Model-Based Spectrum Management

Making Spectrum Management Agile and Enabling Dynamic Spectrum Access (DSA)

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November 2011

MITRE

Purpose

- Familiarize you with
  - Spectrum consumption modeling
  - Using models to improve spectrum management
  - Using models to convey DSA policy
- Inspire you
  - To want to learn more about Model-Based Spectrum Management (MBSM)
  - To download and review the MBSM Modeling Manual
    - http://www.mitre.org/work/tech_papers/2011/11_2071/
  - To contribute to making it better
  - To assist in making it a standard

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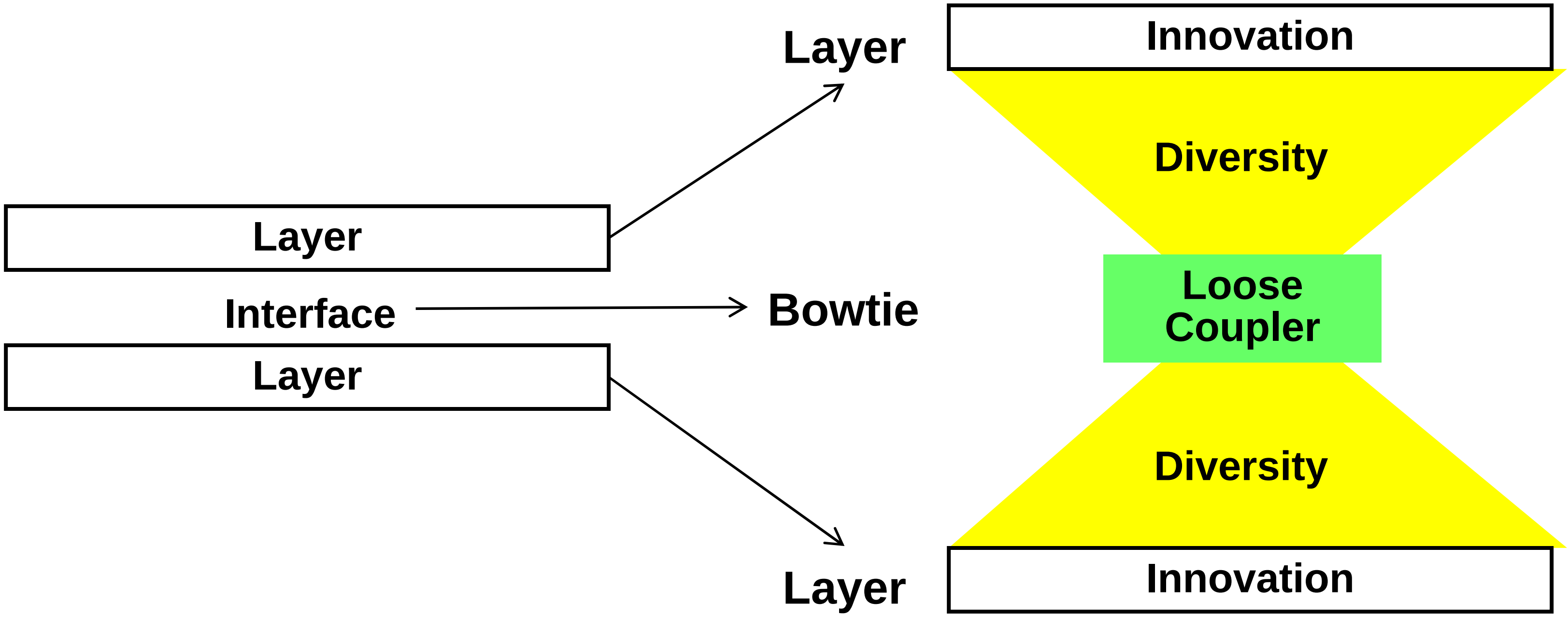
The Vision

Spectrum consumption modeling becomes the core of a very dynamic spectrum management capability serving as a loose coupler among spectrum management (SM) systems and radio frequency (RF) systems and devices

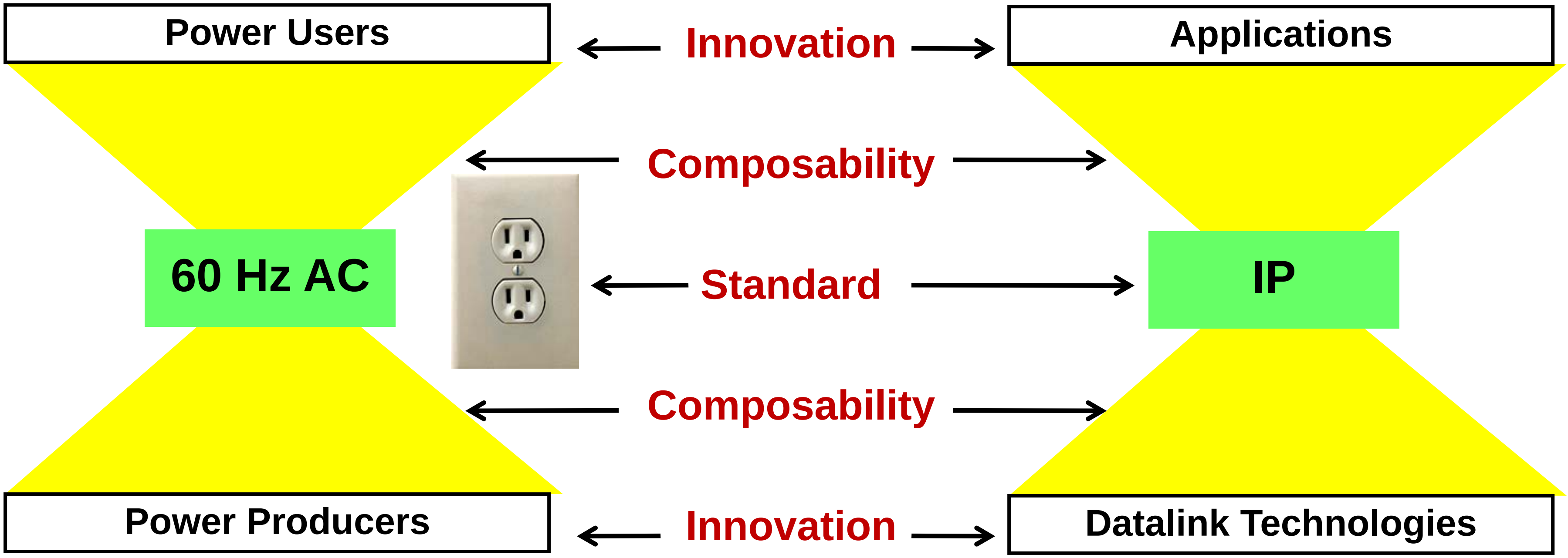
Enables Innovation #6 of the 10 Most Wanted Wireless Innovations: Flexible Regulatory Framework for Temporary, Cooperative and Opportunistic Access

What is a loose coupler?



- A thing that exists at the intersection of a large set of systems that allow them to interoperate and to be integrated
- A key component of innovation and composable capabilities
  - Layers enable local innovation
  - Loose couplers enable integration
  - Bowties enable composability

Well known examples of loose coupling



Power Users ← Innovation → Applications

← Composability →

60 Hz AC ← Standard → IP

← Composability →

Power Producers ← Innovation → Datalink Technologies

- Benefits
  - Integration
  - Interoperability
  - Innovation

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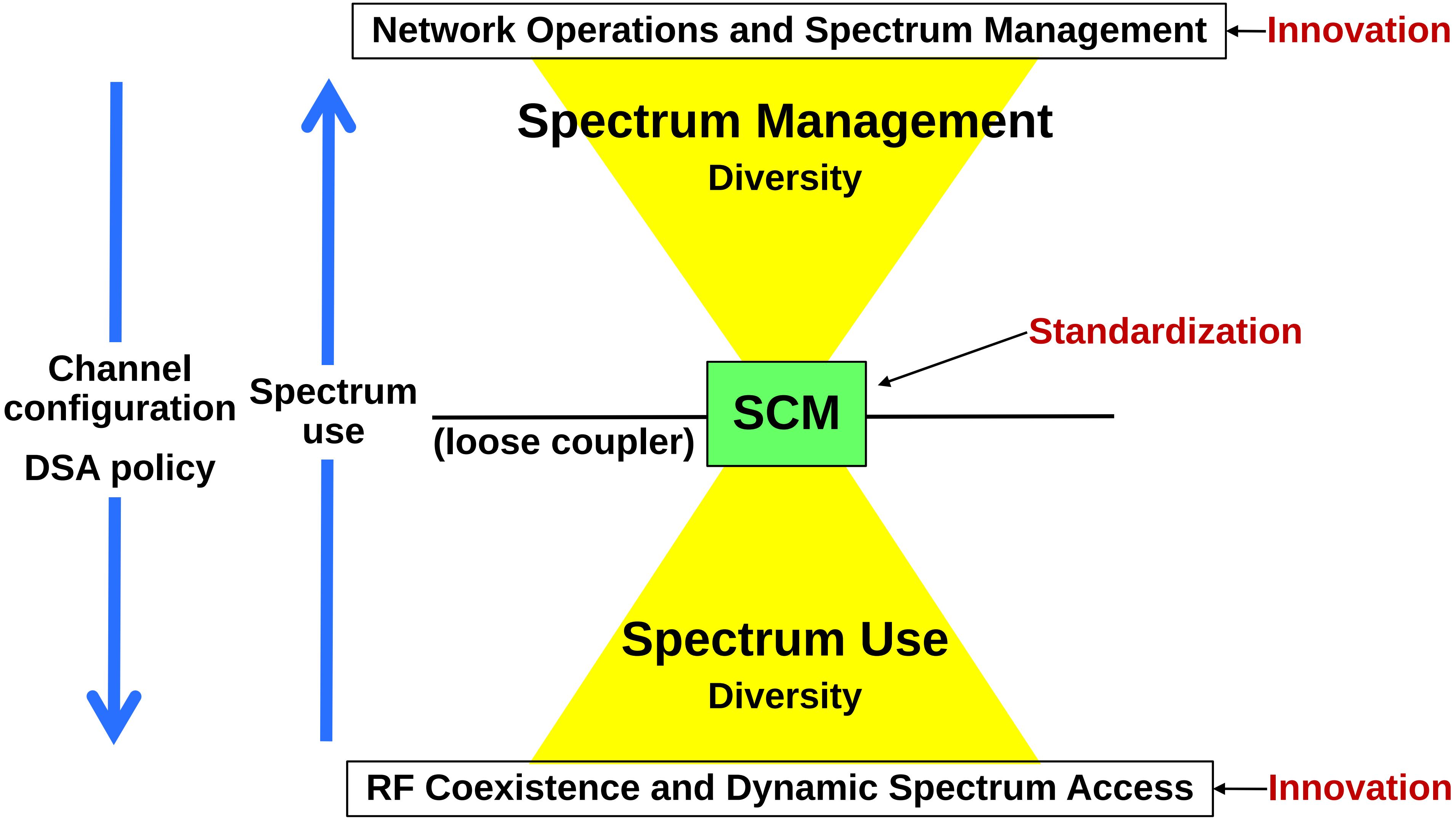
Spectrum Consumption Modeling as a Loose Coupler



