Rapid Coverage Modeling for Space-Based Space Surveillance Constellations

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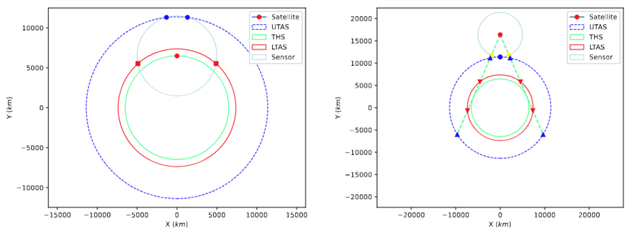
Abstract

- Space-based space surveillance has the potential to enhance the tracking and characterization of space objects by extending coverage and improving observability relative to ground-based systems.
- For optical SBSS systems, the design problem can be posed as maximizing the above-the-horizon coverage of the satellites over a dual-altitude band target region.
- We propose a multi-resolution approach to satellite coverage analysis in three dimensions. The method allows for the specification of geometric constraints in a highly general fashion using constructive solid geometry.
- The coverage is represented efficiently using a linear octree. Multiplicities of coverage for an arbitrary number of satellites are computed by projecting the individual octrees onto the Morton space-filling curve, thereby enabling an efficient partition of the space by multiplicity via a simple interval nesting problem.

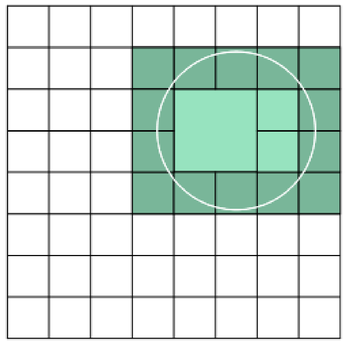
Background - Above the Horizon Coverage

- Most previous studies of above-the-horizon satellite coverage of a dual-altitude band have used simplified analytical models, which assume 2D geometry, omnidirectional sensor profiles, and circular orbits.
- These models are not sufficiently detailed to give a realistic account of constellation performance. A more flexible numerical method is needed.



Methodology - Octree Coverage Model

- Satellite coverage is represented using linear octrees. Octree cells are encoded as bitstrings embedded in a primitive data type.
- Use a constructive solid geometry (CSG) model to represent complex shapes through union, intersection, and complement operations on shape primitives. Runtime is proportional to the surface area of the CSG object.
- Runtime for octree construction is quadratic with respect to grid resolution.
- After octrees for individual satellites are constructed, they can be combined using the multiplicity partition operation. Runtime for the multiplicity partition is log-linear in the total number of satellites.



$F = [0b11100, 0b1110100, 0b1110110]$

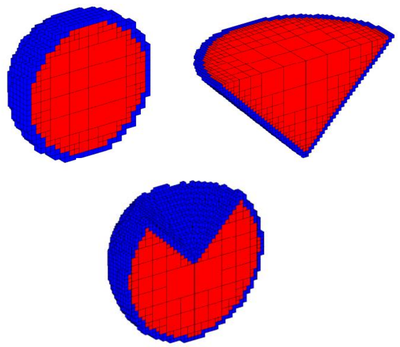
$P = [0b1001111, 0b1011010, 0b1011011, 0b1011110, 0b1011111, 0b1100101, 0b1100111, 0b1101101, 0b1110101, 0b1110111, 0b1111000, 0b1111001, 0b1111100, 0b1111101]$

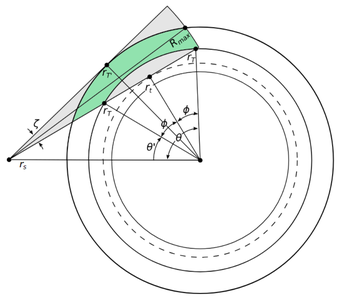
$I = [[0, 16]]$

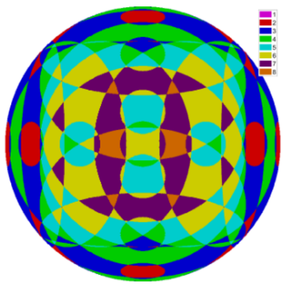
$I = [[0, 3], [4, 7], [15, 15]]$

$I = [[5, 5], [6, 6]]$

$M_1 = [[8, 14]]$
$M_2 = [[0, 4], [7, 7]]$
$M_3 = [[5, 6], [15, 15]]$

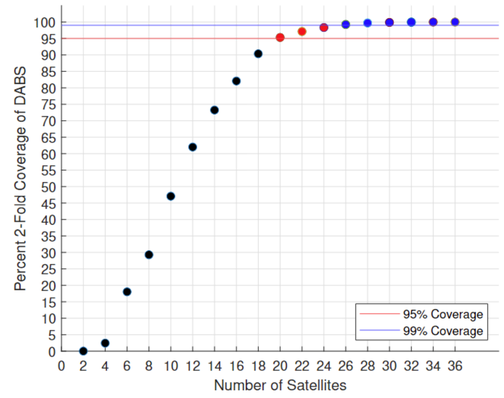






Results - SBSS Constellation Analysis

- In our study of an SBSS constellation designed using a previous analytical method, we show that satellite count can be reduced from 36 to 26 with only a one percent reduction in the two-fold coverage.
- Direct computation of the coverage volume reveals tradeoff between cost and coverage objectives. This analysis is not possible with previous analytical methods.



Future Work

- The octree coverage model can be used to rapidly assess the performance of a given constellation configuration. In future work, we will use the computed coverage metrics to consider the constellation design and optimization problem for an SBSS constellation.
- Coverage volume can be weighted by debris density to give a better performance measure.

Acknowledgements

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