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Author: Mr. Partha Chowdhury
IIIT Delhi, India

Mr. Chinni Prabhunath George
ISTRAC/ISRO, India
Dr. Sanat K Biswas
IIIT Delhi, India

AN UNSUPERVISED LEARNING BASED APPROACH FOR GROUND STATION SELECTION FOR SPACE SITUATIONAL AWARENESS

Abstract

Ground stations are essential for tracking and managing space objects, contributing significantly to space situational awareness (SSA) through accurate orbit determination and collision avoidance. Their strategic placement and selection directly affects the space objects' position estimation accuracy, communication reliability, and operational efficiency. Although previous studies have focused on optimizing ground station networks for cost, coverage, and communication speed, few of them addressed the critical aspect of position estimation accuracy for SSA applications. Minimizing Mean Squared Error (MSE) in space objects' position estimation with optimally chosen ground stations enhances orbit determination accuracy, reduces tracking uncertainty, and improves collision risk assessment, ensuring more reliable and precise space traffic management. This work presents an optimization framework for selecting ground stations within a defined geographic area to reduce the MSE in space object position estimation. MSE in satellite position estimation depends on Position Dilution of Precision (PDOP), which measures how the spatial distribution of ground stations affects space objects' positioning accuracy. Our primary goal is to reduce PDOP, as lower PDOP correlates with improved accuracy. This approach uniquely incorporates PDOP as a crucial optimization factor to ensure that the chosen ground stations provide the most precise satellite position estimates. Several studies have explored the optimal ground station and satellite selection problems for the Global Navigation Satellite System using brute-force search, genetic algorithms (GA), and heuristic methods. Ground station placement has been optimized by considering factors like signal availability, visible satellites, ionospheric effects, and rainfall attenuation, with grid control probability and GA-based methods to minimize Geometric Dilution of Precision (GDOP). Though brute-force search ensures optimal GDOP minimization for satellite selection, it is computationally expensive. Evolutionary algorithms like GA and Particle Swarm Optimization (PSO) have been explored to reduce complexity, while the highest elevation method does not always guarantee low GDOP or high accuracy. We integrate an unsupervised learning based algorithm, which clusters ground stations in the suitable angle domain of the respective orbital frame, using K-means clustering to select ground stations without requiring training data. A meta-cognitive component has also been implemented to enhance efficiency by determining when to learn and when to use previously learned clusters, significantly reducing computation time. Our methodology enhances the accuracy of determining and tracking the orbits of space objects, contributing to improved collision avoidance, debris tracking, maneuver planning, and satellite conjunction assessment which are vital for space situational awareness.