National Aeronautics and Space Administration

SPACE CO NICATIONS AND NAVIGATION

Space Link Extension (SLE) Emulation for High-Throu ut Network Emulation

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Overview

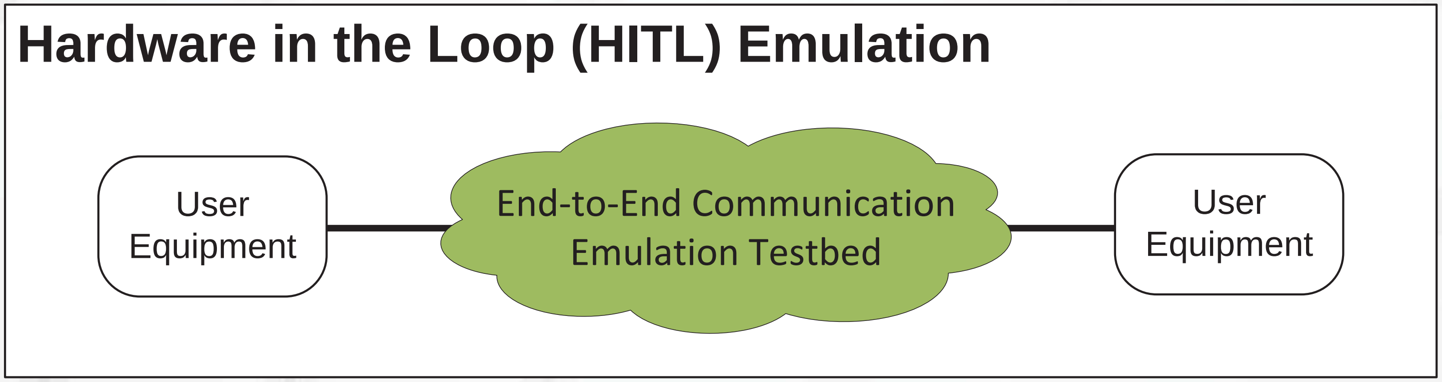
- Introduction
- NASA GRC SCENIC Emulation Lab
- Space Link Extension Overview
- Emulation Test-bed Setup
- Results
- Future Work

Introduction

- Network Simulation:
  - Mathematical approximation of network performance
  - Discrete event based simulation of expected behavior
- Network Emulation
  - High-fidelity network protocol models
  - Performed in real time
  - Can run emulation in parallel with operational hardware
- Benefits of Emulation:
  - System-in-the-loop emulation
    - Can test operational hardware / software in a real end-to-end network path

Introduction

- Real-time Emulation
  - Can test non-ideal networking scenarios
  - Packet drops, excessive delay, etc
  - Observe how actual hardware / code reacts to these situations.



NASA SCaN Program

- **S**pace **C**ommunication **a**nd **N**avigation (SCaN) Program
- Encompasses NASA's three operational space communication networks:
  - Near Earth Network (NEN)
  - Space Network (SN)
  - Deep Space Network (DSN)
- Three of SCaN Program Goals:
  - Develop a unified space communications and navigation network infrastructure capable of meeting both robotic and human exploration mission needs.
  - Assure data communication protocols for Space Exploration missions are internationally interoperable.
  - Continue to meet its commitments to provide space communications and navigation services to existing and planned missions.
- Unified networking infrastructure:
  - Requires extensive emulation and simulation testing
  - Verification that new protocols meet required standards and interoperate with legacy equipment.

SCENIC Emulation Lab

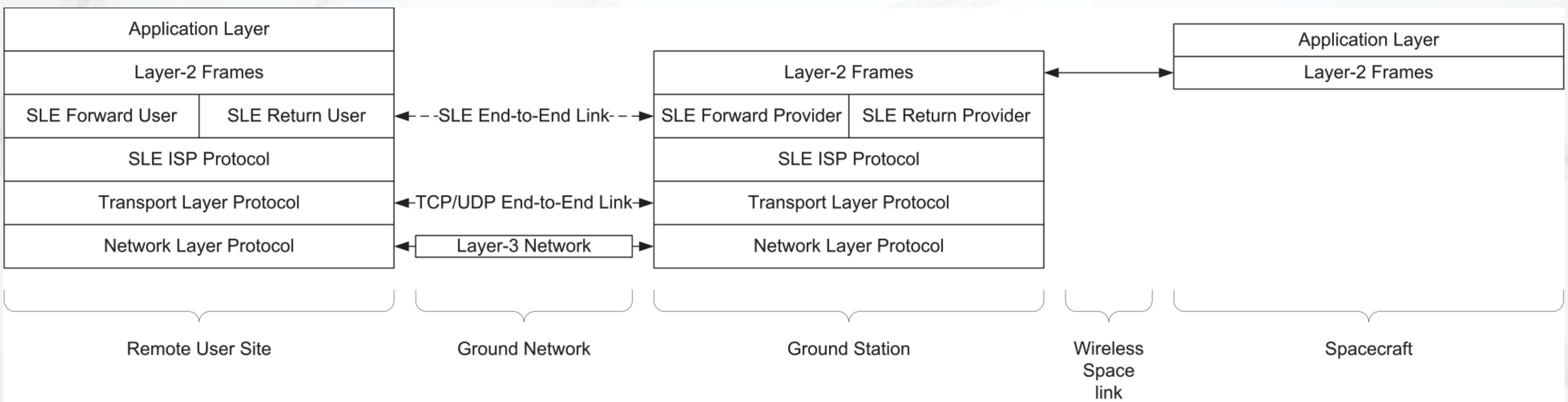
- NASA GRC **S**CaN **C**ompatibility **E**nvironment for **N**etworks and **I**ntegrated **C**ommunications (SCENIC) Emulation Lab
  - Currently under development at NASA Glenn Research Center
  - Identify and address gaps that enable implementation of the NASA Integrated Network Architecture (INA)
  - Provide a SCaN system and network training environment for new Systems Engineers, Co-ops, and interns to practice on NASA SCaN equipment
  - Perform system analysis, design, development and performance evaluation tasks.
  - Evaluate Vendor provide software options in a relevant environment with mission characteristics.
  - Facilitates the validation and verification of the SCaN integrated network to minimize risk, ensure safety and enable overall operational success.

Focus of Research

- Focus of this Emulation Research:
  - Emulation of Space Link Extension (SLE) Protocol
    - New implementation developed by Ingenicomm
    - Designed to support future high data-rate communication links
    - Up to 1.2-Gbps for Ka-Band communication links
- Focus of presented tests:
  - Emulation of expected and worst-cast round-trip-time between SLE User and Provider

Space Link Extension

- CCSDS Recommended Standard
- Tunneling protocol for Layer-2 CCSDS Frames or binary data
- Only used for ground network communications
- Provides interface to underlying transport layer protocol
  - Typically utilizes Transport Control Protocol (TCP)
  - Transport Layer provides reliability and congestion control

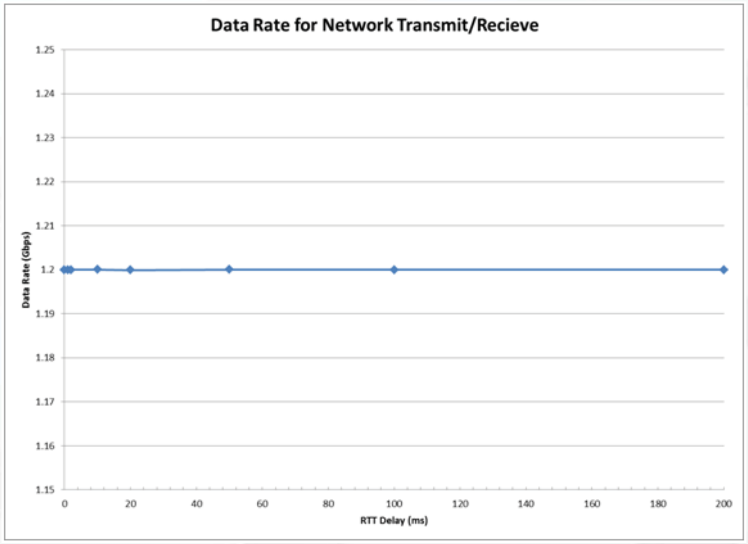


SCENIC Emulation Lab

- SCENIC Emulation Lab for SLE Emulation
  - Space Link Extension (SLE) Servers
    - SLE User – User Site
    - SLE Provider – Remote Ground Station
  - 10 Gbps Fiber network
    - Supports maximum desired rate of 1.2 Gbps
    - Isolation from NASA GRC Network
  - Wide Area Network emulation:
    - Linux Traffic Control (TC) functionality
      - Network delay
      - Jitter
      - Packet drop rate
    - Emulate network characteristics in real-time

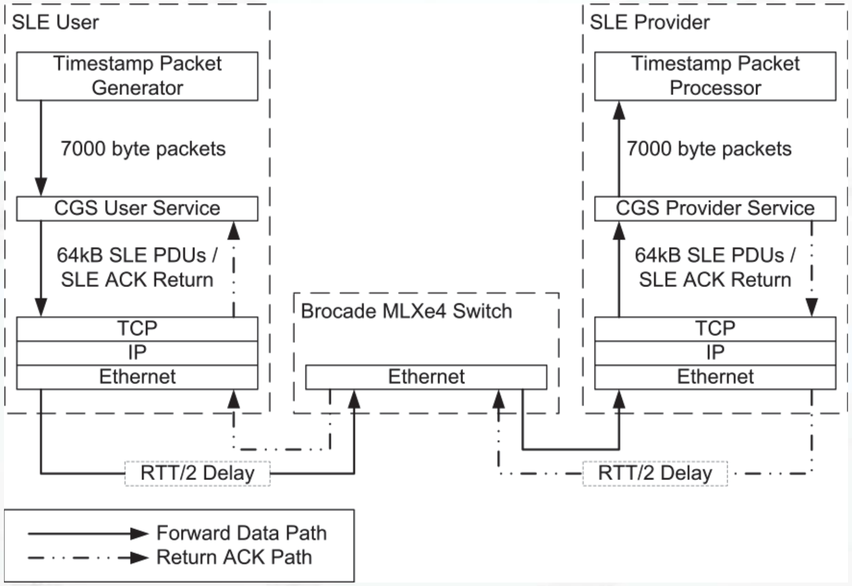
Baseline Network Results

- Initial emulation tests
  - Network connection through Ingenicomm CGS Software
  - Without SLE Encapsulation
    - Timestamp data tunneled directly over TCP/IP
  - Offered load: 1.2 Gbps
    - Maximum data rate for Single-Access Ka-Band communication link
  - Maximum RTT delay: 200 ms
    - Max expected delay for NISN CONUS network connection
  - **Full 1.2Gbps sustained throughout test**



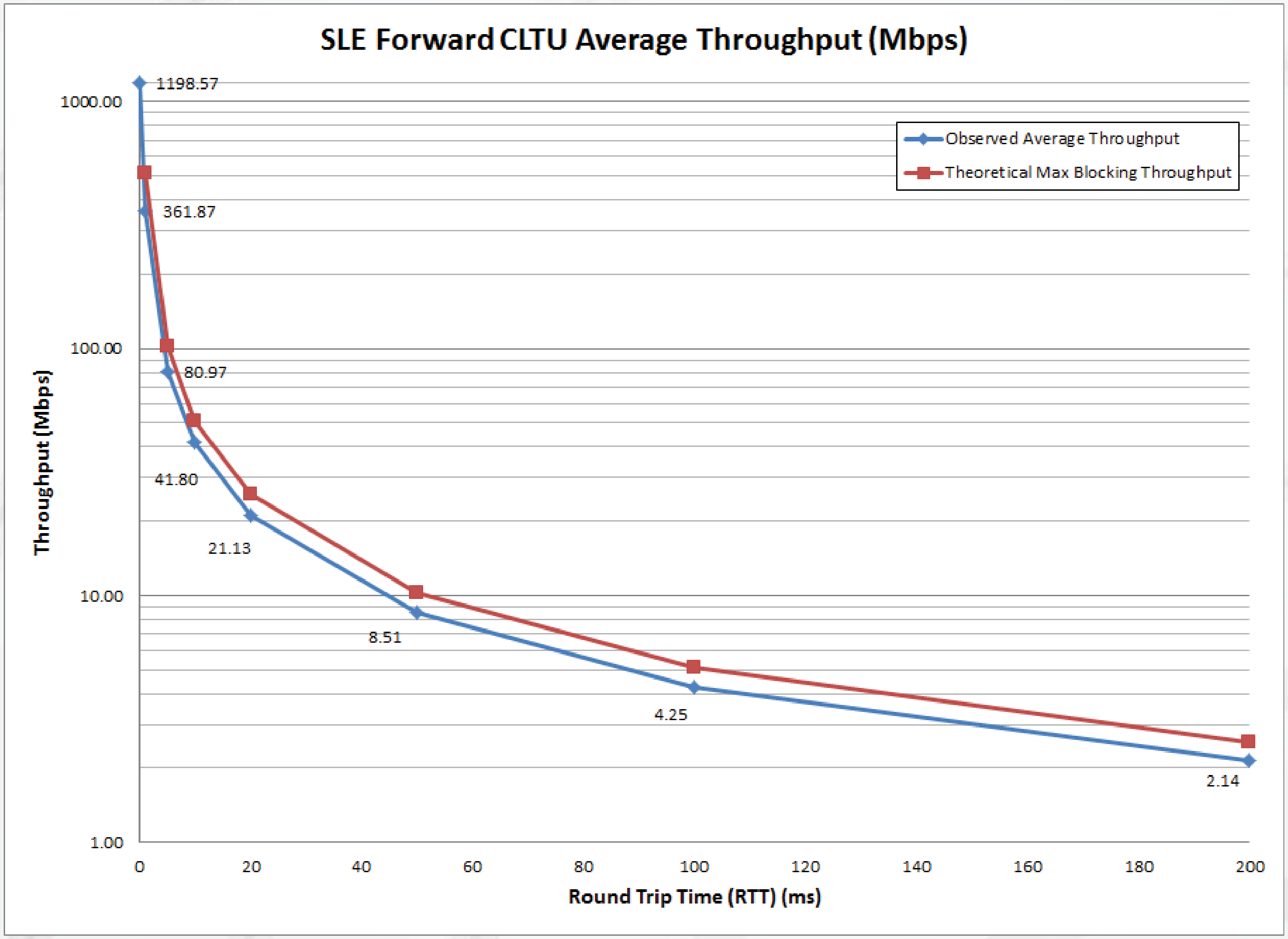
SLE Testbed Configuration

- Ground network emulation through Linux Servers
- Emulate same round-trip-time (RTT) delay as baseline network configuration test.
- Forward (F-CLTU) and Return (RAF) SLE Protocol tests



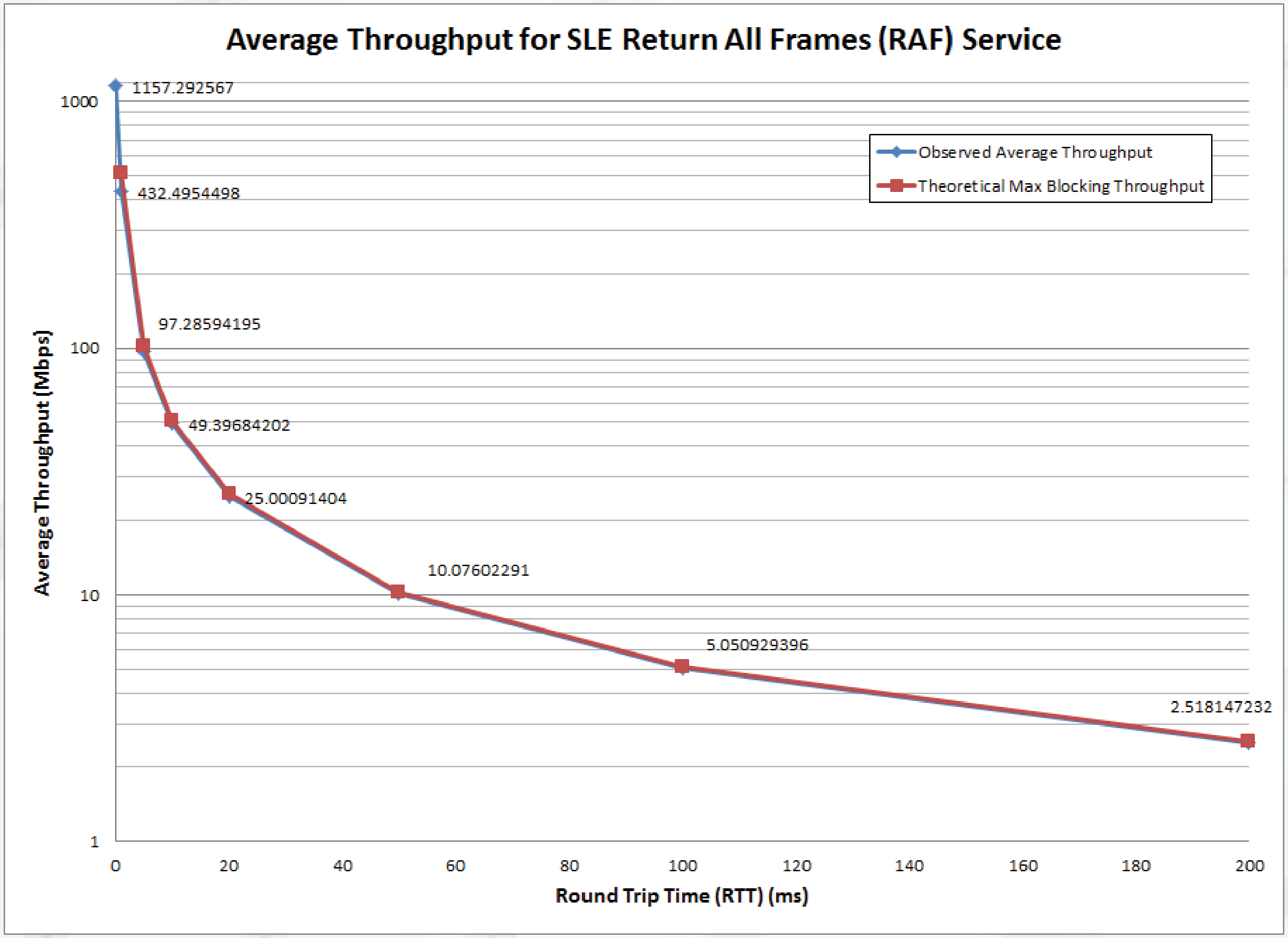
SLE Results

- SLE F-CLTU Protocol Throughput Results:



SLE Results

- SLE Return All Frames Protocol Throughput Results:

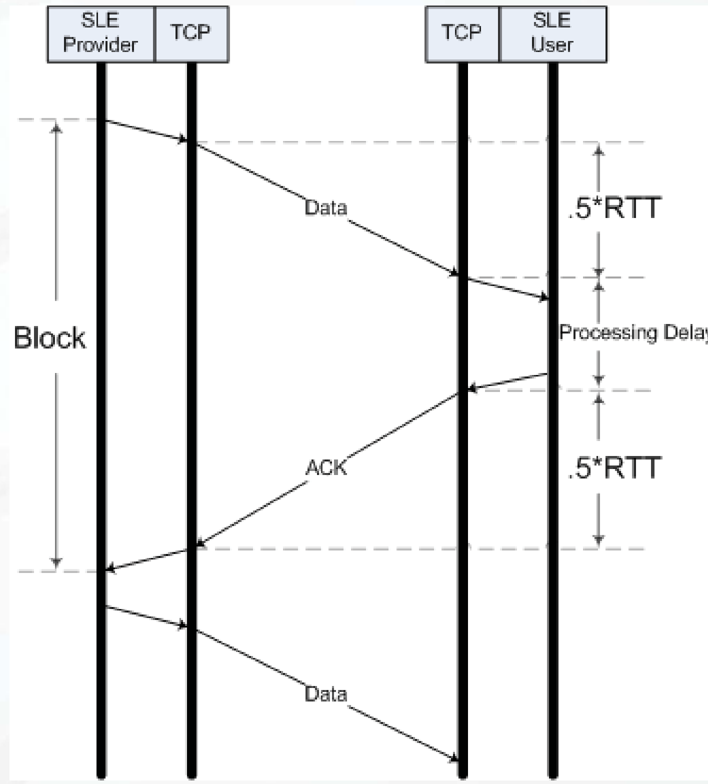


SLE Initial Results

- Significant decrease in achievable throughput with increasing network delay.
- Approximately 2.1-2.5 Mbps throughput with full 200 milliseconds network delay
  - Remaining packets are dropped as SLE transmission queue overflows
- Initial observations:
  - SLE implementation utilized blocking communications
  - Based on observations and collaboration with Ingenicomm SLE developers
  - Supported by CCSDS SLE API Specifications and Standards

SLE Initial Results

- Blocking Communications:
  - Maximum SLE PDU size is 64 kilobytes
  - Ka-Band Single Access Communication Link: 1.2 Gbps
  - Maximum expected round-trip-time delay across CONUS for the NASA Integrated Services Network (NISN)[1]
    - 200 milliseconds
  - Maximum blocking throughput:
    - R = S / T
    - Approximately 2.62 Mbps at 200ms delay



1) NASA Communication Service Office (CSO) Services Document (CSD)

SLE Initial Results

- CCSDS SLE Performance Issues
  - CCSDS API Specifications for F-CLTU
    - Supports both blocking and non-blocking invocations for CLTU-TRANSFER-FRAME
    - Leaves it as an option for the SLE implementation
  - Typically a non-issue
    - SLE is generally used for low data rate S-Band communication links
    - Data rates on the order of 50-100 kbps
  - For high bandwidth-delay product links
    - Significant reduction in achievable throughput

1. an implementation can always pass invocations for which a check has failed to the application
2. an implementation can prevent queuing of invocations by withholding an invocation until the previous invocation has been confirmed by the application. In that case, it can always generate the appropriate return when needed; or
3. an implementation can decide to pass invocations to the application on a case by case basis

