OFCnet 2024 Introduction

Cees de Laat, University of Amsterdam, Netherlands
Reza Nejabati, University of Bristol, United Kingdom
Gwen Amice, EXFO, Canada
Andrew Lord, British Telecom, United Kingdom

Workshop

- Started in 2023, OFCnet brings a new opportunity to the exhibition and demonstrates products, concepts, solutions, research, and architectures in live high-speed optical networks connected to the leading research and education networks worldwide.
- This increased focus on designing and building next-generation Optical Networks will expand exposure to connectivity, emerging and next-generation network technologies such as Quantum Networks, programmable and software-defined optical networks, and their applications such as big data, security, and distributed classical and quantum computing.
- This workshop brings together the innovators and researchers who work on the mentioned topics to enrich the OFCnet community further and expand the contributing parties. We discuss how this initiative should be developed to ensure OFCnet enriches future community participation.

Program

13:00	Opening Workshop	Cees de Laat
13:05	Presentation on the features and demonstrations that comprise OFCnet24	Marc Lyonnais Chair OFCnet
13:15	Introduction of panel on lessons learned from (preparing) technology demonstrations, opportunities, building networks from components, enabling new wave of demo's	Cees de Laat
13:20	1. Duncan Earl, Qubitekk 2. Joe Mambretti, Northwestern University 3. Chris Janson, Nokia 4. Félix Bussières, Morax Idquantique 5. Mehdi Namazi, Quconn 6. Jerome Prieur, Aureatechnology 7. David Rodgers, Exfo	Panel session moderated by Cees de Laat and Gwennael Amice
14:15	Introduction of the Modified Rump Session approach to engage with industry and academic research labs regarding emerging technologies, research and innovation prototyping to be demonstrated at current and future OFCnet's.	Reza Nejabati
14:20	1. Ben Dixon, MIT Lincoln Laboratory 2. Dimitra Simeonidou, University of Bristol, JOINER UK National Test-bed 3. Prem Kumar, Northwestern University, Illinois Express Quantum Network 4. Julia Larikova, Infinera 5. Jorg Peter Elbers, Adva	Rump session moderated by Reza Nejabati and Andrew Lord
15:30	End of workshop	Cees de Laat

OFCnet 2024

Marc Lyonnais, OFCnet
Chair

Highlights

- We are bringing a live Network on the Exhibit floor;
- With 20 live demonstrations of these 9 are about Quantum Networking
- We are 35 volunteers with international presence.
- We are hosting hands-on live course as well as this workshop.
- We are an Open Network with multiple Industry and Academic researchers.
- Optica gave us great support to Reduce the barrier of live demonstrations and collaboration; OFCNet 2024 represents the culmination of 5 years of effort!

The 2024 Team Edition (35 people)

OFCnet
Marc Lyonnais (Chair) Ciena
Jim Stewart (Vice Chair) UETN
Sana Bellamine (Deputy Chair) Will be OFCnet 2025 Chair
Casey Foulds (Program Manager) uTD
Jessica Pagonis Optica Liaison & Biz manager
Randy Giles Optica Scientific Advisor Liaison

Network Architecture
Scott Kohlert (Co-Team Lead) Ciena
Mike Blodgett (Co-Team Lead) ESnet

Logistics
Akbar Kara (Ciena)
Casey Foulds (uTD)

OFCnet Workshop, BoF
Cees de Laat (Team Lead) UVA
Reza Nejabati
Andrew Lord
Gwen Amice (Co-Team Lead), EXFO

Short Course
Gwen Amice (EXFO)
Christine Tremblay (ETS)

Panel Preparation
Casey Foulds (uTD)

Network Build and Vendor Reachout
Management team +
Tunde Sanda CENIC
2 CENIC Engineers
Mike Blodgett Esnet
Jo-Ann Bender (Internet2)
Scotty Stracken (NSHE)
Chris Skaar (University of Illinois)

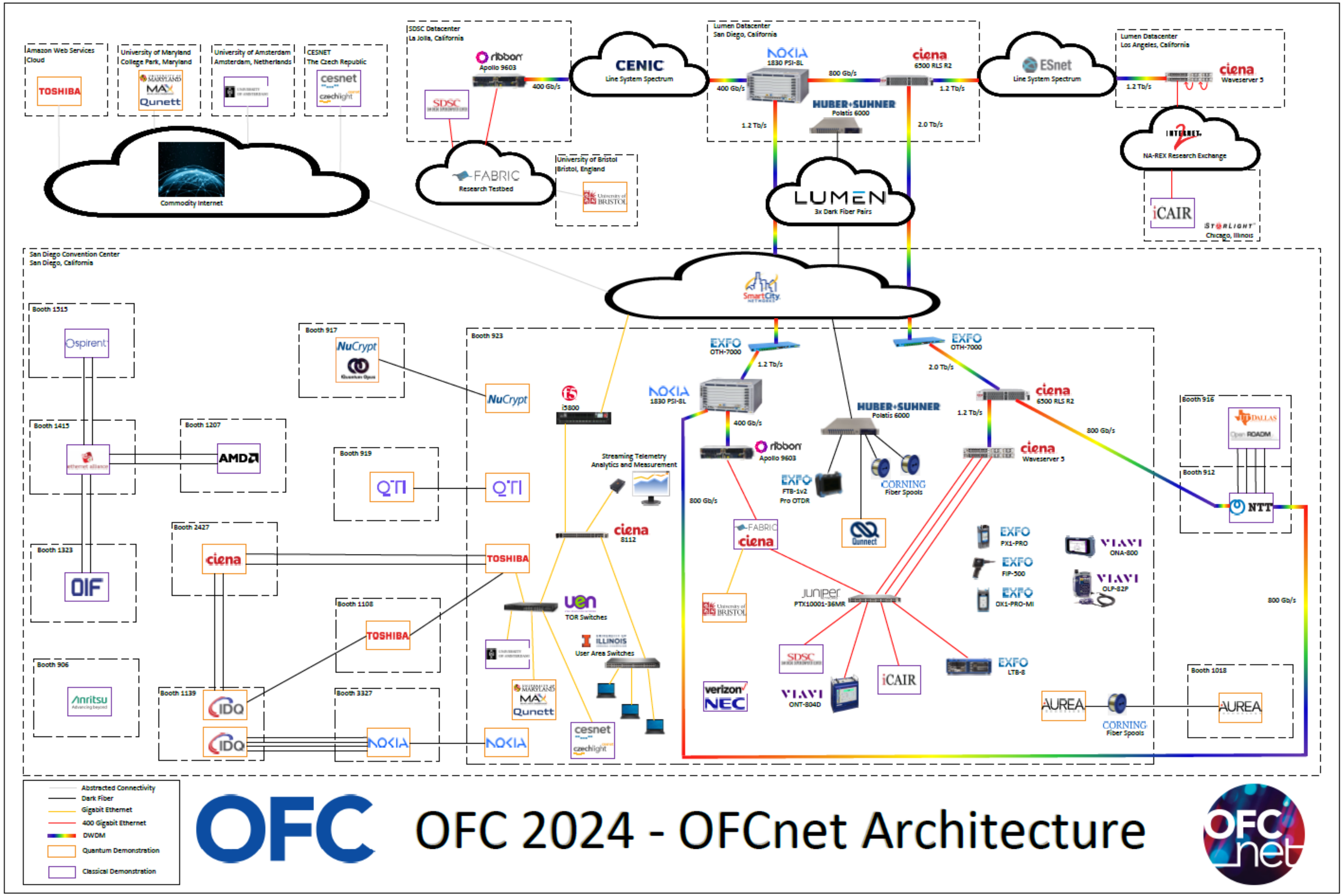
Demonstrations organization
Carl Williams (co-Team lead) CJW Quantum Consulting
Chris Tracy (co-team Lead) Esnet
Sergey Ten or Peter Wigley (Corning)

Security, Analytics and Measurements:
JP Velders (UVA) (co-Team lead)
Gwenn Amice EXFO
Gauravdeep Shami Ciena (Data Lake project) (co-Team lead)
Danial Ebling (UETN)
Tom Hutton (SDSC)
Mariam Kiran (ORNL)

Communications and Signage
Jennifer Inglisa (Optica) (Team lead)
Beth Harrington (Optica)
Ashley Collier (Optica)
Colleen Morrison (Optica)
Eve Griliches (Cisco)
Dave Brown (Nokia)
Rodney Wilson (Ciena)

OFC

Architecture Diagram



OFCnet Exhibiting Companies

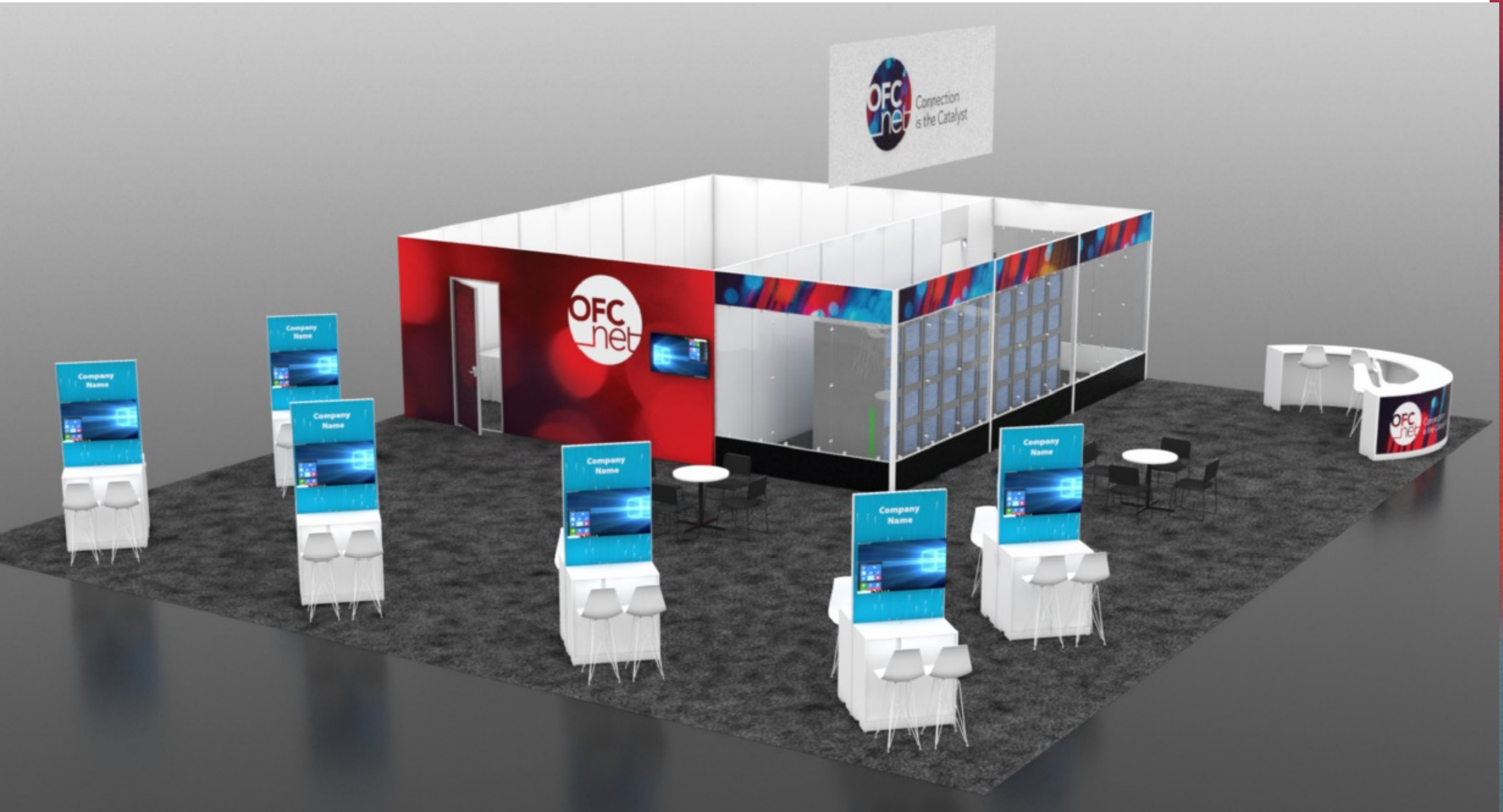
Kiosks (we have 11)

- CESNET, z.s.p.o.
- Ciena/FABRIC/SDSC
- F5, Inc.
- ID Quantique *(share)*
- NEC Laboratories America
- NOKIA *(share)*
- OFS *(share)*
- Qunnect Inc.
- StarLight/International Center for Advanced Internet Research Northwestern University
- University of Amsterdam
- University of Bristol *(they have 2 kiosks)*
- University of Maryland
- Verizon

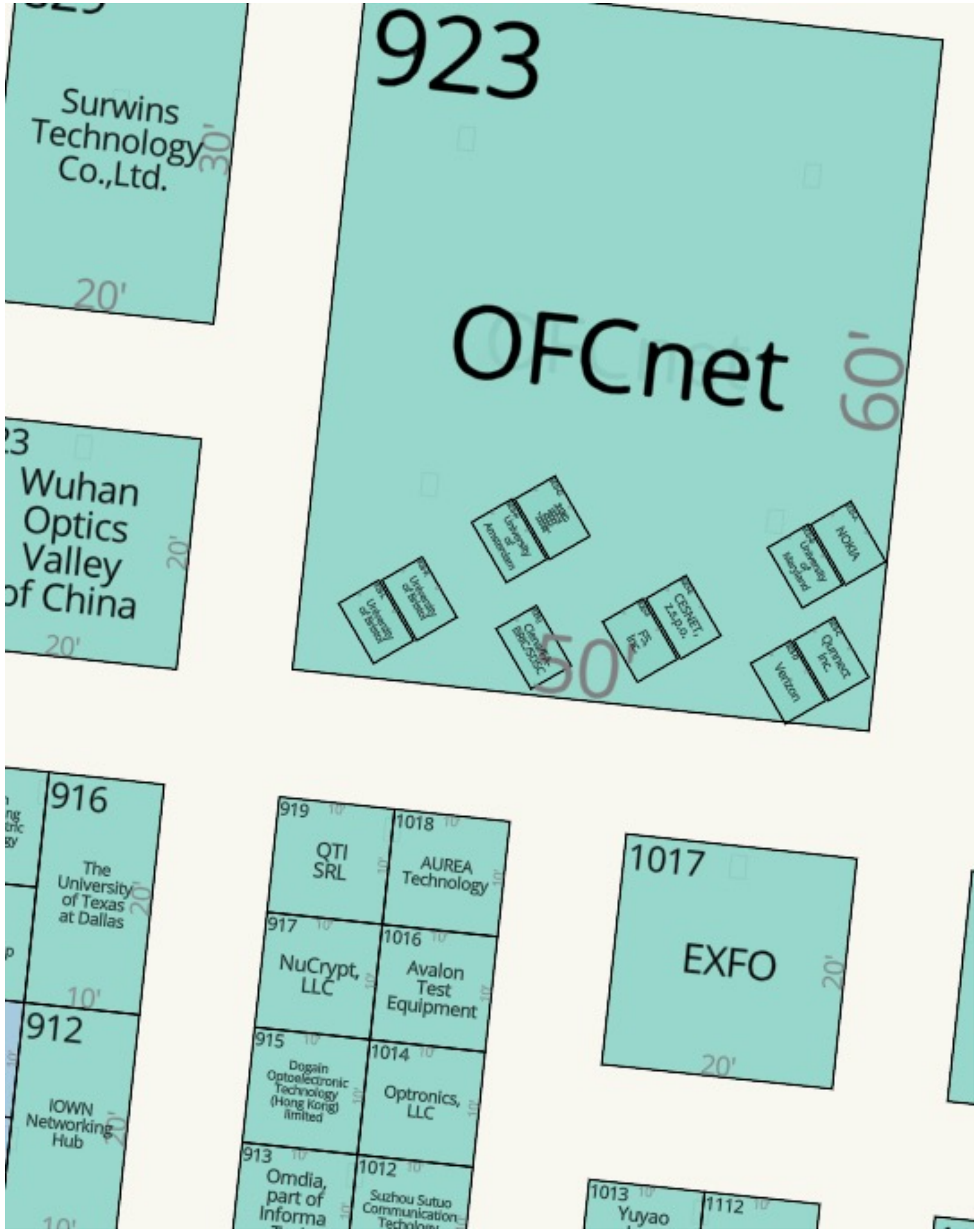
Booths (we have 6)

- AUREA Technology
- ID Quantique
- IOWN Networking Hub *(they have 2 booths)*
- NuCrypt, LLC
- QTI SRL
- The University of Texas at Dallas *(they have 2 booths)*

OFCnet Booth



OFCnet


Surwins Technology Co.,Ltd.
30'
20'
923
OFCnet
60'
50'
Wuhan Optics Valley of China
20'
20'
916
The University of Texas at Dallas
20'
10'
912
IOWN Networking Hub
20'
10'
919
QTI SRL
1018
AUREA Technology
917
NuCrypt, LLC
1016
Avalon Test Equipment
915
Dogain Optoelectronic Technology (Hong Kong) limited
1014
Optronics, LLC
913
Omdia, part of Informa
1012
Suzhou Sutuo Communication
1017
EXFO
20'
20'
1013
Yuyao
1112

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OFCNet Workshop Panel

Dr. Duncan Earl

President & Chief Technology Officer
Qubitekk, Inc.

