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

Advanced Algorithms:
  • Machine Learning
  • Artificial Intelligence
  • Graph Theory
  • Neuromorphic Computing

Delay Tolerant Networking:
  • Distributed Storage
  • Routing
  • Messaging Framework
  • Highly Mobile Nodes
  • SWaP Constrained Platforms

High Performance Computing:
  • GPU Acceleration
  • High Speed I/O
  • Big Data
  • Data Starved Applications

Cognitive Networks

Network Architectures
  • Software Defined Networking
  • Network Function Virtualization
  • Network Modeling
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):

```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: