Delay Tolerant Networking

CCSDS Media Streaming
Test Results Presentation

2024-05-29

A Kármán Line View

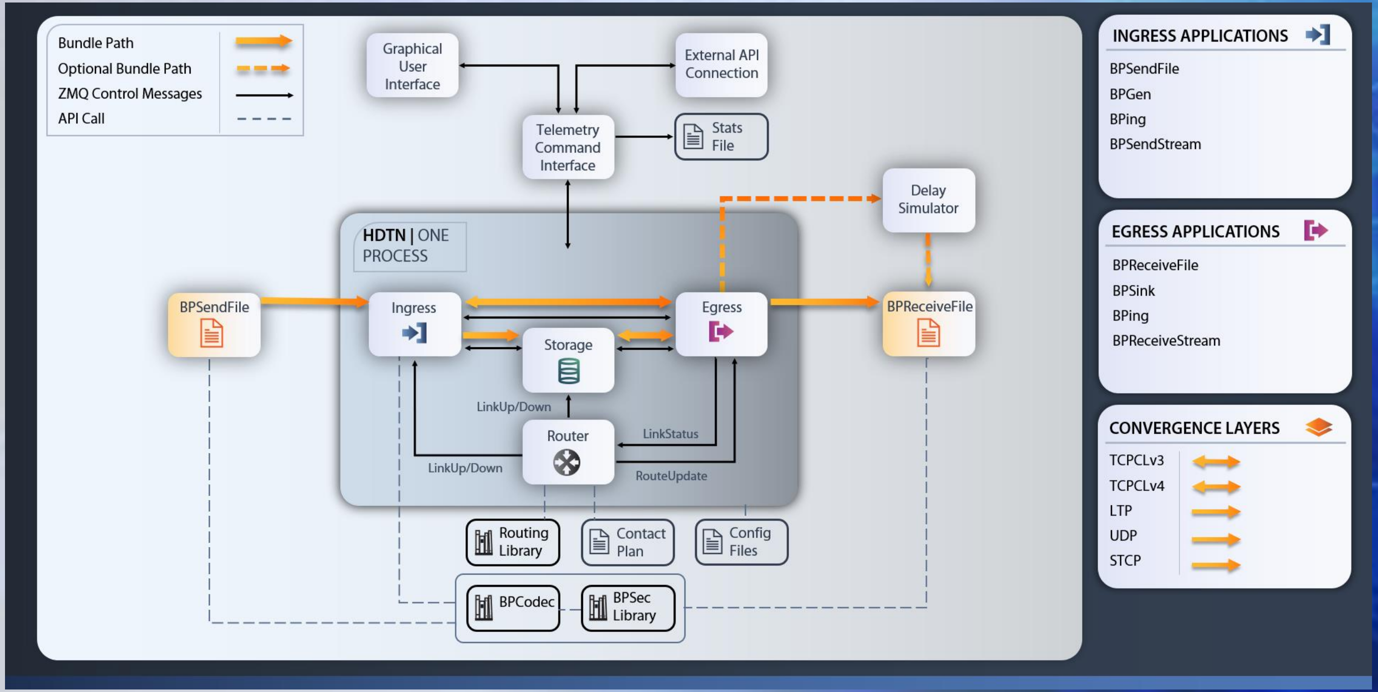
Goal:

Improve network data throughput to meet future user needs,

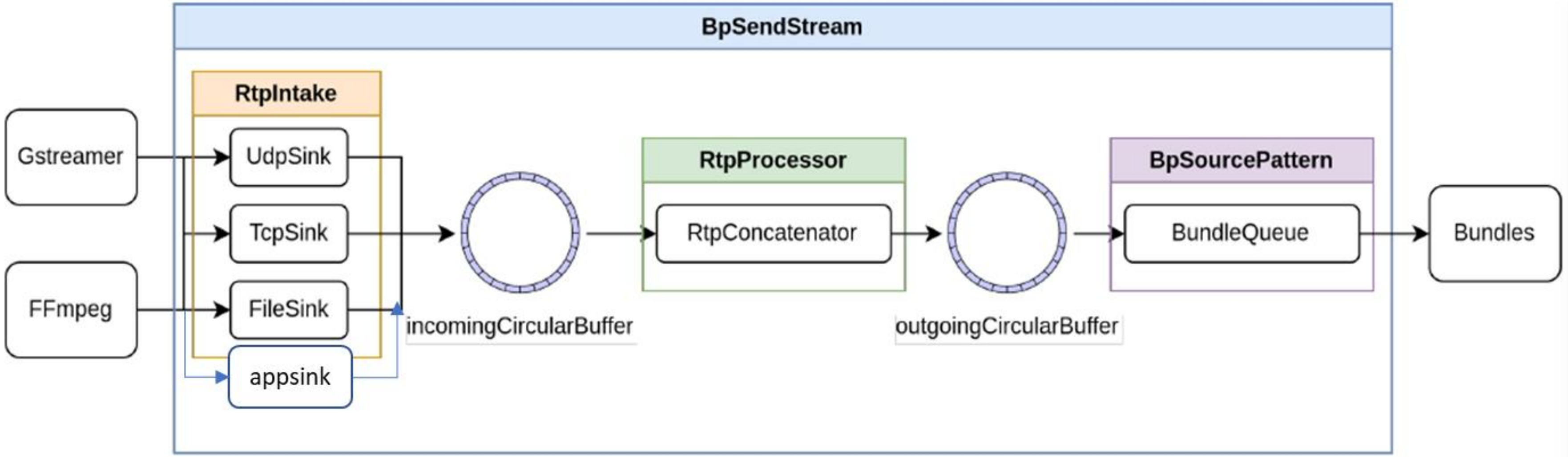
by enhancing communications capability to increase mission science return

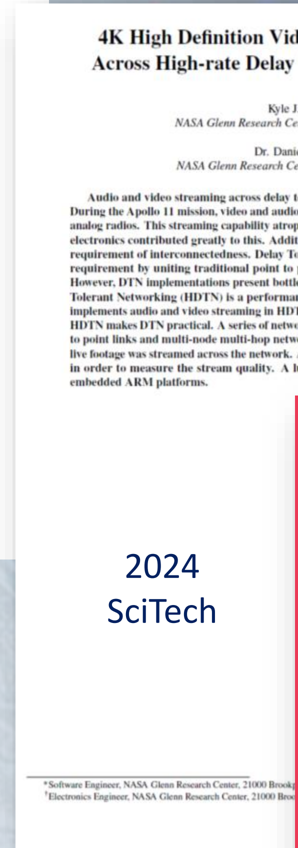
HDTN provides and maintains a store and forward codebase as per the DTN suite of standards, including documentation and NPR compliance, and capable of supporting Gbps transfer rates for emerging laser and RF technologies

- Public release on GitHub
- Features BPv7, storage, scheduling, link status, routing, BPSec and a web interface
- Rates exceeding Gbps may be achieved
- 7150.2D class-B software compliance effort
- Implements 4K HD media streaming



Implementing BP based Real-time Transport Protocol (RTP)




4K High Definition Video and Audio Streaming Across High-rate Delay Tolerant Space Networks

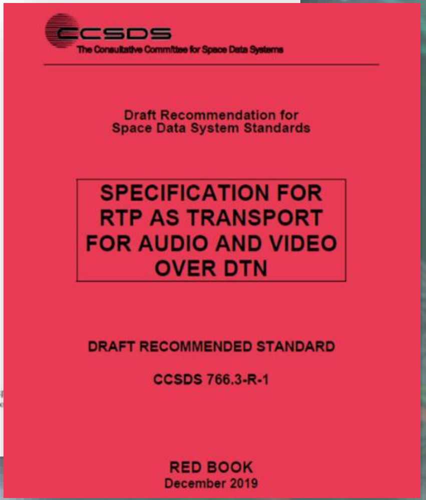
Kyle J. Vernyi *
NASA Glenn Research Center, Cleveland, Ohio, 44135

Dr. Daniel E. Raible†
NASA Glenn Research Center, Cleveland, Ohio 44135

Audio and video streaming across delay tolerant networks are relatively new phenomena. During the Apollo 11 mission, video and audio were streamed directly back to Earth using fully analog radios. This streaming capability atrophied over time. The gradual conversion to digital electronics contributed greatly to this. Additionally, 21st century space systems face the new requirement of interconnectedness. Delay Tolerant Networking (DTN) attempts to solve this requirement by uniting traditional point to point links into a robust and dynamic network. However, DTN implementations present bottlenecks due to low performance. High-Rate Delay Tolerant Networking (HDTN) is a performance-optimized DTN implementation. This work implements audio and video streaming in HDTN. Streaming at high bit rates demonstrates that HDTN makes DTN practical. A series of network topologies were created including simple point to point links and multi-node multi-hop networks. Test media in the form of prerecorded and live footage was streamed across the network. A set of objective quality metrics were established in order to measure the stream quality. A lunar network was emulated using a mixture of embedded ARM platforms.

*Software Engineer, NASA Glenn Research Center, 21000 Brook
†Electronics Engineer, NASA Glenn Research Center, 21000 Broo

2024
SciTech


CCSDS
The Consultative Committee for Space Data Systems

Draft Recommendation for
Space Data System Standards

SPECIFICATION FOR
RTP AS TRANSPORT
FOR AUDIO AND VIDEO
OVER DTN

DRAFT RECOMMENDED STANDARD

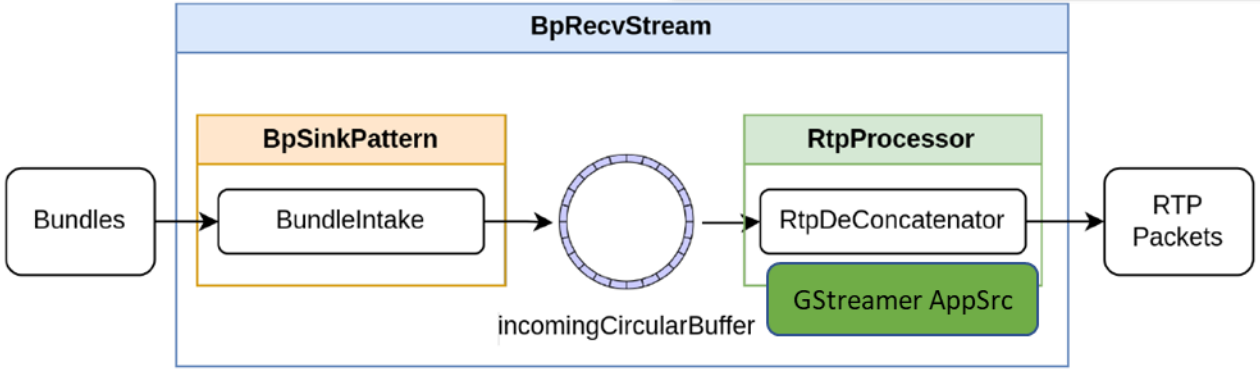
CCSDS 766.3-R-1

RED BOOK
December 2019

ISS *“WaterBubble”* test example:

- Demanding 4K60
- 10bit 4:2:2 color
- ~33Mbps, depending on encoding
- 1, 20, 30 & 45 RTP packets per bundle
- Induced disconnections and 10s delays

Implemented on network of Raspberry Pi-4’s

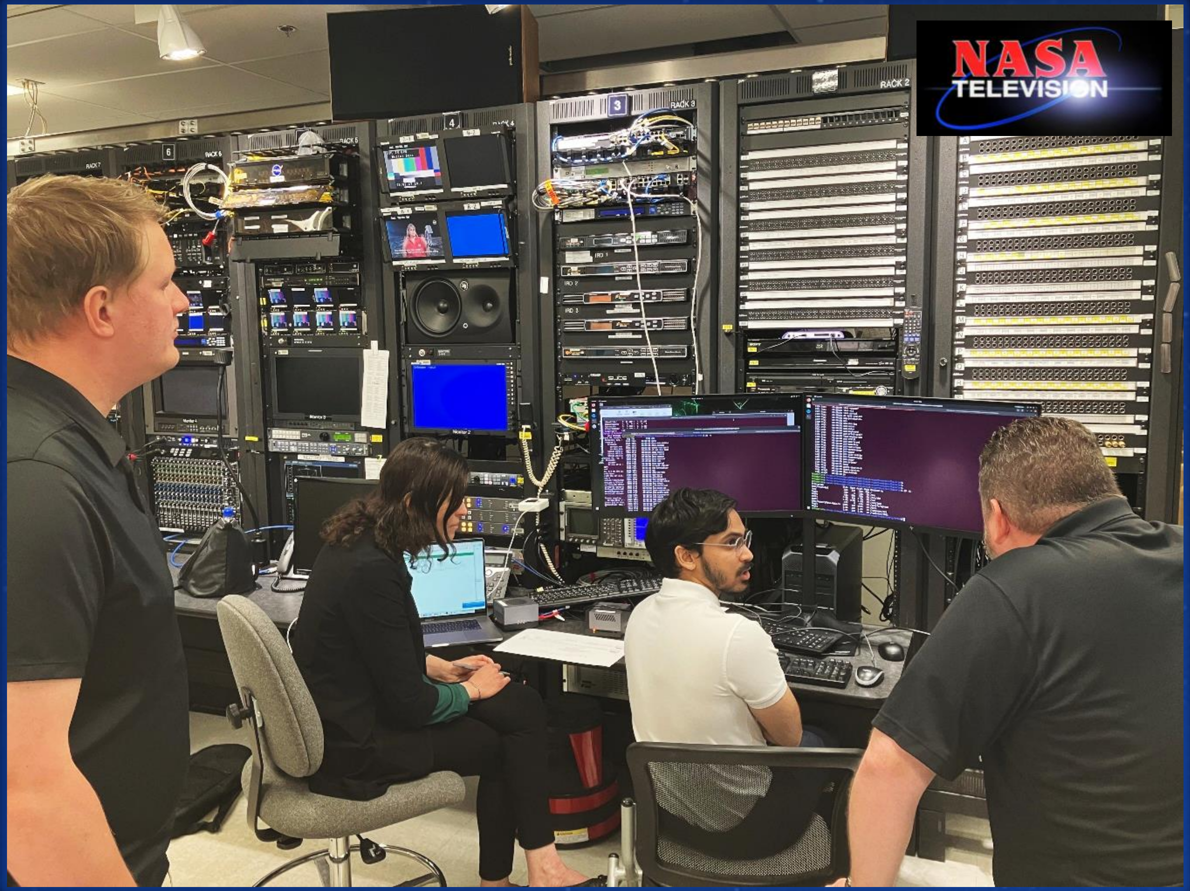


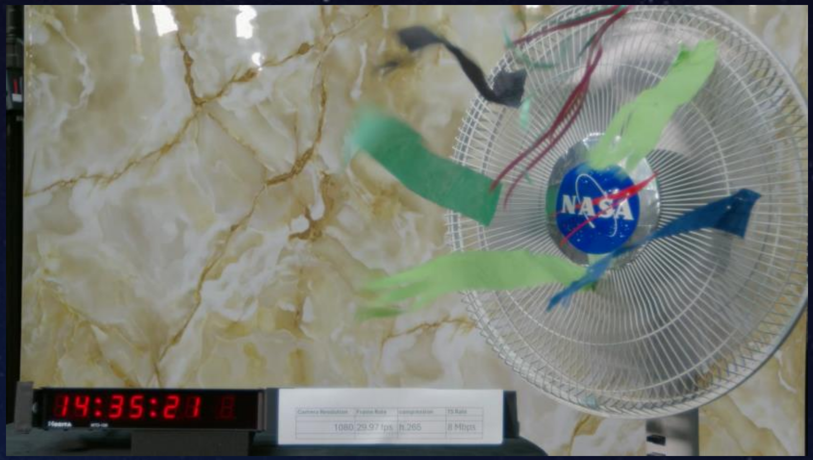
Thanks to Joshua Deaton for steering us toward the draft standards

Performance Metrics:

Media Type	Metric Name	Units	Range	Notes
Video	Peak SNR (PSNR)	dB	-	Not a good indicator of video quality but is industry standard.
Video	Structural Similarity (SSIM)	-	[-1, 1]	Considers image degradation as perceived change in structural information. Moving towards human perception.
Video	VMAF	-	[0, 100]	ML model trained by Netflix. Attempts to model human perception of the media.
Audio	PSNR	dB	-	Standard measurement

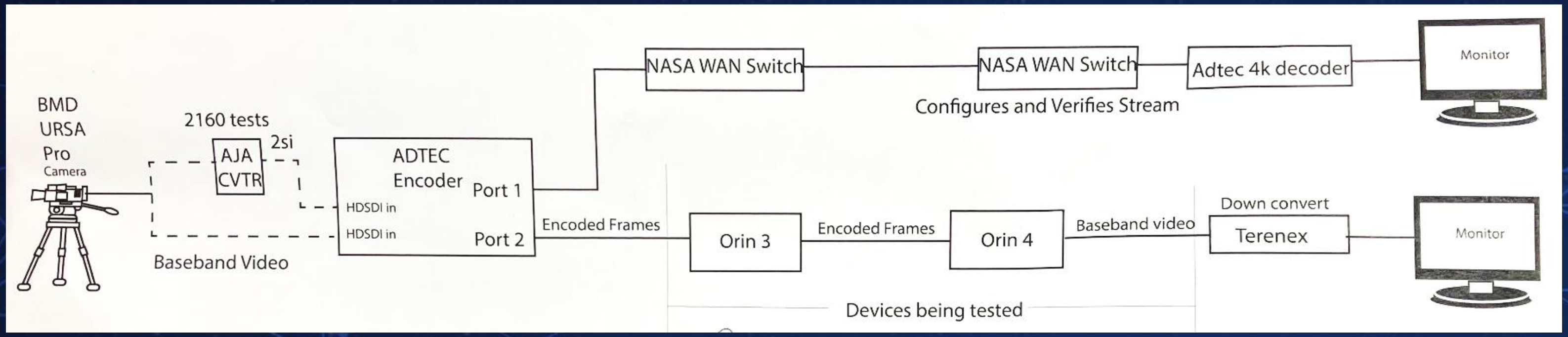
CCSDS Testing Using Hardware Encoding and Live Camera Feed





Hardware encoder test points:

- 720P30 h.264 @ 2 Mbps
- 720P60 h.264 @ 4 Mbps
- 1080P30 h.265 @ 4 Mpbs, 6 Mbps and 8 Mbps
- 1080P60 h.265 @ 6 Mbps and 8 Mbps
- 2160P30 h.265 @ 6 Mpbs and 8 Mbps
- 2160P60 h.265 @ 10, 11, 12, 20 & 30 Mbps



Huge thanks to Hugh Aylward, Jim Firak and Mike Burroughs for offering their assistance in configuring all the equipment and keeping us organized

HDTN Streaming Configurations

Sender:

```
${HDTN_RTP_DIR}/build/bpsend_stream  --bundle-size=65535 --bundle-rate=0 --use-bp-version-7 \
        --my-uri-eid=ipn:8.1 --dest-uri-eid=ipn:7.1 --outducts-config-file=$parentDir/config/orin3/bpsendstream_stcp.json \
        --num-circular-buffer-vectors=10000 --rtp-packets-per-bundle=20 --max-incoming-udp-packet-size-bytes=1460 \
        --induct-type="udp" --incoming-rtp-stream-port=$incoming_rtp_port &
```


```
{
    "outductConfigName": "bpsendstream to orin4",
    "outductVector": [
        {
            "name": "to localhost hdtn one process",
            "convergenceLayer": "stcp",
            "nextHopNodeId": 1,
            "remoteHostname": "localhost",
            "remotePort": 5000,
            "maxNumberOfBundlesInPipeline": 10000,
            "maxSumOfBundleBytesInPipeline": 50000000,
            "keepAliveIntervalSeconds": 17
        }
    ]
}
```


Receiver:

```
# BpRecvStream
${HDTN_RTP_DIR}/build/bprecv_stream  --my-uri-eid=ipn:7.1 --inducts-config-file=$parentDir/config/orin4/bprecvstream_sctp.json --max-rx-bundle-size-bytes 63000 \
        --num-circular-buffer-vectors=10000 --max-outgoing-rtp-packet-size-bytes=1460 --outduct-type="udp" --outgoing-rtp-port=8554 --outgoing-rtp-hostname="127.0.0.1"
```


```
{
    "inductConfigName": "orin4 from local hdtn one process",
    "inductVector": [
        {
            "name": "stcp_bpsink",
            "convergenceLayer": "stcp",
            "boundPort": 7000,
            "numRxCircularBufferElements": 10000,
            "keepAliveIntervalSeconds": 15
        }
    ]
}
```

Streaming Results Across Various Camera and Encoder Configurations

Visual review of the received streams revealed no discernable degradation of the video

Note: these results were obtained on a non-optimized network

Camera	Resolution	Resolution Name	Frame Rate	Encoder	Encoding	Bit Rate (Mbps)	Average Peak Signal-to-Noise Ratio (dB) Between Original and Received File	Average Bit Error Rate (BER) Between Original and Received File	Average BER as a %	Structual Similarity Index (SSIM)
Sony SRG-XB25	2160p	Ultra HD (UHD)	60	Built-in	H.265/HEVC	8	24.025711	0.003957573	0.395757269	0.921279
Sony SRG-XB25	2160p	Ultra HD (UHD)	30	Built-in	H.265/HEVC	8	29.447873	0.001135567	0.113556683	0.976461
Sony SRG-XB25	2160p	Ultra HD (UHD)	30	Built-in	H.265/HEVC	6	29.566445	0.001104983	0.110498275	0.973399
Sony SRG-XB25	1080p	Full HD (FHD)	60	Built-in	H.265/HEVC	8	28.786799	0.00132227	0.132226986	0.964291
Sony SRG-XB25	1080p	Full HD (FHD)	60	Built-in	H.265/HEVC	6	29.790016	0.001049539	0.104953856	0.971046
Sony SRG-XB25	1080p	Full HD (FHD)	30	Built-in	H.265/HEVC	8	25.981402	0.002522666	0.252266627	0.957827
Sony SRG-XB25	1080p	Full HD (FHD)	30	Built-in	H.265/HEVC	6	29.329159	0.001167036	0.116703559	0.972197
Sony SRG-XB25	1080p	Full HD (FHD)	30	Built-in	H.265/HEVC	4	29.788406	0.001049928	0.104992772	0.97294
Sony SRG-XB25	720p	HD	60	Built-in	H.264/AVC	4	29.375692	0.001154598	0.1154598	0.967433
Sony SRG-XB25	720p	HD	30	Built-in	H.264/AVC	2	28.418212	0.001439391	0.143939106	0.959395
BMD URSA Pro (Media Room)	2160p	Ultra HD (UHD)	60	Adtec Afiniti	H.265/HEVC	12	23.902684	0.004071286	0.407128589	0.876792
BMD URSA Pro (Media Room)	2160p	Ultra HD (UHD)	60	Adtec Afiniti	H.265/HEVC	11	24.205668	0.003796935	0.379693533	0.883862

BONUS

Camera	Resolution	Resolution Name	Frame Rate	Encoder	Encoding	Bit Rate (Mbps)	Average Peak Signal-to-Noise Ratio (dB) Between Original and Received File	Average Bit Error Rate (BER) Between Original and Received File	Average BER as a %	Structual Similarity Index (SSIM)
Sony SRG-XB25	2160p	Ultra HD (UHD)	60	Built-in	H.265/HEVC	30	18.812346	0.013145146	1.314514557	0.903893
Sony SRG-XB25	2160p	Ultra HD (UHD)	60	Built-in	H.265/HEVC	20	21.674586	0.006800509	0.680050869	0.907503

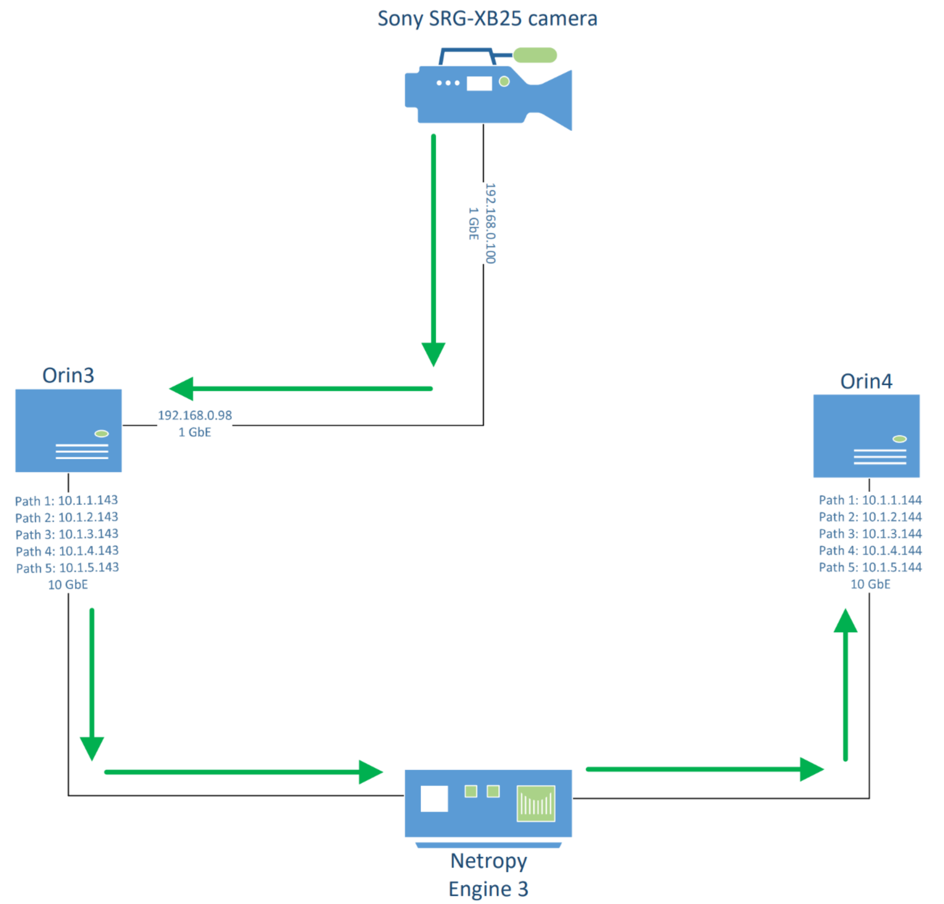
TREND

Camera	Resolution	Resolution Name	Frame Rate	Encoder	Encoding	Bit Rate (Mbps)	Average Peak Signal-to-Noise Ratio (dB) Between Original and Received File	Average Bit Error Rate (BER) Between Original and Received File	Average BER as a %	Structual Similarity Index (SSIM)
Sony SRG-XB25	2160p	Ultra HD (UHD)	60	Built-in	H.265/HEVC	**8**	24.025711	0.003957573	0.395757269	0.921279
BMD URSA Pro (Media Room)	2160p	Ultra HD (UHD)	60	Adtec Afiniti	H.265/HEVC	**11**	24.205668	0.003796935	0.379693533	0.883862
BMD URSA Pro (Media Room)	2160p	Ultra HD (UHD)	60	Adtec Afiniti	H.265/HEVC	**12**	23.902684	0.004071286	0.407128589	0.876792
Sony SRG-XB25	2160p	Ultra HD (UHD)	60	Built-in	H.265/HEVC	**20**	21.674586	0.006800509	0.680050869	0.907503
Sony SRG-XB25	2160p	Ultra HD (UHD)	60	Built-in	H.265/HEVC	**30**	18.812346	0.013145146	1.314514557	0.903893

Video quality	SSIM value
Excellent	0,93 or more
Good	0,88-0,93
Fair	0,84-0,88
Poor	0,78-0,84
Bad	0,78 or less

Thanks to Rodney, Walt, Beth, Sandy and Jeremy for hooking us up with gear and guidance to conduct these tests

HDTN Streaming Layout Using Delay and Disruption (reordering and duplication)



Netropy Path	Reordering Probability	Reordering Timeout	Duplication Probability	Side 1 Name	Side 1 IP	Side 2 Name	Side 2 IP
Path 1	10%	750 ms	0%	orin3-test1	10.1.1.143	orin4-test1	10.1.1.144
Path 2	10%	750 ms	10%	orin3-test2	10.1.2.143	orin4-test2	10.1.2.144
Path 3	50%	1500 ms	0%	orin3-test3	10.1.3.143	orin4-test3	10.1.3.144
Path 4	10%	100 ms	0%	orin3-test4	10.1.4.143	orin4-test4	10.1.4.144
Path 5	Variable*	Variable*	Variable*	camera	192.168.0.100	orin4-test5	10.1.5.144

*When routing directly to the camera without HDTN, settings on Path 5 were updated for each test to match the other Paths. In these cases, orin4 was configured to use orin3-test5 as an IP router to the camera to pull data through the Netropy.

HDTN Streaming Results Using Delay and Disruption (reordering and duplication)

Camera Settings: 1080P60 H.265 @ 8 Mbps

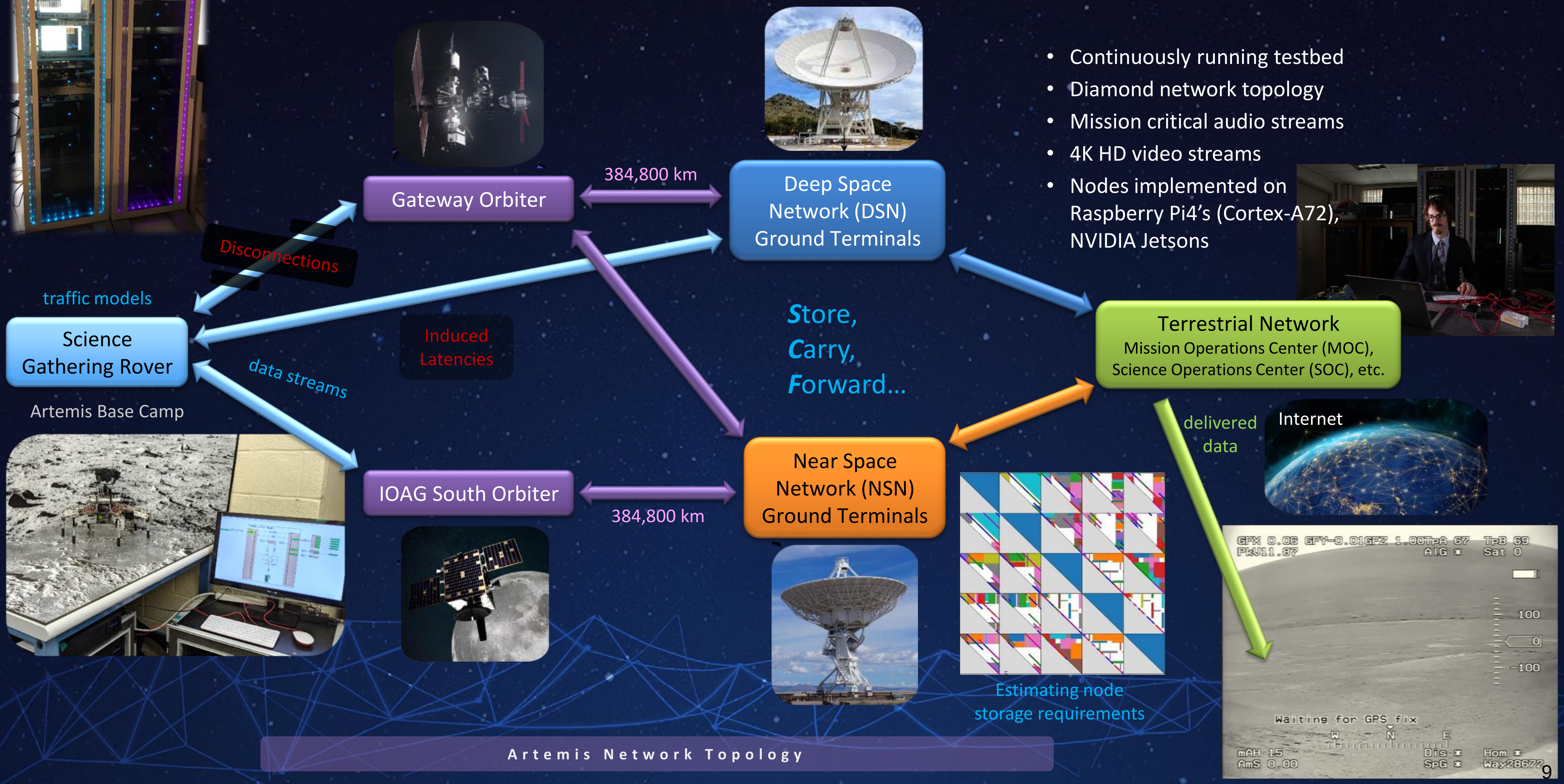
Netropy Path	Reordering Probability	Reordering Timeout	Duplication Probability	Side 1 Name	Side 1 IP	Side 2 Name	Side 2 IP
Path 1	10%	750 ms	0%	orin3-test1	10.1.1.143	orin4-test1	10.1.1.144
Path 2	10%	750 ms	10%	orin3-test2	10.1.2.143	orin4-test2	10.1.2.144
Path 3	50%	1500 ms	0%	orin3-test3	10.1.3.143	orin4-test3	10.1.3.144
Path 4	10%	100 ms	0%	orin3-test4	10.1.4.143	orin4-test4	10.1.4.144

Scenarios	Configuration	Average Peak Signal-to-Noise Ratio (dB) Between Baseline and Received	Structual Similarity Index (SSIM) Between Baseline and Received
1	No DTN (just RTP over UDP)	11.264069	0.661995
2		11.674342	0.686143
3		9.786832	0.514632
4		10.2071	0.595434
1	HDTN with 1 RTP packet per bundle	10.935887	0.6765
2		9.388365	0.540245
3		9.012866	0.497818
4		10.669843	0.656239
1	HDTN with 5 RTP packets per bundle	27.847981	0.921007
2		24.573204	0.904236
3		28.190421	0.925601
4		26.974887	0.906726
1	HDTN with 20 RTP packets per bundle	28.913023	0.93251
2		28.783082	0.934622
3		29.327898	0.948557
4		30.874348	0.983011

Demos: Simulating & Emulating LunaNet Internetworked Operations

Buffering data until a transmit opportunity arises, where an end-to-end path may not be available

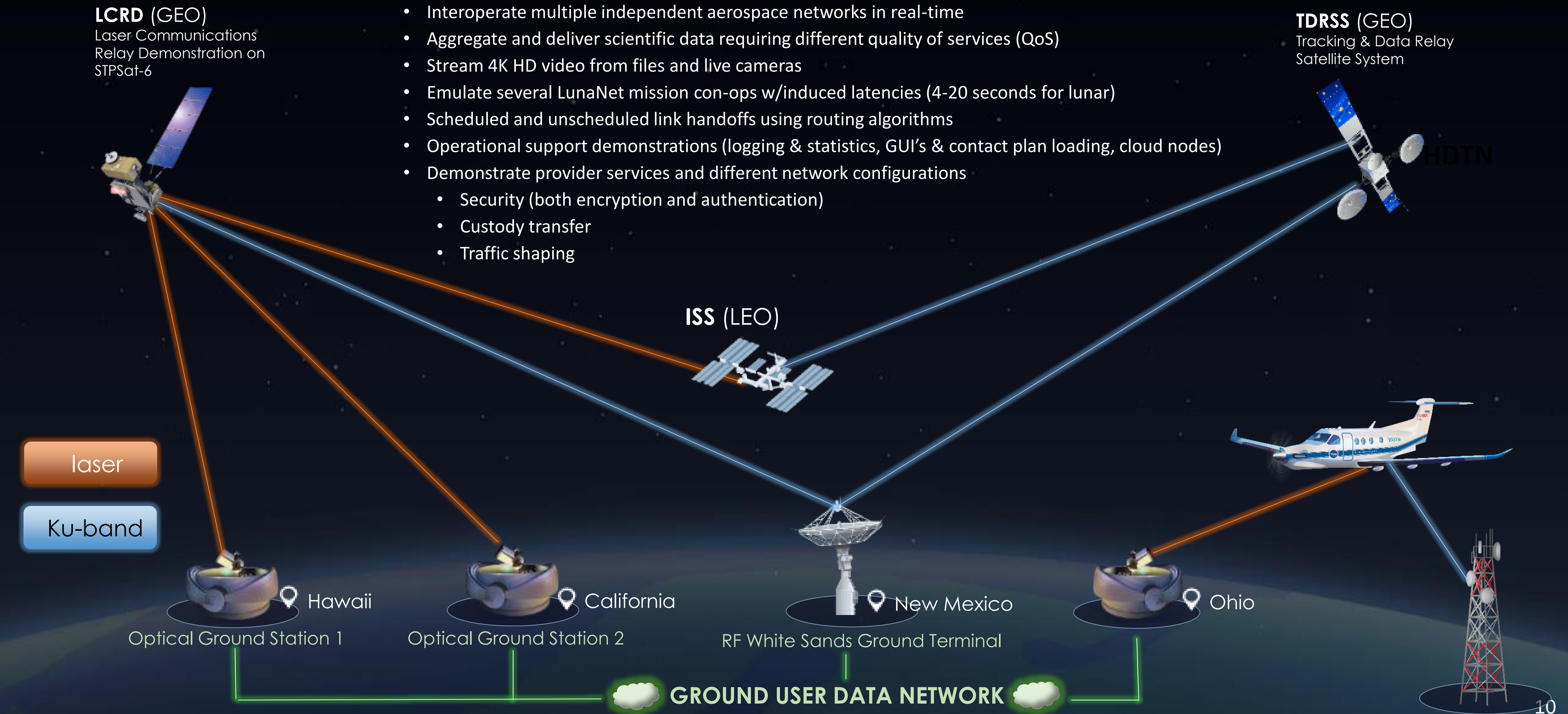
- Continuously running testbed
- Diamond network topology
- Mission critical audio streams
- 4K HD video streams
- Nodes implemented on Raspberry Pi4's (Cortex-A72), NVIDIA Jetsons



2024 Internetworked ISS Experiments

Enabling Networked Optical Communications Rates

- Interoperate multiple independent aerospace networks in real-time
- Aggregate and deliver scientific data requiring different quality of services (QoS)
- Stream 4K HD video from files and live cameras
- Emulate several LunaNet mission con-ops w/induced latencies (4-20 seconds for lunar)
- Scheduled and unscheduled link handoffs using routing algorithms
- Operational support demonstrations (logging & statistics, GUI's & contact plan loading, cloud nodes)
- Demonstrate provider services and different network configurations
  - Security (both encryption and authentication)
  - Custody transfer
  - Traffic shaping



Mission Infusion: Preparing for Artemis Mission Capability Needs

The rationale for transitioning to Class B is to give DTN the required pedigree to allow it to be utilized in operational non-human space-rated systems

NASA Research and Technology Program and Project Management Requirements NPR 7120.8

NASA Software Engineering Requirements NPR 7150.2D

User Features Request

Software Assurance and Safety Standard NASA STD-8739.8

Project

- Project Schedule 3
- Configuration and Data Mgmt. Plan (CDMP) 2
- Con Ops/User Scenarios 2
- Interface Requirements (IRD) 2

Planning and Process

- 7150 Compliance Matrix 2
- SW Development Management Plan (SDMP) 5
- SW Configuration Mgmt. Plan (SCMP) 2
- Requirements Mgmt. Plan (RMP) 2
- SW V&V Plan 2
- SW Metrics Report 1
- SW Inspection Report 1
- SW Change Requests 1

Development

- SW Requirements Specification (SRS) 5
- Cybersecurity Analysis 2
- Architecture/Design Description 5
- SW Data Dictionary 2
- Interface Description (IDD) 2
- Code
- Test Procedures 4
- Verification Report 2
- Version Description 2
- Requirements Traceability Matrix 3
- User Manual 3

SW Assurance

- SW Assurance & Safety Plan (SASP) 3
- Safety Critical Assessment 1
- SA Audit Results 1

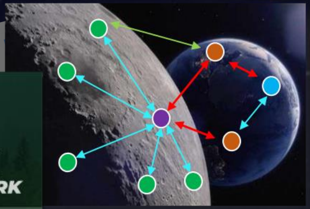
Legend

- External Requirements/Guidance
- Documents
- Code
- Progress: Completed / Incomplete
- # Document complexity 1=low, 5 = high

7150.2D Class-B Software Documentation Tree Status

HDTN Technology Readiness Level (TRL) Path to Artemis

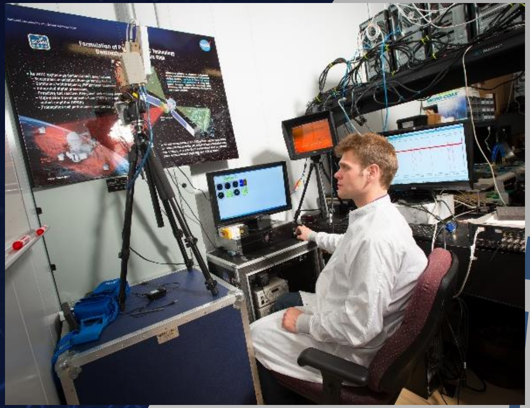
Technology Development and Testing: 2015 – 2022
Implementation and documentation of reference design
Establish space networking emulation laboratory at GRC for verification
Integrated testing at JSC Software Development and Integrated Laboratory (SDIL)
Field testing with GRC aircraft laser communications
Public release of products on GitHub
TRL 4-6

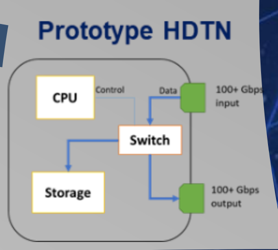


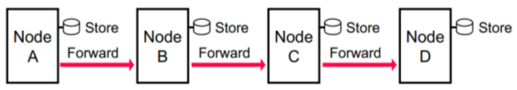
Infusion into Artemis LunaNet operations: 2025 ->
Supporting human and robotic missions
TRL 9

Flight Technology Demonstrations: 2023 - 2024
Laser Communications Relay Demonstration (LCRD) and
International Space Station (ISS)
experiments conducted in relevant environments
Compliance with NPR-7150.2D engineering requirements
TRL 7-8

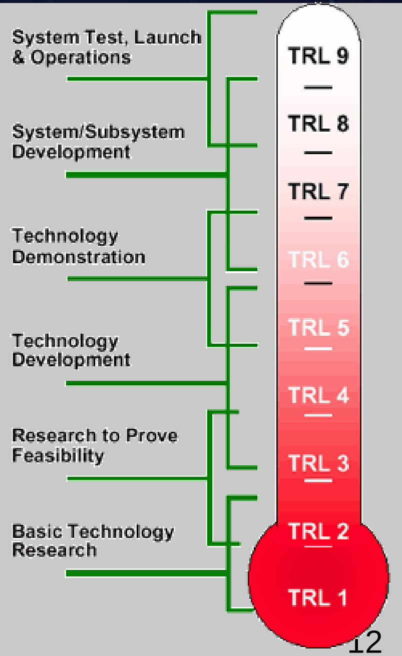
GitHub







Research and Formulation: 2009 – 2014
Problems associated with high rate space networking analyzed
Concept of operations established, feasibility proven with separate control & data planes
Critical components identified including scheduling, routing, storage, security, streaming
Contribute to international open standards communities
Performance-optimized architecture proposed, prototyped and demonstrated in laboratory
TRL 2-3



Mission Infusion: Near Space Network (NSN) Plans

Task	Description
Development and Implementation of DTN Routing Features (including trade studies & improvements)	• Schedule-based Routing • Profile-based Routing • Multicast • Intra-domain Routing • Storage-constrained Routing • Cognitive Routing
Development and Implementation of DTN Security Features	• BPSec in DTN • DTN Security Testbed • BPSec in SCaN network
Development and Implementation of DTN Network Management Features	• Cognitive Networking Implementation • Software Defined Networking Implementation • Accounting and Reporting • Performance Monitoring • Address Management • Nodal Configuration Management • Node Validation Automation • Automated Route Updates
Testbed Development for V&V	• Common DTN Performance Testing Environment • Large-scale DTN Simulation and Emulation • DTN Security Testbed • DTN Multi-center Testing Support
Development and Implementation of DTN Traffic Management Features	• Congestion Control • Source/Destination QoS • Fragmentation Control • Storage QoS
DTN Resource Collaboration	• Common DTN Performance Testing Environment • Common GUI • BPSec Demonstration Interoperability and Development

General goals:

- Easy to configure using support tools, so the deployment is scalable just as the software is
- Team availability to help manage / configure / support / develop during operations

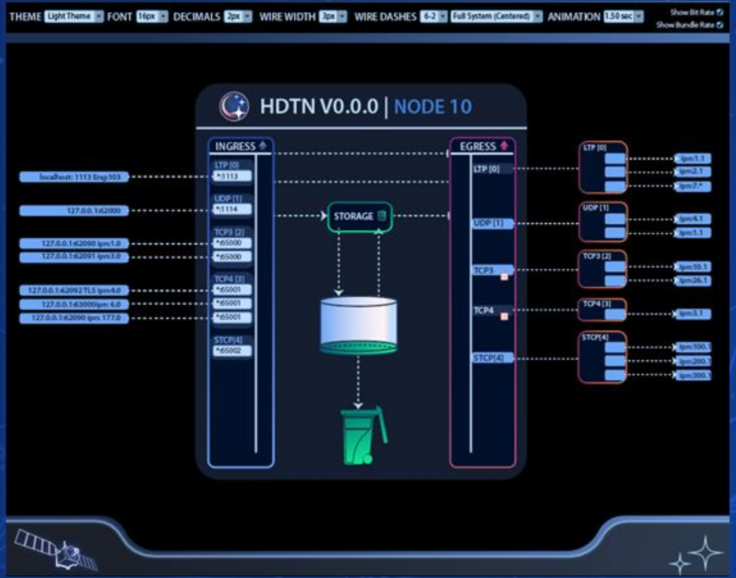
Internetworked ISS Experiments

Mission Networking Risks We Aim to Retire

- It will be difficult to configure widely disparate information streams (size, priority, security, etc.)
- End to end connectivity across independently owned networks (US gov, private industry, international partners) will be cumbersome
- Layers of security will cause significant performance degradation due to processing overhead
- Internal system performance metrics will not be readily available to perform system optimizations and effective network management
- Deploying new nodes in a complex network will be challenging
- Obtaining high network performance will require high degrees of engineering expertise
- Performing network maintenance will disrupt operations
- Reconfiguring the network to adapt to mission changes will be slow and tedious
- The DTN protocol will limit the data rates sent across the network
- Recovery from link interruptions will be slow and require operator intervention
- Coordinating multiple mission operation types on the same network will be cumbersome (human, robotic, tele-science, autonomous, etc.) especially during critical flight phases

Next Steps

- Continue gathering and post-processing data, look at VMAF
- Upgrade LunaNet scenario to hardware encoders, add microphones
- Reintroduce delays & disconnections, link handoffs
- Stress test system with other challenging video content, and HDTN optimizations
- Examine variations of parameter:
  - Video lengths, RTP per bundle numbers, bundle sizes, LTP tunings, etc.
  - Constant Bit Rate (CBR) to Variable Bit Rate (VBR)
- Stack additional services such as BPSec, video conferencing application
- Demonstrate multi-source and multi-destination BP services
- Field testing on the ISS / LCRD networks…
- Publish combined results of LunaNet duration testing, CCSDS configuration verification and ISS/LCRD performance results



Jellyfish Video Bitrate Test Files

this page is a mirror from http://jell.yfish.us/ thanks to his autor !!

Below are a number of H.264 and H.265/HEVC encoded .mkv video clips that can be used for testing the network streaming and playback performance of media streamers & HTPCs.

