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Author: Mr. Pol Mesalles Ripoll
SpaceNav, LLC, United States, pol@space-nav.com

Mr. Matthew Duncan
United States, matt@space-nav.com

DATA-DRIVEN EVENT AND MANEUVER FREQUENCY ESTIMATION FOR LARGE-SCALE SATELLITE CONSTELLATIONS

Abstract

With the increasing number of objects in low-Earth orbit and the unprecedented growth in large-scale satellite constellations, owner/operators have shown the need for tools to accurately estimate the expected number of conjunctions and required risk mitigation maneuvers (RMMs) in the preliminary design and planning phases for new satellites. At the same time, policymakers are starting to show an interest in protecting the space environment by creating regulations to enforce collision avoidance capabilities for all space systems.

In this context, we present a method to estimate the conjunction event frequency experienced by an arbitrary satellite constellation. Using SpaceNav's *Close Approach Service* and propagated GP elements, we can generate the geometry of thousands of simulated close approaches over the span of a year within a predefined screening volume. The latter is typically selected to be $2 \times 25 \times 25$ km in the primary-centered RIC frame to be consistent with what the 18^{th} and 19^{th} Space Defense Squadrons of the U.S. Space Force use for conjunction assessment operationally.

Once the conjunction geometry has been generated, realistic covariances can be assigned to each simulated event using a data-driven method. This relies on historical conjunction data messages (CDMs) from satellites in similar orbits and takes into account the propagation time (from last observation to time of closest approach), as well as the secondary object type and its ballistic coefficient. Next, using the state vectors with covariance for both the primary and secondary objects, along with hard-body radii based on object type, we use Foster's method to compute the probability of collision (P_c) for each encounter.

Finally, we use a Monte Carlo method to estimate an expected risk mitigation maneuver frequency. For each sample, values are drawn from the event frequency distribution to determine the number of events per each day of a predefined time interval. Then, using the methodology outlined above, simulated conjunction event geometries are paired with data-driven covariances to generate an array of collision probability values. Counting the number of events whose P_c exceeds the defined RMM threshold, the number of maneuvers over the analysis interval is estimated. By using a large number of Monte Carlo samples, we can obtain maneuver rate statistics.

We present validation results for NASA's Aqua mission of both the event and maneuver frequency by comparing our results with historical CDMs and average yearly number of RMMs performed, respectively. Additionally, we compare our maneuver frequency results to those obtained with ESA's DRAMA tools.