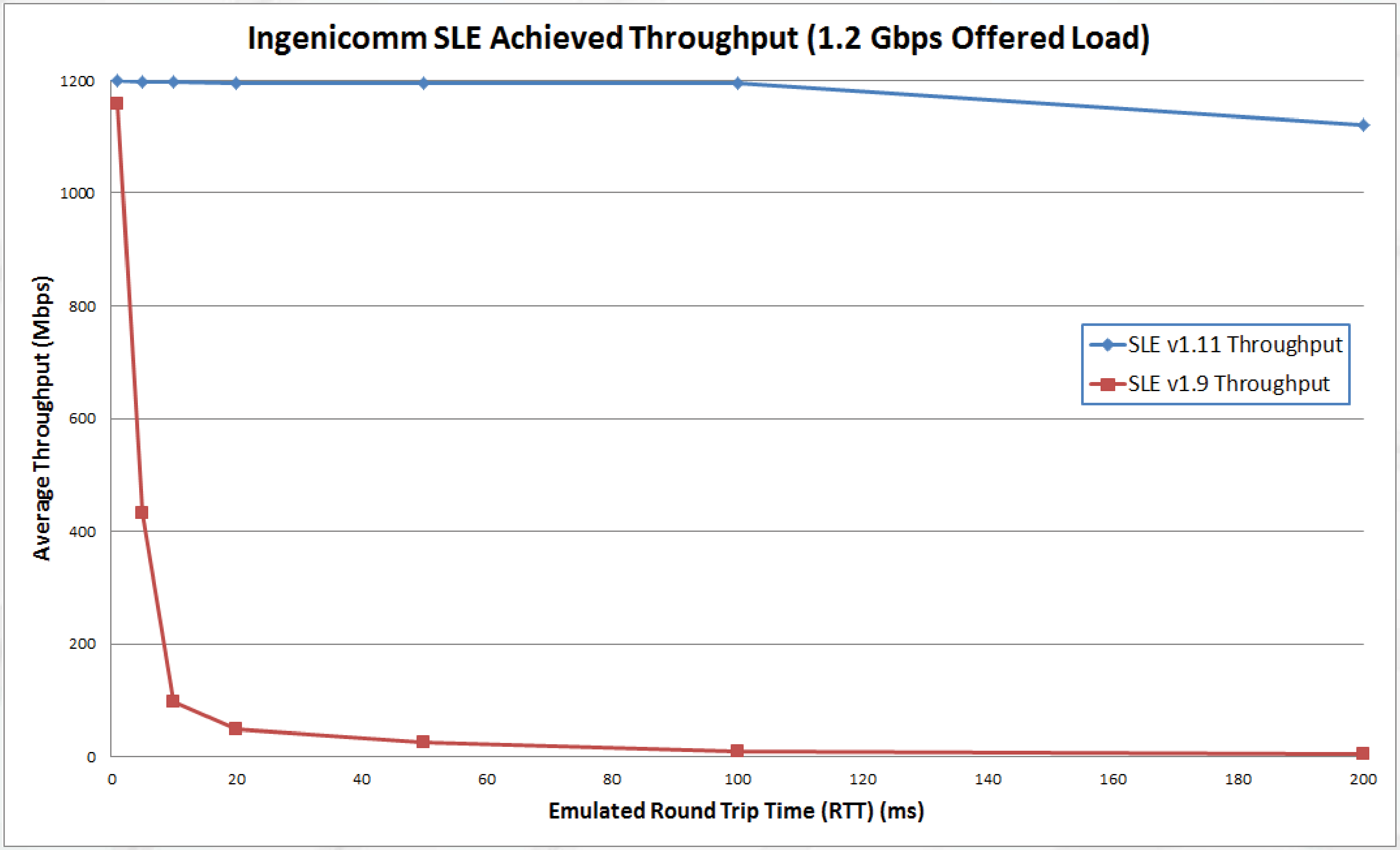
Options for SLE Handling of CLTU-TRANSFER-FRAME Return Message
SLE F-CLTU API Specifications, Section 2.2.8.3

SLE Initial Results

- Reaction to Initial Results:
  - Collaboration with SLE Vendor, Ingenicomm
  - Several weeks of narrowing down issue
  - Could not precisely determine issue:
    - No access to proprietary source code
  - Reported observations to SLE Vendor via NASA Technical Report

