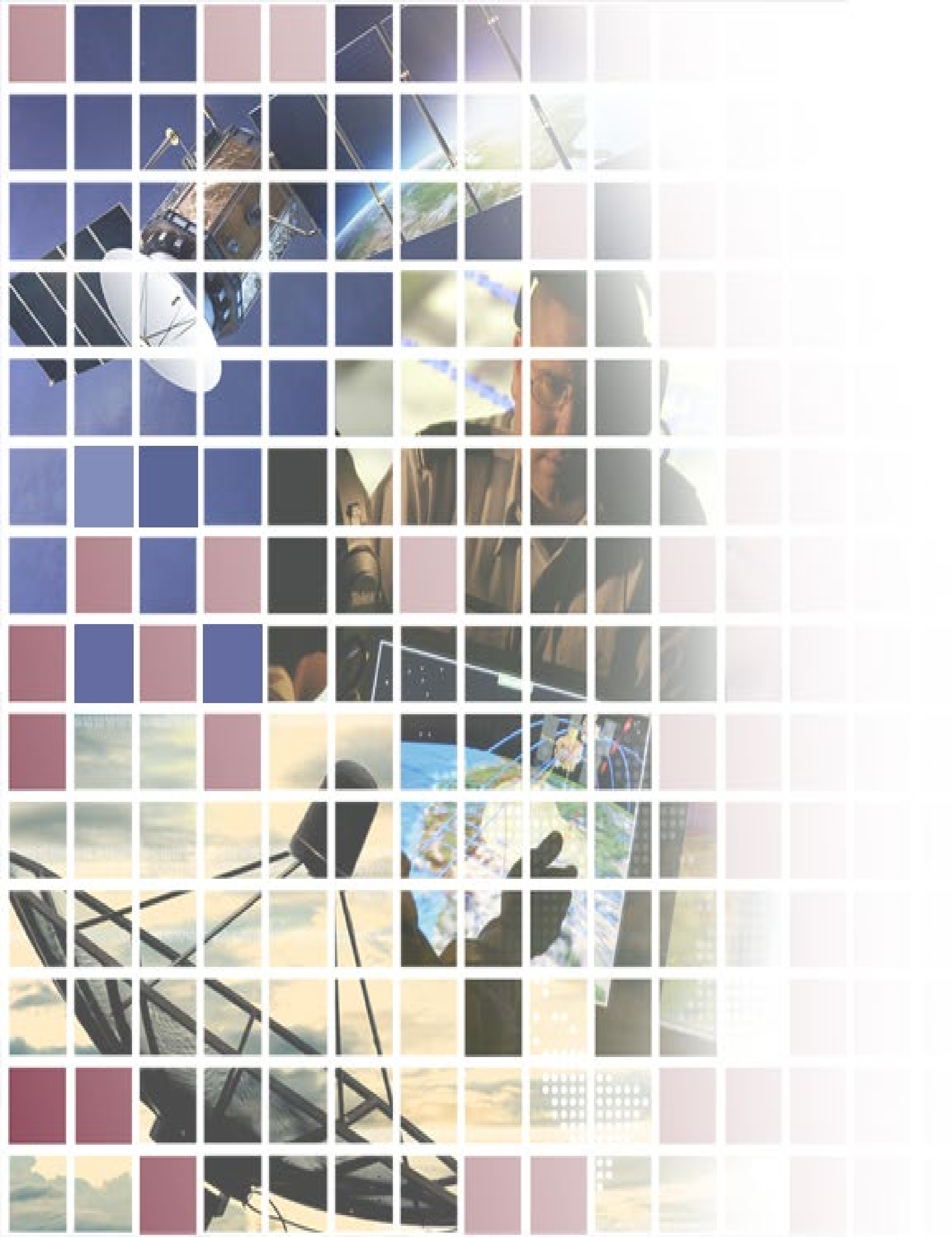

Cognitive Radio Communications for Reduced Interference

GSAW 2019

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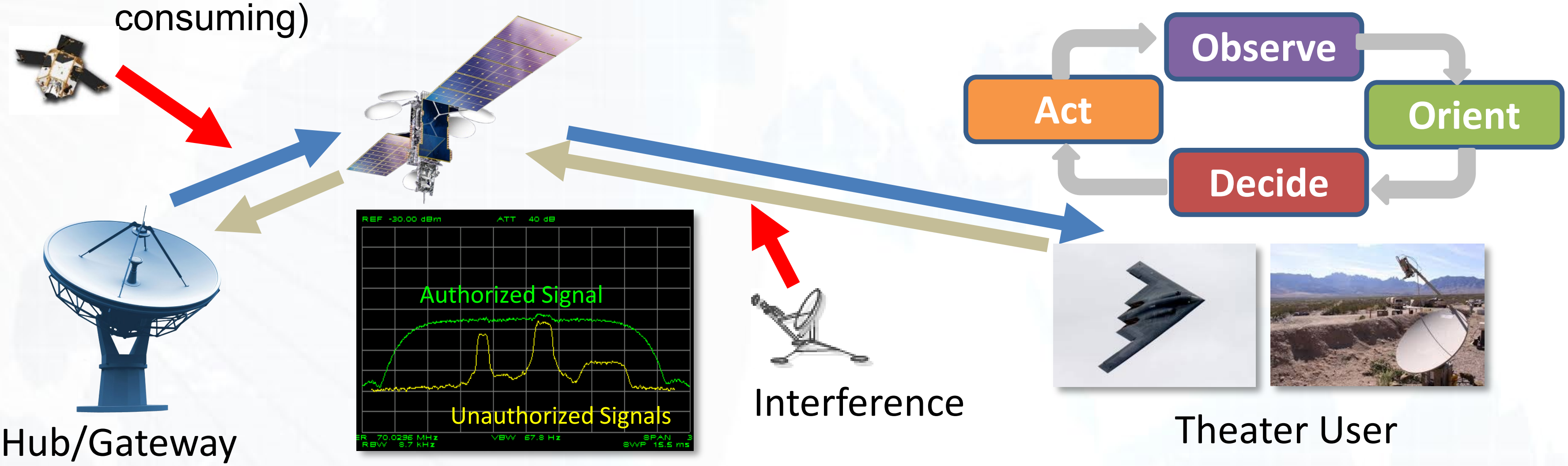
The Problem

- Threats continue to increase while legacy methods for communicating have not evolved sufficiently to stay ahead
- Current generation radios provide programmability but so far, little machine-to-machine coordination is deployed that includes integrating real time EMI awareness with real time waveform adaption
