National Aeronautics and Space Administration

Networked Constellation Communications Technologies

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Program: Strategic Initiative

Project Objective:

This task is focused on the design and demonstration of communications and networking technologies enabling mission concepts utilizing a constellation of spacecraft.

This task demonstrates Disruption/Delay Tolerant Networking (DTN) over a commercial WiFi-based communications systems to achieve range extension at the edge of a multi-robot network by automatically discovering assets and establishing relay communications without a priori knowledge of network topology.

Demonstration of this DTN mesh network prototype will be carried out in collaboration with the MOSAIC project (6x R&TD SI) to emulate an in-situ distributed computing scenario with a challenged environment characterized by unplanned communications outages and near real-time topology changes due to autonomous mobility.

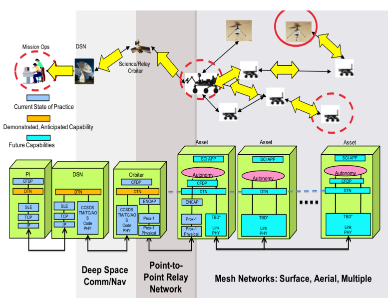

Figure 1. Architecture of end-to-end communications for DTN-based multi-spacecraft mission

Benefits to NASA and JPL:

The technology developed for this demonstration will enable future multi-spacecraft robotic missions such as planetary terrain survey and cave precursors for human exploration involving rovers and aerial vehicles of different capabilities as shown in Figure 1. It advances JPL's leadership role in Delay Tolerant Networking (DTN) technology by demonstrating a true multi-hop disruption-delay tolerant network designed to support robotic operations. Our demonstration is the first such demonstration using the ION implementation of DTN, integrated with distributed computing robotic systems.

The energy-aware routing and data mule capabilities demonstrated in our task addresses the unique challenges of adapting operations and communications to energy availability, distributed tasking, and drive planning. These new capabilities also have potential applicability for sub-terranean explorations.

Prototype of DTN Mesh Network for Distributed Computing (MOSAIC)

In FY2019, a functional prototype of DTN Mesh Network was built and integrated with advanced scheduling/cloud-computing technologies. Figure 2 shows the basic architecture of the prototype system. The Interplanetary Overlay Network (ION), a JPL implementation of DTN, is interfaced with commercial Wi-Fi system operating in a reconfigured 'mesh point' mode. The mesh network is capable of handling transmission/reception of data, the automated discovery of neighboring nodes, and estimating the capacity (data rate) of established links. Information collected by the mesh network was utilized to generate a 'contact graph', a database of network connectivity and expected capacity for each link (contact) essential for routing decisions, to the DTN protocol.

A *consensus* process is carried out by software to ensure that locally discovered changes in network topology is shared with other nodes at a controlled cadence to synchronize network views among the nodes and to prevent formation of routing loops. Figure 3 is a notional representation of this process, in which each node will locally identify 'new' information learned from neighbors or the underlying mesh communications system and distribute the updates to the rest of the network.

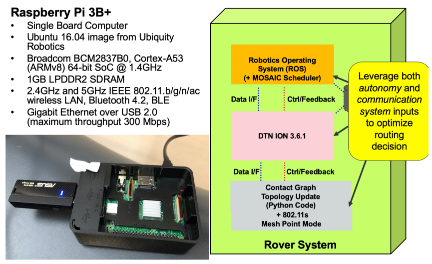

Figure 2. Prototype Configuration

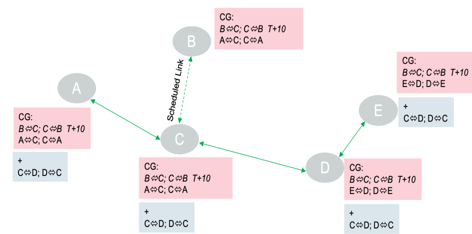

Figure 3. Contact Graph Consensus

In April 2019, we demonstrated the integrated communications system supporting distributed computing applications. Figure 4 is shows one of the 10-node network scenario demonstrated. The blue areas are exploration zones and the red bar represent an obstruction in terms of mobility and communications. Data collected in the exploration zone are relayed back to the base station [node at far left] through various relay paths. By manually changing the energy reserve in each node, we demonstrated that the system can autonomously reconfigure itself to construct a different relay path, thus re-distributing the energy burden to prevent shutdown – this action prolongs the operating life for specific assets and allocates energy to high priority tasking before an assets reaches end of operating life. A follow-on demonstration has been planned for the end of FY2019 to demonstrate deeper integration with mobility planning through a data mule scenario. The DTN mesh network platform developed by this task will be used by the MOSAIC project in FY2020 as a foundational communications/networking technology for further research.

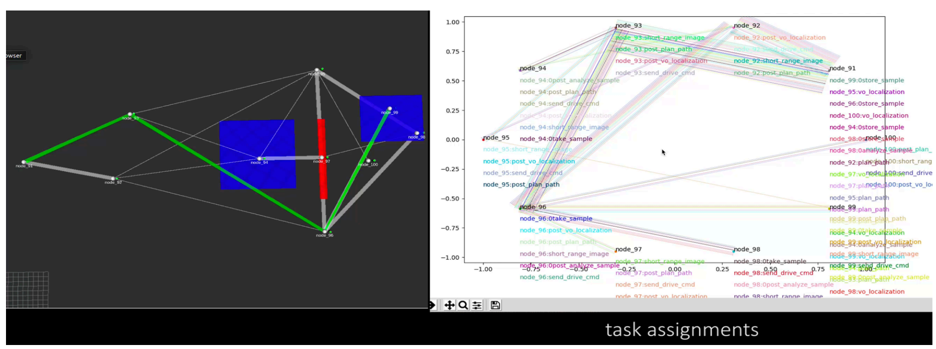

Figure 4. Visualizations of DTN mesh network demo with MOSAIC

Publications:

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- A. A. Fraeman, J. C. Castillo, E. J. Wyatt, S. A. Chien, S. J. Herzig, J. L. Gao, M. Troesch, T. Stegun Vaquero, W. B. Walsh, K. V. Belov, K. L. Mitchell, J. Lazio, "Assessing Martian Cave Exploration for the Next Decadal Survey," Mars Exploration Program Analysis Group (MEPAG), Spring 2018, April 2018, Washington, DC.
- T. Vaquero, M. Troesch, M. Sanchez Net, J. Gao, S Chien, "Energy-Aware Data Routing for Disruption Tolerant Networks in Planetary Cave Exploration", ICAPS , July 2019.
- E. Jay Wyatt, Julie Castillo-Rogez , Steve Chien, Abigail Fraeman, Jay Gao, Sebastian Herzig, T. Joseph W. Lazio, Tiago S. Vaquero, "AUTONOMOUS NETWORKING FOR ROBOTIC DEEP SPACE EXPLORATION", International Symposium on AI and Robotics in Space (i-SAIRAS), Madrid, Spain, June 6, 2018.

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