Cognitive Scheduling and Resource Allocation for Space to Ground Communications

Cognitive Communications for Aerospace Applications Workshop

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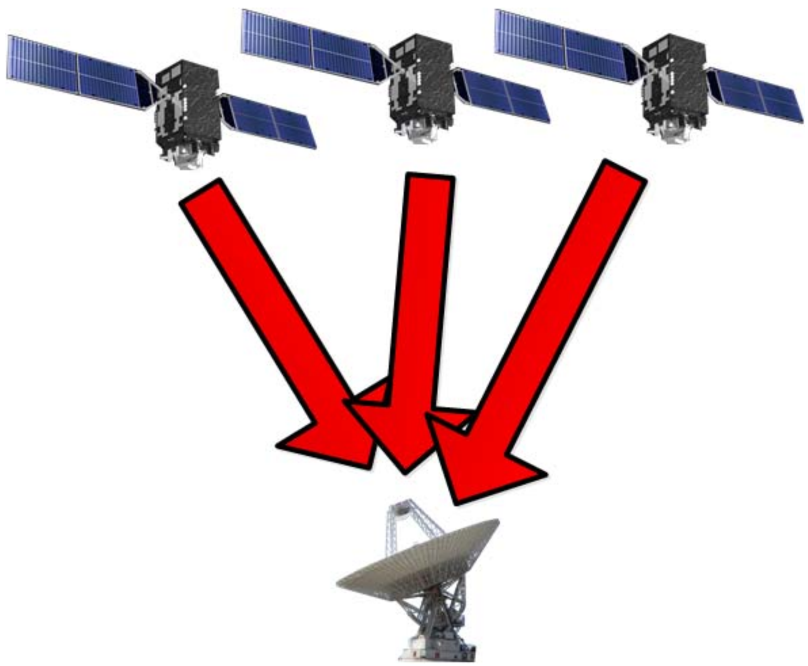
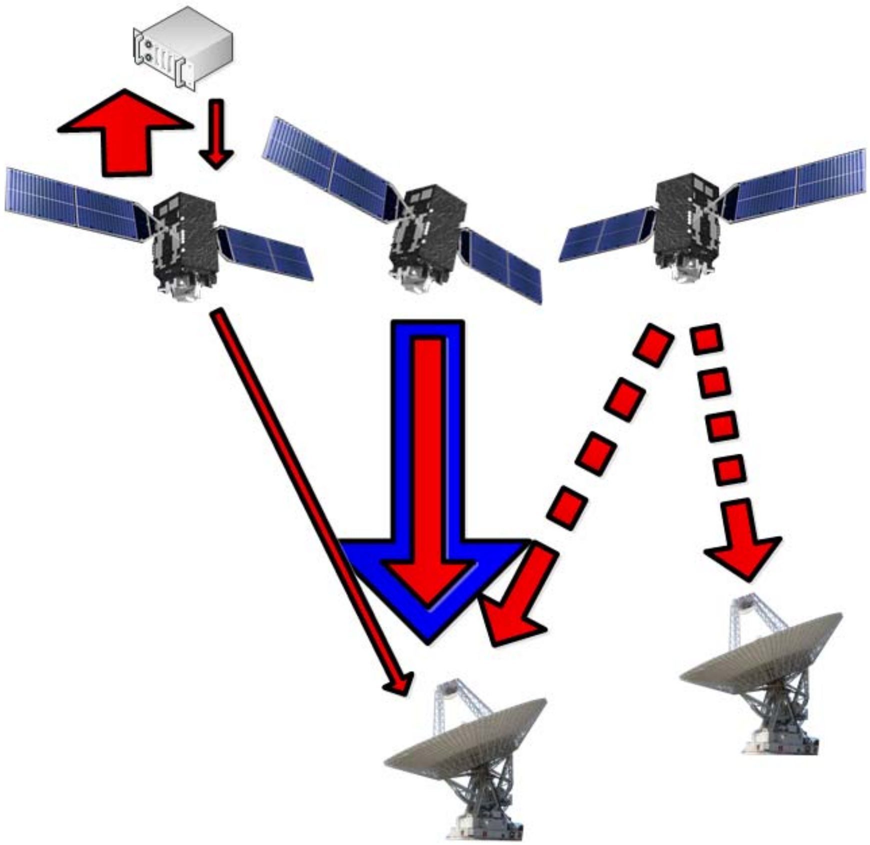
The Problem

- Too much data, Too little bandwidth
  - New sensors and instruments produce data at higher rates and in larger volumes
  - Many more spacecraft transmitting
  - We can't add bandwidth
  - We can't gain much in spectral efficiency
- We consider the case of space to ground communications
  - Applicable to important real-world systems
    - Scientific observation
    - Earth imagery
- Techniques applicable to other communications applications



How to Solve the Problem

- Automated analysis on the spacecraft
  - Reduce the volume of data that must be transmitted to the ground
  - Extract meaningful or valuable information from the data
- More capable communications technologies
  - Optical Links
    - European Data Relay System (EDRS)
  - New RF bands
- Use the communications resources more efficiently
  - *This is the approach we're talking about today*



