

information such as CPU availability, etc., is required, the PCS Task Wrapper provides this information to the underlying PGE.

After this information is collected, the PGE is executed, and its output Product file and Metadata generation is managed via the PCS Task Wrapper framework. The innovation is responsible for marshalling output Products and Metadata back to a PCS File Management component for use in downstream data processing and pedigree. In support of

this, the PCS Task Wrapper leverages the PCS Crawler Framework to ingest (during pipeline processing) the output Product files and Metadata produced by the PGE.

The architectural components of the PCS Task Wrapper framework include PGE Task Instance, PGE Config File Builder, Config File Property Adder, Science PGE Config File Writer, and PCS Met file Writer. This innovative framework is really the unifying bridge between the execution of a step in the over-

all processing pipeline, and the available PCS component services as well as the information that they collectively manage.

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*This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47160.*

## Time Synchronization and Distribution Mechanisms for Space Networks

*NASA's Jet Propulsion Laboratory, Pasadena, California*

This work discusses research on the problems of synchronizing and distributing time information between spacecraft based on the Network Time Protocol (NTP), where NTP is a standard time synchronization protocol widely used in the terrestrial network. The Proximity-1 Space Link Interleaved Time Synchronization (PITS) Protocol was designed and developed for synchronizing spacecraft that are in "proximity" where "proximity" is less than 100,000 km distant. A particular application is synchronization between a Mars orbiter and rover. Lunar scenarios as well as outer-planet deep space mother-ship-probe missions may also apply.

Spacecraft with more accurate time information functions as a time-server,

and the other spacecraft functions as a time-client. PITS can be easily integrated and adaptable to the CCSDS Proximity-1 Space Link Protocol with minor modifications. In particular, PITS can take advantage of the time-stamping strategy that underlying link layer functionality provides for accurate time offset calculation. The PITS algorithm achieves time synchronization with eight consecutive space network time packet exchanges between two spacecraft. PITS can detect and avoid possible errors from receiving duplicate and out-of-order packets by comparing with the current state variables and timestamps. Further, PITS is able to detect error events and autonomously recover from unexpected events that can possibly occur during the time synchro-

nization and distribution process. This capability achieves an additional level of protocol protection on top of CRC or Error Correction Codes. PITS is a lightweight and efficient protocol, eliminating the needs for explicit frame sequence number and long buffer storage.

The PITS protocol is capable of providing time synchronization and distribution services for a more general domain where multiple entities need to achieve time synchronization using a single point-to-point link.

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## Local Estimators for Spacecraft Formation Flying

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A formation estimation architecture for formation flying builds upon the local information exchange among multiple local estimators. Spacecraft formation flying involves the coordination of states among multiple spacecraft through relative sensing, inter-spacecraft communication, and control. Most existing formation flying estimation algorithms can only be supported via highly centralized, all-to-all, static relative sensing. New algorithms are needed that are scala-

ble, modular, and robust to variations in the topology and link characteristics of the formation exchange network. These distributed algorithms should rely on a local information-exchange network, relaxing the assumptions on existing algorithms.

In this research, it was shown that only local observability is required to design a formation estimator and control law. The approach relies on breaking up the overall information-exchange network into sequence of

local subnetworks, and invoking an agreement-type filter to reach consensus among local estimators within each local network. State estimates were obtained by a set of local measurements that were passed through a set of communicating Kalman filters to reach an overall state estimation for the formation.

An optimization approach was also presented by means of which diffused estimates over the network can be incorporated in the local estimates obtained