Dynamic Channel Assignments for Efficient Use of Aviation Spectrum Allocations

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Outline

- Background
- Modelling and Simulation Tool
- Graph Coloring Resource Allocation
- Simulation and Results
- Ongoing Work

Background

- **Spectrum Challenges**
  - **Increasing demand for radio spectrum**
  - **Emerging airspace users – AAM and UAM**
- **Proposed new aviation spectrum management concept**
  - **Intelligent and Autonomous**
  - **Enhanced sustainability and accessibility**
  - **Dynamic frequency management system (e.g. CBRS Spectrum Access System)**
- **Phased Approach**
  - **Phase 1: Concept Development**
  - **Phase 2: Technology investigation**
    - Deep Reinforcement Learning
    - Graph Coloring (focus of this presentation)

Resource Allocation - Study Areas

What is the specific algorithm for RM? Does it depend on prediction method?

What are the configurable resources? Spectrum, power, ... What others?

To what do we assign the resources?

- To individual aircraft within the same region? So, can a transmitting station use multiple frequencies?
- To regions of airspace? So, a single transmitting station has a single allocation for all aircraft in the region?

How are allocations communicated to (or requested by) air/ground assets?

- What are the latency requirements? i.e., how quickly do allocations need to be distributed?
- How long does it take for assets to implement the new configuration?

What channel feedback can be obtained from air/ground assets?

- What benefits (if any) does this provide?

What is the mechanism for storing/retrieving available channels?

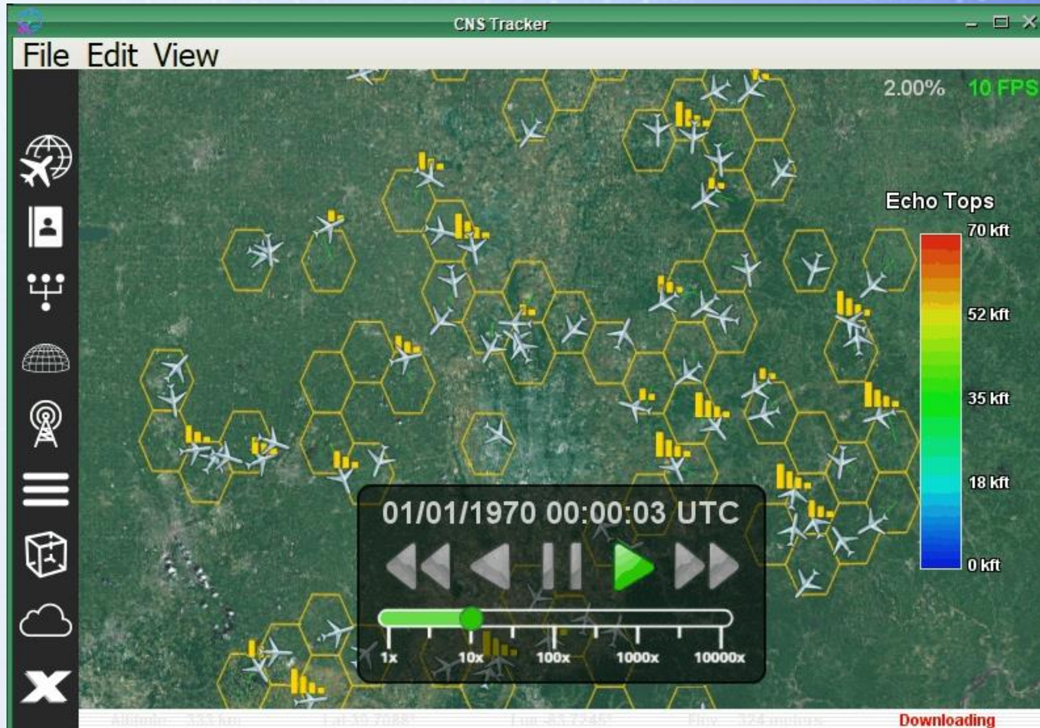
- What are the latency requirements?

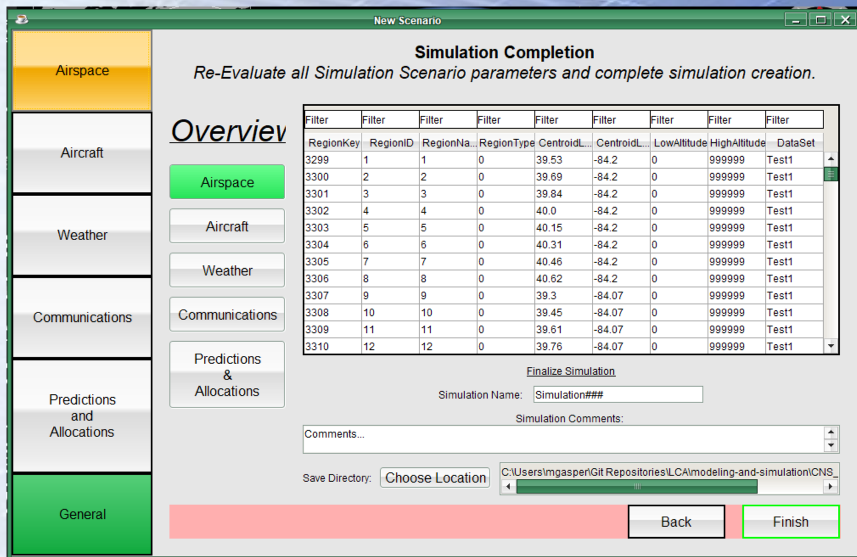
How to evaluate the concept performance?

