Stochastic Control of Throughput and Delay for Flows in Air Traffic Management

Alex T. Nguyen and John S. Baras

Abstract

Attempts to manage air traffic by either decreasing delay or increasing flow can have the reverse effect on the other. In the NAS, flights typically depart at their chosen times, and flow management techniques are implemented in the air in and effort to maximize flow, while possibly leading to delay for individual aircraft. Other areas of the world allow flights to depart only at predetermined slot times knowing that there is a clear unobstructed path, leading to minimal delays but possibly underutilizing airspace.

We propose a novel approach to identify the flows of air traffic using a clustering-based methodology. The trajectory is first broken into a series of great circle segments. Each trajectory is then partitioned into segments using a density-based approach that takes into account the proximity, heading, timing, and other metrics of the segments. Finally, a representative trajectory is identified for each cluster.这些问题 then are converted into a network of cells which can model the movement of aircraft along each route to determine the effects of different control methods have on throughput and delay.

In practice, the model is envisioned to initially run offline to determine a preliminary solution to the current state of the system. Solutions for subsequent changes in actual state can be determined by running the model online for the incremental state change. Stochastic events such as convective weather clearing times or capacities can be included in the model to better see the benefits and impacts of pre-positioning traffic to take advantage of possible future clearing.

I. Determination of Main Flows for Network

We propose a novel approach to identify the flows of air traffic using a clustering-based methodology. The trajectory is first broken into a series of great circle segments. Partitioning each trajectory into segments identifies turns in the trajectories using heuristics in order to identify the start and end of the segments.

Then, the segments are clustered using a density-based approach that takes into account the proximity, heading, timing, and other metrics of the segments. Finally, a representative trajectory is identified for each cluster.

II. Flow Optimization

Highway Kinematic Wave Model has following key parameters:

Throughput: 
\[ v_{\text{free}} \] free flow speed \[ v_{\text{jam}} \] max flow (capacity) \[ w \] backward propagation speed \[ k_{\text{jam}} \] jam density

Flow into individual cells is governed by:

\[ q = \min \left\{ v_{\text{free}}, v_{\text{jam}} - n(k, j) \right\} \quad 0 \leq k \leq k_j \]

Application to Aviation

The network is composed of a set of logical cells and physical cells. Each aircraft moves from origin to destination along a path that is composed of a set of logical cells. When the paths of different aircraft cross the same physical region, the logical cells of the two paths belonging to the same physical cell at the intersection.

The network is composed of a set of logical cells and physical cells. Each aircraft moves from origin to destination along a path that is composed of a set of logical cells. When the paths of different aircraft cross the same physical region, the logical cells of the two paths belonging to the same physical cell at the intersection.

Summary & Future Work

• Approach for identifying flow patterns of air traffic involving three steps:
  • Partitioning each trajectory into segments
  • Grouping the segments into clusters
  • Identifying the representative trajectory for each cluster

• Identifying a key ability of algorithm will be to dynamically and incrementally cluster new flight segments with existing clusters without having to re-cluster the entire data set each time.

• Flow paths are used to construct network with separate logical paths from origin to destination, each consisting of series of cells.

• Initial model for optimizing throughput with minimal delay that can be used to trade-off between the two.

• Future steps include:
  • Include stochastic factors such as random convective weather clearing times or random capacity
  • Adapt to ability to incrementally update network state based on current conditions and re-optimize
  • Develop heuristic to quickly find reasonably optimal solution

• Model can be used to evaluate variations in flow strategies between US and Europe that emphasize increased throughput vs minimal delay.