Network Operations and Spectrum Management ← **Innovation**

Spectrum Management

Diversity

Standardization

Channel configuration

DSA policy

Spectrum use

(loose coupler)

SCM

Spectrum Use

Diversity

RF Coexistence and Dynamic Spectrum Access ← **Innovation**

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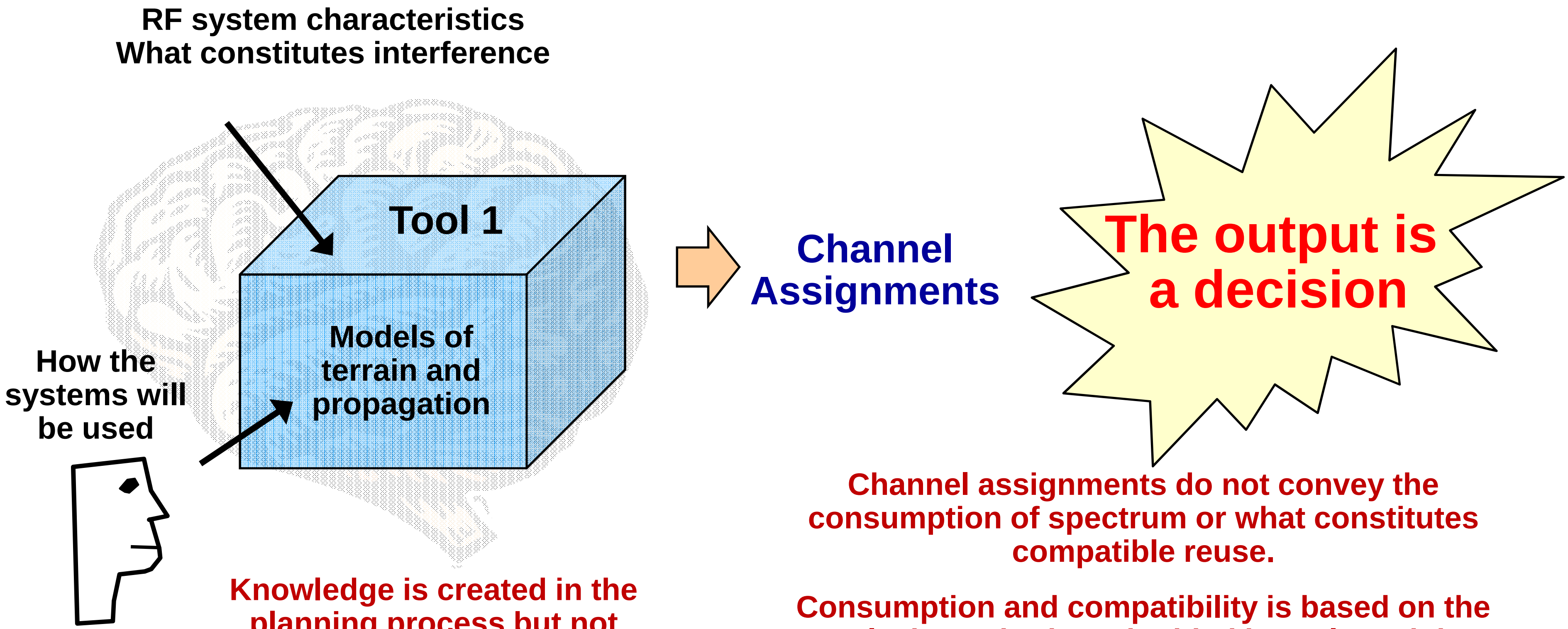
What is the problem with current approaches?



RF system characteristics
What constitutes interference

Tool 1

Models of terrain and propagation

How the systems will be used

Channel Assignments

The output is a decision

Knowledge is created in the planning process but not captured in the output

Channel assignments do not convey the consumption of spectrum or what constitutes compatible reuse.

Consumption and compatibility is based on the analysis methods embedded in tools and the judgment of the spectrum manager

Analysis methods vary from tool to tool and understanding of intent and judgment vary from manager to manager.

Managers must study the problem but the thought processes of the study are lost in the output

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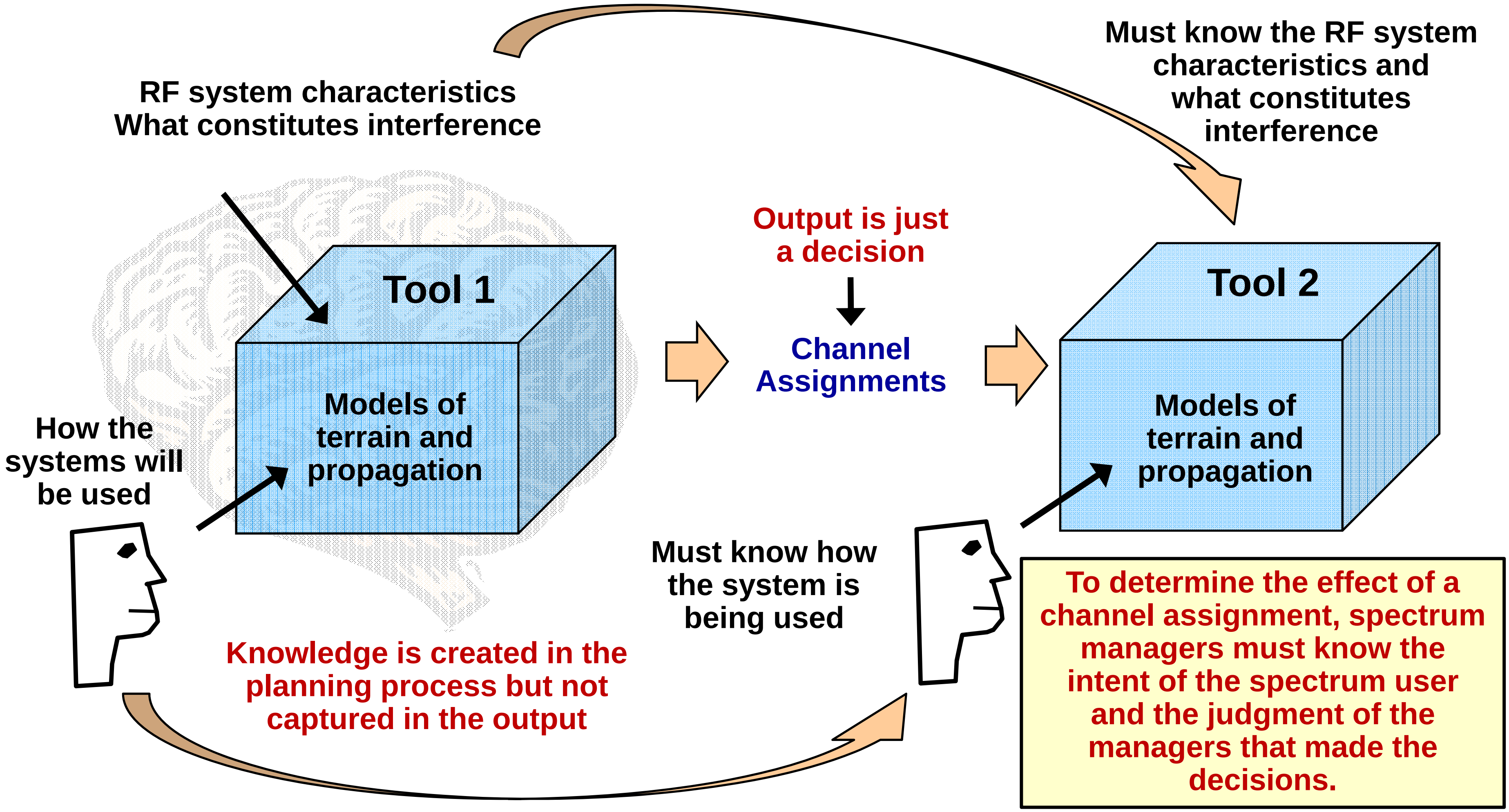
Why is this a problem?



RF system characteristics
What constitutes interference

Must know the RF system characteristics and what constitutes interference

Tool 1

Models of terrain and propagation

How the systems will be used

Output is just a decision

Channel Assignments

Tool 2

Models of terrain and propagation

Must know how the system is being used

Knowledge is created in the planning process but not captured in the output

To determine the effect of a channel assignment, spectrum managers must know the intent of the spectrum user and the judgment of the managers that made the decisions.

A hard problem that results in managers seeking persistent solutions

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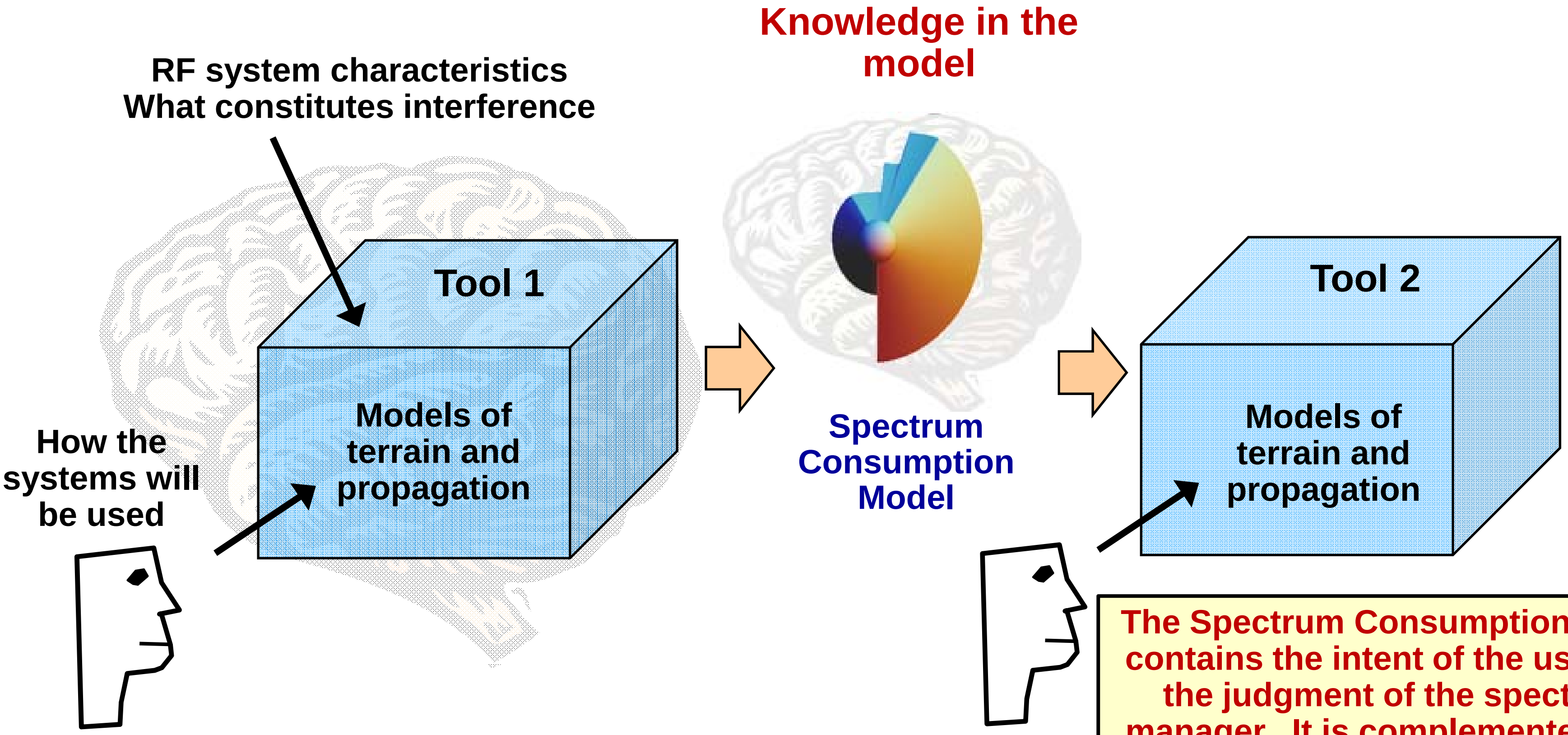
How MBSM is different



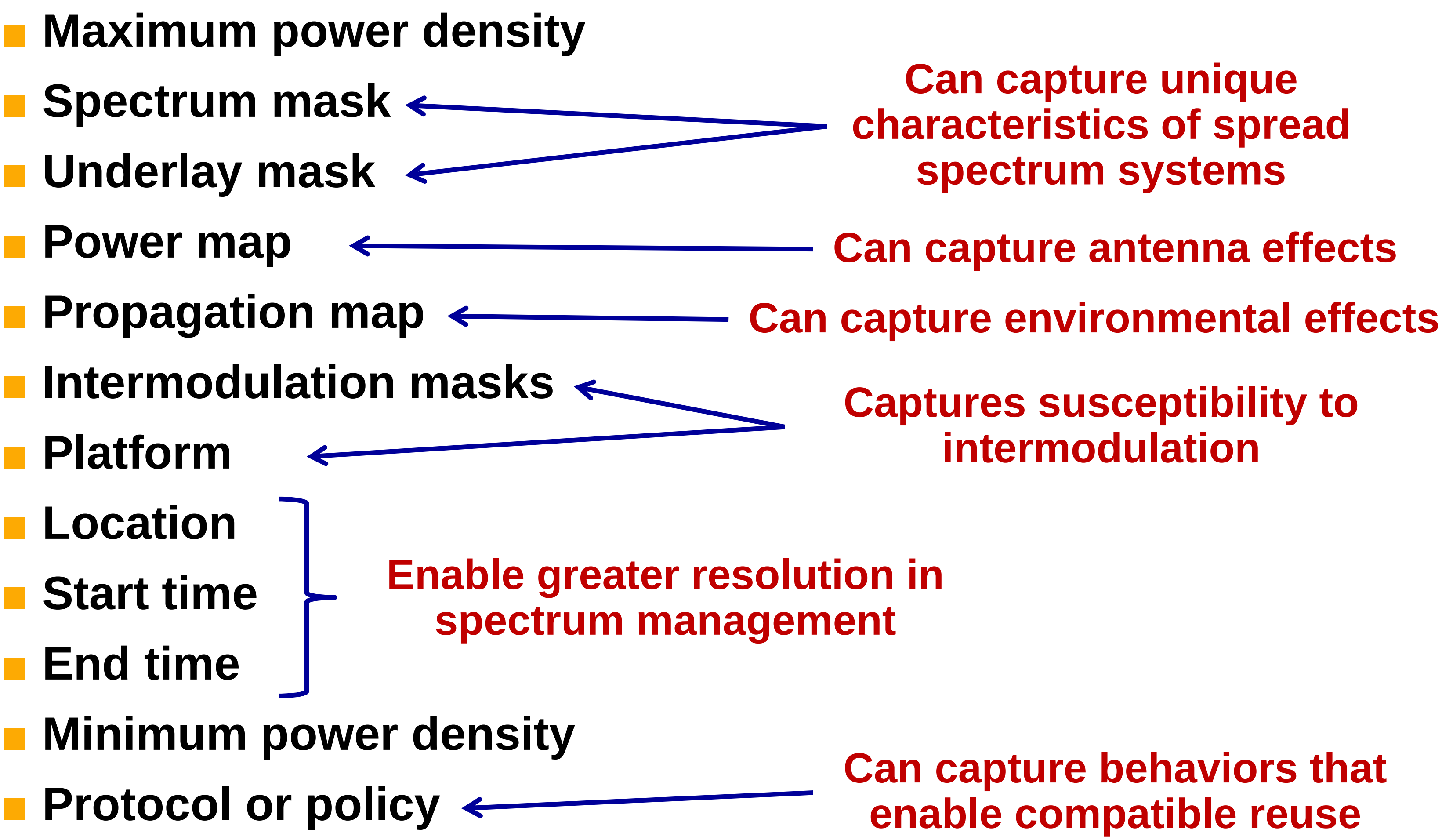
The Spectrum Consumption Model contains the intent of the user and the judgment of the spectrum manager. It is complemented with a specified approach to compute compatibility

Spectrum Consumption Models convey the consumption of spectrum and what constitutes compatible reuse

Why add modeling?

- Captures and allows sharing of judgment and intent
- Enables distribution of the spectrum management problem
- Changes nature of spectrum management
  - From seeking persistent solutions to one seeking dynamic solutions
  - Greater spatial and temporal resolution
- Enables creation of algorithms for improved spectrum management
  - Assessing compatibility of uses
  - Automation of channel assignment
  - Searching for suitable spectrum
- Supports Dynamic Spectrum Access
  - Models are policy
  - Models are machine readable
  - Provides means to manage DSA systems
- Conceals sensitive details of equipment and its use while still revealing spectrum consumption for spectrum management tasks

Proposed modeling constructs



- Maximum power density
- Spectrum mask
- Underlay mask
- Power map
- Propagation map
- Intermodulation masks
- Platform
- Location
- Start time
- End time
- Minimum power density
- Protocol or policy

Can capture unique characteristics of spread spectrum systems

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

Not data about a system but used to build a model of spectrum use
Models are information!

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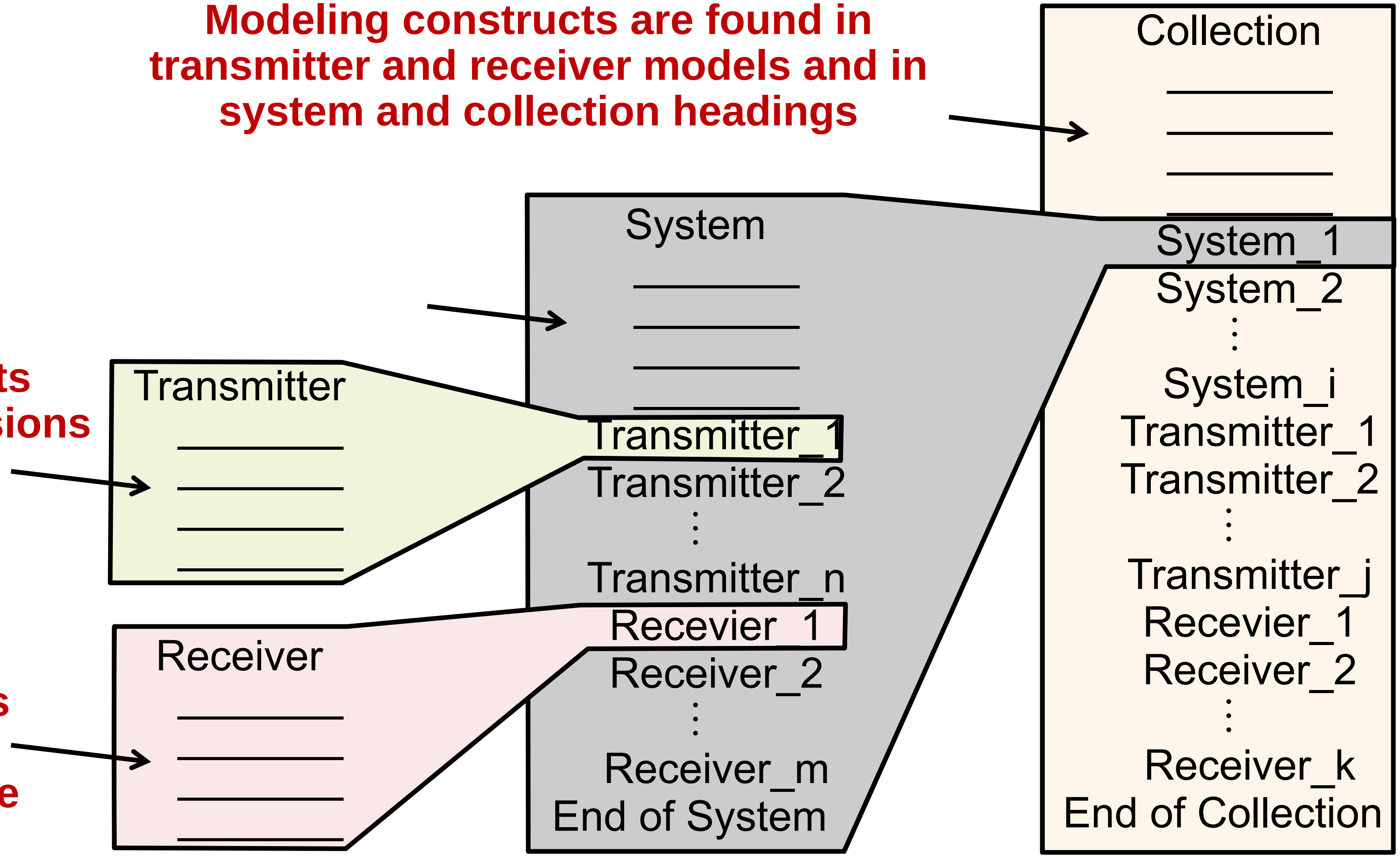
Combining constructs into models



Modeling constructs are found in transmitter and receiver models and in system and collection headings

Constructs define emissions

Constructs define interference

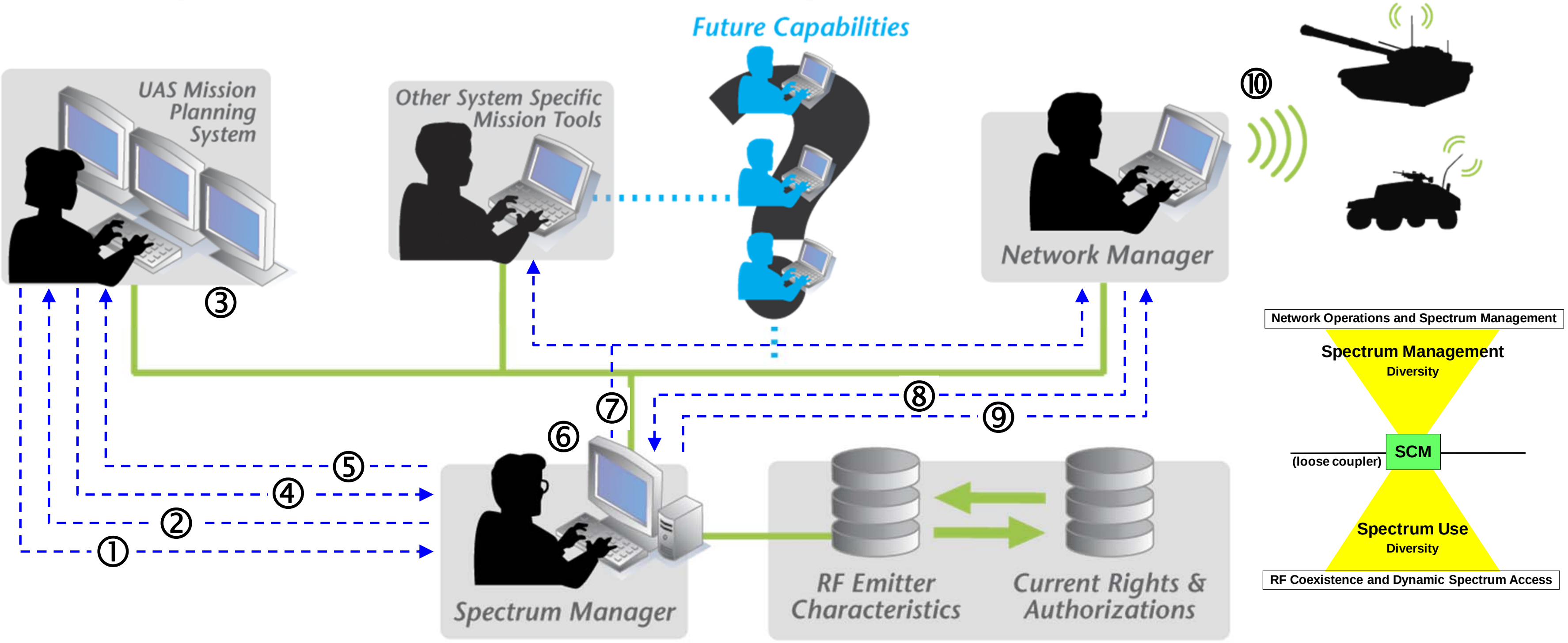
Proposal provides an XML schema for this type of model construction

Model and collection function

- System Model
  - Constructs in heading define the boundaries of system operation
  - Lists transmitter and receiver models with more limiting constructs
- Collective Consumption Listing
  - Constructs in heading define the limits to which the collection is complete
  - Lists systems, transmitters and receivers of spectrum consumers that consume spectrum within the limits of the collection
- Spectrum Authorization Listings
  - Constructs in the heading define the limits of the overall authorization
  - The lists of system, transmitter, and receiver models identify available spectrum
- Spectrum Constraint Listings
  - Constructs in the heading define the limits of the collection of constraints
  - The lists of system, transmitter, and receiver models identify existing uses of spectrum that have precedence

Dynamic spectrum management

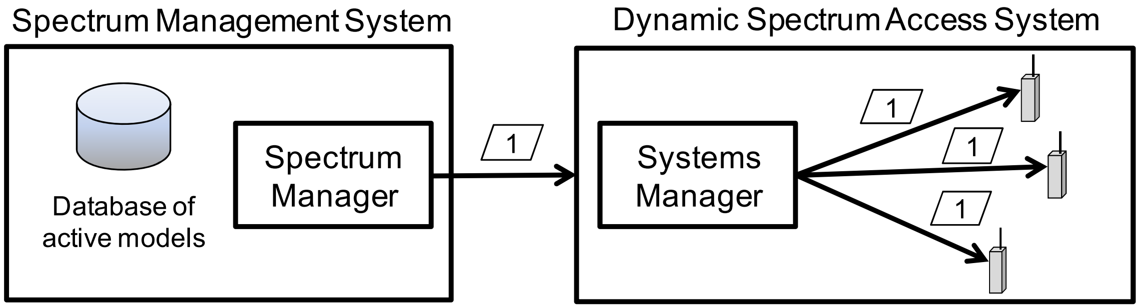
Build systems that exploit modeling



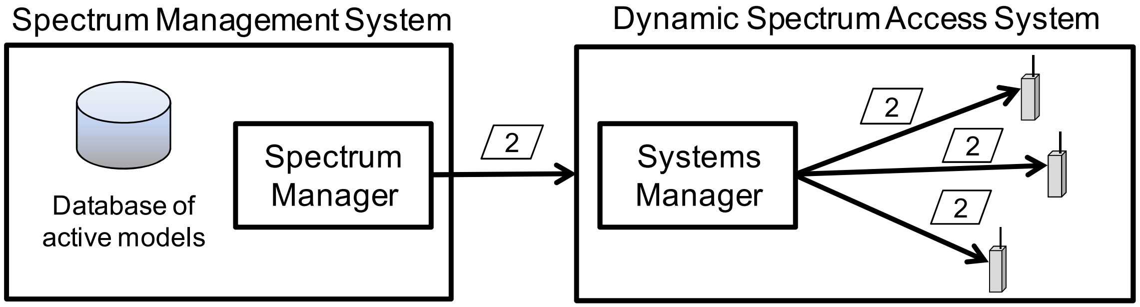
1. Request spectrum
2. Spectrum manager (SM) sends authorization listing
3. Mission planner creates plan and the necessary spectrum consumption models (SCM)
4. Mission level SCM sent to the SM as a request
5. Mission level spectrum use granted
6. SM identifies reuse opportunities
7. Potential users of spectrum notified of opportunities with a collective listing
8. Network manager (NM) identifies reuse and requests spectrum using a SCM
9. SM reviews NM's request and authorizes use
10. NM informs cognitive radios of policy using SCM

