The IEEE 1900.5.2 Standard for Modeling Spectrum Consumption

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Outline

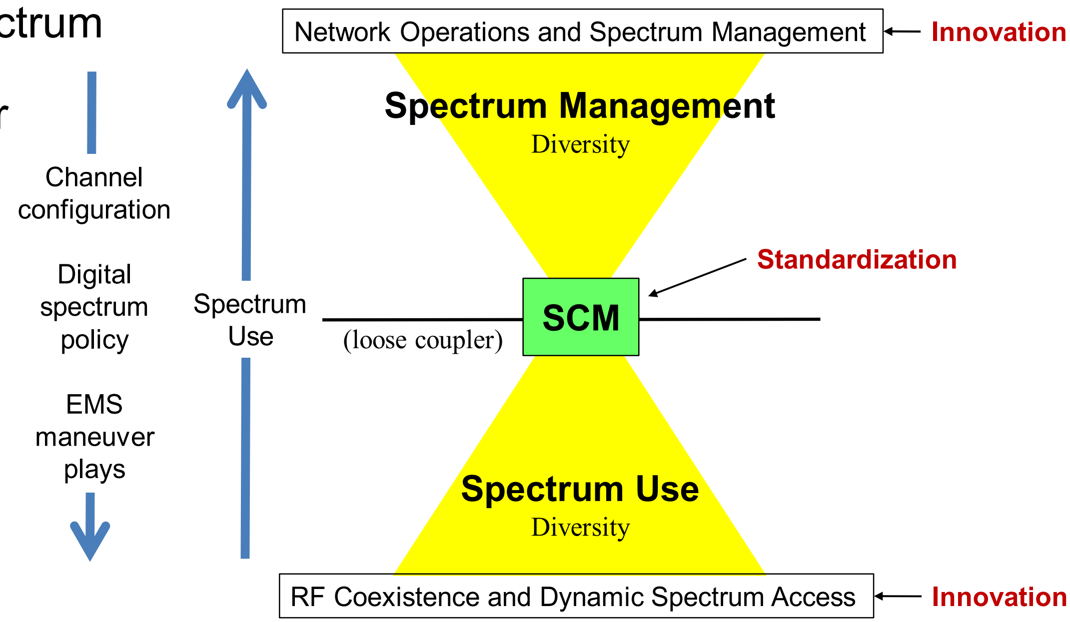
- **Introduction**
- **The IEEE 1900.5.2 Standard**
  - Model constructs
  - System modeling
  - Assessing compatibility with spectrum consumption models (SCMs)
- **Benefits**
  - Robust tool development
  - Rapid decision making
  - Specialized algorithms
- **SCM Builder and Analysis Tool (SCMBAT)**
- **Conclusions and Future Steps**

Introduction and Background

- **Spectrum-sharing mechanisms are becoming more common**
  – Database-managed sharing and the National Spectrum Access System (SAS)
    - 3.5 GHz band (CBRS – Citizen's Broadband Radio Service)
    - Other bands being considered
- **Dynamically sharing spectrum requires defining the boundaries of spectrum use**
  – Defining how systems emit EM radiation
  – Defining what is interference to a system
  – Defining how these qualities of systems are different in time and space
  – Identifying behaviors that allow sharing
- **SCMs define boundaries of spectrum use**
  – Defines the computation of compatibility among SCMs and removes the ambiguity of "what is harmful interference" before decisions are made
  – Can greatly support interactions in database-managed spectrum sharing

Model-Based Spectrum Management (MBSM)

- **Spectrum management (SM) based on the creation and exchange of SCMs**
  - SCMs capture the consumption of spectrum not the details of systems
  - SCMs have attendant computations for assessing compatibility among models (A common means across the entire SM system)
  - SCMs attempt to be loose couplers for the SM system
    - The minimal amount of data at the intersection of the activities of SM
    - Captures the intent of users and the judgment of spectrum managers
    - Conveys spectrum use policy



- **Benefits**
  - Greater resolution in spectrum management
  - More agile spectrum management (i.e., real time)
  - Enables devices and systems to collaborate in spectrum sharing

IEEE 1900.5.2: Standard Method for Modeling Spectrum Consumption

- **Objectives of the standard**
  - Define the data model constructs for SCMs
  - Define procedures to arbitrate compatibility among combinations of RF devices and/or systems that have expressed the boundaries of their spectrum use with SCMs
  - Provide the means to generate machine-readable SCMs: together with the standardized compatibility calculation mechanisms, these provide (among other benefits) the means to automate the identification of spectrum reuse opportunities and dynamically coordinate spectrum access.

- **Final version of the standard was produced by the IEEE DYSPAN-SC workgroup 1900.5 in December 2017**
- **Official version published June 2018**

SCM Constructs (IEEE 1900.5.2)

- Reference power
- Spectrum mask
- Underlay mask
- Power map
- Propagation map
- Intermodulation masks
- Platform
- Location
- Schedule
- Minimum power spectral flux density
- Protocol or policy

Captures the spectral content of the signal and the unique characteristics of spread spectrum systems

Captures a definition of interference

Can capture antenna effects

Can capture environmental effects

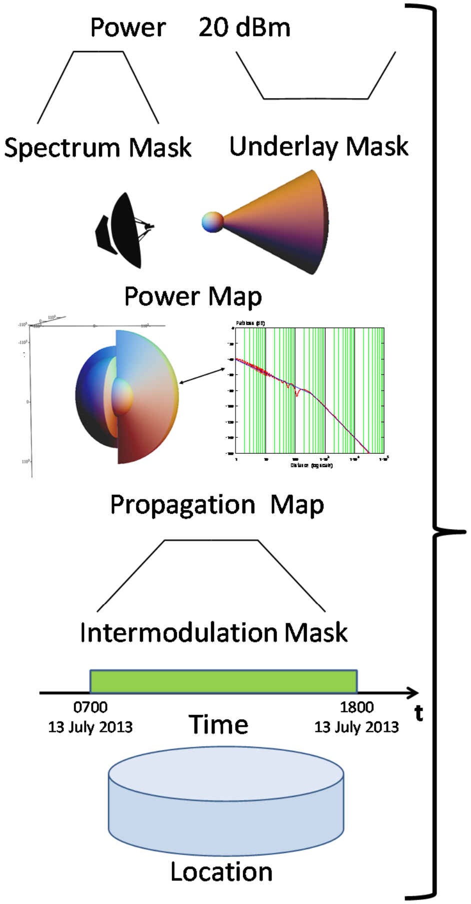
Captures susceptibility to intermodulation

