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END-OF-LIFE FOR SATELLITE SWARMS

Abstract

Satellite swarms offer a high-capability mission architecture with a variety of potential applications in space exploration and discovery. Swarm-based architectures —which comprise multiple agents operating collectively as a distributed system— have been proposed for Earth observation, astronomy, planetary exploration, and heliophysics. Some of the key technology demonstration missions have already successfully flown in the past decades. The increasing interest in satellite swarms suggest that this innovative architecture will be adopted in a variety of future missions in the coming years— raising the question of how to dispose of satellite swarms at the end of their operational lifetimes. Mega constellations or swarms comprising of numerous small satellites are difficult to track by Earth-based networks. They also increase the risk of collisions, particularly during end-of-life when these small satellites cannot be manoeuvred to avoid collisions with functional satellite systems.

Previous distributed small satellite missions such as KickSat-2 and SpaceBEES 1-4 were designed to passively deorbit and burn up during atmospheric re-entry at the end of their lifetimes. However, disposing of satellite swarms outside low LEO (Low-Earth Orbit) has no trivial solution which both meets space situational awareness requirements and aligns with the philosophy of space sustainability. The distributed functionality which makes swarm missions so flexible and adaptable also means that many individual swarm agents have to be disposed of at end-of-life, rendering traditional approaches such as migration to the GEO (Geosynchronous Earth Orbit) graveyard orbit problematic. The challenges of disposing satellite swarms are as varied as the environments they could operate in — swarms used for planetary exploration will have to respect planetary protection policies while swarms engaged in Earth observation missions will have to be safely deorbited amidst an increasingly crowded LEO environment.

In this paper we explore how the autonomy and distributed nature of swarms both complicates end-of-life disposal and simultaneously enables novel solutions to post-mission disposal. We then survey existing end-of-life scenarios for satellite swarms and investigate novel approaches to swarm disposal that comply with both legal requirements and the philosophy of space sustainability. The proposed solutions are investigated for specific target applications, such as satellite internet constellations, space-based interferometry, and satellite-swarms for Earth observation.