- Metrics: System capacity (i.e., number aircraft served), spectrum usage efficiency (i.e., how many channels are free vs. occupied)
- Use cases: Need to define

Modelling and Simulation

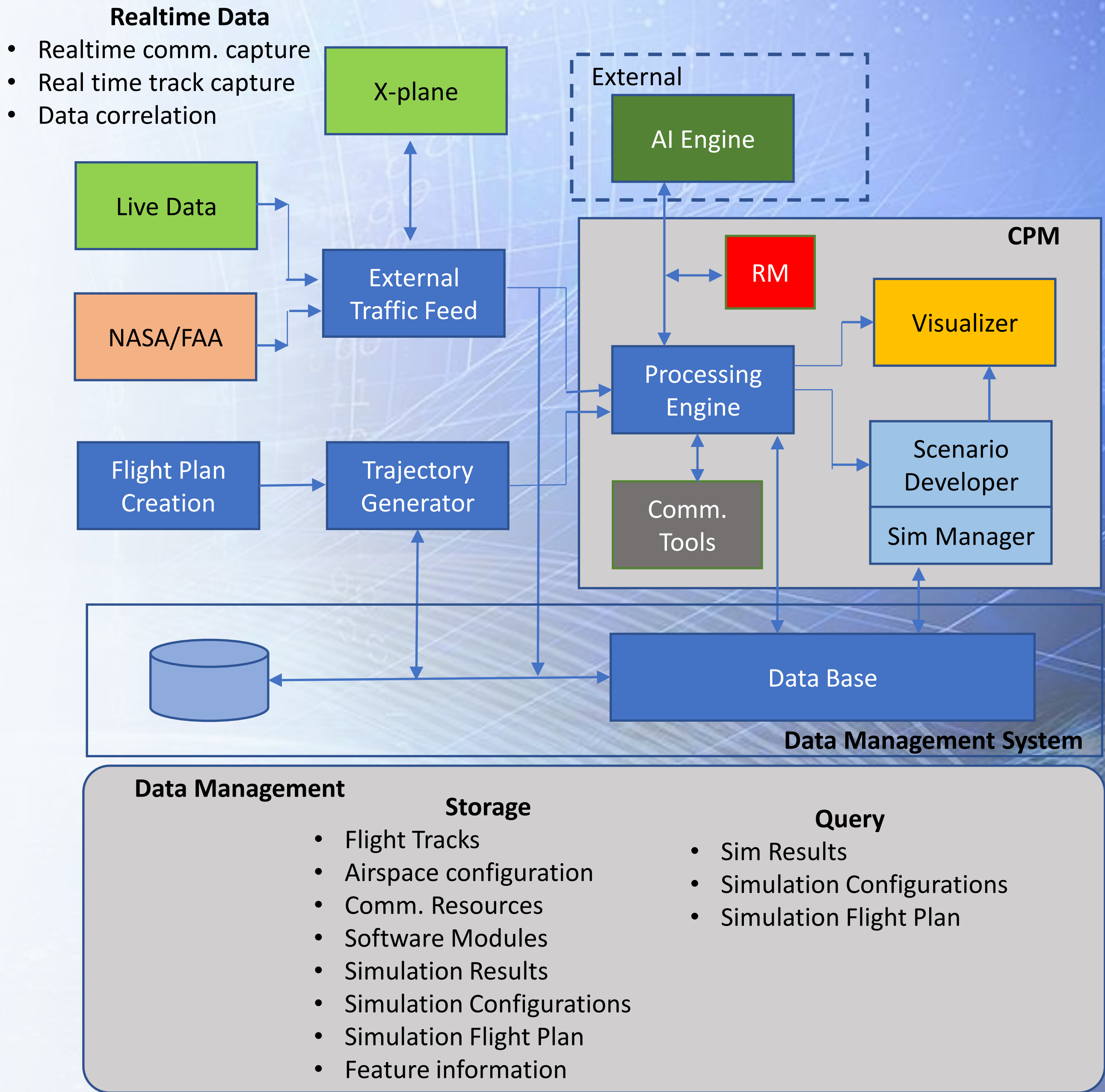
- **Evaluation of proposed spectrum management**
  - **Graphical, mathematical, and data analysis tools**
- **Evaluate the performance of neural networks and other learning-based models using realistic airspace operational scenarios to assess concept feasibility, accuracy, scalability, and efficiency**



