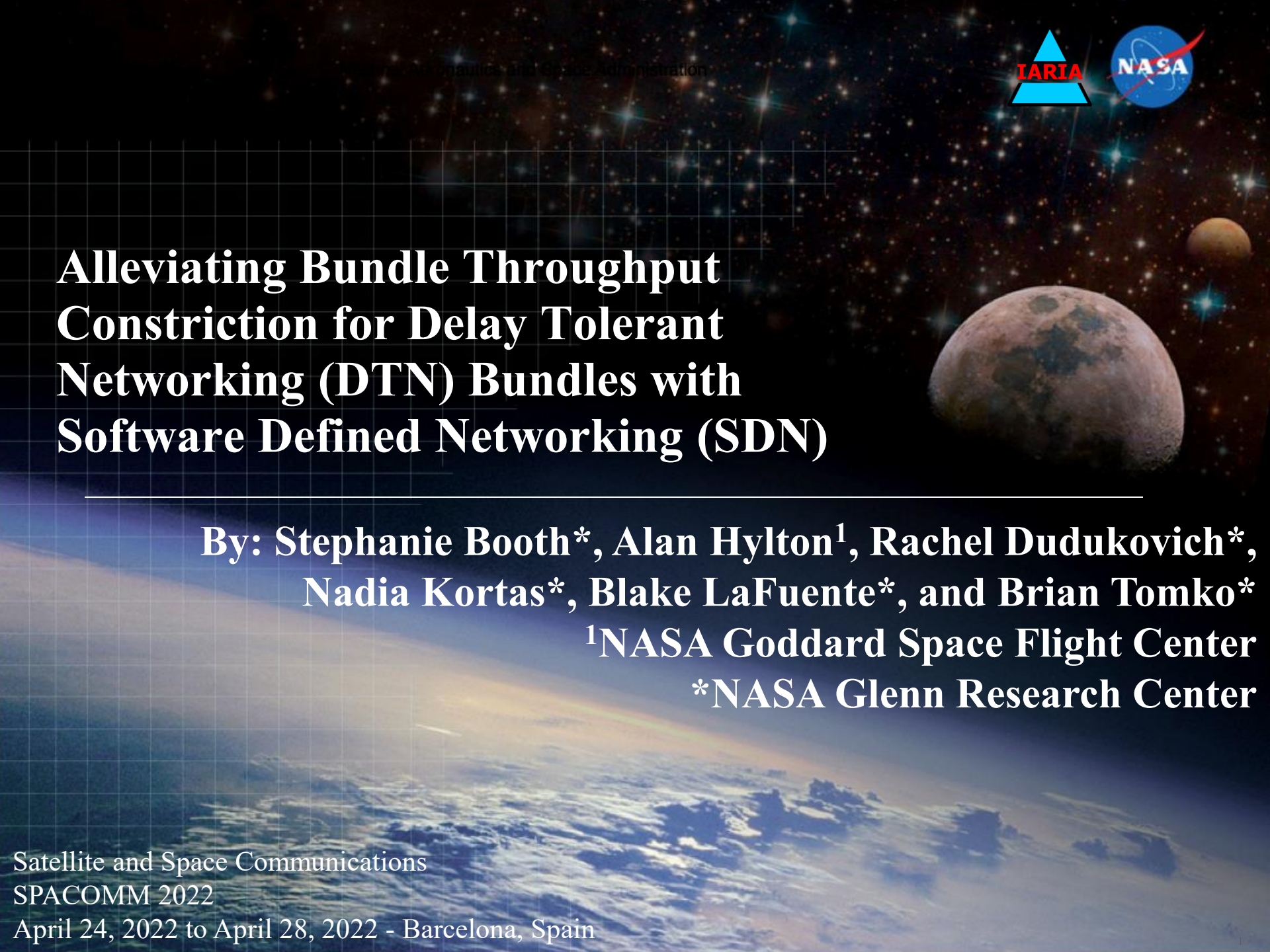

Alleviating Bundle Throughput Constriction for Delay Tolerant Networking (DTN) Bundles with Software Defined Networking (SDN)

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Her work and interest lies in software defined networking, delay tolerant networking, and testing high temperature SiC electronics. In addition, she has had previous work involving link analyses and free-space optics.