Conveying Policy to DSA Systems

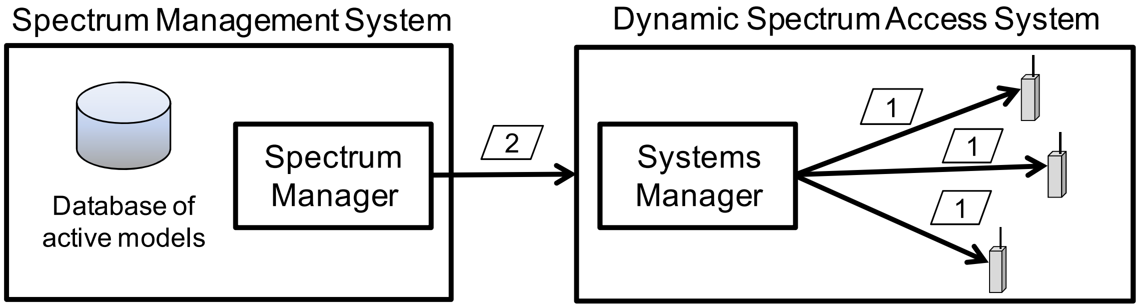
End-to-end direct authorization



End-to-end dynamic authorization



Hybrid authorization



Direct Authorization

1

A collection of models that define spectrum that may be used

Dynamic Authorization

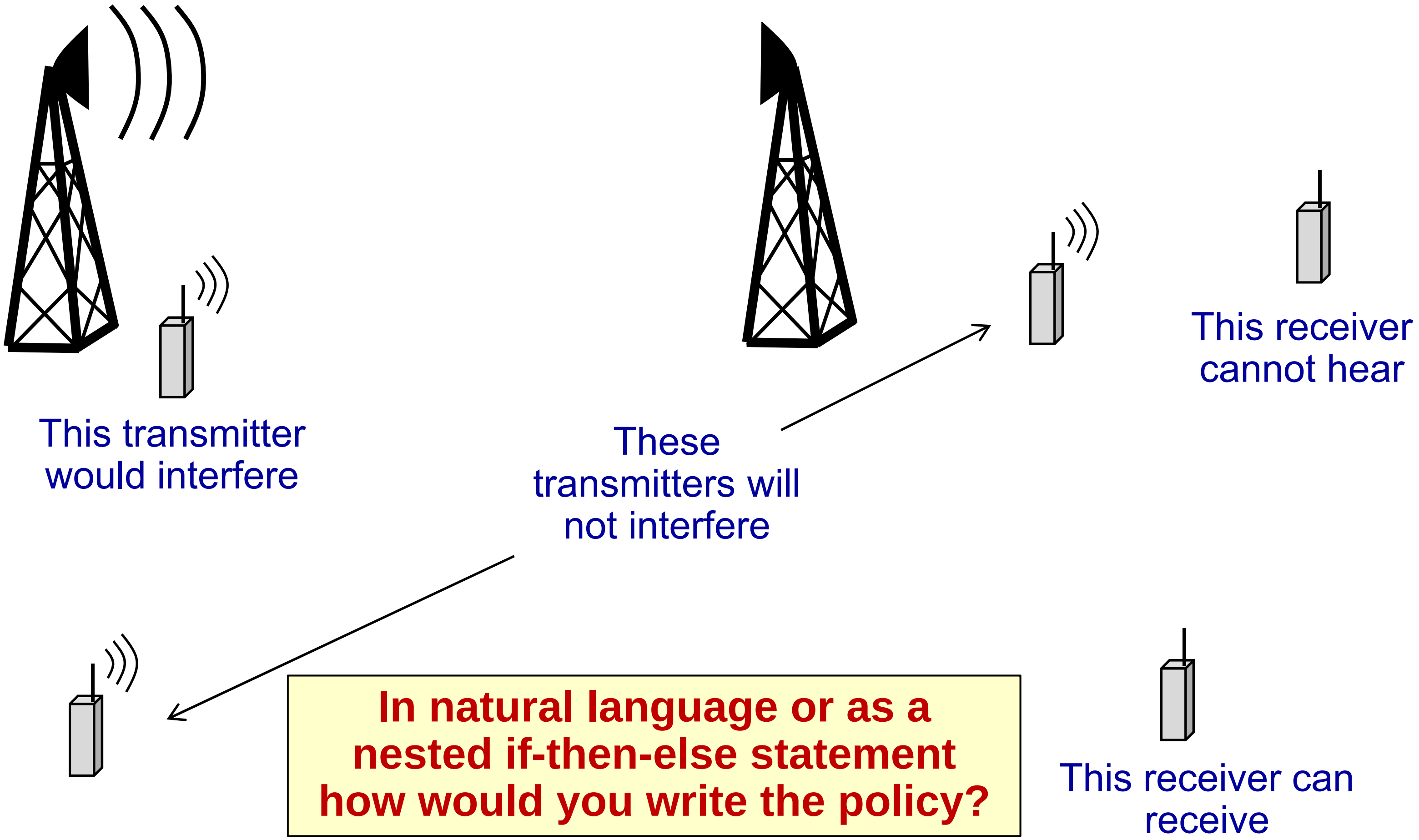
2

A collection of two types of models:

1. Models that define in general spectrum that may be used
2. Models that constrain that use

Dynamic Authorization

Example of a primary system with a single transmitter and a single receiver



This transmitter would interfere

These transmitters will not interfere

This receiver cannot hear

This receiver can receive

In natural language or as a nested if-then-else statement how would you write the policy?

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Dynamic Authorization - 2

- **Modeling the transmitter and receiver pair**

Components used to model a simplex radio link

Model Constructs	System Heading	Transmitter	Receiver
Maximum Power Density		R	R
Spectrum Mask		R	
Underlay Mask			R
Propagation Map		R	R
Power Map		R	R
Intermodulation Mask		O	O
Platform Name		O	O
Location		R - Point	R - Point
Start Time	R		
End Time	R		
Minimum Power Density			
Protocol or Policy	O		

R - Required, O - Optional, T - Typical (To provide a refined definition)

Spectrum consumption models are policy !

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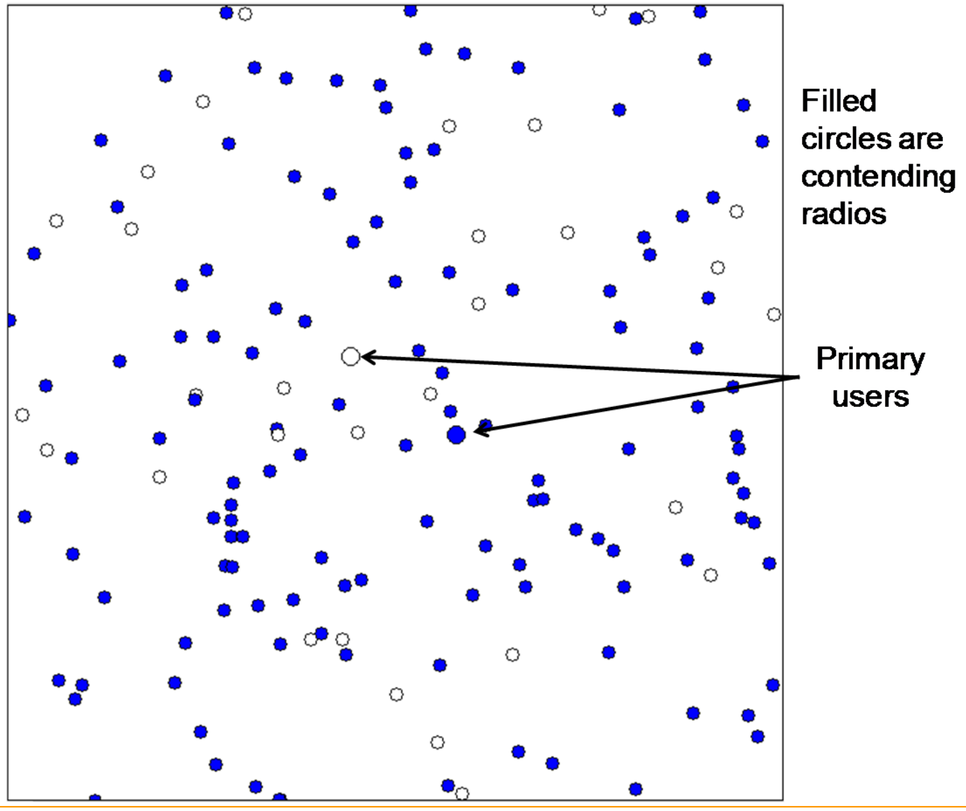
Protocol or Policy- 1

- Rationale
  - Enables finer resolution sharing through behaviors at components
    - Means to specify how spectrum sensing may be used to inform spectrum use decisions
    - Means to exploit reuse opportunities that come from knowing the specific behaviors of incumbents
  - Protocols specify specific access mechanisms while policies specify conditions for use – policy driven systems can choose their own access mechanism among themselves
- Data Structure
  - Name plus parameters
- Units
  - Units of parameter values are specified as part of the named protocol or policy definition
- Dependencies
  - Apply to spectrum in the larger model
  - DSA systems must be rated for the different policies and protocols to use them

A protocol example

- The scenario
  - Multiple co-located MANETs with one a primary user
  - Goal is to ensure primary users get precedence and secondary users can use whatever spectrum the primary users do not use



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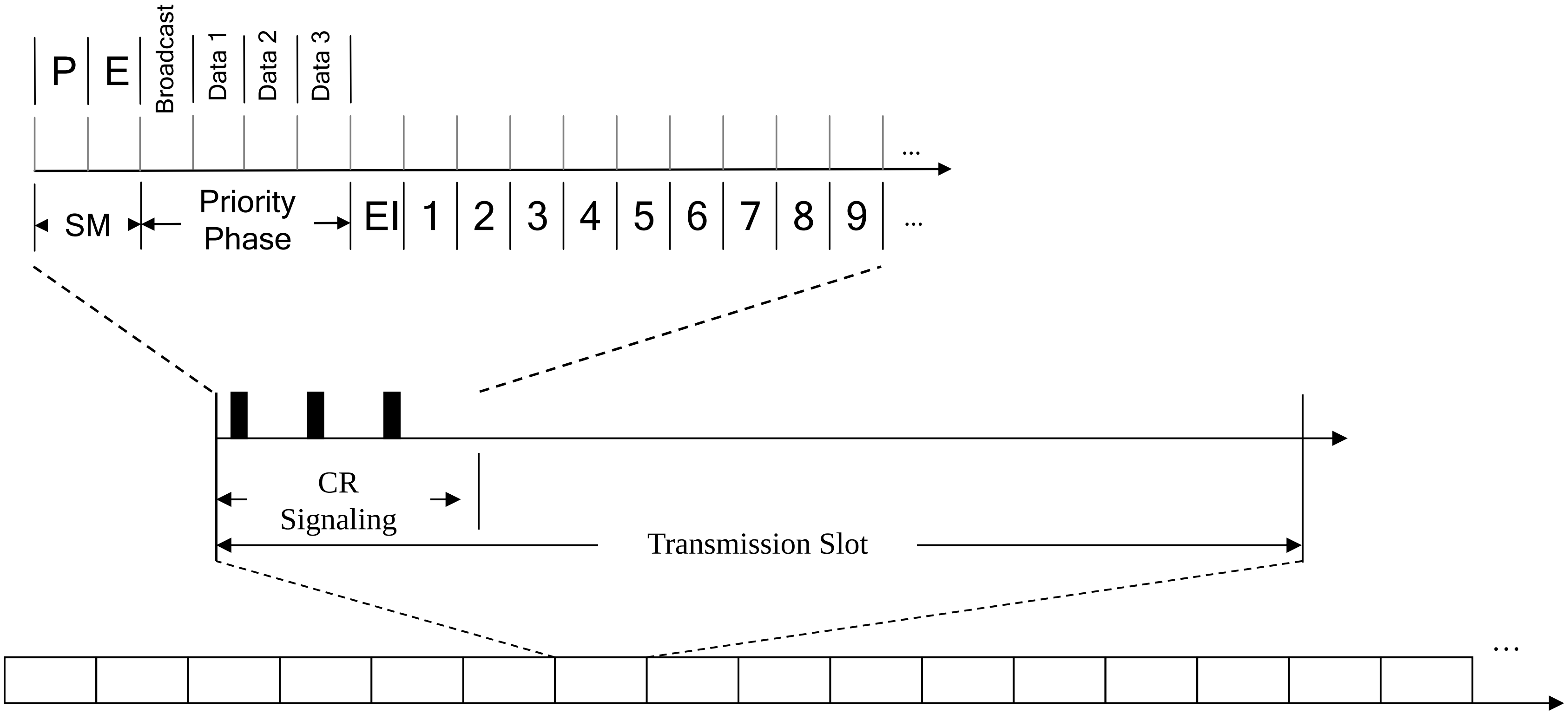
A protocol that enables sharing

- **Synchronous Collision Resolution (SCR) – a slotted protocol using signaling to arbitrate access**



