Test and Evaluation/Science and Technology Program
Spectrum Efficient Technology Focus Area

Algorithms for a *Spectrum Management System* A Tool to Aid Efficient Frequency Planning at Test Ranges

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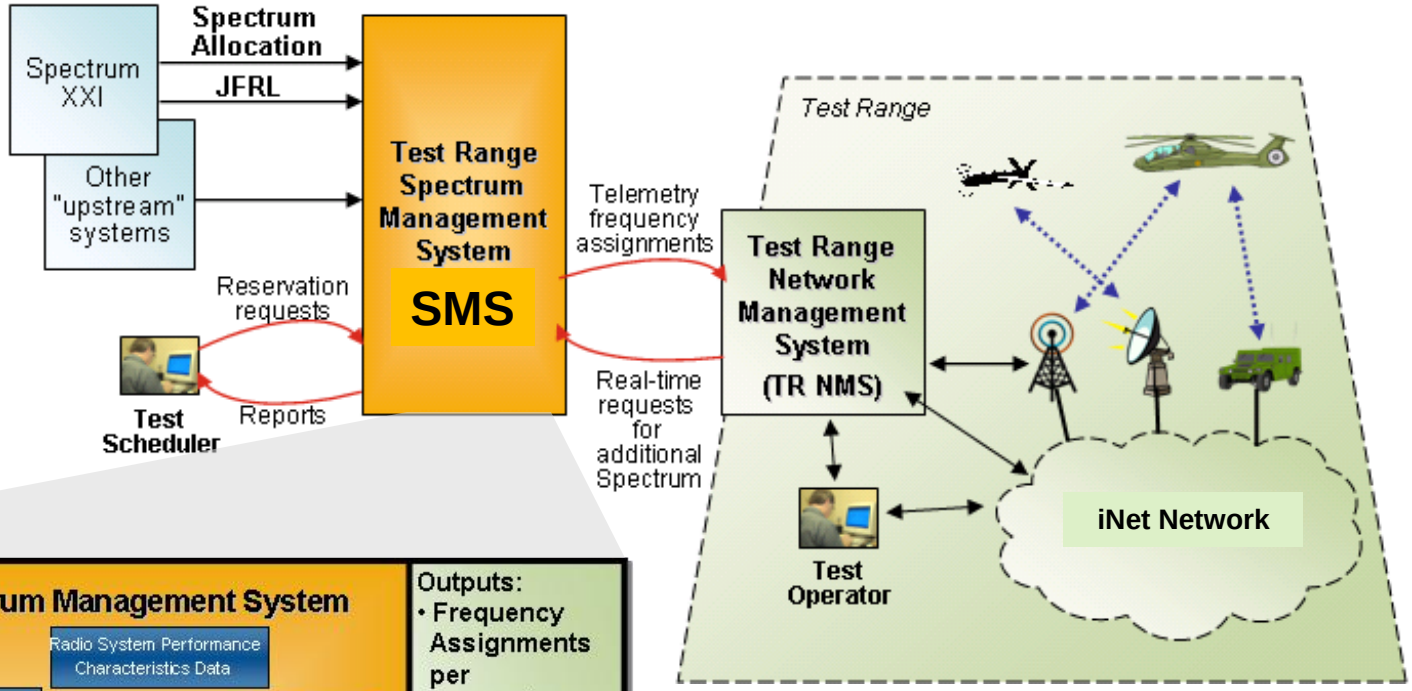
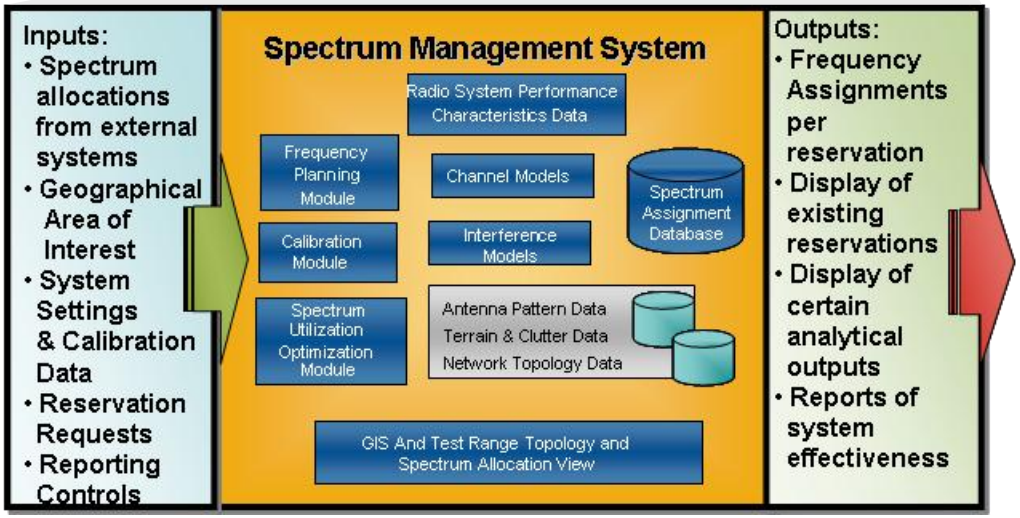
Problem Statement

- **Test & Evaluation Needs**
  - With increased bandwidth demands and a shrinking pool of available spectrum, only recourse is to significantly improve the 'test throughput' across the MRTFB
  - Manage available spectrum to maximize test range utilization
  - Dynamically share spectrum among concurrent test activities based on instantaneous demand
  - Rapid re-plan and re-assignment of spectrum during test execution in response to changes in real-time bandwidth needs and interference conditions
- **Science & Technology Challenges**
  - Develop effective frequency planning/optimization algorithms that enable high spectral efficiency and maximize test range utilization with sufficient link quality to meet MRTFB needs
  - Significantly improve the throughput of test ranges through:
    - Closer spacing of tests given a finer-grain view of frequency-band and air-space utilization
    - GUI visuals that allow the frequency manager to 'see' link quality, interference and gaps in spectrum usage
    - Frequency reuse
  - Spectrum planning in five dimensions – estimating capacity and link quality as functions of space, time and frequency