Enable greater resolution in spectrum management

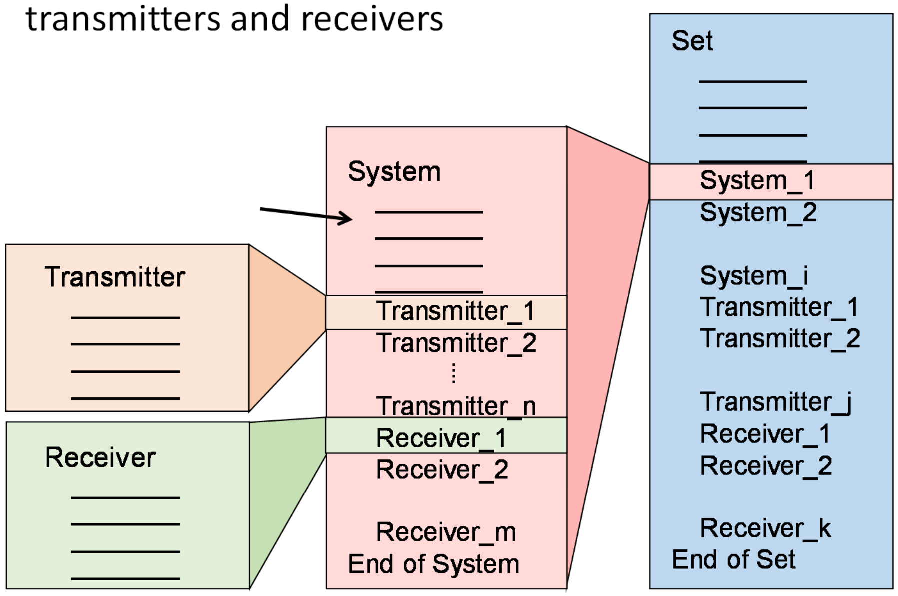
Can capture behaviors that enable compatible reuse

Most constructs have probability data elements to declare confidence in parts that are variable or are uncertain

Combining Constructs into Models

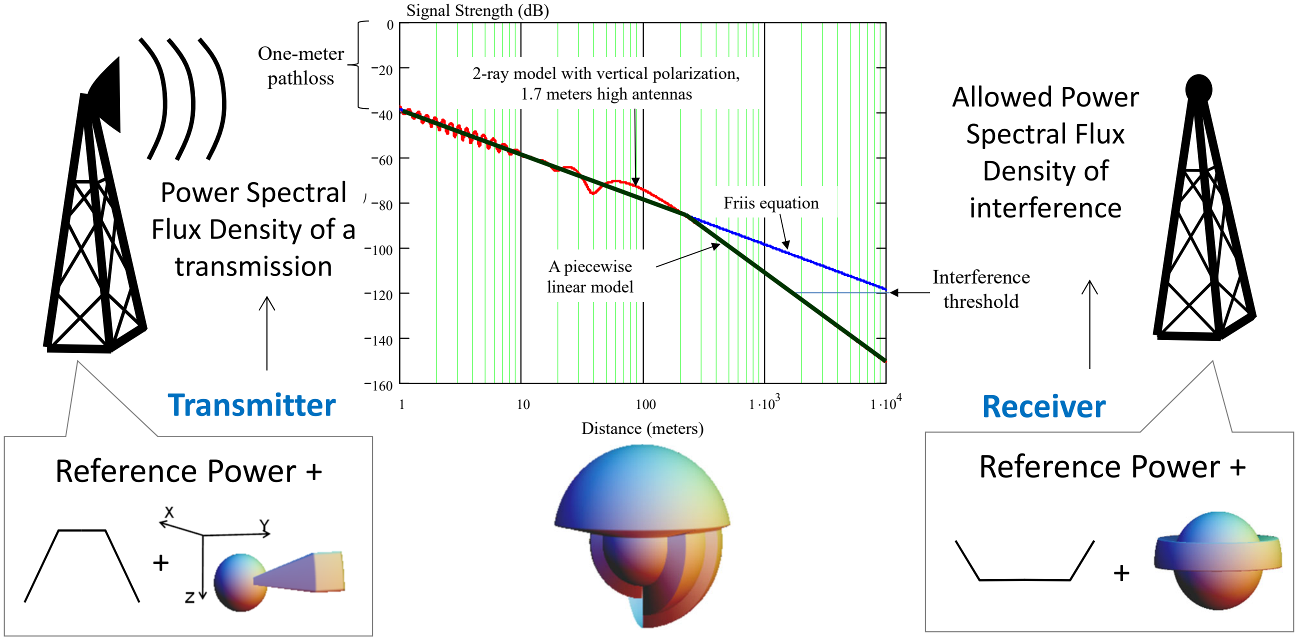


Constructs are used to model transmitters and receivers



- **Model and set functions**
  - System Model
    - Consists of transmitter and receiver models that are part of a system
  - Collective Consumption Set
    - Lists uses of spectrum by systems, transmitters, and receivers
    - Heading identifies the time, space, and frequencies over which the list is complete
  - Spectrum Authorization Set
    - List of system, transmitter, and receiver models identifying spectrum boundaries within which use is authorized
  - Spectrum Constraint Set
    - List of system, transmitter, and receiver models identifying existing uses of spectrum that have precedence and with which new uses must be compatible

Compatibility Computations

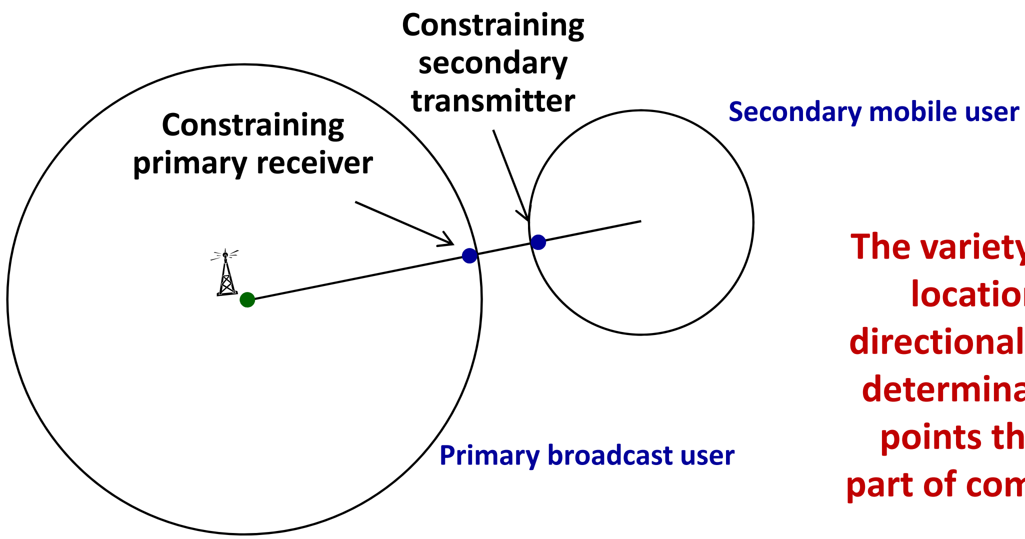


- **Constructs are a means to specify the factors that determine a link budget in all directions**
- **Modelers build SCMs to identify the power spectral flux density of transmissions and allowed interference**

SCMs are built to protect, not to predict!