March 2024

QUANTUM NETWORKS TODAY

1. **EPB Quantum Network (deployed/commercial)**
2. Center for Quantum Networks (CQN) - Tucson
3. Boston-Area Quantum Network(BARQNET) - Boston
4. MIT Quantum Network Testbed - Boston
5. Chicago Quantum Exchange (CQE) - Chicago
6. Quantum Application Network Testbed for Novel Entanglement Technology (QUANT-NET) - Berkeley
7. MSU Quantum Network – Bozeman
8. AFRL Quantum Network – Rome
9. DC-QNet – Washington, DC
10. Hybrid Quantum Architectures and Networks (HQAN) – Urbana-Champaign
11. Tri-City Quantum Network – Sherbrooke
12. Los Alamos National Lab Quantum Network

OVER THE NEXT 5 YEARS…

- Early network "frameworks" are currently being adopted – winners and losers to follow
- Quantum network components will expand rapidly:
  - Memories
  - Efficient frequency converters
  - Active channel correction
  - Timing and synchronization
  - Network simulators
  - Control and monitoring software
- Lots of industry education coming
  - Fiber optic asset owners are still currently trying to figure out what quantum is and means for their business
  - OFCNet could provides hands-on education and training to industry
  - OFCNet could coordinate network operators and identify best-practices for rest of industry

"Common-use" quantum hardware in the EPB Commercial Quantum Network

Qubitekk

Thank You

Contact:
Dr. Duncan Earl
e-mail: dearl@qubitekk.com

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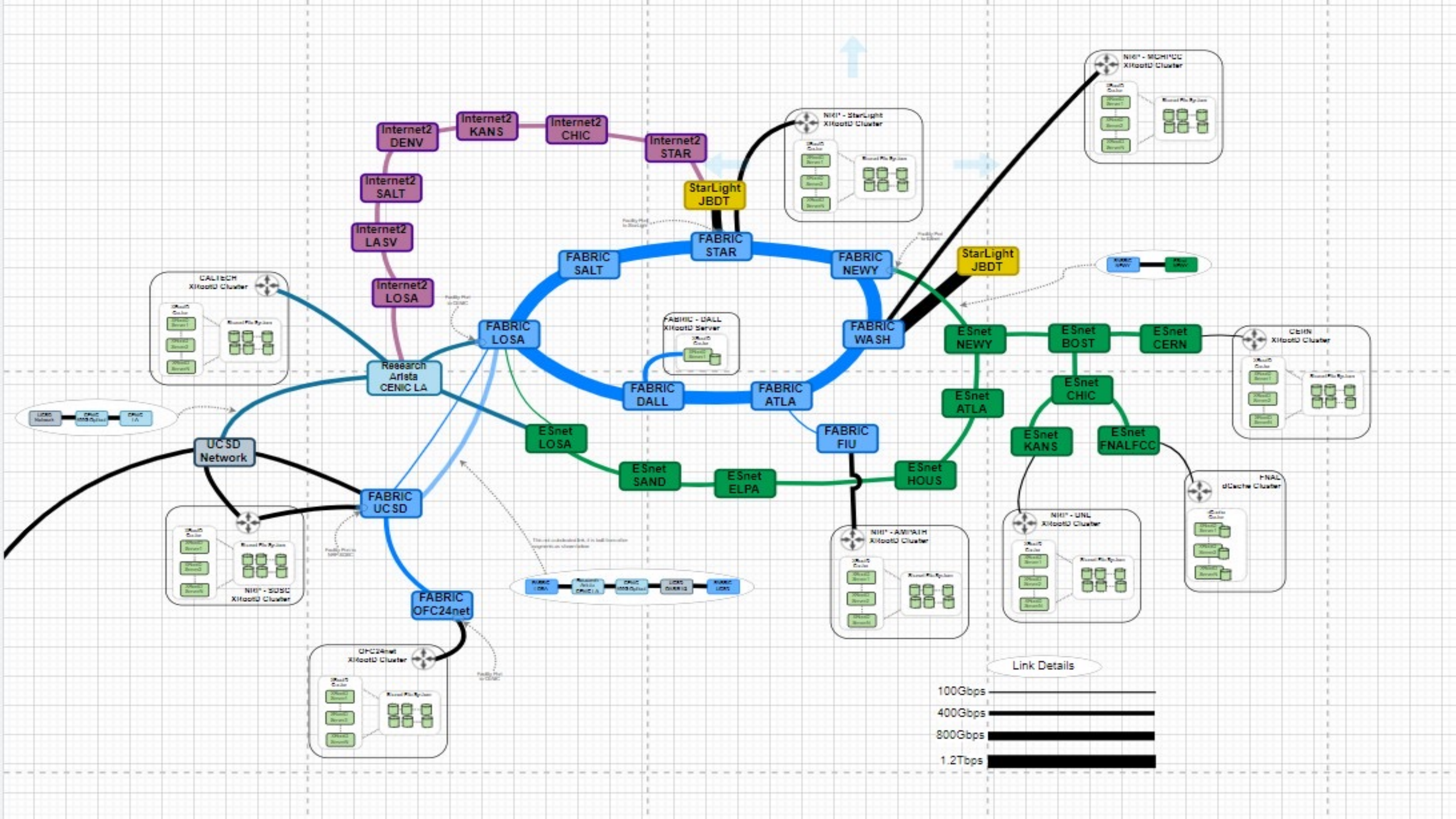
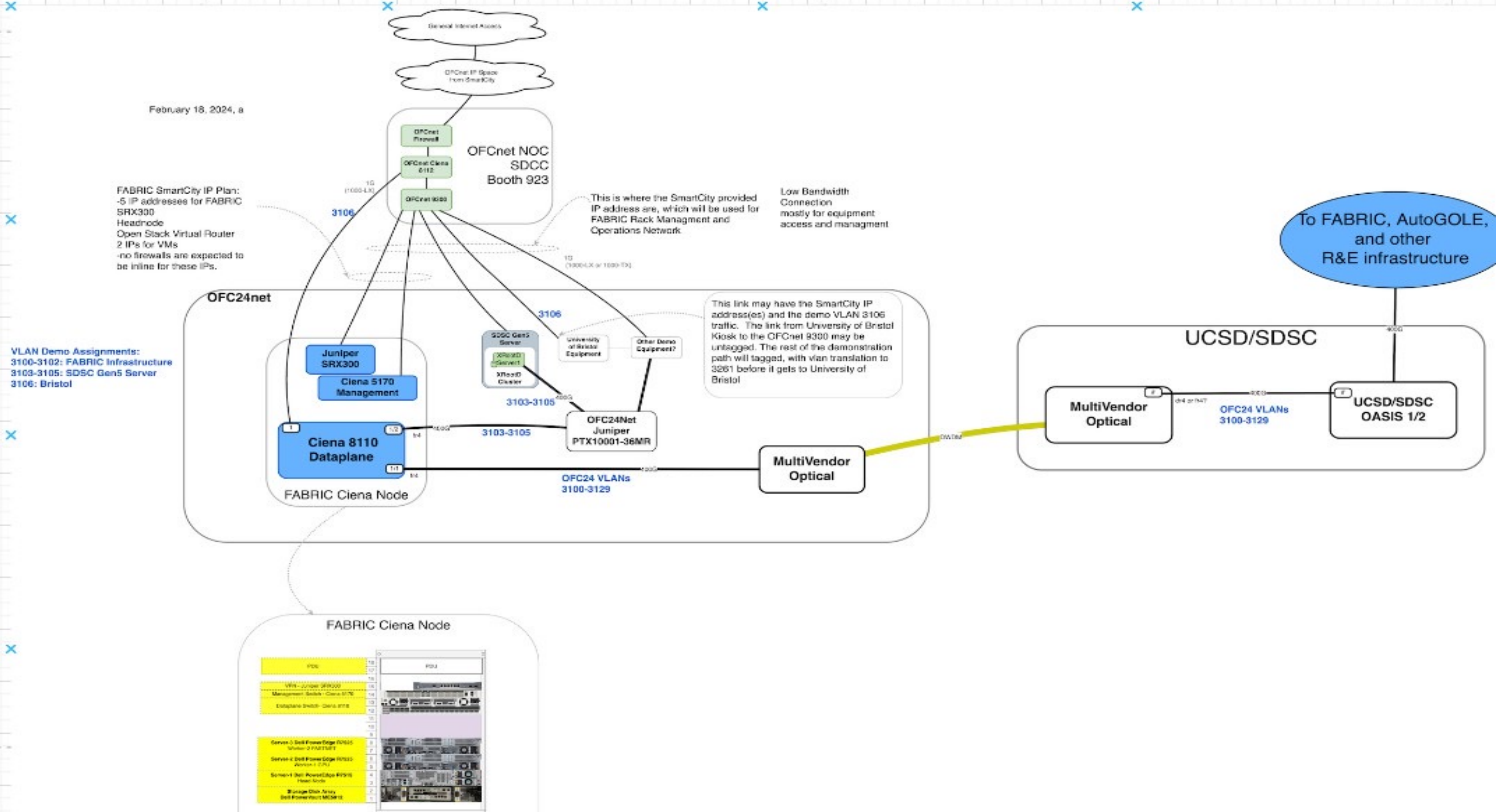

Internet2 DENV
Internet2 KANS
Internet2 CHIC
Internet2 STAR
Internet2 SALT
Internet2 LASV
Internet2 LOSA
StarLight JBDT
FABRIC STAR
FABRIC SALT
FABRIC NEWY
StarLight JBDT
FABRIC LOSA
FABRIC WASH
FABRIC DALL
FABRIC ATLA
FABRIC FIU
FABRIC UCSD
FABRIC OFC24net
CALTECH XRootD Cluster
FABRIC - DALL XRootD Server
Research Arista CENIC LA
UCSD Network
ESnet LOSA
ESnet SAND
ESnet ELPA
ESnet HOUS
ESnet ATLA
ESnet NEWY
ESnet BOST
ESnet CERN
ESnet CHIC
ESnet KANS
ESnet FNALFCC
CERN XRootD Cluster
FNAL dCache Cluster
NRP - StarLight XRootD Cluster
NRP - SDSC XRootD Cluster
NRP - AMPATH XRootD Cluster
NRP - UNL XRootD Cluster
OFC24net XRootD Cluster
Link Details
100Gbps
400Gbps
800Gbps
1.2Tbps



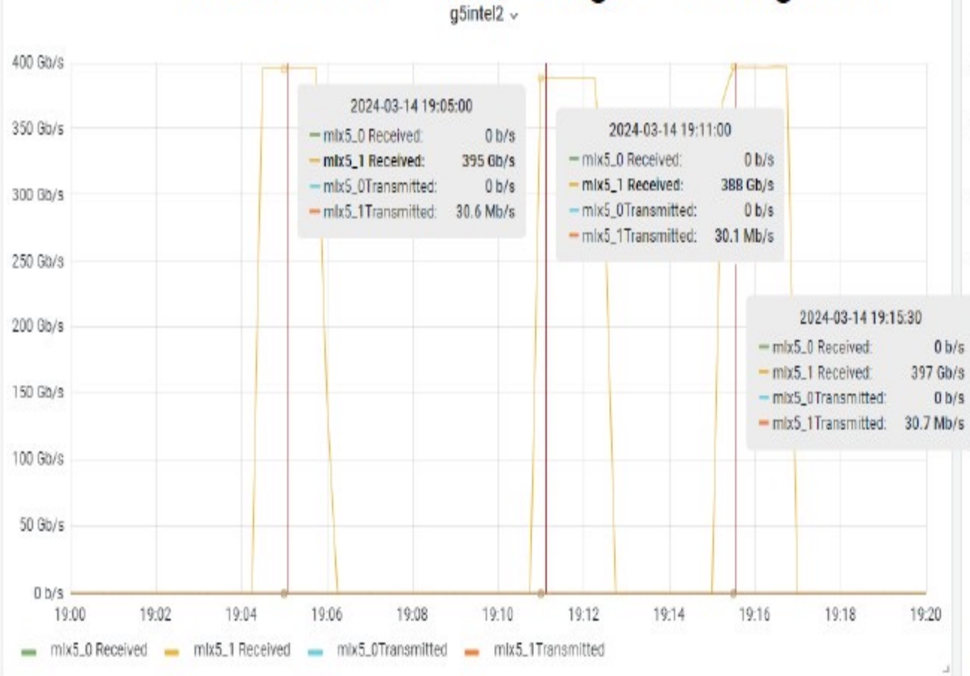
General Internet Access
OFCnet IP Space from SmartCity
February 18, 2024, a
OFCnet Firewall
OFCnet Ciena 8112
OFCnet 9300
OFCnet NOC
SDCC
Booth 923
FABRIC SmartCity IP Plan:
-5 IP addresses for FABRIC
SRX300
Headnode
Open Stack Virtual Router
2 IPs for VMs
-no firewalls are expected to be inline for these IPs.
3106
This is where the SmartCity provided IP address are, which will be used for FABRIC Rack Managment and Operations Network
Low Bandwidth Connection mostly for equipment access and managment
To FABRIC, AutoGOLE, and other R&E infrastructure
OFC24net
VLAN Demo Assignments:
3100-3102: FABRIC Infrastructure
3103-3105: SDSC Gen5 Server
3106: Bristol
Juniper SRX300
Ciena 5170 Management
SDSC Gen5 Server
XRootD Cluster
University of Bristol Equipment
Other Demo Equipment?
3106
This link may have the SmartCity IP address(es) and the demo VLAN 3106 traffic. The link from University of Bristol Kiosk to the OFCnet 9300 may be untagged. The rest of the demonstration path will tagged, with vlan translation to 3261 before it gets to University of Bristol
UCSD/SDSC
3103-3105
OFC24Net Juniper PTX10001-36MR
Ciena 8110 Dataplane
3103-3105
MultiVendor Optical
MultiVendor Optical
UCSD/SDSC OASIS 1/2
OFC24 VLANs 3100-3129
OFC24 VLANs 3100-3129
FABRIC Ciena Node
FABRIC Ciena Node

Extend Data Center Services Over 400G WAN

Prototype Solution Initial Results:

Single stream RDMA/RoCE over 400G network at different distance

(1) CENI Chicago - McLean VA | (2) NA-REX Chicago -L.A /San Diego | (3) FABRIC + NA-REX Chicago-L.A



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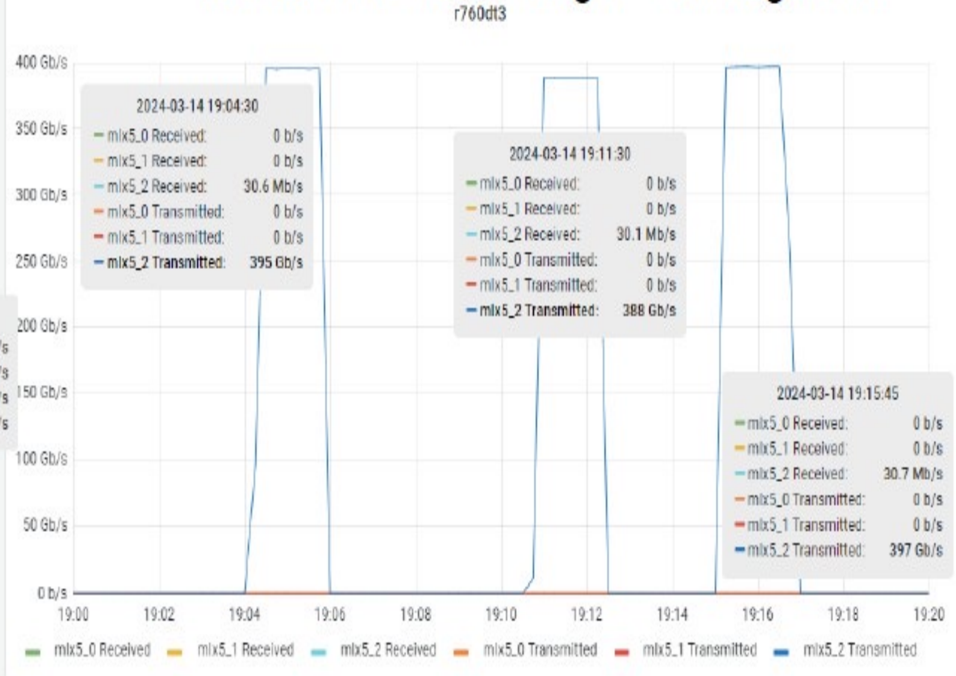

SL loopbacks: (1) Rtt 27 ms @ **395G** (2) Rtt87 ms @ **388G** (3) Rtt 108 ms @ **397G**

iCAIR STARLIGHT SDX

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NOKIA

QKD demonstration

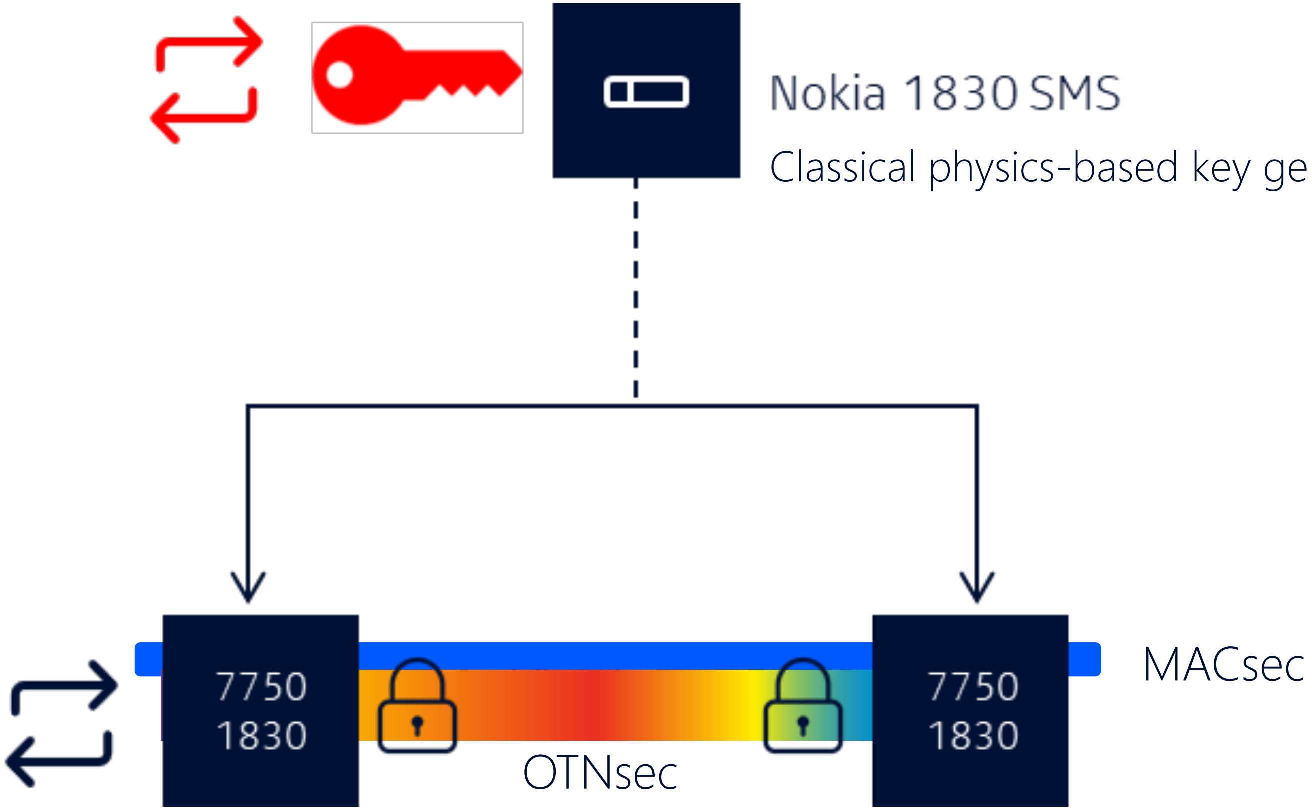
OFCnet

Amplify your network

OFC 2024

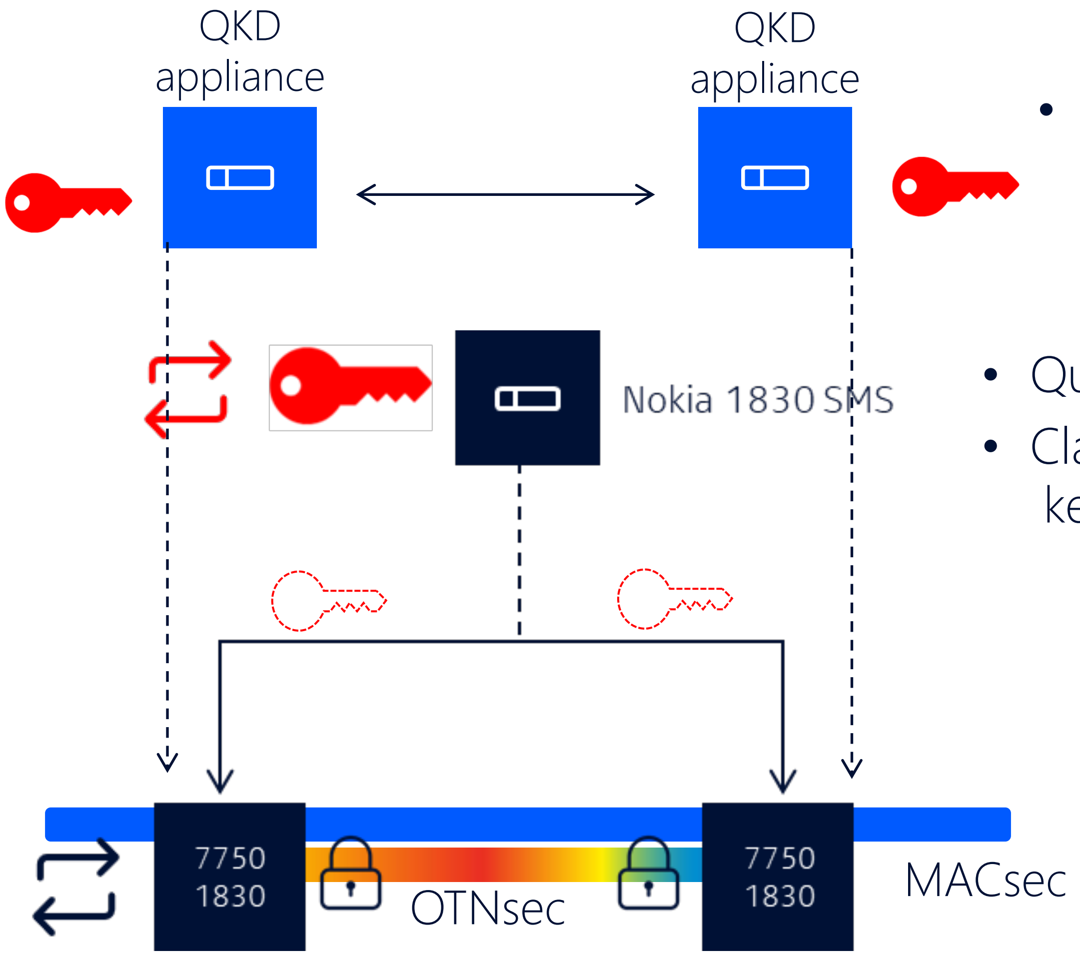
Nokia Quantum-Safe Networks

Automated, pre-shared, symmetric key distribution



Nokia Quantum-Safe Networks

QKD with automated, pre-shared, symmetric key distribution

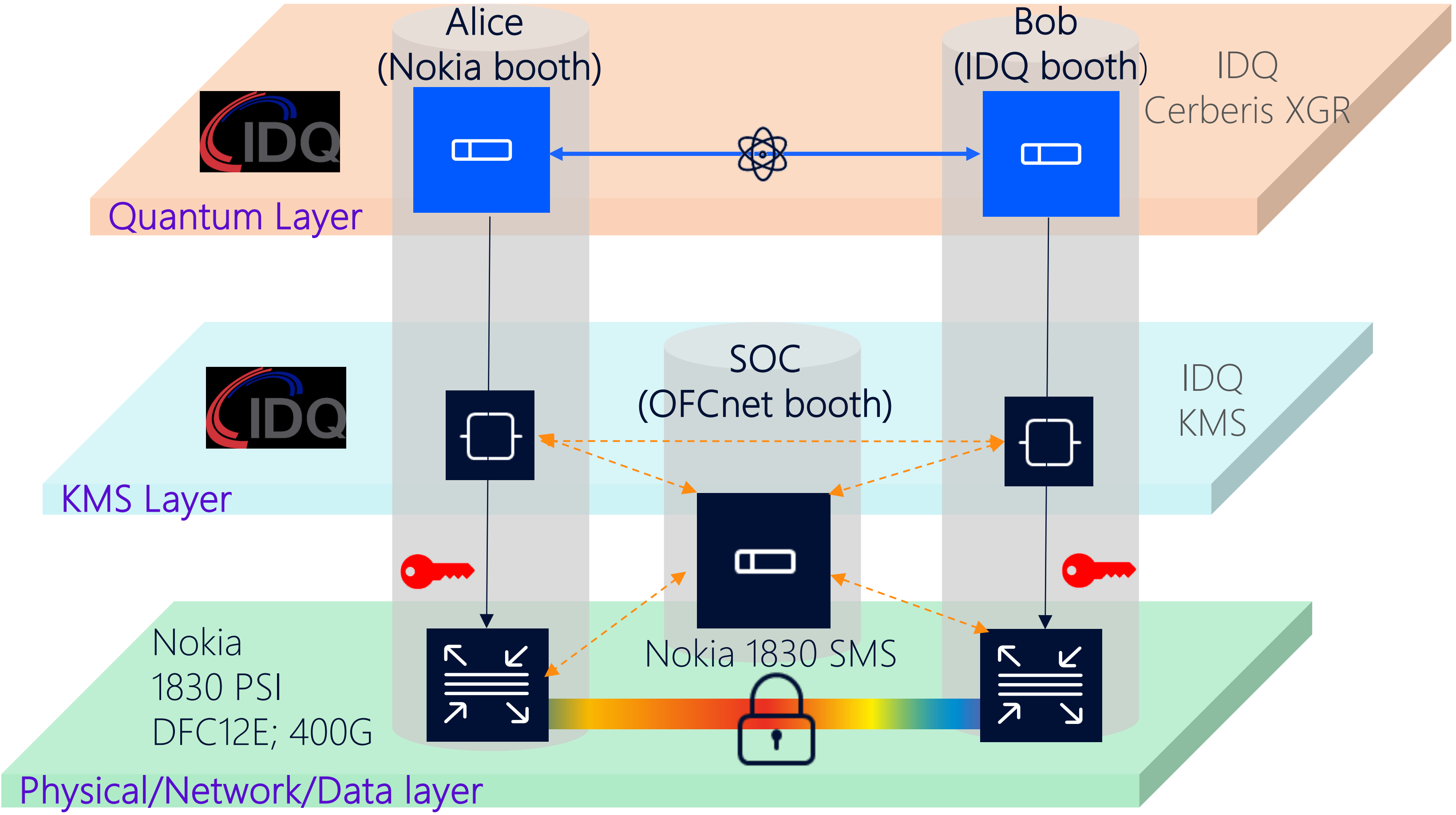


- Quantum key generation/ distribution

- Quantum key orchestration
- Classical physics-based key generation

OFCnet

QKD hybrid key management demonstration



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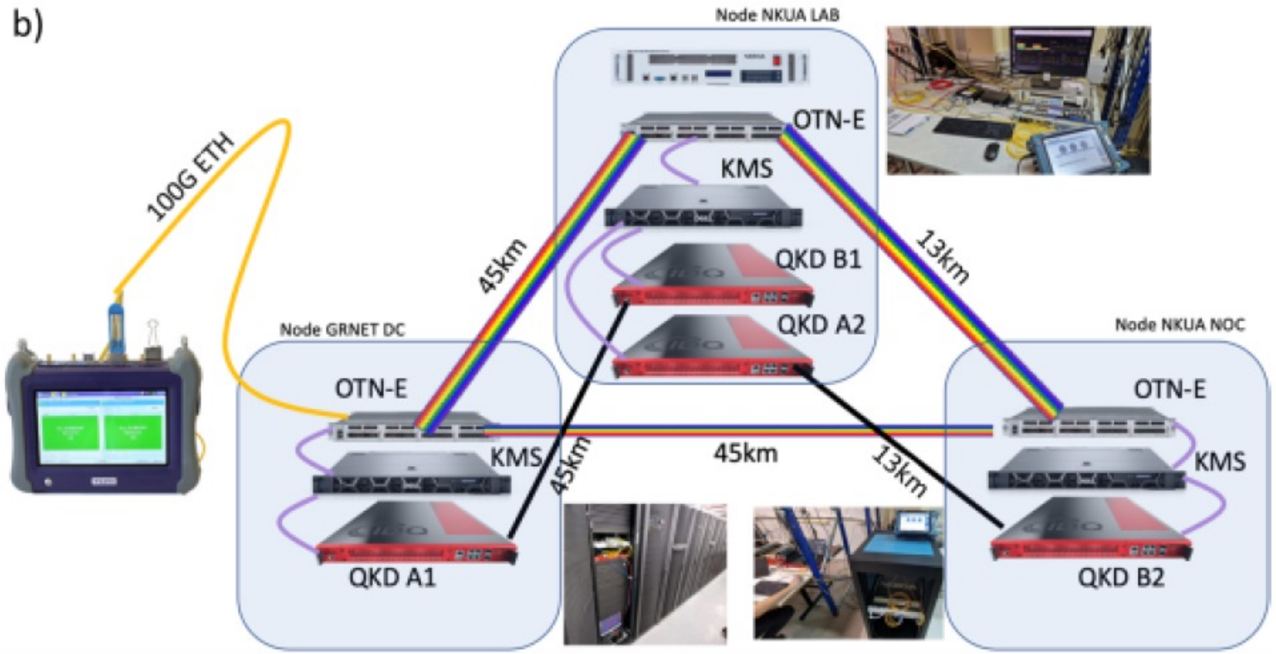
GRNET QKD-hybrid demonstration facts

- Nokia 1830SMS acts as key orchestrator; both for quantum (thru KMS) and classic keys
- KMS attack simulated by disabling KMS, QKD attack by blocking Q-channel
- Reverts to classic key usage when QK not available
- Key rotations tested at 1, 5, 15, 60 mins
- Quantum key buffers with up to 1K keys, exp in 4 hours



NOKIA

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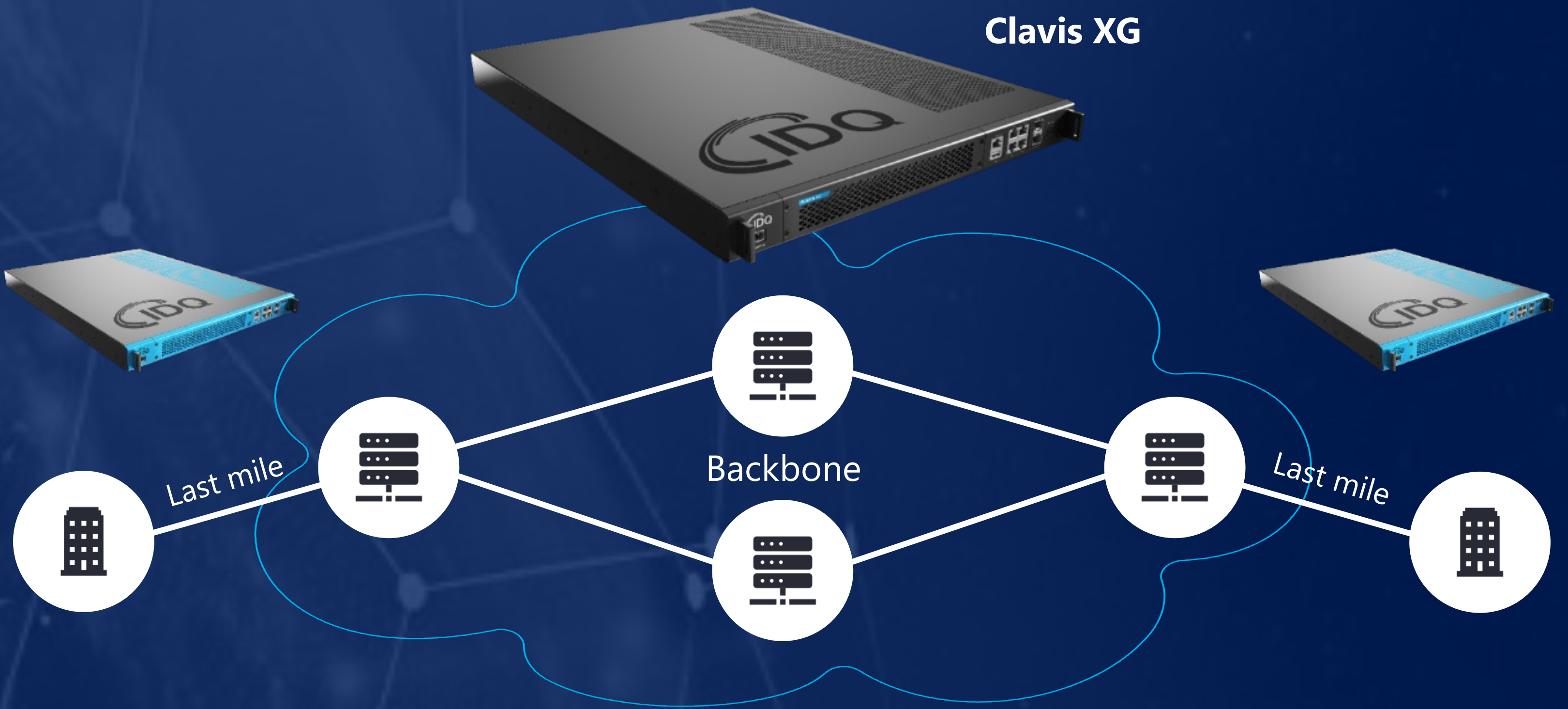
IDQ's comprehensive range of Quantum Key Distribution solutions

- Proven and highly reliable technology
- Designed for complex topologies and large-scale deployments



Korean National Convergence Network Project

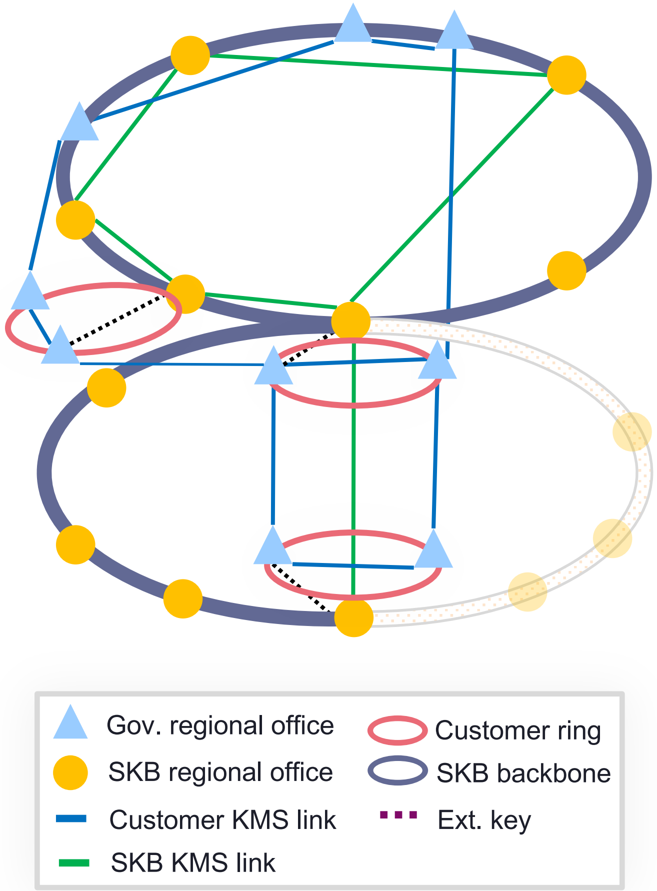
IDQ and SK Broadband selected for the construction of the first nation-wide QKD network in Korea

2000 kilometers

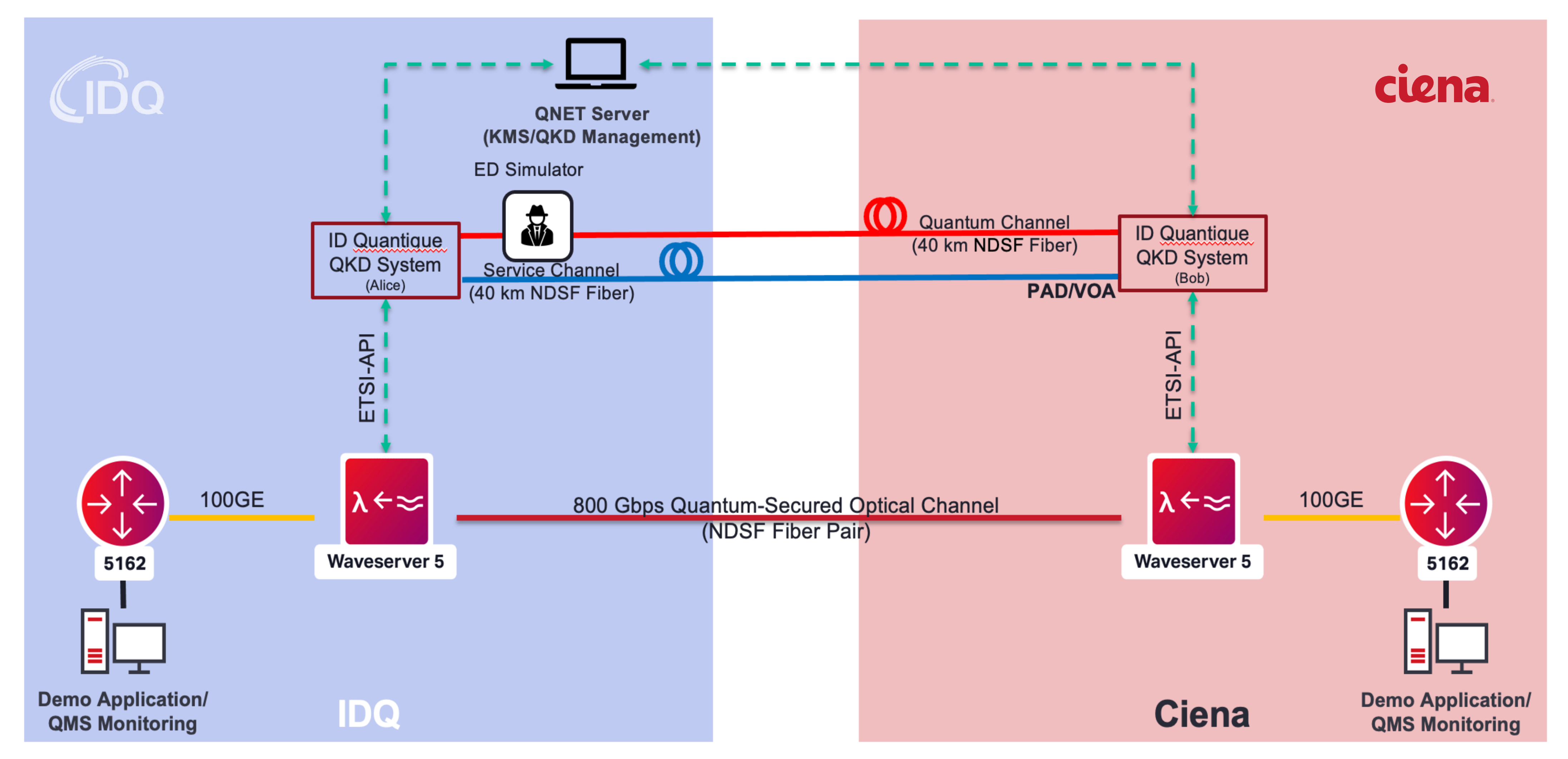
48 government organizations

Security, stability & efficiency

[QKD & KMS Network]



OFCnet 2023 – Joint Ciena/IDQ demo



OFCnet 202x – Arising topics on which the OFCnet community can play a role

- Confronting the physical challenges of integrating QKD into classical networks (classical/quantum mix, network topology limits)
- Key management systems (KMS) : scalability, interoperability between vendors
- Ultra-high-rate QKD/Ultra-long-distance QKD : how to integrate the supporting (still maturing) technologies in classical networks?
- The rise of quantum networks that exchange entanglement : totally different that what we have today

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Pioneering Solutions for The Quantum Internet

Mehdi Namazi
Chief Science Officer
Qunnect Brooklyn

Qunnect

What is our end goal?

Practical distribution
of
useful entanglement
over
longer (and longer) distances

Our core capabilities

Generating Entanglement

QU-SOURCE
Only source on the market that can be used for applications beyond secure communication

QU-LOCK
High precision reference for stabilizing lasers driving QU-SOURCE

QU-LAS (available mid 2024)
Turnkey laser solution to drive QU-SOURCE

Preserving Entanglement

QU-APC
Auto Polarization Compensator
Maintains high channel fidelity and network uptime resulting in low QBER (quantum bit error rate)

QU-VAL (available mid 2024)
Validating entanglement for networking protocols

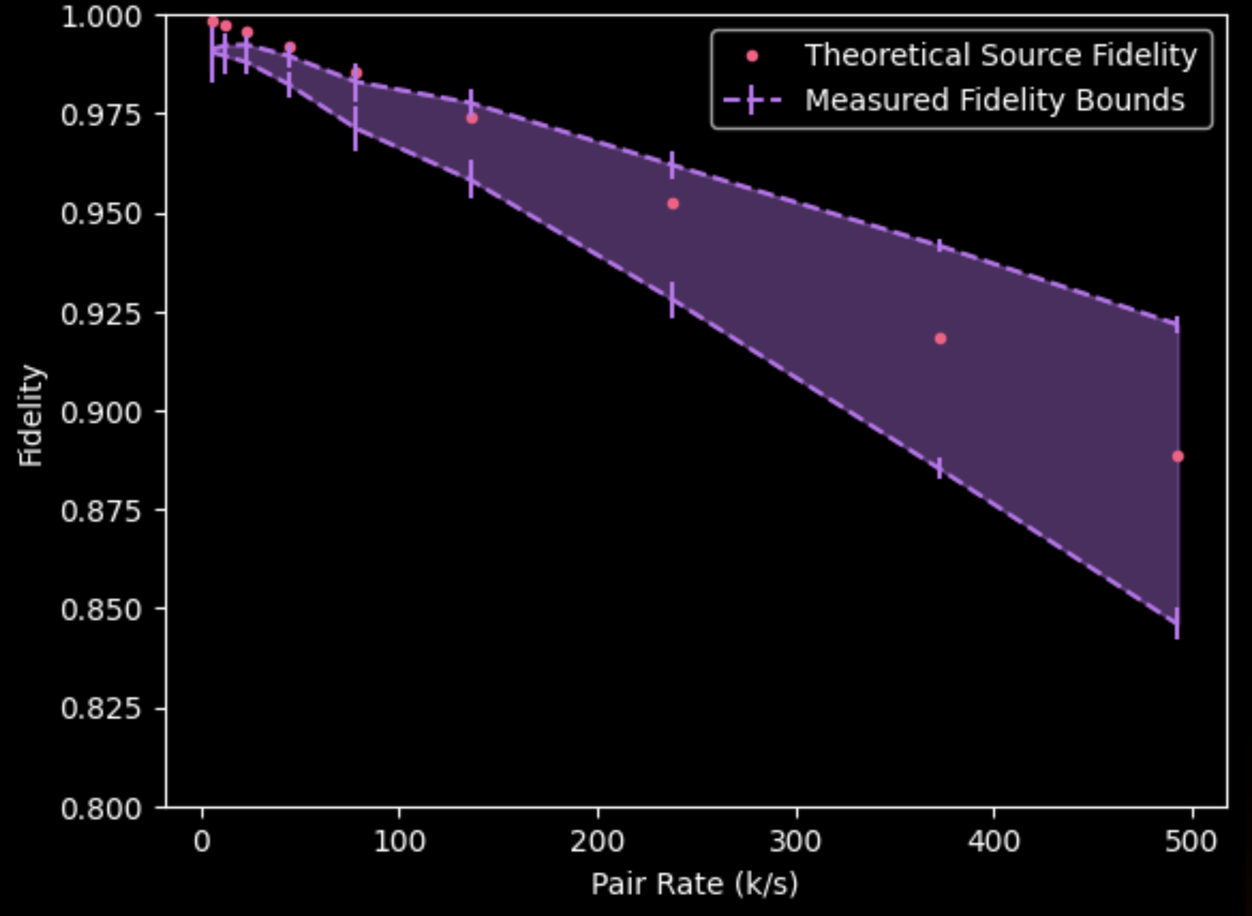
Storing Entanglement

QU-MEM Quantum Memory
Providing temporal control to quantum networks

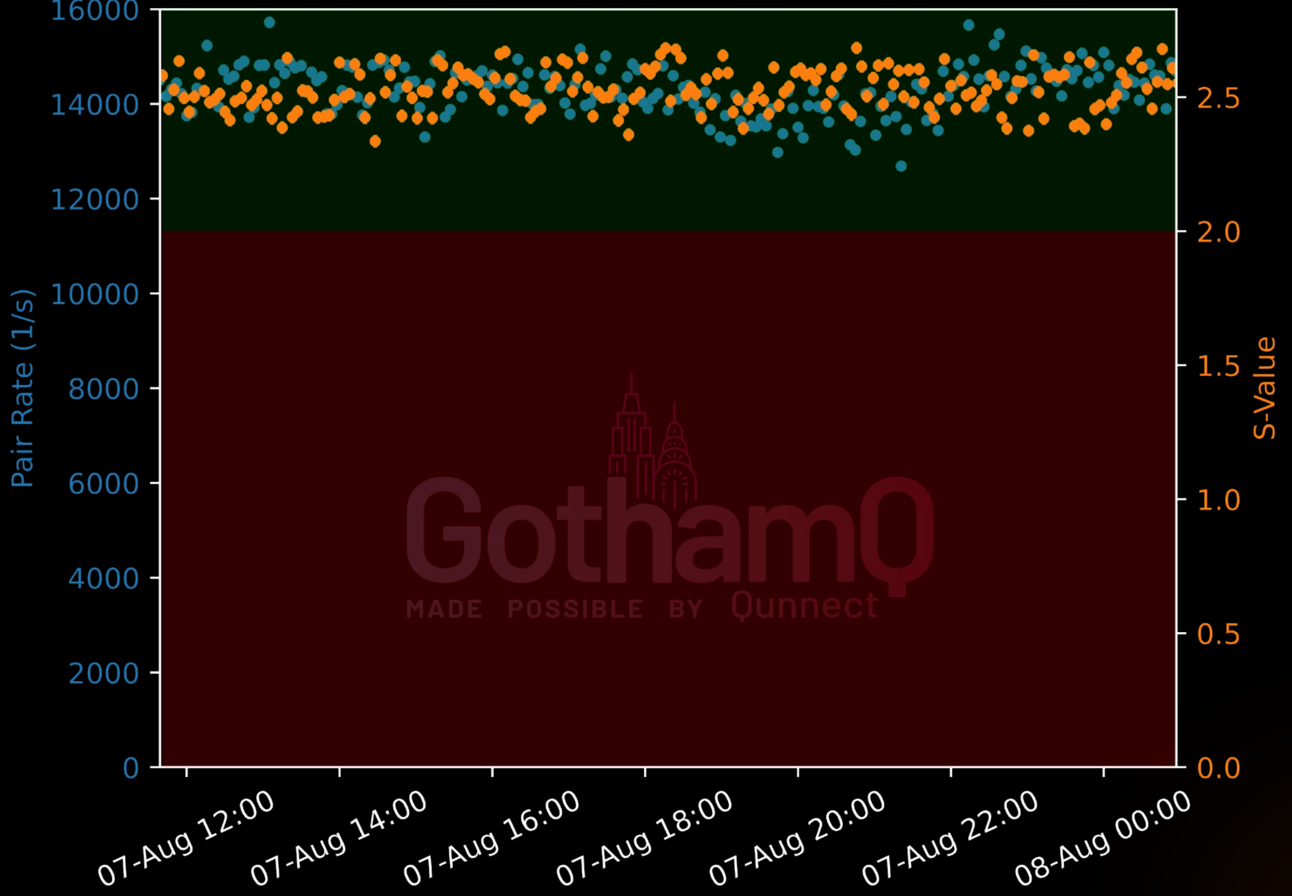
QU-MEM Broadband (2025)
Improved performance specs for optimal interfacing

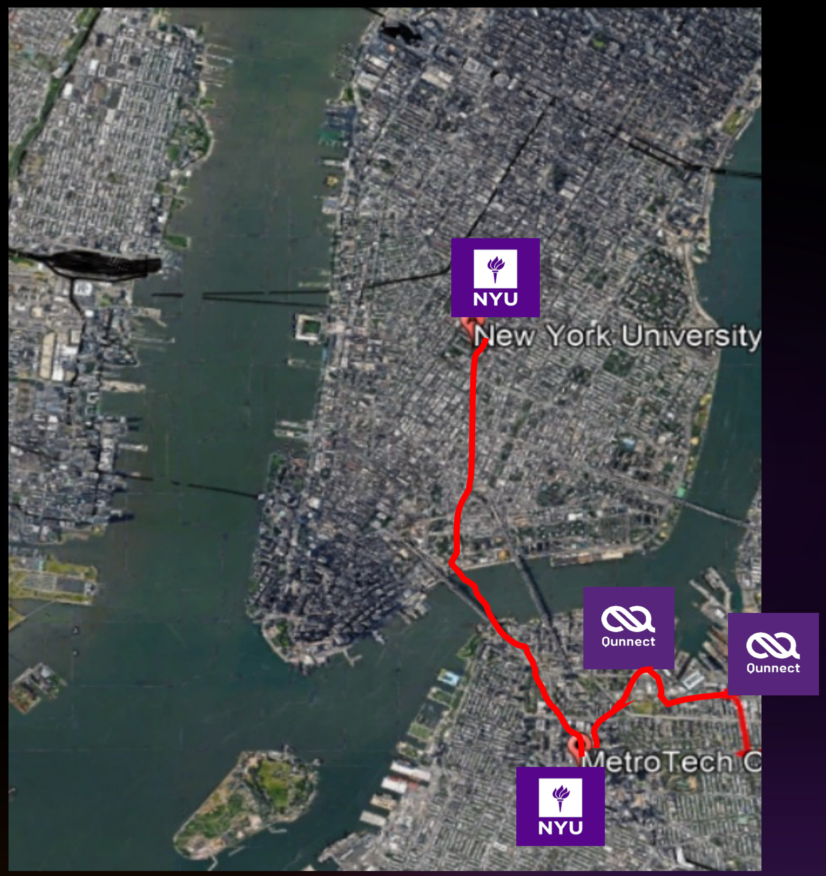
GothamQ

Ent. Distribution over 34km of NYC's fibers



Qunnect(BrooklynQ)←→NYU (BroadwayQ)

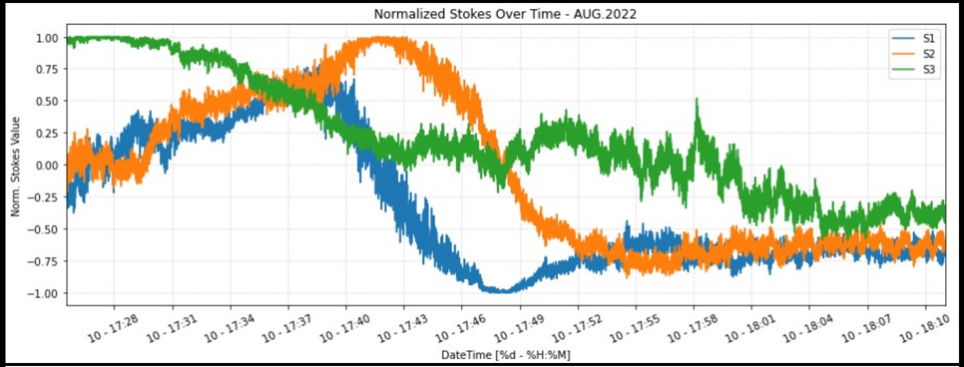


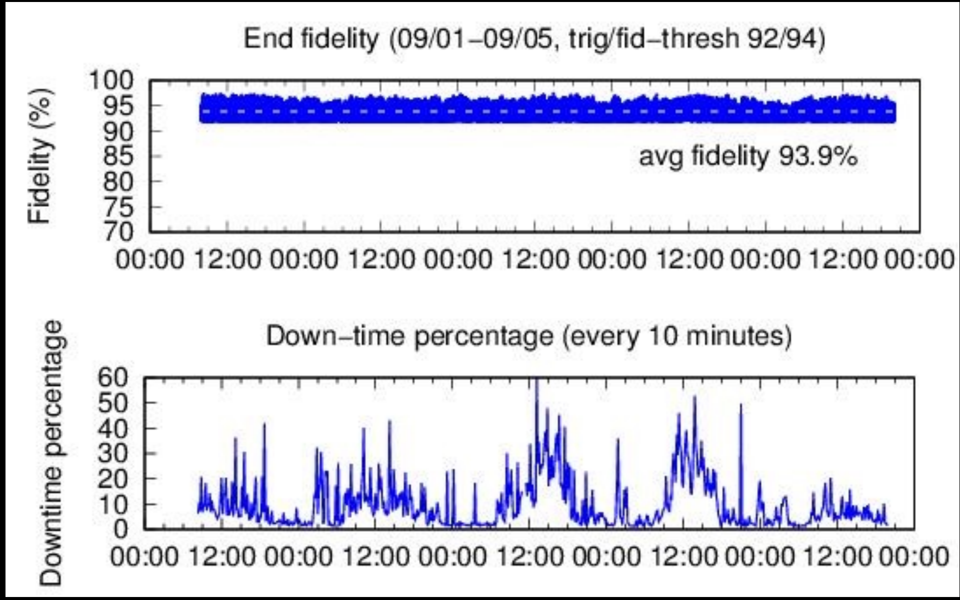


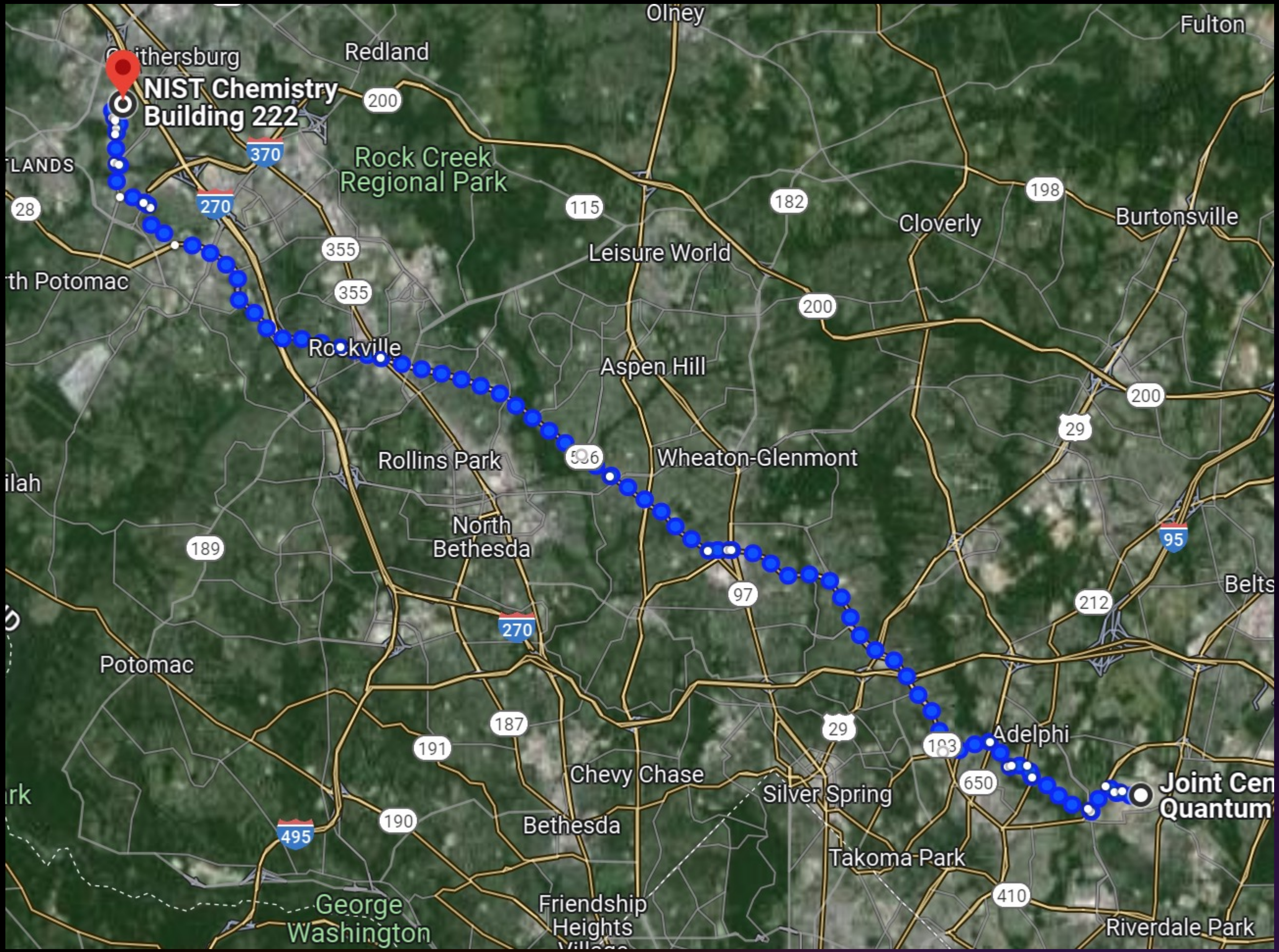
In collaboration with: NYU's CQIP

NIST←→JQI (U Maryland)

- ~ 60km aerial fiber (22dB loss @ 1550)
- Recent compensation results over 5 days, 94% avg Fidelity @ 90% uptime.





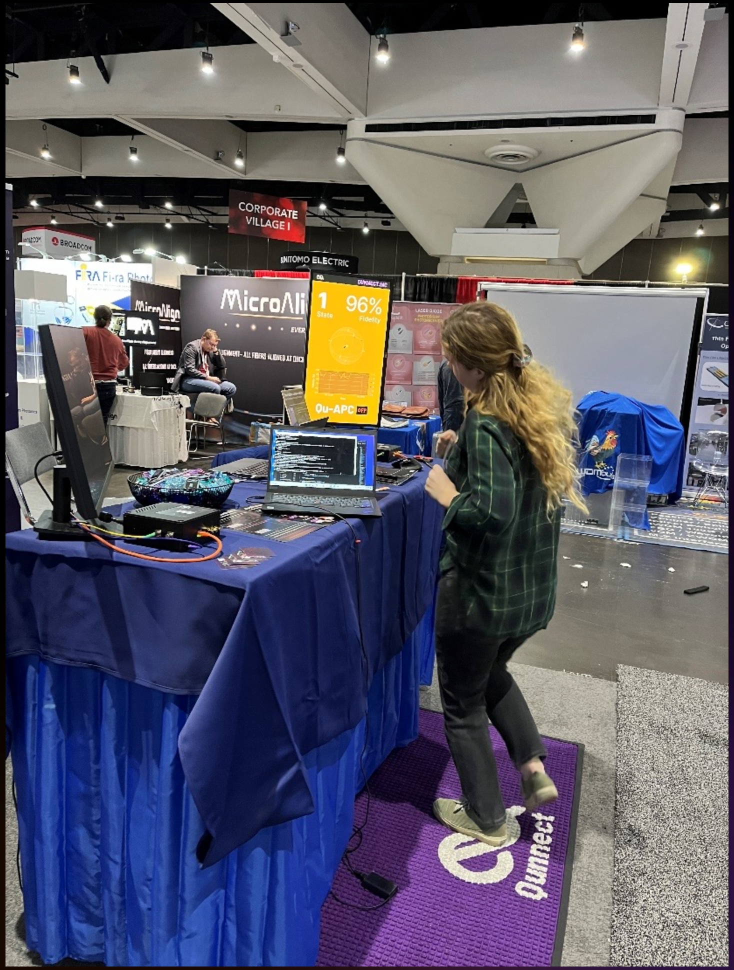


In collaboration with:
Yicheng Shi, Mheni Merzouki, Abdella Battou, Oliver Slattery, Thomas Gerrits

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

GothamQ OFC 2023

Demo of the real-time performance of our Qu-APC by stomping the fiber!



GothamQ From Devices to solutions

World's first plug and play, automated rack solution for distributing useful entanglement

World's first atomic-based entanglement source
10 M pairs/s | 95% fidelity | sub-GHz linewidth

World's fastest polarization compensating device
99% fidelity | <2dB loss | fully automated

Automated inter-node entanglement validation
configurable to user's requirements

Integrated lasers and telecom wavelength reference

Integrated multichannel TDCs with inter-link ns
Synchronization and multiplexed single photon detectors

Classical network routing and servers for control
and automation

Qunnect

HARDWARE, NOT HYPE

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15:30	End of workshop	Cees de Laat

WDM Entangled Quantum Communications at OFCnet

Jerome Prieur, March 2024, OFCnet San Diego

AUREA
TECHNOLOGY

World-class Quantum-safe Communications

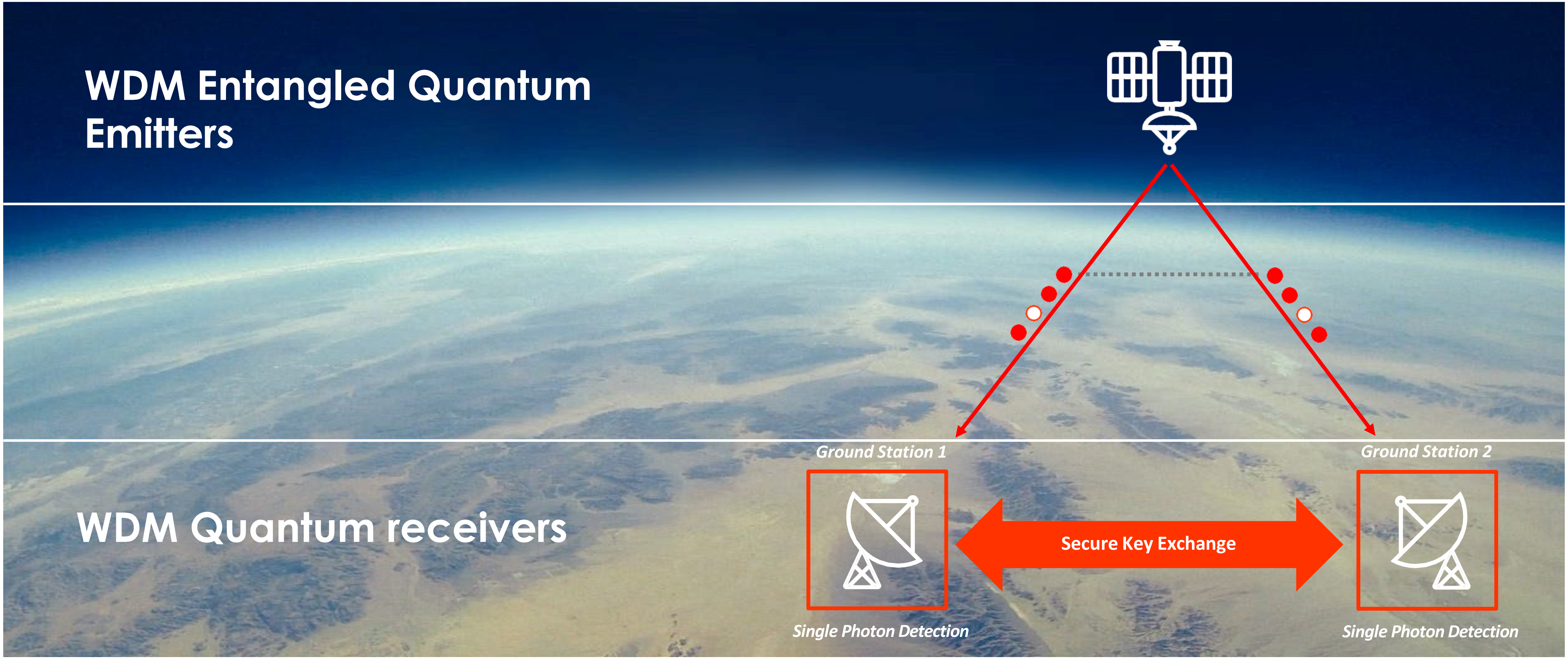
Entangled Photon Sources

Single Photon Detectors

Time taggers

Visit us booth 1018 at OFC on 24-26 March 2024 in San Diego

WDM Entangled Quantum Communications

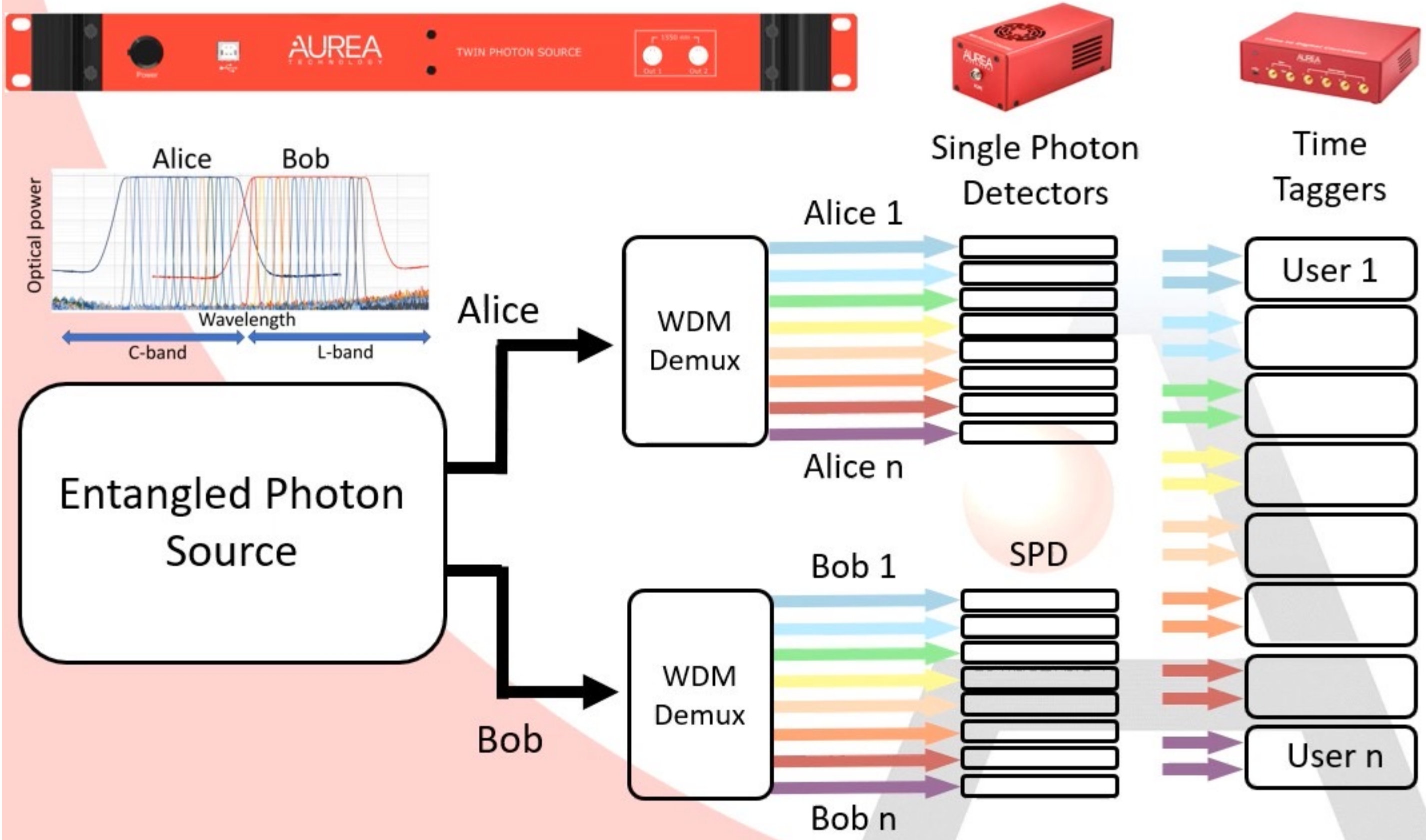


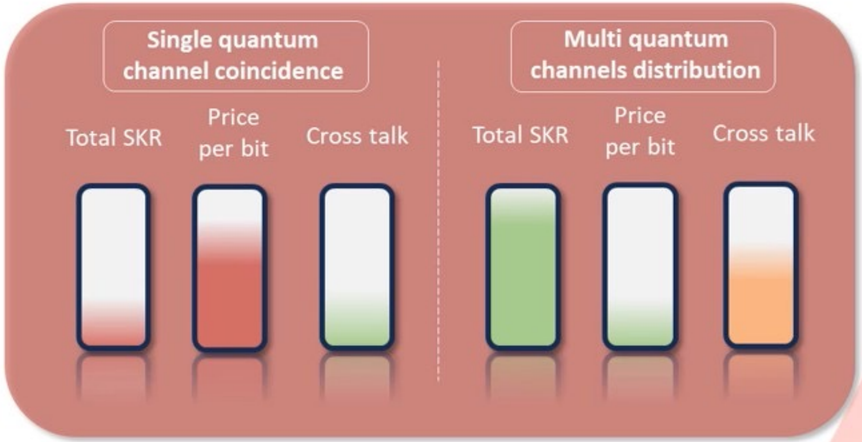
WDM entangled photon distribution using efficient entangled photon source

Catch statements:

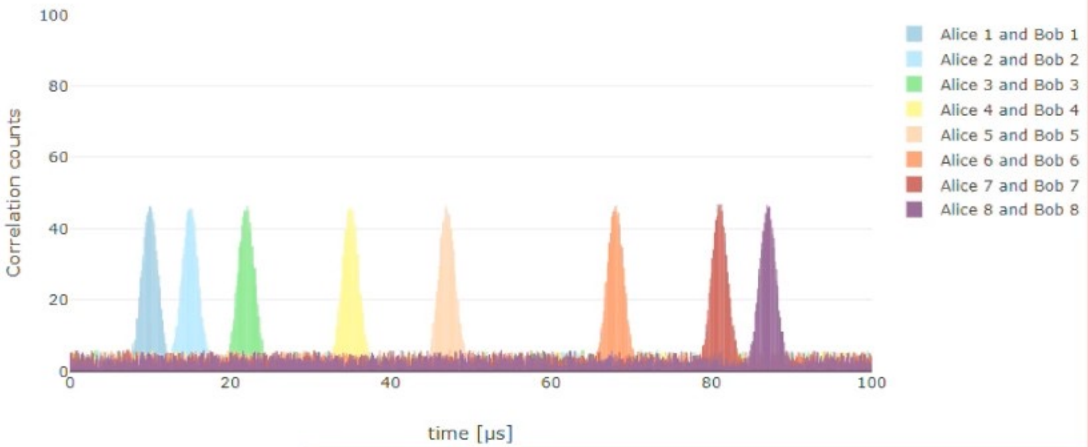
- WDM quantum channels
- Multi channels/users scalabality
- C and L-band bandwidth

→ This live demonstration exhibits the capabilities of performing WDM quantum entangled channel distribution using cutting-edge commercially available building blocks from AUREA Technology.





WDM entangled photon distribution and correlation



Thank you!

AUREA TECHNOLOGY

Jerome Prieur, CEO and co-founder

Program

13:00	Opening Workshop	Cees de Laat
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OFC 2024 ETHERNET ALLIANCE PANEL “LESSONS LEARNED FROM PREPARING INTEROPERBILITY DEMONSTRATIONS…”

DAVID J. RODGERS

24 MARCH 2024

ethernet alliance

www.ethernetalliance.org

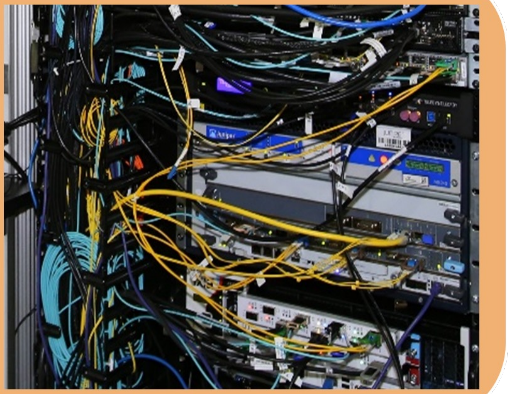
The Ethernet Alliance

A Global Community of End Users, System Vendors, and Component Suppliers

- **<u>Our Mission</u>**
  - <u>To promote</u> industry awareness, acceptance and advancement of technology and products based on, or dependent upon, both <u>existing and emerging IEEE 802 Ethernet standards</u> and their management.
  - <u>To accelerate industry adoption</u> and remove barriers to market entry by providing a cohesive, market-responsive, industry voice.
  - ***<u>Provide resources to establish and demonstrate multi-vendor interoperability.</u>***

The Ethernet Alliance – (if there was only 1 thing) Investment in Multi-vendor Interoperability

- **Plugfests**
  - High Speed Networking
  - NBASE-T
  - SPE
- **Public Demonstrations Trade Shows**
  - OFC
  - SC
  - ECOC
  - BICSI

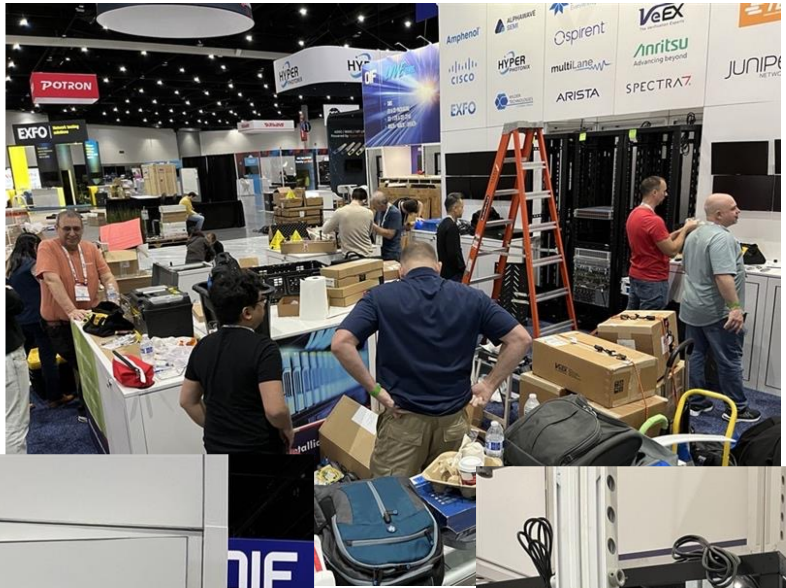


Building the Demo requires a TEAM!

- **Coordinator/Coach**
- **On-Field Captains - Tech Leads**
- **Position Players**
- **Practice, practice, practice**

- ***Provide resources to enable the success of the demonstration and multi-vendor interoperability.***

Chaos becomes Cohesion



Learn More About Ethernet Alliance

- **Ethernet Alliance:**
  visit www.ethernetalliance.org;
  - **Follow @EthernetAllianc on Twitter**
  - **Join the Ethernet Alliance LinkedIn group**
  - **Visit the Ethernet Alliance Facebook page**
- **PoE Certification Program:**
  visit www.ethernetalliance.org/poecert/

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How Can OFC, with a Real Life Test-Bed, Accelerate Innovation in the Optical Photonic Networks?

Rump Session

Reza Nejabati , Andrew Lord

Objective

Do we need OFC pop-up style optical network test-bed ?

If so, how it should look like ?

Rump Session Speakers

- Jorg-Peter Elbers, *Adtran, Germany*

- Julia Larikova, *Infinera, United States*

- Dimitra Simeonidou, *University of Bristol, United Kingdom*

- Prem Kumar, *Northwestern University, United State*

- Ben Dixon, *MIT Lincoln Laboratory, United States*

Questions

- Do we require field trial testbeds for scientific and engineering breakthroughs
- Why can't we rely solely on lab-based test-beds, virtual test-beds, and test-bed emulation?
- Is there a role for a short-term interop / multi-partner PoC, compared to longer-term standards-based trials (e.g. OIF)?
- Is there any role/place for a pop-up short term test-bed?
- What are the essential features of a field trial testbed for future telecom?
- What role do fiber/optical networks play in a holistic telecom network testbed?
- Is OFC a right venue for such a test-bed ? Why not MWC…, Where that would be?
- Who are target users?

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Boston Area Quantum Network Testbed Development

P. Ben Dixon – MIT Lincoln Laboratory

Presented at OFC Conference 2024

24 March 2024

LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

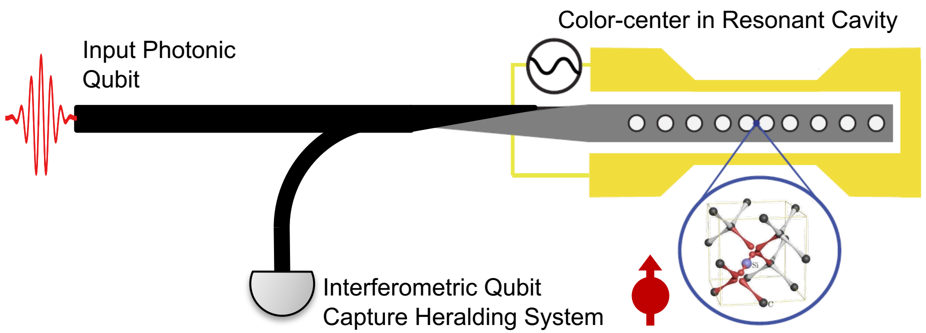
This material is based upon work supported by the National Reconnaissance Office under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Reconnaissance Office.

Boston-Area Quantum Networking Testbed

Quantum Network Testbed Goal

Develop capabilities to incorporate emerging quantum memory technologies into Boston-area fiber testbed

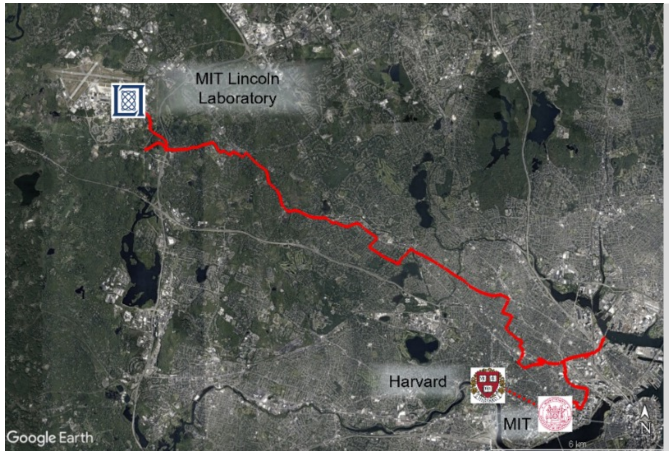
Silicon Vacancy Quantum Memory System



Quantum Memory Input Requirements for Photonic Qubits

- **Timing jitter: <10 ns for low inter-symbol-interference**
- **Polarization jitter: <0.5 radian for high efficiency**
- **Optical frequency noise: <1 MHz for low error heralding**
- **Flux: <10 M photons per sec (-90 dBm) to avoid saturation**

Boston-area Quantum Network Testbed



- **Two optical fibers from LL to MIT and Harvard**
- **Dark telecom fiber links**
- **50 km optical path length**

Testbed Development Effort

- **Characterize fiber-induced degradations**
- **Design fiber compensation system that maintains photonic qubits an operates with -90 dBm noise floor**
- **Test system by transmitting quantum states across compensated fiber and capturing them in quantum memory**

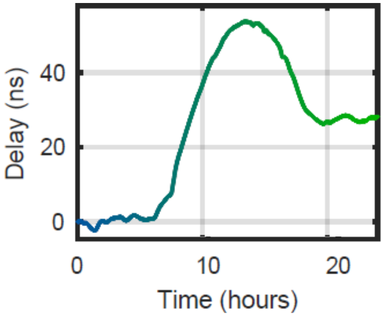
LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Fiber Channel Characterization

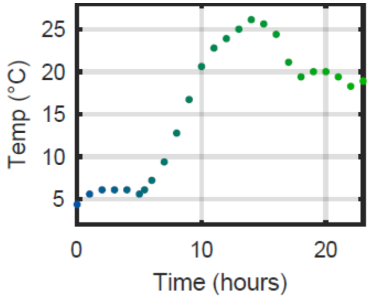
Timing Drift

Requirement: <10 ns timing precision

Optical Path Length



Ambient Temperature

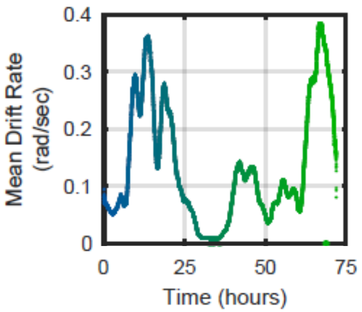


- **Maximum optical fiber path length timing drift of 40 ns**
- **Timing drift highly correlated to ambient temperature**
  - $2.6\ \mathrm{ns/^\circ C},\ R^2 = 0.96$
- **Maximum drift rate of 10 ns per hour**
- **Impact: Minute-class time synchronization needed**

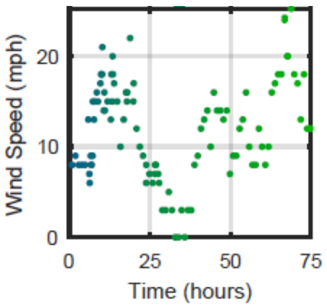
Polarization Drift

Requirement: <0.5 radian polarization stability

Polarization Drift Rate



Ambient Wind Speed

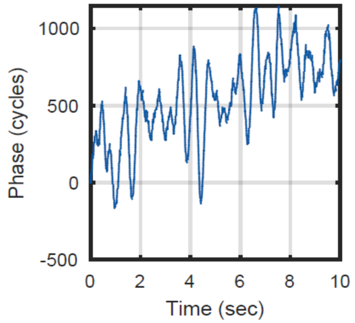


- **Polarization drift rate drift correlated to environmental wind speed**
  - $1.7\ \mathrm{mrad/sec} \cdot \mathrm{mph}^2,\ R^2 = 0.42$
- **Maximum drift rate of 0.5 radians per second**
- **Impact: Second-class polarization stabilization needed**

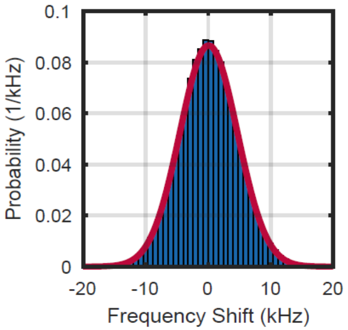
Optical Frequency Noise

Requirement: <1 MHz frequency transfer

Phase Drift



Optical Frequency Spread



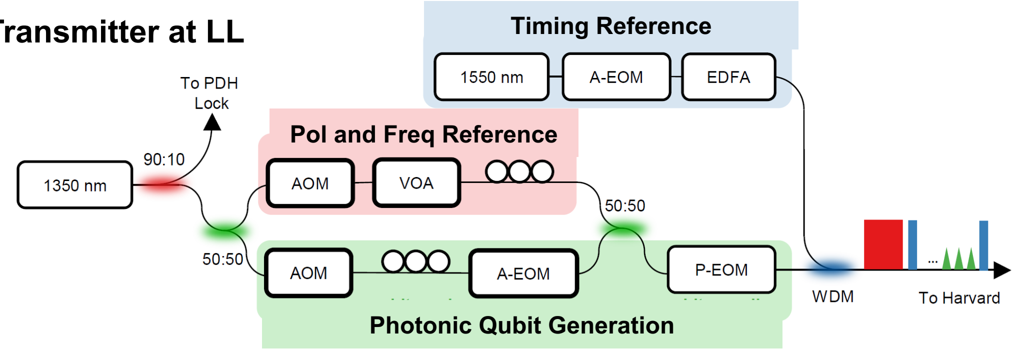
- **Fiber induced frequency noise consistent with Brownian process**
  - **Gaussian width** $\sigma = 4.6\ \mathrm{kHz}$
- **Transmitted light has frequency broadened by 4.6 kHz**
- **Impact: No optical frequency stabilization system needed**

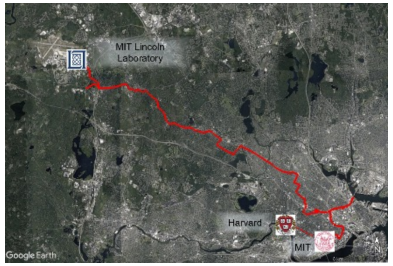
Fiber-induced degradations characterized, second-class timing synch ad polarization stabilization needed, optical frequency can be transferred without active fiber stabilization

Integrating Quantum Memories into Quantum Network

Integrated Fiber Compensation System and Qubit Transmitter

Transmitter at LL

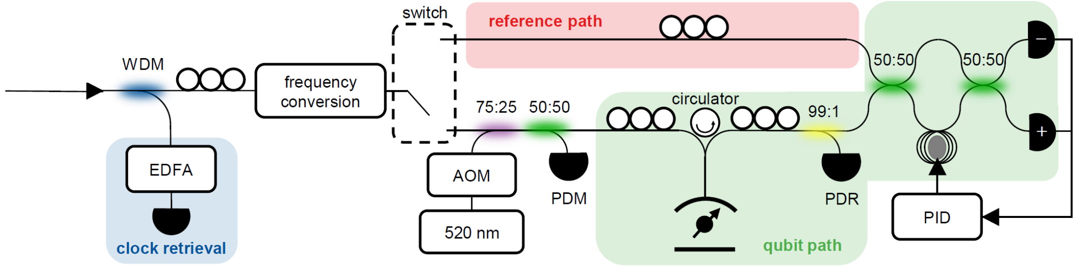




Polarization and Frequency Reference (1350 nm)
- 1 second repetition rate
- AOM and Mems-based VOA gives 120 dB of extinction for low noise floor

Timing Reference (1550 nm)
- 1 sec repetition rate
- 200 nm spectral separation gives high extinction (>100 dB) for low noise floor

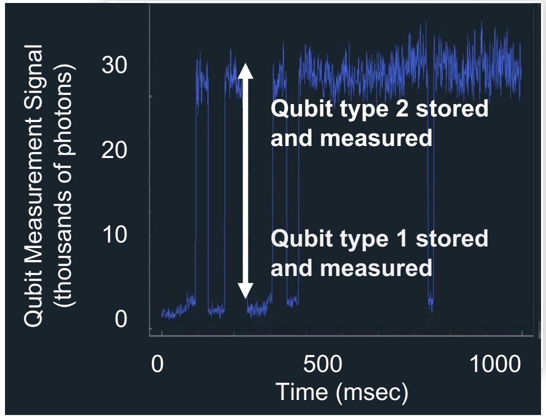
Transmitter at Harvard



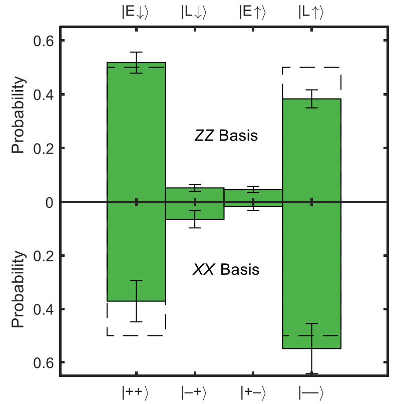
Photonic Qubit (1350 nm)
- Time bin weak coherent state qubits

Cross-Fiber Qubit-Memory Interaction

First Light Data



Qubit Characterization



Testbed Development Effort
- Fiber compensation built and integrated with fiber testbed and quantum memory
- Preliminary data confirmed noise floor operation of system
- Full characterization demonstrates 87% fidelity transfer of transmitted qubit into quantum memory

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The UK’s Joint Open Infrastructure for Networks Research (JOINER)

Dimitra Simeonidou, University of Bristol, UK

University of BRISTOL
Smart Internet Lab

JOINER

University of BRISTOL
Smart Internet Lab

1. A UK national testbed with representative heterogeneity, complexity and scale

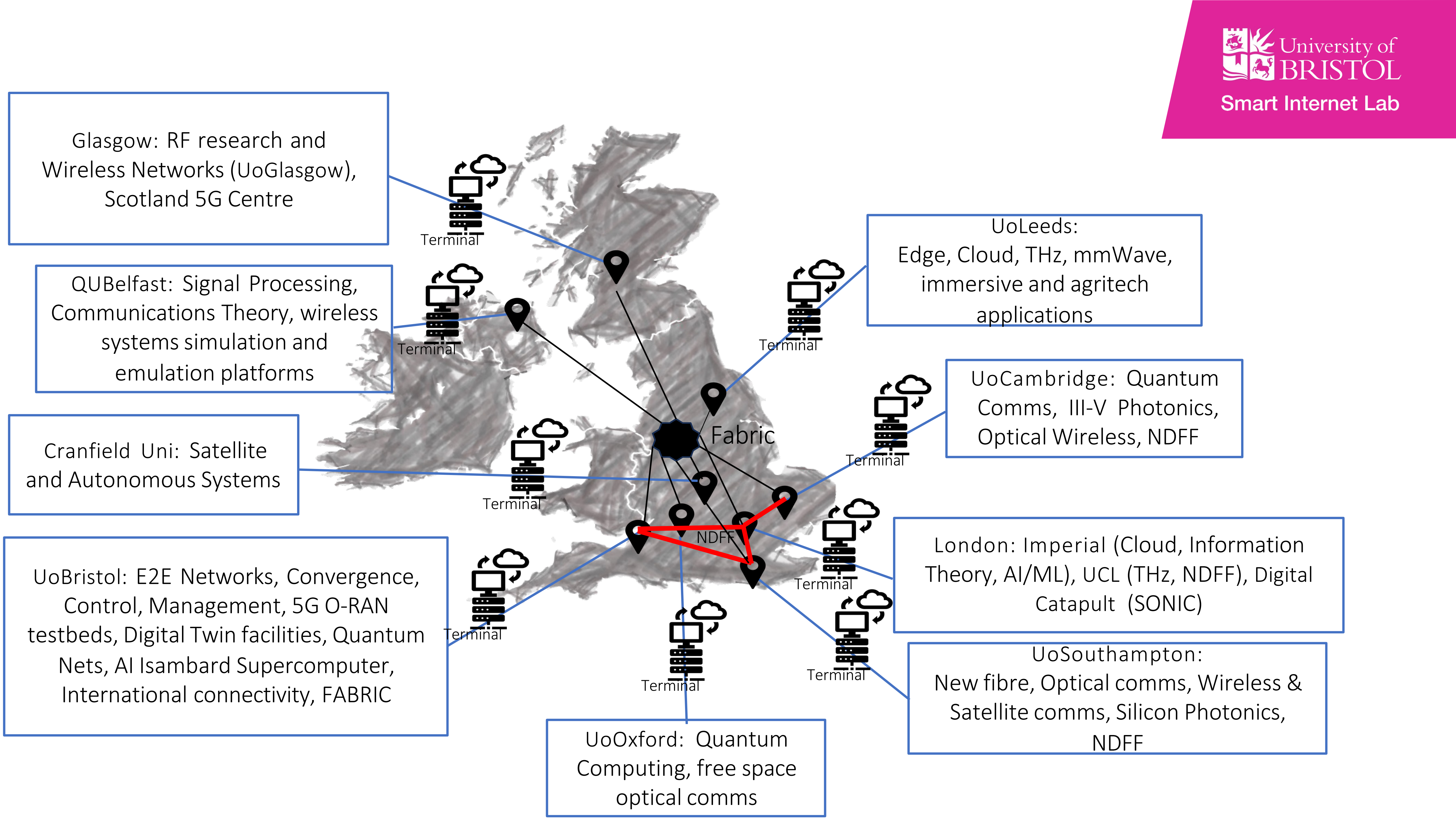
2. Provides key scientific instrumentation for future networks research

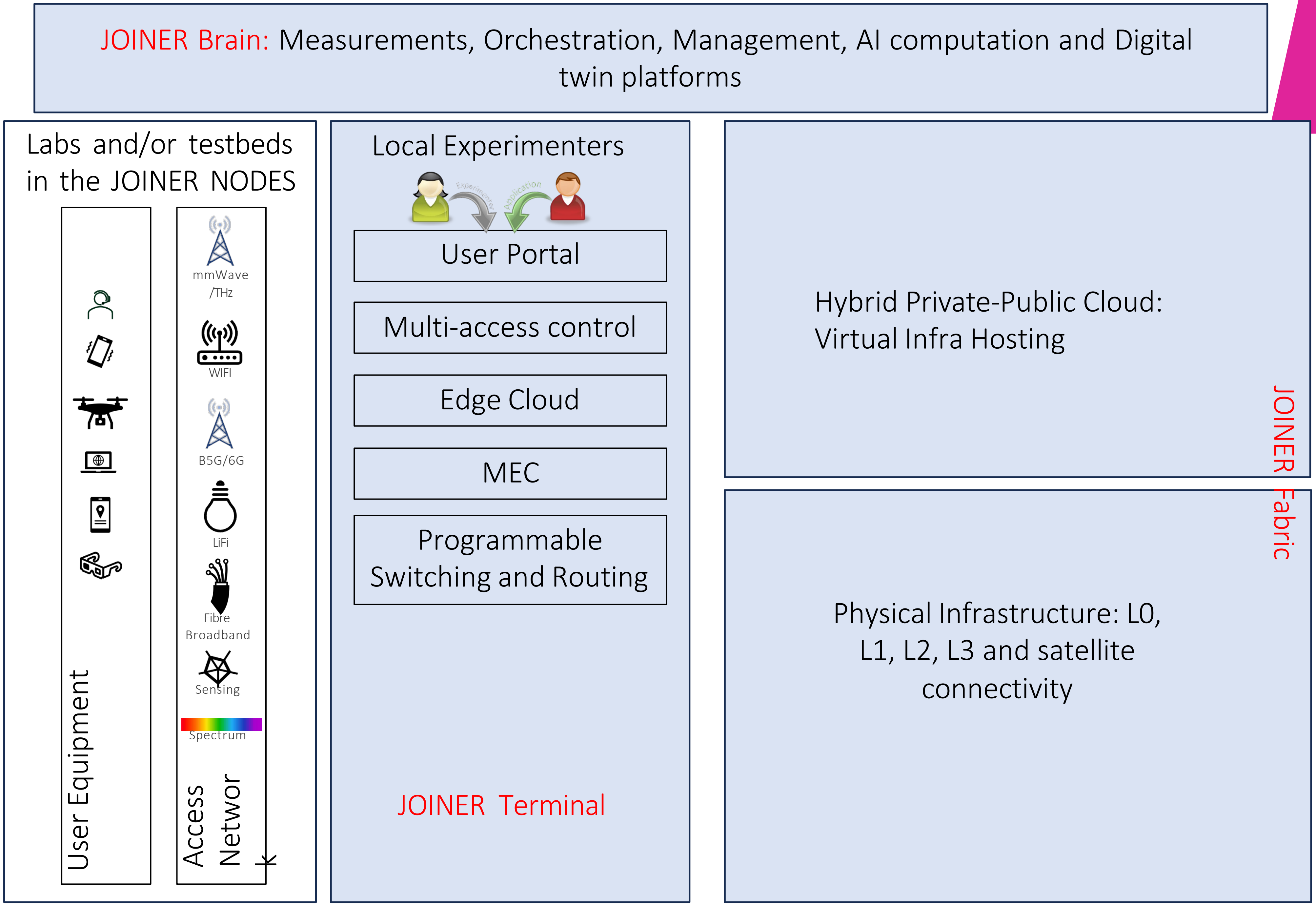
3. Enabling experimental collaboration, introducing new technologies, services and applications resulting from academic and industrial R&D programmes

4. A platform to accelerate TRL advancement of early-stage research and provide credible experimental evidence towards the introduction of new IP and standards

5. A place for hands-on training on telecoms systems and therefore a key contributor to a national (multidisciplinary) skills development pipeline.

6. It will allow to explore new research questions challenging end-to-end assumptions and developing system thinking to Future Networks research:
   - Evaluation of Machine Learning algorithms for large scale networks
   - System-wide energy consumption optimisation in 6G networks
   - Evaluation of end-to-end and multi-layer network security solutions
   - Global automated spectrum management and assignment techniques


University of BRISTOL
Smart Internet Lab
Glasgow: RF research and Wireless Networks (UoGlasgow), Scotland 5G Centre
QUBelfast: Signal Processing, Communications Theory, wireless systems simulation and emulation platforms
Cranfield Uni: Satellite and Autonomous Systems
UoBristol: E2E Networks, Convergence, Control, Management, 5G O-RAN testbeds, Digital Twin facilities, Quantum Nets, AI Isambard Supercomputer, International connectivity, FABRIC
UoOxford: Quantum Computing, free space optical comms
UoLeeds: Edge, Cloud, THz, mmWave, immersive and agritech applications
UoCambridge: Quantum Comms, III-V Photonics, Optical Wireless, NDFF
London: Imperial (Cloud, Information Theory, AI/ML), UCL (THz, NDFF), Digital Catapult (SONIC)
UoSouthampton: New fibre, Optical comms, Wireless & Satellite comms, Silicon Photonics, NDFF
Fabric
NDFF
Terminal



University of Bristol
Smart Internet Lab

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OFC

How Can OFC, with a Real-Life Test-Bed, Accelerate Innovation in the Optical Photonic Networks?