  - Lack of interoperable systems enabling the machine to machine coordination
  - Lack of integrated EMI awareness capability
  - Lack of real-time adaptable waveforms
  - Continued need to have humans in the loop to respond to any interference (time consuming)



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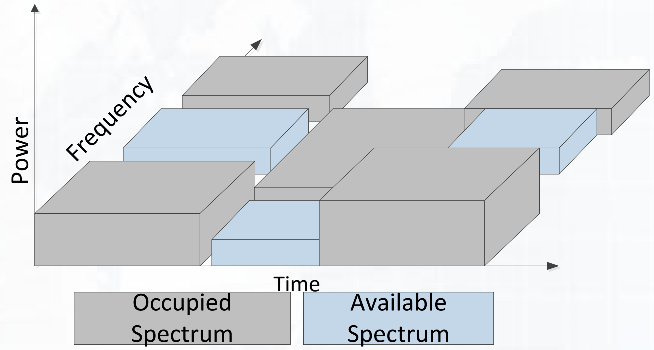
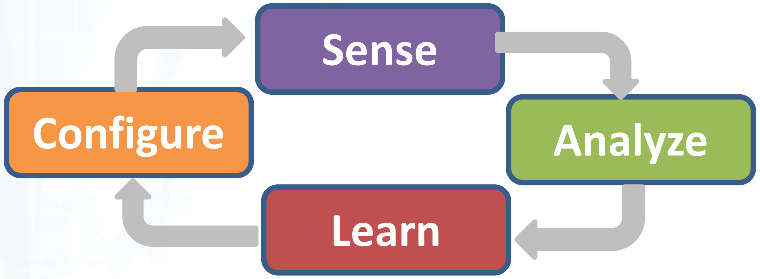
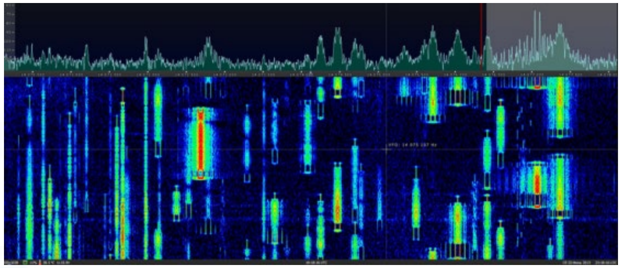
The Basics of Cognitive Processing

