Ensuring Flexibility and Security in SDN-Based Spacecraft Communication Networks through Risk Assessment

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OUTLINE

1. Overview of NASA Networks
2. SDN Integration in Space Networks
3. Flexibility vs Security Issues
4. SDN Testbed for Space Communications
5. Vulnerability Study
6. Conclusion & Future Direction
OVERVIEW OF NASA NETWORKS
Traditional Space Communication Networks

• Not fully networked (some ground networking)
  – End-to-end transmission relies on circuit switching
• RF/Microwave for ground-to-space
• “Relay satellites” (orbiting bent-pipe transponders)
• Consultative Committee for Space Data Systems (CCSDS) communications protocols
• Closed networks & manual configuration


space communication protocol stack - future

baseline icsis protocol stack*

*international communication system interoperability standards (icsis)
https://www.internationaldeepspacestandards.com/

bundle protocol (ccsds 734.2-b-1) provides “network functionality, e.g., network addressing, routing, and qos management, in end-to-end communications environment of intermittent connectivity” enabling “multiplex/demultiplex capability to deal with multiple data streams from multiple sources over heterogeneous links.” (icsis, feb. 2018)

asynchronous message service (ccsds 735.1-b-1) “provides a standard, reusable infrastructure for the exchange of information among data system modules in a manner that is simple to use, highly automated, flexible, robust, scalable, and efficient. (icsis, feb. 2018)
Changes in the Space Industry

- Growing trends:
  - Commercial Space
  - SmallSats/CubeSats & large satellite constellations

- Growing communications requirements (throughput and number of nodes)

Example of a CubeSat (Pedersen)

Emerging Space Communication Trends

• New technologies driving future spacecraft missions
  – Laser Communications $\rightarrow$ Higher data rates
  – Delay/Disruption-Tolerant Networking (DTN) $\rightarrow$ Store-and-forward networking

• Integrated space communication/navigation networks
  – NASA Space Communications & Navigation (SCaN)
  – Integrating orbital, human exploration & deep-space network resources


Future Space Networks

Software Defined Network (SDN)

- Technology used in cloud computing to abstract network resources
- Fundamentally: separates network’s Control Plane from Data Plane
- Supports easier centralized network configuration through administrative applications

Role of SDN in Space Networks

- SDN can provide centralized view & control of a large space network for network managers and mission operators
- Time-dependent relay/antenna distribution & beamforming
- On-demand routing


SDN INTEGRATION IN SPACE NETWORKS
Introduction to SDN

Logical Architecture of SDN (ONF Fig. 1)
Commercial SDN

- Open Networking Foundation (ONF): OpenFlow CDPI protocol
  - Enable/disable ports, modify QoS settings
  - Controller implementations: OpenDaylight, Ryu, Open Network Operating System (ONOS)
- Google: Espresso SDN routing infrastructure
- Cisco: Application Centric Infrastructure (ACI)


SDN Security Studies and Solutions

- Security Advantages/Capabilities:
  - Security policy & service deployment
  - Cyber forensics
  - Realtime intrusion detection & mitigation

- Security Challenges
  - DoS attacks on controller
    - AVANT-GUARD throttles control plane data to prevent this
    - CPRecovery controller failover
  - Malicious flow alteration
    - Trust systems and role-based authentication

Integrating Space Communications

• NASA SCaN Program
  – Near-Earth Network (NEN), Deep Space Network (DSN) & Space Network (SN)

• Federated Satellite System
  – Distributed spacecraft collaborating to provide services

• Cognitive Networking
  – Identification & autonomous handling of network conditions

• Delay/Disruption-Tolerant Networking (DTN)
  – Internet-like networking across interplanetary distances (RFC 4838)
  – Bundle Protocol (BP)/RFC 5050: Transmitting “bundles” using store-and-forward paradigm


SDN For Space Networks

• Temporospatial SDN
  – Google Project Loon: Network nodes moving with respect to time & space

• Software Defined Naval Network for Satellite Communications (SDN-SAT)
  – U.S. Navy: Using OpenFlow & MPTCP to support satellite-based ship navigational networks

• Software Defined Framework for Integrated space tErrestrial satellite Communication (SERvICE)
  – China National Basic Research Program: Using SDN with NFV for satellite communications

FLEXIBILITY VS SECURITY ISSUES
Combined Space Communication Networks (Near-Term)

• Diverse customers and missions using shared network resources, ranging from universities to human exploration
• Higher data requirements & larger number of nodes
• Scaling circuit-switched network segments may no longer be feasible
Solar System Internet (Long-Term)

- Long-term, space networking nodes may be distributed across the Solar System
- As with Internet, traffic may be forwarded through nodes unknown to endpoints

Depiction of a Solar System Internet (“Interplanetary Internet”)
Limits to the Current Space Network Architecture

• Circuit switching requires dedicated connections
  – Packet switching: fuller bandwidth utilization
  – Increased connections & lower bandwidth utilization: higher cost
• Manual configuration & control: scalability challenges
SDN as a Solution

- Packet-switched networking & centralized network control
- Scalable with hierarchical controllers
- Synchronized spacecraft commanding & transponder control
- Automatic network reconfiguration
  - Traffic rerouting during cloud occlusion
Impact of an Open Network Architecture on Security

- Interconnected networks create more attack vectors
  - More interconnected nodes
  - A single compromise can have a greater reach
- Decoupled & centralized control plane can result in single point-of-failure
SDN TESTBED FOR SPACE COMMUNICATIONS
Experiment Environment Setup: Testbed with Mininet

- **Mininet**: Open-source network emulation tool
  - Uses Linux Kernel’s network stack
  - Capable of running real network device software/firmware

- **SDN testbed**:  
  - Ground switches (OpenFlow)  
  - OpenFlow controller  
  - Raspberry Pi w/ core Flight System (cFS) & OpenFlow switch


Experiment Environment Setup:
Testbed with Mininet (cont.)

