Internet2 Update

South American – African Astronomy Coordination Committee (SA3CC) Meeting
May 2024

Chris Wilkinson
Sr Director, Network Infrastructure

INTERNET2

Internet2: A Member Consortium

COMMUNITY

Internet2 is a non-profit consortium providing research support, cloud solutions and custom services tailored for Research & Education.

A trusted, adaptable, secure network that empowers higher education, research institutions, government entities and cultural organizations.

BY THE NUMBERS

330+
HIGHER EDUCATION MEMBERS

100+
COUNTRIES & RESEARCH NETWORKS CONNECTIONS

80,000+
COMMUNITY ANCHOR INSTITUTIONS

500+
NET+ SUBSCRIBERS

50+
AFFILIATE & GOVERNMENT MEMBERS

800G+
WAVELENGTHS OF NETWORK CAPABILITY

1000+
INCOMMON PARTICIPANTS

50+
INDUSTRY MEMBERS

1100+
EDUROAM SUBSCRIBERS

50+
COMMUNITY GROUPS SHAPING PRIORITIES

50+
CLOUD SCORECARD PARTICIPANTS

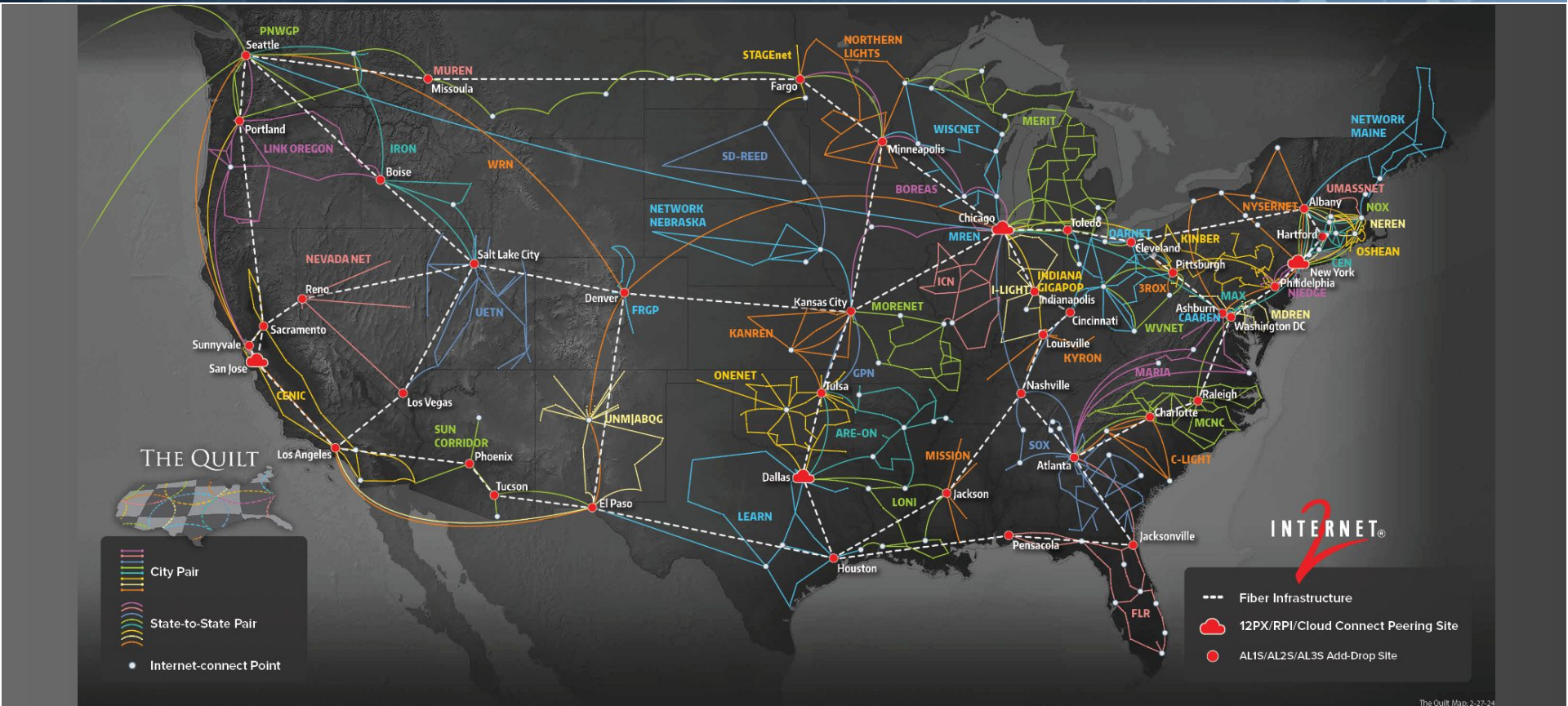
750+
NET+ CLOUD CONTRACTS

46
REGIONAL & STATE NETWORKS

20+
NET+ SERVICE OFFERINGS

32Tbps
CAPACITY PER LINK

Internet2 National Research & Education Network (NREN) + US Regional Research & Education Networks (RENs)



A Brief Technical History

vBNS (gen -2)	Abilene (gen -1)	Internet2 Network (gen 1)	Internet2 Network BTOP (gen 2)	Internet2 Network (gen 3)	Internet2 Network (gen 4)	Internet2 Network (gen5)
1995	2002	2007	2011	2016	2021	2025
622 Mbps, 2.4 Gbps	10 Gbps	10 x 10 Gbps	Native 100 Gbps (high density)	Native 100 Gbps (high density)	Native 400 Gbps	**Native 800 Gbps ?**
Cisco 12008 GSR	Juniper T640	Juniper T640 Ciena CoreDirector	Juniper T1600 Brocade MLXe-16 Juniper MX960	Juniper MX960 Juniper MX10003	Cisco 8201 Cisco 8202 Cisco NCS55A1	**Core Vendor ?** Cisco 57D2 ?
IPv4, IPv6	IPv4, IPv6	IPv4, IPv6	Openflow IPv4, IPv6	MPLS IPv4, IPv6	SR-MPLS IPv4, IPv6	SR-MPLS IPv4, IPv6
Qwest DS-3 OC-3c OC-12 OC-48	Qwest OC-192 (2003)	Infinera DTN	Ciena 6500 50 Ghz Ciena OCI/OCLD Ciena OTR	Ciena 6500 50 Ghz Ciena OCI/OCLD Ciena OTR	Ciena 6500 Flex Grid Ciena Waveserver 5	Ciena 6500 Flex Grid **Optical Overlay ?** **Coherent Optics ?**

Hardware

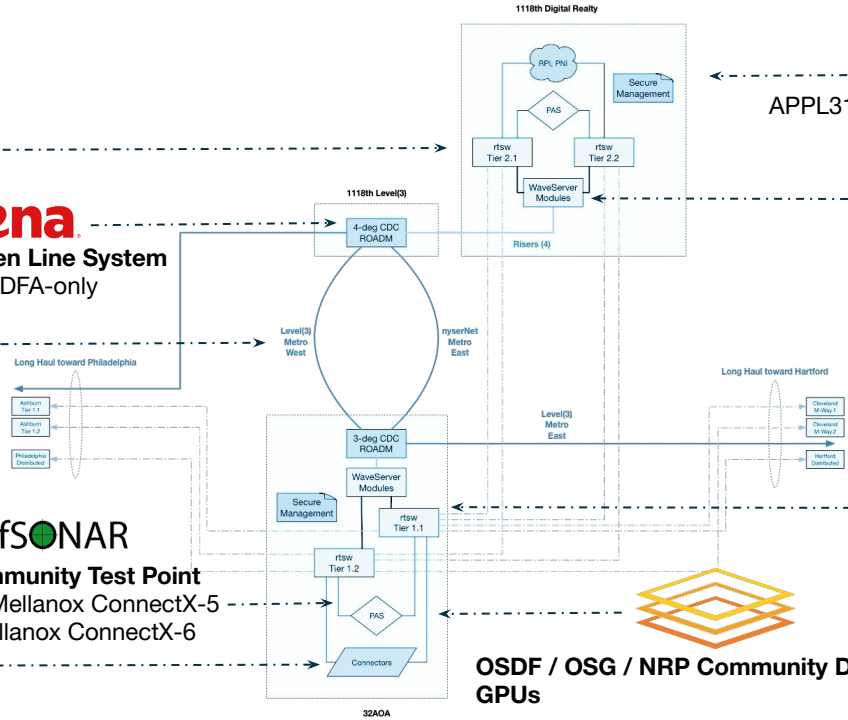
Terabit-Scale Cloud Edge
8202, NCS55A1
(NCS57D2 Coming Soon)

Flex-Grid Open Line System
6500, EDFA-only

Fiber Optic Cable
SMF28-Ultra (plus some LEAF and…)

2x100 Community Test Point
Dell R6515, Mellanox ConnectX-5
R6525, Mellanox ConnectX-6

400G Global Exchange
7280PR3K



Management Network
EX4600, SRX1500, SRX 345
APPL3100 IM7232, OM2216

400G - 800G Transponders
WaveServer 5

Core Transport and Access Layer
8201

OSDF / OSG / NRP Community DTN GPUs

Services

LAYER 1 SERVICE

Point-to-point 10, 100 & 400G links and flexible grid spectrum to support private network needs.

LAYER 2 SERVICE

Effective and efficient wide area 100 gigabit Ethernet technology.

LAYER 3 SERVICE

For IP network and peer exchange needs.

PEER EXCHANGE

Provides institutions with access to commercial peers across the national footprint.

RAPID PRIVATE INTERCONNECT

Allows Internet2 connectors to present themselves for private peering at selected national peering locations.

R&E

Provides institutions with access to each other across the national footprint.

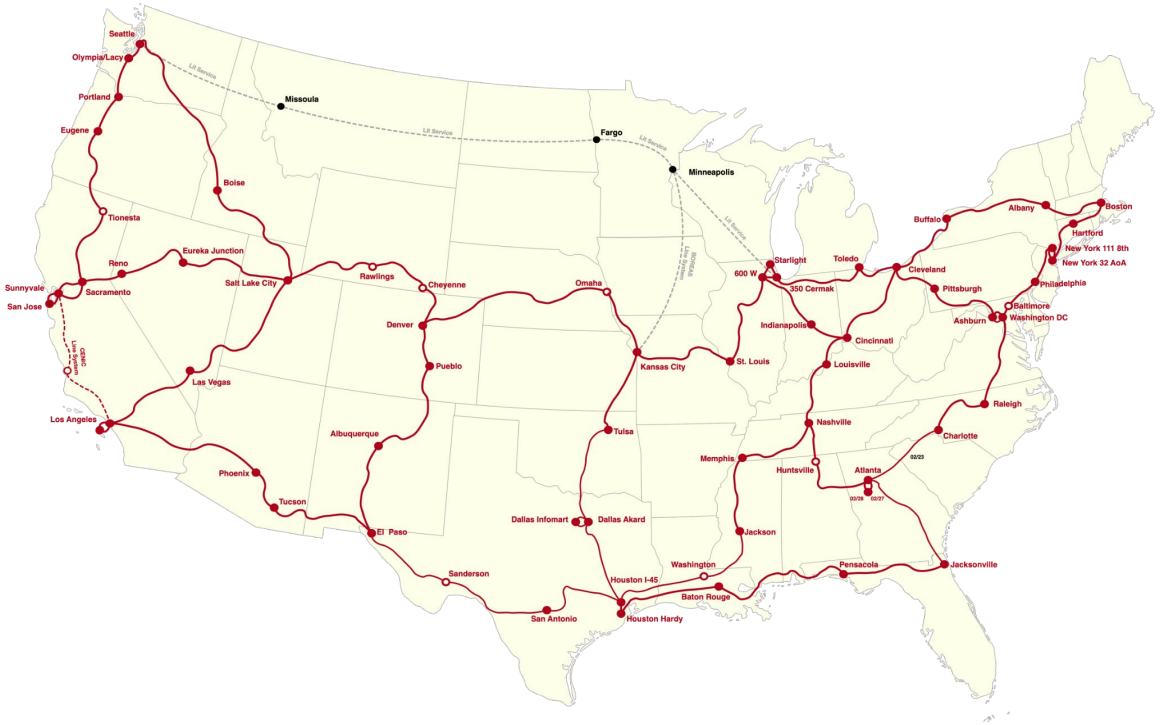
CLOUD CONNECT

Uses regional's infrastructure in conjunction with the Internet2 Network to reach cloud resources.

GLOBAL DDoS PROTECTION

Our cloud-based, volumetric DDoS mitigation service was procured on behalf of the community.

Layer 1 Services



Stats

- 26,000 kilometers of optical fiber
- Ultra SMF28 + a little eLEAF
- Flexible with 74+ add/drop sites
- Open line system, (not locked to a single vendor)

Backbone Waves (400G)

- **94** 400 Gbps Backbone Circuits (WaveServer 5)
- **4** 400 Gbps Backbone Coherent Pluggables

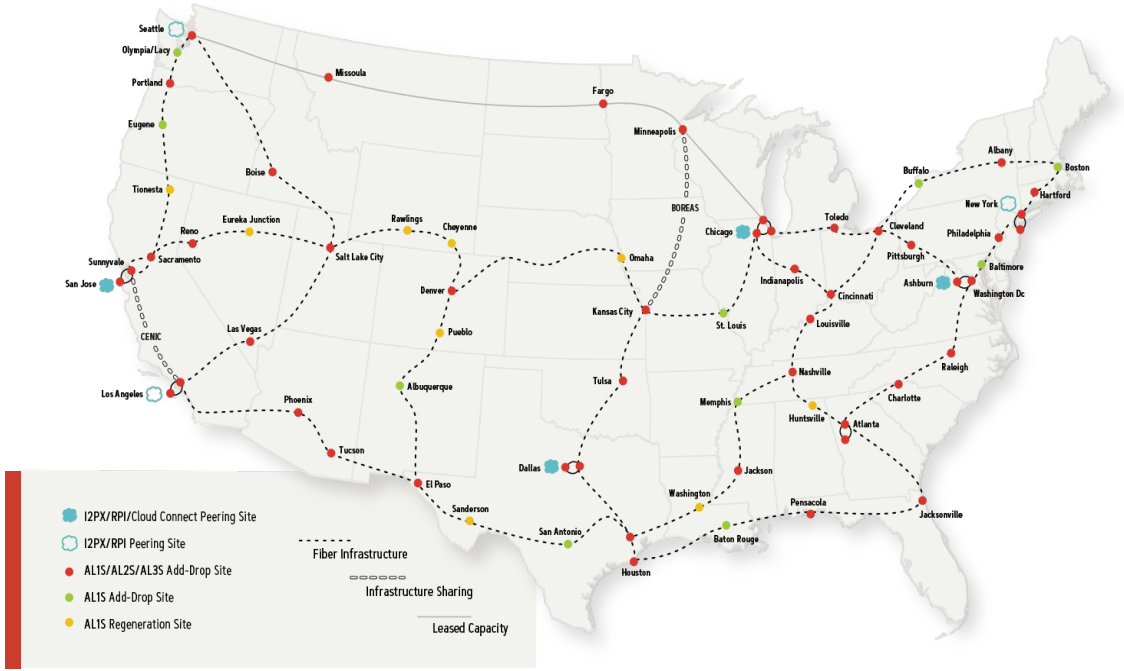
Foreign Waves

- **6** point-to-point alien waves

Customer Services

- **10** 400 Gbps Circuits
- **50** 100 Gbps Circuits
- **60** 10 Gbps Circuits
- **7** Managed Spectrum (Community) 600-800 Gbps