General Process for Computing Compatibility

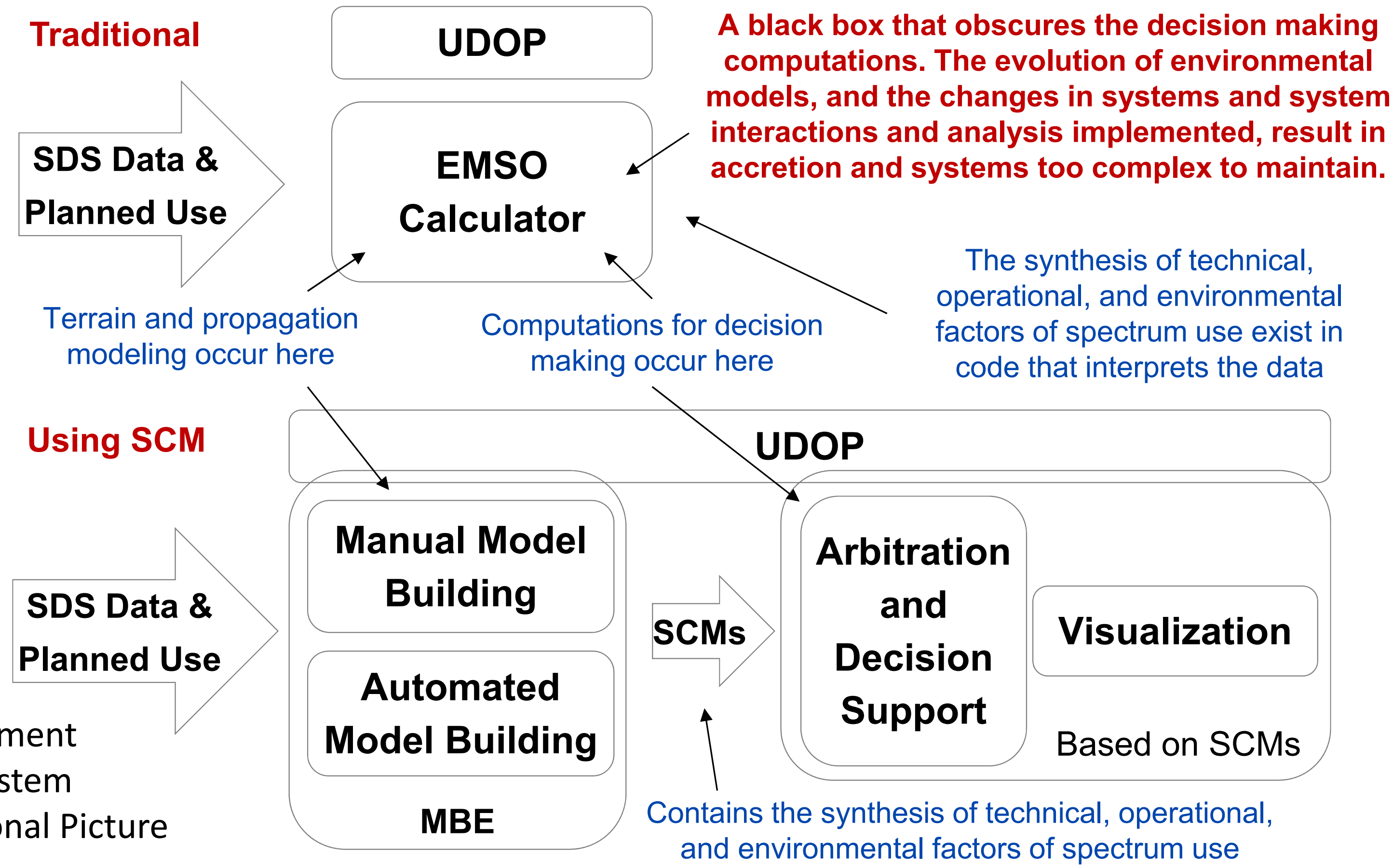
- Determine if uses will overlap in time and spectrum
- Determine the constraining points (the point of primary operation and the point of secondary operation that most restrict the secondary user)
- Compute the allowed transmit power of the secondary



The variety of means to specify locations and the use of directional antennas makes the determination of constraining points the most challenging part of computing compatibility

Architectural Differences in Tools

Key difference is in how and where the synthesis of the technical, operational, and environmental factors of spectrum use occurs



MBE – Model Building Environment
SDS – Spectrum Dependent System
UDOP – User Defined Operational Picture

