Cooperative Clustering Techniques For Space Network Scalability

Cognitive Communications for Aerospace Applications
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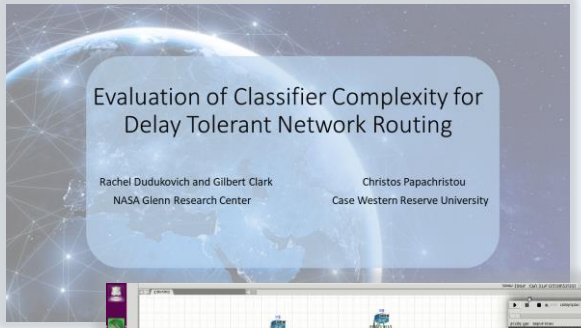
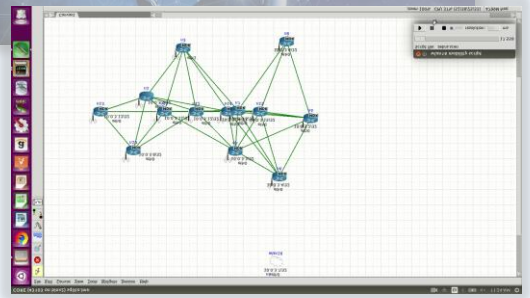
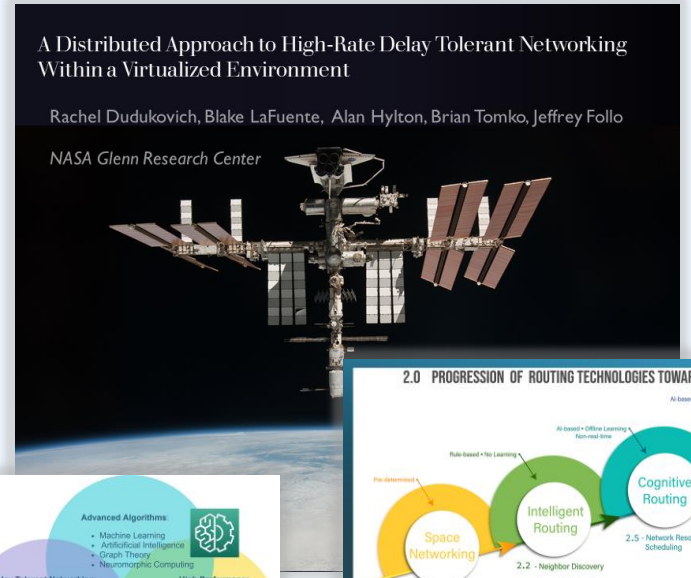
Cognitive Networking Progression Over Time

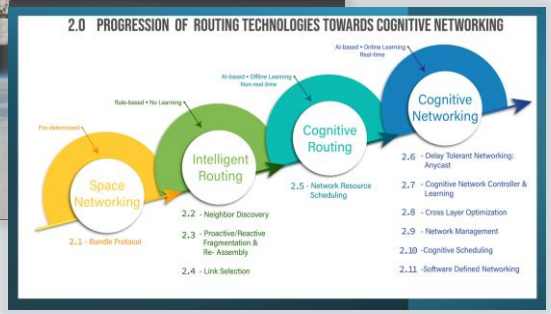


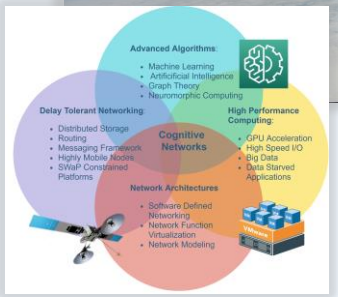


CCAAW 2019:

- Develop basic emulations and concepts for routing and messaging
- Software implementations lack maturity
- Missing a robust framework for cognitive networking and space networks

