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ACCELERATING MEGA-CONSTELLATION DESIGN: EFFICIENT VISIBILITY COMPUTATION AND MULTI-SHELL OPTIMISATION

Abstract

The increasing use of mega-constellations in various fields presents a unique challenge: the design of an optimal orbital layout. The key challenge lies in maximising satellite visibility over a specific region of the Earth with a given total number of spacecraft. Traditional optimisation methods, typically applied for constellations of up to 100 satellites, prove computationally inefficient for systems comprising thousands or tens of thousands of spacecraft. This inefficiency arises from the limitations in orbit propagation and visibility computation for such large numbers. Therefore, it becomes crucial to explore efficient computation of visibility for large constellations. Furthermore, as mega-constellations typically comprise multiple layers, or shells, determining the optimal shell distribution for given visibility requirements is of significant interest.

This work aims to address these challenges. Firstly, we demonstrate how visibility can be efficiently computed for large constellations, including special cases of Walker constellations. Secondly, we apply this efficient visibility computation to a test case, providing insights into shell distribution in a constellation optimised for uniform visibility.

To achieve this, we developed a Python tool for efficient visibility computation, leveraging vectorisation and GPUs for massive parallelisation. This tool facilitated a 200-1000x speed-up (depending on hardware used) in visibility computation, unlocking the potential for parametric analysis of large Walker constellations requiring visibility computations for thousands of layouts. Further observations led to a decrease in computational time, resulting in a 400-120,000x speed-up. We also discovered a linear relationship between mean visibility and the number of satellites, enabling efficient scaling from smaller to larger constellations.

Capitalising on this improved computational efficiency, we delved into the design of multi-shell constellations. A case study aimed at achieving uniform visibility over Europe with a minimal number of satellites provided insights into shell distribution in two- and three-shell constellations consisting of 7,000-10,000 satellites. For constellations with an even higher number of shells, we developed an innovative method. This approach begins with the computation of visibility of high-inclination shells and progressively reduces the inclination of subsequent shells. This approach decreases computation time significantly while maintaining optimal visibility distribution. The reduction in computation time for three-shell layouts exceeds 150x and becomes even more substantial for a higher number of shells.

By addressing the computational bottleneck of visibility analysis, this work contributes to acceleration of design and optimisation of multi-shell mega-constellations.