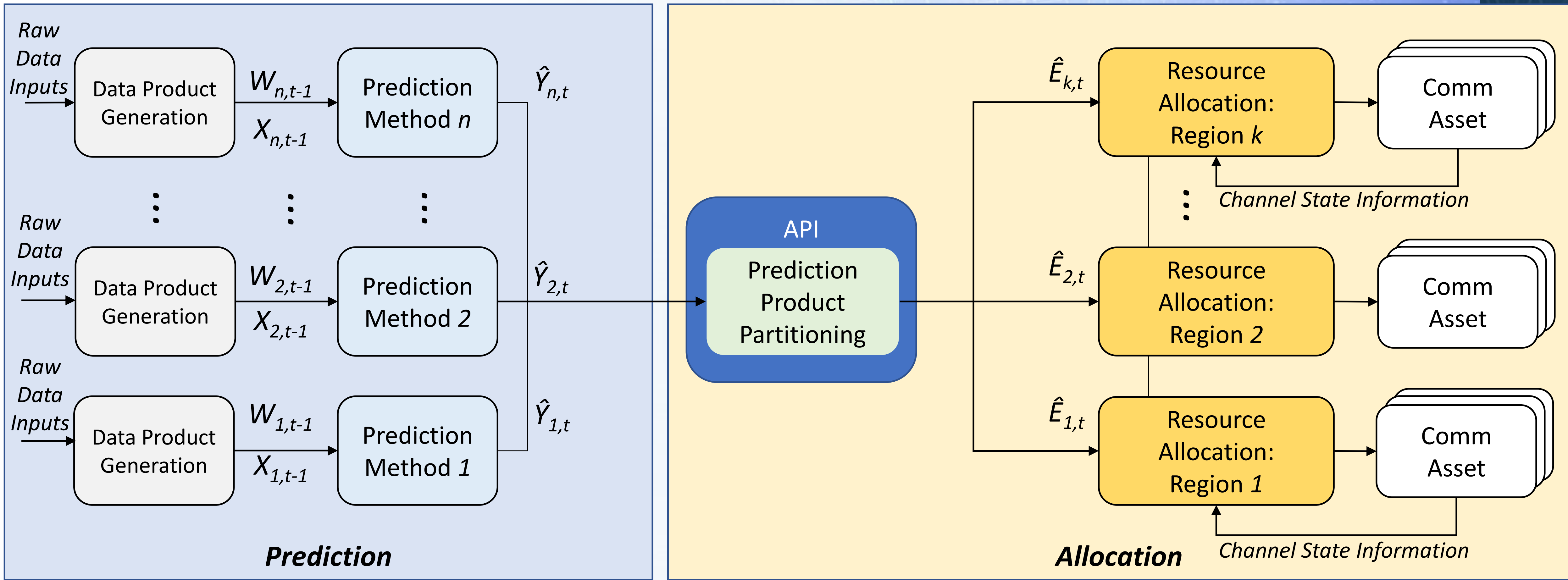


Modelling and Simulation

- Flight Plan Creation: Enables development of flight plans tailored to test specific concept evaluation
- Trajectory Generator: Develops tracks in accordance to flight plan guidelines with consideration to airspace and airway route structures
- Scenario Developer and Configuration: Enables development of specific test cases and configures simulation environment.
- Processing Engine: Conducts all mathematical and engineering calculations
- Data Base: SQL data base retrieval and storage system. Stores/retrieves simulation results
- Visualizer: Renders graphical representation of simulation results and configuration in real time.
- External Traffic Feed: Source of traffic generated by outside entities e.g. FAA, AMES
- **AI Engine: Provides predictions and allocations during simulation.**
- Sim Manager: controls execution of simulation, module selection
- Frequency Engineering evaluation – Evaluates AI assignments and reports interference.

