

Cooperative Clustering Techniques Applied to Contact Graph Routing

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The Challenge

- **Routing in Delay Tolerant Networks (DTN) faces many challenges:**
 - Frequent delays and disruptions
 - Long propagation delays
 - High node mobility
 - Current solution: Contact Graph Routing (CGR)
- **Main issue: Scalability!**
 - CGR requires knowledge of the entire network
 - Extremely slow in large networks



Proposed Solution: *Clustering*

In this talk we will explore various clustering algorithms and techniques and adapt them to the setting of CGR.

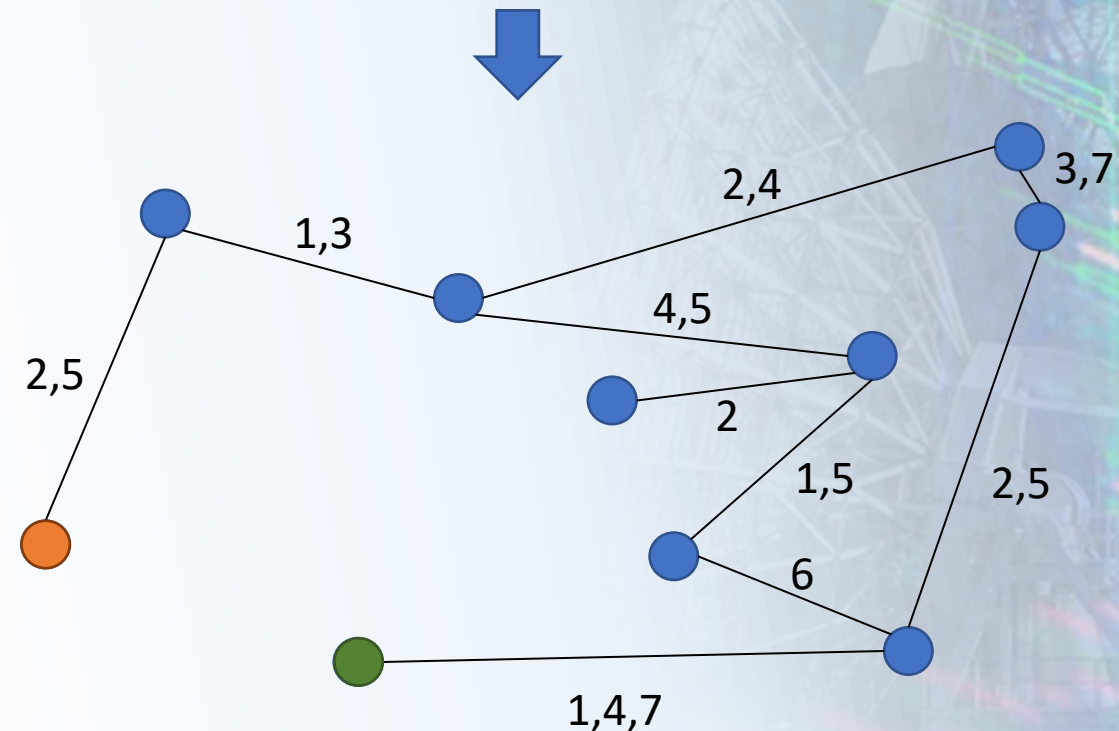
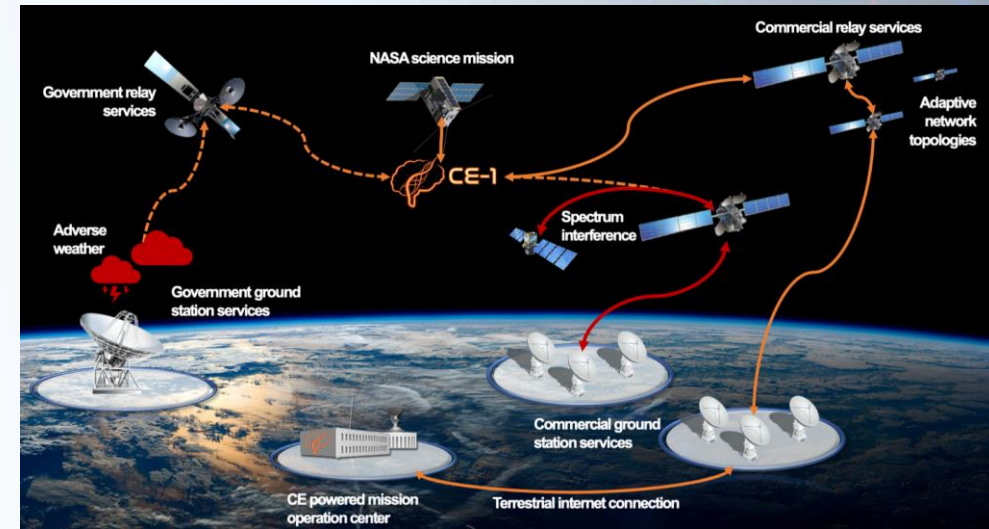
The result: Delay Tolerant Clustering Protocol (DTCP)