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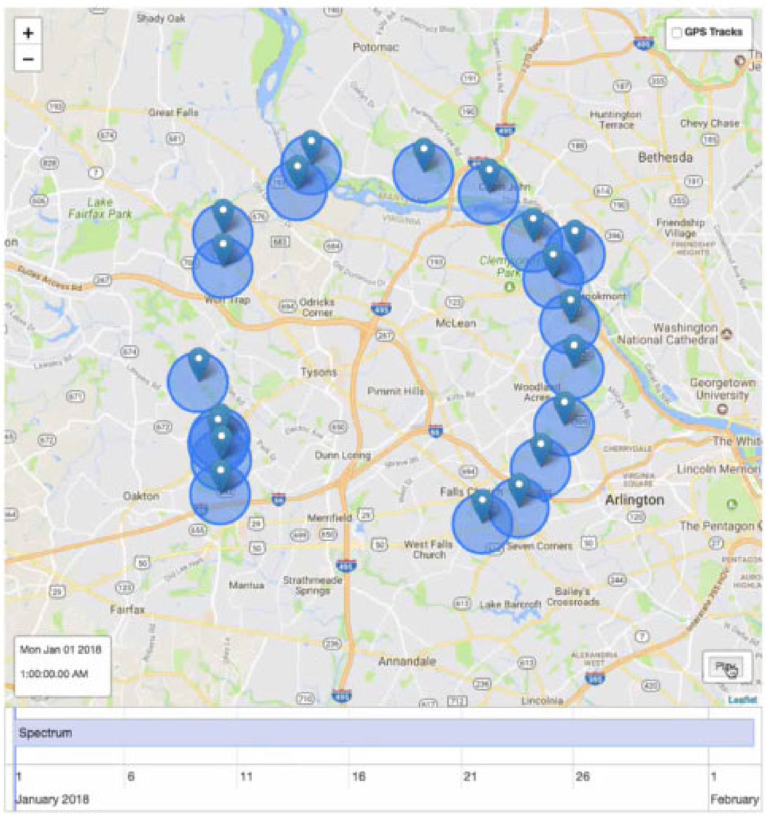
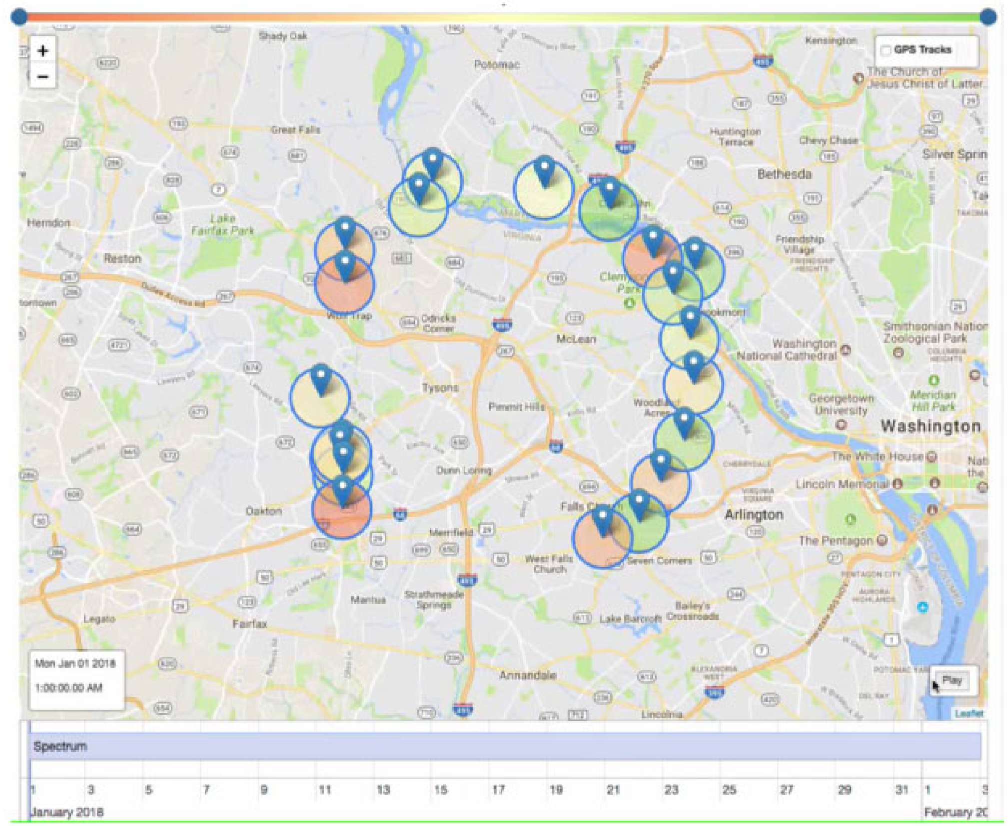
Algorithmic Spectrum Deconfliction

User Mobility, No Deconfliction

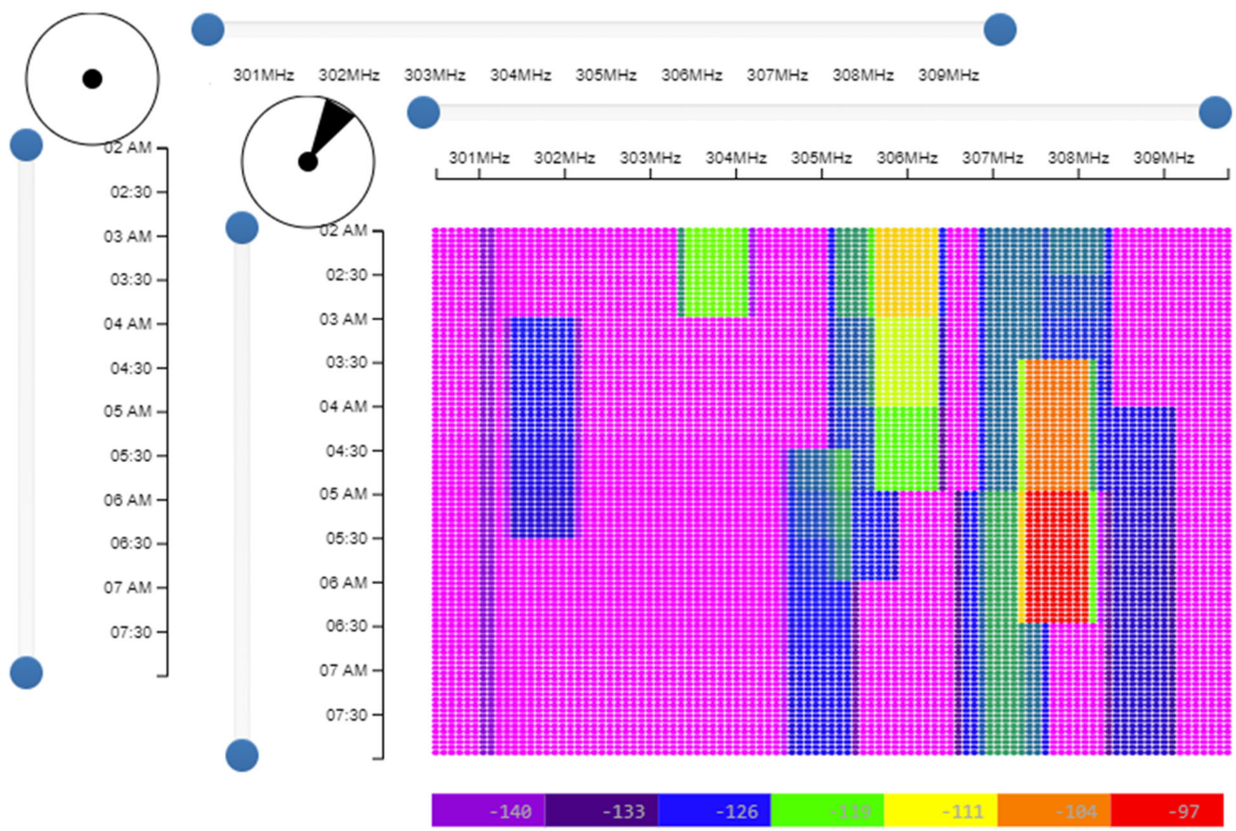


User Mobility, Algorithmically Deconflicted



Visualization – Understanding the Environment and Finding Whitespace

- **Provides a view of spectrum use**
  - Spectrally
  - Temporally
- **Uses waterfall plot**
  - Omnidirectional
  - Directional



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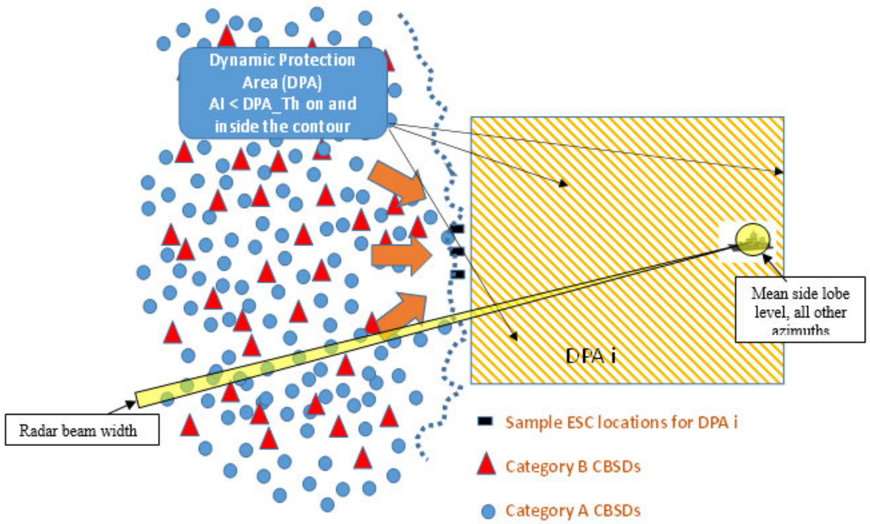
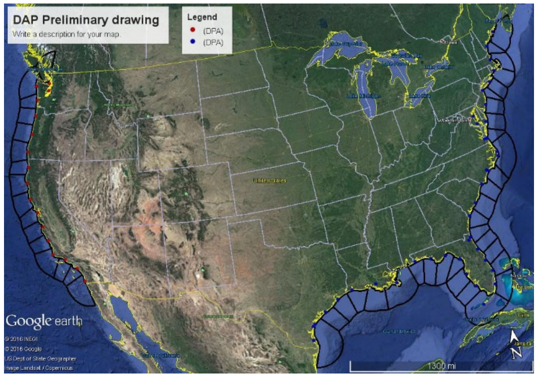
The CBRS Use Case

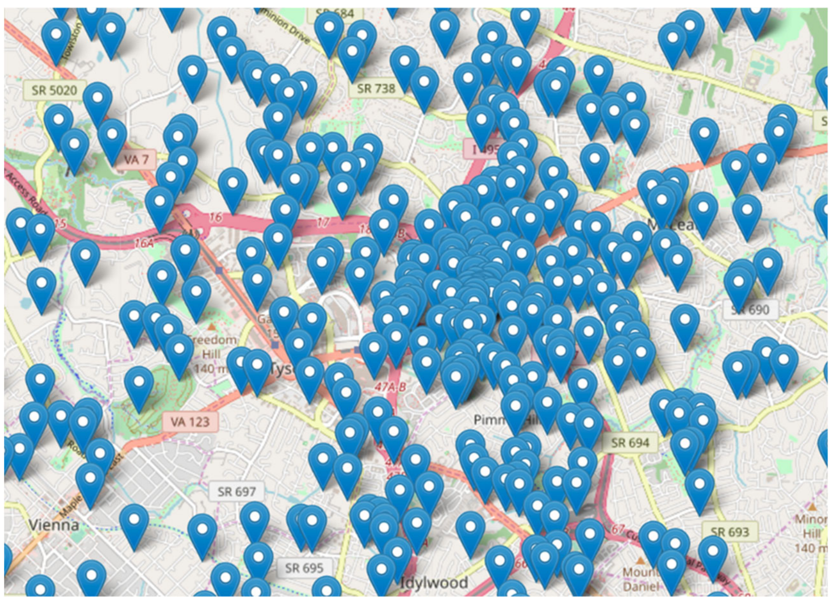
- **Channel assignment to CBSDs**
  - Multiple priority levels
  - Initial assignment
  - N+1 assignment
- **Find an alternative reaction to Dynamic Protection Areas (DPAs)**
  - Current reaction is to turn off devices within exclusions zones surrounding the DPA
  - The alternative is to thin the set of CBSDs operating to meet the protection criteria

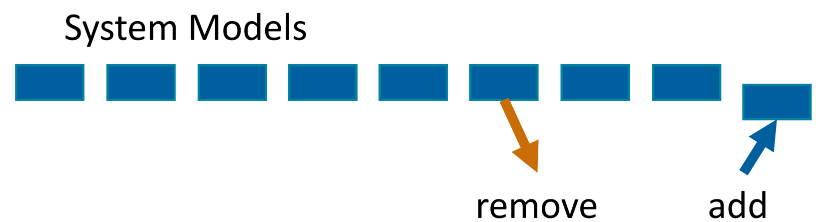




Large-Scale Channel Assignment

- **Problem: Find solutions for 100,000+ system scenarios in under 10 minutes**





- **Solution: Maintain running estimate of scenario**
  - Dynamic updating of interference adjacencies as scenario changes
  - Cut off insignificant interference adjacencies
  - Improve cache protection through insignificance detection
  - Parallel computation of interference