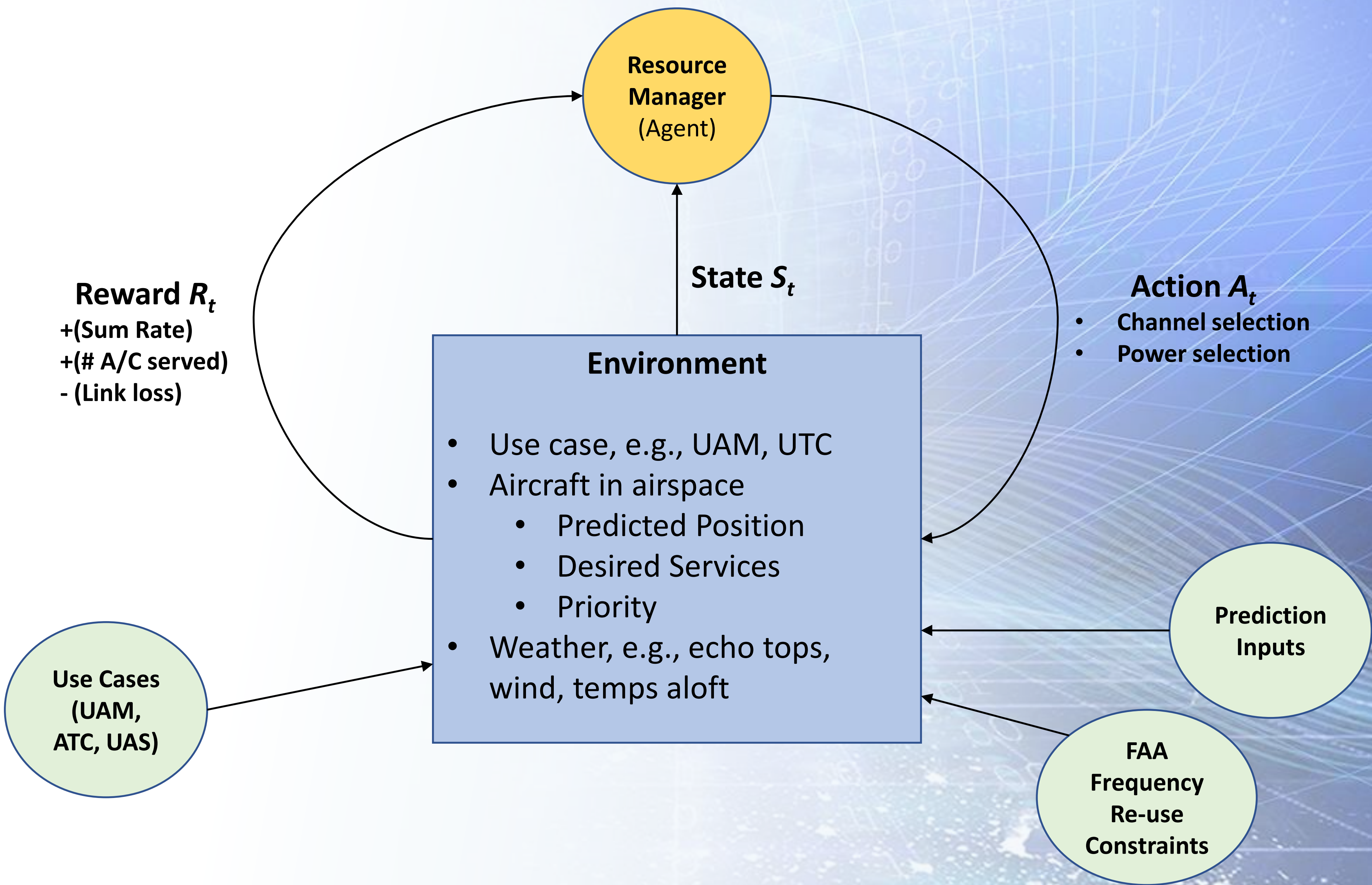


Demand Prediction & Resource Management



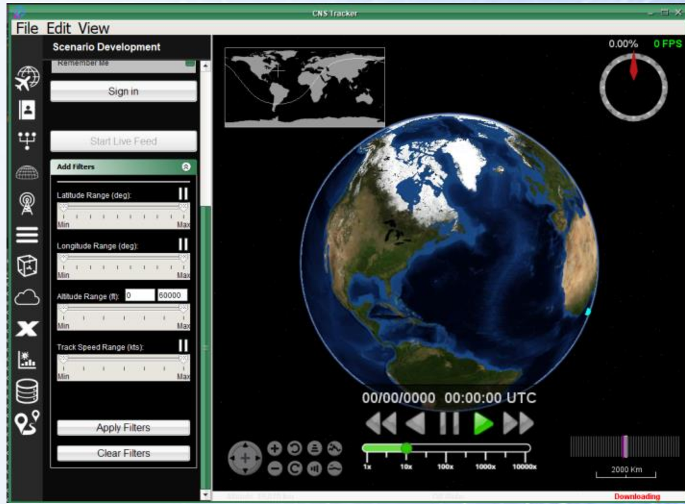
$X_{n,t}$: Data Product Input to Method n at time t
$W_{n,t}$: Data Product Input to Method n at time t
$\hat{Y}_{n,t}$: Prediction product of Method n at time t
$\hat{E}_{k,t}$: Predicted Traffic Flow in Region k at time t

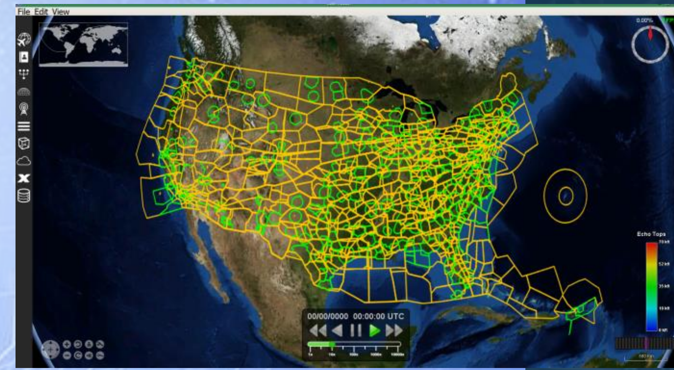
RM: Reinforcement Learning Approach

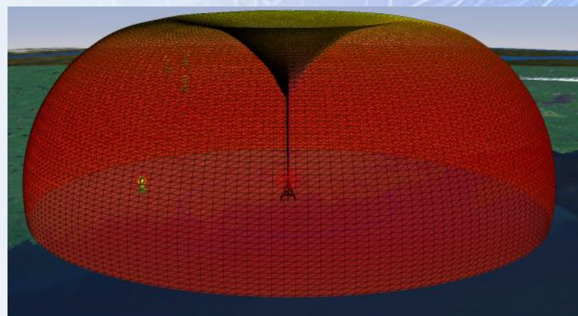


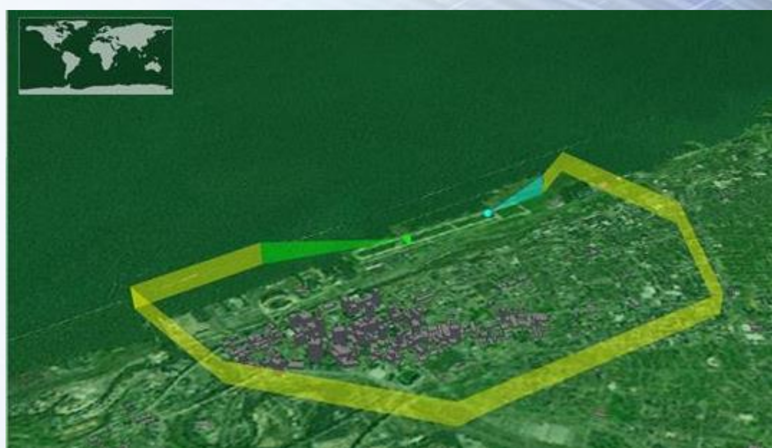
User Interface

- **NASA WorldWind**
  - **Developed by Ames Research Center –** allows developers to quickly and easily create interactive visualizations of 3D globe, map and geographical information
- **Scenario Development: User input parameters**
- **Map overlays**
- **Aircraft, Ground Station, Airspace visualization**