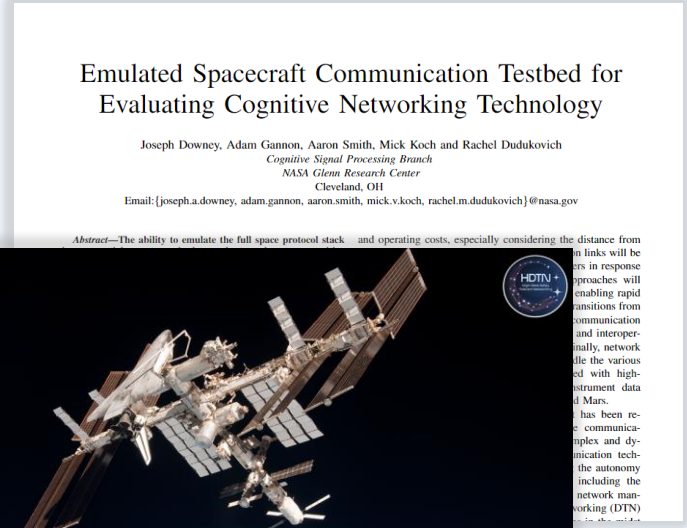


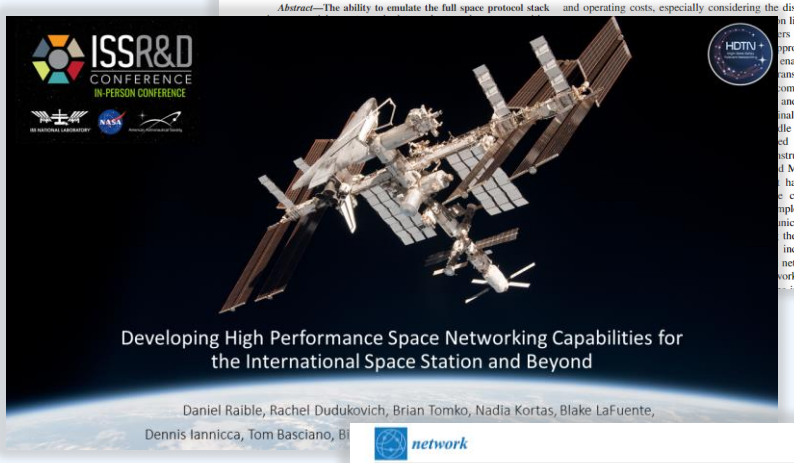


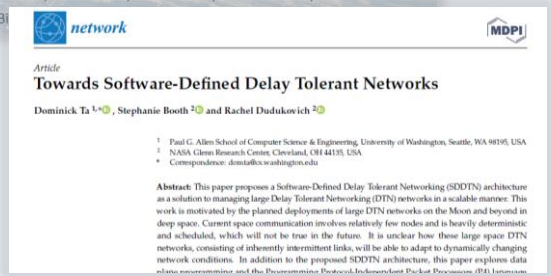


CCAAW 2021:

- Basic DTN functionality in HDTN is operational
- Developing cognitive technology roadmap







CCAAW 2023:

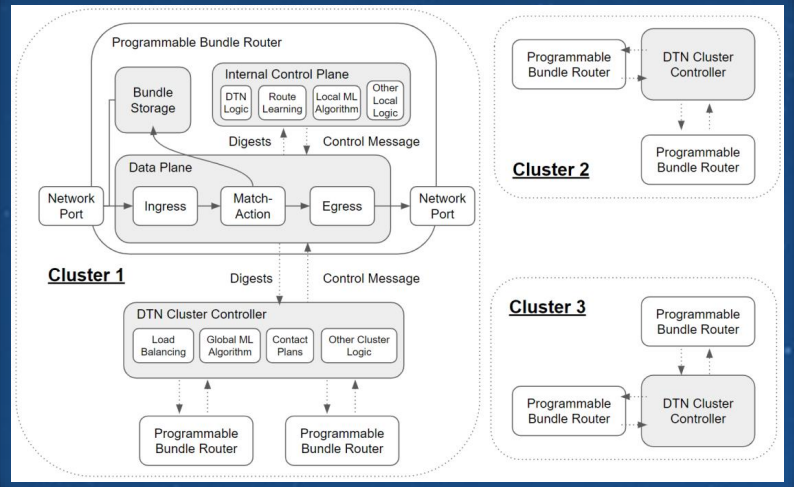
- HDTN is fully functional, tested on RF testbed and JSC Software Development and Integration lab
- Developing lunar emulations
- Integration with SDN approaches
- Supports multiple algorithms and on-demand contacts
- Developing future concepts for discovery, network management, multicast and much more

Goal:
Develop building blocks to enable cognitive networks

- What are the gaps in our current DTN approach?
- Contact plan concept is not scalable
- Requires preplanned schedule
- Requires nodes to have significant knowledge of the network
- Creates a problem of contact plan updates and distribution

- *Need to improve network management and inter-node messaging*

Possible Approaches



Software Defined DTN

DTN Research Group
Internet-Draft
Intended status: Experimental
Expires: May 7, 2016

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November 04, 2015

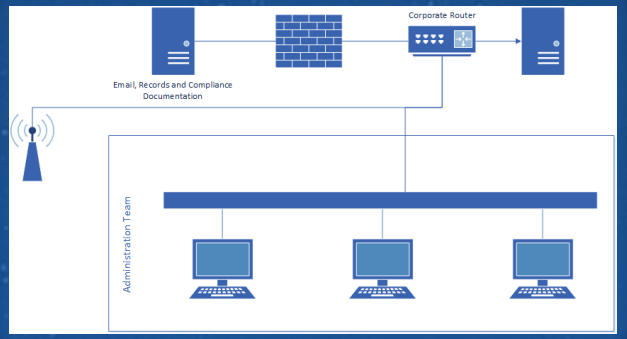
DTN IP Neighbor Discovery (IPND)
draft-irtf-dtnrg-ipnd-03

Abstract

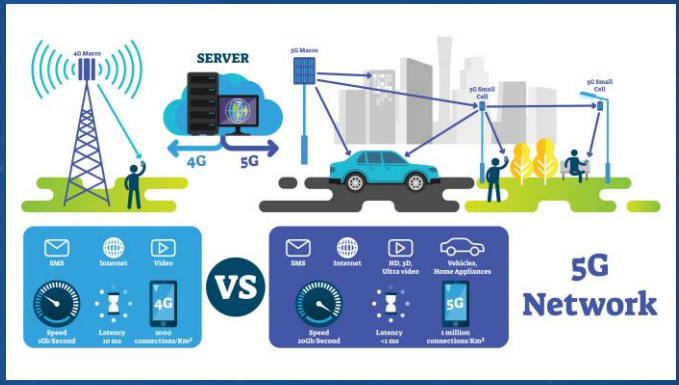
Disruption Tolerant Networking (DTN) IP Neighbor Discovery (IPND), is a method for otherwise oblivious nodes to learn of the existence, availability, and addresses of other DTN participants. IPND both sends and listens for small IP UDP announcement "beacons." Beacon messages are addressed to an IP unicast, multicast, or broadcast destination to discover specified or unspecified remote neighbors, or unspecified local neighbors in the topology, e.g. within wireless range. IPND beacons advertise neighbor availability by including the DTN node's canonical endpoint identifier. IPND beacons optionally include service availability and parameters. In this way, neighbor discovery and service discovery may be coupled or decoupled as required. Once discovered, new neighbor pairs use advertised availabilities to connect, exchange routing information, etc. This document describes DTN IPND.

