
# Fiber Sensing Workshop

Internet2 Community Exchange
April 28, 2025

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*Research Professor*
*AmLight Principal Investigator*

# Outline

- About AmLight
- AmLight's Optical Infrastructure
- Fiber Sensing capabilities planned for AmLIght
- DAS and SoP on AmLight

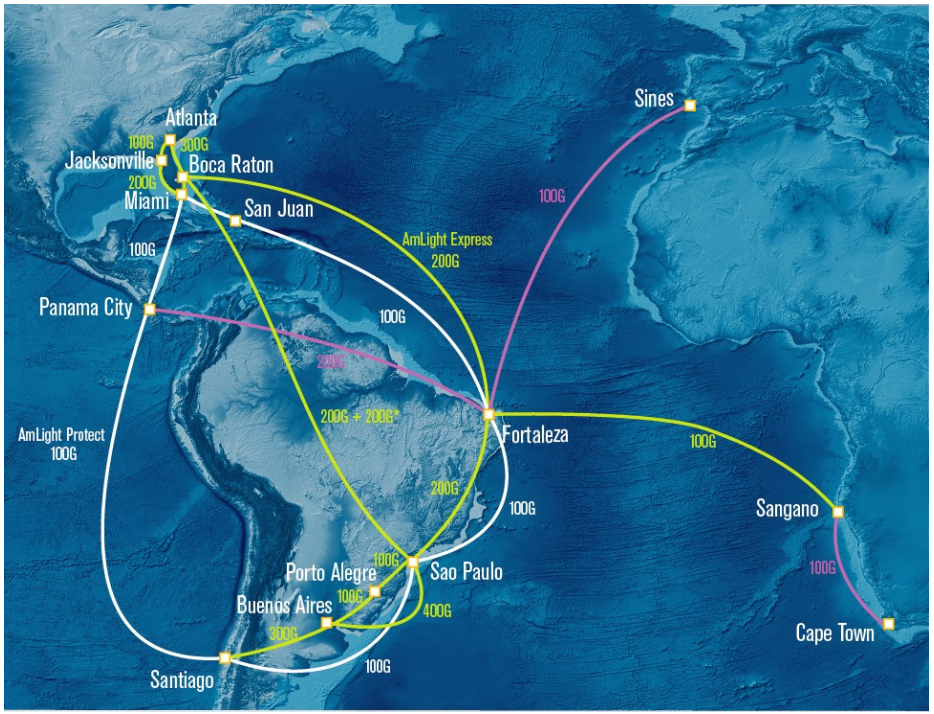
# AmLight Express and Protect Project

- AmLight-ExP is an international R&E network built to enable collaboration among Latin America, Africa, the Caribbean and the U.S.
- Supported by NSF and the IRNC program under award #OAC-2029283
- Partnerships with R&E networks in the U.S., Latin America, Caribbean and Africa, built upon layers of trust and openness by sharing:
  - Infrastructure resources
  - Human resources

AmLight ExP
Americas Lightpaths Express & Protect
(NSF Award # OAC-2029283)

# AmLight Network Infrastructure

- 39x 100G links:
  - 2.1+ Tbps of international connectivity
  - AmLight will reach 5+ Tbps of total capacity[2025]
  - Dark fiber, spectrum, waves, and lit services
- 11x Sites:
  - Miami, Boca Raton, Jacksonville, Sao Paulo, Fortaleza, Santiago, San Juan, Panama City, Cape Town, Atlanta, and Buenos Aires
- Network and Monitoring Instrumentation:
  - 20x programmable switches and 5x Juniper routers
  - 10x 10G perfSonar nodes
  - 4x 100G DTN servers
  - 4x In-band Network Telemetry (INT) collectors
    - ~10Mpps & 96TB of telemetry data per day