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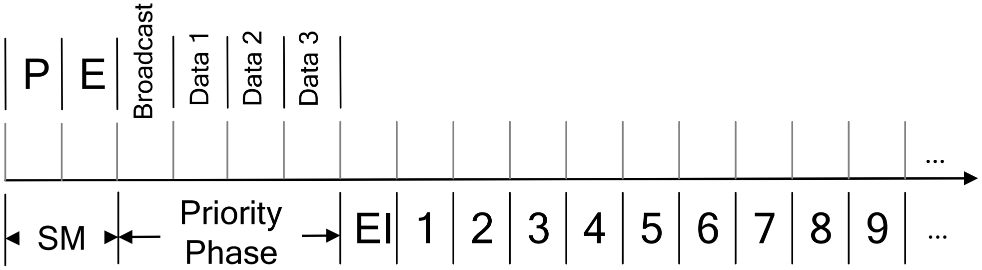
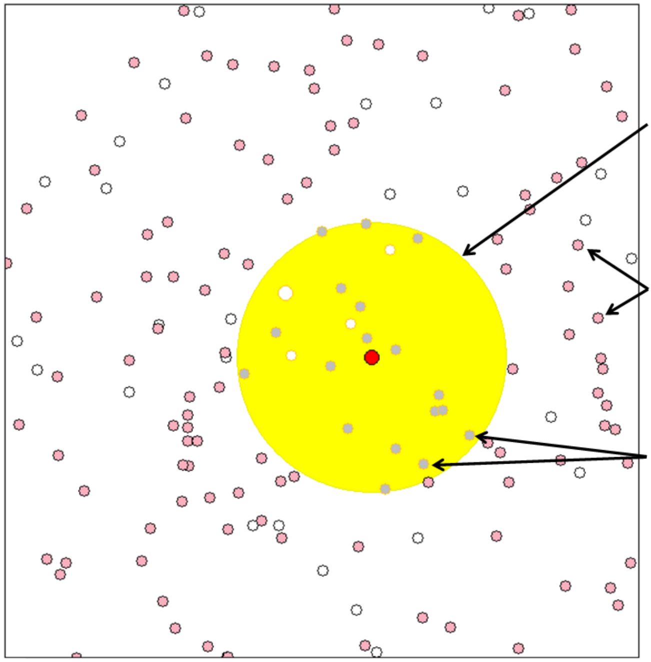
A protocol that enables sharing

- **Differentiating primary and secondary use**

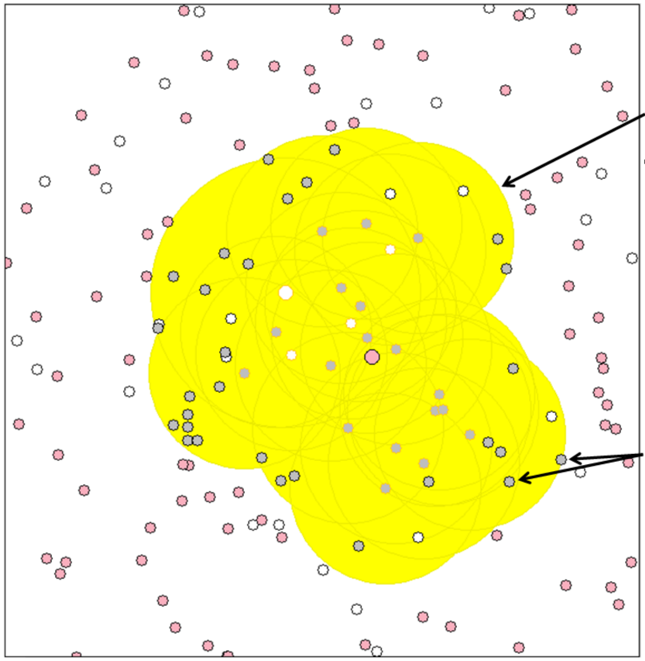




Large circle shows range of signals

Pink circles remain contenders

Grey circles lost the contention

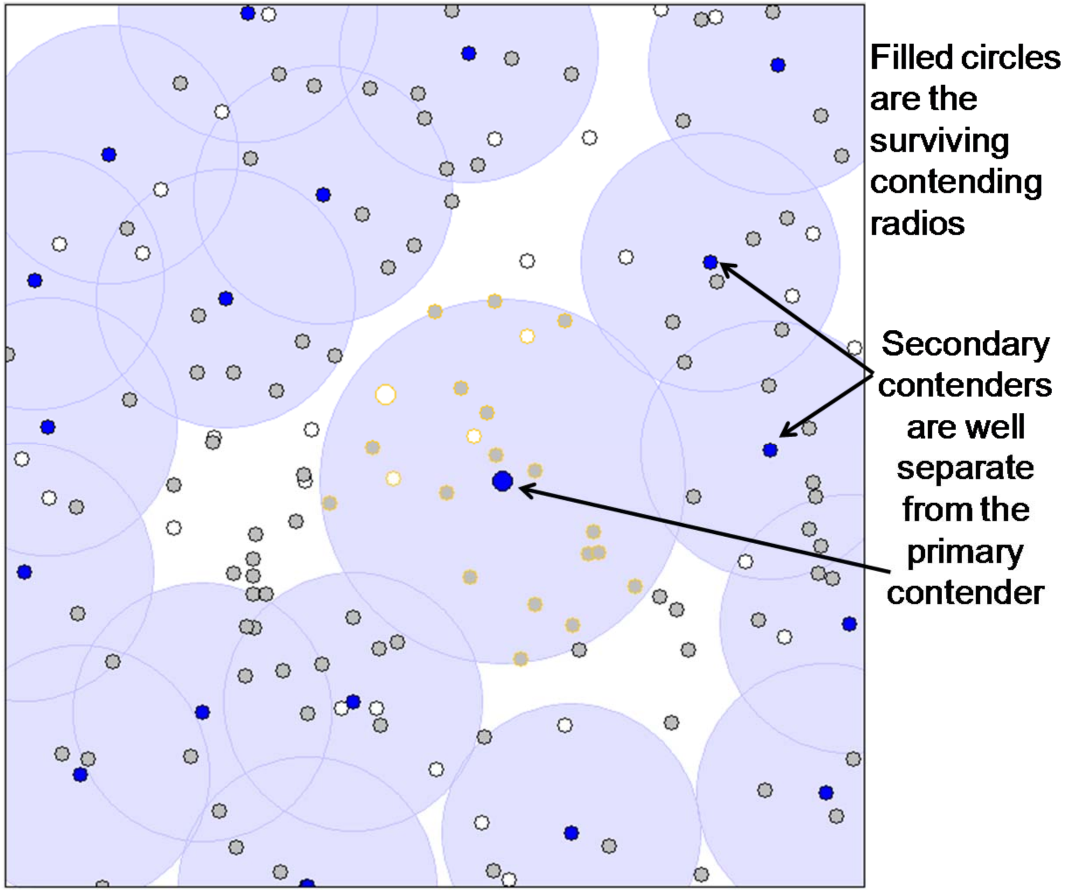


Overlapping circles show coverage of echo signals

Echo signals defeat more contenders

The Result

- The primary always get precedence in access
- Secondary users can fill in the spaces around the primary user



Filled circles are the surviving contending radios

Secondary contenders are well separate from the primary contender

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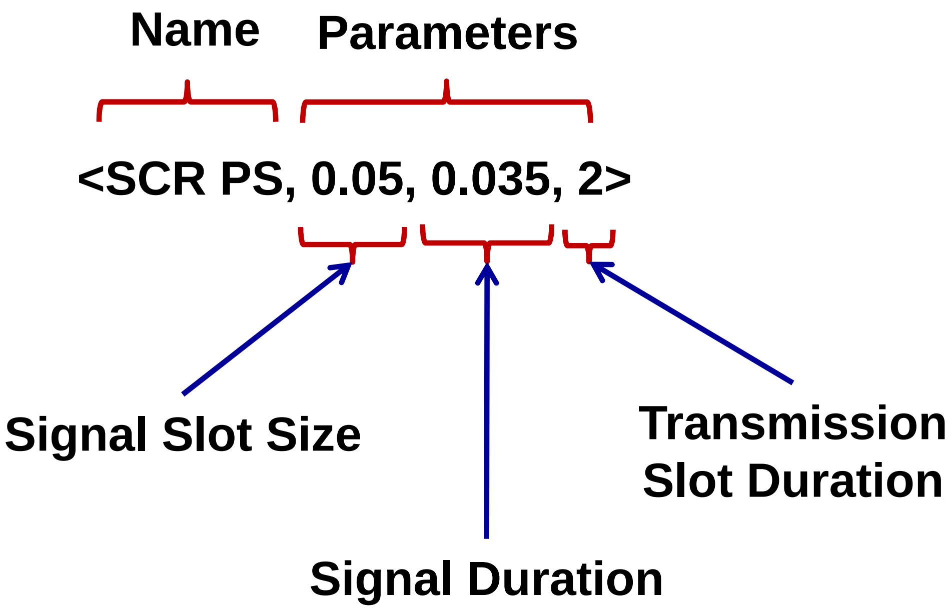
Specifying the Protocol



Name

Parameters

<SCR PS, 0.05, 0.035, 2>

Signal Slot Size

Signal Duration

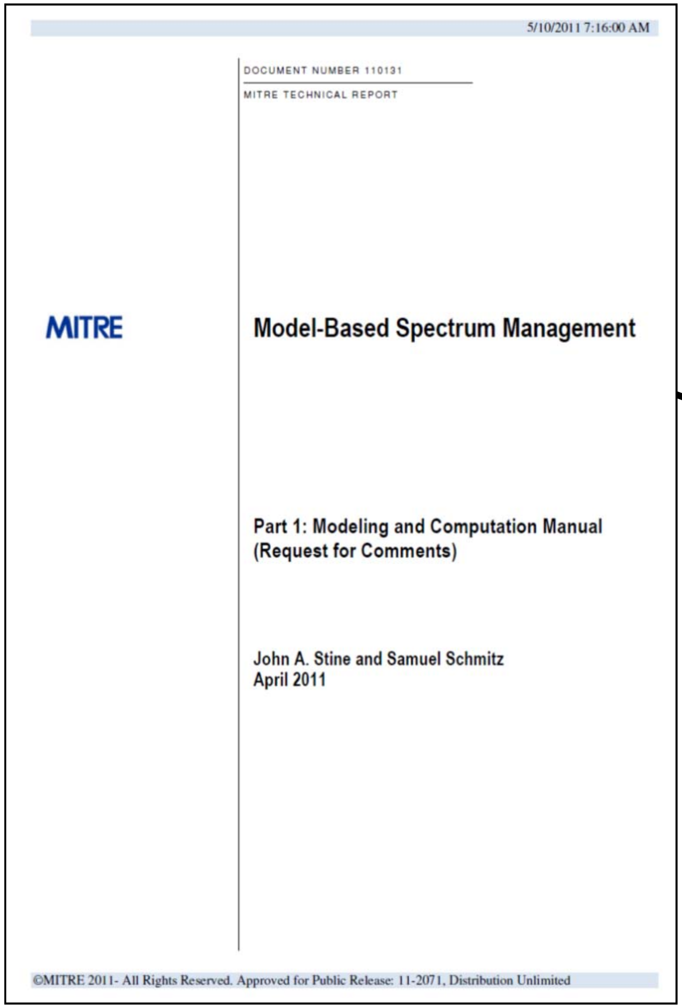
Transmission Slot Duration

Policy Example

- A policy is a generalized behavior with no restriction on the protocols used by the system for arbitrating its own access
- Simple sensing
  - Sense the channel for a particular power threshold, p_{th}
    - A duration of non-use indicates availability, t_f
  - A sensing period for verifying availability, t_s
  - An abandonment time, t_a
- Policy Description

$$\left\langle Simple\_Sensing, p_{th}, t_f, t_s, t_a \right\rangle$$

What we want you to do



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MITRE TECHNICAL REPORT

MITRE

Model-Based Spectrum Management

Part 1: Modeling and Computation Manual
(Request for Comments)