Status of This Memo

Discovery Protocols



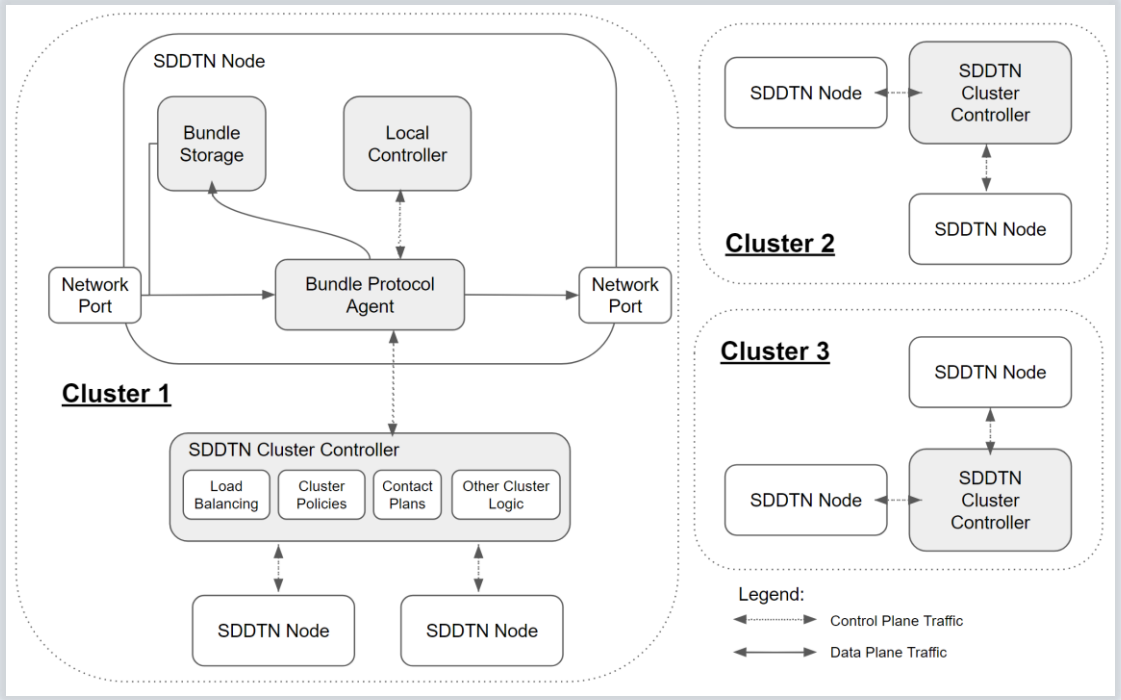
Network Management

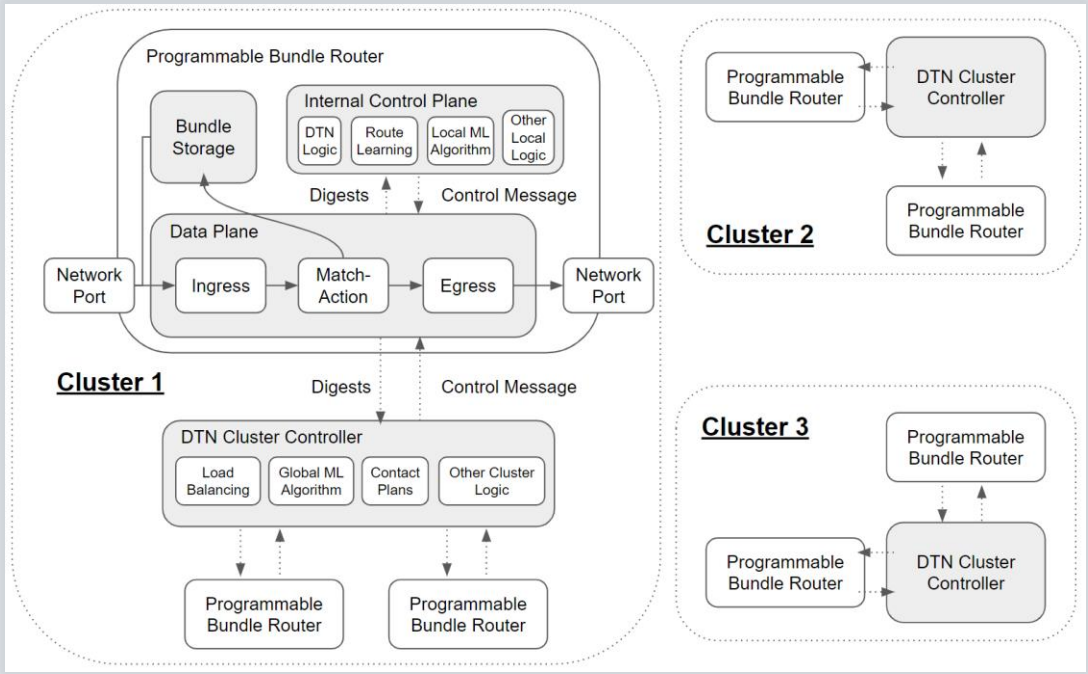


Modern Terrestrial Networks

Concept: Clustering Methods for DTN and SD-DTN

- We investigated:
  - Game theory
  - Graph theory
  - Contact graph routing improvements
  - Software defined networking
  - Discovery protocols