Contact Graph Routing (CGR)

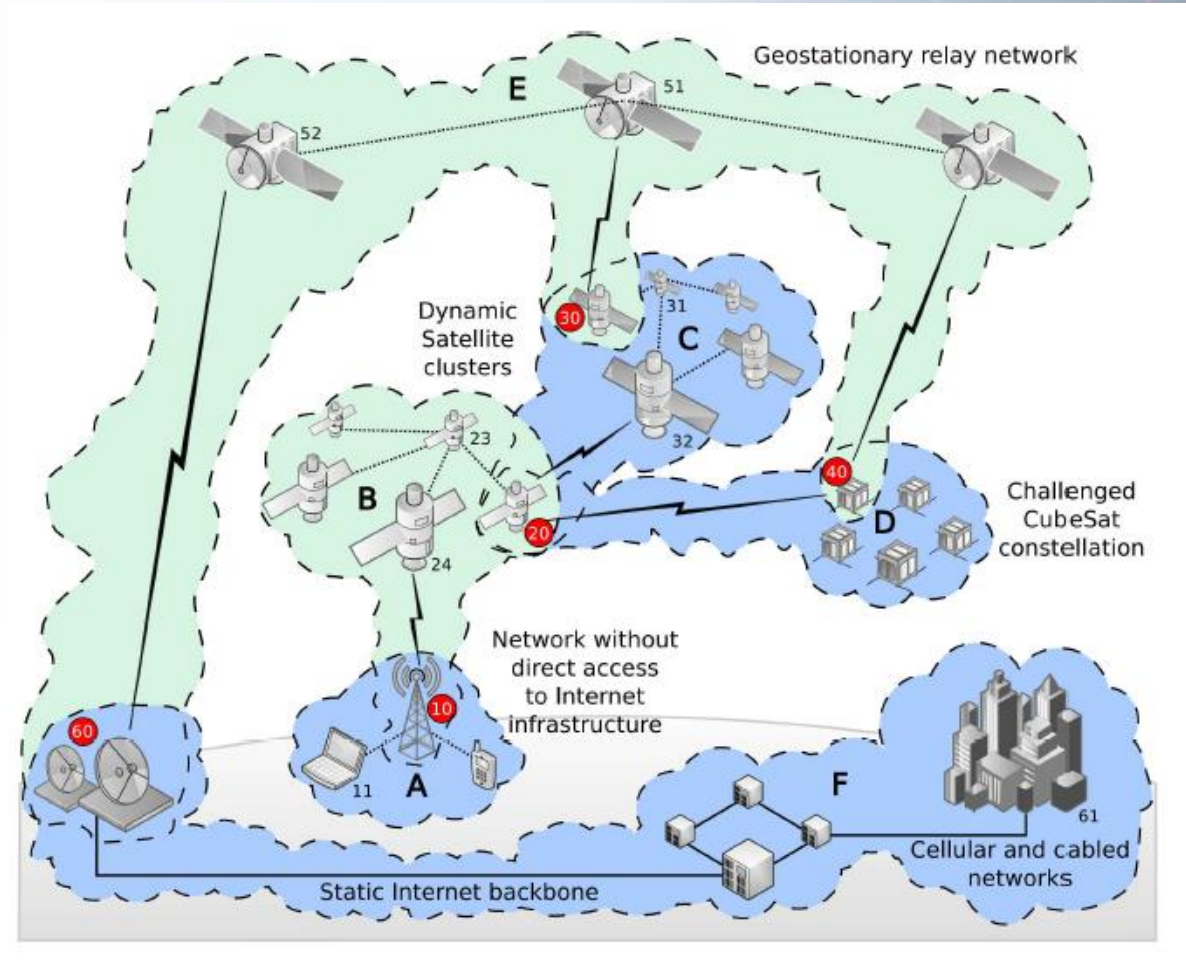
- Represent the network as a *Contact (multi)-Graph*
- Contact – period of time when two nodes can communicate.
- Connectivity – edge data
- Routing → pathfinding
- **Goal:** find the fastest way to send data through the network
- **Problem:** need knowledge of all current and future connections in the network.