John A. Stine and Samuel Schmitz
April 2011

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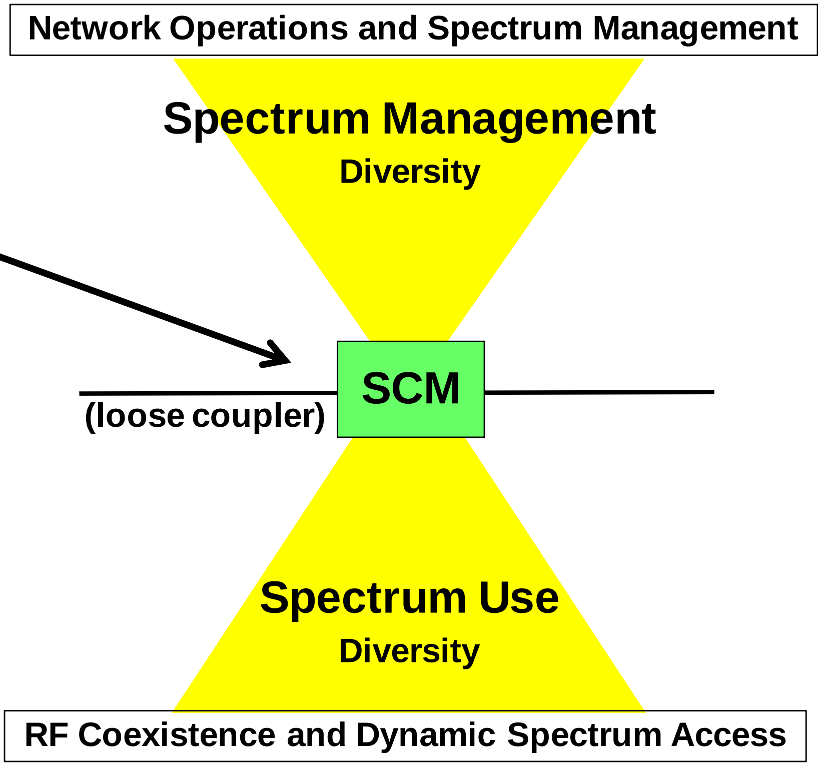
Support the development of a spectrum consumption modeling standard and consider its use for spectrum use databases and for specifying DSA policy



Network Operations and Spectrum Management

Spectrum Management

Diversity

SCM

(loose coupler)

Spectrum Use

Diversity

RF Coexistence and Dynamic Spectrum Access

The "Modeling and Computation Manual" is a first attempt to create a standard and is available at http://www.mitre.org/work/tech_papers/2011/11-2071

Conclusion

- Model-Based Spectrum Management has the potential to greatly improve spectrum management and to liberalize access to spectrum
- MBSM enables the management of DSA systems
- MITRE has made a first attempt to create a standard for modeling which we want you to review and try to make better

  http://www.mitre.org/work/tech_papers/2011/11_2071/

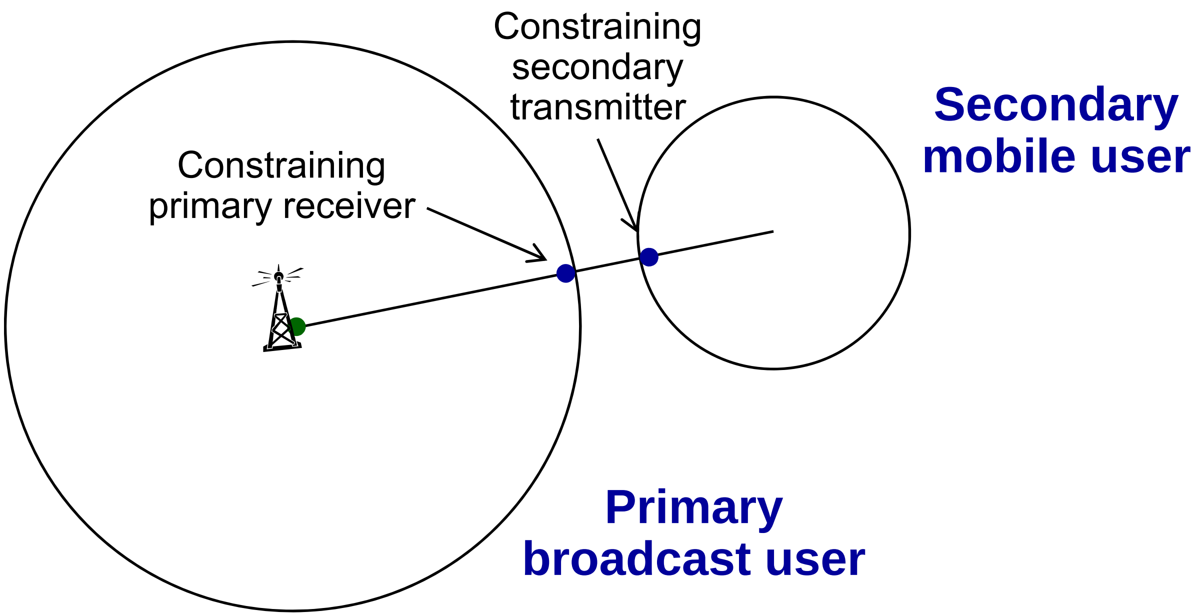
- You can join our collaboration workspace by sending me a request

  jstine@mitre.org

Backup

General process of 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 user

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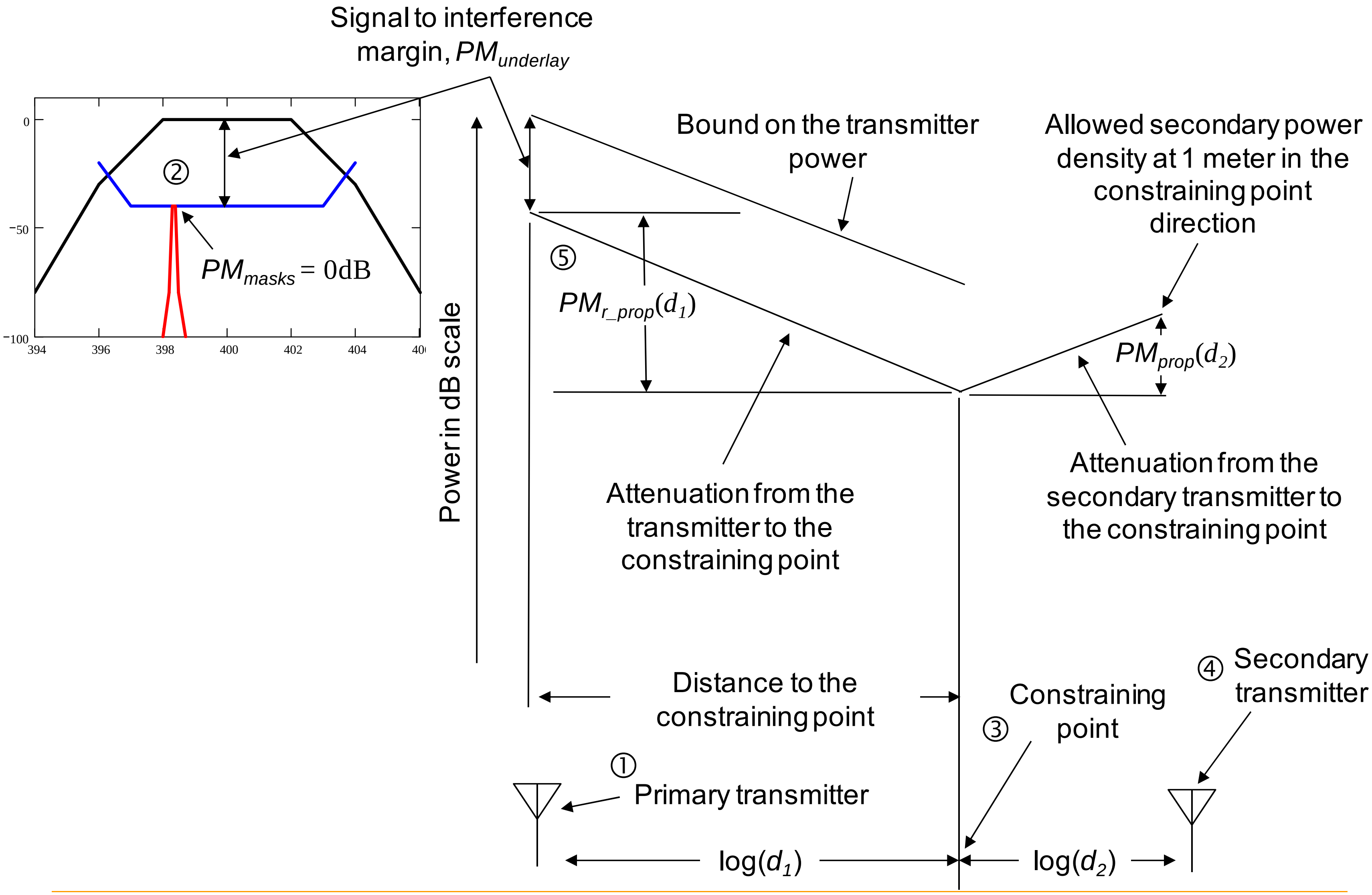
Determining compatible reuse