Spectrum Management System (SMS) Project Description

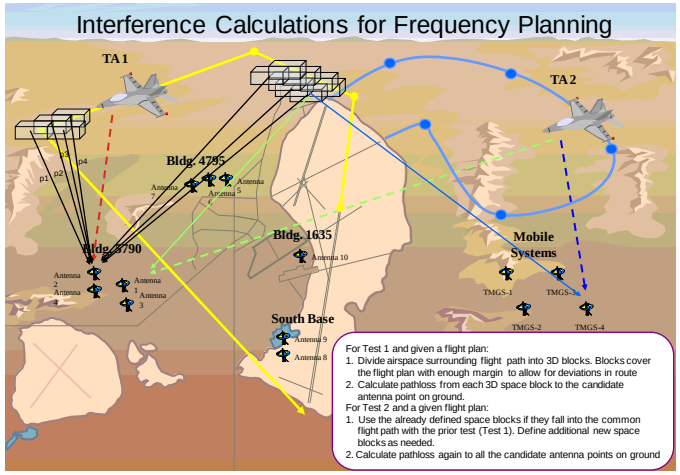


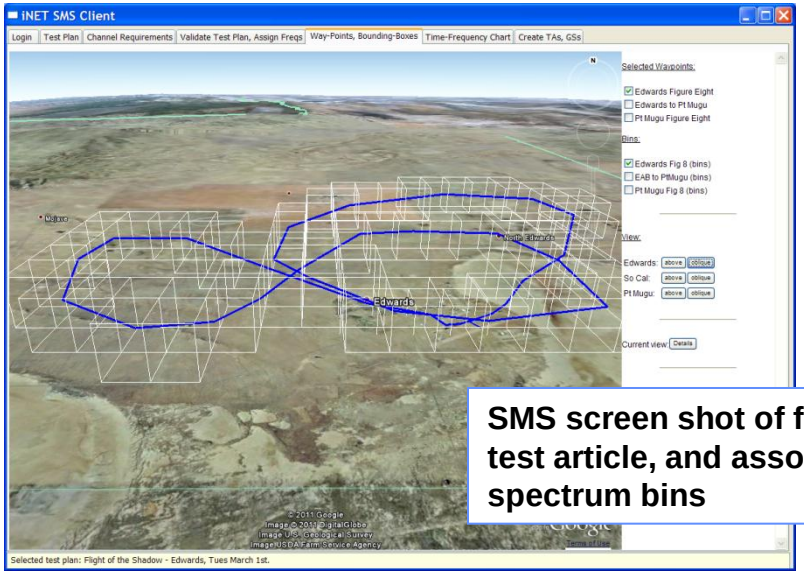


Design, prototype and demonstrate a Spectrum Management System that incorporates realistic channel models, and accurate models for advanced radio system functionality to provide flexible operations and efficient use of the radio spectrum.

SMS Phase 1 Accomplishments

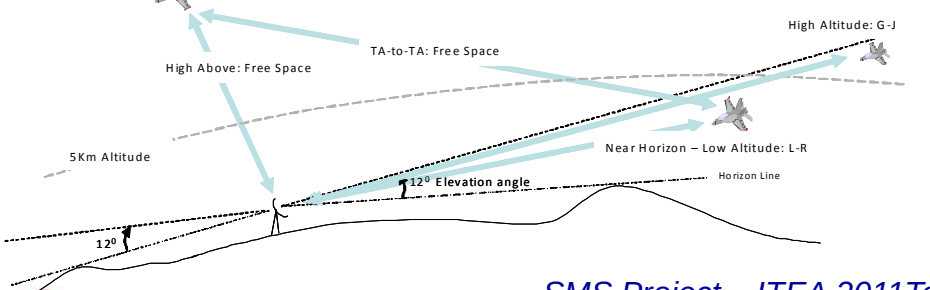
- Designed the SMS architecture, data model, and Engineering Prototype user interface
- Created preliminary software requirements for the SMS Phase 2 Build Prototype
- Devised and developed advanced frequency planning algorithms that extend reuse to 3D
- Developed a high fidelity Composite Aeronautical Path loss Model (CAPM) appropriate for use in the Test Range environment





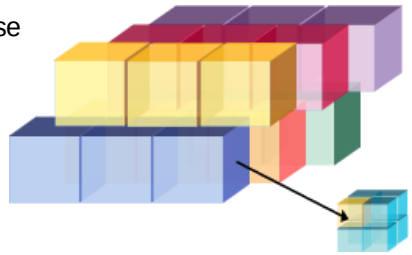
SMS screen shot of flight path of test article, and associated spectrum bins

Channel models used in the SMS



Innovative 3D Frequency Reuse Approach

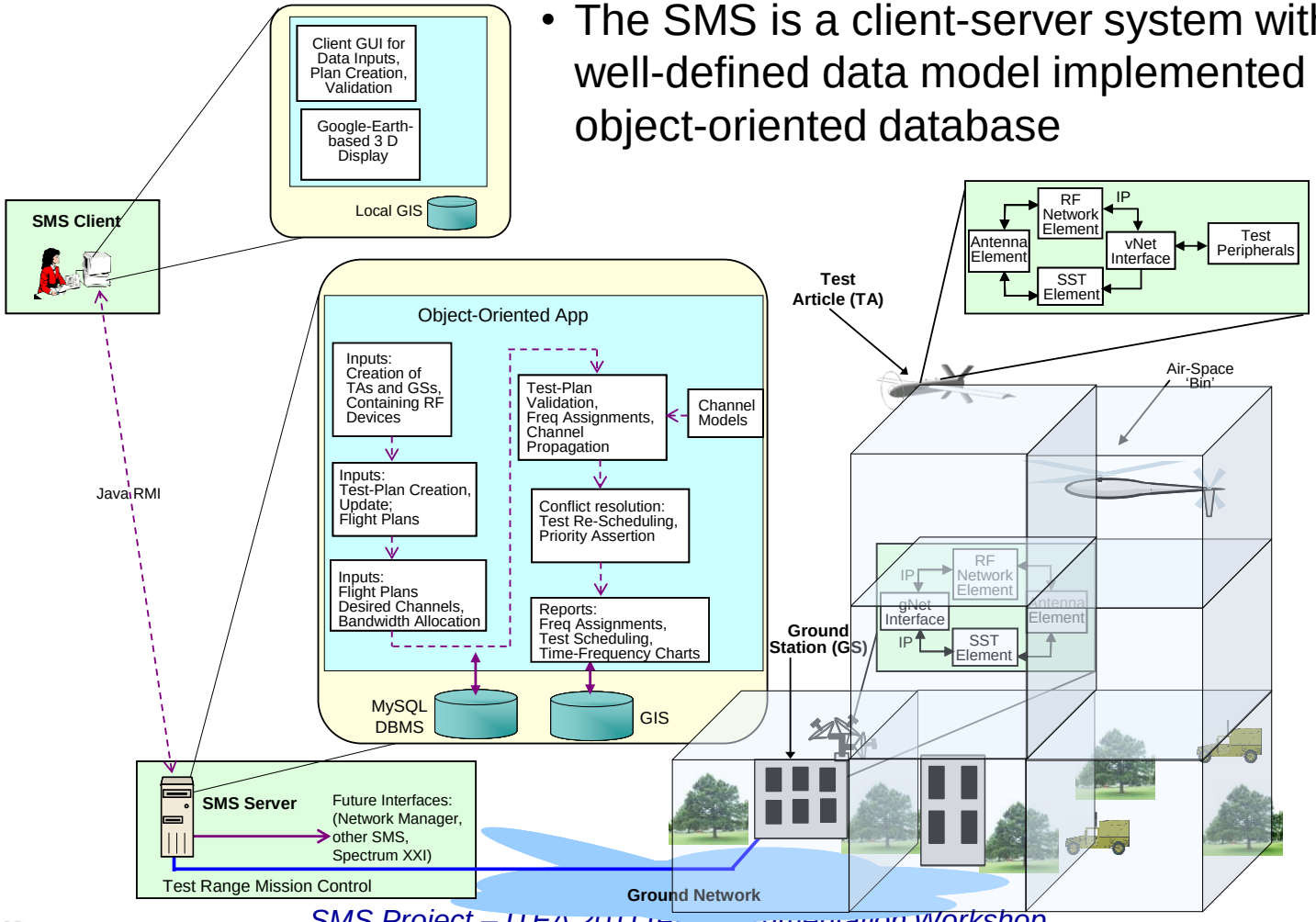
Developed a concept of 3D reuse as an extension of 2D reuse in terrestrial cellular networks that provides for a conservative yet efficient allocation of frequency resources supporting time-coincident reuse of spectrum