Improved Results

- Improved Ingenicomm CGS SLE Results

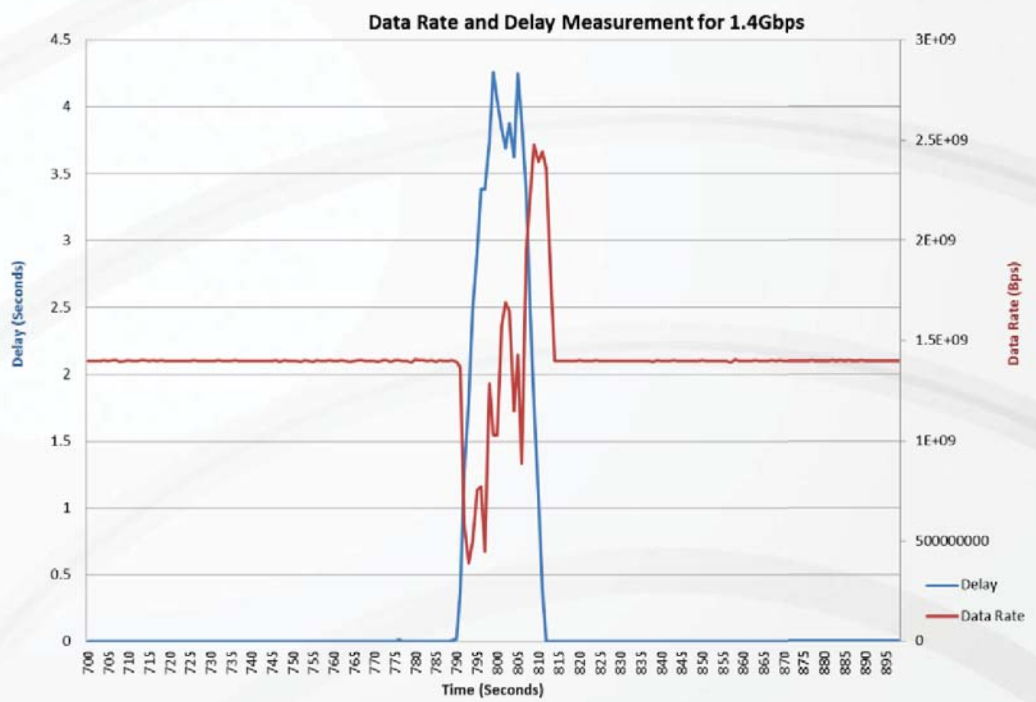


Improved Results

- Improved results:
  - Updated version of Ingenicomm CGS SLE Software
  - Based on direct collaboration with Ingenicomm developers
  - Issues with blocking communication resolved
- Still reduced throughput at 1.2Gbps offered load
  - Packet error caused temporary TCP throttling
  - Brings down average throughput, no packet loss
  - Buffering at remote ground station required to maintain constant bitstream to satellite modem

Future SLE Work

- Additional SLE Emulation Tests Required:
  - How do packet drops affect SLE data flow
  - Current observations:
    - TCP throttling
    - Temporary reduction in data throughput:
  - Future research:
    - Expected behavior of TCP
    - How can we work around this behavior
      - Additional buffering?
      - Other protocols besides TCP?



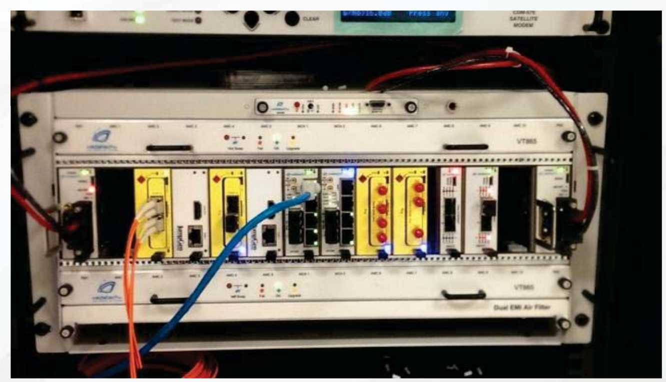
Future Work in SCENIC Lab

- SLE is only one ground network protocol
  - Legacy protocols must be tested in the INA Network Environment to ensure compatibility
  - Future protocols can be tested to determine compatibility with space-based technologies
- Ingenicomm SLE is only one flavor of SLE
  - Compatibility testing with other SLE vendors
  - RT-Logic, VEGA, etc

Future Work in SCENIC Lab

- Full End-to-End Emulation Lab
  - Space-link emulation
  - Software Defined Radio (SDR) Development
    - Test proposed network protocols / waveforms
    - Fully integrated with ground network emulation testbed

Spacecraft → Wireless Channel → Software Defined Radio → Remote Ground Station → **SCENIC Ground Network Emulation** → End-User



Acknowledgements

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Thank you!

Questions?