Cognitive Communications

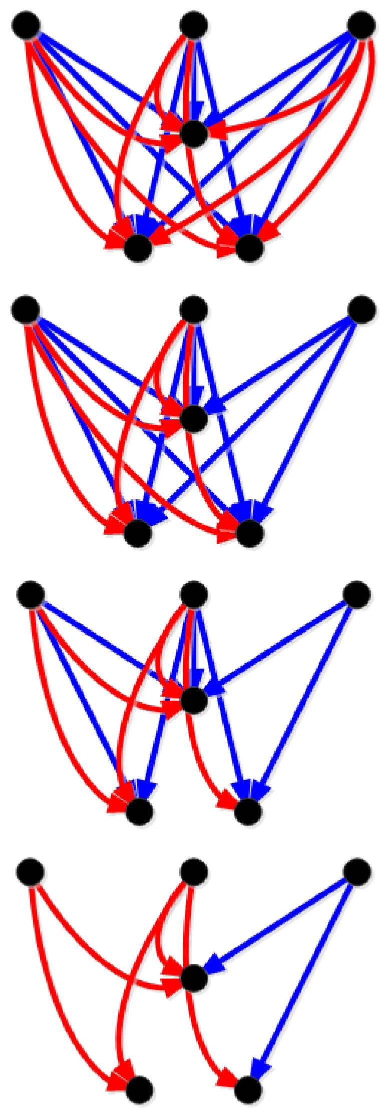
- **Automated reasoning**
- Requires a formal representation of communications and networking problems
  - Unambiguous and precise
  - Sufficiently rich to address realistic problems
- Requires a mechanism for processing problems expressed in the formal representation
  - Operate on the problem description
  - Produce desirable solutions

Formal Representation

- Flexible enough to capture a variety of problems
- Complete and detailed enough to make generated solutions applicable to real-world problems
- Precise enough to yield specific, actionable plans
- Supports the generation of actual solutions
- Reasonable computational complexity
- Sacrifice of detail is inevitable
- Incompleteness in inevitable

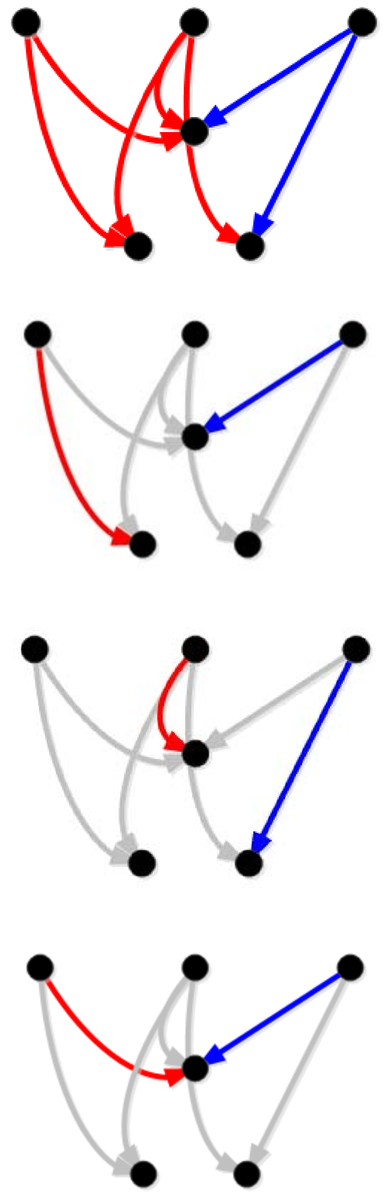
Model Elements

- Communicators
  - Can be extended beyond the space to ground problem
- Communications Channels
  - Opportunities to elaborate and extend
- Capabilities
  - Heterogeneous and evolving spacecraft capabilities
- Visibility
  - Orbital dynamics a key aspect of any space communications systems
- Exclusions
  - Avoid unrealizable solutions
- Demand
  - Complex, time-varying need for data transport



Building a Schedule

- Scheduling
  - Assigning the use of communications channels to specific communicators at specific times
  - Avoiding conflict
  - Meeting demand
- Timing Granularity
  - Duration of a resource allocation
  - Scaled appropriate to the problem
  - Impacts complexity of scheduling
- Rescheduling
  - Update communications plan as circumstances and needs change