Signal to interference margin, $PM_{underlay}$

Bound on the transmitter power

Allowed secondary power density at 1 meter in the constraining point direction

$PM_{masks} = 0\text{dB}$

Power in dB scale

$PM_{r\_prop}(d_1)$

$PM_{prop}(d_2)$

Attenuation from the transmitter to the constraining point

Attenuation from the secondary transmitter to the constraining point

Distance to the constraining point

Constraining point

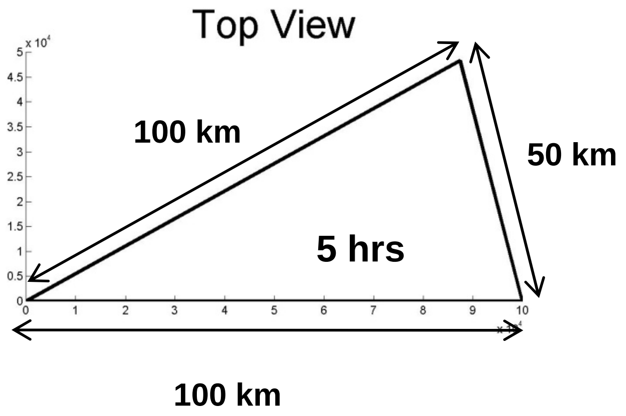
Secondary transmitter

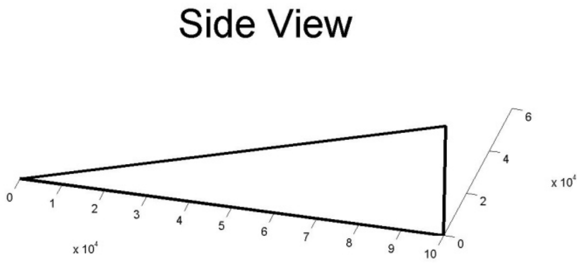
Primary transmitter

$\log(d_1)$

$\log(d_2)$

Value of Modeling – an Example





- As an example, imagine modeling the spectrum consumption of a UAV that flies along the path shown above

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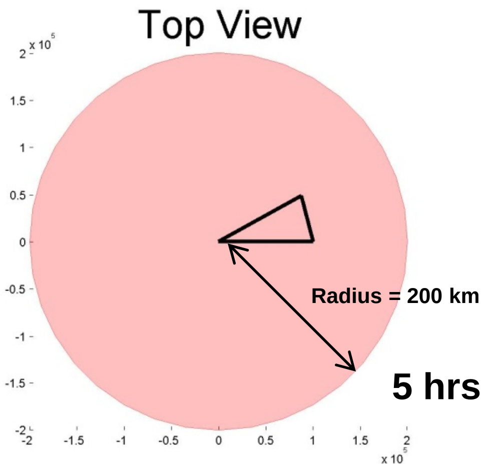
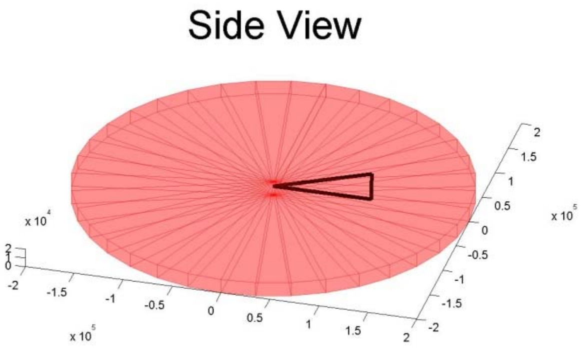
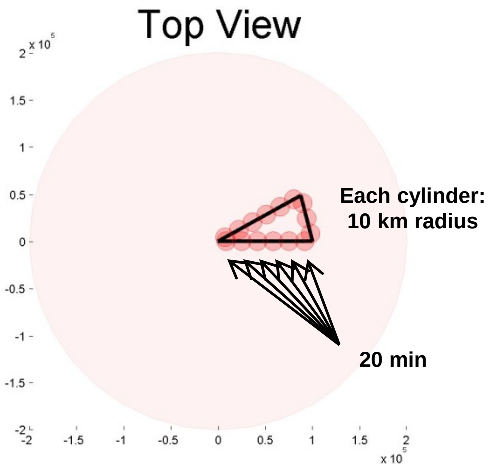
Value of Modeling – an Example





- Without a model, a secondary user does not have complete knowledge of the UAV’s use
- To avoid interference, secondary user assumes UAV’s location may be anywhere within a larger area that fully captures the actual path

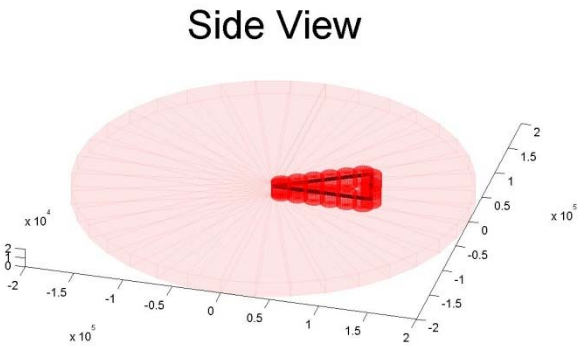
Value of Modeling – an Example


Top View

Each cylinder:
10 km radius

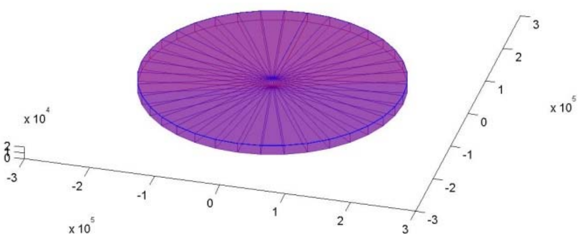
20 min

Total time = 5 hrs


Side View

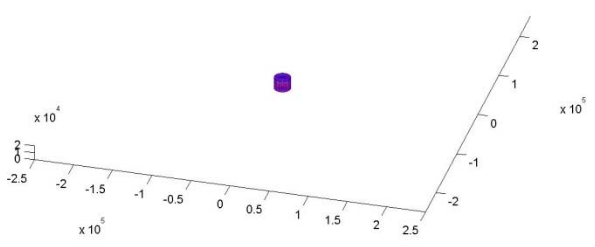
- By using a finer model, the path can be covered by a series of smaller cylinders, each covering 20 minutes of the route

Value of Modeling – an Example



Coarse Model

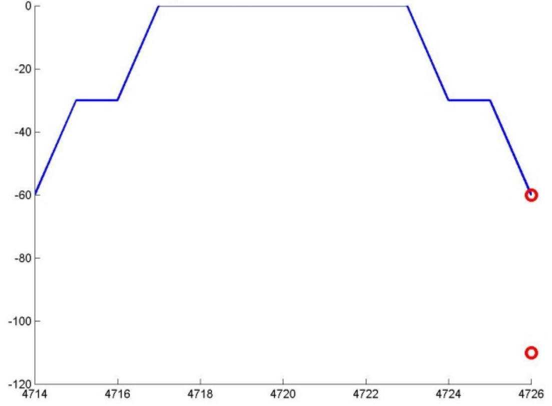
Volume: 1.931e+015 m^3



Refined Model

Volume: 5.119e+012 m^3

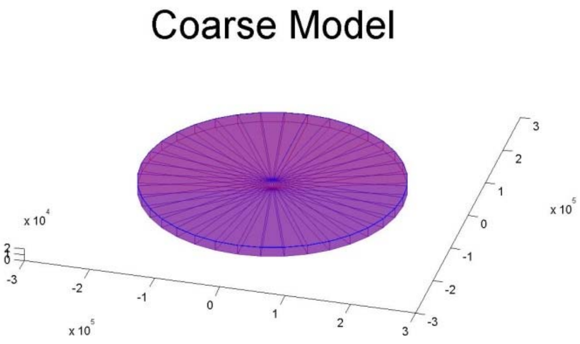
- To determine consumption, we must integrate over time, space, and spectrum
- The volume of the region that experiences interference changes depending on the frequency



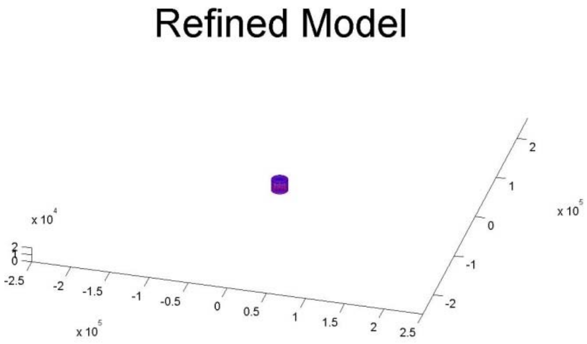
Spectrum Mask

Power Difference: -50 dB

Value of Modeling – an Example

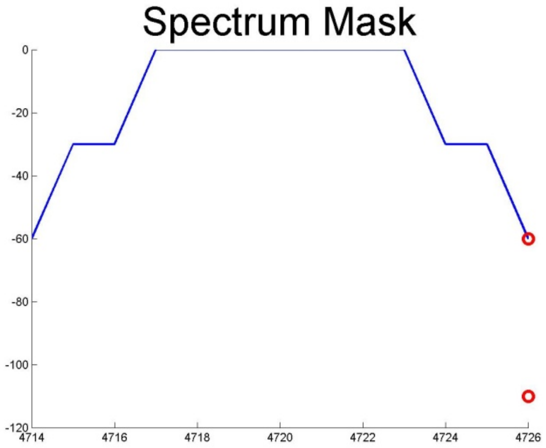

Coarse Model

Total Consumption: 1.387e+018 dBW*MHz*m ^{3}*hrs


Refined Model

Total Consumption: 4.736e+017 dBW*MHz*m ^{3}*hrs

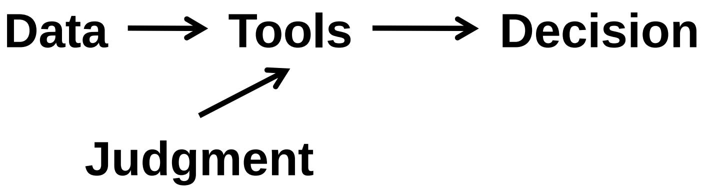
- **Computing the consumptions of both models, we can see that the total consumption of the refined model is ~1/3 that of the coarse model**


Spectrum Mask

Power Difference: -50 dB

Key differences in future tools

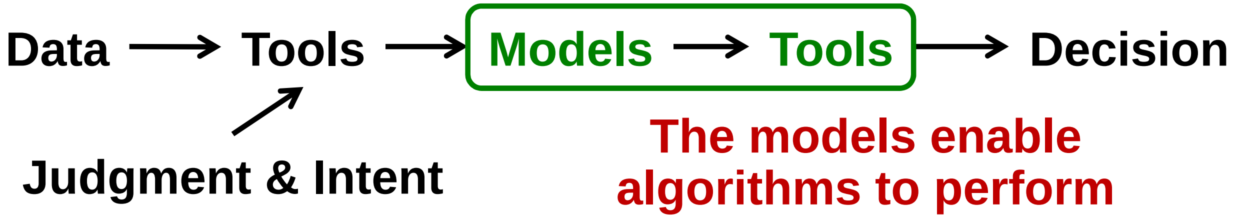
Today



The judgment of the spectrum manager is lost after the decision is made

The judgment of the spectrum manager and the intent of the user is embedded in the model

Proposed



The models enable algorithms to perform hard spectrum management tasks