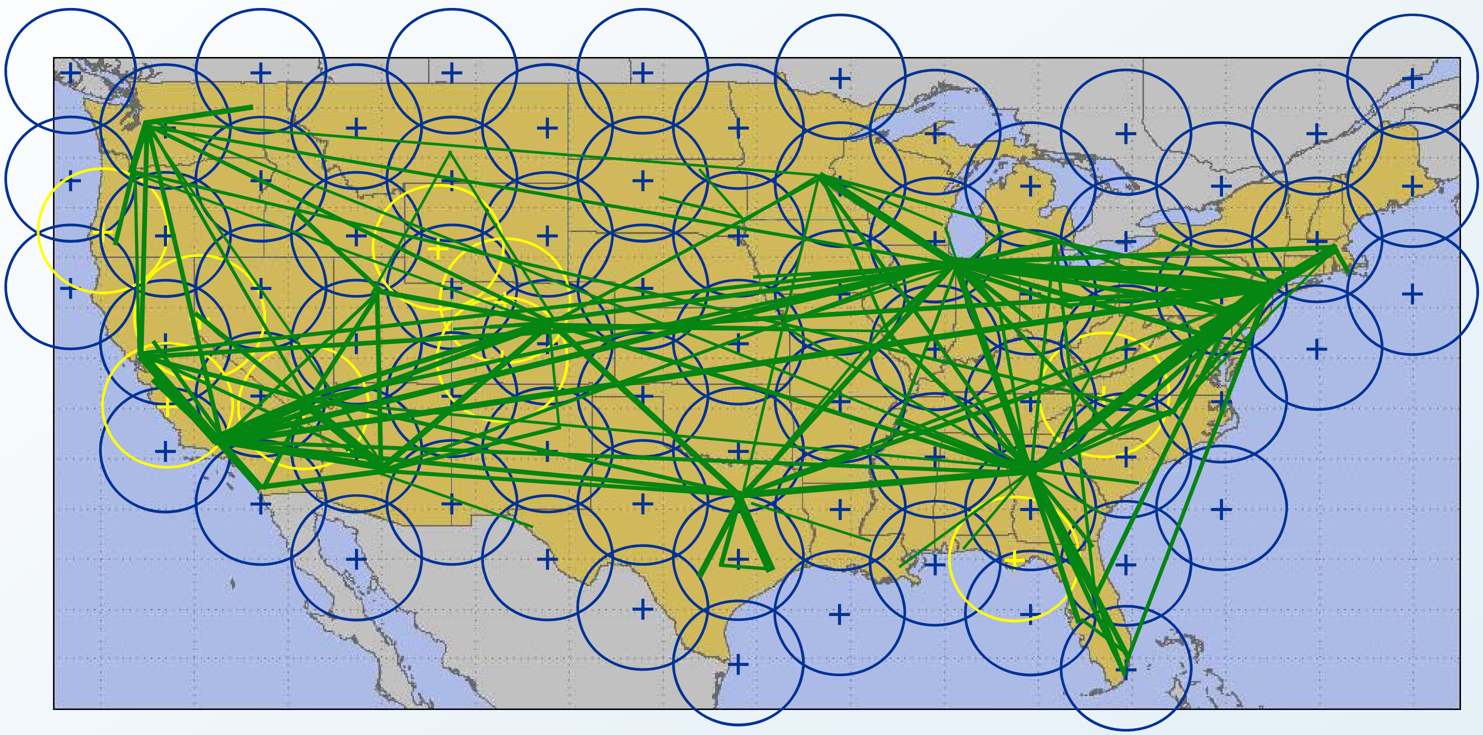
What About Hidden Terminals?

- Same process as before, but includes additional ground stations
  - Each ground station has the same number of aircraft
- Positions of objects creates hidden terminals due to curvature of the earth
  - Ground stations do not see each other
- Results analyzed only for central ground station and its aircraft



Static Simulation Concerns

- Ground station layout
  - Need to account for coastlines, borders, and terrain
- Aircraft placement and density
  - Varies greatly over the CONUS



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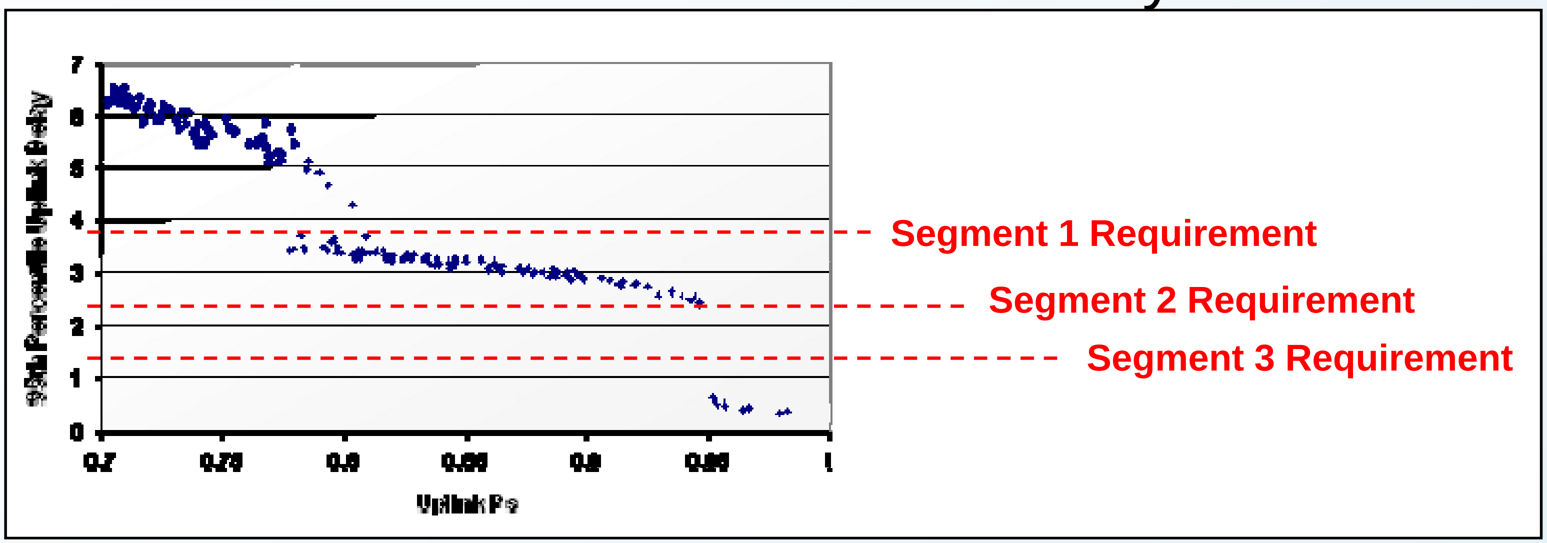
Simulate a Dynamic Environment?

- We could bring a more realistic dynamic scenario into the simulations
  - Moving aircraft following realistic flight paths
  - More realistic ground station locations
  - Terrain data
- But there are some problems
  - Need a large sample size to compute 95th percentile delays
    - Use a long simulation run, or
    - Use a large number of shorter runs
  - Need to worry about data dilution
    - Due to time density
    - Due to area density
- These problems can be overcome with proper simulation planning, large numbers of runs, and analysis
  - Biggest hurdle is time

Alternative: An Analytical Model

- An analytical model could solve some of these issues
  - It is based on probabilities, not samples
- Need to find some correlation to 95th percentile delay
- What contributes to the subnetwork delay?



- Is there a relationship to retransmissions?
  - There is a relationship to the probability of success

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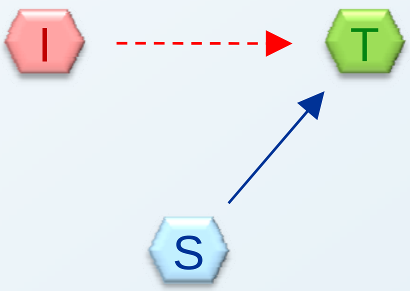
Design Goals

- Estimate the probability of success on radio-by-radio basis
  - Account for visible and hidden terminals
- Break some common analytical assumptions
  - Constant propagation delay
    - Usually the largest propagation delay is used to determine lower bound of performance
  - Zero-length acknowledgements
    - VDL Mode 2 acknowledgments need to be considered
  - Fixed-length messages
    - Large variations in message sizes can impact performance
  - Symmetry
    - All radios are not the same and transmit different amounts of traffic
- Keep it (relatively) simple
  - Many analytical methods for hidden transmitter are very complicated
  - Sacrifice some accuracy for simplicity (and speed)
  - Abstract the MAC channel access process
- Not meant to be a replacement for simulations