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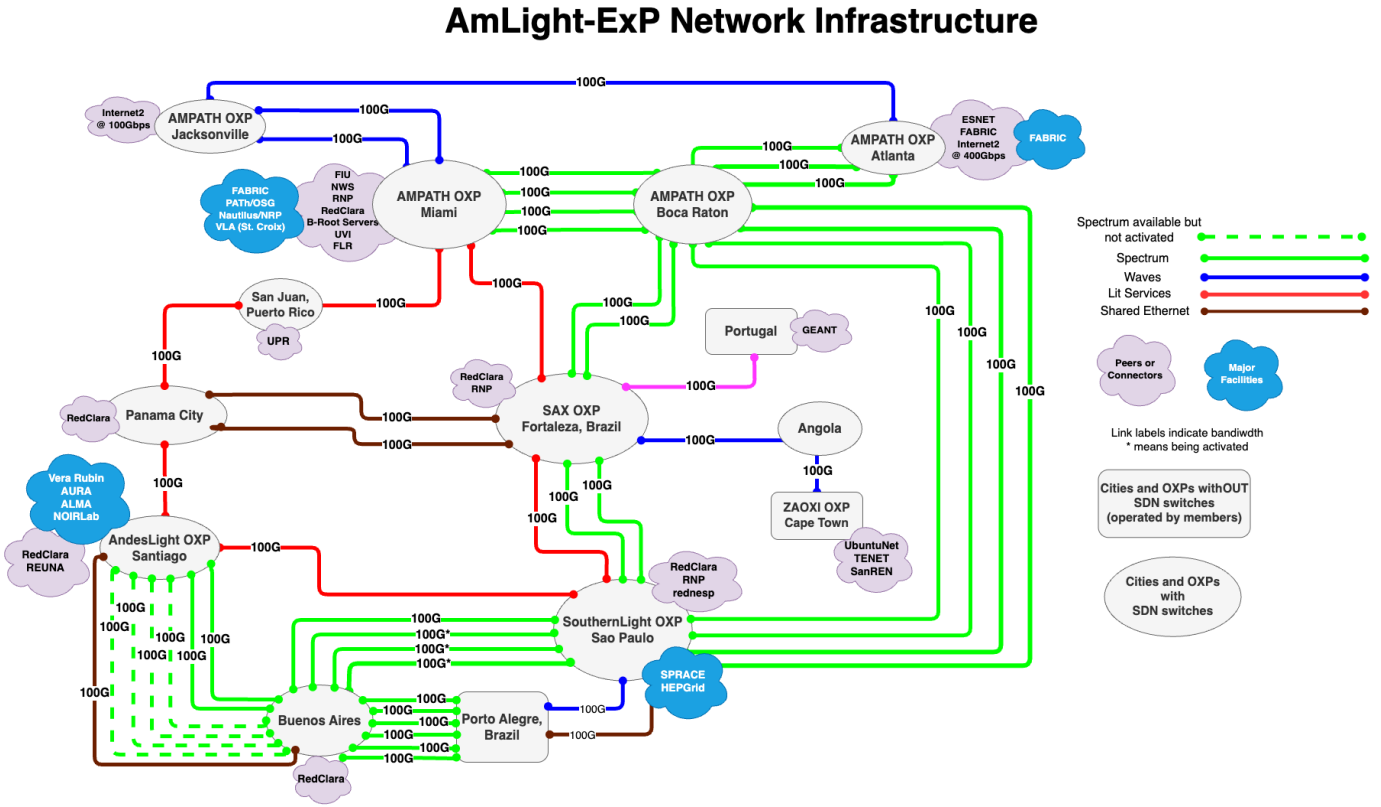
# AmLight Network Infrastructure - Detailed

- Dark fiber, spectrum, waves, and lit services connect at OXPs
- 10 OXPs: Miami, Boca Raton, Jacksonville, Atlanta, San Juan, Panama City, Fortaleza, Sao Paulo, Santiago, Buenos Aires
- Major facilities are connected in Chile, Brazil, USVI, Florida, Georgia
- Open Exchange Points provide the flexibility to place computation and storage closer to major facilities



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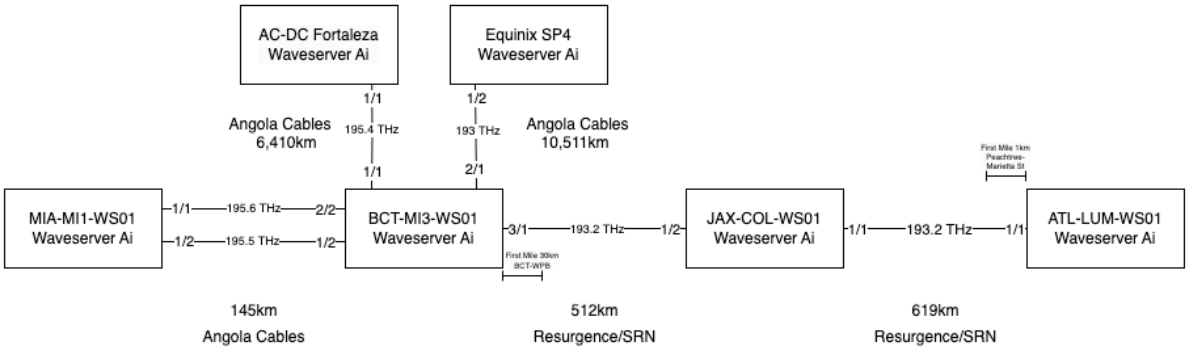
# AmLight Optical Network Infrastructure

- Ciena WaveServers that are managed by AmLight
- Distance between transponders over the optical fiber (km)
  - Note difference in distances between terrestrial and submarine
- Frequency of the Wave (in THz)
- Fiber between Miami (MIA) and Boca Raton (BCT)
- Spectrum between BCT and Jacksonville (JAX)
- Spectrum between JAX and Atlanta (ATL)
- Spectrum between BCT and Fortaleza (FTZ) on Monet
- Spectrum between BCT and Sao Paulo (SAO)



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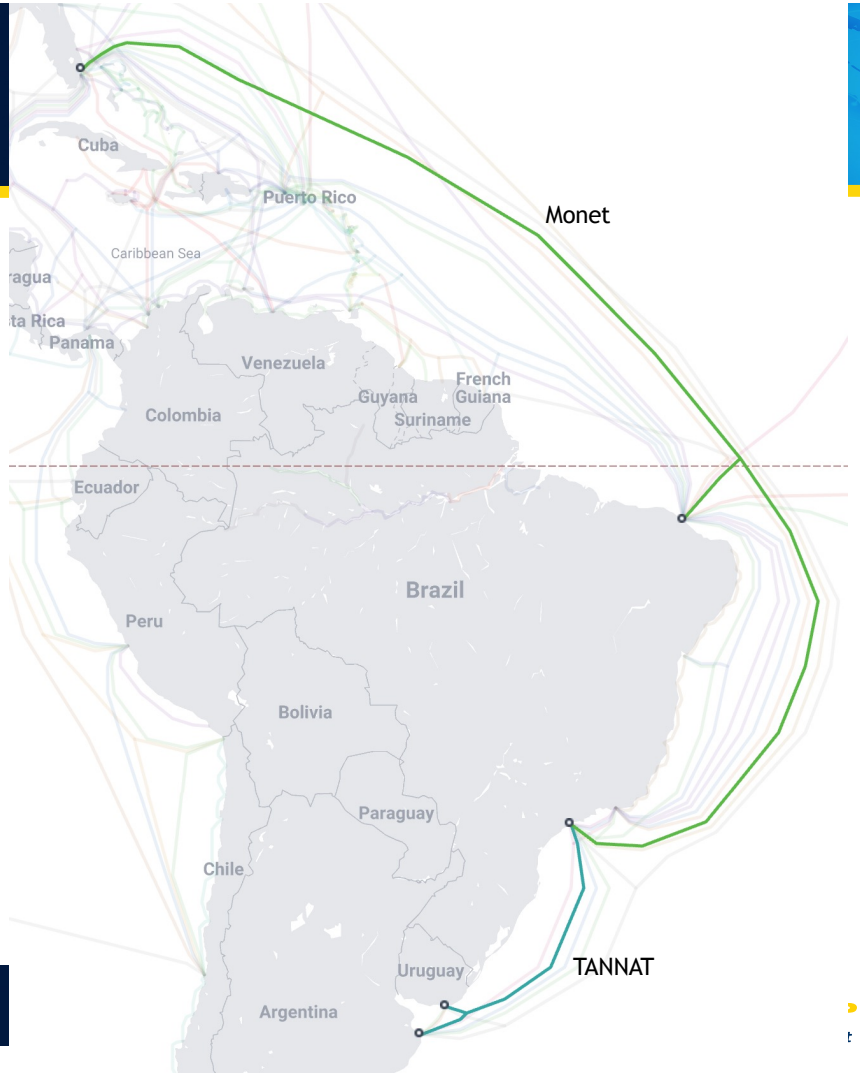
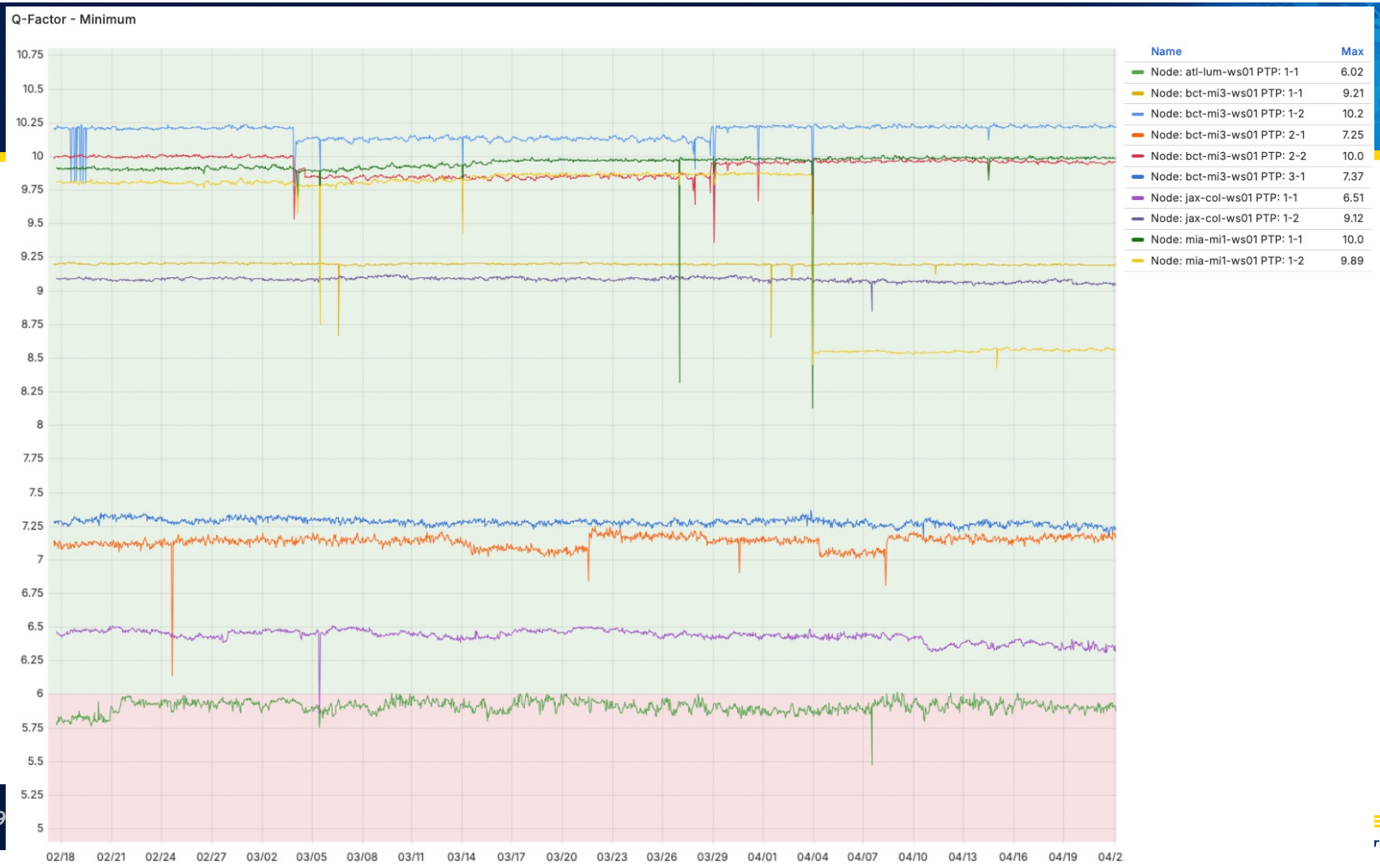
# Submarine Cables

- Monet
  - Transponders managed by AmLight
  - 6,410km, Boca Raton to Fortaleza
  - 10,511km, Boca Raton to Sao Paulo
- TANNAT
  - Transponders managed by provider
  - 2,410km, Sao Paulo to Buenos Aires



# Optical Metrics from the Ciena transponders

| Optical Metric: | Description: |
|---|---|
| Transmission (Tx) Optical Power Levels | Optical power launched by the transmitter into the fiber (measured in dBm). |
| Receiving (Rx) Optical Power Levels | Optical power received at the transponder input, important for signal health. |
| Optical Signal to Noise Ratio (OSNR) | Ratio of signal power to noise power; higher values mean better signal quality. |
| ***Q-Factor*** | ***Indicator of signal quality and noise tolerance; higher is better.*** |
| ***Pre-FEC Bit Error Rate*** | ***Bit error rate measured before Forward Error Correction is applied.*** |
| FEC Error Uncorrected Count | Number of errors that Forward Error Correction could not fix. |
| FEC Error Uncorrected Seconds | Number of seconds with at least one uncorrected FEC error. |
| FEC Error High Correction Count Seconds | Seconds during which a high number of FEC corrections occurred, suggesting poor signal quality. |
| Chromatic Dispersion (CD) | Spreading of optical pulses due to varying speeds of different wavelengths. |
| Differential Group Delay (DGD) | Difference in arrival times of different polarization components (PMD effect). |
| Effective Signal-to-Noise Ratio (ESNR) | Advanced SNR measurement considering dispersion and non-linear effects. |
| Cyclic Slip Indicator | Signals instability where cycle slips occur in carrier recovery loops. |


Q-Factor - Minimum
10.75
10.5
10.25
10
9.75
9.5
9.25
9
8.75
8.5
8.25
8
7.75
7.5
7.25
7
6.75
6.5
6.25
6
5.75
5.5
5.25
5
02/18
02/21
02/24
02/27
03/02
03/05
03/08
03/11
03/14
03/17
03/20
03/23
03/26
03/29
04/01
04/04
04/07
04/10
04/13
04/16
04/19
04/2
Name
Max
Node: atl-lum-ws01 PTP: 1-1 6.02
Node: bct-mi3-ws01 PTP: 1-1 9.21
Node: bct-mi3-ws01 PTP: 1-2 10.2
Node: bct-mi3-ws01 PTP: 2-1 7.25
Node: bct-mi3-ws01 PTP: 2-2 10.0
Node: bct-mi3-ws01 PTP: 3-1 7.37
Node: jax-col-ws01 PTP: 1-1 6.51
Node: jax-col-ws01 PTP: 1-2 9.12
Node: mia-mi1-ws01 PTP: 1-1 10.0
Node: mia-mi1-ws01 PTP: 1-2 9.89