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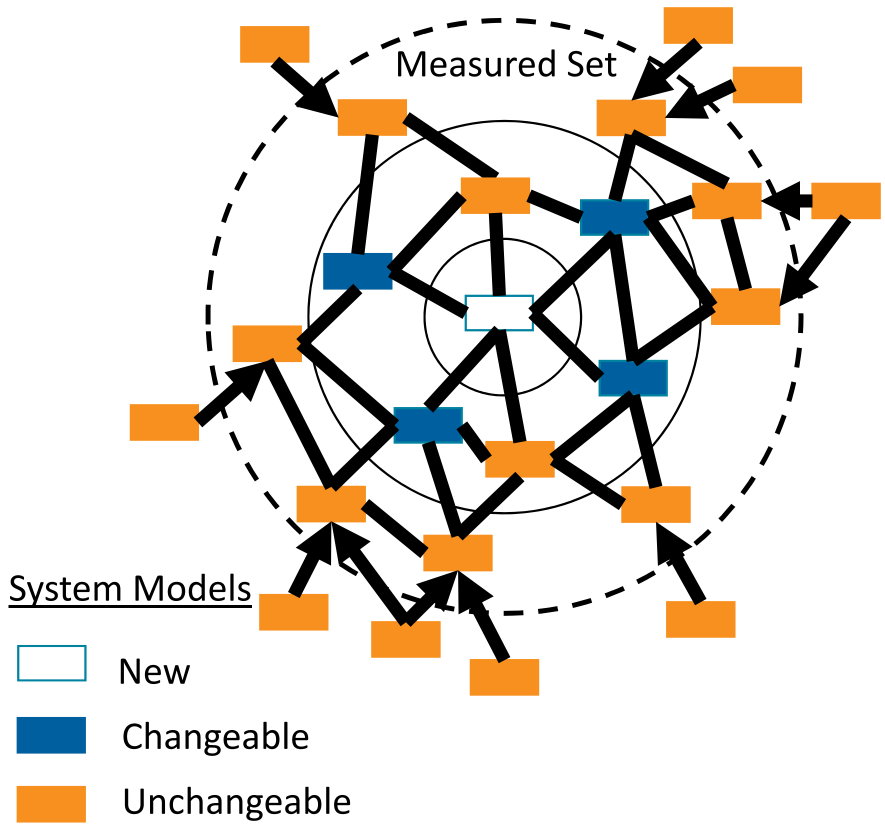
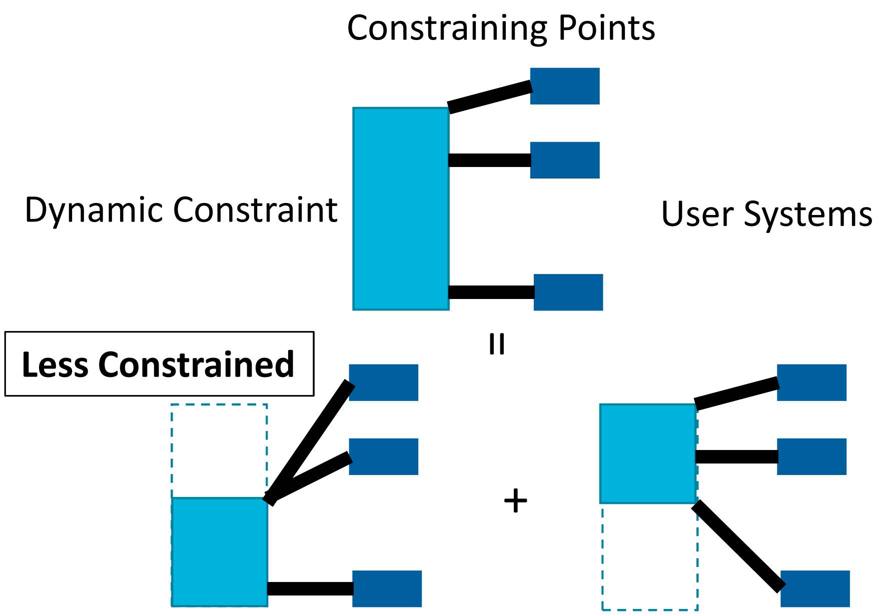
N+1 Channel Assignment and Reassignment

- **Problem: Assign channel to new system in 100,000+ scenarios, targeting real time**
- **Solution: Dynamic scenario creation out of running estimate**
  - Parameter controls
    - Time limit
    - Hop depth to consider
    - System ownership
    - Channels allowed to switch
  - Cut out unnecessary arbitration through adjacency list manipulation

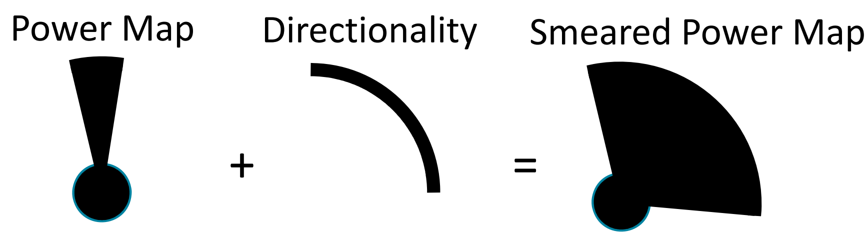


Alternative Responses to DPA Activation

- **Problem: Keep customers on without interfering with system of unknown location and directionality**



Power Map Smearing Functionality

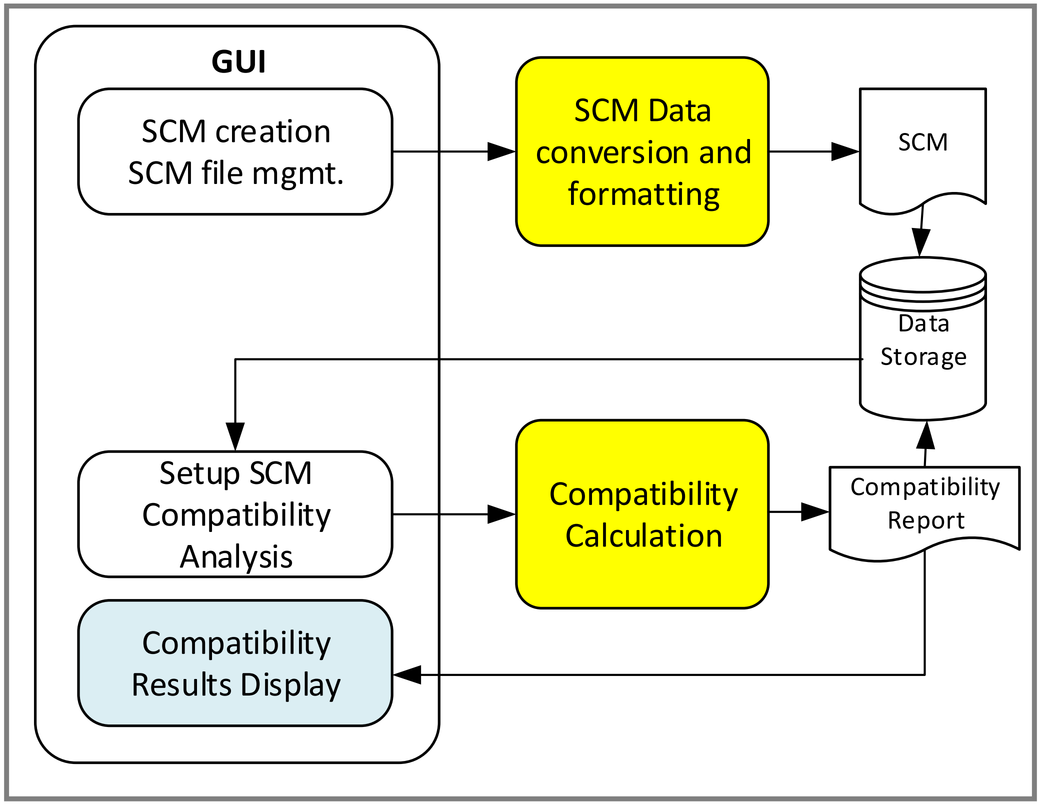


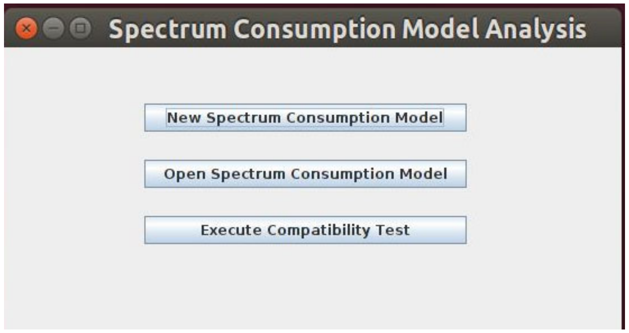
- **Solution: Dynamic constraints**
  - Branch and Relax method developed and implemented
    - Start with large area and wide directionality range
    - Divide and conquer with locations and directionality
  - Uses SCMs with transmitter densities to reduce arbitration computations

