A Distributed Approach to High-Rate Delay Tolerant Networking Within a Virtualized Environment

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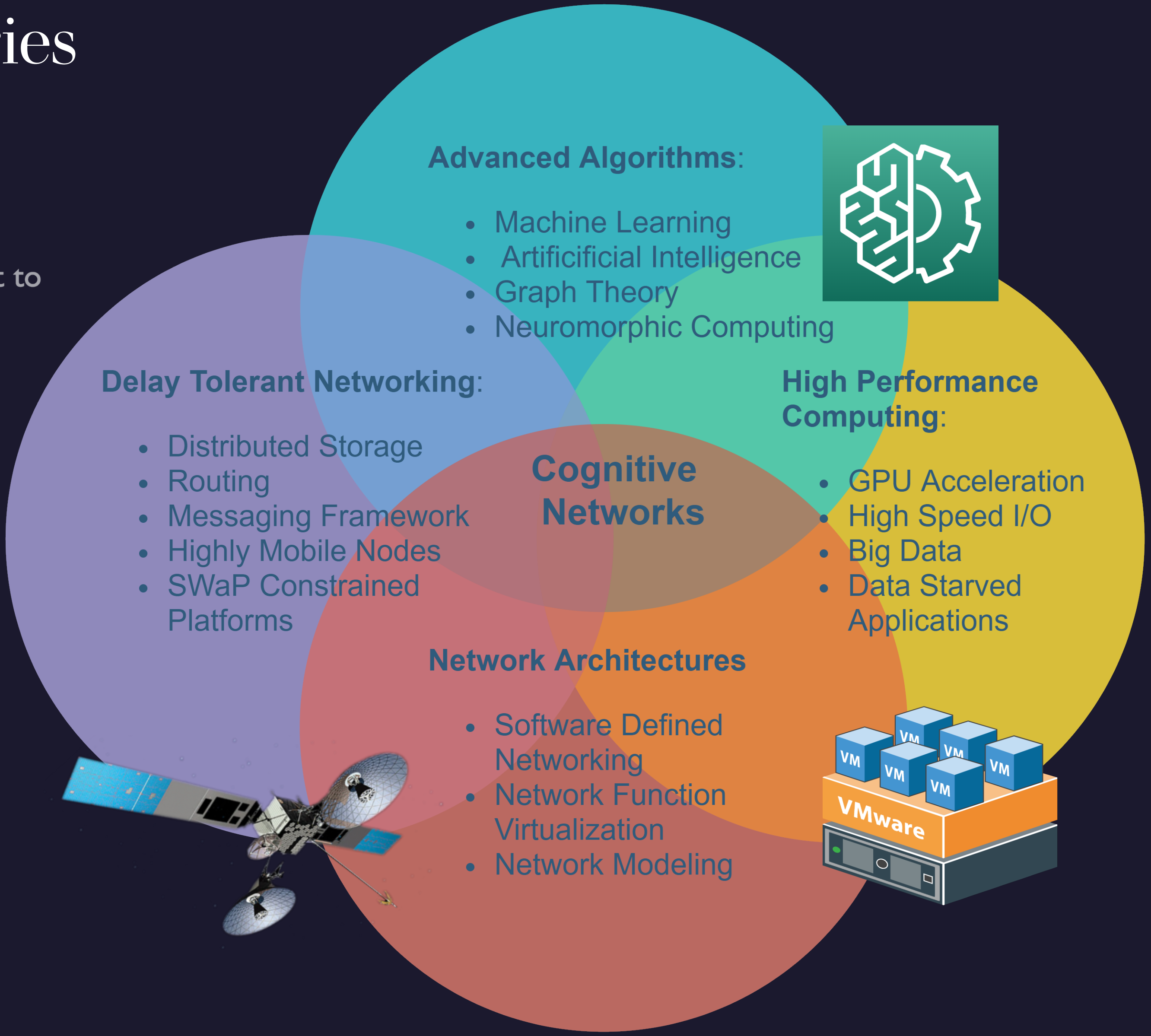
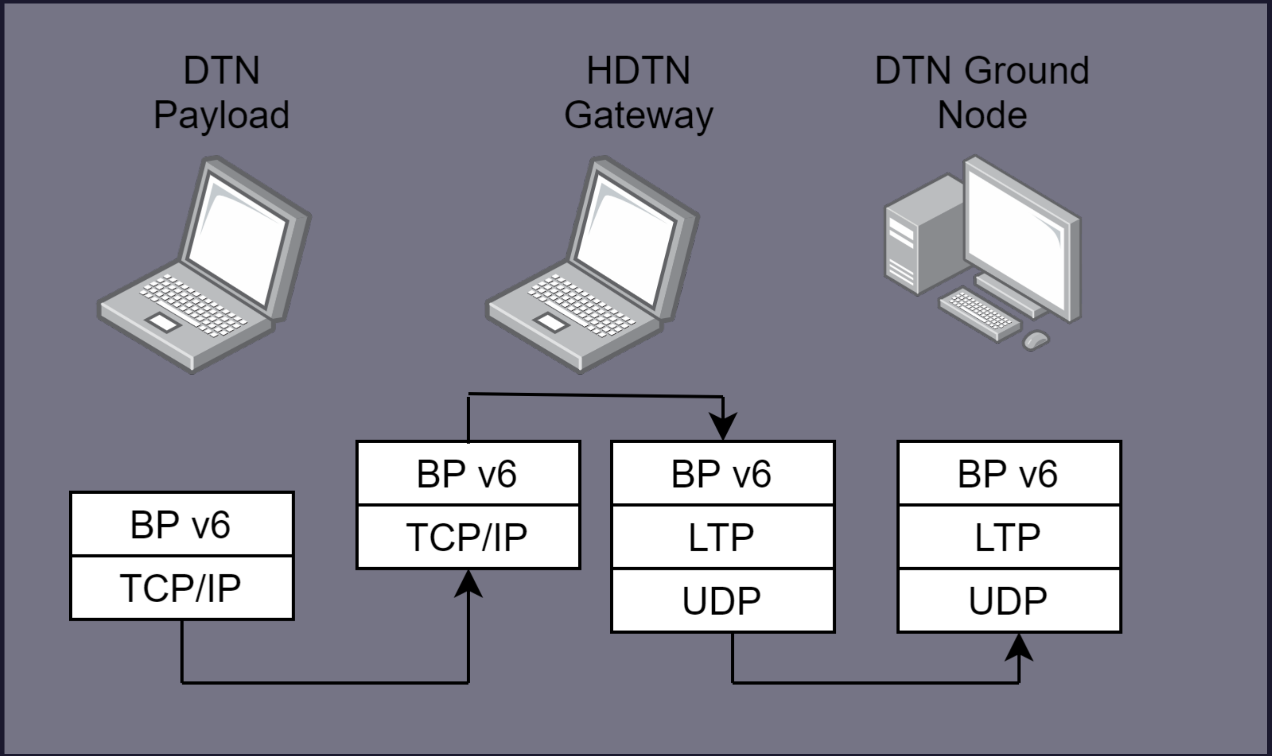
Cognitive Networking Technologies