With current techniques, path computation can take 40 seconds in large networks!



Clustering

- Divide the network into subnetworks (clusters)
- Reduce computation overhead
- Allows integration of commercial networks
- Combine cognitive networking with SDN



Challenge: create a clustering algorithms that uses **local** information and **low communication overhead**

Game Theory

- 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

Biological competition

	 hawk	 dove
 hawk	 lose -5	 gain +10
 dove	 gain none, lose none	 gain +5

	3\$		8\$
	4\$		7\$
			5\$

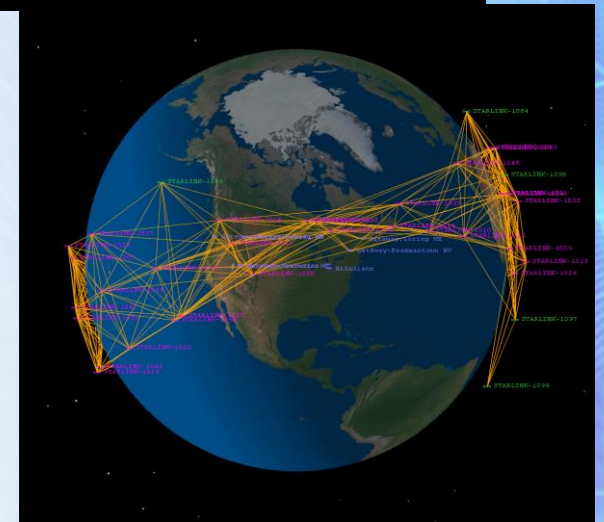
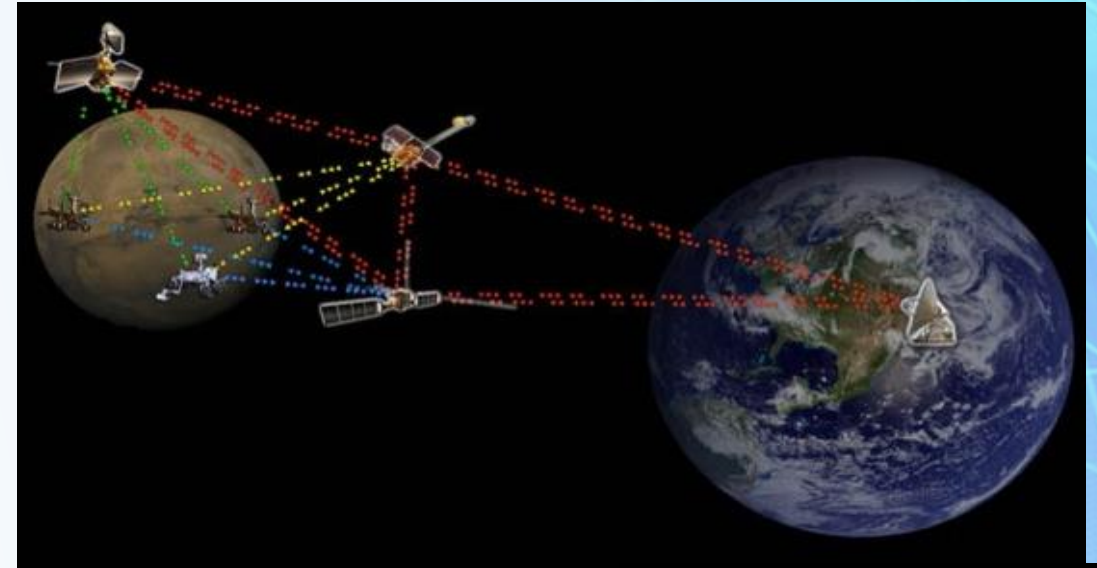
Using Games for Clustering

