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MODELING AND CONTROL OF INTER-SATELLITE GEOCENTRIC ANGLE BOUNDARY FOR MEGA CONSTELLATION REGIONAL COVERAGE

Abstract

Mega constellation is a giant distributed space system composed of thousands of low-Earth orbit satellites locating at different altitudes, different orbital planes and different phases. SpaceX has deployed nearly 4000 Starlink satellites to provide telecommunication and remote sensing services. China plans to construct Guowang (GW) constellation totaling 12992 satellites. The dramatic number of satellites increases the difficulty of mega constellation control in view of TT&C requirements, computational efficiency, etc. Constellations are generally controlled to keep the designed global configuration in current research, and the configuration is optimized under coverage and collision avoidance constraints. Such control method based on global configuration will lead to heavy monitoring and calculation pressure, and frequent maneuver caused by complicated perturbations. Researchers deduced the control strategy of OneWeb and Starlink according to their TLE data, and results show that OneWeb satellite is controlled once every 16.6 days on average and Starlink control is more frequent.

To reduce the control frequency for mega constellations, this paper transforms the global configuration constraint to inter-satellite geocentric angle constraint under coverage requirements. Constellation satellites do not follow the exact configuration, but fly loosely within the feasible region that satisfies the geocentric angle constraint. The regional coverage is emphasized and discussed in this paper. According to the coverage analysis based on 2D-map, the geocentric angle boundary constraint between two adjacent coplanar satellites is determined. Based on that, the regional coverage can be realized by cooperation between satellites locating at different orbital altitudes.

The boundary model of geocentric angle of large-scale relative motion with different semi-major axis is established. To simplify the derivation of the boundary model, the exact relative motion model along three axes in the Cartesian relative coordinate system is not concerned. The geocentric angle in terms of orbital elements is directly derived according to cosine theorem. The nonlinear parameters of time, e.g. the true anomaly f, are transformed to eccentricity expansions, where mean anomaly M is the only time-varying variable. Based on the first-order time-explicit analytical solution of the geocentric angle, the boundary with different semi-major axes is studied by the extreme value principle. Since the boundary relates with the difference of mean anomaly, it is feasible to maintain regional coverage by adjusting satellites' semi-major axes only. The semi-major axis cooperation rule between adjacent satellites is proposed, by which the mega constellation can realize regional coverage with little control consumption and low control frequency.