SMS Architecture

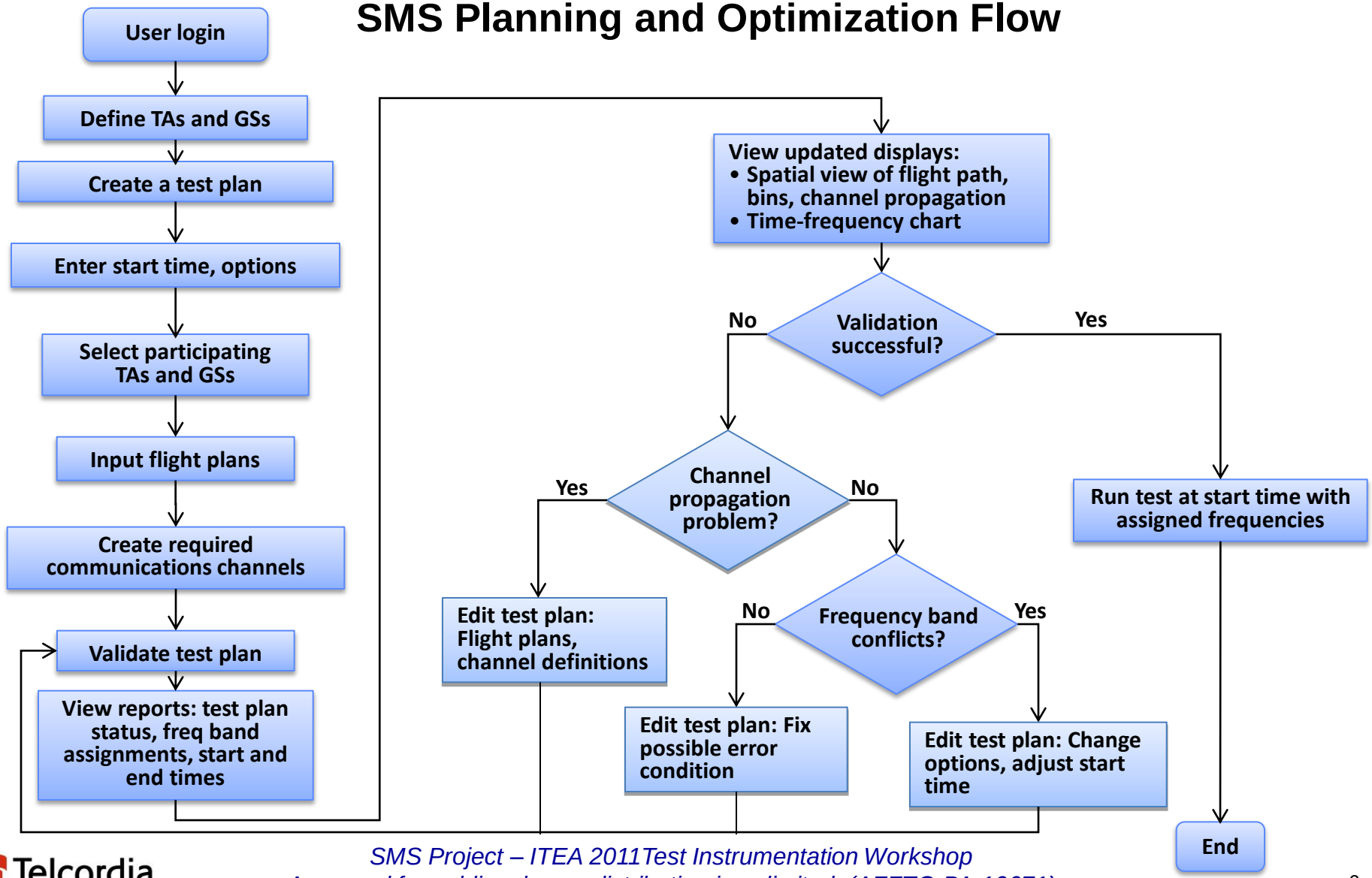
- The SMS is capable of planning frequency assignments for test plans across multiple test ranges including the flight corridors between them

- The SMS is a client-server system with a well-defined data model implemented by an object-oriented database



