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A FAULT DETECTION STRATEGY FOR SATELLITE CLUSTERS BASED ON ROBUST PRINCIPAL COMPONENT ANALYSIS

Abstract

In the near future, appreciable amounts of space missions tend to be supported by dozens of interoperable satellites. These spacecraft can form clusters with complex communication and navigation networks. However, present networking in space is point-to-point and scheduled on the ground stations. To ensure its operability, failure detectors with constant heartbeat intervals are sufficient. Nevertheless, in the case of satellite clusters, this detection mechanism is no longer practicable due to dynamic interplanetary conditions and coordination requirements. Therefore, new strategy has become critical in the application of the future satellite network.

Detecting faulted participants in an ensemble of satellites can be modeled as a fault-tolerance problem in a large-scale distributed system. Its network condition is unlike to the traditional Internet environment. The high probability of message delays, losses and the rapid changing of cluster topology need to be addressed.

In this paper, we propose a new Fault Detection method mainly based on robust Principal Component Analysis (robust PCA), to achieve reliable monitoring results under the above difficulties. Firstly, Satellites are assumed to broadcast their heartbeats to other nodes in the clusters. In addition, accrual fault detectors with flexible timeout and thresholds are introduced rather than traditional constant margins. The heartbeat arrival time is theoretically analyzed. Finally, for a certain spacecraft, it collects groups of accrual values to generate a low-rank, incomplete matrix. The robust PCA completes the matrix and collectively filters the mixed data to estimate satellites' states. A recommendation list is obtained to determine the scope of clusters dedicated to a certain mission.

Theoretical analysis of the strategy indicates the potential for increasing the detection accuracy. A Python-based simulation experiment also reveals the method's validity. In the simulation, the message delays and losses are defined as the Poisson process, and the Bernoulli process, respectively. They are randomly generated by the PyMC3 Module. Moreover, the Multi-thread Module is employed to simulate distinct satellites and their message passing. Results prove the effectiveness of the proposed strategy. To draw a conclusion, the combination of multidirectional communications and machine learning techniques appears to form a novel prospect in which the collaboration awareness for satellites improves robustness.