Paper ID: 101728
student

23rd IAA SYMPOSIUM ON SPACE DEBRIS (A6)
Space Carrying Capacity Assessment and Allocation (10-E9.4)

Author: Ms. Qian Shi
Purdue University, United States

Mr. Mahhad Nayyer
Purdue University, United States
Prof. David Arnas
Purdue University, United States

IMPACT OF TRACKING UNCERTAINTIES ON ORBITAL SLOTTING STRATEGIES AND ORBITAL CAPACITY

Abstract

As low Earth orbit becomes increasingly congested, structured slotting strategies have been proposed to maximize orbital capacity while maintaining safe separation between satellites. Prior work by Lifson and Arnas introduced a shell-based slotting approach using satellite constellation theory demonstrating the potential of these orbital structures to optimize orbital capacity. However, the effectiveness of such slotting mechanisms is inherently dependent on the accuracy of tracking data and the consistency of measurements, which influence both collision risk assessments and slot definition. This work explores how tracking uncertainty impacts the theoretical limits of orbital capacity under a slotting-based framework.

To that end, an analysis is conducted to model a range of tracking uncertainties in the in-track, cross-track, and radial directions, assessing their effects on shell thickness, inter-satellite spacing, and slot variability. Uncertainty data is derived from covariance characteristics across different tracking regimes, ranging from state-of-the-art sensor networks to legacy or low-cost systems with greater observational errors. Trade-offs between reducing separation margins and maintaining a conjunction free slotting architecture are evaluated, with key thresholds identified where tracking errors can significantly impact slotting efficiency and satellite safety.

Additionally, the inherent relations between orbit uncertainty and slotting architectures are examined, focusing on how worst-case tracking scenarios influence overall orbital capacity and safety. By analyzing the extent to which tracking limitations constrain orbital capacity, this study aims to identify conditions under which slotting strategies remain viable despite degraded tracking precision. This can be achieved, for instance, by establishing increased separation distances and compatible slot definition strategies. The implications of dynamically adapting slotting structures in response to environmental, political, and technological changes are also explored, including the assessment on the technical feasibility that this mechanisms may have under different limiting factors.

Beyond technical considerations, this work also considers the potential policy implications of these results. In particular, the feasibility of slot allocation rules based on operator tracking capabilities is considered. Such an approach could incentivize investment in high-precision tracking infrastructure to improve orbital capacity and safety, consequently promoting industry norms and practices that enhance long-term space sustainability.

By framing orbital capacity within the constraints of real-world tracking performance, this research aims to provide a technical foundation able to quantify the impact that tracking capabilities have in achieving optimal orbital capacity and space sustainability. As such, this work addresses important technical and policy gaps currently present in space traffic management, while providing technical tools to better understand the problem.