Layer 2 and Layer 3 Services



I2 Cloud Connect

539 Connections

I2 RPI

42 10G Interfaces
2 100G Interfaces

I2 DDOS

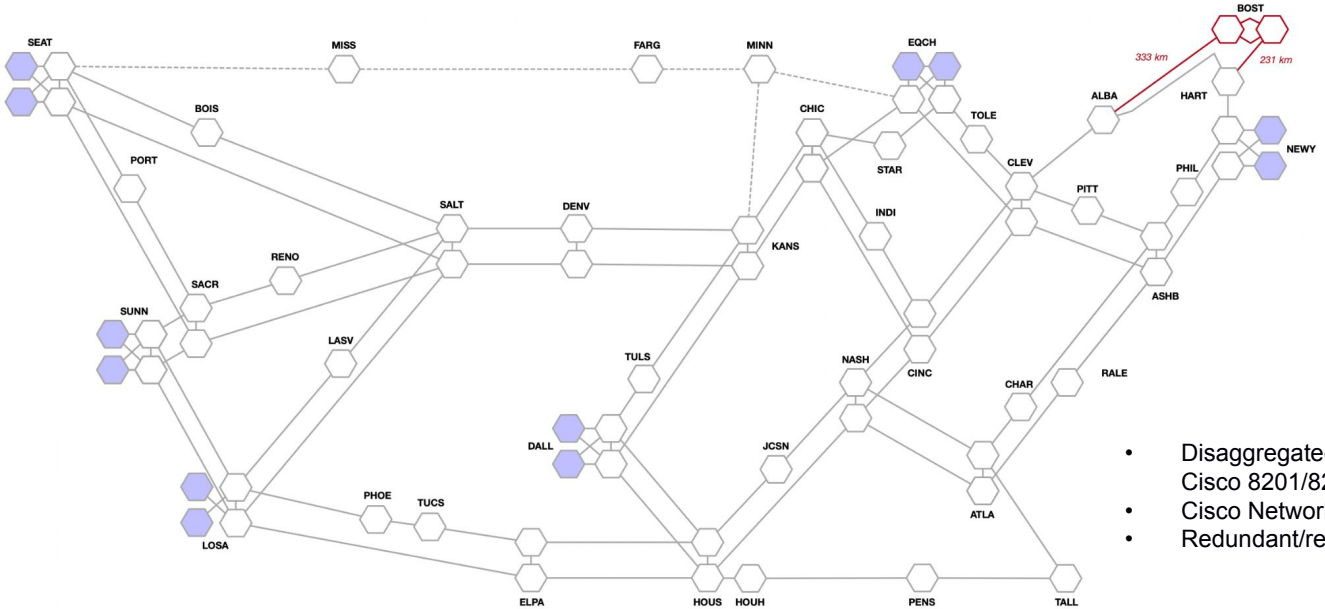
14 Subscribers
95 Tenants

I2 Insight Console (November 2023 - February 2024)

217 Layer 2 Connections Created or Updated
90 Layer 3 Connections Created or Updated
48,000 Looking Glass Queries Executed

Packet Network Topology

- Fifth generation of the Internet2 backbone
- Ninety-four 400 Gbps Backbone links
- 27,600 Tbps of deployed capacity
- 1.6 Tbps available contiguously coast to coast
- Each link is on non-regenerated wave



- Disaggregated Switching/Routing Platform
  Cisco 8201/8202 - 77 Routers, 47 Sites
- Cisco Network Services Orchestrator (NSO)
- Redundant/resilient routers, dual-connected cloud peers

Spectrum, Transponders, and Pluggables

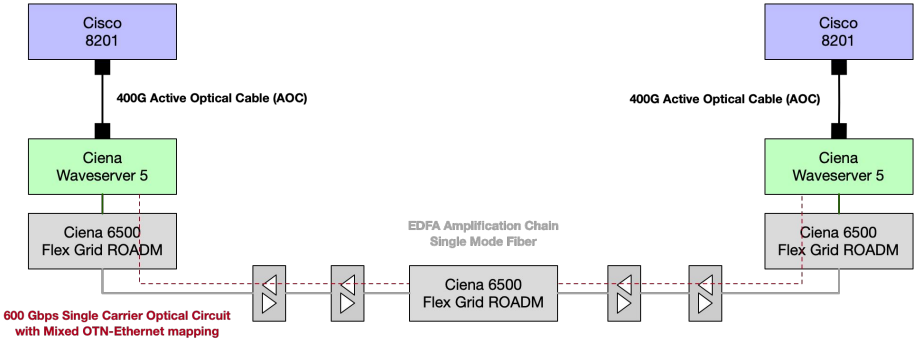
NGI was designed based on a traditional “transponder” model using Waveserver 5 Modules, each module delivering 400G backbone links on 112.5 Ghz

Advantages:

- can achieve up to 800G line rate
- provides additional capacity beyond baseline backbone demands
- mixed-mode capacity for 400G GE, 100G GE, and OTL 4.4
- high launch power (-9 to +4 dBm) and SNR margins to maximize distances achieved

Disadvantages:

- space and power are required for chassis, modules
- high current utilization required for launch power, DSPs ~ 330 W per module



Spectrum, Transponders, and Pluggables

In early-2022 Acatia brought to market “bright” 400G QSFP-DD Pluggable Coherent Optical Modules (PCOM) based on their Greylock 7nm Digital Signal Processor (DSP).

Marked the first commercial DWDM QSFP-DD pluggable with enough power and DSP processing to cross ROADM boundaries for both metro and shorter-long haul distances.

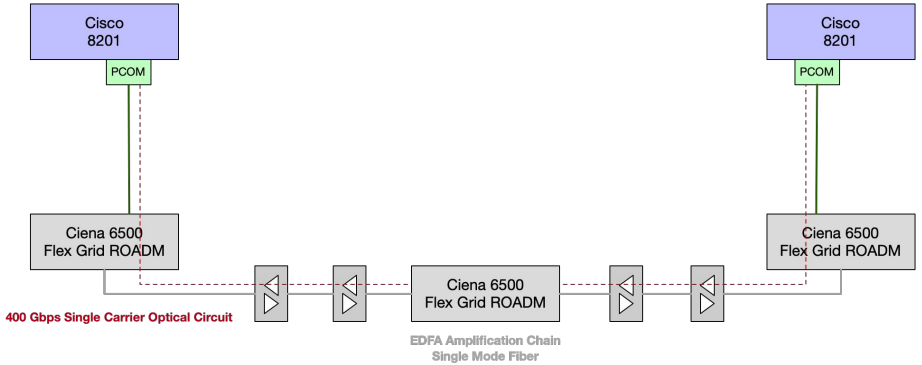
Tested by a variety of community members, including CENIC.

Advantages:

- Lower power envelope 22.5 watts vs 330 watts (WS5)
- Reduces the number of components needed for a 400G link

Disadvantages:

- Limited to router-to-router connections; no muxponding option
- Distances are limited due to launch power and DSP complexity (likely sub 1000 km)
- Wattage may impose limitations on cooling and electrical bus on older devices