Prem Kumar
Professor, ECE & Physics
Center for Photonic Communication and Computing
Northwestern University
E-mail: kumarp@northwestern.edu

Illinois Express Quantum Network (IEQNET)

Fermilab | U.S. DEPARTMENT OF ENERGY | Office of Science

Illinois Express Quantum Network (IEQNET) – Metropolitan-Scale Experimental Quantum Network

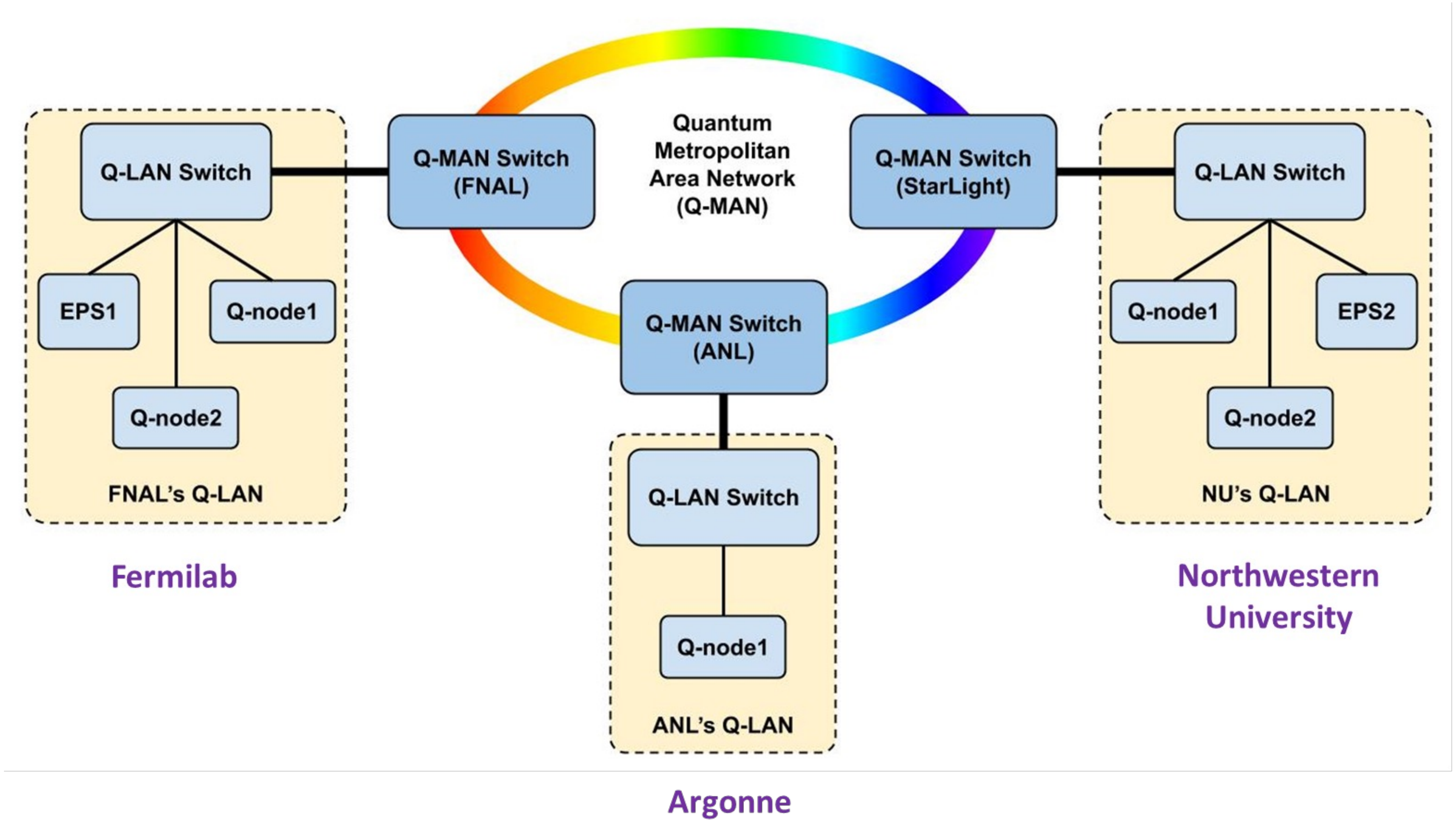
Research team leads:

- **Fermilab:** *P. Spentzouris (PI), C. Pena, W. Wu, S. Xie*
- **Argonne:** *R. Kettimuthu, J. Chung*
- **Caltech:** *M. Spiropulu, N. Lauk, R. Valivarthi*
- **Northwestern:** *P. Kumar, G. Kanter*

The IEQNET collaboration: Fermilab, Argonne National Laboratory, Caltech, Northwestern University, HyperLight, NuCrypt

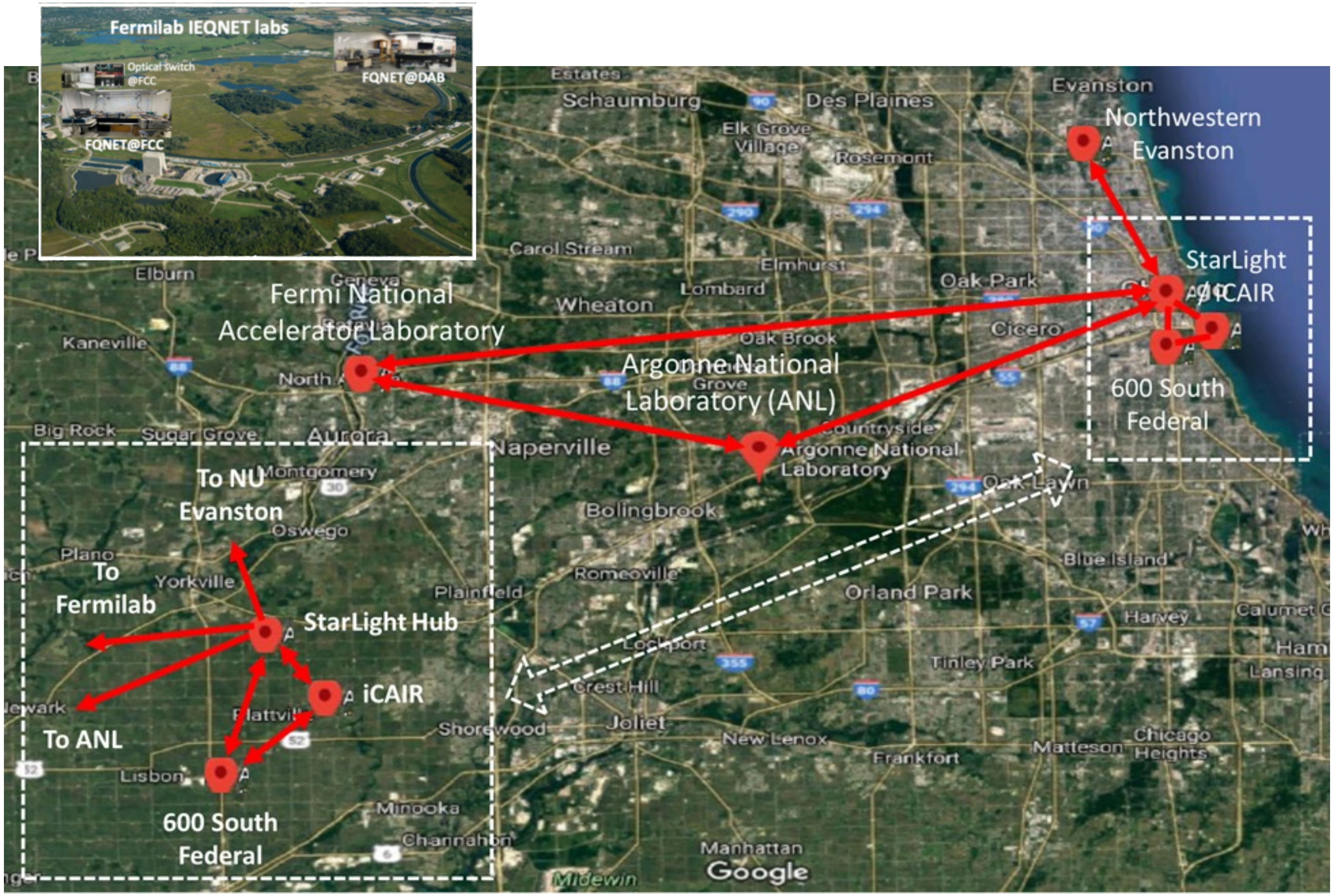
2 9/23/2021 IEQNET Collaboration

IEQNET Topology

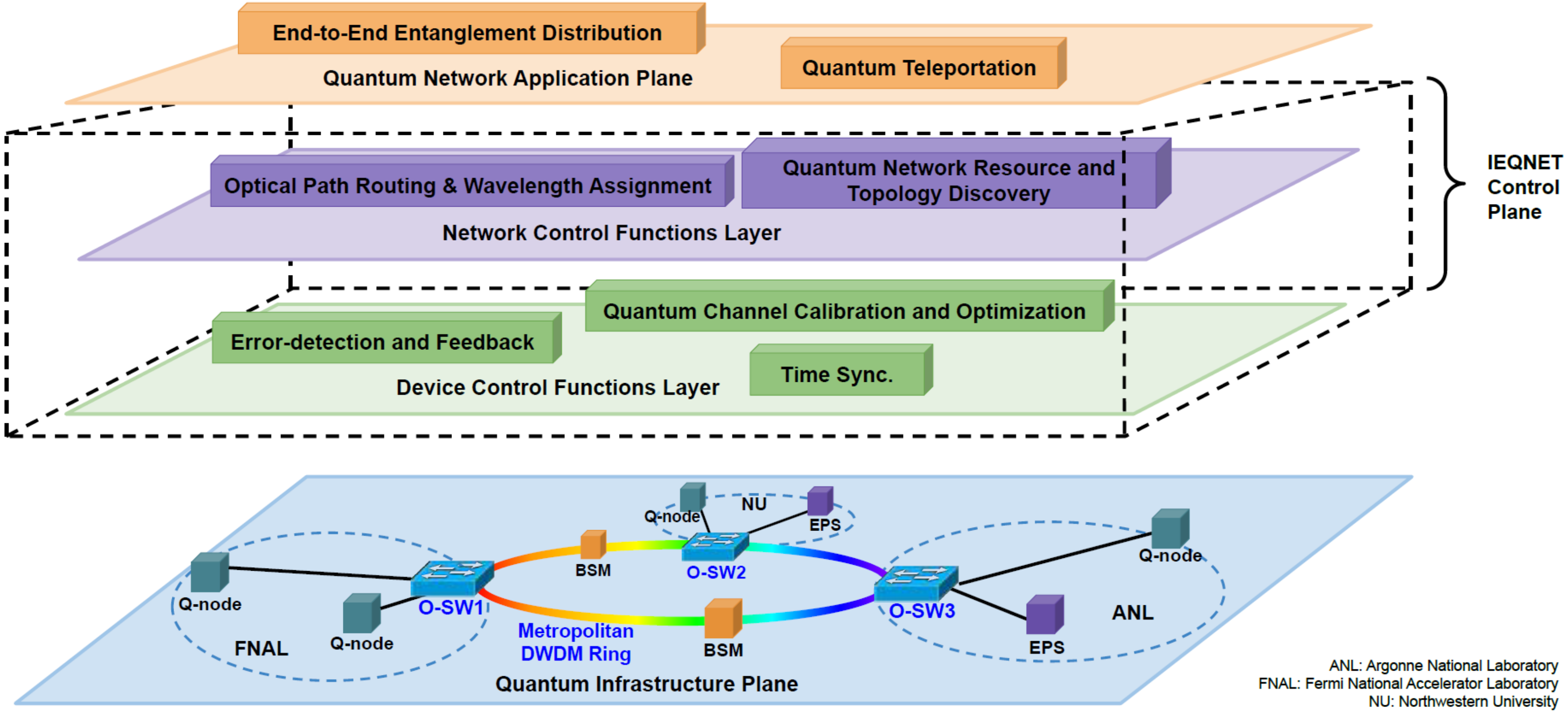


J. Chung, G. Kanter, N. Lauk, R. Valivarthi, W. Wu, R. R. Ceballos, C. Peña, N. Sinclair, J. Thomas, S. Xie, R. Kettimuthu, P. Kumar, P. Spentzouris, and M. Spiropulu, "Illinois Express Quantum Network (IEQNET): metropolitan-scale experimental quantum networking over deployed optical fiber," Proc. SPIE 11726, 1172602 (12 April 2021); https://doi.org/10.1117/12.2588007.

IEQNET Physical (proposed)



IEQNET's Quantum Networking Architecture (three planes)



ANL: Argonne National Laboratory
FNAL: Fermi National Accelerator Laboratory
NU: Northwestern University

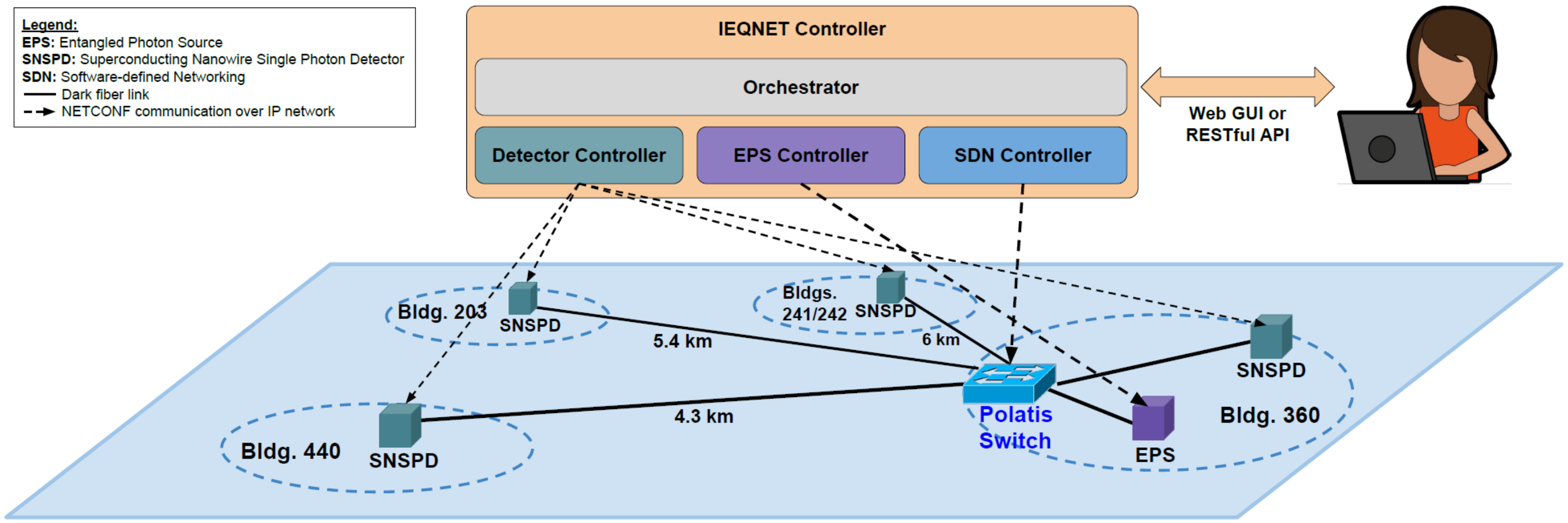
IEEE Transactions on Quantum Engineering
Chung et al.: DESIGN AND IMPLEMENTATION OF THE ILLINOIS EXPRESS QUANTUM METROPOLITAN AREA NETWORK

Vol. 3, 4100920 (2022) | *Digital Object Identifier 10.1109/TQE.2022.3221029*

Orchestration of Entanglement Distribution over a Q-LAN using the IEQNET Controller

Joaquin Chung,[1,*] Anirudh Ramesh,[1,2] Shariful Islam,[1] Gregory S. Kanter,[3] Cristián Peña,[4] Si Xie,[4] Raju Valivarthi,[5] Neil Sinclair,[5] Panagiotis Spentzouris,[4] Maria Spiropulu,[5] Prem Kumar,[2] and Raj Kettimuthu[1]

[1] *Argonne National Laboratory, Lemont, IL. USA*
[2] *Northwestern University, Evanston, IL. USA*
[3] *NuCrypt LLC, Park Ridge, IL. USA*
[4] *Fermi National Accelerator Laboratory, Batavia, IL. USA*
[5] *California Institute of Technology, Pasadena, CA. USA*



Quantum Classical Coexistence in the IEQNET

1. Time Synchronization

1310 nm classical clock light coexisting with 1536 nm photon pairs for picosecond synchronization over 59 km

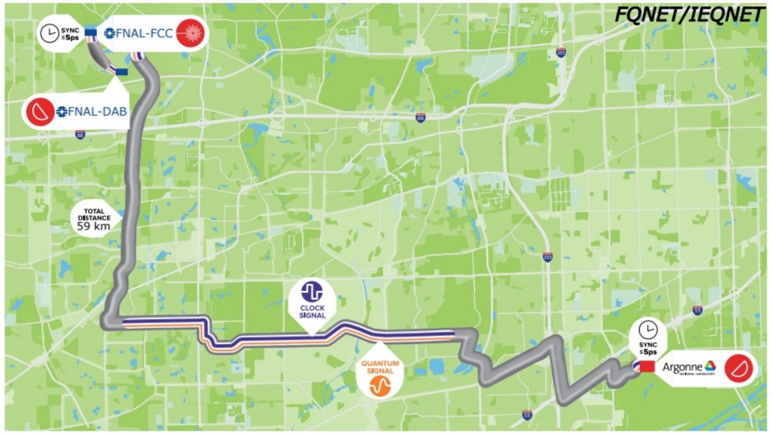
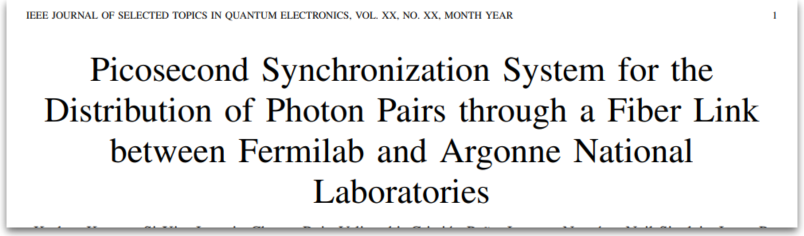


Fig. 1: This image depicts the separation of the nodes in our network. FNAL-FCC and FNAL-DAB are connected with 2 km of dark fiber and FNAL-FCC and ANL are connected with 57 km of dark fiber. We keep our master clock at FNAL-FCC, and distribute the signal to FNAL-DAB and ANL, choosing the path via an optical switch located at FNAL-FCC. The FNAL nodes are depicted by the blue rectangles and the ANL node is depicted by the red rectangle.

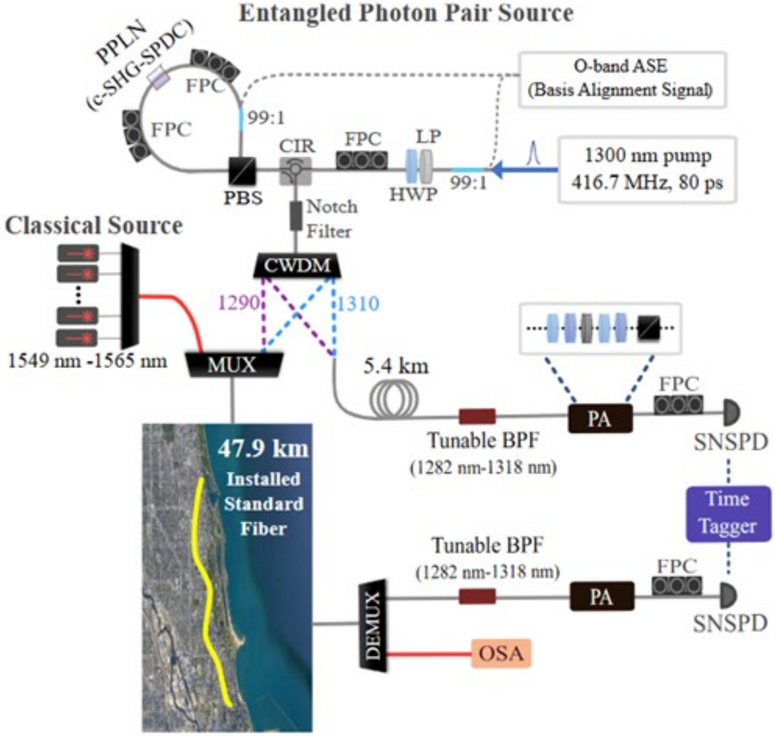


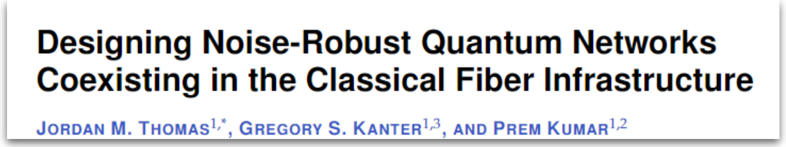
IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. XX, NO. XX, MONTH YEAR 1

Picosecond Synchronization System for the Distribution of Photon Pairs through a Fiber Link between Fermilab and Argonne National Laboratories

2. O-band Quantum Networking Beyond Dark Fiber

Coexistence with milliwatt power C-band classical light over >45 km fiber using O-band quantum entangled photons