- Cognitive networking encompasses several technology areas in an effort to develop:
  - Autonomous network implementations that sense and adapt to optimize network and system level performance
- Meet the challenges of:
  - Unlimited scalability of the network
  - Low Size, Weight, and Power (SWaP) platforms
  - Manage data storage, prioritization, custody, and security
  - Interoperability across heterogenous protocols
  - Increased data return
  - Mobile, intermittently connected network
- Develop implementations beyond simulation
  - Realistic protocol stack
  - Hardware representative of flight systems



Delay Tolerant Networking

- Currently in use on-board ISS
- Considered a key technology for future Lunar architecture
- DTN architecture can serve as a framework to:
    - Mitigate link disruptions with store-and-forward capability
    - Address asymmetric data rates (forward vs. return rates)
    - Provide a common network layer among dissimilar nodes
    - Provide reliability
    - Provide a basis for routing in an intermittently connected network
- Continue to build upon and develop flight heritage



Advanced Algorithms and Decision-Making

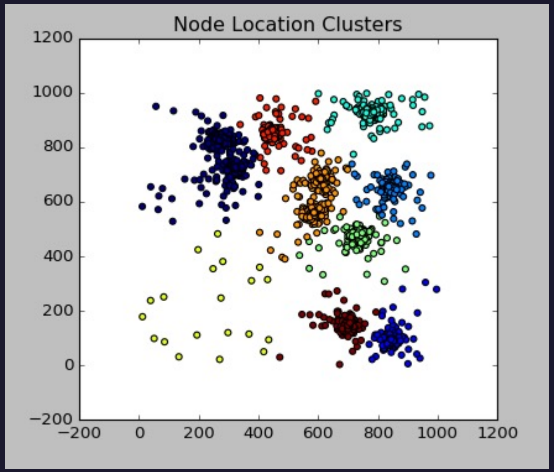
Optimizations can be developed at the satellite system level and the network level