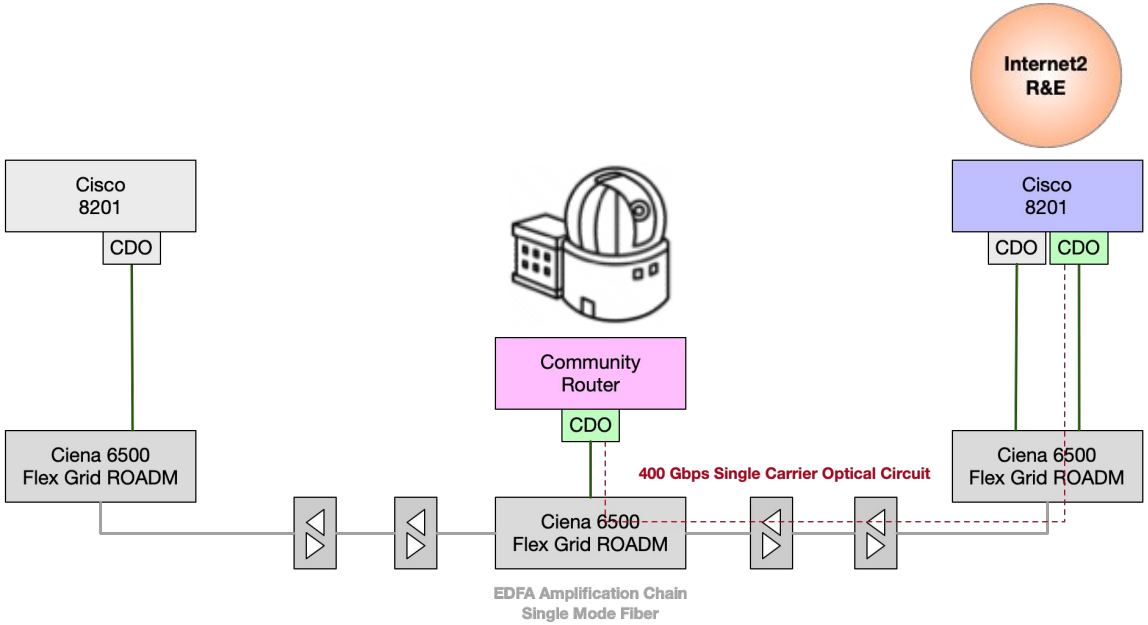


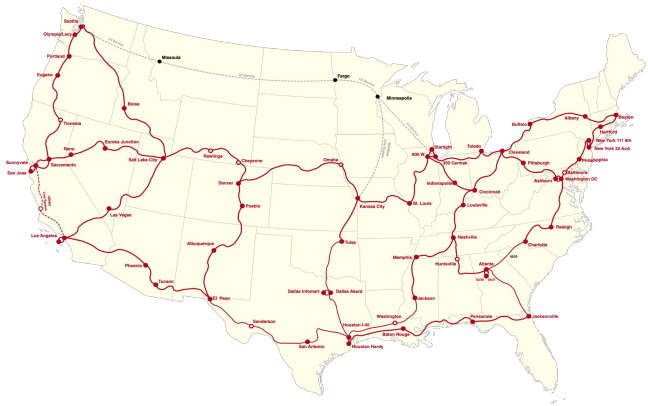
```
Optics Type:  QDD 400G BRT ZRP

DWDM carrier Info: C BAND, MSA ITU Channel=Non-ITU, Frequency=193.6812THz,
Wavelength=1547.866nm
...
Actual TX Power = -2.98 dBm
Actual TX Power(mW) = 0.50 mW
RX Power = -4.52 dBm
RX Power(mW) = 0.35 mW
RX Signal Power = -10.31 dBm
...
Baud Rate =  60.1385459900 GBd
Modulation Type: 16QAM
Chromatic Dispersion 2408 ps/nm
Configured CD-MIN -2400 ps/nm  CD-MAX 2400 ps/nm
Second Order Polarization Mode Dispersion = 49.00 ps^2
Optical Signal to Noise Ratio = 23.90 dB
SNR = 15.30 dB
...
Temperature = 58.00 Celsius
Voltage = 3.27 V
...
Name                    : CISCO-ACACIA
OUI Number              : 7c.b2.5c
Part Number             : DP04QSDD-HE0-190
...
```

550 km Test Link

Use Case: Coherent Onramp

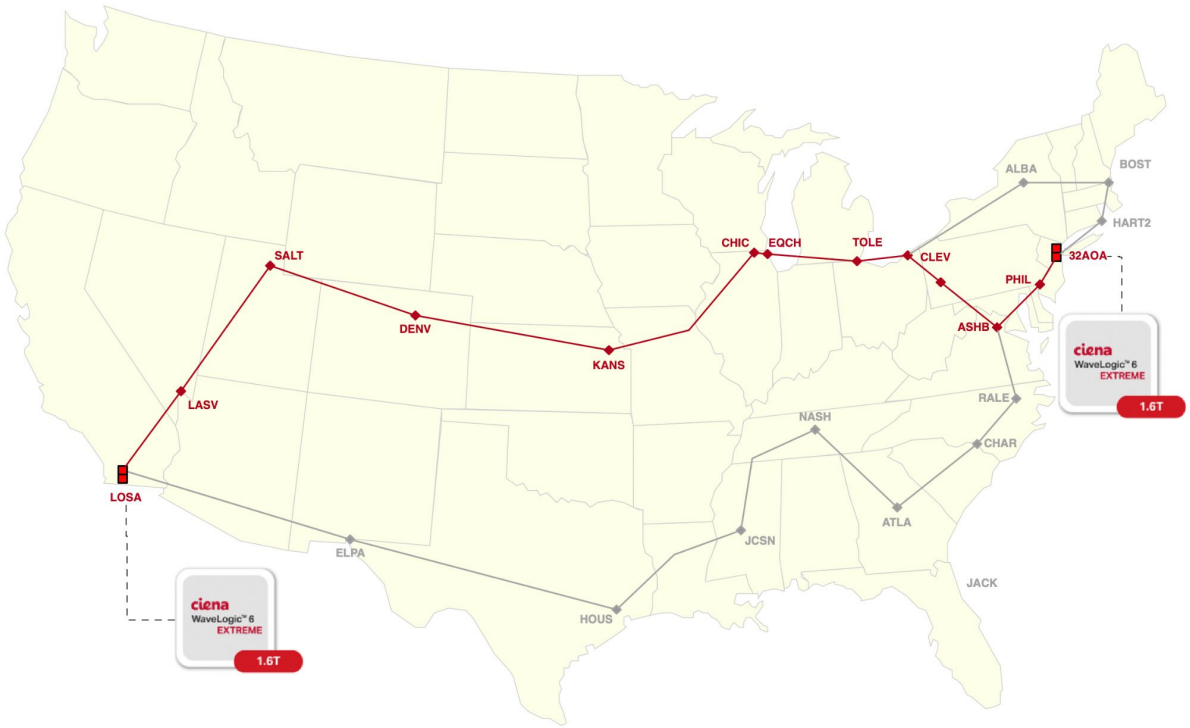
- Provides a potential solution for a community partner who is not near a router location; also may allow fewer routers on the overall platform
- Community partner can launch from their own gear - even using coherent digital optics
- May accommodate a small metro dark-fiber segment between ROADM and community partner





Use Case:
Coast to Coast 400G

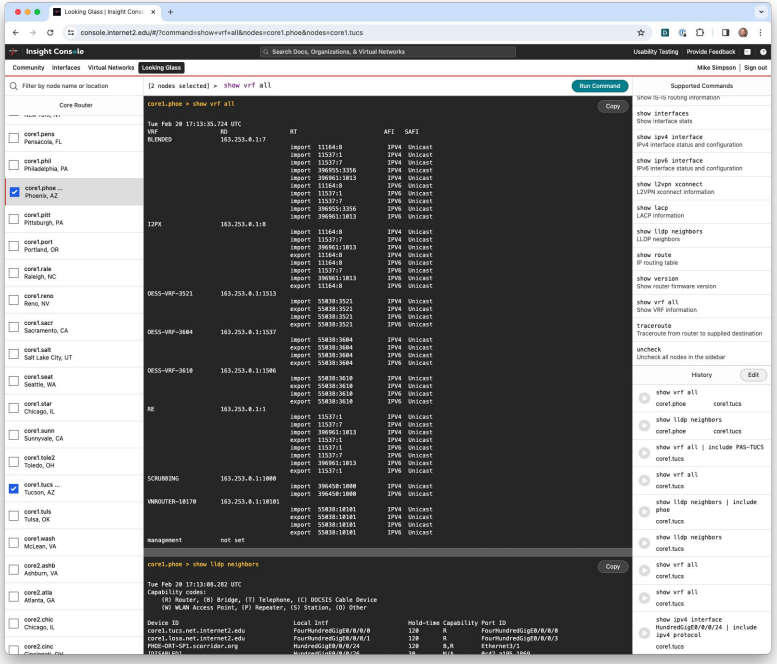
- Custom solution for an international partner
- Potential solution for NREN diversity, network research, and other custom applications
- Los Angeles to New York without regen
- Minimizes Latency on Primary Path
- Potentially offers multiple backup paths through Layer 0 Control Plane
- Based on Ciena Wavelogic 6 with a channel size > 112.5 Ghz
- Demonstrates where modules still very much have a role to play!!
- Suggests that R&E offerings ahead commercial networks

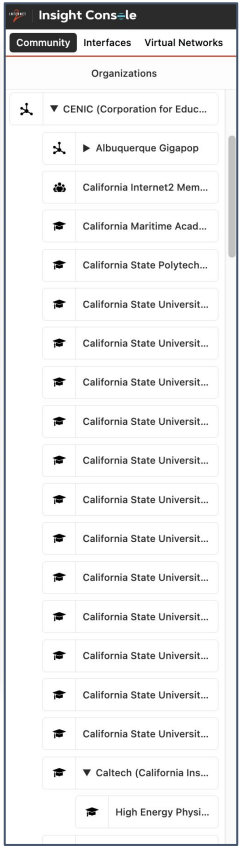


INTERNET2

Insight Console

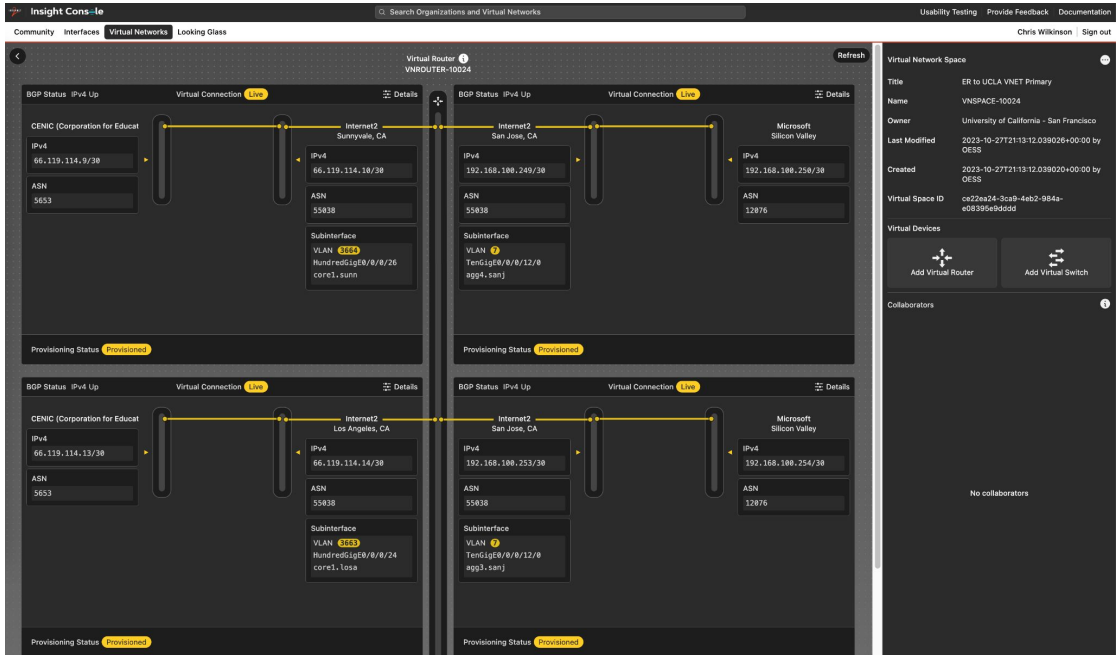
- A web-based tool for **visualizing**, **managing**, and **troubleshooting** all Internet2 **network services**.
- The most visible part of the **Insight** architecture.
- Authentication and authorization integrated with **Internet2 Identity Services** (a.k.a. “InCommon SSO”).
- Functions delivered in 2023:
    - **Looking Glass**: Run commands (in a safe and secure environment) against our production devices and get live results.
    - **Community**: Self-management of organizations, people, and roles.
    - **Interfaces**: Visualization of network ports and services.
    - **Virtual Networks**: Creation and management of L2 and L3 overlay networks, including CloudConnect.
- Functions planned for 2024:
    - **Routing Intentions**: Visualization and management of I2RE and I2PX routes and routing policy.





Virtual Networks

- **Visualization**, **management**, and **troubleshooting** for L2 and L3 **overlay networks**; a re-implementation and enhancement of similar functionality previously delivered via OESS/CloudConnect.
- **Virtual spaces** provide a canvas within which different organizations can **collaborate** on building overlays.
- **Virtual devices** (switches and routers) can be added to spaces to **establish** L2 and L3 overlays.
- **Virtual connections** can be added to devices to **connect** the overlays to interesting places: other Internet2 members or downstream sponsored parties, government and industry partners, cloud partners (AWS, Azure, GCP, OCI), etc.
- Provisioning of the overlay networks on Internet2's production network is handled via **Insight API** calls, with backend automation provided through **NTC Nautobot**, **Cisco NSO,** and other supporting tools.



Services

LAYER 1 SERVICE

Point-to-point 10, 100 & 400G links and flexible grid spectrum to support private network needs.

LAYER 2 SERVICE

Effective and efficient wide area 100 gigabit Ethernet technology.

LAYER 3 SERVICE

For IP network and peer exchange needs.

PEER EXCHANGE

Provides institutions with access to commercial peers across the national footprint.

RAPID PRIVATE INTERCONNECT

Allows Internet2 connectors to present themselves for private peering at selected national peering locations.

R&E

Provides institutions with access to each other across the national footprint.

CLOUD CONNECT

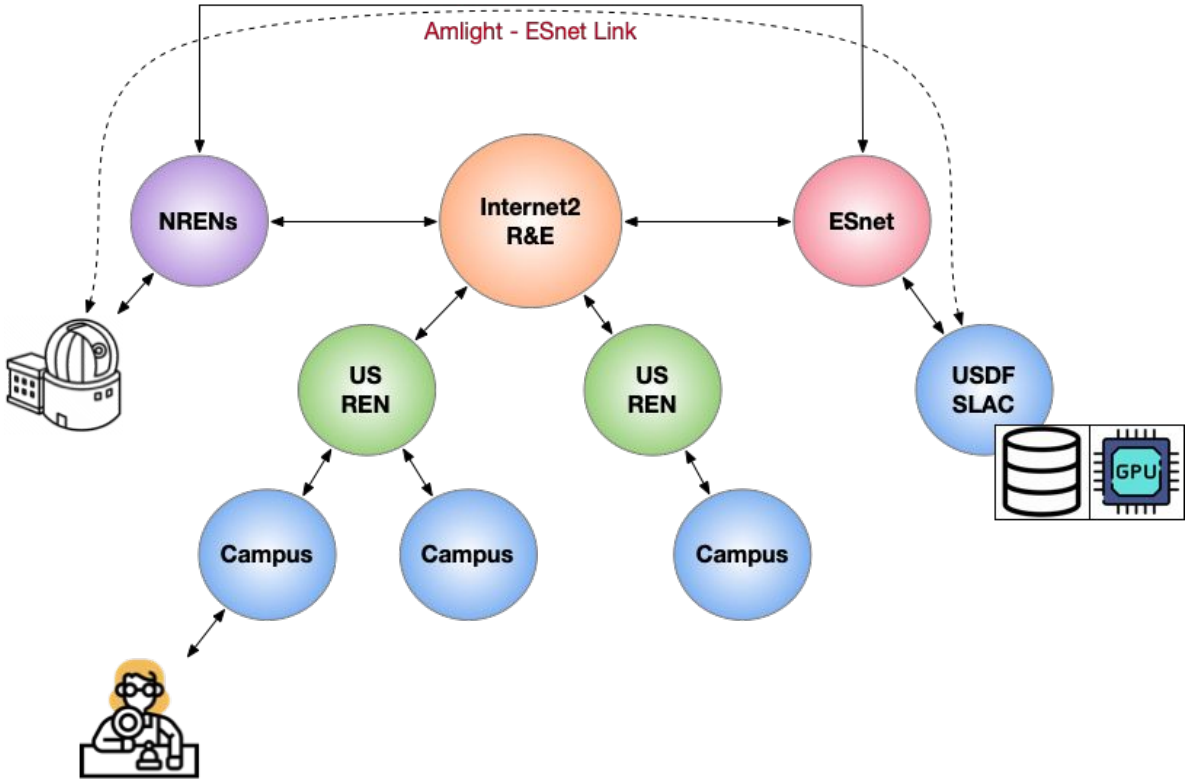
Uses regional's infrastructure in conjunction with the Internet2 Network to reach cloud resources.

GLOBAL DDoS PROTECTION

Our cloud-based, volumetric DDoS mitigation service was procured on behalf of the community.

Use Case: R&E and L3VPN

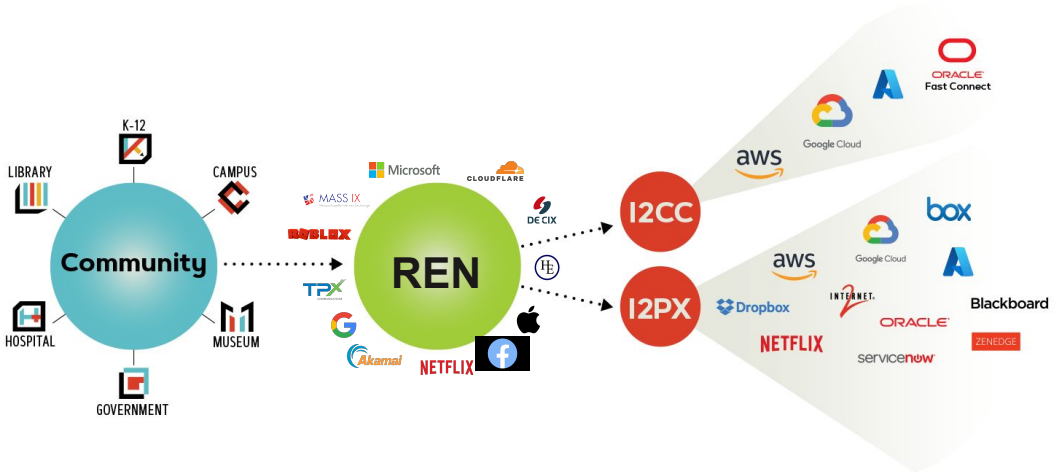
- Part of the larger R&E ecosystem
- Transit is permitted by AUP - institutions can connect to other institutions
- Dedication to specialized R&E traffic
- Engineering that allows wide reachability across the R&E community
- Abundant bandwidth optimized for peak performance
- Engineered to minimize dropped packets, jitter and other underperformance characteristics often found in commodity networks.
- High reliability, and connections to a fabric of other national R&E networks around the globe
- L3VPNs can be configured in Insight Console to provide “private” routed services that run in parallel



INTERNET2

Use Case: I2PX & Cloud Connect

- Community members leverage their existing Internet2 Network investments
- Directly augments commercial services demand
- Provides high-speed access to network-intensive off-net applications, such as social networking and high-definition video
- I2PX provides high performance, low latency, and efficient (often 1 hop) access to some of the top content destinations in the world including: Google, Zoom, Netflix, and other commercial content providers. The service supports IPv4 and IPv6. Transit between subscribers is not permitted.
- Individual community members can also use Cloud Connect for private connections to Amazon Direct Connect, Google Cloud Partner Interconnect, Microsoft Azure Express Route or Oracle Fast Connect services.



Use Case: Hypothetical Workflow

- Multiple paths may exist for data to flow down to a PI or student from a given resource
- Dedicated connections may exist from GCP to Researchers via Cloud Connect

  …or…

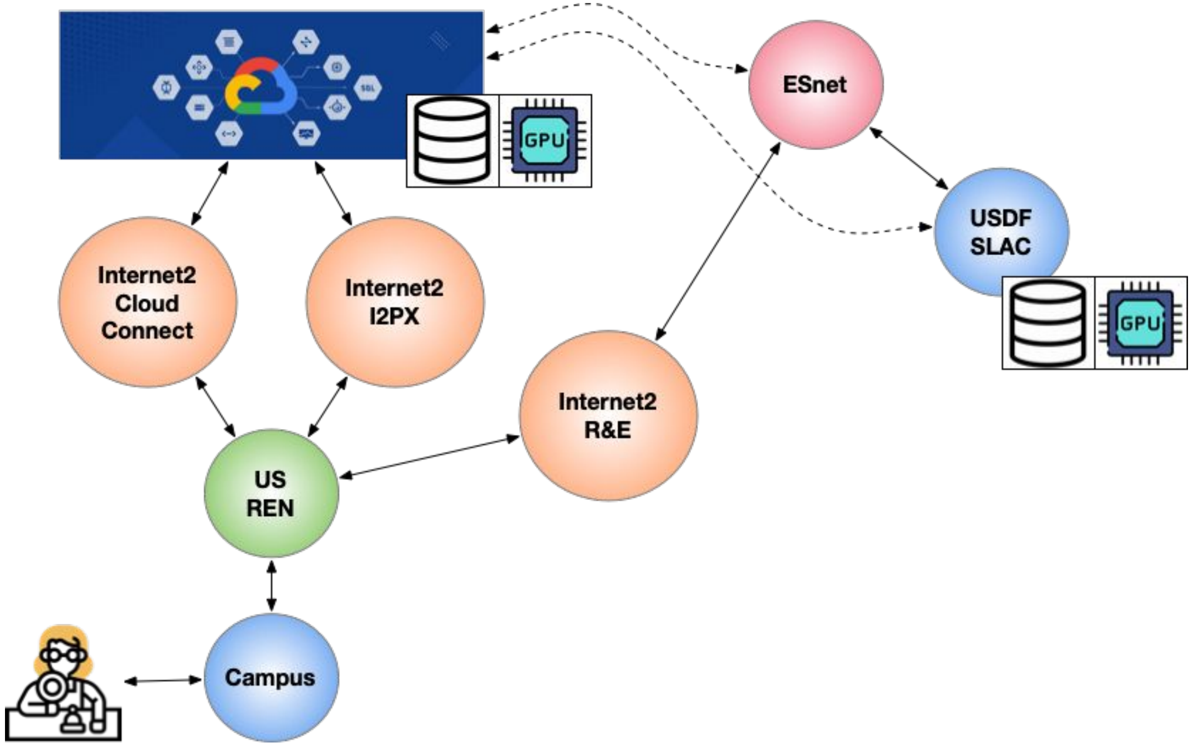
- General GCP access may be made available through I2PX