- Popular definition: Radio with the configurability to <u>intelligently</u> use the best channels; dynamic spectrum management







- **Key aspects of cognitive systems:**
  - **Ability to Sense (Observe)**
    - Collect data from the environment
  - **Ability to Analyze (Orient)**
    - Generate information from spectral data and extract features to feed the decision process
  - **Ability to Learn & "Think" (Decide)**
    - Synthesize the features, compare with past experience, and decide what to do
  - **Ability to Self-Configure (Act)**
    - Modify the waveform behavior to overcome the threat

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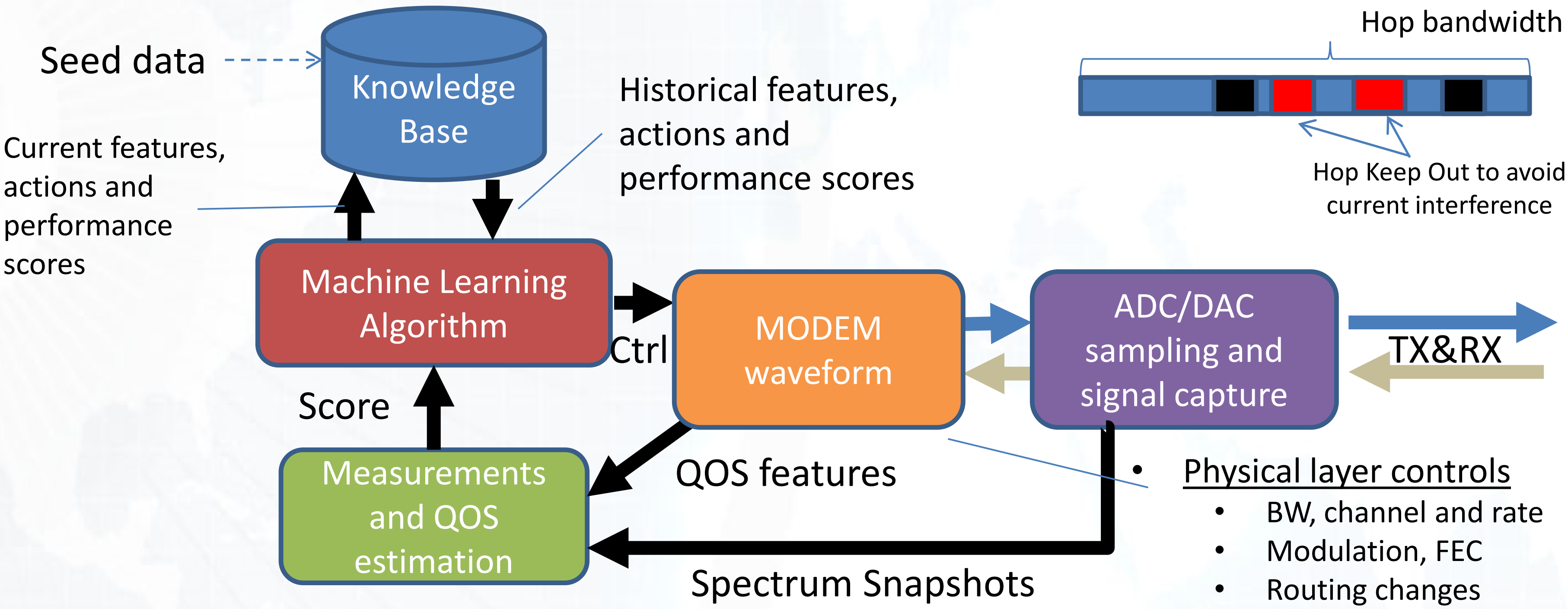
What Does a Cognitive Radio Look Like?