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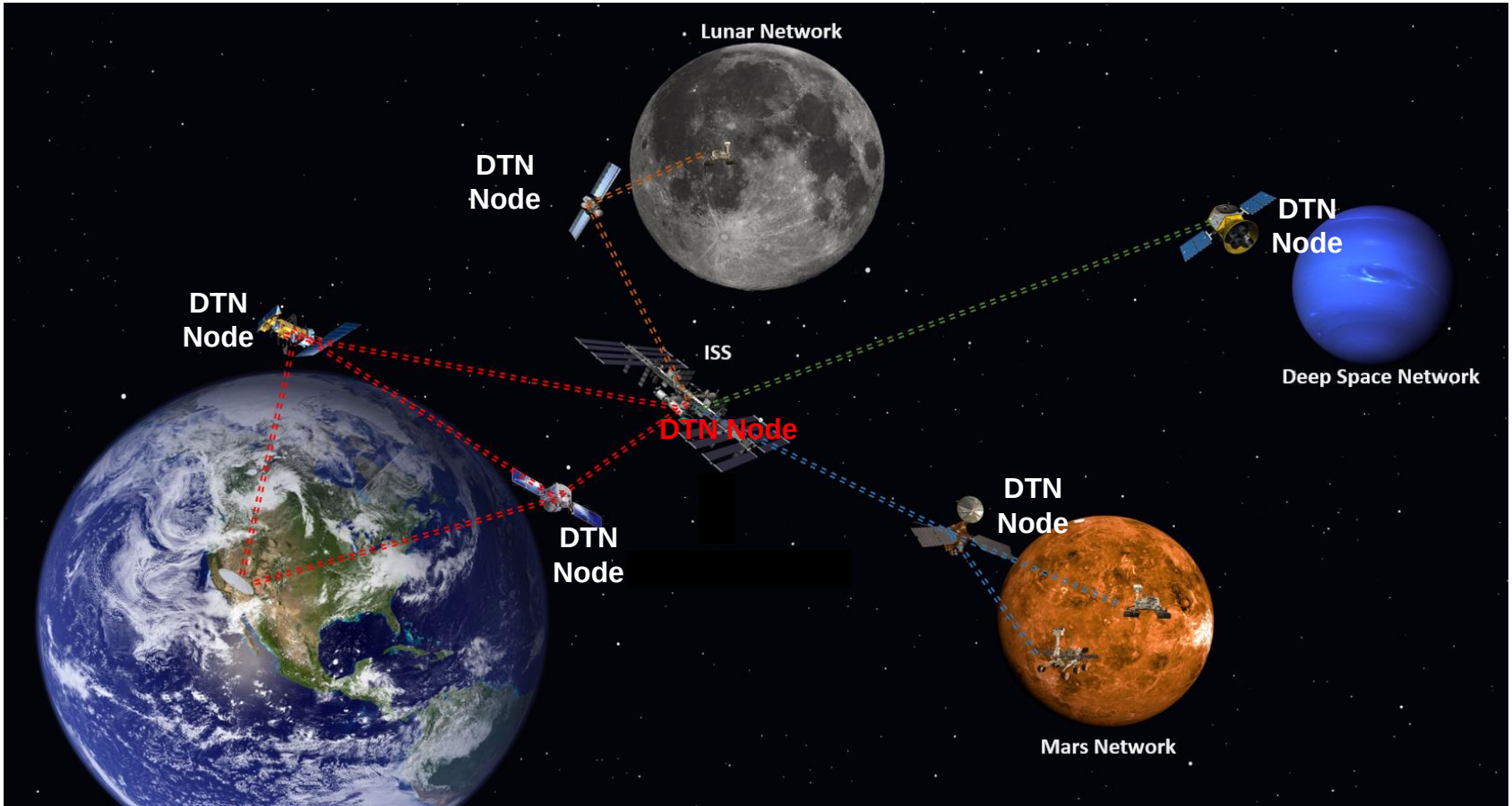
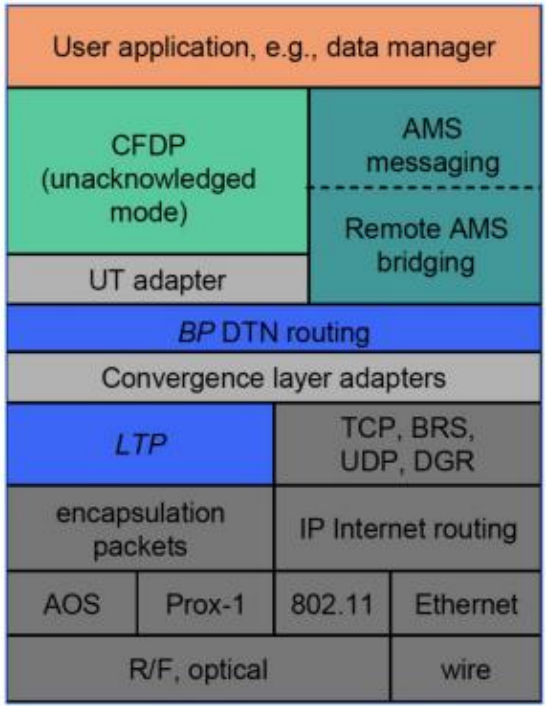
Problem Statement

- **Networks are expanding and becoming more complex. Therefore, they are also increasing bundle packet throughput within the system.**
- ***IF*** **DTN nodes are constricted in packet throughput, how would the system act? Would it just drop the packet without a flag? What happens** ***IF*** **all DTN node's send at their limits to the ISS DTN node?**



DTN Implementation: ION

- **Delay Tolerant Networking is the answer to space's long latencies and intermittent connections.**
  - A bundle can be fragmented into smaller bundles
  - Bundles are made up of blocks: Primary, Extension, Payload
- **Interplanetary Overlay Network (ION) will be the Delay Tolerant Networking (DTN) implementation used and compared against in this presentation.**
- **ION use Bundle Protocol (BP) version 6 (BPv6) but BPv7 is underway.**



DTN Protocol Stack

ION's Design Overview

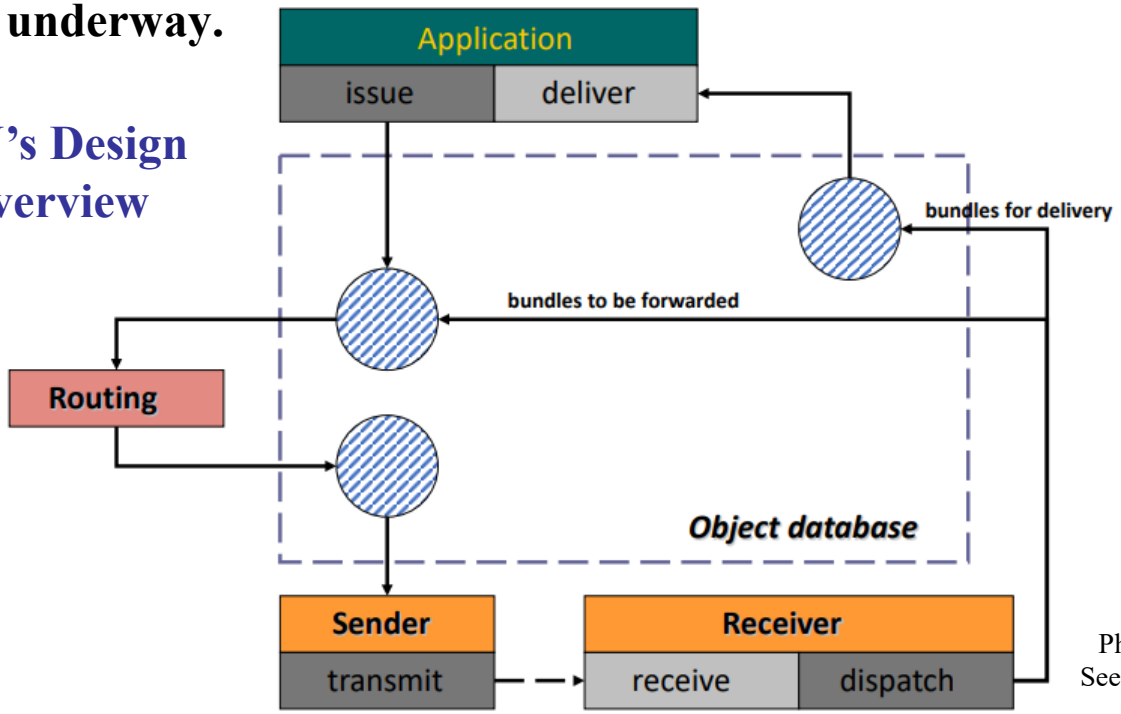


Photo Credit:
See Reference 1

Software Defined Networking (SDN) Switch

- **An Aurora 710 networking switch by Netberg was used.**
- **This switch contains**
  - 32 x 100 GbE four-lane Quad Small Form-factor Pluggable (QSFP) interfaces
  - Intel Tofino switching Integrated Circuit (IC)
- **This switch is Programming Protocol-Independent Packet Processors (P4) capable.**

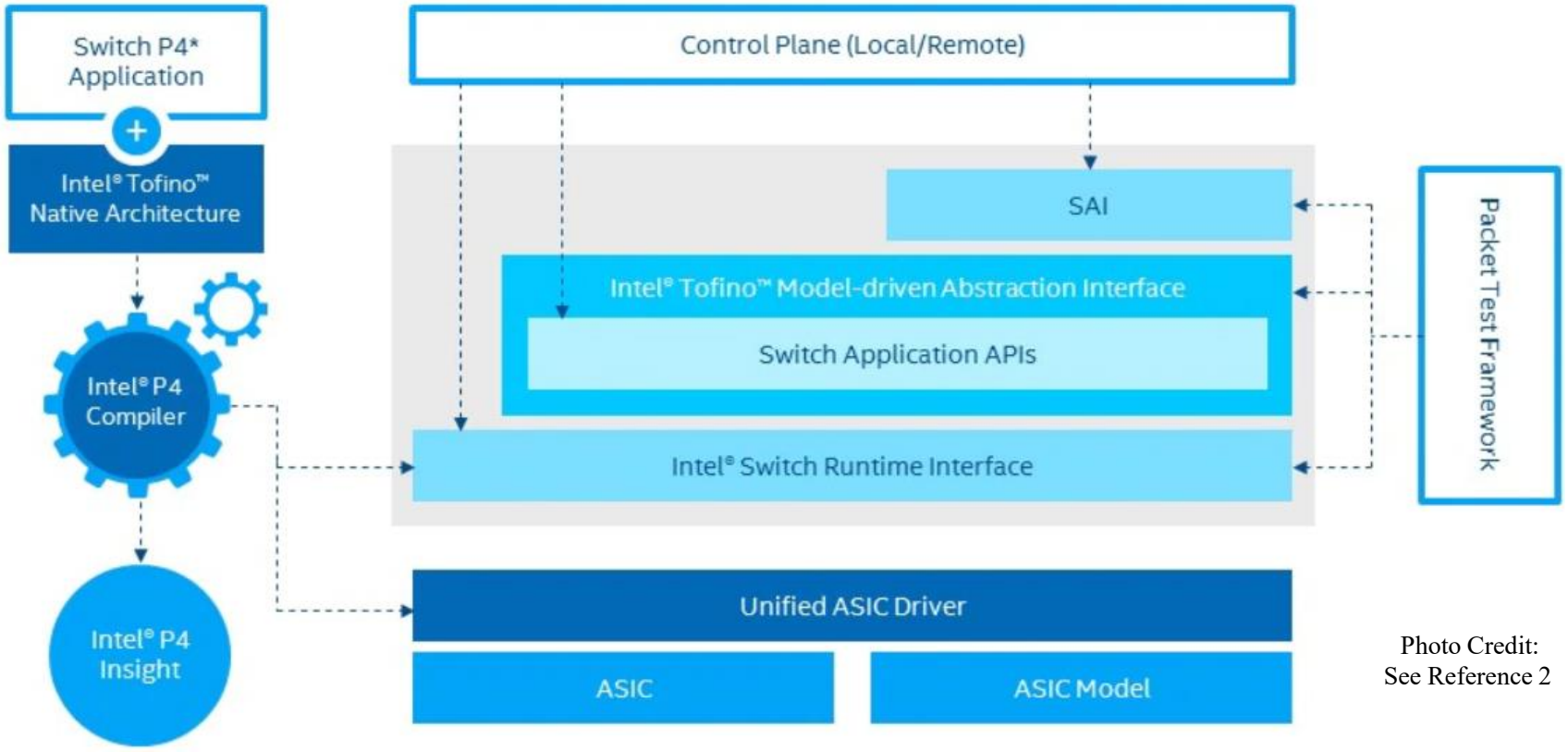
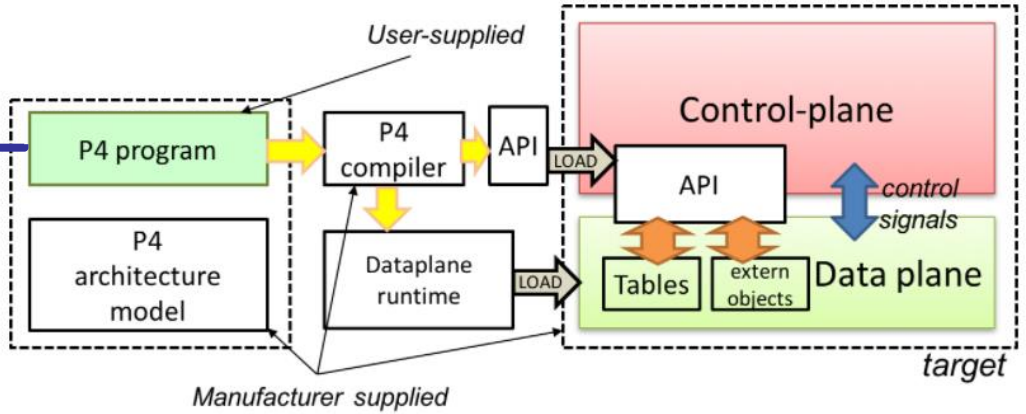


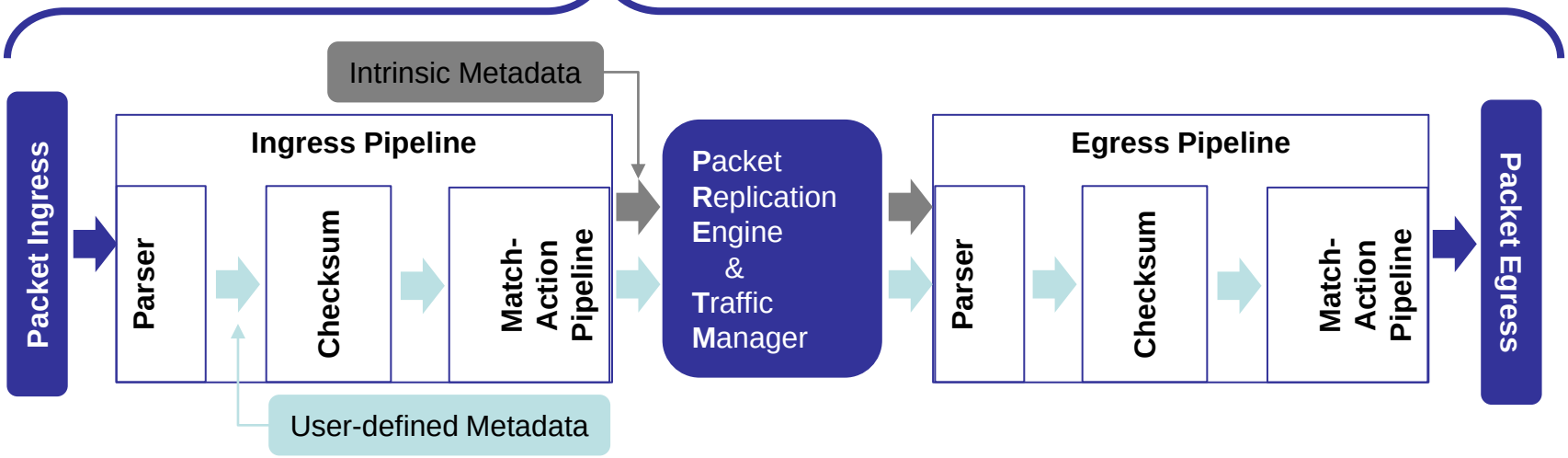
Photo Credit:
See Reference 2

P4 – Programming Protocol-independent Packet Processors

- **P4 allows implementing specific behavior in a network within minutes.**
- **P4 enables control over the programmable data plane.**
- **P4 can be used for a network to handle one or many, current and future protocols.**
- **Two major language reworks ie $P4_{14}$ and $P4_{16}$**

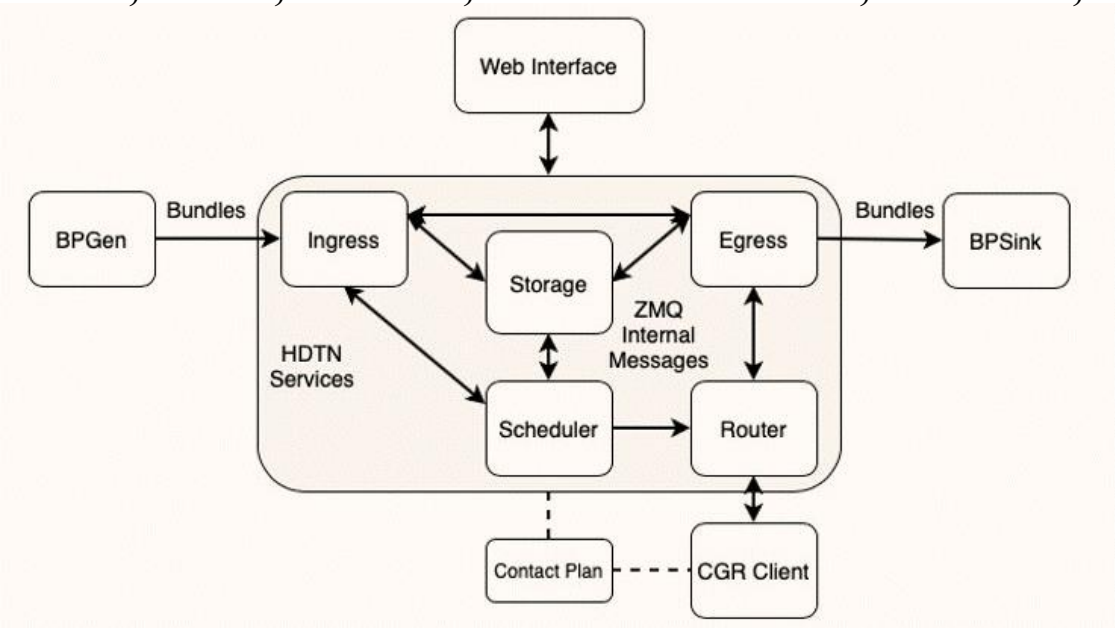


↑ Photo Credit: See Reference 3



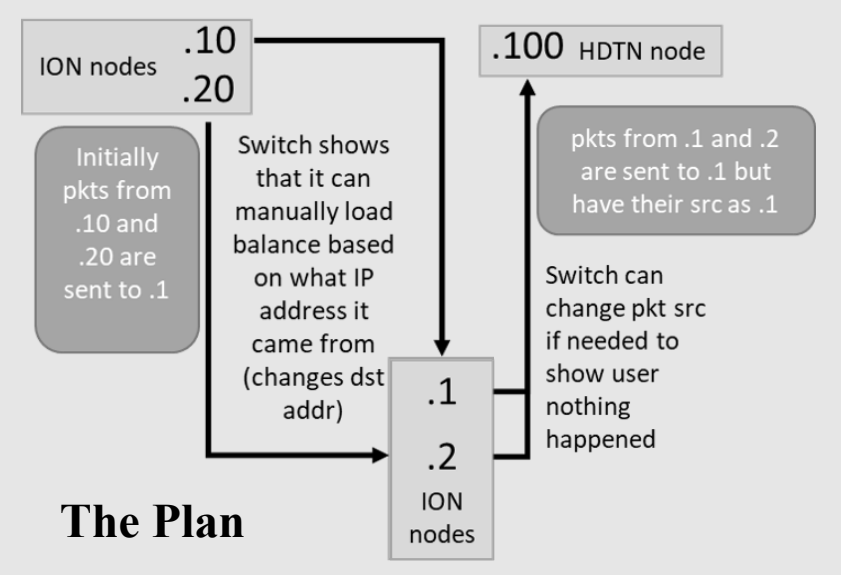
HDTN – High-rate DTN

- **HDTN was initially developed to support optical communication data rates exceeding 1 Gbps.**
- **Software bottlenecks caused by shared memory and locking mechanisms have been removed to allow for high speed, asynchronous message processing.**
- **Based on message bus architecture using ZeroMQ.**
- **Released under NASA Open Source Agreement:**
  - https://github.com/nasa/HDTN
- **Supports: BP v6, BP v7, UDPCL, TCPCL v3 and v4, STCPCL, and LTPCL.**



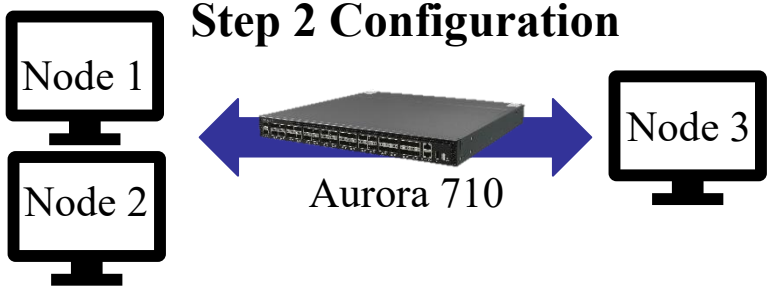
Initial Setup

- **The overarching goal is to follow The Plan figured below. First stage will be Step 1 configuration between the two ION nodes of the plan. Second stage follows Step 2 configuration for two ION nodes to one ION node or to one HDTN node**
- **The Aurora 710 networking switch was provided blank, meaning, without understanding any networking protocol. The steps taken were:**
  - Code in P4 to understand packet switching on layer 3/IP logical addressing
  - Then take layer 4/protocol into account, ie, UDP
  - Since packet altering happens if UDP packet is on a certain port, conditioning code was written



Step 1 Configuration

Step 2 Configuration



Initial Setup (continued)

- **Aurora platform contained compiled code, hardware ports were enabled and up, and tables were loaded**
- **Once operational, preliminary tests of the P4 software was conducted using a packet creation software called Scapy before adding in the DTN implementation. Following the NAT rules Table, the results showed that:**
  - Code changes packet if UDP bundle on port 4556
  - Source IP address changes follows Table I properly
  - Destination IP address changes follows Table I properly
  - TCP/IP and all other UDP packets are switched as normal

Table 1

Original		Modification
IP Source	IP Destination	
10.10.10.[10-19, 100]	10.10.10.1	No change
10.10.10.[20-29, 100]	10.10.10.1	Destination → 10.10.10.2
10.10.10.[30-39, 100]	10.10.10.1	Destination → 10.10.10.3
10.10.10.1	10.10.10.[10-19, 100]	No change
10.10.10.2	10.10.10.[20-29, 100]	Source → 10.10.10.1
10.10.10.3	10.10.10.[30-39, 100]	Source → 10.10.10.1

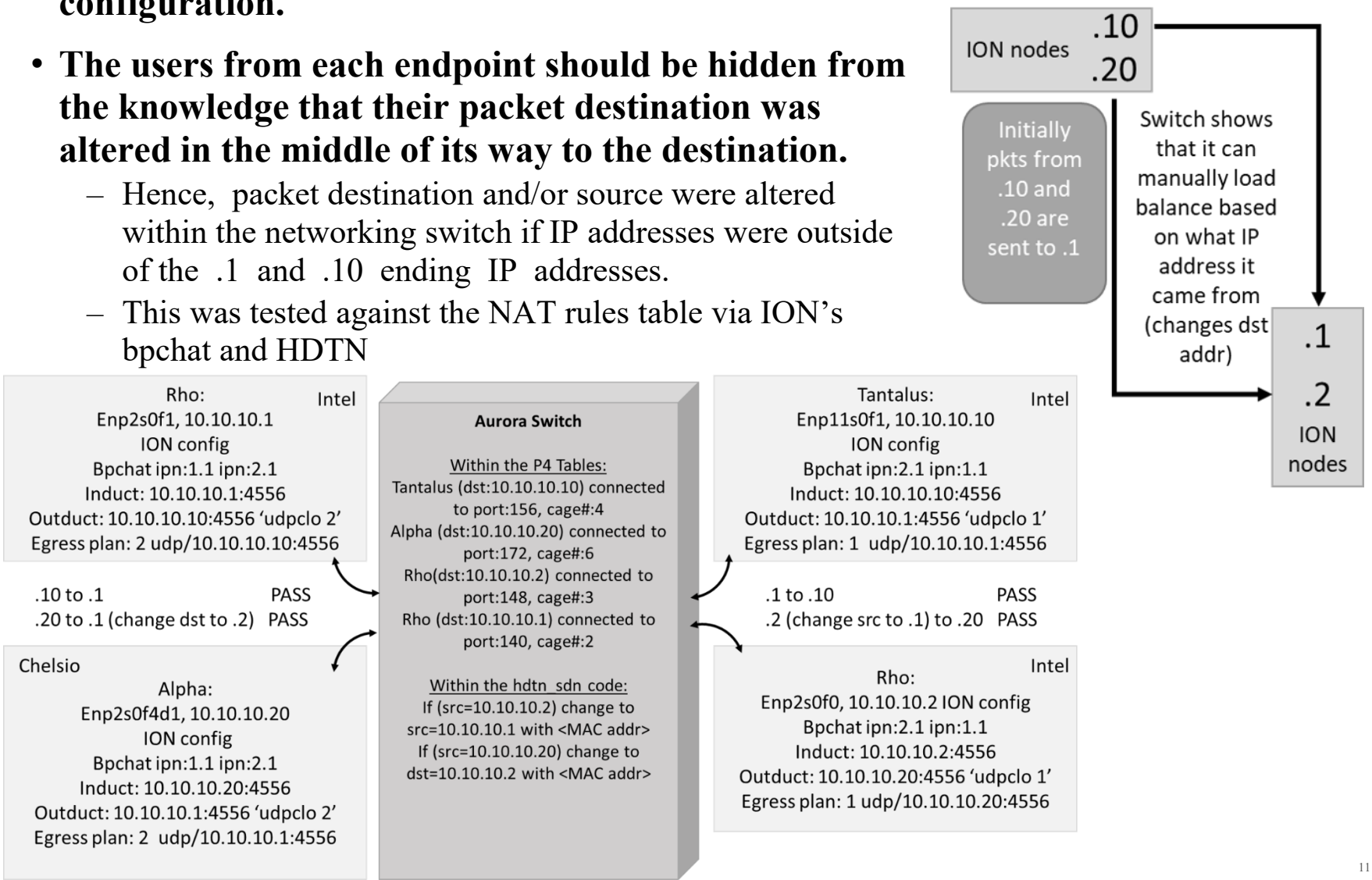
```
bf-sde> pm show
-----+----+---+----+-------+----+---+---+---+--------+----------------+----------------+-
PORT |MAC |D_P|P/PT|SPEED  |FEC |RDY|ADM|OPR|LPBK    |FRAMES RX       |FRAMES TX       |E
-----+----+---+----+-------+----+---+---+---+--------+----------------+----------------+-
1/0  |23/0|132|2/ 4|40G    |NONE|YES|ENB|UP |  NONE  |             213|               0|
2/0  |22/0|140|2/12|40G    |NONE|YES|ENB|UP |  NONE  |             219|               0|
3/0  |21/0|148|2/20|40G    |NONE|YES|ENB|UP |  NONE  |             220|               0|
4/0  |20/0|156|2/28|40G    |NONE|YES|ENB|UP |  NONE  |             216|               0|
5/0  |19/0|164|2/36|40G    |NONE|YES|ENB|UP |  NONE  |               3|               0|
6/0  |18/0|172|2/44|40G    |NONE|YES|ENB|UP |  NONE  |             218|               0|
```

```
Table ipv4_host:
----- ipv4_host Dump Start -----
Default Entry:
Entry data (action : NoAction):

pipe.Ingress.ipv4_host entries fo
hdr.ipv4.dst_addr    port
-------------------  ------
0x0A0A0A0A           0x9C
0x0A0A0A14           0xAC
0x0A0A0A02           0xA4
0x0A0A0A64           0x84
0x0A0A0A01           0x8C
```

Node to Node Configuration

- **Each link was tested individually following Step 1 configuration.**
- **The users from each endpoint should be hidden from the knowledge that their packet destination was altered in the middle of its way to the destination.**
  - Hence, packet destination and/or source were altered within the networking switch if IP addresses were outside of the .1 and .10 ending IP addresses.
  - This was tested against the NAT rules table via ION's bpchat and HDTN



ION to ION bpchat Results

SDN Manually Load Balancing ION to ION

Tantalus [.10] → Rho [.1]

Wireshark capture on Tantalus (shows how packet left):

```
Frame 1: 99 bytes on wire (792 bits), 99 bytes captured (792 bits) on interface enp11s0f1, id 0
Ethernet II, Src: [redacted], Dst: [redacted]
Internet Protocol Version 4, Src: 10.10.10.10, Dst: 10.10.10.1
User Datagram Protocol, Src Port: 47258, Dst Port: 4556
Bundle Protocol
```

Wireshark capture on Rho (shows no change):

```
Frame 1: 99 bytes on wire (792 bits), 99 bytes captured (792 bits) on interface 0
Ethernet II, Src: [redacted], Dst: [redacted]
Internet Protocol Version 4, Src: 10.10.10.10, Dst: 10.10.10.1
User Datagram Protocol, Src Port: 47258, Dst Port: 4556
Bundle Protocol
```

Rho [.1] → Tantalus [.10]

Wireshark capture on Rho (shows how packet left):

```
Frame 2: 99 bytes on wire (792 bits), 99 bytes captured (792 bit
Ethernet II, Src: [redacted], Dst: [redacted]
Internet Protocol Version 4, Src: 10.10.10.1, Dst: 10.10.10.10
User Datagram Protocol, Src Port: 54574, Dst Port: 4556
Bundle Protocol
```

Wireshark capture on Tantalus (shows no change):

```
Frame 2: 99 bytes on wire (792 bits), 99 bytes captured (792 bit
Ethernet II, Src: [redacted], Dst: [redacted]
Internet Protocol Version 4, Src: 10.10.10.1, Dst: 10.10.10.10
User Datagram Protocol, Src Port: 54574, Dst Port: 4556
Bundle Protocol
```

ION bpchat working!

ION bpchat on Rho

```
slbooth@rho:~/ion-3.7.0/tests/bpchat$ sudo bpchat
from rho to tant
from tant to rho
```

ION bpchat on Tantalus

```
slbooth@tantalus:~/ion-3.7.0/tests/bpchat$ sudo bp
from rho to tant
from tant to rho
```

Alpha [.20] → Rho [.1]

Will see it on Rho [.2] (IP dst change!) only if UDP dst port 4556

Wireshark capture on Alpha (shows how packet left):

```
Frame 2: 100 bytes on wire (800 bits), 100 bytes captured (800 bits) on interface 0
Ethernet II, Src: [redacted], Dst: [redacted]
Internet Protocol Version 4, Src: 10.10.10.20, Dst: 10.10.10.1
User Datagram Protocol, Src Port: 57932, Dst Port: 4556
Bundle Protocol
```

Wireshark capture on Rho (shows the change):

```
Frame 2: 100 bytes on wire (800 bits), 100 bytes captured (800 bits) on interface 0
Ethernet II, Src: [redacted] Dst: [redacted]
Internet Protocol Version 4, Src: 10.10.10.20, Dst: 10.10.10.2
User Datagram Protocol, Src Port: 57932, Dst Port: 4556
Bundle Protocol
```

Rho [.2] → Alpha [.20]

Will see if on Alpha [.2] as source Rho [.1] only if UDP dst port 4556

Wireshark capture on Rho (shows how packet left):

```
Frame 1: 91 bytes on wire (728 bits), 91 bytes captured (728 bits) on interface 0
Ethernet II, Src: [redacted] Dst: [redacted]
Internet Protocol Version 4, Src: 10.10.10.2, Dst: 10.10.10.20
User Datagram Protocol, Src Port: 44734, Dst Port: 4556
Bundle Protocol
```

Wireshark capture on Alpha (shows the change):

```
Frame 2: 91 bytes on wire (728 bits), 91 bytes captured (728 bits) on interface 0
Ethernet II, Src: [redacted] Dst: [redacted]
Internet Protocol Version 4, Src: 10.10.10.1, Dst: 10.10.10.20
User Datagram Protocol, Src Port: 44734, Dst Port: 4556
Bundle Protocol
```

ION bpchat working!

```
slbooth@rho:~/ion-3.7.0/tests/bpchat$ sudo bpchat ipn:2.1 ipn:1.1
from alpha to rho
from rho to alpha
```

```
slbooth@alpha:~/ion-3.7.0/tests/bpchat$ sudo bpchat ipn:1.1 ipn:2.1
from alpha to rho
from rho to alpha
```

ION to ION bpchat Results

Tantalus [.10] → Rho [.1

Wireshark capture on

```
Frame 1: 99 bytes on wi
Ethernet II, Src:
Internet Protocol Versi
User Datagram Protocol,
Bundle Protocol
```

Wireshark capture on

```
Frame 1: 99 bytes on wi
Ethernet II, Src:
Internet Protocol Versi
User Datagram Protocol,
Bundle Protocol
```

Rho [.1] → Tantalus [.10

Wireshark capture on

```
Frame 2: 99 bytes on wi
Ethernet II, Src:
Internet Protocol Versi
User Datagram Protocol,
Bundle Protocol
```

Wireshark capture on

```
Frame 2: 99 bytes on wi
Ethernet II, Src:
Internet Protocol Versi
User Datagram Protocol,
Bundle Protocol
```

ION bpchat working!

ION bpchat on Rho

```
slbooth@rho:~/ion-
from rho to tant
from tant to rho
```

ION bpchat on Tantalu

```
slbooth@tantalus:~
from rho to tant
from tant to rho
```

Alpha [.20] → Rho [.1]

Will see it on Rho [.2] (IP dst change!) only if UDP dst port 4556

Wireshark capture on Alpha (shows how packet left):

```
Frame 2: 100 bytes on wire (800 bits), 100 bytes captured (800 bits) on interface 0
Ethernet II, Src:                                    , Dst:
Internet Protocol Version 4, Src: 10.10.10.20, Dst: 10.10.10.1
User Datagram Protocol, Src Port: 57932, Dst Port: 4556
Bundle Protocol
```

Wireshark capture on Rho (shows the change):

```
Frame 2: 100 bytes on wire (800 bits), 100 bytes captured (800 bits) on interface 0
Ethernet II, Src:                                    Dst:
Internet Protocol Version 4, Src: 10.10.10.20, Dst: 10.10.10.2
User Datagram Protocol, Src Port: 57932, Dst Port: 4556
Bundle Protocol
```

Rho [.2] → Alpha [.20]

Will see if on Alpha [.2] as source Rho [.1] only if UDP dst port 4556

Wireshark capture on Rho (shows how packet left):

```
Frame 1: 91 bytes on wire (728 bits), 91 bytes captured (728 bits) on interface 0
Ethernet II, Src:                                    Dst:
Internet Protocol Version 4, Src: 10.10.10.2, Dst: 10.10.10.20
User Datagram Protocol, Src Port: 44734, Dst Port: 4556
Bundle Protocol
```

Wireshark capture on Alpha (shows the change):

```
Frame 2: 91 bytes on wire (728 bits), 91 bytes captured (728 bits) on interface 0
Ethernet II, Src:                                    Dst:
Internet Protocol Version 4, Src: 10.10.10.1, Dst: 10.10.10.20
User Datagram Protocol, Src Port: 44734, Dst Port: 4556
Bundle Protocol
```

ION bpchat working!

```
slbooth@rho:~/ion-3.7.0/tests/bpchat$ sudo bpchat ipn:2.1 ipn:1.1
from alpha to rho
from rho to alpha
```

```
slbooth@alpha:~/ion-3.7.0/tests/bpchat$ sudo bpchat ipn:1.1 ipn:2.1
from alpha to rho
from rho to alpha
```

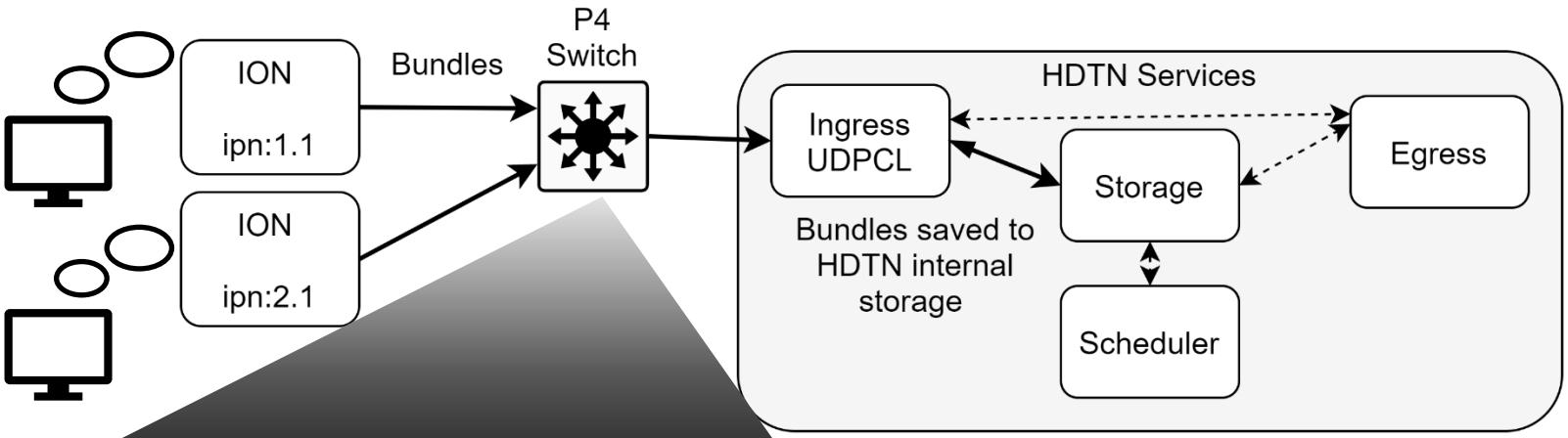
Node to Node Benchmarking Results

- **Once the networking switch was checked out, benchmarking results were collected to see bottleneck limits. ION to ION node results are shown for comparison with a HDTN test.**
- **Results only PASS when all bundles are received.**