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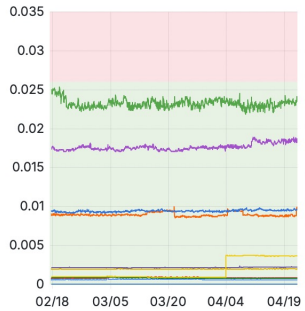
## Pre-FEC Bir Error Rate (BER)

There is no minimum measurement

### Pre-FEC Bit Error Rate - Average




| Name | Max |
|---|---|
| Node: atl-lum-ws01 PTP: 1-1 | 0.0253 |
| Node: bct-mi3-ws01 PTP: 1-1 | 0.00206 |
| Node: bct-mi3-ws01 PTP: 1-2 | 0.000972 |
| Node: bct-mi3-ws01 PTP: 2-1 | 0.00998 |
| Node: bct-mi3-ws01 PTP: 2-2 | 0.000969 |
| Node: bct-mi3-ws01 PTP: 3-1 | 0.00980 |
| Node: jax-col-ws01 PTP: 1-1 | 0.0189 |
| Node: jax-col-ws01 PTP: 1-2 | 0.00231 |
| Node: mia-mi1-ws01 PTP: 1-1 | 0.000886 |
| Node: mia-mi1-ws01 PTP: 1-2 | 0.00372 |
| Node: mia-mi1-ws01 PTP: 3-1 | 0 |

### Pre-FEC Bit Error Rate - Maximum

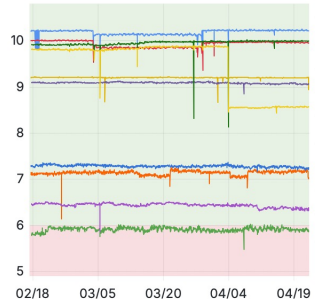

| Name | Max |
|---|---|
| Node: atl-lum-ws01 PTP: 1-1 | 0.0302 |
| Node: bct-mi3-ws01 PTP: 1-1 | 0.00335 |
| Node: bct-mi3-ws01 PTP: 1-2 | 0.00124 |
| Node: bct-mi3-ws01 PTP: 2-1 | 0.0213 |
| Node: bct-mi3-ws01 PTP: 2-2 | 0.00166 |
| Node: bct-mi3-ws01 PTP: 3-1 | 0.0112 |
| Node: jax-col-ws01 PTP: 1-1 | 0.0248 |
| Node: jax-col-ws01 PTP: 1-2 | 0.00281 |
| Node: mia-mi1-ws01 PTP: 1-1 | 0.00540 |
| Node: mia-mi1-ws01 PTP: 1-2 | 0.00418 |
| Node: mia-mi1-ws01 PTP: 3-1 | 0 |

Q-Factor refers to a performance monitoring metric that indicates the signal quality of an optical transmission link, essentially measuring the ratio of the signal strength to the noise level on the link; a higher Q-factor signifies a better signal quality with less noise, which is crucial for reliable data transmission on the network.

The Q-factor is calculated based on the received optical signal power and the noise level, providing a single value to assess signal quality.

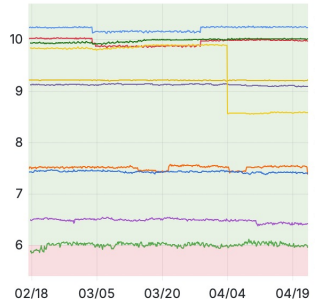
## Q-Factor Measurements

### Q-Factor - Minimum



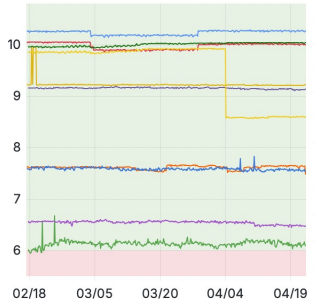

| Name | Max |
|---|---|
| Node: atl-lum-ws01 PTP: 1-1 | 6.02 |
| Node: bct-mi3-ws01 PTP: 1-1 | 9.21 |
| Node: bct-mi3-ws01 PTP: 1-2 | 10.2 |
| Node: bct-mi3-ws01 PTP: 2-1 | 7.25 |
| Node: bct-mi3-ws01 PTP: 2-2 | 10.0 |
| Node: bct-mi3-ws01 PTP: 3-1 | 7.37 |
| Node: jax-col-ws01 PTP: 1-1 | 6.51 |
| Node: jax-col-ws01 PTP: 1-2 | 9.12 |
| Node: mia-mi1-ws01 PTP: 1-1 | 10.0 |
| Node: mia-mi1-ws01 PTP: 1-2 | 9.89 |

### Q-Factor - Average




| Name | Max |
|---|---|
| Node: atl-lum-ws01 PTP: 1-1 | 6.11 |
| Node: bct-mi3-ws01 PTP: 1-1 | 9.22 |
| Node: bct-mi3-ws01 PTP: 1-2 | 10.3 |
| Node: bct-mi3-ws01 PTP: 2-1 | 7.57 |
| Node: bct-mi3-ws01 PTP: 2-2 | 10.0 |
| Node: bct-mi3-ws01 PTP: 3-1 | 7.47 |
| Node: jax-col-ws01 PTP: 1-1 | 6.55 |
| Node: jax-col-ws01 PTP: 1-2 | 9.15 |
| Node: mia-mi1-ws01 PTP: 1-1 | 10.0 |
| Node: mia-mi1-ws01 PTP: 1-2 | 9.91 |

### Q-Factor - Maximum




| Name | Max |
|---|---|
| Node: atl-lum-ws01 PTP: 1-1 | 6.68 |
| Node: bct-mi3-ws01 PTP: 1-1 | 9.96 |
| Node: bct-mi3-ws01 PTP: 1-2 | 10.3 |
| Node: bct-mi3-ws01 PTP: 2-1 | 7.66 |
| Node: bct-mi3-ws01 PTP: 2-2 | 10.1 |
| Node: bct-mi3-ws01 PTP: 3-1 | 7.83 |
| Node: jax-col-ws01 PTP: 1-1 | 6.60 |
| Node: jax-col-ws01 PTP: 1-2 | 9.19 |
| Node: mia-mi1-ws01 PTP: 1-1 | 10.0 |
| Node: mia-mi1-ws01 PTP: 1-2 | 9.93 |

# More effective use of Optical and Packet data

- Utilize production data from AmLight to study, develop research questions, and experiment to address network management challenges

- Methodology:
  - Catalog data gathered from AmLight
  - Understand how the data are related and how they can be utilized
  - Provide data samples
  - Publish findings in research articles

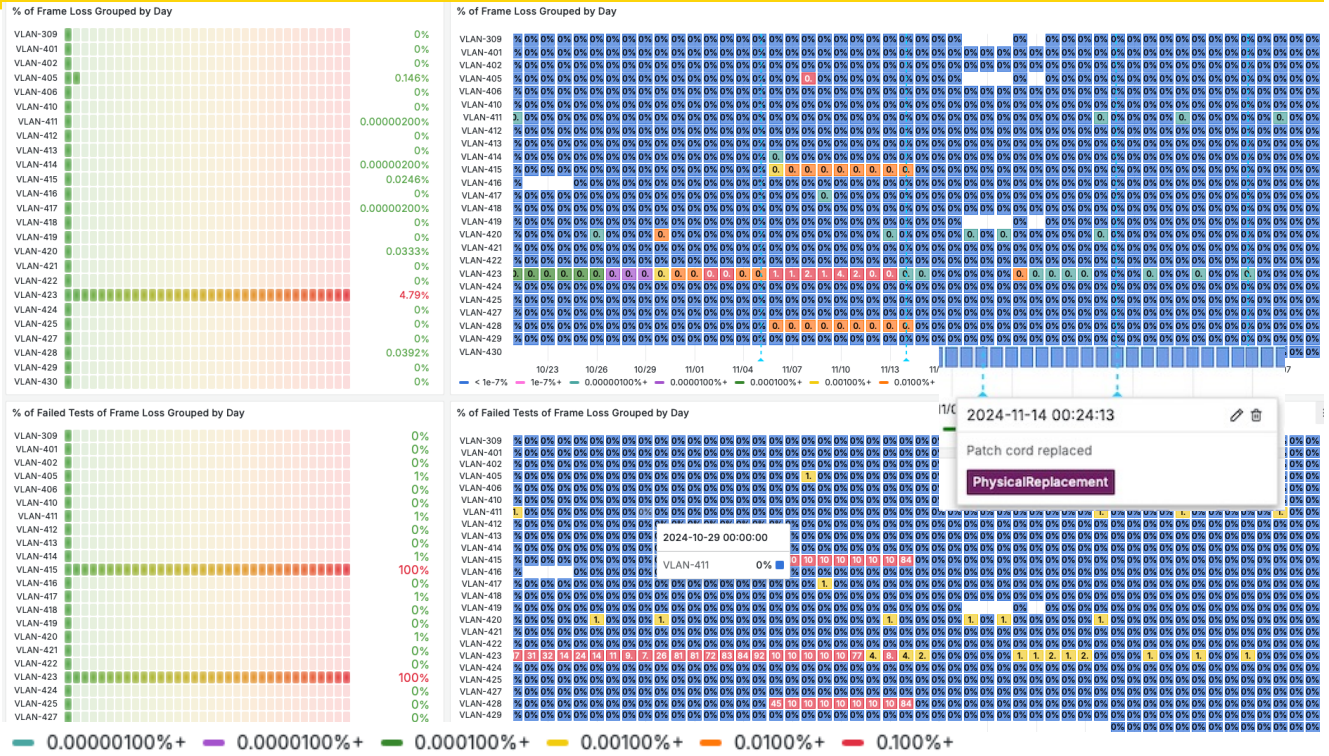
- *So what does more effective use of optical and packet data look like?*