SMS Notional CONOPS

SMS Planning and Optimization Flow

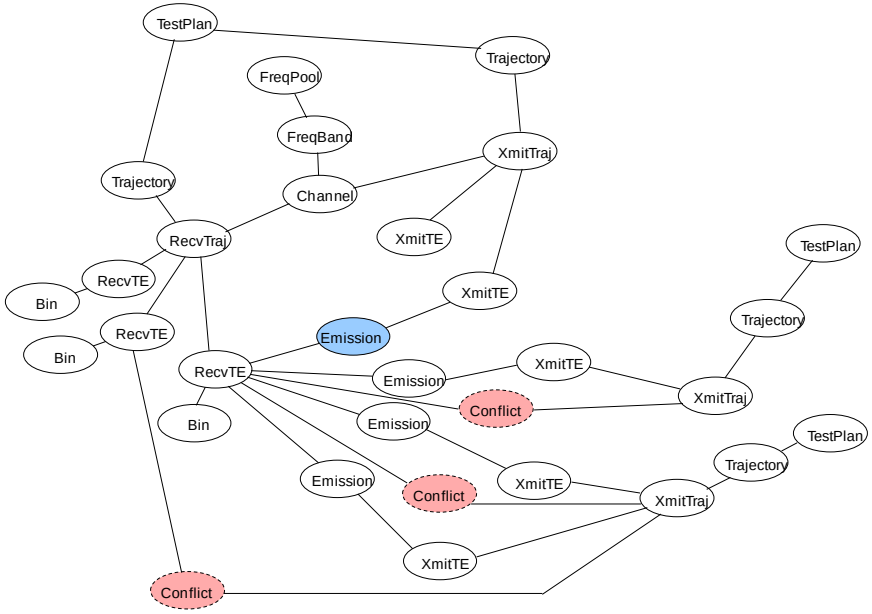


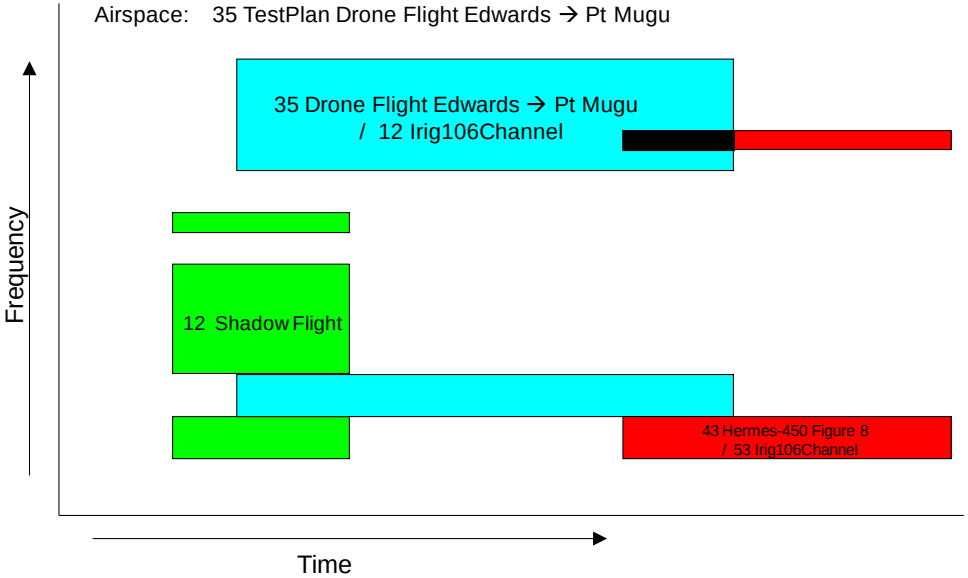
SMS Planning and Optimization Flow

- SMS reference data includes test ranges, terrain data, spectrum allocations, current inventory of TAs and GSs, the RF transmitters and receivers, their frequency and power attributes, antennas and their attributes
- Test Planner creates a 'Test Plan'
- SMS runs a 'Validate' process on the test plan
  - Check integrity of: TAs, GSs in test, flight paths, channel definitions
  - Creates frequency assignments for each transmitter and receiver in test
    - First tries without employing frequency reuse. If none available assigns with frequency reuse by determining the signal-to-interference ratio for each 'bin' of air-space in the test article's flight-path.
  - SMS validates RF propagation for each requested channel using appropriate channel models for the scenario
- If the SMS determines conflicts with other test plans, responds to Planner with a 'recommended start time' when there will be no conflicts
- Once test is validated, frequency assignments are available as tabular reports, or are input directly over the interface to the Network Manager
- Flight paths, air-space 'bin' occupancy, spectrum assignments, propagation and interference are viewable in 3-D on SMS client GUI

SMS Planning and Optimization Flow

- SMS Client shows ‘Frequency-Time’ chart of scheduled tests for designated regions of air-space. Allows Planner to see frequency-occupancy ‘gaps’, or otherwise manually re-arrange start times for tests.
- During a test mission, the SMS supports real time requests from the NMS for additional spectrum, dynamic spectrum re-allocation, priority changes, and bandwidth changes.
- Additional inputs and outputs may be provided by interfaces with upstream and downstream systems.