- Nodes measures the RF environment using signal and data metrics
- Systems share information and coordinate changes to counter the threat, effectively "routing" data through/around the interference on the fly
- Threats and effectiveness of response are scored and learned over time to improve performance
- Physical layer waveform is dynamically adjusted to avoid threat



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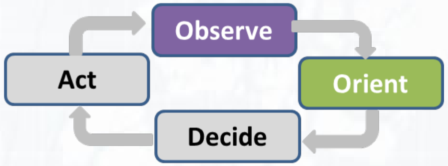
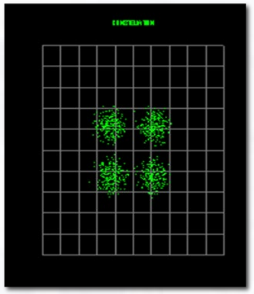
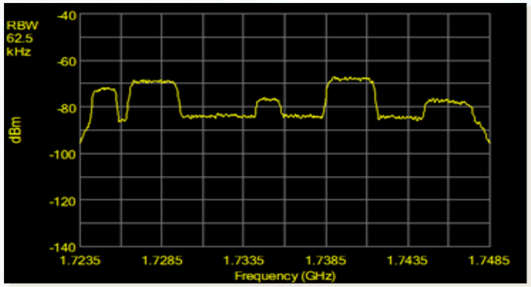


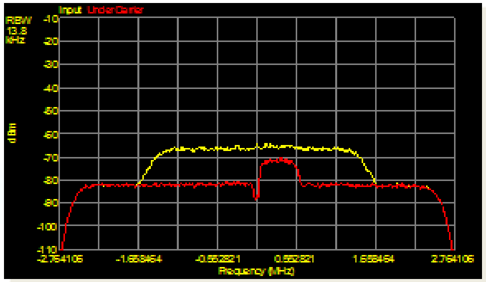
Spectral Awareness

- **Reuse ADC samples in snapshots for “Observe”**
- **Methods & Techniques for Cognitive Radio Sense and Analyze Functions**

Category	Parameter
Signal Characteristics / Quality	Rx Power
	SNR
	Center Frequency
	Bandwidth
	Modulation Type
Channel Estimation	Rain Fade, Distortion
Interference Detection	Presence Level of Interfering Signal
RF Environment	Occupied BW, Total BW, # observed signals







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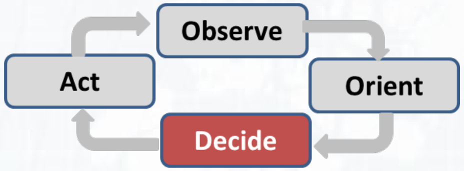
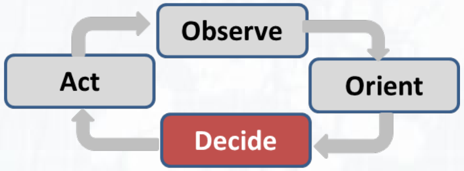


Machine Learning

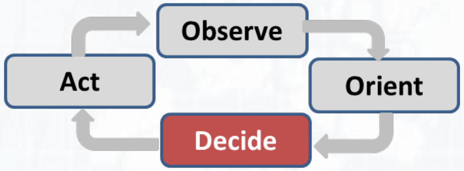
- Two approaches for decision phase: rule based and machine learning
- Rule Based
  - N rules, each of which is made up of a question and two consequences
  - Rule-based engine provides a first approximation of intelligence
  - No mechanism to learn what behaviors are good or bad
  - Only update mechanism is for expert to modify the ruleset based on desired actions
    - Ruleset may need to be more complex than is feasible to maintain
  - Machine learning solves some of the shortcomings of a rule-based decision engine



Machine Learning (2)