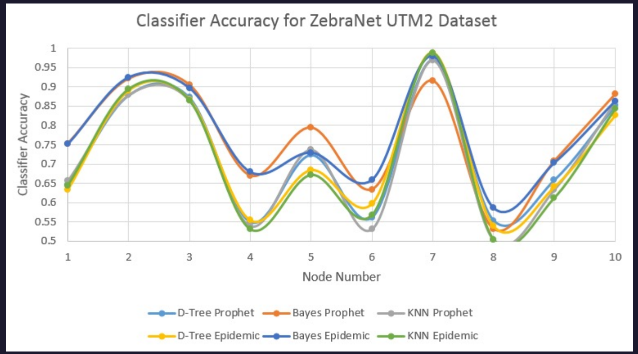
- An example of the Lunar network could be further divided into a network of networks
- Can be a mix of cognitive and conventional regions within the network
- Cognitive system may optimize both the physical and network layers
- Must account for constraints of link schedule and availability

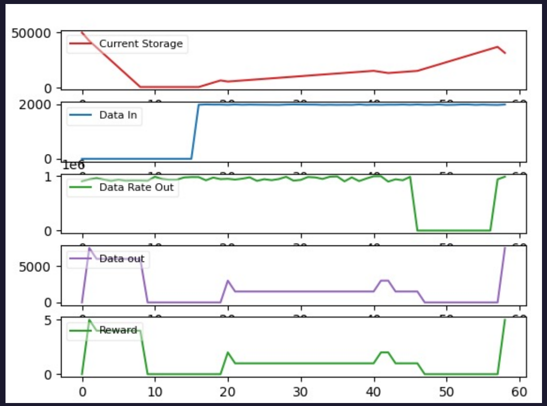
Areas to apply decision-making:

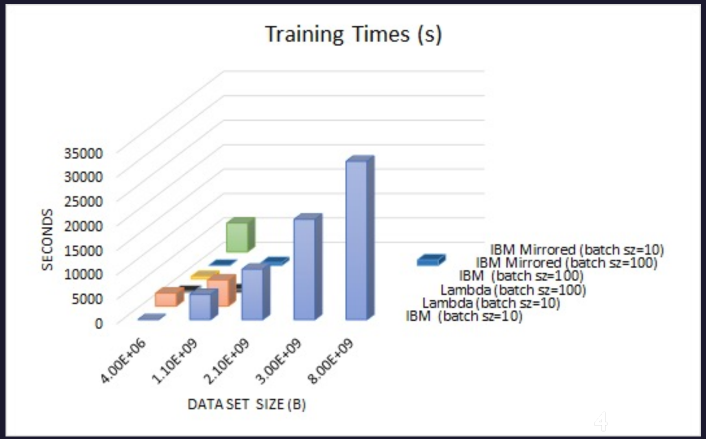
- Determine and handle data priority, data management
- Optimize decisions related to fragmentation and reassembly
- Link Selection
- Routing (multi-hop)
- Neighbor discovery
- Scheduling
- Network management

- Areas of interest include:
  - Spiking neural networks and neuromorphic systems
  - Deep learning
  - Graph theory
  - Reinforcement learning
  - Multi-agent systems
  - Multi-objective decision-making
  - Clustering