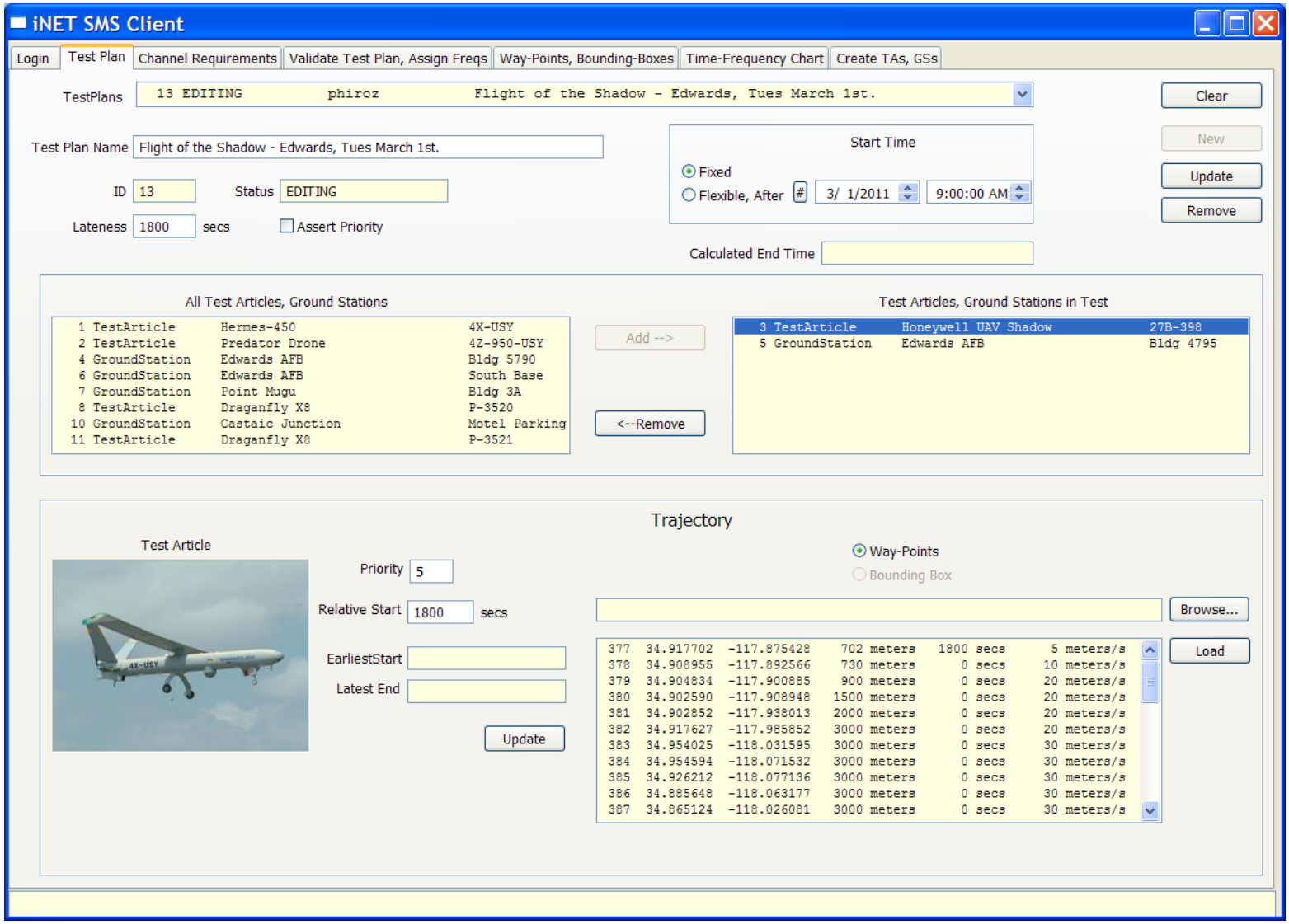


SMS Engineering Prototype

- **Engineering Prototype demonstrates SMS tool to aid Frequency Managers in planning tests in the MRTFB**
  - Prototype verifies proof-of-concept and supports architecture and algorithm development
- **Allows a Frequency Manager to create and edit a test plan...**
  - Define test articles with their flight plans, ground stations and their locations
  - Configure them with RF devices
  - Specify RF channels (IRIG-106 and iNET) with their bandwidth requirements
    - Supports TDMA for iNET channels
  - Specify test plan options: fixed / flexible start time, priority-based preemption, frequency reuse
- **Validates the test plan and assigns a frequency to each link**
  - Verifies channel propagation during the test
  - Verifies signal-to-interference ratio for frequency reuse option
  - Allows for multiple receiving ground stations, and hand-off
- **Displays**
  - 3-D display over terrain of flight paths and spectrum bins
  - Time-frequency chart of frequency band occupancy of test plans over time

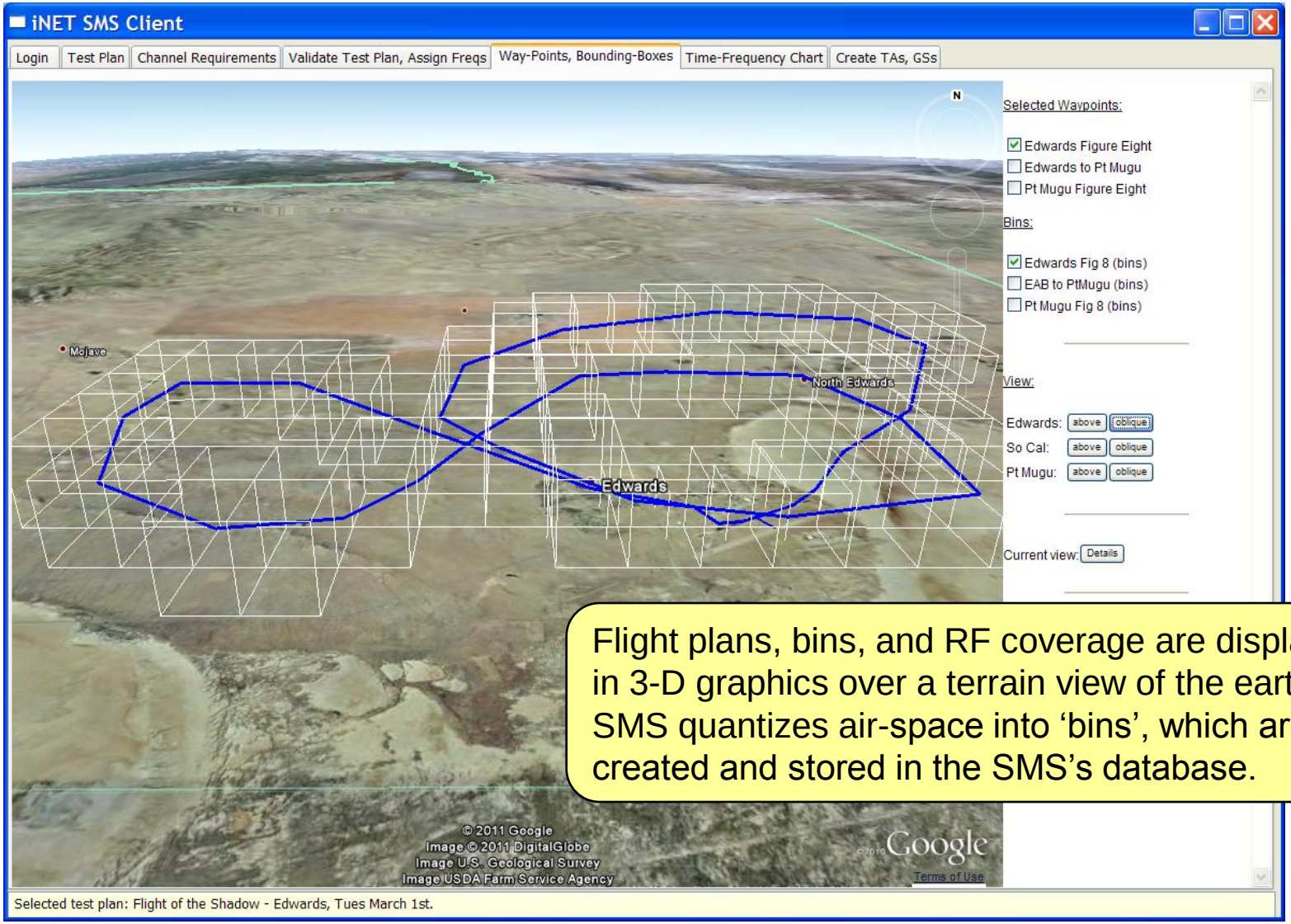
SMS Engineering Prototype screen shots follow ⇨