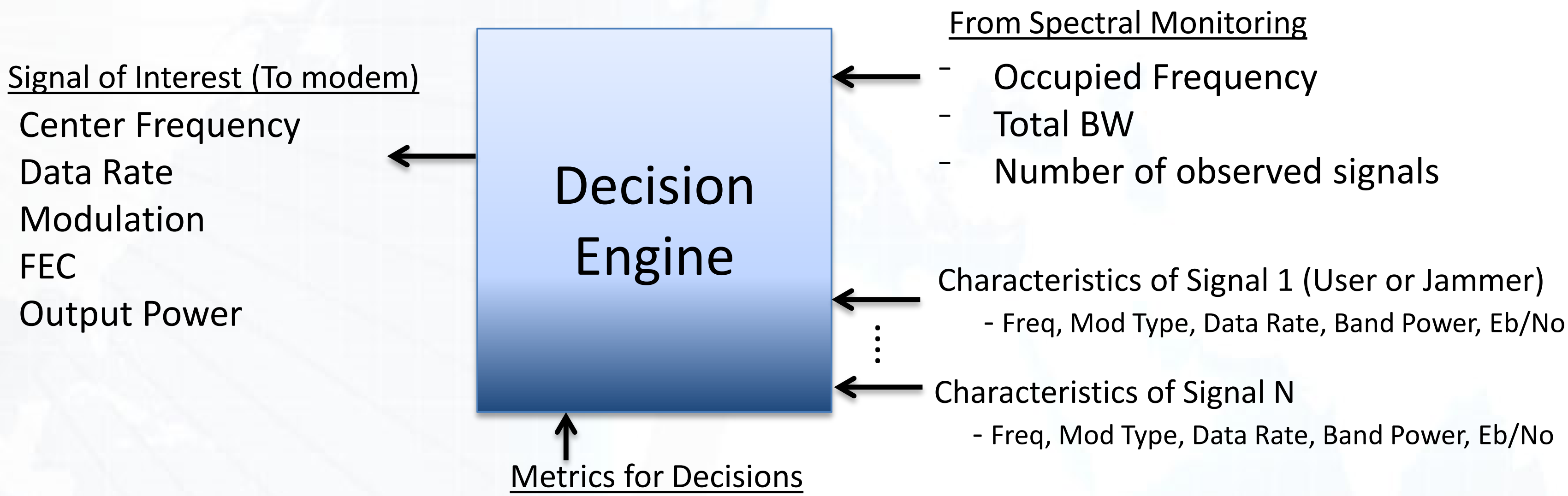
- Supervised Learning
  - "I know how this data is ordered and want to teach a machine how to do the same"
- Unsupervised Learning
  - "I believe there are patterns to this data and want a machine to attempt to find those patterns"
- Reinforcement Learning
  - "I know the result I want but not how to get there"

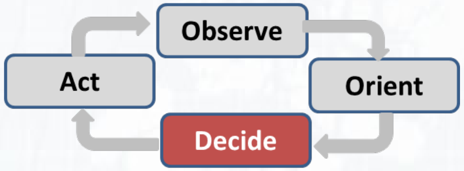
Category	Technique	Application
Unsupervised Learning	Dirichlet Process	Signal identification
	K-means	Signal identification
	Game Theory	Multi agent spectrum usage optimization
Supervised Learning	Artificial Neural Network	Estimating performance given channel parameters Signal identification
	Support Vector Machine	Signal identification
Reinforcement Learning	Q-Learning	Optimum channel identification and usage



Decision Engine

- Employ Reinforcement Learning
  - Goal of maximizing bit throughput without degrading a primary user's throughput
- Use an approximate solution to the multi-armed bandit
  - Handles the exploration versus exploitation tradeoff





Prognostic Cognitive Approach

- Use machine learning to learn what is normal in order to detect abnormal conditions

- Unsupervised learning techniques (k-means, mixture models) seek to find order behind data
  - Make an assumption that measurements stem from (one or more) underlying processes and that measurements are just noisy observations of those processes

- Apply clustering algorithm to the demodulator's SNR estimate
  - Train an algorithm to understand what a 'normal' SNR is