Cooperative:

- Select the most *central* nodes as cluster heads
- Use *Shapley Value* to measure centrality

Non-cooperative:

- Create a game where players optimize residual energy
- Dove strategy – volunteer to be cluster head
- Hawk strategy – do not volunteer
- Analyze *Equilibrium State* of the game

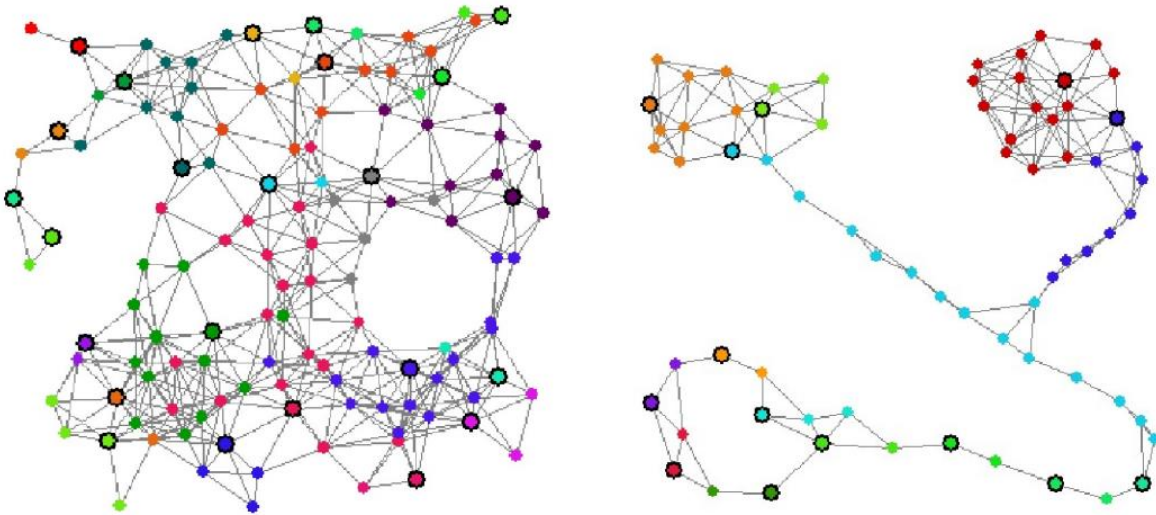


Using Graph Theory for Clustering

- Local Dynamic Clustering
- Optimize cluster fitness:

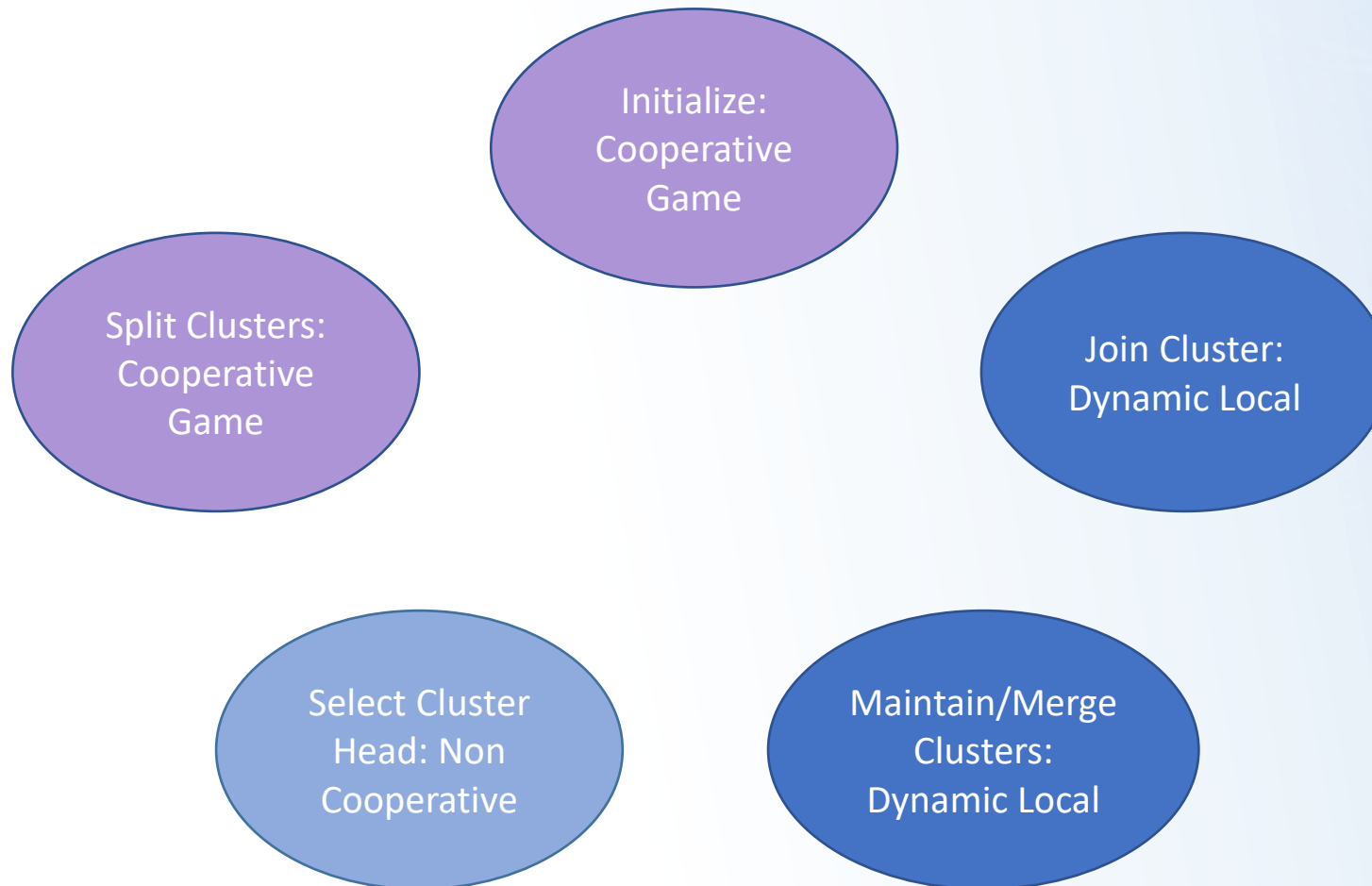
$$f(C) = \frac{2 \deg_{\text{int}}(C)^2}{|C|(|C| - 1)(\deg_{\text{int}}(C) + \deg_{\text{ext}}(C))}$$