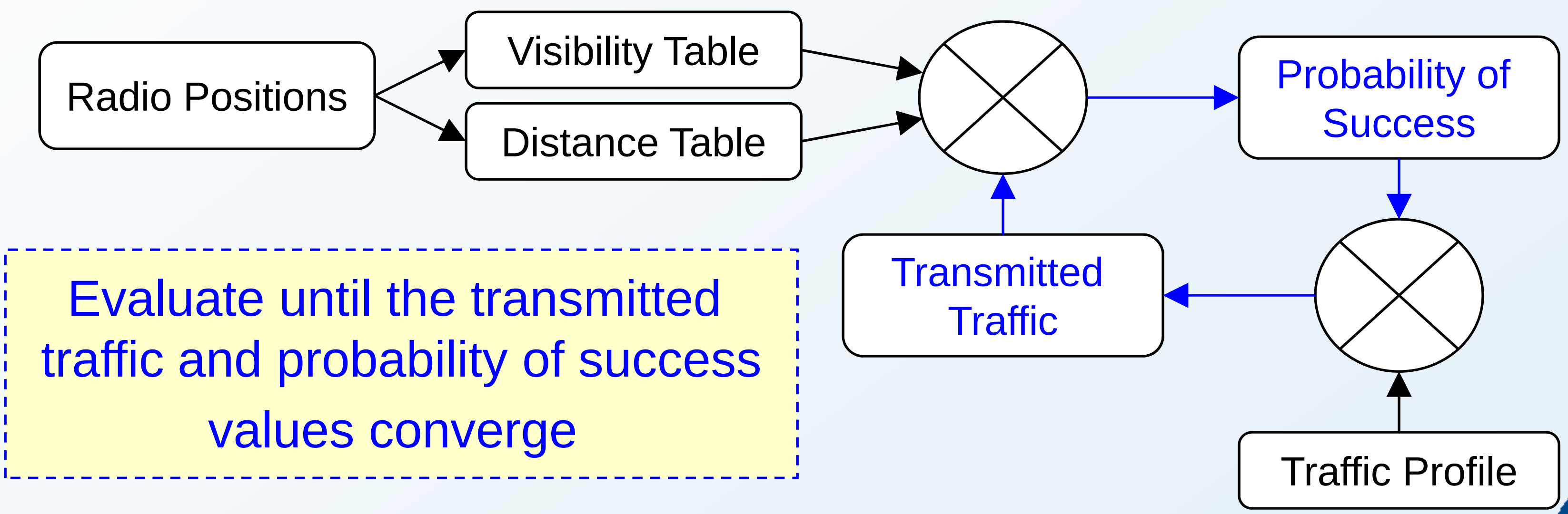
Analytical Model

- The model breaks the problem down
  - Given that source S sends a message to target T, find the probability that it will not be interfered with by I
  - Figure this out for all possible interferers, then multiply all the individual probabilities together
- A few complications
  - Requires knowledge of transmitted traffic (data, retransmissions, and acknowledgements)
  - Retransmissions are based on the probability of success
- Details on the equations can be found in the paper:
  - Bretmersky and Apaza, "Estimation of VDL Mode 2 with Hidden Transmitters", 2009 IEEE Aerospace Conference.



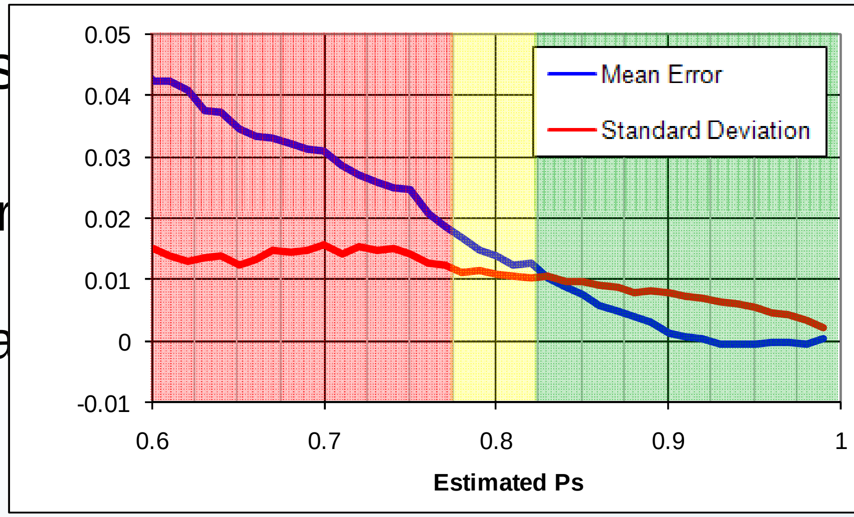
Estimate Process

- Derive visibility and distance tables from the radio positions, terrain
- Use the visibility, distance, and amount of transmitted traffic to determine the probability of success for each radio
- Use the traffic profile and probability of success to determine the amount of transmitted traffic
  - Includes traffic in profile plus retransmissions and acknowledgements
- Use iterative approach to resolve circular dependence between the probability of success and transmitted traffic



Estimate Test

- Estimate tes scenario with varying ocations
  - 100 scenar ft loads and locations
  - 18,200 tota mulations and estimate
- Test results



  - Estimate worsens as probability of success decreases, but is r
  - F nts
  - W s that need to be performed.