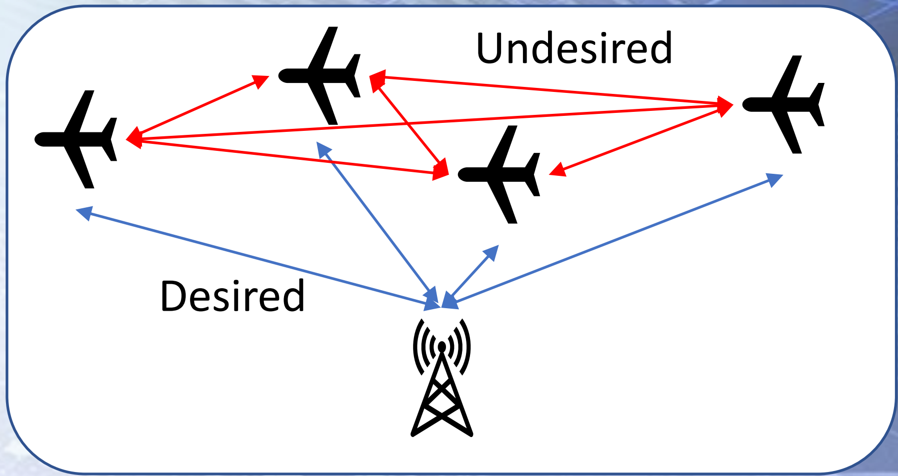






Link Analysis – Assumptions

- **Air-to-Ground links**
- **Aeronautical communications**
  - **Consideration for other radio services not currently included**
- **FAA spectrum management assumptions (Order 6050.32B)**
  - **Only co-channel and first adjacent channels are interfering with the channel of interest**
  - **Adjacent-channel signals are suppressed 60 dB**
  - **No interference received from beyond line-of-sight transmitters**
  - **Constant antenna gain and transmit power**
- **Desired-to-Undesired (S/I+N) limits of 14 dB**

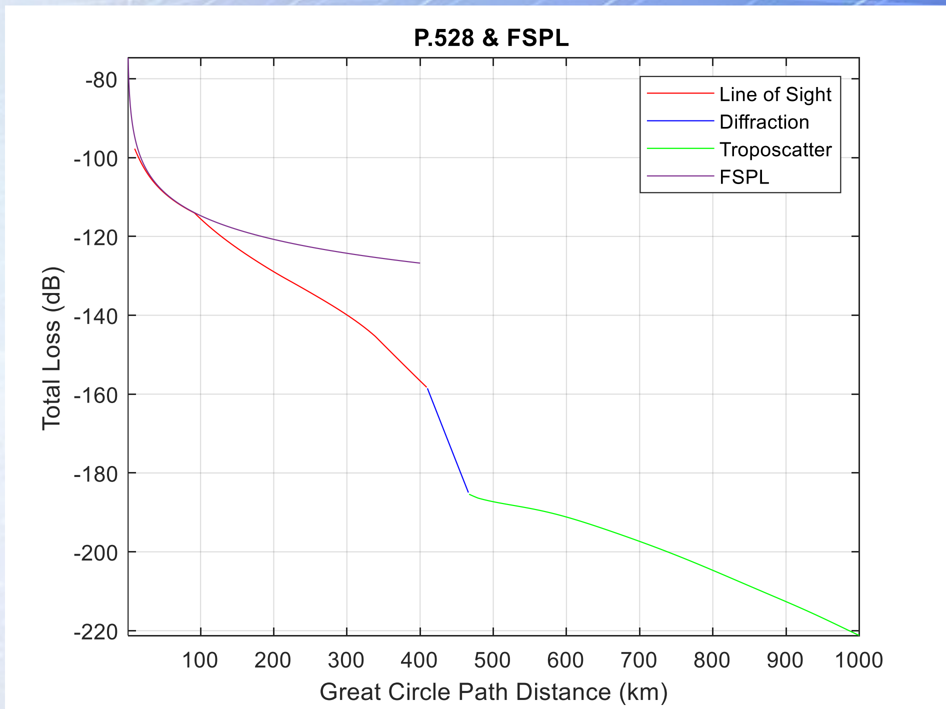


Link Analysis – Calculations

- **Link Equation - Received Signal at an aircraft (n^th^ timestep, i^th^ source)**
  - $R_{i,n[\text{dBW}]} = P_{\text{TX } i,n} + G_{\text{TX } i,n} + G_{\text{RX } i,n} - L_{\text{Prop } i,n} - L_{\text{Misc } i,n}$

$P_{\text{TX } i,n}$: peak source transmitter power into current channel (dBW);
$G_{\text{TX } i,n}$: source antenna gain towards receiver of interest (dBi);
$G_{\text{RX } i,n}$: receiver antenna gain towards source of interest (dBi);
$L_{\text{Prop } i,n}$: propagation losses, FSPL, P.528, IF77, etc. (dB);
$L_{\text{Misc } i,n}$: other losses considered, cable losses, etc. (dB).