Filename (Click to Download)	Bitrate (Overall)	Resolution	Codec	Profile	Level	Tier	File Size
jellyfish-3-mbps-hd-h264.mkv	3 Mbps	1920x1080	H.264	High	4.0	N/A	11 MB
jellyfish-3-mbps-hd-hevc.mkv	3 Mbps	1920x1080	HEVC	Main	4.0	High	11 MB
jellyfish-3-mbps-hd-hevc-10bit.mkv	3 Mbps	1920x1080	HEVC	Main10	4.0	High	11 MB
jellyfish-5-mbps-hd-h264.mkv	5 Mbps	1920x1080	H.264	High	4.0	N/A	18 MB
jellyfish-5-mbps-hd-hevc.mkv	5 Mbps	1920x1080	HEVC	Main	4.0	High	18 MB
jellyfish-10-mbps-hd-h264.mkv	10 Mbps	1920x1080	H.264	High	4.0	N/A	36 MB
jellyfish-10-mbps-hd-hevc.mkv	10 Mbps	1920x1080	HEVC	Main	4.0	High	36 MB
jellyfish-10-mbps-hd-hevc-10bit.mkv	10 Mbps	1920x1080	HEVC	Main10	4.0	High	36 MB
jellyfish-15-mbps-hd-h264.mkv	15 Mbps	1920x1080	H.264	High	4.0	N/A	53 MB
jellyfish-15-mbps-hd-hevc.mkv	15 Mbps	1920x1080	HEVC	Main	4.0	High	53 MB
jellyfish-20-mbps-hd-h264.mkv	20 Mbps	1920x1080	H.264	High	4.0	N/A	71 MB
jellyfish-20-mbps-hd-hevc.mkv	20 Mbps	1920x1080	HEVC	Main	4.0	High	75 MB
jellyfish-20-mbps-hd-hevc-10bit.mkv	20 Mbps	1920x1080	HEVC	Main10	4.0	High	75 MB
jellyfish-25-mbps-hd-h264.mkv	25 Mbps	1920x1080	H.264	High	4.1	N/A	89 MB
jellyfish-25-mbps-hd-hevc.mkv	25 Mbps	1920x1080	HEVC	Main	4.0	High	93 MB
jellyfish-30-mbps-hd-h264.mkv	30 Mbps	1920x1080	H.264	High	4.1	N/A	106 MB
jellyfish-30-mbps-hd-hevc.mkv	30 Mbps	1920x1080	HEVC	Main	4.1	High	110 MB
jellyfish-35-mbps-hd-h264.mkv	35 Mbps	1920x1080	H.264	High	4.1	N/A	126 MB
jellyfish-35-mbps-hd-hevc.mkv	35 Mbps	1920x1080	HEVC	Main	4.1	High	129 MB
jellyfish-40-mbps-hd-h264.mkv	40 Mbps	1920x1080	H.264	High	4.1	N/A	142 MB
jellyfish-40-mbps-hd-hevc.mkv	40 Mbps	1920x1080	HEVC	Main	4.1	High	146 MB
jellyfish-40-mbps-hd-hevc-10bit.mkv	40 Mbps	1920x1080	HEVC	Main10	4.1	High	146 MB
jellyfish-45-mbps-hd-h264.mkv	45 Mbps	1920x1080	H.264	High	4.1	N/A	160 MB
jellyfish-45-mbps-hd-hevc.mkv	45 Mbps	1920x1080	HEVC	Main	4.1	High	166 MB
jellyfish-50-mbps-hd-h264.mkv	50 Mbps	1920x1080	H.264	High	4.2	N/A	180 MB
jellyfish-50-mbps-hd-hevc.mkv	50 Mbps	1920x1080	HEVC	Main	5.0	High	182 MB
jellyfish-55-mbps-hd-h264.mkv	55 Mbps	1920x1080	H.264	High	4.2	N/A	208 MB
jellyfish-55-mbps-hd-hevc.mkv	55 Mbps	1920x1080	HEVC	Main	5.0	High	199 MB
jellyfish-60-mbps-hd-h264.mkv	60 Mbps	1920x1080	H.264	High	5.0	N/A	213 MB
jellyfish-60-mbps-hd-hevc.mkv	60 Mbps	1920x1080	HEVC	Main	5.0	High	220 MB
jellyfish-60-mbps-hd-hevc-10bit.mkv	60 Mbps	1920x1080	HEVC	Main10	5.0	High	218 MB
jellyfish-70-mbps-hd-h264.mkv	70 Mbps	1920x1080	H.264	High	5.0	N/A	251 MB
jellyfish-70-mbps-hd-hevc.mkv	70 Mbps	1920x1080	HEVC	Main	5.0	High	256 MB
jellyfish-80-mbps-hd-h264.mkv	80 Mbps	1920x1080	H.264	High	5.0	N/A	286 MB
jellyfish-80-mbps-hd-hevc.mkv	80 Mbps	1920x1080	HEVC	Main	5.0	High	290 MB
jellyfish-90-mbps-hd-h264.mkv	90 Mbps	1920x1080	H.264	High	5.0	N/A	322 MB
jellyfish-90-mbps-hd-hevc.mkv	90 Mbps	1920x1080	HEVC	Main	5.0	High	329 MB
jellyfish-90-mbps-hd-hevc-10bit.mkv	90 Mbps	1920x1080	HEVC	Main10	5.0	High	330 MB
jellyfish-100-mbps-hd-h264.mkv	100 Mbps	1920x1080	H.264	High	5.0	N/A	358 MB
jellyfish-100-mbps-hd-hevc.mkv	100 Mbps	1920x1080	HEVC	Main	5.1	High	365 MB
jellyfish-110-mbps-hd-h264.mkv	110 Mbps	1920x1080	H.264	High	5.0	N/A	394 MB
jellyfish-110-mbps-hd-hevc.mkv	110 Mbps	1920x1080	HEVC	Main	5.1	High	401 MB
jellyfish-120-mbps-4k-uhd-h264.mkv	120 Mbps	3840x2160	H.264	High	5.1	N/A	431 MB
jellyfish-120-mbps-4k-uhd-hevc-10bit.mkv	120 Mbps	3840x2160	HEVC	Main10	5.1	High	438 MB
jellyfish-140-mbps-4k-uhd-h264.mkv	140 Mbps	3840x2160	H.264	High	5.1	N/A	502 MB
jellyfish-140-mbps-4k-uhd-hevc-10bit.mkv	140 Mbps	3840x2160	HEVC	Main10	5.1	High	525 MB
jellyfish-160-mbps-4k-uhd-h264.mkv	160 Mbps	3840x2160	H.264	High	5.1	N/A	573 MB
jellyfish-160-mbps-4k-uhd-hevc-10bit.mkv	160 Mbps	3840x2160	HEVC	Main10	5.2	High	586 MB
jellyfish-180-mbps-4k-uhd-h264.mkv	180 Mbps	3840x2160	H.264	High	5.1	N/A	647 MB
jellyfish-180-mbps-4k-uhd-hevc-10bit.mkv	180 Mbps	3840x2160	HEVC	Main10	5.2	High	658 MB
jellyfish-200-mbps-4k-uhd-h264.mkv	200 Mbps	3840x2160	H.264	High	5.1	N/A	718 MB
jellyfish-200-mbps-4k-uhd-hevc-10bit.mkv	200 Mbps	3840x2160	HEVC	Main10	5.2	High	731 MB
jellyfish-250-mbps-4k-uhd-h264.mkv	250 Mbps	3840x2160	H.264	High	5.1	N/A	897 MB
jellyfish-250-mbps-4k-uhd-hevc-10bit.mkv	250 Mbps	3840x2160	HEVC	Main10	6.1	High	914 MB
jellyfish-300-mbps-4k-uhd-hevc-10bit.mkv	300 Mbps	3840x2160	HEVC	Main10	6.1	High	1.0 GB
jellyfish-400-mbps-4k-uhd-hevc-10bit.mkv	400 Mbps	3840x2160	HEVC	Main10	6.1	High	1.4 GB

Delay Tolerant Networking (DTN)

We get your data home

Follow-up CCSDS Motion Imagery & Applications (MIA) Tests

Setup:
Camera<->Hardware Encoder<->HDTN<->Netropy<->HDTN<->Hardware Decoder<->Viewer and file archive for post processing

Camera at fixed resolution: 1080P60 h.265 @ 6 Mbps and 8 Mbps/bit rate

Test Sets:
No DTN just RTP over UDP by itself (acquires baseline degradation specs)
1 RTP packet per bundle
5 RTP packets per bundle
20 RTP packets per bundle

Netropy at out-of-order with a 100ms->1.5 second window, and between 10%-50% probability. Finally, enable duplication for one or more tests.