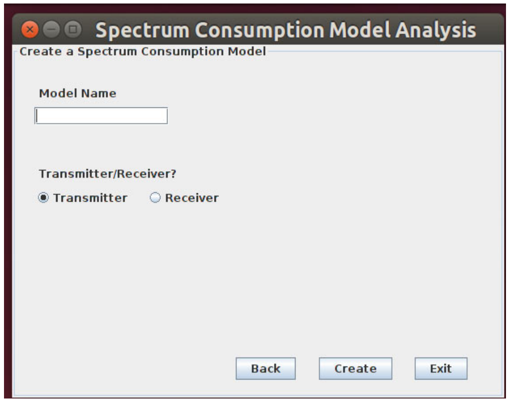
SCM Builder and Analysis Tool (Objectives)

- Open source software tool for elaborating/defining SCMs in conformance with the 1900.5.2 standard.
- Incorporates algorithms to compute the compatibility among SCMs
  - Several single Tx to single Rx receiver cases covered
  - Evolving to support more complex scenarios
- Identify limitations in the use of SCMs
- Code available form GitHub (https://github.com/ccaicedo/SCMBAT)

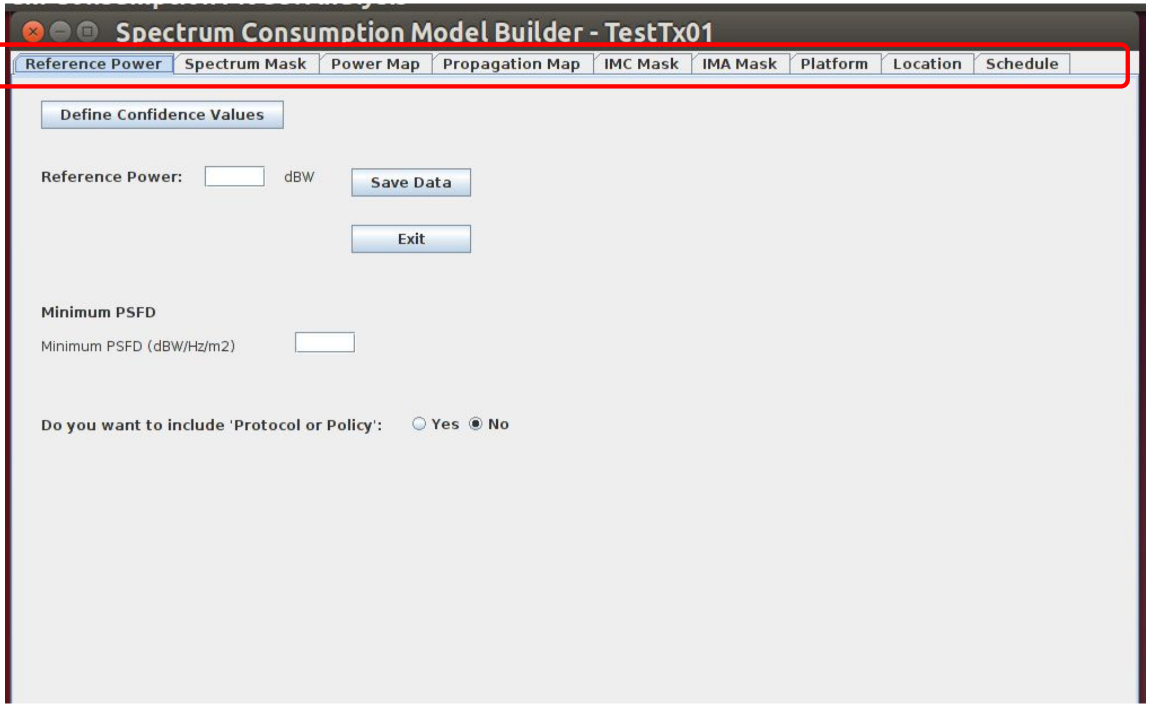
SCMBAT

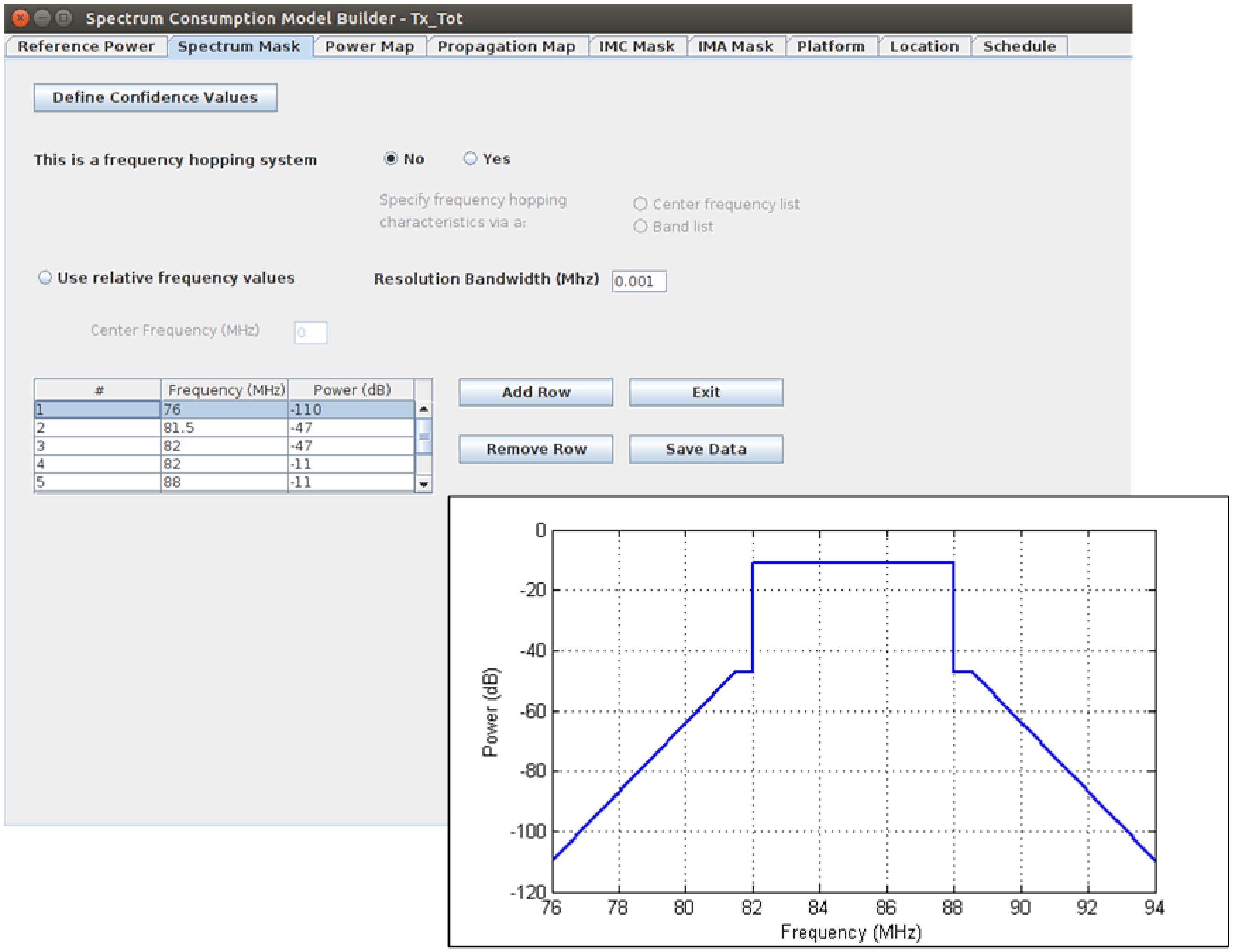






Tabs to input information for a Tx Model

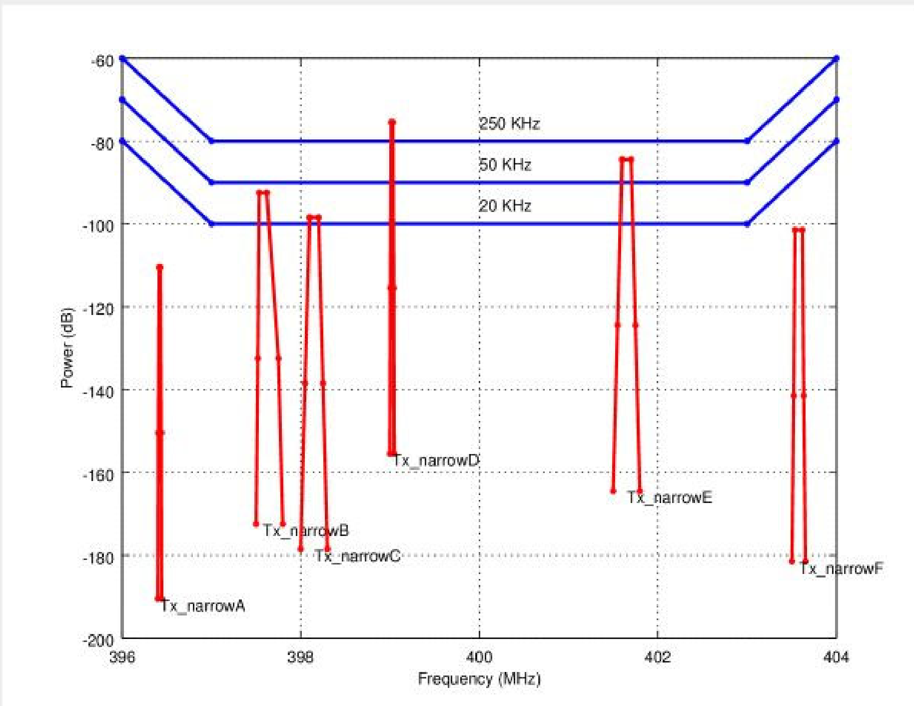




Spectrum Consumption Model Builder - Tx_Tot
Reference Power
Spectrum Mask
Power Map
Propagation Map
IMC Mask
IMA Mask
Platform
Location
Schedule
Define Confidence Values
This is a frequency hopping system
No
Yes
Specify frequency hopping characteristics via a:
Center frequency list
Band list
Use relative frequency values
Resolution Bandwidth (Mhz)
0.001
Center Frequency (MHz)
0
| Frequency (MHz) | Power (dB)
1 | 76 | -110
2 | 81.5 | -47
3 | 82 | -47
4 | 82 | -11
5 | 88 | -11
Add Row
Exit
Remove Row
Save Data
Power (dB)
0
-20
-40
-60
-80
-100
-120
76
78
80
82
84
86
88
90
92
94
Frequency (MHz)

Compatibility Analysis Report

Graphical result



Not Compatible

Tx_narrowD

Compatible with all

Compatible with specific masks

Tx_narrowA with [0.25, 30.0, 0.05, 20.0]
Tx_narrowB with [0.25, 30.0]
Tx_narrowC with [0.25, 30.0]
Tx_narrowE with [0.25, 30.0]