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



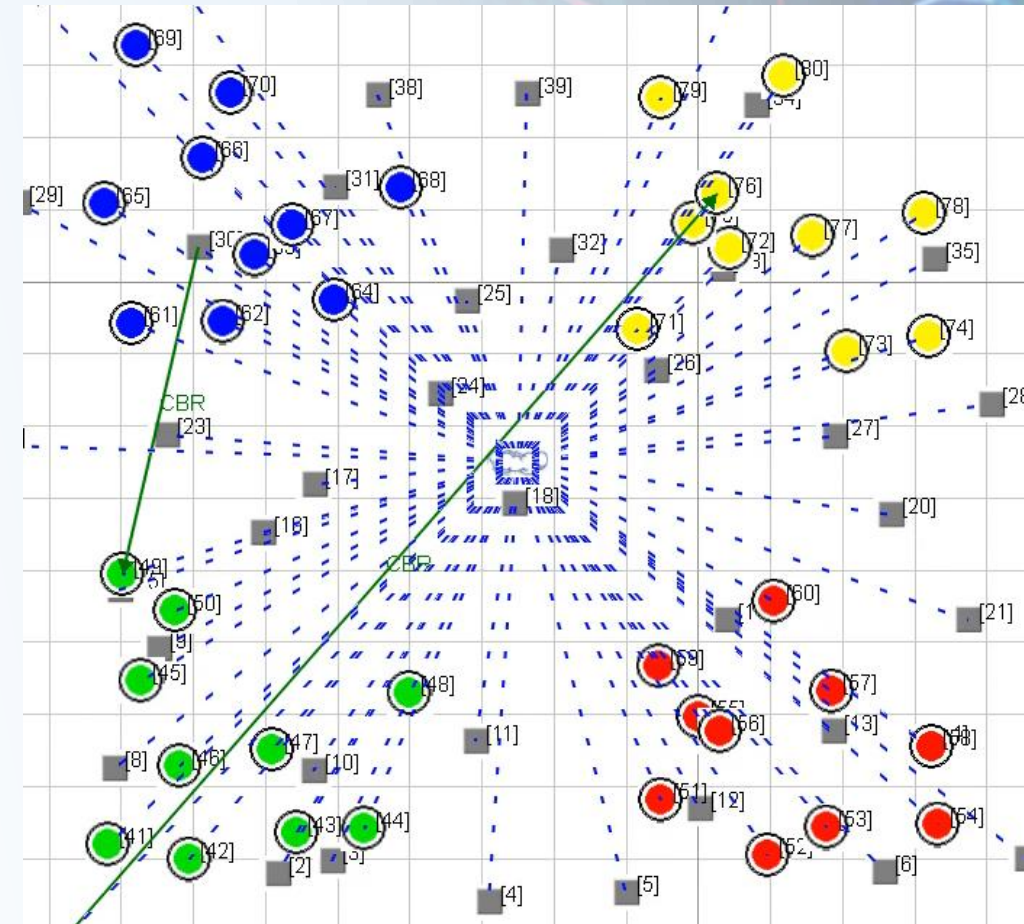
Delay Tolerant Clustering Protocol - DTCP

- Adapt the clustering algorithms to Contact (multi)-Graphs
- Combine the three algorithms:



Enabling Autonomy

- CGR requires the distribution of contact plans throughout the network
 - Updating the contact plan for all nodes becomes unwieldy in large networks
 - Scheduling methods vary throughout the network (LEO versus Lunar)
- Defining regions of the network can:
 - Account for deterministic and opportunistic paradigms
 - Develop associations for trusted neighbors
 - Enable interoperability between a diverse set of protocols
- Develop a hierarchy among nodes
 - Cluster head will require more capable hardware (compute and communication system)
 - Cluster members may be “consumable” low-cost nodes



The Impact

- **DTCP can be implemented and incorporated in HDTN**
 - International Space Station DTN network
 - Future LunaNet missions
 - Laser Communication Relay Demonstration (LCRD)
- **Support LunaNet's goal of a 'network of networks'**
 - Provide the framework for LunaNet's increased number of nodes



Questions?

Special thanks to –

My mentors: Rachel Dudukovich and Robert Short.

My fellow interns:

Matt Piekenbrock, Michael Moy, Emma Waldvogel, Dominic Ta and Prash Choksi.



The poster features a central image of a human head with a glowing, circuit-like brain, set against a background of a satellite in space and binary code. The text is arranged in a clear, hierarchical manner, with the main title in large, bold letters. Logos for NASA, AIAA, and IEEE are prominently displayed at the bottom. A QR code and a website URL are provided for more information.

National Aeronautics and Space Administration 

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