# BERToD - Bit Error Rate Testing on Demand

- BERToD is an automated packet loss detection framework
  - It uses granular per-packet network telemetry (INT), a customized networking pipeline, and a hardware-based packet generator to detect bit error rates as low as $1x10^{-12}$
- BERToD leverages recent developments at AmLight:
  - Flexible forwarding rules provided by the SDN switches
  - Link and buffer utilization monitoring provided by In-band Network Telemetry (INT)
  - Topological data and dynamic service instantiation provided by the Kytos-ng SDN Controller
- Achieves near deterministic results due to specialized network hardware being used end-to-end:
  - Highly accurate with granular results

# BERToD – Experiment Results

- Using Grafana to plot each test's loss per day
- Great way to correlate events and identify patterns
- Filters available to visualize test results based on frame size and individual paths
- Used with annotations to add context



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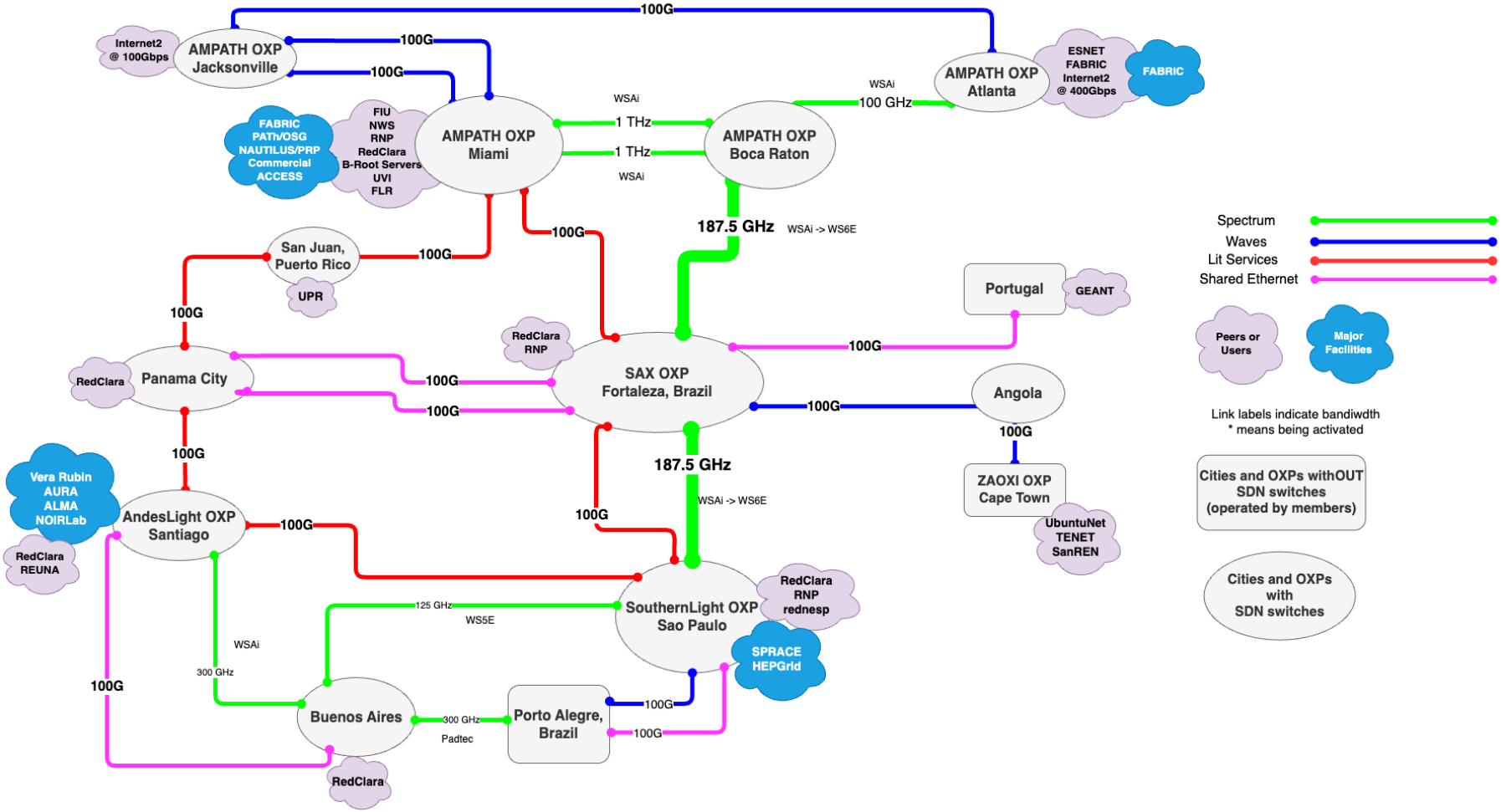
# BERToD - Bit Error Rate Testing on Demand