Compatibility calculation example. Multiple interferers vs. a bandwidth rated underlay mask ([BW Rating (MHz), Power Adjust (dB)]={[0.25, 30], [0.05, 20], [0.02, 10]})

Conclusions and Future Steps

- **Spectrum consumption modeling**
  - Is a supporting framework for current spectrum management initiatives
  - SCMs are standardized in IEEE 1900.5.2
    - Non-proprietary
    - Vendor independent
    - SCMs support rapid decision making and creation of innovative algorithms for better spectrum use
- **Spectrum sharing will drive the need for innovations in RF spectrum management**
- **Workgroup 1900.5 of the IEEE Dynamic Spectrum Access Networks Standards Committee (DySPAN-SC) continues work on:**
  - IEEE 1900.5.1 : Standard Policy Language for Dynamic Spectrum Access Systems
  - IEEE 1900.5.2a : Adding Schemas to 1900.5.2
    - XML, JSON
  - Join us: http://grouper.ieee.org/groups/dyspan/5/index.htm

Resources on 1900.5.2

- IEEE 1900.5.2-2017 - IEEE Standard for Method for Modeling Spectrum Consumption **https://standards.ieee.org/standard/1900_5_2-2017.html**
- The Spectrum Consumption Model Builder and Analysis Tool (SCMBAT)
  https://github.com/ccaicedo/SCMBAT
- (accepted) IEEE 1900.5.2: Standard Method for Modeling Spectrum Consumption – Introduction and Use Cases, IEEE Communications Standard Magazine (2018)
- Model Based Spectrum Management – Part 1: Modeling and Computation Manual v.2.0 (2014) https://www.mitre.org/publications/technical-papers/model-based-spectrum-management-part-1-modeling-and-computation-manual