Robust Capacity-Constrained Scheduling and Data-Based Model Refinement for Enhanced Collision Avoidance in Low-Earth Orbit

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More than a half million pieces of space debris are in low-Earth orbit, of which about 5% are considered a threat to operational satellites. Collisions, such as the one that occurred on February 10, 2009 between the decommissioned Russian military communications satellite Kosmos-2251 and a operational U.S. Iridium communications satellite, produce yet more debris, and the accumulation of space debris renders low-Earth orbit increasingly dangerous and unusable. Space debris are tracked by NORAD, NASA, and the European Space Agency, and orbit-prediction methods, based on state-estimation techniques, play a fundamental role in this activity by combining models and measurements to optimize predictions. Improving the accuracy of space-debris tracking can reduce the frequency of collisions by facilitating evasive maneuvers, thereby protecting valuable space assets and helping to prevent runaway space-debris production. In order to achieve this objective, more accurate nowcasts (current conditions) and forecasts (future conditions) of the thermospheric winds and density are needed for improved debris trajectory prediction.

This project is focused on the conceptual and technological foundation for a cyber-physical system involving a constellation of *Cubesat satellites* in orbits that cover the globe. These satellites will collect atmospheric data, which will be communicated through ground stations located worldwide for use in modeling and prediction. One of the challenges of Cubesat technology is that the available space communication infrastructure is geared toward monolithic satellites with large power sources and large antennas. Collecting data from a constellation of Cubesats with limited on-board power is thus a challenging problem in *optimal capacity-constrained scheduling*. The data collected from the satellites will be used to improve models of the thermosphere through a process called *data-based model refinement*. These models can then be used within data assimilation algorithms to provide atmospheric data estimates, which, in turn, can be used for orbit trajectory prediction for space debris. This technology has direct application to space weather prediction, which affects both space- and ground-based assets. The combination of atmospheric science, algorithm development, and systems engineering crosses the boundaries of physics, engineering, systems science, and computer science. To realize these objectives, the project team includes experts on space physics, satellite engineering, optimization, model identification, and data assimilation from the University of Michigan and National Center for Atmospheric Research (NCAR).

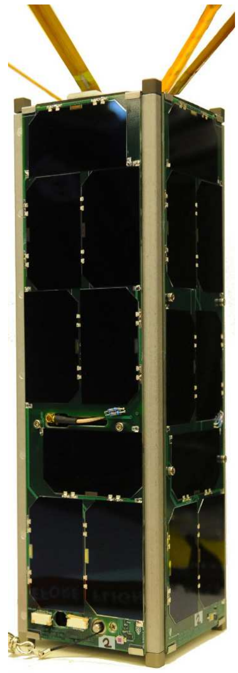

Figure 1: The Radio Aurora Explorer (RAX) triple Cubesat developed for NSF at the University of Michigan.

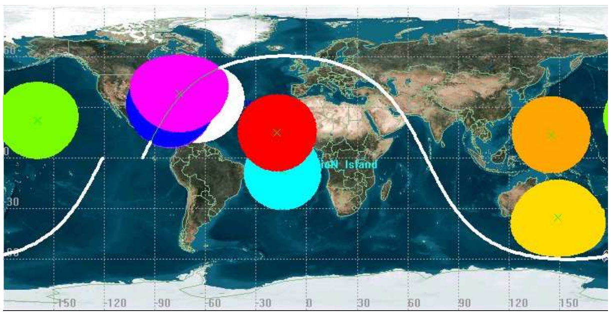

Figure 2: This orbit ground track shows several ground station locations and their ranges. At some locations, the satellite sees several ground stations, whereas, at other locations, the satellite is just barely out of range. Robust capacity-constrained scheduling is aimed at optimizing the transfer of data from space to ground.