SMS Engineering Prototype
Test Plan creation and editing



SMS Engineering Prototype

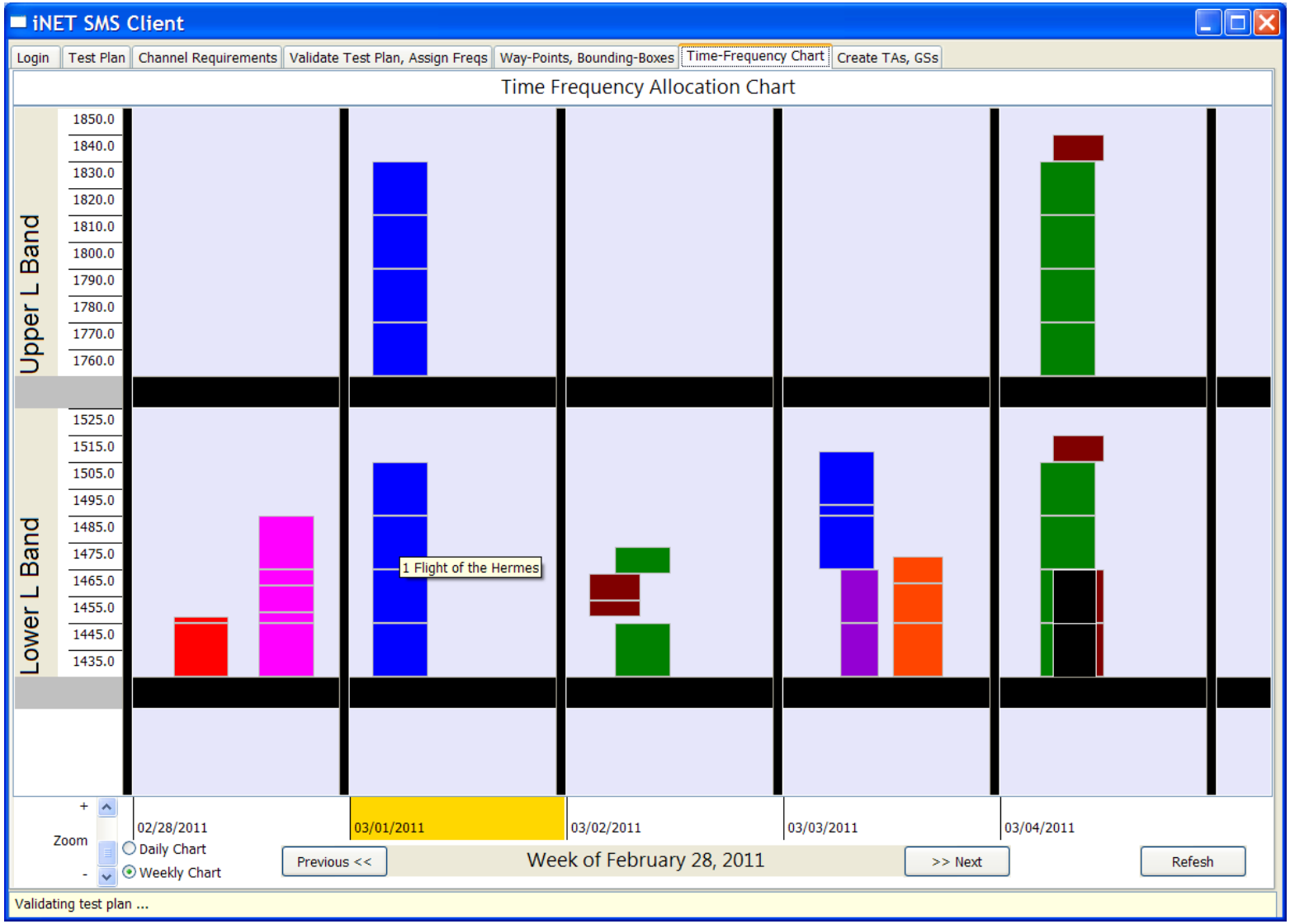
Flight path of Test Article and spectrum bins



Flight plans, bins, and RF coverage are displayed in 3-D graphics over a terrain view of the earth. SMS quantizes air-space into ‘bins’, which are created and stored in the SMS’s database.