Mininet testbed topology
VULNERABILITY STUDY
ISO 27000 Series

• ISO/IEC 27000 Series of Standards on IT Security Techniques

• Assets:
  – Ground stations & relays
  – Operations centers (mission, science, network)
  – Network
  – Data
  – Spacecraft
C.I.A. Triad

Availability

Confidentiality

Integrity
Confidentiality

Confidential Data Compromise

Data Redirection
- Gain Controller Access (Compromise Endpoint Integrity)
- Modify Flow Rules to Send Data to Attacker Node

Unauthorized Data Access
- Gain Ground Node Access (Compromise Endpoint Integrity)
- Obtain Trusted User Credentials

Attack tree for a confidentiality compromise.
Data Integrity

Attack tree for a data integrity compromise.
Endpoint Integrity

Attack tree for an endpoint integrity compromise.
Availability

Availability Compromise

Disrupt Spacecraft Availability
  - Flood DoS Attack
    - Send High Volume Commands to SC
      - Gain SC LOS via Custom Transceiver
  - Disable SC Flows
    - Alter SC Flow Tables
      - Gain Ground Station Access (Compromise Endpoint Integrity)

Disrupt Ground Node Availability
  - Flood DoS Attack
    - Send High Volume Data to Node
      - SDN Controller Spoof
        - Gain Controller Access (Compromise Endpoint Integrity)
  - Physically Disable Node
  - Flood DoS Flows
    - Alter Node Flow Tables
      - Gain SC Access (Compromise Endpoint Integrity)

Disrupt SDN Controller Availability
  - Physically Disable Controller
  - Flood DoS Attack
    - Send High Volume Messages to Controller
      - Connect Attacker Device to Controller
      - Gain Trusted Device Access (Compromise Endpoint Integrity)

Attack tree for an availability compromise.
# Risk Register

## Table 1: Classification of risks to spacecraft and associated assets

<table>
<thead>
<tr>
<th>Asset</th>
<th>Threat/Vulnerability</th>
<th>Existing Controls</th>
<th>Likelihood</th>
<th>Consequence</th>
<th>Level of Risk</th>
<th>Risk Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability, availability and integrity of spacecraft</td>
<td>Attacks/errors affecting spacecraft (i.e. DoS)</td>
<td>Space Data Link security; direct connection; command verification</td>
<td>Rare</td>
<td>Catastrophic/Doomsday</td>
<td>Extreme</td>
<td>1</td>
</tr>
<tr>
<td>Integrity and availability of ground nodes</td>
<td>Attacks/errors affecting ground nodes</td>
<td>Space Data Link security</td>
<td>Unlikely</td>
<td>Moderate</td>
<td>Medium</td>
<td>2</td>
</tr>
<tr>
<td>Confidentiality of spacecraft telemetry/commands</td>
<td>Interception of telemetry or commands</td>
<td>Data encryption</td>
<td>Unlikely</td>
<td>Moderate</td>
<td>Medium</td>
<td>3</td>
</tr>
<tr>
<td>Integrity of spacecraft commands</td>
<td>Corruption or loss of command data</td>
<td>Error Detection &amp; Correction codes</td>
<td>Possible</td>
<td>Minor</td>
<td>Medium</td>
<td>4</td>
</tr>
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### Table 1: Classification of risks to spacecraft and associated assets

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<td>Integrity of spacecraft telemetry</td>
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<td>Possible</td>
<td>Minor</td>
<td>Medium</td>
<td>5</td>
</tr>
<tr>
<td>Integrity and availability of SDN controller</td>
<td>Attacks/errors affecting controller; corruption/loss of SDN control messages</td>
<td>Configuration; controller authentication</td>
<td>Possible</td>
<td>Moderate</td>
<td>High</td>
<td>6</td>
</tr>
</tbody>
</table>

- 2 New Risks in SDN-based spacecraft network:
  - Spacecraft Availability
  - SDN Controller Integrity/Availability
Availability Challenges

• Spacecraft could be susceptible to DoS attacks
• Invalid messages sent to spacecraft at high data rate will consume clock cycles
• Compromised control plane can be made to flood spacecraft with messages or disconnect spacecraft
Controller Integrity and Availability

- **Controller Integrity Compromise**: Inauthentic controller and/or messages
  - Attacker has control over network configuration

- **Loss of Controller Availability**: Controller unable to update network configuration
  - No Control Plane functionality

- **Vulnerabilities also prevalent in terrestrial SDN**
  - AVANT-GUARD & CPRecovery
  - Trust Systems & Role-based Authentication
Need for DoS Attack-Resilient System

• Although rare, spacecraft DoS could be catastrophic
  – Asset Destruction
  – Mission Failure
  – Loss-of-Life

• Decreasing attack likelihood alone insufficient

• Detection and real-time DoS attack mitigation
  – Flow Sampling
  – Quality-of-Service (QoS)/network throttling
CONCLUSION & FUTURE DIRECTION
DoS and Control Plane Attacks

• Vulnerability study: these two attacks not handled by existing space networking security controls
• Impact of DoS attack on space systems makes DoS resiliency necessary
• Decoupled Control Plane $\rightarrow$ potential new vulnerabilities
  – Mitigation mechanisms (i.e. trust systems, role-based access control) for terrestrial implementations can apply
Future Work

- Controller-based active DoS attack mitigation
  - Flow sampling, heuristics
  - Network-wide attack handling
- Non-terrestrial SDN protocol implementation
- Flight hardware testing and hardware acceleration


National Aeronautics and Space Administration, Artist, Interplanetary Internet. [Art]. 2018.

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THANK YOU

QUESTIONS?