Tx Computer	Rx Computer	Status
Rho	**Eta**	
Stopping bpdriver. Total bundles: 100 Time (seconds): 0.535 Total bytes: 100000 Throughput (Mbps): 1.495	Stopping bpcounter; bundles received: 100 Time (seconds): 9.486 Total bytes: 100000 Throughput (Mbps): 0.084	PASS
Stopping bpdriver. Total bundles: 1000 Time (seconds): 5.338 Total bytes: 1000000 Throughput (Mbps): 1.499	Stopping bpcounter; bundles received: 438 Time (seconds): 20.130 Total bytes: 438000 Throughput (Mbps): 0.174	FAIL
Omicron	**Eta**	
Stopping bpdriver. Total bundles: 100 Time (seconds): 0.558 Total bytes: 100000 Throughput (Mbps): 1.433	Stopping bpcounter; bundles received: 100 Time (seconds): 12.765 Total bytes: 100000 Throughput (Mbps): 0.063	PASS
Stopping bpdriver. Total bundles: 1000 Time (seconds): 2.656 Total bytes: 1000000 Throughput (Mbps): 3.012	Stopping bpcounter; bundles received: 810 Time (seconds): 23.921 Total bytes: 810000 Throughput (Mbps): 0.271	FAIL

HDTN System Setup

- **The HDTN node was configured first to non-volatile storage.**
- **The HDTN node only listened to an IP destination of 10.10.10.100.**
- **Each packet received is to come from and IP address ending in .1.**



Original		Modification
IP Source	IP Destination	
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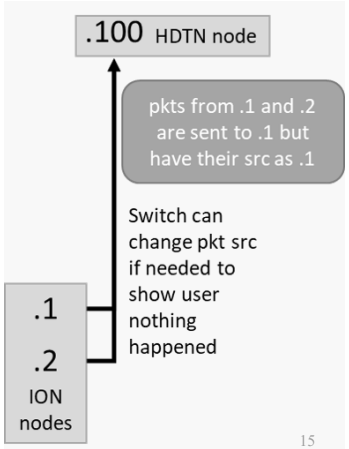
10.10.10.[20-29, 100]	10.10.10.1	Destination → 10.10.10.2
10.10.10.[30-39, 100]	10.10.10.1	Destination → 10.10.10.3
10.10.10.1	10.10.10.[10-19, 100]	No change
10.10.10.2	10.10.10.[20-29, 100]	Source → 10.10.10.1
10.10.10.3	10.10.10.[30-39, 100]	Source → 10.10.10.1



2 Nodes to 1 HDTN Node

- **The results brought forth all successes for both 2 nodes to 1 node**

Tx Computer	Rx Computer	Status
Rho -hdtn_host1.rc **Omicron -hdtn_benchmark1.rc**	**Eta ./runscript.sh** **Only to Storage**	
@rho: bpdriver 100 ipn:1.1 ipn:2.1 -1000 t30 Stopping bpdriver. Total bundles: 100 Time (seconds): 0.580 Total bytes: 100000 Throughput (Mbps): 1.378 **@omicron:** bpdriver 200 ipn:1.1 ipn:2.1 -1000 t30 Stopping bpdriver. Total bundles: 200 Time (seconds): 0.782 Total bytes: 200000 Throughput (Mbps): 2.046	**@eta:** hdtn m_bundleCountStorage: 302 m_bundleCountEgress: 0 m_bundleCount: 302 m_bundleData: 312083	PASS
@rho: bpdriver 1000 ipn:1.1 ipn:2.1 -1000 t30 Stopping bpdriver. Total bundles: 1000 Time (seconds): 2.565 Total bytes: 1000000 Throughput (Mbps): 3.119 **@omicron:**	**@eta:** hdtn m_bundleCountStorage: 2002 m_bundleCountEgress: 0 m_bundleCount: 2002	PASS

2 Nodes to 1 HDTN Node

- The

Tx Computer	Rx Computer	Status
Rho -hdtn_host1.rc **Omicron -hdtn_benchmark1.rc**	**Eta ./runscript.sh** **Only to Storage**	
@rho: bpdriver 100 ipn:1.1 ipn:2.1 -1000 t30 Stopping bpdriver. Total bundles: 100 Time (seconds): 0.580 Total bytes: 100000 Throughput (Mbps): 1.378 **@omicron:** bpdriver 200 ipn:1.1 ipn:2.1 -1000 t30 Stopping bpdriver. Total bundles: 200 Time (seconds): 0.782 Total bytes: 200000 Throughput (Mbps): 2.046	**@eta:** hdtn m_bundleCountStorage: 302 m_bundleCountEgress: 0 m_bundleCount: 302 m_bundleData: 312083	PASS
@rho: bpdriver 1000 ipn:1.1 ipn:2.1 -1000 t30 Stopping bpdriver. Total bundles: 1000 Time (seconds): 2.565 Total bytes: 1000000 Throughput (Mbps): 3.119 **@omicron:** bpdriver 1000 ipn:1.1 ipn:2.1 -1000 t30 Stopping bpdriver. Total bundles: 1000 Time (seconds): 3.109 Total bytes: 1000000 Throughput (Mbps): 2.573	**@eta:** hdtn m_bundleCountStorage: 2002 m_bundleCountEgress: 0 m_bundleCount: 2002 m_bundleData: 2083906	PASS

On-Going and Future Work

Conclusion

- **With increasing network throughput and capability needs, bottle-necks are important to avoid. Some options have been found to circumvent performance restriction of the network for DTN implementation nodes.**
  - Manually load balancing packets with a SDN switch and/or
  - Using an HDTN receiver node
- **Current work involves**
  - SDN development to provide solutions to 100Gbps data rates for HDTN.
  - Teaching the Aurora network switch platform how to automatically load balance traffic between ports without the need of the IP changes hard-coded into the P4 code.
- **Future work will incorporate the bundle egress to neighboring nodes and finding limitations to HDTN's capabilities.**

Any Questions?

References

1. https://www.nasa.gov/sites/default/files/atoms/files/1.2_lecture_-_intro_to_ion_implentation_of_the_dtn_architecture.pdf
2. https://www.intel.com/content/www/us/en/products/network-io/programmable-ethernet-switch/p4-suite/p4-studio.html
3. https://p4.org/p4-spec/docs/P4-16-v1.2.0.html

Extra

Helpful Websites

- ION
  - https://www.nasa.gov/directorates/heo/scan/engineering/technology/disruption_tolerant_networking_software_options_ion
- P4
  - www.P4.org
- HDTN
  - https://github.com/nasa/HDTN
- Intel Tofino / SDN
  - https://opennetworking.org/wp-content/uploads/2021/05/2021-P4-WS-Vladimir-Gurevich-Slides.pdf