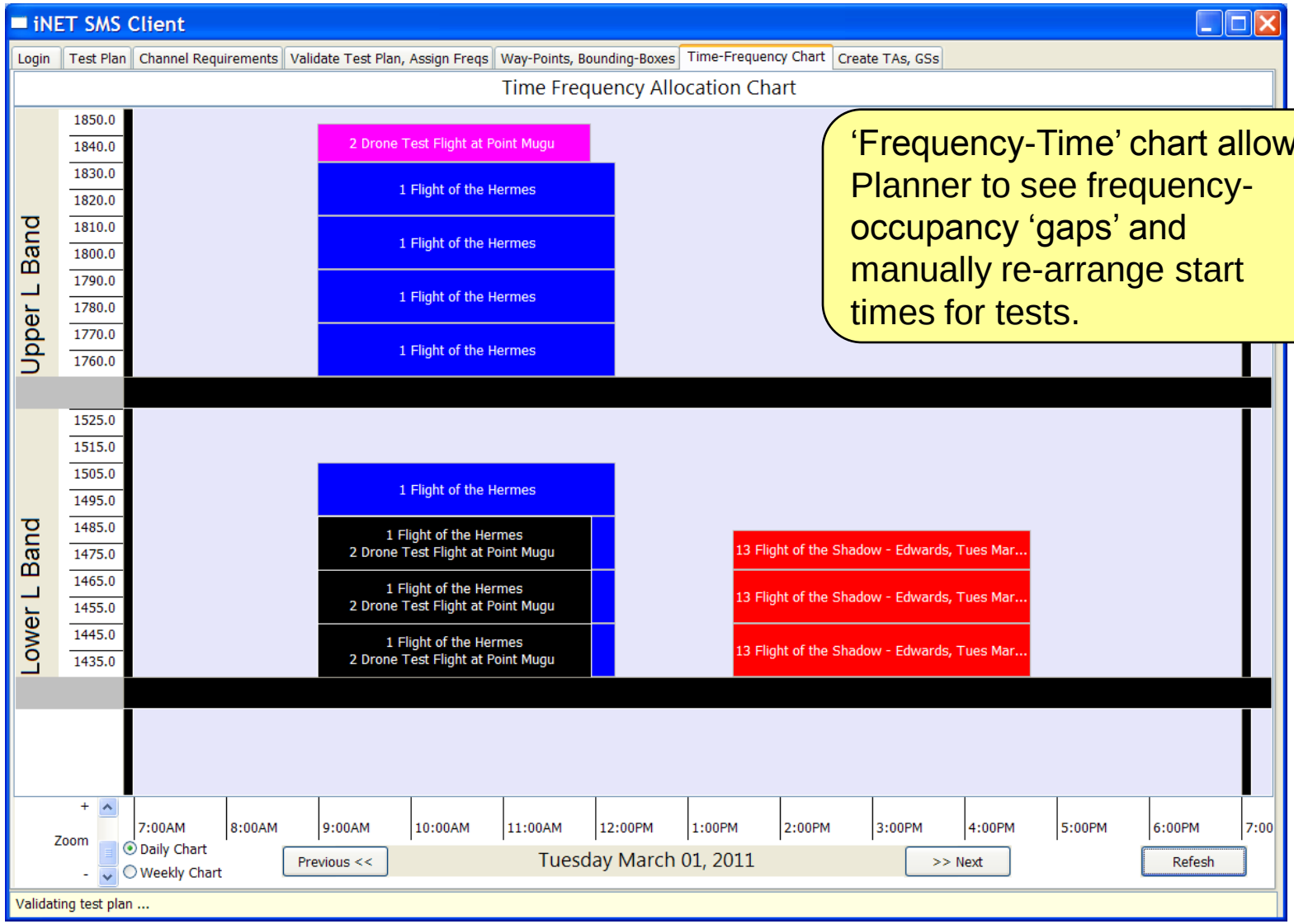
SMS Engineering Prototype

Time-Frequency Chart, weekly view



SMS Engineering Prototype

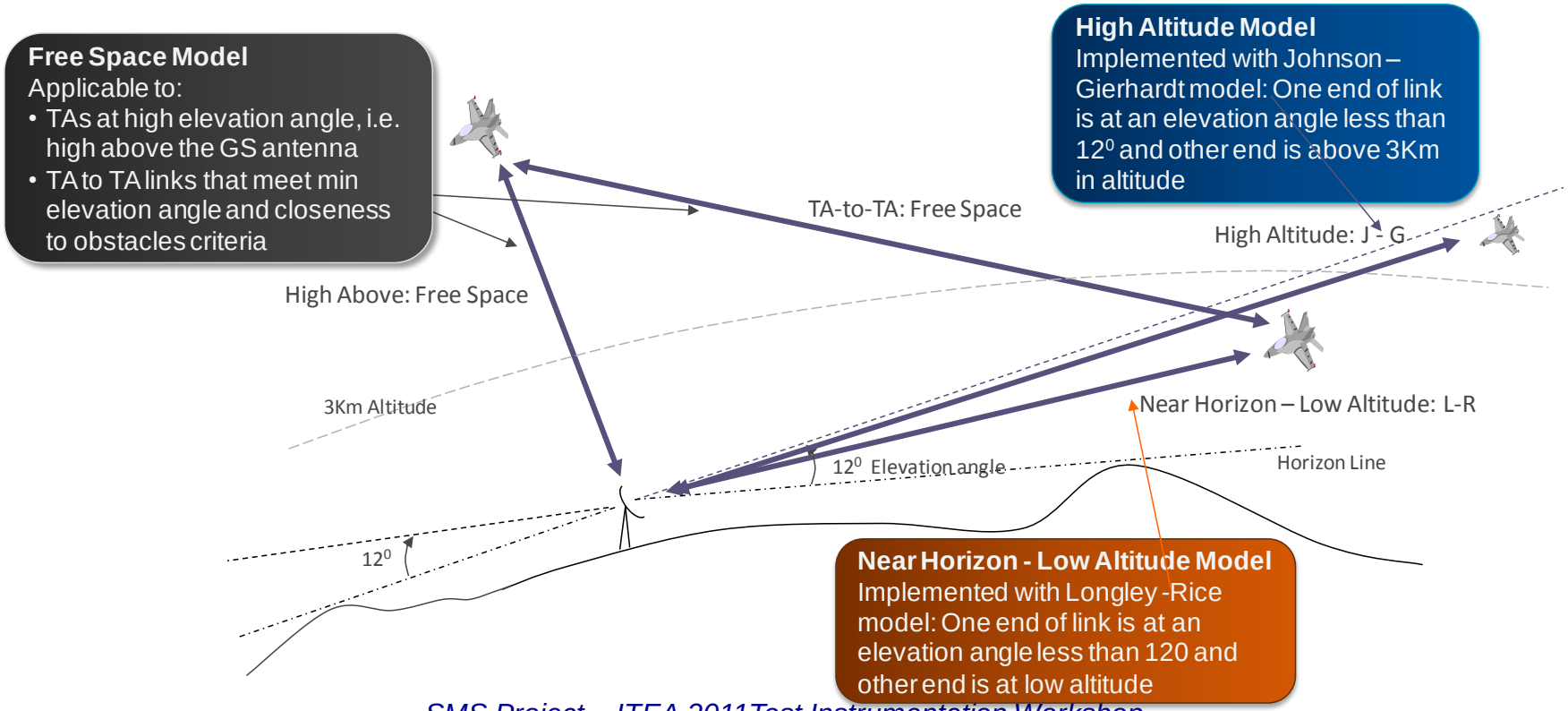
Time Frequency Chart, daily view – with frequency reuse



'Frequency-Time' chart allows Planner to see frequency-occupancy 'gaps' and manually re-arrange start times for tests.