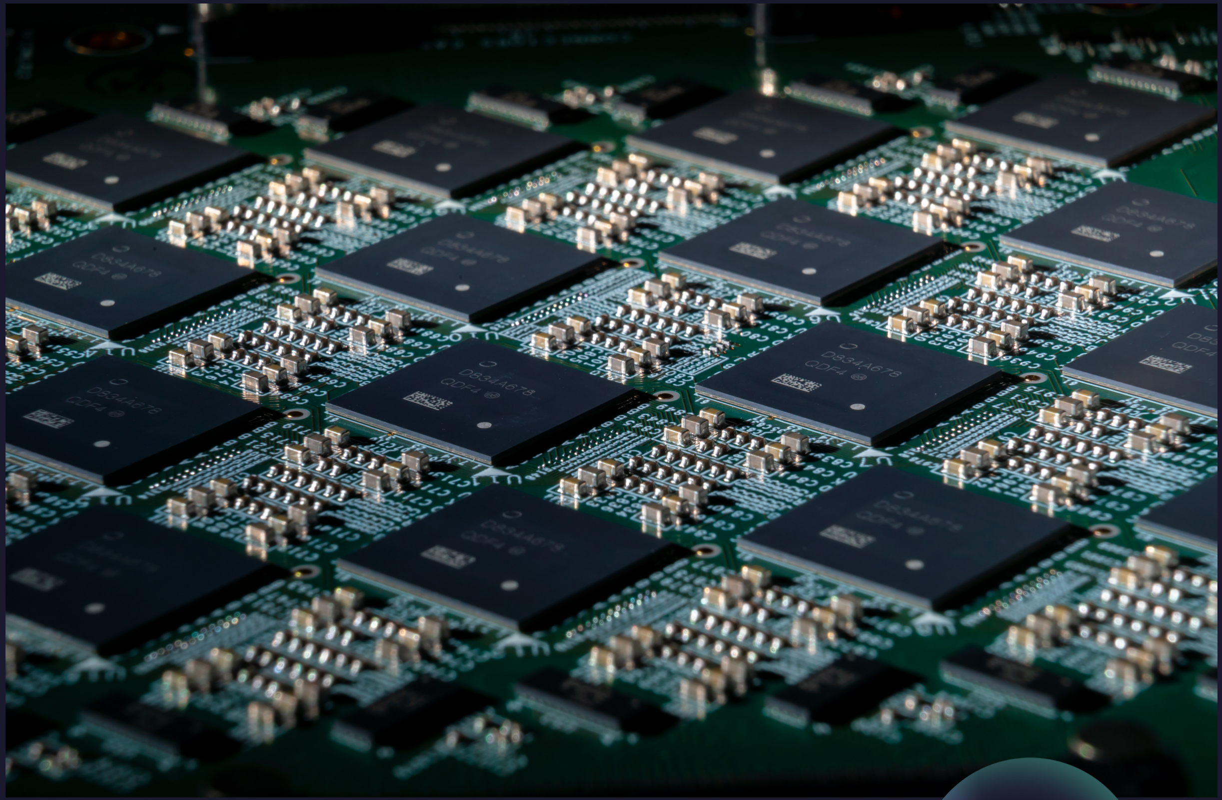




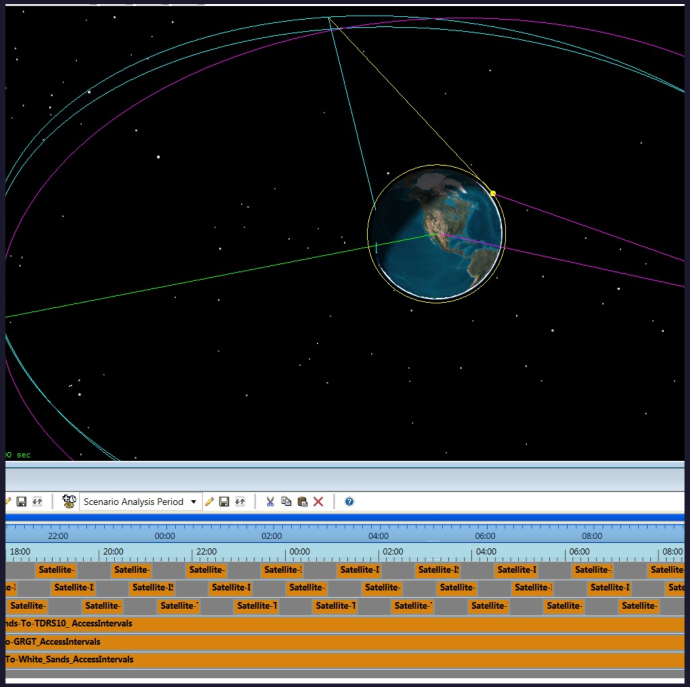


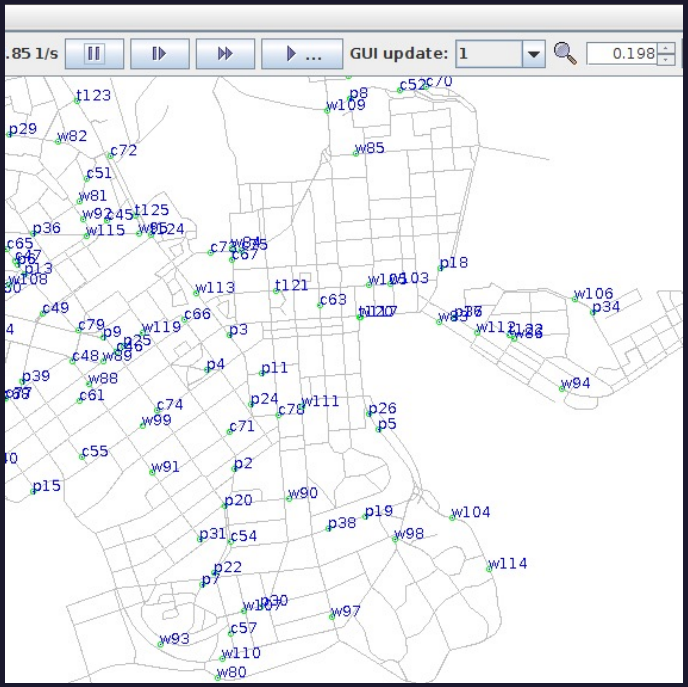


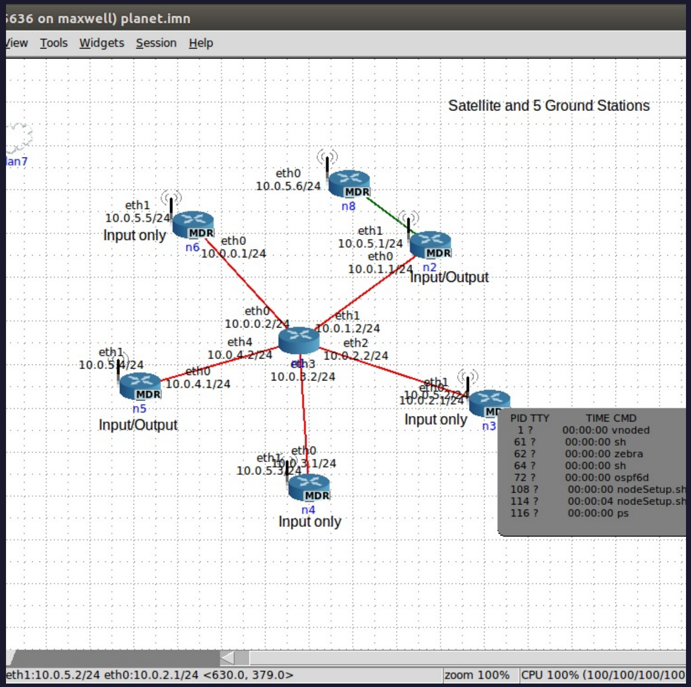
High Performance Computing



- Determine how, if possible, to utilize COTS solutions for:
  - GPU acceleration
  - Neuromorphic computing
  - High Speed I/O
  - Big Data
  - Data starved applications
  - Cloud and container-based systems
- Determine how to translate to low SWaP platforms





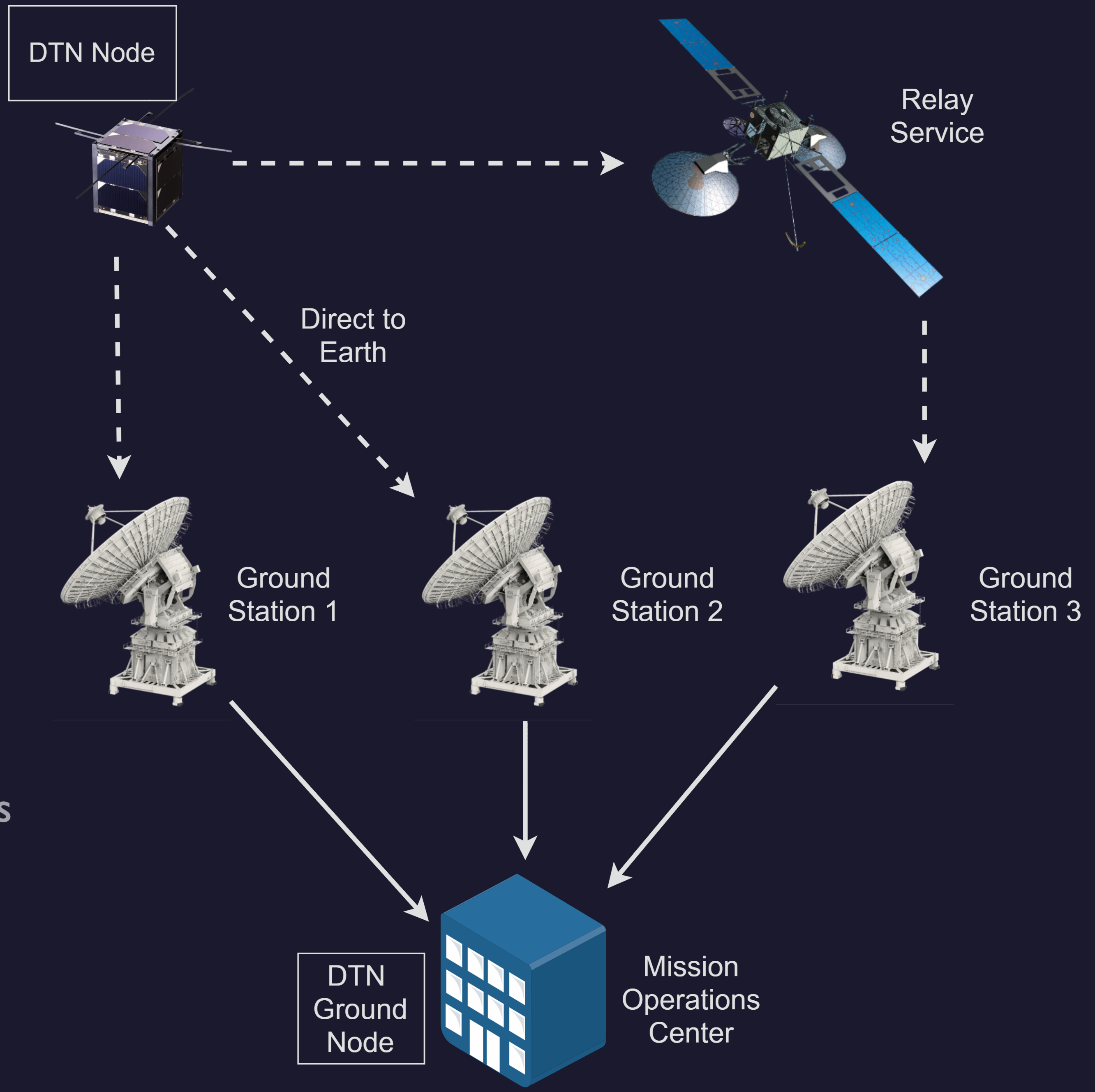


Network Architectures

- To optimize the system, must understand the network model and characteristics
- Provide input to develop simulations and emulations needed to test algorithms and protocols
- Apply modern techniques used in terrestrial systems if possible:
    - Software Defined Networking
    - Network Function Virtualization

Demonstrations and Infusion

- Cognitive Communications project must partner with missions that can provide opportunities to demonstrate cognitive technologies
  - Advance TRL
- Develop concept of operations for SmallSat and Lunar missions
- Build upon existing engineering efforts
- High-rate Delay Tolerant Networking project is developing a DTN bundle agent which can serve as a framework to implement a variety of cognitive processes