- Extend application to entire communication system
  - Discover the tens or hundreds of 'normal' states to a communication system based on any available inputs
  - Early discovery of hardware degradation or failure, jamming (unintentional or intentional) or misconfigured equipment

Agile, Flexible Modems

- Software definable radio (SDR) are good examples for CR solutions
  - Modem standards exist the allow for “on the fly” optimization
    - DVB-S2 or EBEM
- To maximize throughput and minimize spectrum usage several parameters should be made available for use by the decision engine

QOS Degradation Parameters

Output Signal Power Variation
Modulation Order Adjustment
FEC Modification
Frequency Agility
Pulse-Shaping
Data Rate Modification

Optimization of Spectral Usage Parameters

Modulation Order Adjustment
FEC Modification
Frequency Agility
Pulse-Shaping
Data Rate Modification

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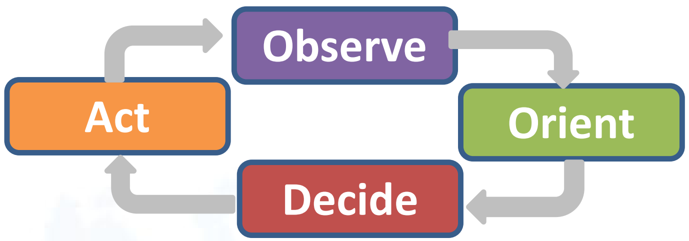
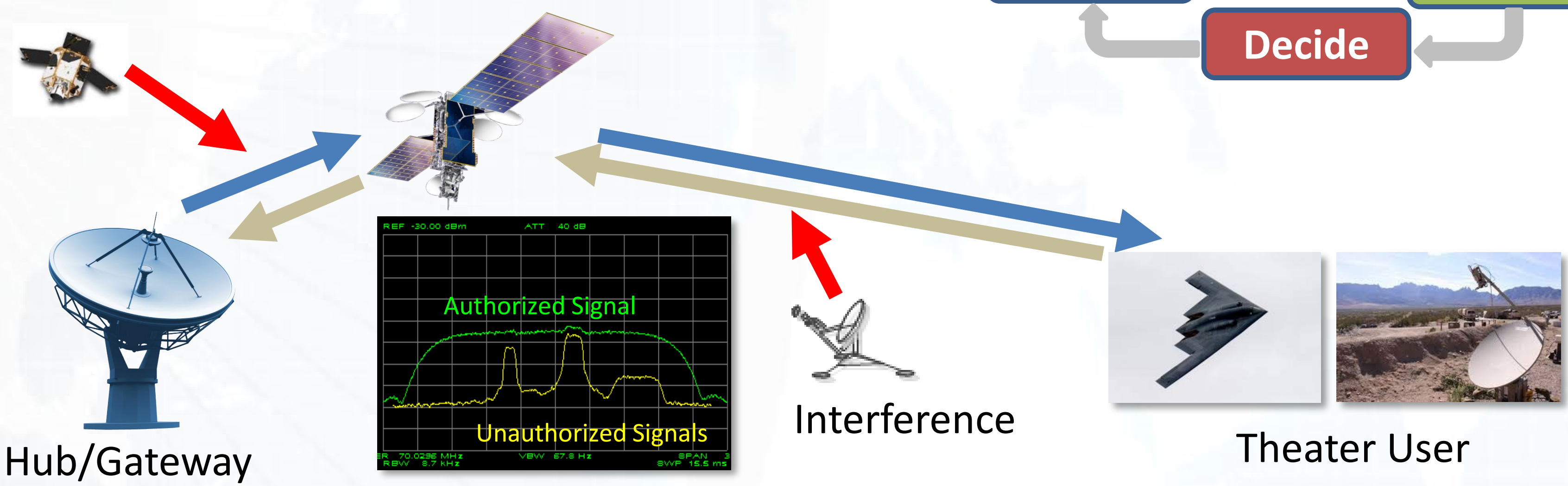
Summary

- Cognitive Radio and machine Learning can be applied for satellite interference
- Cognitive Radio is an extension of today's software defined radio
- Utility is dependent upon data sets and model training





Thank You!

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