- For a deeper dive about BERToD, watch the CI Engineering Lunch and Learn, Feb 28th, 2025, by Jeronimo Bezerra
  - *BERToD: An automated BER testing framework to search for packet loss at AmLight*

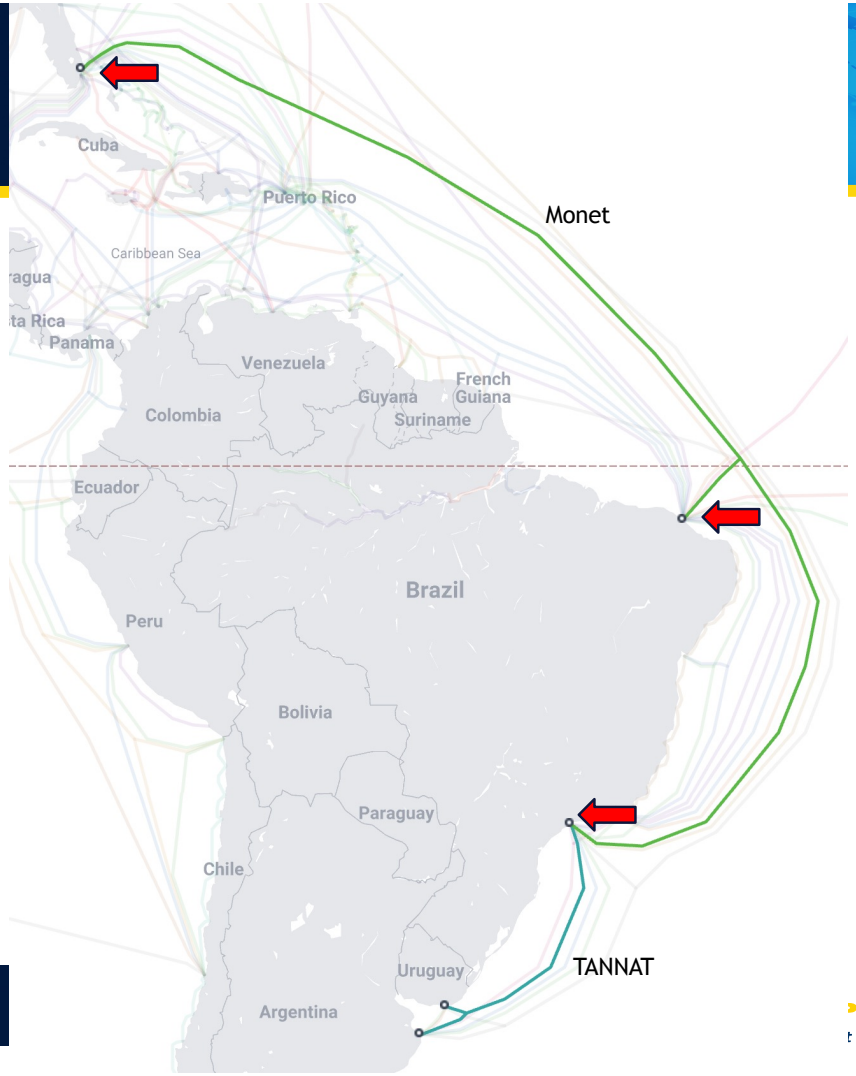
- Next, the Ciena WaveLogic 6E and fiber sensing on AmLight

# AmLight-ExP Network Infrastructure: Fiber Sensing



# Fiber sensing on AmLight

- Monet
  - Ciena WaveLogic 6E Transponders managed by AmLight
    - Adds fiber sensing features
  - 6,410km, Boca Raton to Fortaleza
  - 10,511km, Boca Raton to Sao Paulo
- TANNAT
  - Transponders managed by provider
  - 2,410km, Sao Paulo to Buenos Aires



# WaveLogic 6E on AmLight

- 1.2 Tbps of bandwidth capacity is expected between Boca Raton, Fortaleza, and Sao Paulo

- Available bandwidth for use by
  - Network Operations
  - Major Facilities
  - Testbeds for experimentation
    - E.g., environmental sensing

# DAS and SOP

- **Digital Acoustic Sensing (DAS)** uses optical fibers as sensors to detect acoustic vibrations to
  - Monitor infrastructure integrity
  - Environment conditions
- The improved sensitivity and signal processing in WL6e could support DAS functionalities

- **State of Polarization (SoP) Monitoring** tracks changes in the polarization state of light within optical fibers
- These changes can indicate environmental disturbances, such as mechanical vibrations or seismic activities
- The WL6e improves spectral efficiency and signal fidelity by enhancing DSP
- These enhancements facilitate more precise SoP tracking
  - enabling better detection of environmental changes

# DAS and SoP

- AmLight is anticipating information from Ciena about the features of the WL6E and its programmability and its API
- AmLight has had several meetings with the environmental sensing group at UW-Madison about using AmLight for environmental sensing
- Onward …


# THANK YOU

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