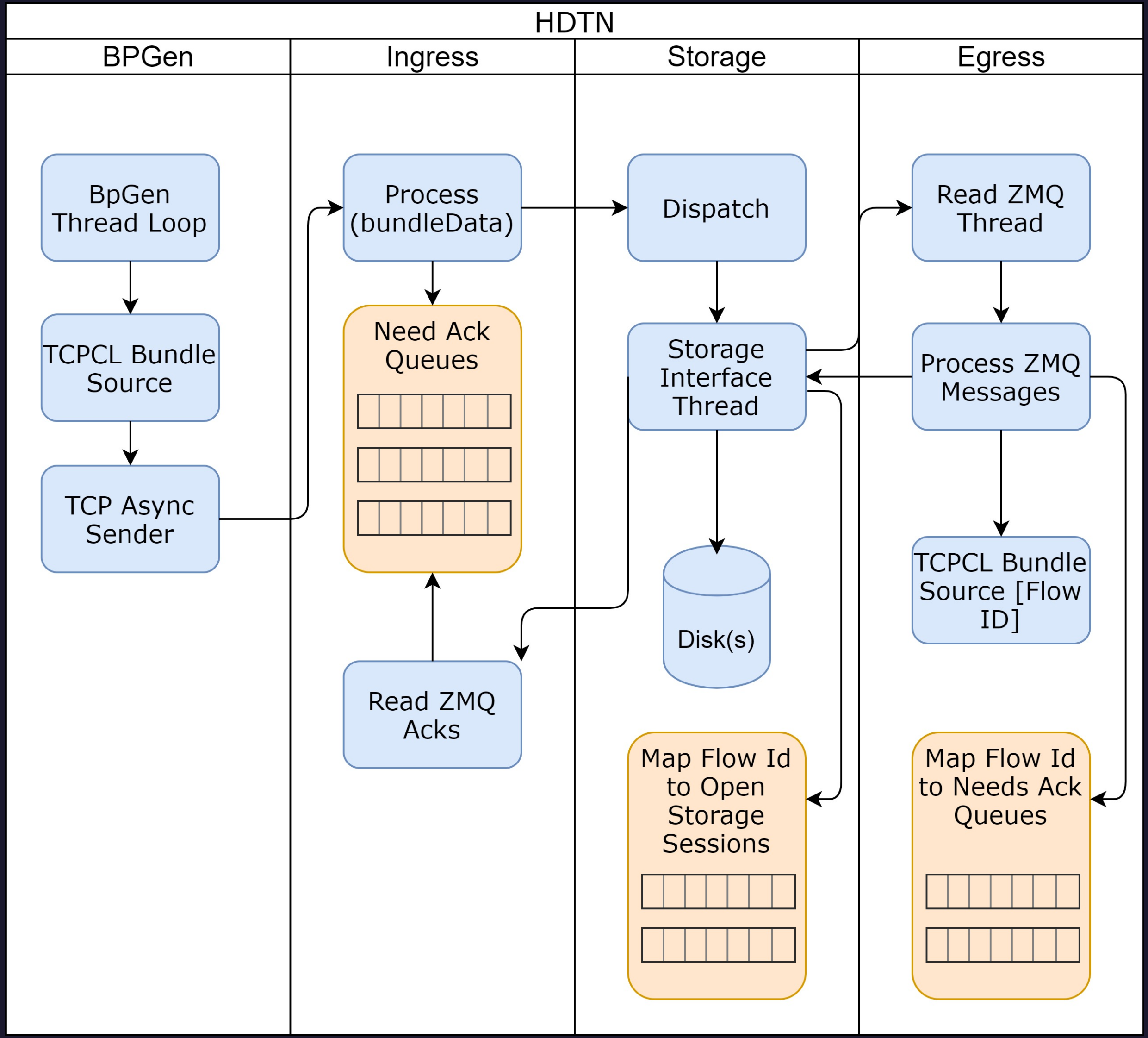


HDTN Software Development Timeline

- **HDTN Software** — Develop store-and-forward, UDP, TCP, STCP, LTP, logging and statistics, benchmark utilities. Spring 2021
- **SDIL Testing** — Test software with realistic environment similar to ISS DTN network. Summer 2021
- **ISS Demo** — Provide latest revision to ISS DTN team as experimental DTN gateway. Summer 2021
- **Routing Interface** — Develop interface to allow various algorithms to trigger data storage and egress events. Fall 2021
- **Discovery Interface** — Enable nodes to share connectivity information with new neighbors. Winter 2021-22

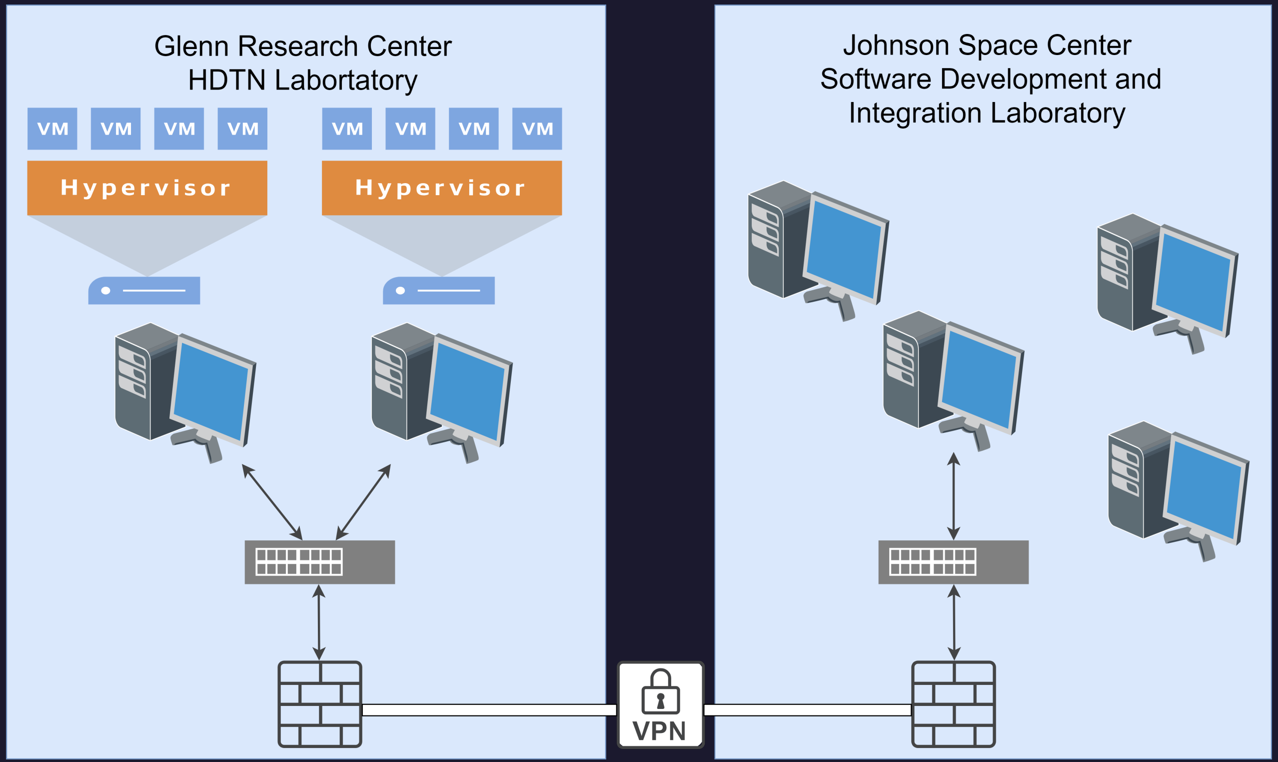
Software Development

- Initial version of bundle encoding/decoding and benchmarking utilities release through NASA Open Source Agreement
- https://github.com/nasa/HDTN-BPCodec
- Bundle storage completed
- Ingress and egress support UDP, TCP, STCP, and LTP
- Bundle agent uses message bus to share data between distributed processes
  - Could exist on separate physical machines or containers
- Bundle agent to be released tentatively summer 2021