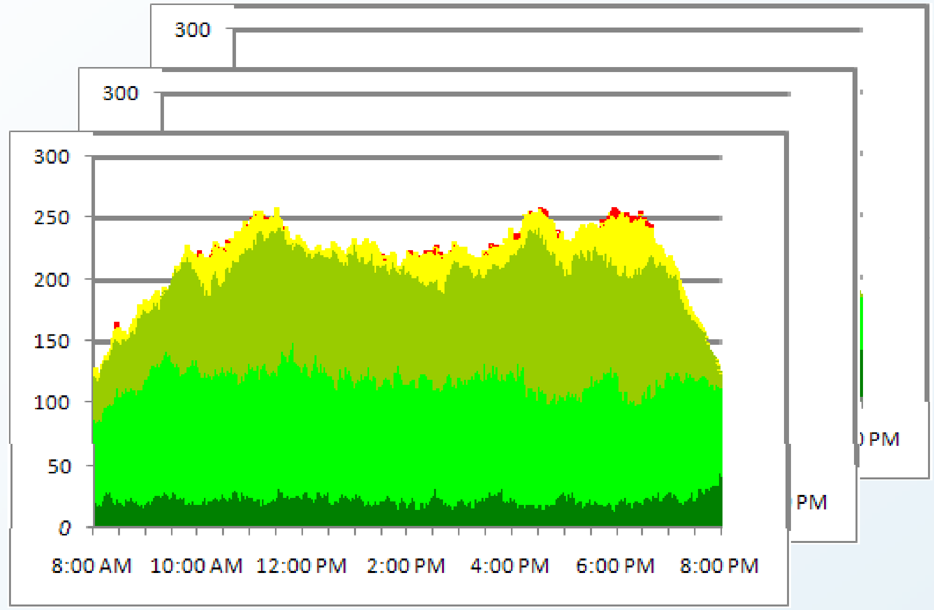
Simulations took over 50 hours to run, but all 100 scenarios were estimated in under 3 minutes total

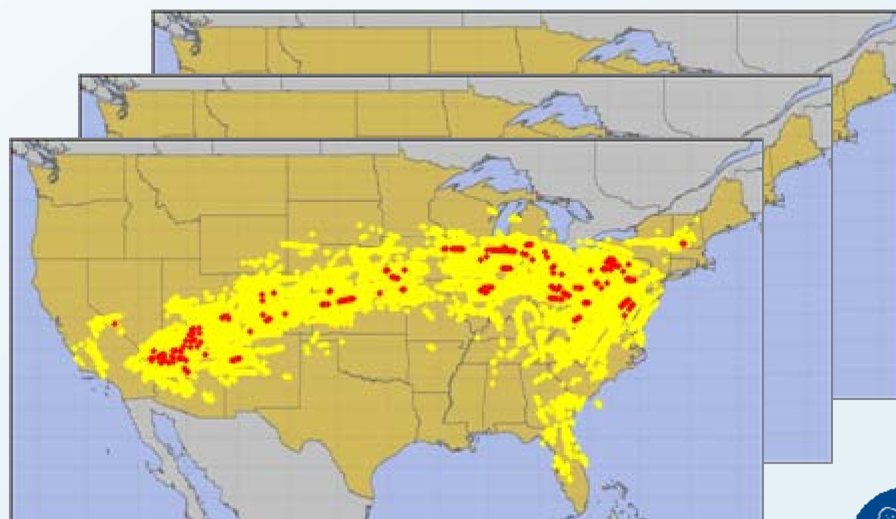
Dynamic Scenarios

- Use ground station locations at existing RCAG sites
  - 220 sites identified by MITRE for continuous CONUS coverage
- Use actual flight tracks
  - CONUS tracks over a large portion of a busy day
  - Includes latitude, longitude, altitude, and time
  - Limit locations to those within 200 NM of a ground station, above 16,000 ft
- Evaluate the performance in one-minute increments
- Adjust load by changing the equipage rate
  - Probabilistically equip aircraft

Example Analysis

- Estimate allows us to look at performance
  - By time
  - By location
- Examples
  - 4% Equipage
  - 5% Equipage
  - 6% Equipage
- Charts quickly identify where the problem areas are





Planned Uses

- Airspace scenarios
  - Enroute
  - Terminal
- Biased equipage scenarios
  - Impact of commercial / cargo / GA equipage
  - Impact of carrier equipage
- Multi-frequency evaluations
  - Shared-frequency performance
  - Distributed-frequency performance

Conclusions

- Dynamic scenarios necessary to understand performance in real-world settings
- Analytical model can be used to estimate performance
  - Benefits
    - Provides fast means of approximating system performance
    - Process lends itself to examining large-scale scenarios
  - Downfalls
    - Approximations are not perfect, simulations are still required for verification
    - Simplifying assumptions limits its use
      - Cannot investigate VDL parameter impact
      - Cannot account for issues due to higher layer protocols (queuing, flow control)
    - Has some scalability issues for very large numbers of radios
    - Model is untested for other traffic profiles, domains
      - Must be validated for these scenarios before it is used

Questions?