Valid Schedules

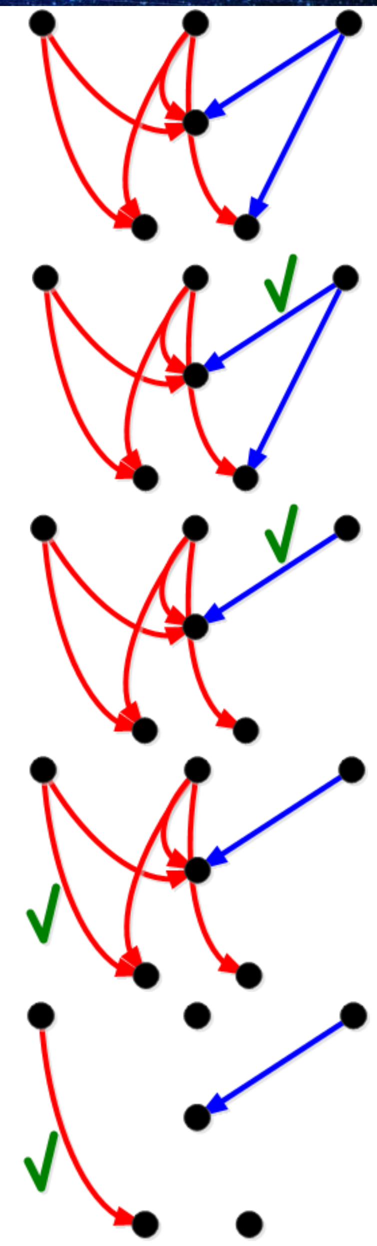
- Only allocate communications channels a communicator can use
- A communicator can only use a channel for one purpose
- A communicator cannot send and receive on a channel at the same time
- A communicator cannot use a channel if it would interfere with other scheduled communications

Good Schedules

- Mechanism to choose a *desirable* schedule from a collection of *valid* schedules
- Characteristics
  - Only schedule communications if there is demand to transfer data
  - Only schedule enough resources to meet demand
  - Schedule more data transfer if there is more demand
- Philosophy of good schedules
  - Heuristic objectives
  - Distinct from optimality
  - Yields improvements in computational complexity

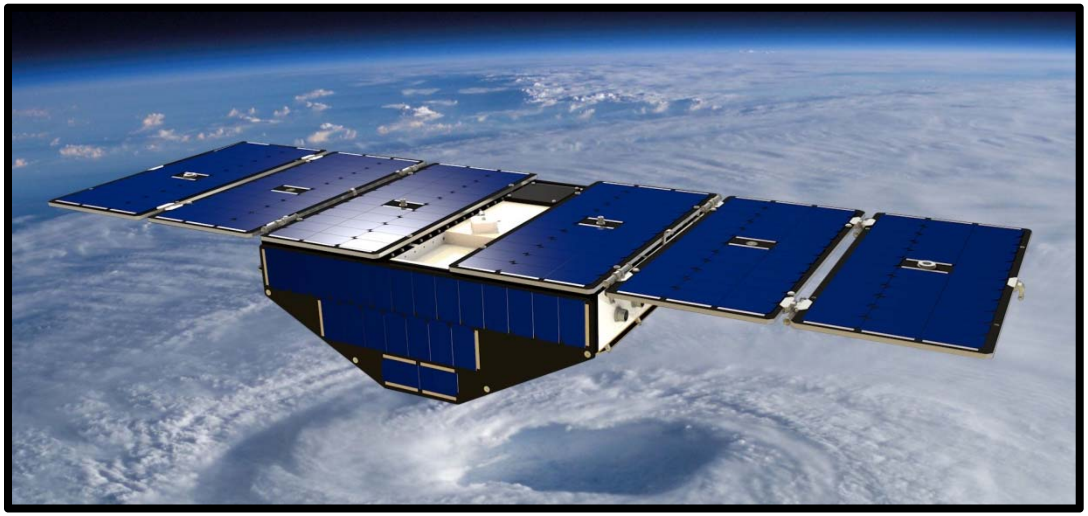
Reasoning

- Reasoning Process
  - Begin with a connectivity graph
  - Allocate edges to meet demand
  - Prune the graph to enforce validity
  - Explore options to identify a good schedule
  - Repeat for each time interval
- Reduces to canonical scheduling problem
- Implementation
  - We have employed Answer Set Programming
  - Other metaheuristic techniques are relevant



CYGNSS Mission

- Cyclone Global Navigation Satellite System
- Measure ocean surface wind field to characterize development of tropical cyclones
- Constellation of eight microsatellites in LEO
- Launched December 2016
- Model mission for cognitive scheduling performance analysis



Performance

- Problem Scenario
  - Eight LEO spacecraft, slow distribution of orbits
  - Three ground stations
  - RF communications on eight channels
    - Equivalent capacity on all channels
    - No interference between channels
  - More data transfer demand than capacity
- Comparison
  - Static allocation of channels to satellites
  - Cognitive solution using Answer Set Programming

Day	Demand Scheduled		
	Fixed	Good	Increase (%)
1	90,020	107,424	19
28	94,117	442,240	370
43	90,890	572,592	530
58	89,917	637,576	609

Conclusions

- Cognitive Communications and Networking
  - Rigorous, expressive formulation for describing communications problems
  - Automated reasoning to find solutions to the problems
- Abstract model describing key characteristics of space to ground communications
- Proof of principle implementation using Answer Set Programming
  - Outperforms static, preplanned schedule
  - Reasonable computation times
- Future Directions
  - Extend the expressivity of the model
  - Explore additional reasoning strategies
  - Apply to more complex, real-world problems
  - Extend the approach to other aspects of space operations