  …or…

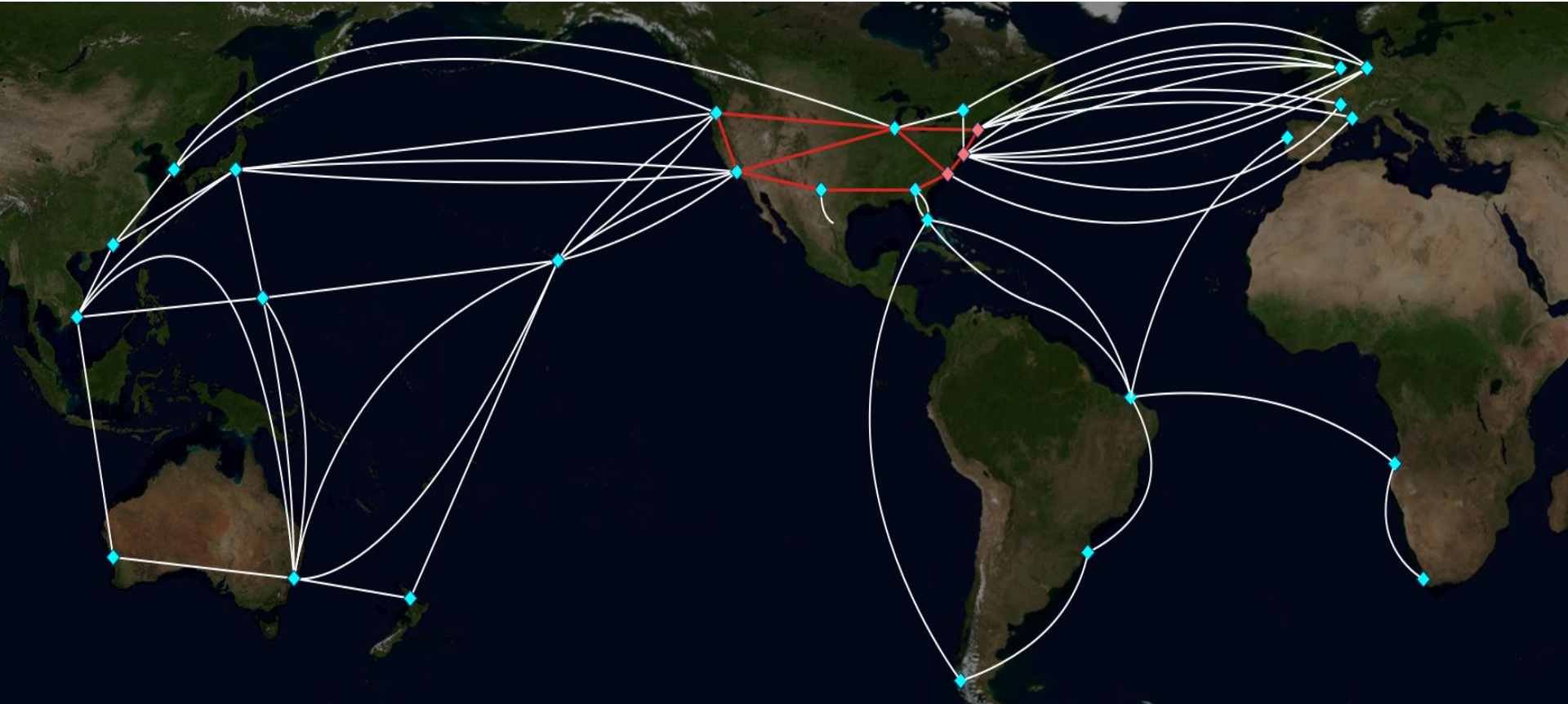
- Connections to USDF may be available through ESnet via R&E

  …or…

- Something yet to be designed/architected



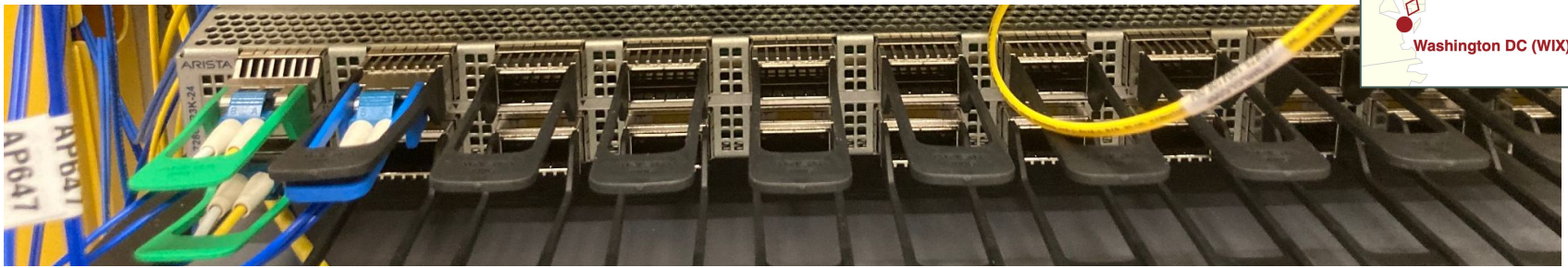
International Connectivity (NREN to NREN) via multiple partnerships and consortiums



400G Global Exchange Points

Deployment of Arista DCS-7280PR3K-24 Switches

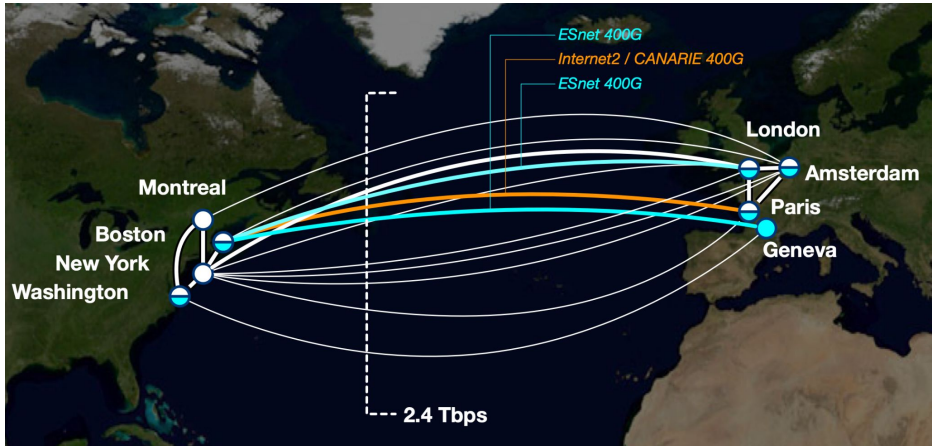
- Global Exchange Points are currently Layer 2
- Now installed and operating at Boston (BIX), New York (MAN LAN), and Washington (WIX)
- In the process of fully integrating them into the core backbone, NSO, and Insight Console (Virtual Networks, APIs)
  - Intend to integrate into AutoGOLE/SENSE
- First 400G links are online!
- **Inter-GXP links will likely be pluggables - just waiting for the release of “bright” OSFP**

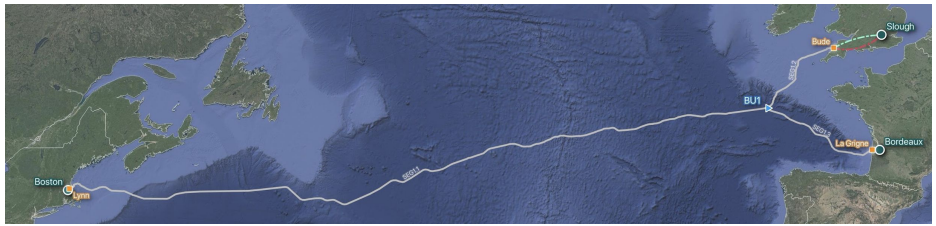


400G in the Atlantic

First General Purpose R&E Circuit Online

- A key part of the global ecosystem for R&E
- Continuity from European 400G networks to North American networks
- Under Final Test and Provisioning
- Amitié cable
- Part of Advanced North Atlantic
- Primarily a collaboration between CANARIE, ESnet, and Internet2; however success depends on all the ANA partners!
- ESnet also has two dedicated links as part of system
- First of Many Expected





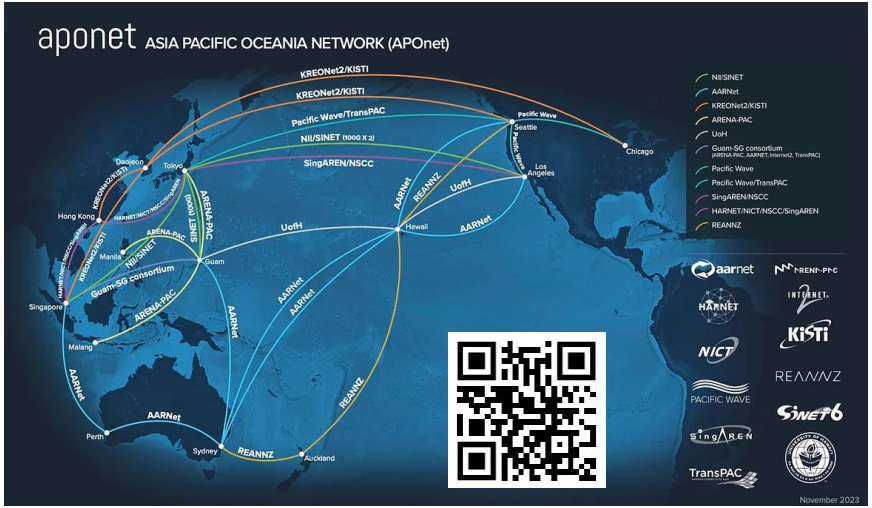
Global Partnerships: ANA & APONET

Advanced North Atlantic (ANA)

- KREONET and NII have joined ANA.
  - KREONET - 100G Chicago to Amsterdam
  - NII - 100G New York to Amsterdam
- New NREN working group formed to advance multi-domain network provisioning and failover. Currently surveying members and exploring potential solutions.
- Massive documentation and operational procedure overhaul.
- ANA specific dashboard created by Indiana University.