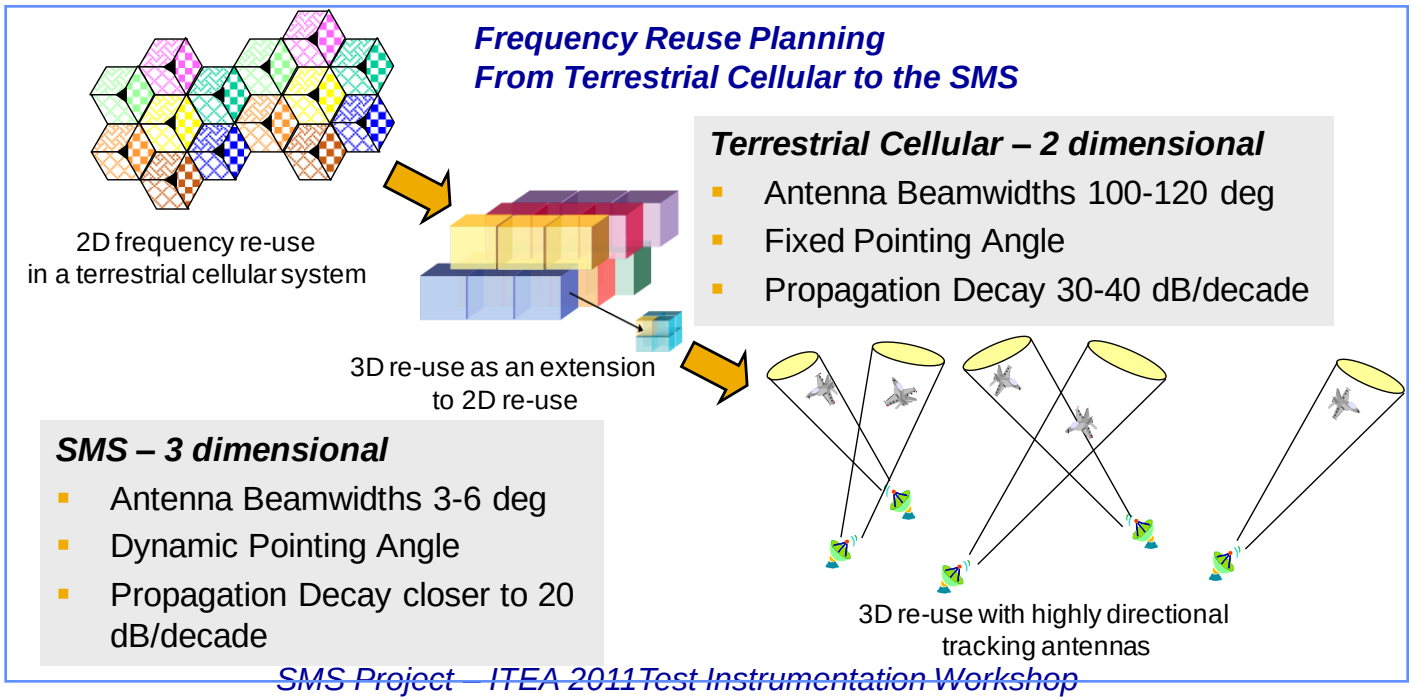
SMS Channel Models

- Reviewed three standard path loss models that are appropriate for use in the Test Range environment (free-space, Longley-Rice, and Johnson-Gierhart) and models based on recent measurement campaigns by Rice et al.
- Developed the *Composite Aeronautical Path Loss Model (CAPM)* that incorporates the above models, categorizes the environment based on geography, transmitter/receiver location, altitudes, and geographic features and includes a link reliability metric. Environments include: high altitude link, low altitude – near the horizon link, high and above link, tarmac link, and test article to test article link.



Frequency Planning Algorithms

- **Developed an *innovative frequency planning algorithm* that provides for a conservative yet efficient allocation of frequency resources supporting time-coincident reuse of spectrum**
  - Identifies and quantifies potential interference between time-coincident tests using a series of geospatial calculations performed in 3-Dimensional space
  - Interference and additional constraints (e.g., priority) are mapped into a frequency reuse constraint matrix that lends itself naturally to a sequential solution that is computationally efficient and whose solution space can be represented using a trellis formulation
  - To support the practical use case in which requests for frequency allocations at a given time are expected to arrive over a period of time, the solution solves for the frequency needs of all known tests; when an additional request arrives, the solution attempts to assign frequencies to the new test without changing the allocations made previously
  - The solution obtained is used by the SMS to enumerate the frequency assignments that satisfy the needs of a set of test plans



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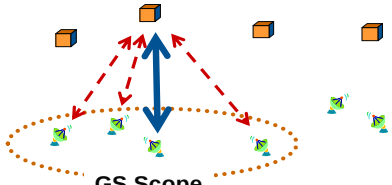
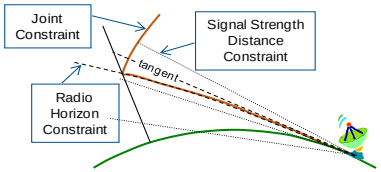
Frequency Planning Algorithms

A Mosaic of Modeling Concepts



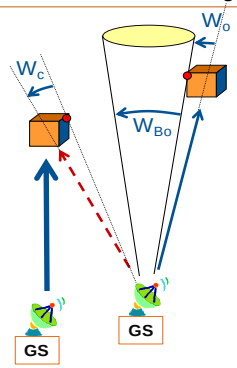
GS Scope

Scope: Which Ground Stations (GS) need to be involved in interference calculations



The calculation of GS Scope

Radio Horizon vs. Propagation – former is often the limiting factor



Threshold of relevance for GS-to-TA geometric calculations

- Quantization of locations of Test Articles (TA) into bins – improves computational speed
- Antenna pointing uncertainty

A Basis in Theory - A Practical Design

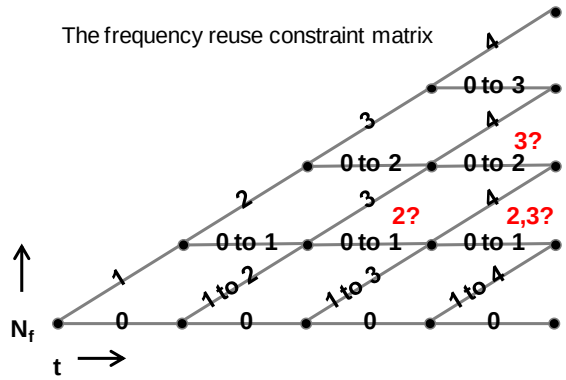
	TA# 1	TA# 2	TA# 3	TA# 4	TA# 5
TA# 1	0				
TA# 2		0			
TA# 3			0		
TA# 4				0	
TA# 5					0

Contains a "0" or a "1"
0: No Constraint
1: Constraint

Symmetric About Diagonal – Need only look at upper triangle

Diagonal all zeros

The frequency reuse constraint matrix



Trellis formulation of the solution of the frequency reuse constraint matrix

Theory

- Formulate Frequency Assignment as a system of constraints which preclude a pair of TAs from using the same frequency
- Sequential solution not unique – difficult to find optimum – but good solution is easy to find
- Priority handled automatically by order in which solution is found

Practical Design

- Desire to allocate frequencies for tests as requests come in rather than wait for all requests and find solution
- Up-to-date view of what is allocated and what is available
- Priority more difficult as earlier tests may need to be preempted or reallocated

Summary

- **Spectrum Management System Project Objectives**
  - Design, prototype and demonstrate a system that incorporates realistic channel models to assist Frequency Managers in planning frequency band assignments at test ranges
  - Demonstrate spectrum planning in five dimensions – estimating capacity and link quality as functions of time, spatial coordinates (latitude, longitude and altitude), and frequency.
  - Significantly improve the spectrum utilization at test ranges through frequency reuse and closer spacing of tests
- **Current Achievements/Progress**
  - Completed initial SMS architecture, requirements and Engineering Prototype
  - Developed SMS channel model and frequency planning algorithms
- **Future efforts**
  - Work with frequency managers to refine SMS CONOPS
  - Develop and trial SMS Build Prototype