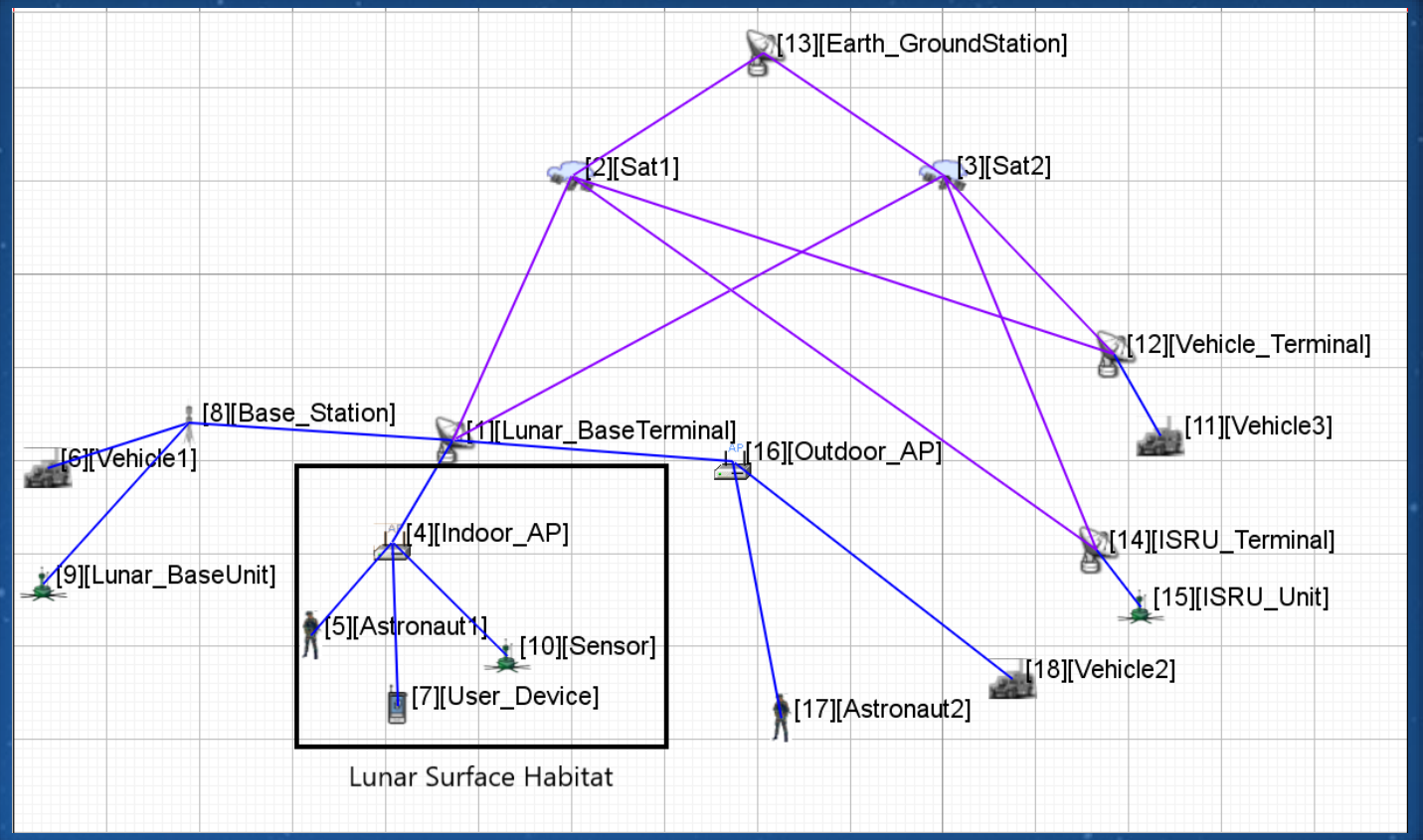




- Clustering can intelligently partition large networks
- Our method can help solve SDN controller placement problem

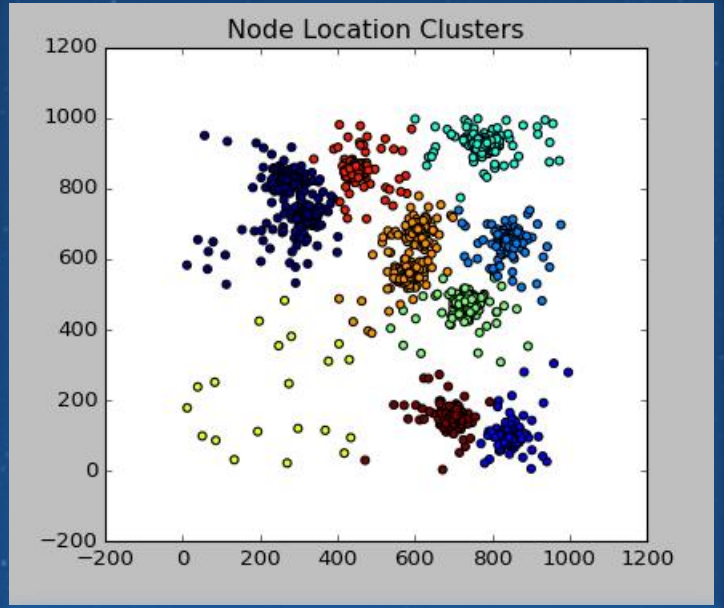
Related Works:
Region-based and Hierarchical Networks