Asia Pacific Oceanic Network (APONET)

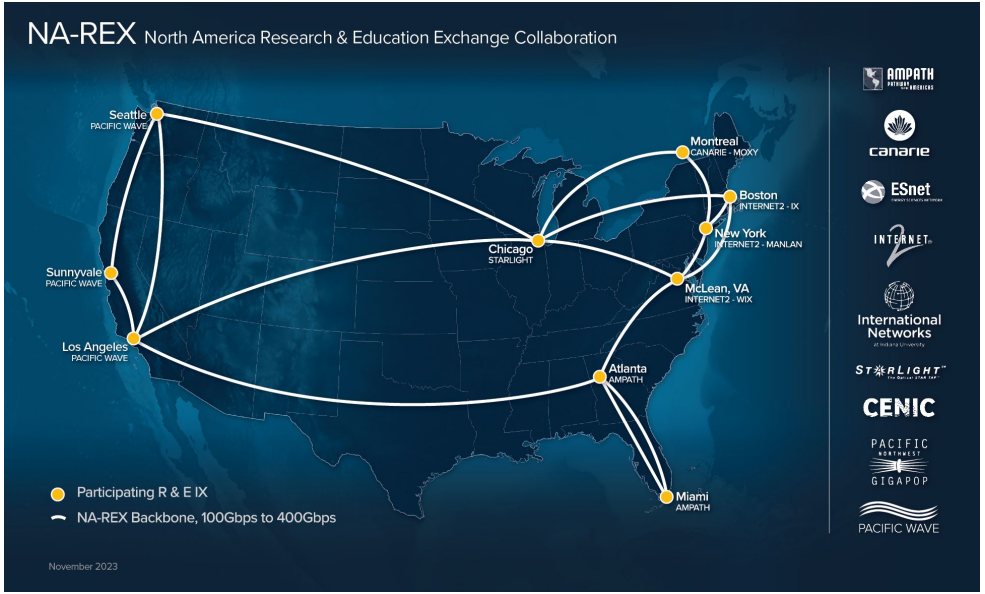
- Internet2 joined in 2021 through the Guam-Singapore Connectivity Consortium.
  - Partners: AARNET, ARENA-PAC, Indiana University, Internet2
  - Exchange providers: GOREX and SingAREN
- Recently supported a dedicated satellite data downloads connection for the ISRO-NOAA Data Exchange and Cooperation (INDEC) with the help of NII, NKN, Pacific Wave, SingaREN and TransPAC.



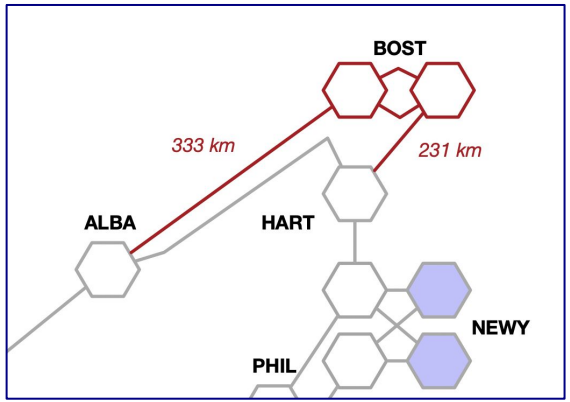
NA-REX: Collaboration, Overlay

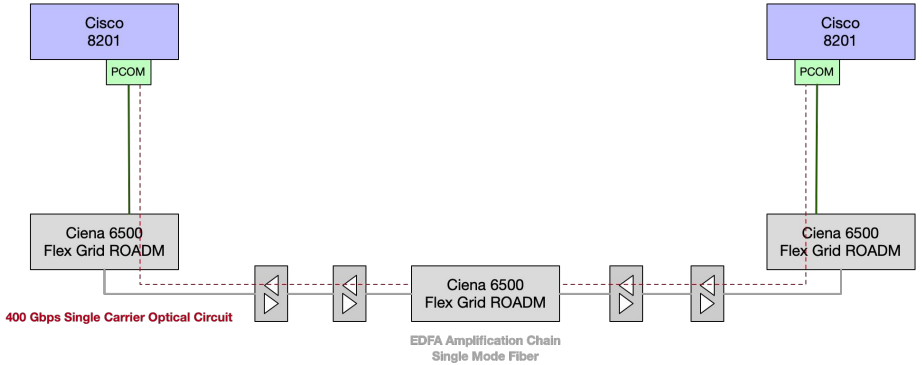
International Collaboration: NA-REX

- North American consortium of Exchange Point Operators, Connectivity Providers, Science Networks
- Improve coordination, establish common operating principles
- Leverage common toolsets, provisioning mechanisms
- Support dedicated links for experimental traffic, network research
- Initial links online:
  - Chicago and Seattle (dedicated)
  - Chicago and Los Angeles (dedicated)
- Links were successfully leveraged by Supercomputing NREs (Network Research Experiments) and OFCnet
- Currently planned for 2024:
  - Deployment of dashboard based on NetSage
  - Bring additional 400G links online
  - Restore API functionality to I2 Exchange Points (Q2)



Spectrum, Transponders, and Pluggables





In December 2023, Internet2 placed its first coherent pluggables online in the northeast, fully deploying a new site with no WaveServer 5 devices.

Two sites in boston BOST (300 Bent) and BOST2 (1 Summer) are:

- Linked to each other by two channels (E and W)
- Also linked to adjacent sites:
  - Albany (ALBA) 333 km
  - Hartford (HART) 231 km

Spectrum, Transponders, and Pluggables

Internet2 is also operating a number of foreign / alien wave circuits and managed spectrum services nationwide. These leverage inherent capabilities in the line system and allow partners to leverage the community investment in the optical platform

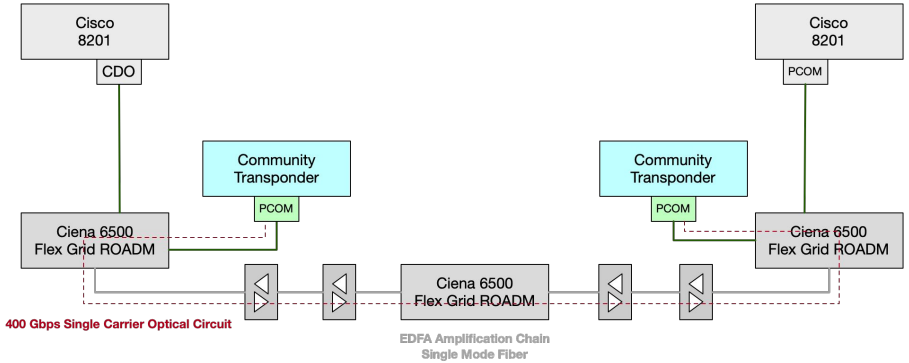
Foreign / Alien Waves ← 6 in service, more planned

- Allows community partner to connect their equipment at two sites
- Community partner owns and operates equipment
- Assumes equipment has appropriate launch power (~0 db)
- Channels and power levels are coordinated in advance; devices are not part of power management control loops (SPLI, etc)
- Optionally, dedicated add/drop structures are used

Managed Spectrum Services ← 7 in service

- Allows community partner to connect their equipment at two sites
- Community partner owns, but does not operate equipment
- Channels and power levels part of power management control loops (SPLI, etc)
- Requires hardware to be the same as that used by Internet2; equipment must be able to connect to our management plane

In many ways, backbone links using pluggables are this type, though automation with the line system is still theoretically possible within the Console!



Questions ?