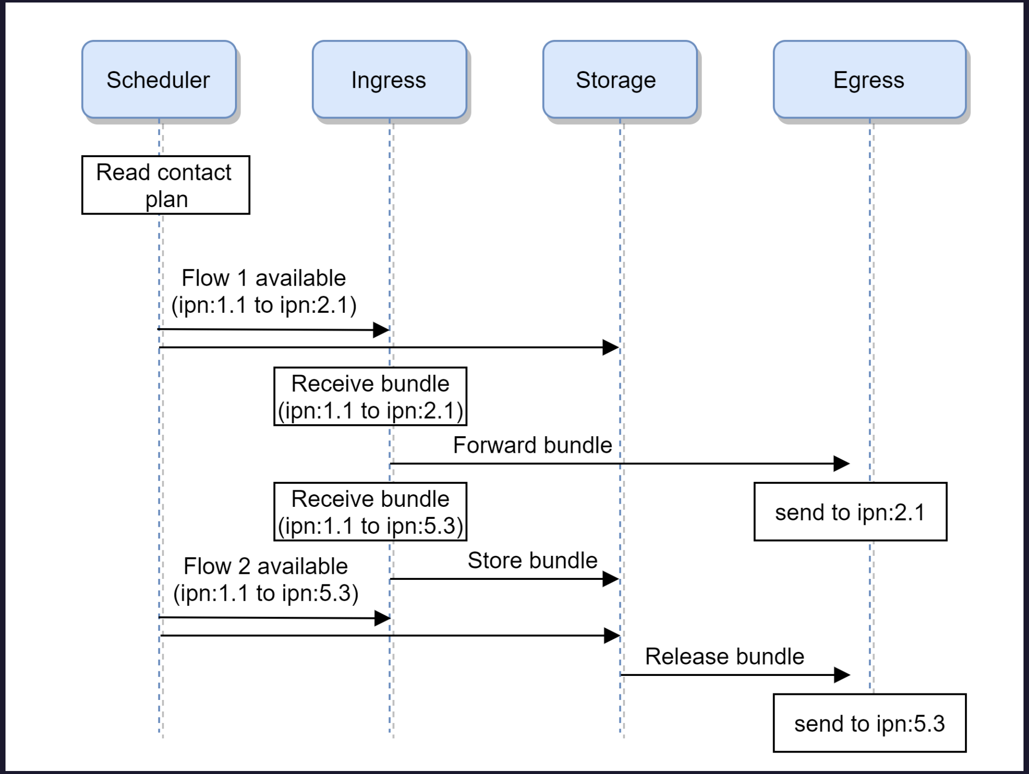
Lab Environment

- HDTN gateway on ISS will run inside of a Kernel-based Virtual Machine (KVM)
- The software will be tested over a remote connection to the Johnson Space Center Software Development and Integration Laboratory (SDIL)
- The SDIL emulates the ISS DTN network and will flow realistic traffic through HDTN
- Network connection between labs has been established
- Testing to begin in end of June 2021
- Initial test will consist of ION payload node to generate data, HDTN gateway, and ION ground node
  - Nodes will use BPv6, TCP and LTP convergence layers



Event Scheduling and Routing Interface

- Event scheduler component has been developed to read contact plan information
  - Contact start and stop times, node numbers, data rate, and distance
- Functions a simple flow-based process to trigger the transmission, storage, and release of data
- ZMQ message bus shares events between modules
  - Supports Python and C/C++
- The basic mechanism will evolve into a routing interface to support contact graph routing and many other routing algorithms



- Contact plan example (JSON):

```
{"contact plan":[
   {"contact":"0", "source":"1","dest":"4", "flow ID":"0","start time":"0","duration":"3600","rate":"10000000"},
{"contact":"1", "source":"5","dest":"2", "flow ID":"1","start time":"0","duration":"7200","rate":"10000000"},
{"contact":"2", "source":"1","dest":"3", "flow ID":"2","start time":"10000","duration":"7200","rate":"10000000"},
]}
```

Future Work

- Additional convergence layers can be developed to support software defined radios, other CubeSat/SmallSat radios
- Develop support for multicast and anycast
- Network statistics from HDTN tests can be used to develop a dataset that can serve as input for machine learning and artificial intelligence models
- Develop for support cognitive routing algorithms
- Develop neighbor discovery mechanism
- Test in multi-hop emulation

Thank You

References

Image slide 5: https://www.intel.com/content/www/us/en/newsroom/resources/press-kits-neuromorphic-computing.html#gs.3s87fv