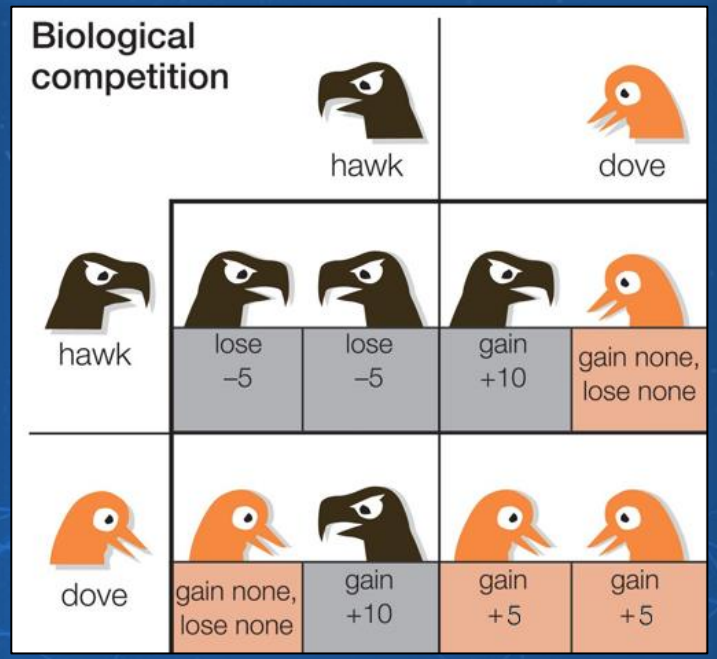
- *Managing Routing Scalability in Space DTNs,* P. Madoery et al.
  - Develops Inter Region Routing concept
  - Reduces need for global knowledge of the network
  - Reduces route computation time
  - Lends itself to how a space network really is/will be
- *Dynamic Local Clustering for Hierarchical Ad Hoc Networks,* P. Nikander et al.
- *Application of Machine Learning Techniques to Delay Tolerant Network Routing,* R. Dudukovich
  - Proposes K-means clustering approach to DTN routing
  - Divides network into deterministic and opportunistic/ad-hoc regions



Why Game Theory?

- We still need to solve the global knowledge problem
- Nodes modeled as agents can broadcast information intelligently
- Study conflict and cooperation between intelligent rational decision makers
- Non-cooperative games: Hawk and Dove
- Individual Strategies -> Global equilibrium
- Cooperative games: coalition formation
- Solution: Shapley Value
  - Measures the relative importance of each player (nodes in the network)



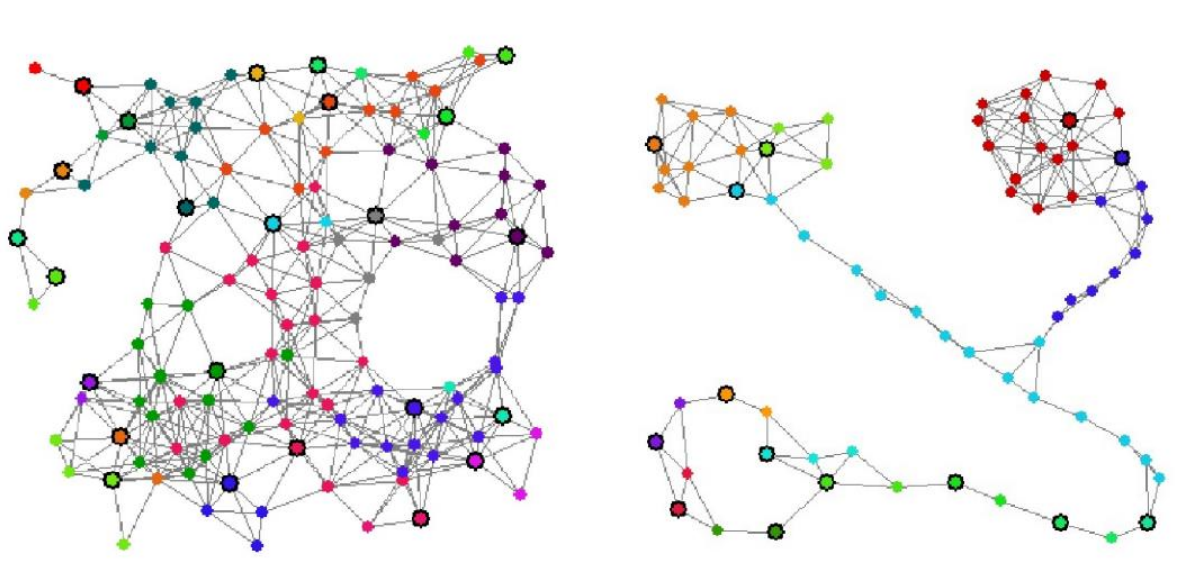


Using Graph Theory for Clustering

- Local Dynamic Clustering
- Optimize cluster fitness:

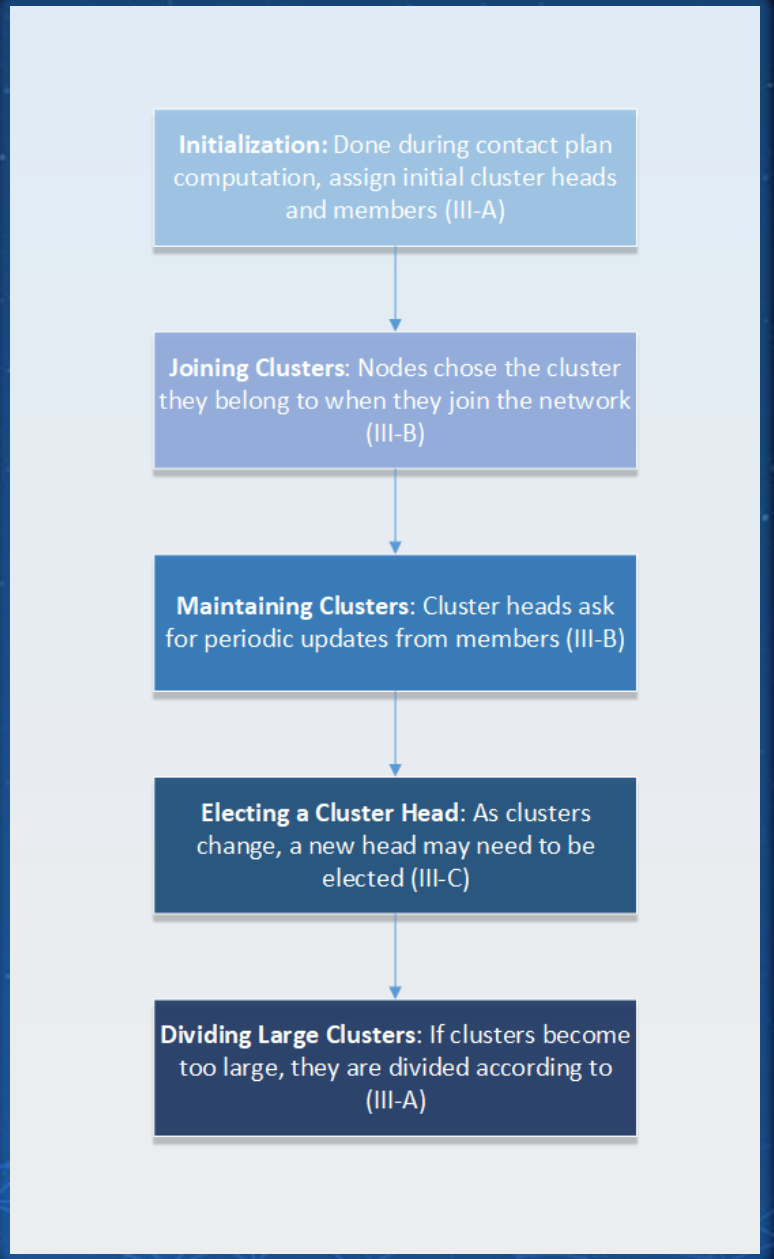
$$f(C) = \frac{2\deg_{\text{int}}(C)^2}{|C|\,(|C|-1)(\deg_{\text{int}}(C)+\deg_{\text{ext}}(C))}$$

- Uses only 3 parameters regarding the cluster, easy to maintain



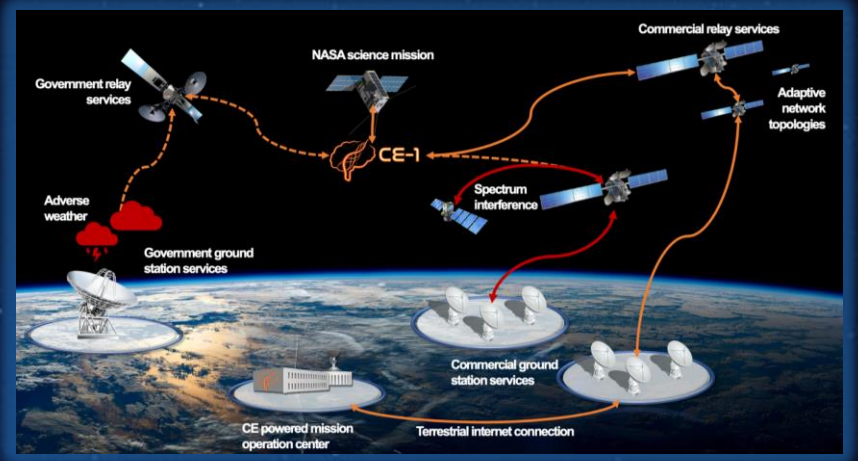
Approach

- Cooperative Game Based Clustering (III-A)
  - Divide the network by computing each node's Shapley Value
  - Iterate and choose node with the highest value each time to be cluster head
  - Assign nodes close to it as members
- Dynamic Local Clustering (III-B)
  - When a node joins the network, it queries its neighbors
  - Neighbors respond with the cluster it belongs to
  - New node will compute which cluster will create the highest increase in fitness
  - Cluster head is the first node that joined the cluster
- Non-Cooperative Game Based Cluster Head Selection (III-C)
  - Centered on the selection of cluster heads
  - Each node joins the cluster with the closest head
  - Nodes attempt to optimize their individual residual energy
  - Can volunteer to be a cluster head or stay out of the game

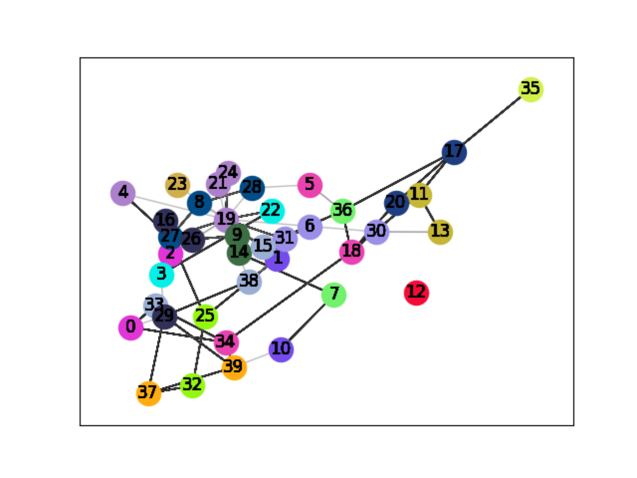


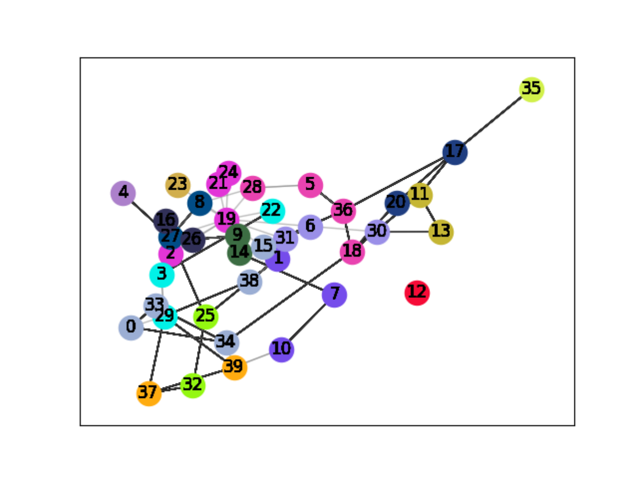
Proposed Protocol:
Delay Tolerant Clustering Protocol

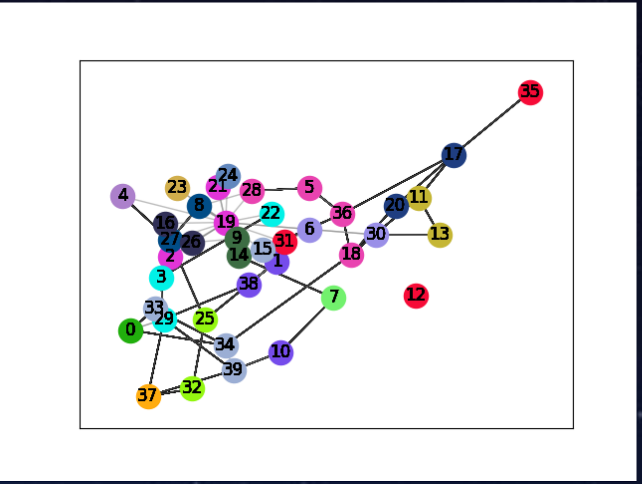
- In total, there are five types of DTCP packets:
  - CLUSTER INFO: Sent periodically by a cluster head, or by a cluster member when prompted. Contains the cluster ID, cluster head, cluster size, cluster internal degree and external degree.
  - CLUSTER QUERY: Sent by a node not associated to a cluster. Doesn't contain any information, prompts any node that receives it to send an info packet.
  - CLUSTER JOIN: Sent by a node to announce joining a cluster. Contains the ID of the node and the cluster it joined.
  - CLUSTER LEAVE: Sent by a node/cluster head to announce leaving a cluster. Contains the ID of the leaving node and the cluster it left.
  - CLUSTER UPDATE: Sent by a cluster member periodically, containing its ID, the cluster it belongs to and its contribution to the internal and external degree.