- **Desired link: Ground-to-Air**
- **Undesired Link: Interference is aggregated from all co-channel and adjacent-channel Air-to-Air links**



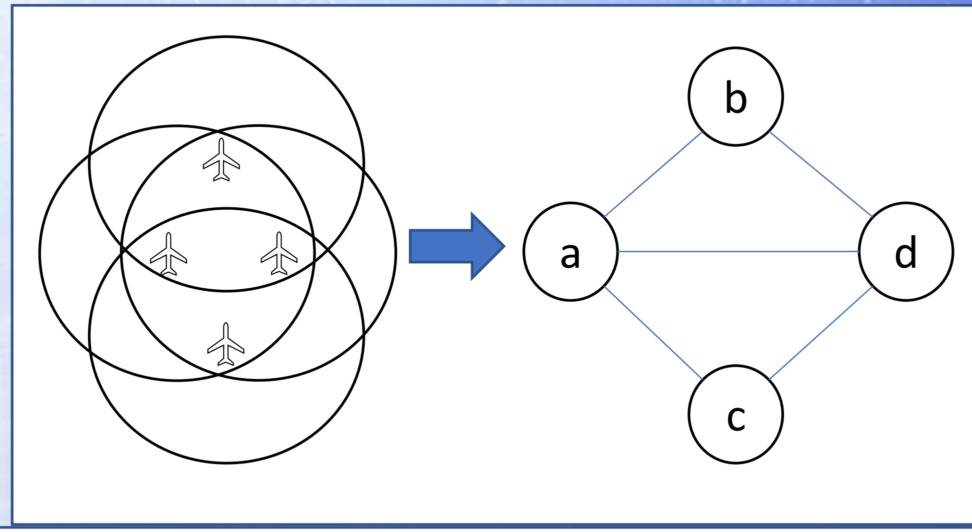
Graph Coloring Resource Allocation

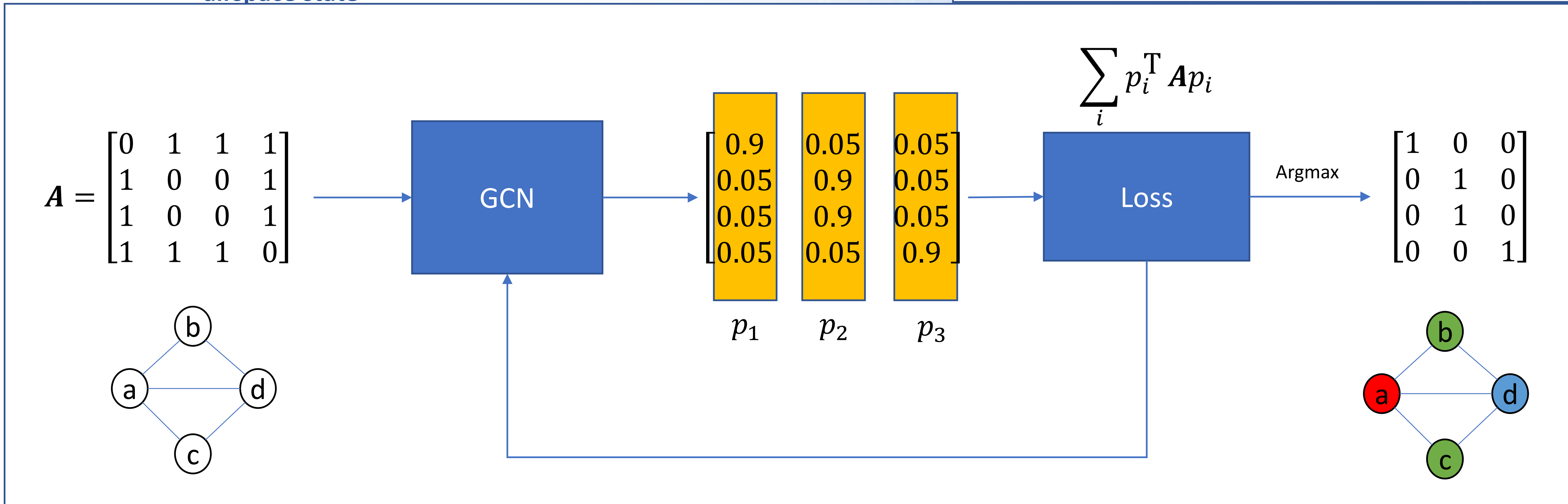
Adjacency Matrix

- Matrix that defines the nodes and edges of our graph – defined by the configuration and current state of the airspace.
- This is the input to the network

Allocation Output

- Matrix containing the channel assignments for the given airspace state

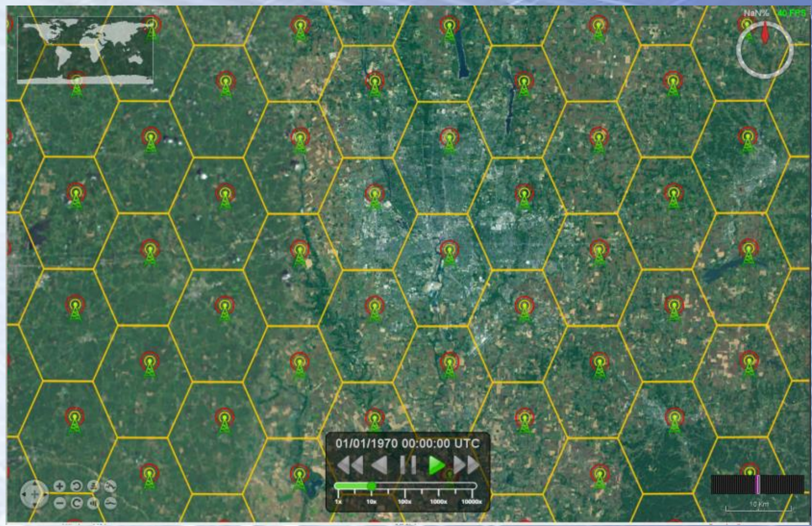




Simulation Parameters – Airspace

Airspace and aircraft setup

- **Given Assumptions:**
  - Airspace – 269 *sectors*
  - 100 Aircraft – randomized origin/destination (UML-4 CONOPS estimates 100-500 aircraft in an urban area)
  - 100 time steps – aircraft move from origin to destination in that time.
  - Number of channels available for use (eg 10, 20…)
  - Power/gain is constant among all AC and GS. Link quality becomes dependent on distance only. Assume that maximum interference level dominates.
  - Adjacency matrix defined with radii around aircraft. Radius is equal to 6 times the distance towards the connected GS. Preliminary tests also assume symmetric matrix, undirected graph.
- **Examine:**
  - Number of interference events – number of aircraft experiencing D/U < 14 dB
  - Number of channels utilized
  - Using 3 Allocation Methods:
    - Greedy: unoptimized first come, first serve
    - GCN – network trained using entire data series
    - GCN – network trained at each time step



Simulation Parameters – Graph Convolution Network

AI Allocation Function - GCN

- **Two layers**
  - Layer 1 (input): TAGConv with ReLU
  - Layer 2 (output): TAGConv with Softmax
  - Dimensional embedding (feature vector size) = 60
  - Hidden layer size = 60
- **Allow for 100,000 epochs**
- **Early termination if Loss < 1 for 100 epochs or loss changes by less than 1e-9 for 5000 epochs**
- **No dropout. Early testing with dropout caused many instances of the network never converging. May be too few network layers and hidden layers to be useful.**
- Topology Adaptive Graph Convolutional Networks

Loss function

- **Evaluate occurrences of invalid assignments**
  - Network aims to minimize loss

Simulation Process

Update

- Propagate aircraft and update locations and links

Map airspace to graph

- Generate adjacency matrix defining potential interfering links

Simplify graph

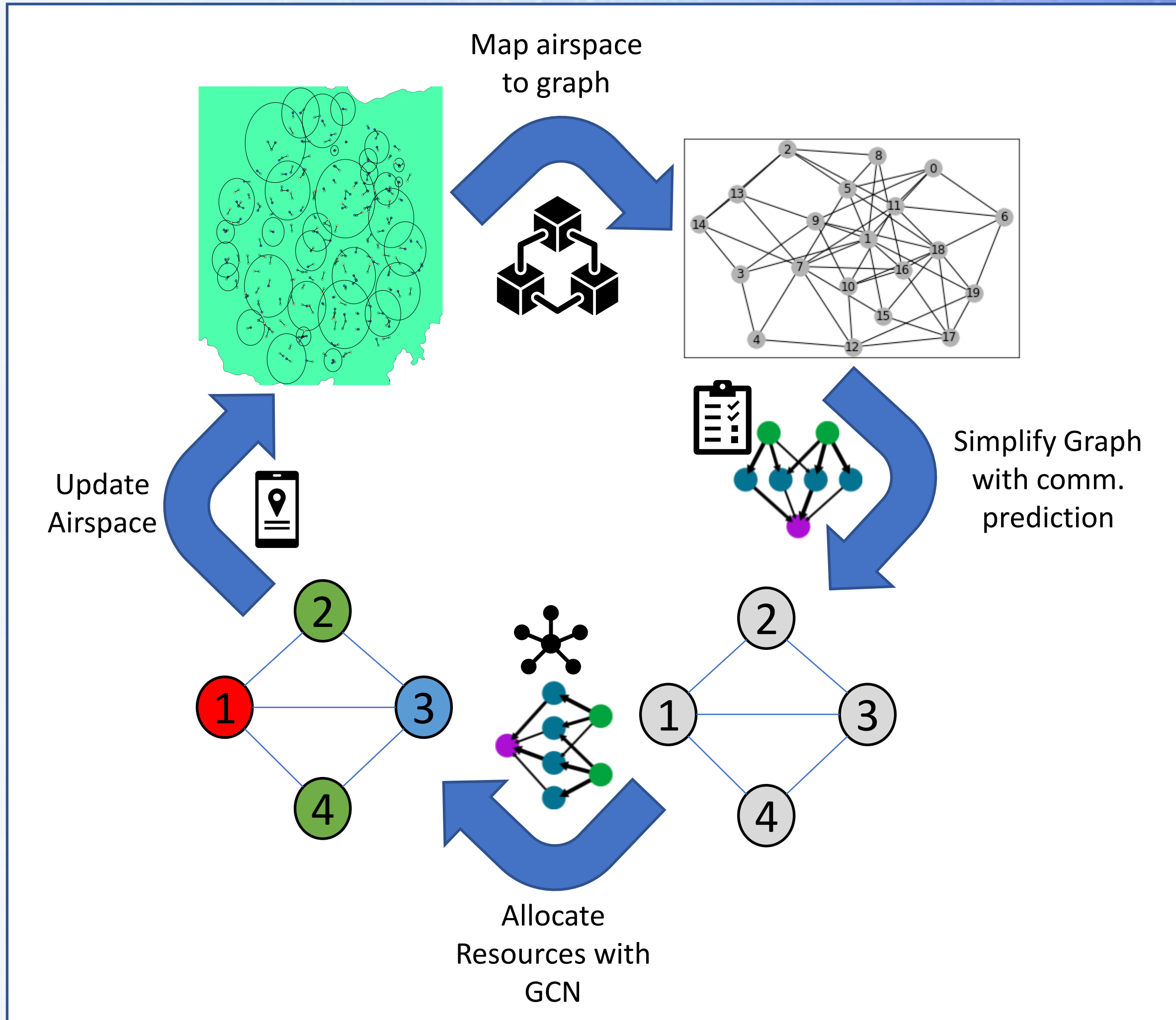
- Simplify the graph structure, removing links predicted to be inactive at the time step

Allocate resources

- Assign resources to each link to minimize interference (channels, power, etc)

Evaluate

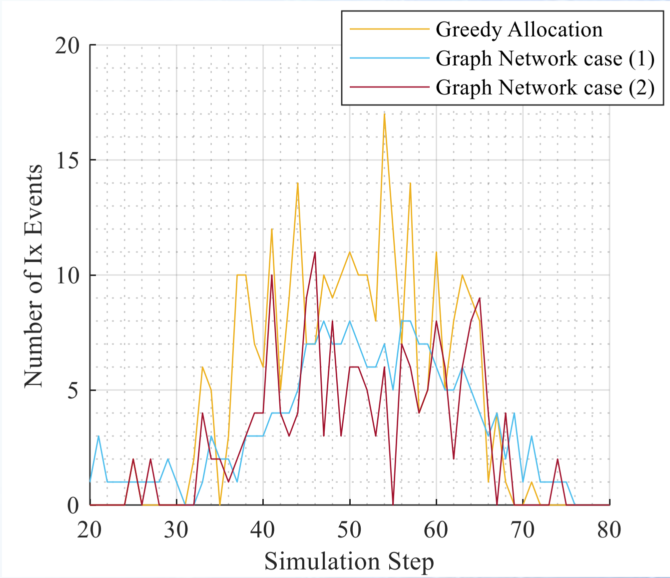
Repeat…

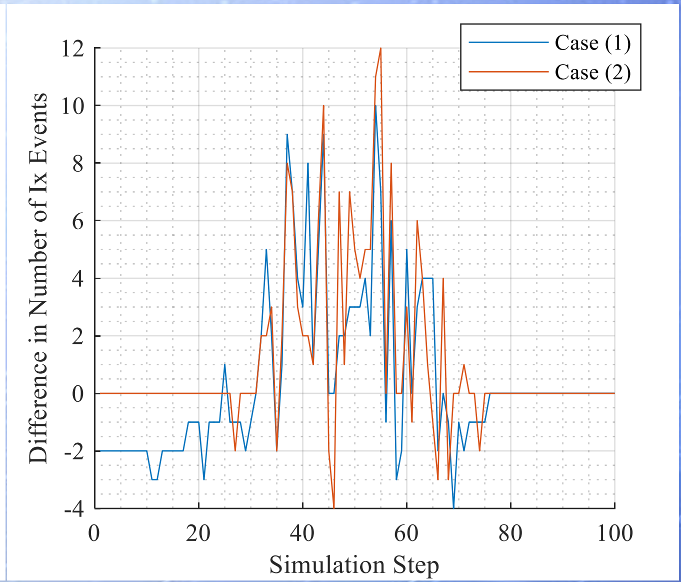


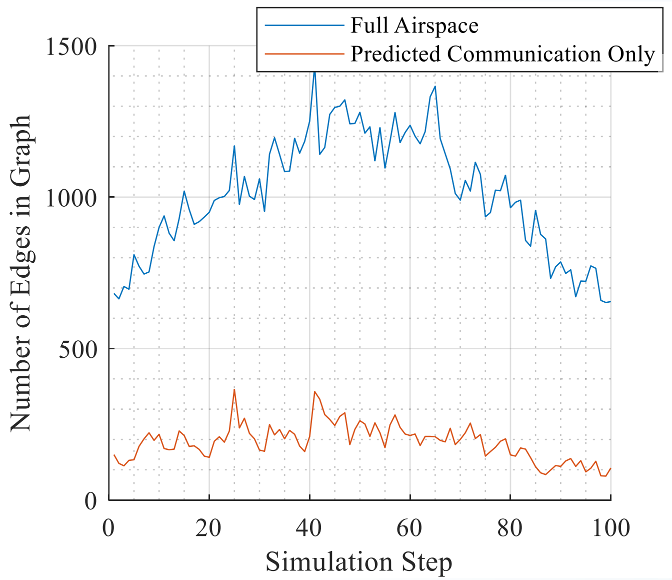
Simulation Results

Results

- **20 Channels**
  - > Graph Network outperforms the greedy allocation when the aircraft density is higher
  - > In cases of **low aircraft density**, the AI performs the same or worse than greedy.







- **Simplified Airspace**
  - > Communication Demand Prediction Scenario
  - > Significant reduction in the number of edges in the graphs
  - > Creates low aircraft density in terms of potential interferers
  - > Little to no instances of interference in all cases.

Simulation Results

Other observations

- **10 Channels available**
  > Greedy and AI methods perform similarly – too few available channels

- **60 Channels available**
  > Too many available channels shows no instances of interference

- **Tuning of hyperparameters may improve AI performance**
  > Learning rate
  > Dimensional embedding
  > Hidden layers
  > Layers of the network

- **Prediction and Allocation**
  > AI allocation is helpful in cases of high aircraft density, when resource are constrained
  > Communication demand prediction can turn a high-density case to a low-density case, reducing the benefit of the AI allocation
  > A combination of resource allocation schemes would provide the greatest benefit

Outlook

- Vehicle-to-Vehicle communications
  - Currently examining to A-G links only
- Operation in bands shared with other radiocommunication services
  - Requires greater knowledge of environment. Systems akin to CBRS.
- Optimize graph network
  - Hyperparameter tuning
  - Graph representation: weighted adjacency matrix, directed graph
- Utilize recurrent network or LSTM in resource allocation
  - Time dynamic graph coloring, consider allocations at previous time steps
- Explore options for airspace structure
  - Structured airspace may offer finite graph representation compared with unstructured, random scenarios

Questions?

Thank You!