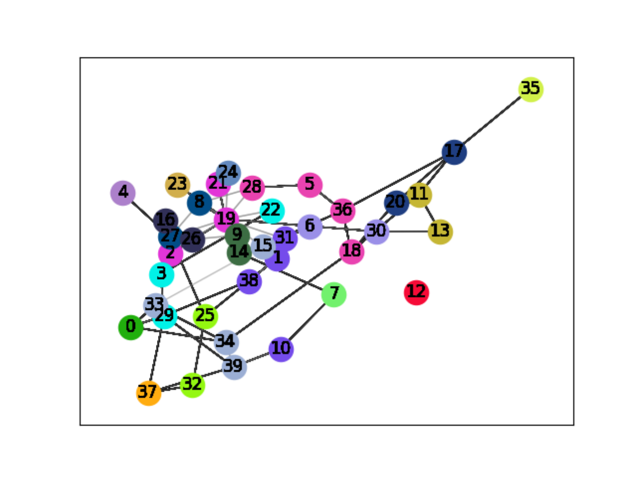


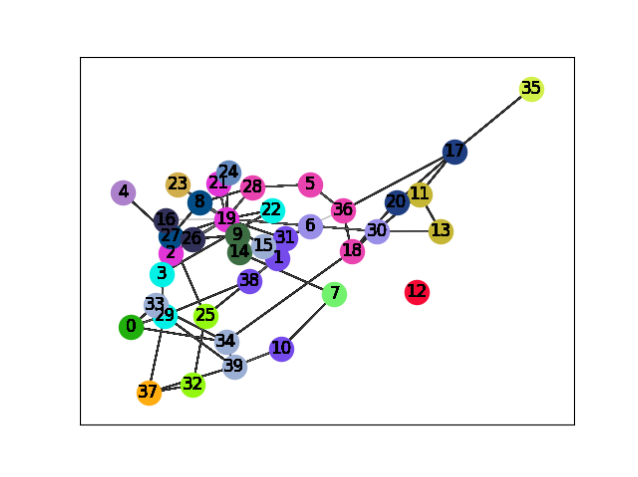
Simulation Results

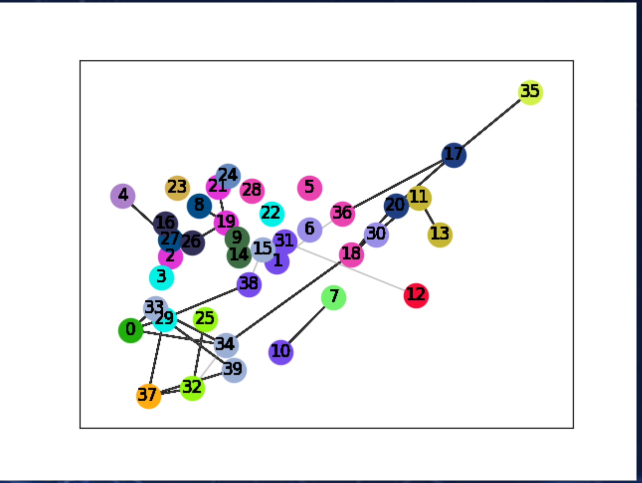






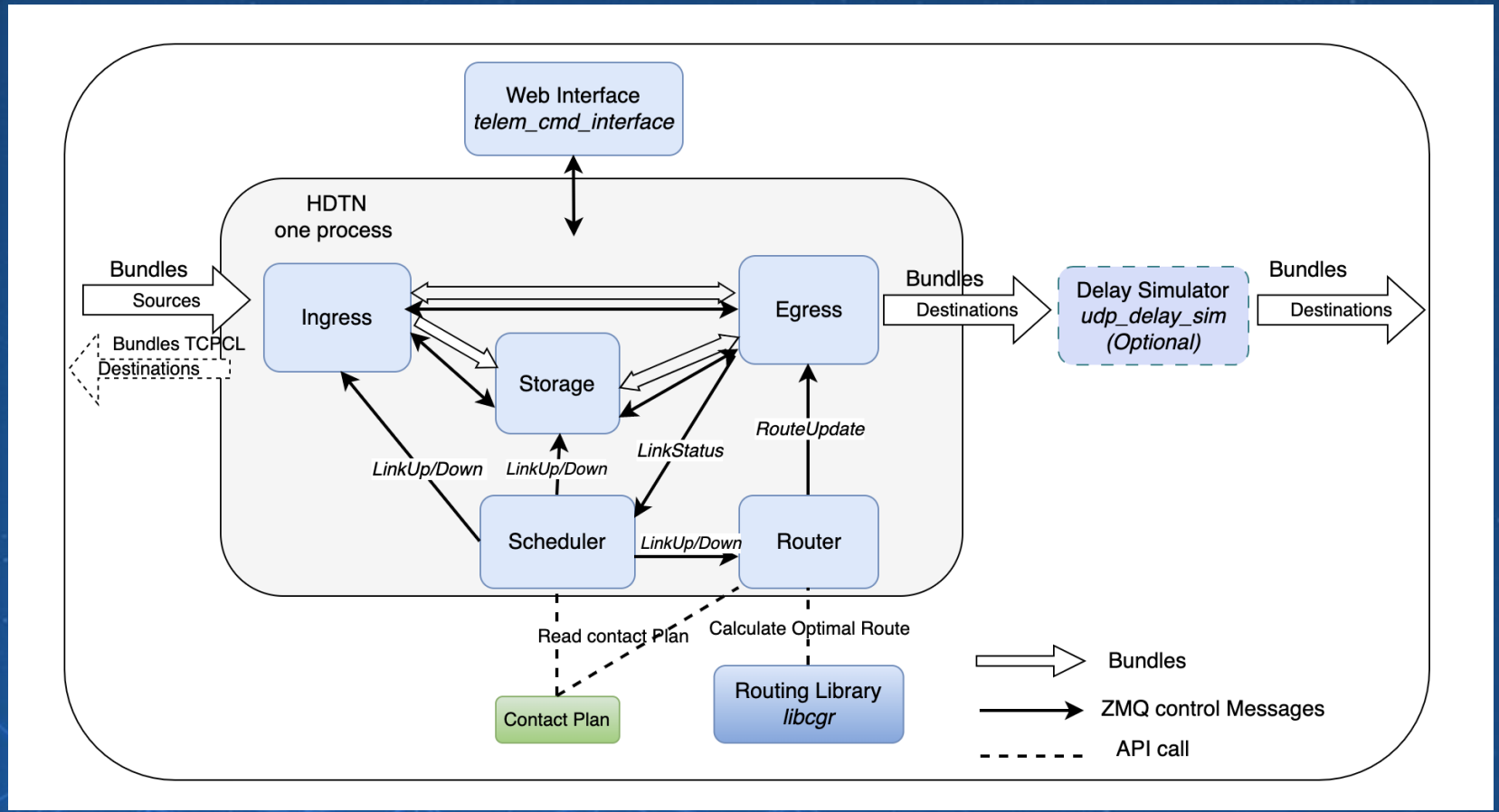






Implementation Considerations

- Existing HDTN implementation lacks inter-node messaging
- Interplanetary Multicast (IMC) is planned
- Discovery capability will be built on top of IMC
- Several aspects of discovery can be used to implement DTCP functionality




Thank you!