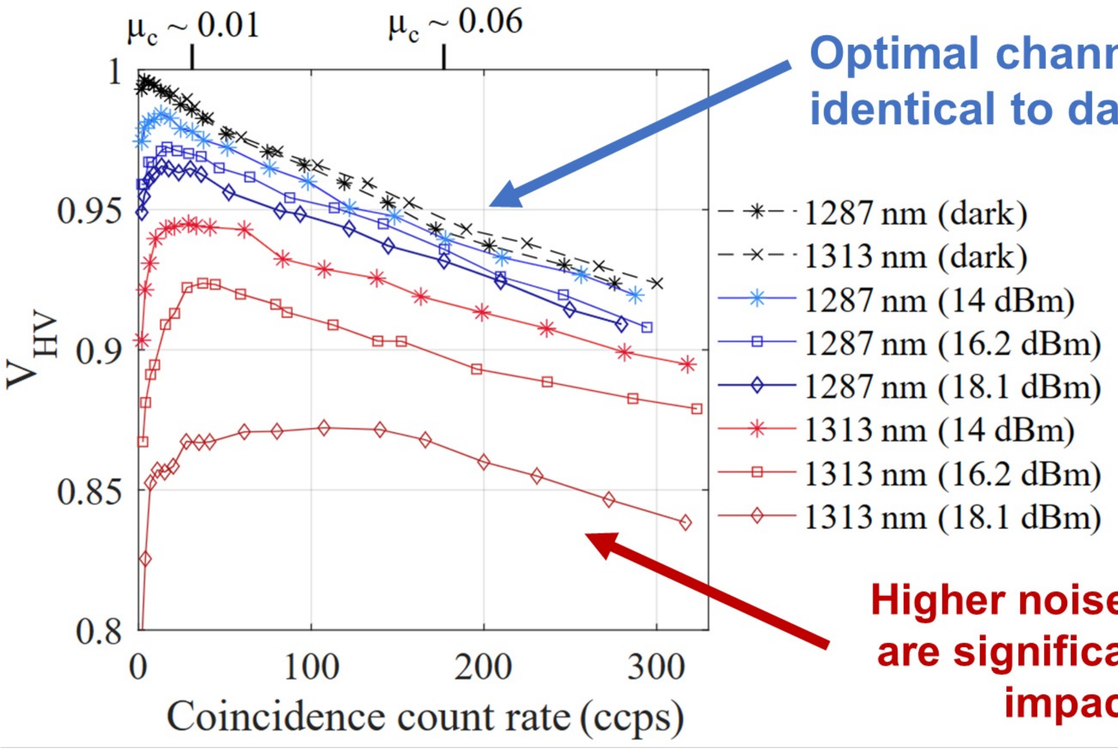




Designing Noise-Robust Quantum Networks Coexisting in the Classical Fiber Infrastructure

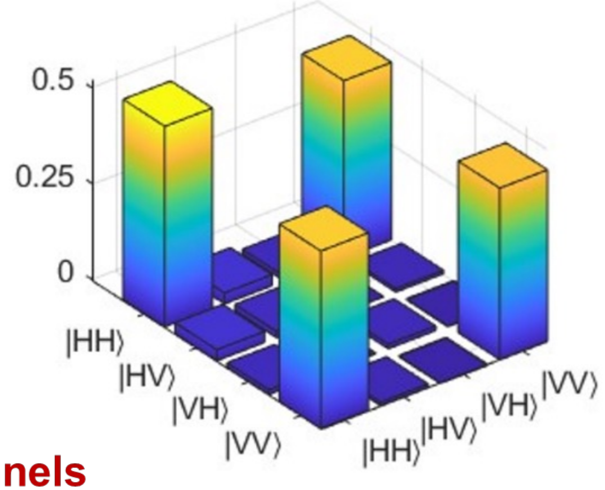
JORDAN M. THOMAS[1,*], GREGORY S. KANTER[1,3], AND PREM KUMAR[1,2]

O-band Pol. Ent. Visibility vs. Pair Rate w/ C-band Coexistance



Optimal channels nearly identical to dark fiber

Higher noise channels are significantly more impacted



- ❑ Using the optimal quantum channel and narrow spectral-temporal filtering, >95% fidelity to the nearest Bell state is achieved with >18 dBm C-band power.

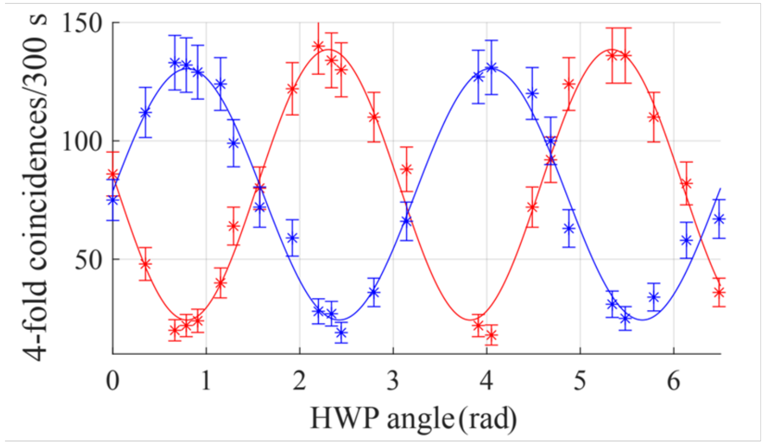
[2304.09076] Designing Noise-Robust Quantum Networks Coexisting in the Classical Fiber Infrastructure (arxiv.org)

Quantum Teleportation Coexisting with 11 dBm 400 Gbps C-band Signal

4-fold coincidence fringe as Bob rotates his polarization basis for Alice transmitting:

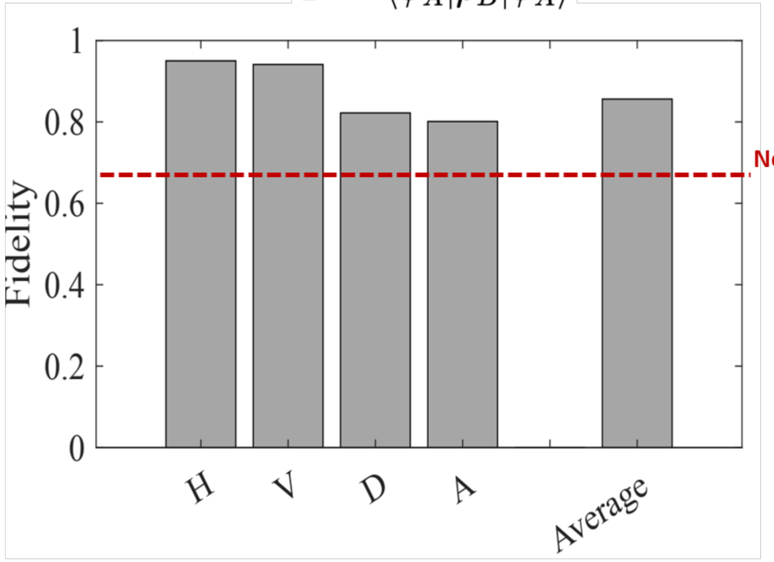
$$|D\rangle = \frac{1}{\sqrt{2}}|H\rangle + |V\rangle$$

$$|A\rangle = \frac{1}{\sqrt{2}}|H\rangle - |V\rangle$$



Fidelities of Bob's qubit to Alice's ideal state, measured via quantum state tomography

$$F = \langle \phi_A | \rho_B | \phi_A \rangle$$



$$F_{\text{avg}} = 85.6 \pm 4.0\%$$

Quantum Teleportation Over Optical Fibers Carrying Conventional Classical Communications Traffic

Th.C.3.7

Jordan Thomas[1], Fei Yeh[2], Jim Chen[2], Joe Mambretti[2], Scott Kohlert[3], Gregory Kanter[4], Prem Kumar[1]

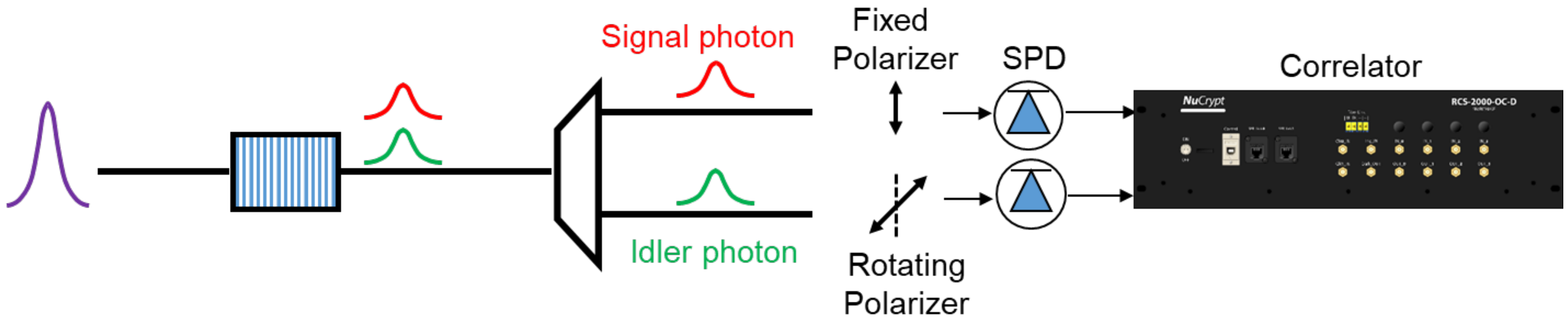
[1] Northwestern University, Evanston, USA. [2] International Center for Advanced Internet Research, Chicago, USA. [3] Ciena Corporation, Hanover, USA. [4] NuCrypt LLC, Park Ridge, USA

ECOC 2023

OFC’23 Show Floor Demo

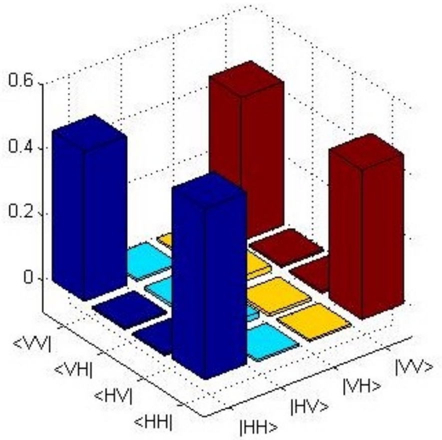
Distribution of Quantum Entanglement through Fiber with Co-Propagating Classical Data

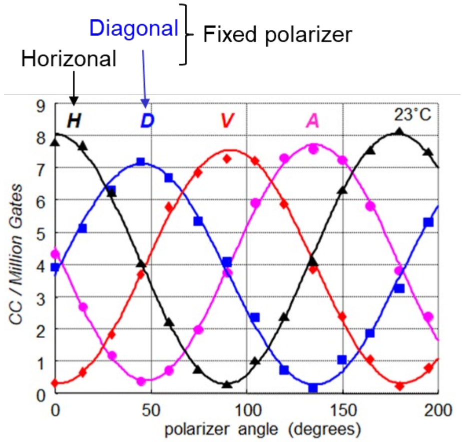
D. R. Reilly, K. F. Lee , P. Moraw, T. M. Rambo, A. J. Miller, J. Mambretti, P. Kumar , and G. S. Kanter



NuCrypt
Gregory Kanter
kanterg@nucrypt.net

Quantum Opus
STARLIGHT
HUBER+SUHNER Polatis





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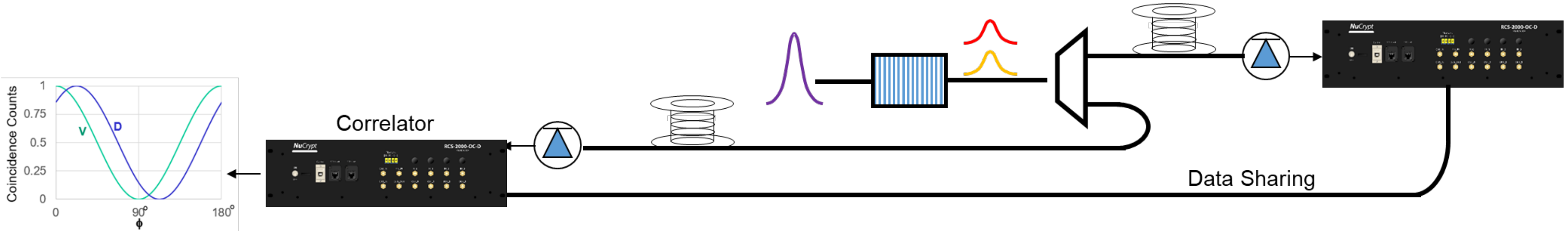
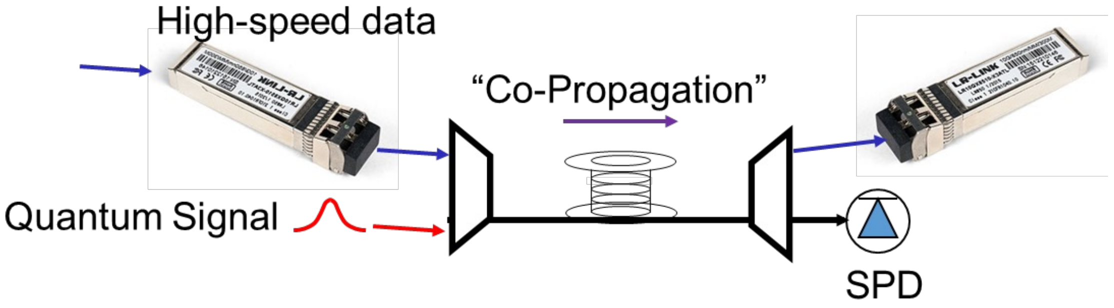
Demonstration Objectives

1. **Generation of entangled photons (distributed over fiber)**
2. **Data communication between distant Quantum Nodes**



3. **Co-Propagation of quantum and classical data**



Distribution of Quantum Entanglement through Fiber with Co-Propagating Classical Data | IEEE Conference Publication | IEEE Xplore

Northwestern
McCORMICK SCHOOL OF ENGINEERING

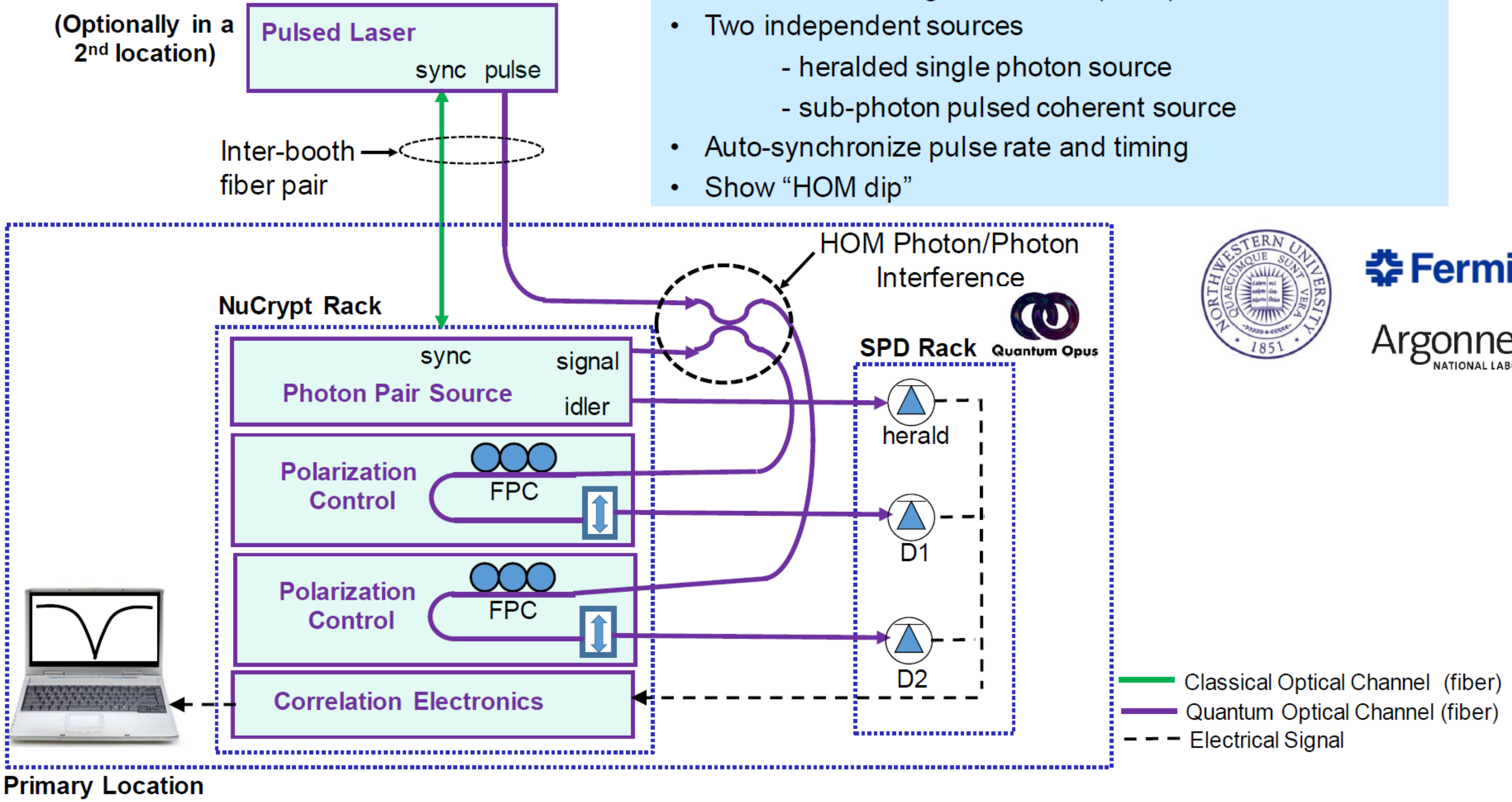
Reilly, Kanter, & Moraw at OFC'23 Show Floor

CPCC

Photon Interference from Independent Sources

Gregory S. Kanter,[1,*] Joaquin Chung,[2] Cristián Peña,[3]
Aaron Miller,[4] and Prem Kumar,[5]

- Demonstrate Hong-Ou-Mandel (HOM) Photon Interference
- Two independent sources
  - heralded single photon source
  - sub-photon pulsed coherent source
- Auto-synchronize pulse rate and timing
- Show “HOM dip”



Fermilab

Argonne NATIONAL LABORATORY

Reflections on the Assigned Questions

- Do we require field trial testbeds for scientific and engineering breakthroughs in telecom networks? Why can't we rely solely on lab-based test-beds, virtual test-beds, and test-bed emulation?
- What are the essential features of a field trial testbed for future telecom?
- What role do fiber/optical networks play in a holistic telecom network testbed?

Program

13:00	Opening Workshop	Cees de Laat
13:05	Presentation on the features and demonstrations that comprise OFCnet24	Marc Lyonnais Chair OFCnet
13:15	Introduction of panel on lessons learned from (preparing) technology demonstrations, opportunities, building networks from components, enabling new wave of demo's	Cees de Laat
13:20	1. Duncan Earl, Qubitekk 2. Joe Mambretti, Northwestern University 3. Chris Janson, Nokia 4. Félix Bussières, Morax Idquantique 5. Mehdi Namazi, Quconn 6. Jerome Prieur, Aureatechnology 7. David Rodgers, Exfo	Panel session moderated by Cees de Laat and Gwennael Amice
14:15	Introduction of the Modified Rump Session approach to engage with industry and academic research labs regarding emerging technologies, research and innovation prototyping to be demonstrated at current and future OFCnet's.	Reza Nejabati
14:20	1. Ben Dixon, MIT Lincoln Laboratory 2. Dimitra Simeonidou, University of Bristol, JOINER UK National Test-bed 3. Prem Kumar, Northwestern University, Illinois Express Quantum Network 4. Julia Larikova, Infinera 5. Jorg Peter Elbers, Adva	Rump session moderated by Reza Nejabati and Andrew Lord
15:30	End of workshop	Cees de Laat

Large scale field testing

Julia Larikova

March 2024, OFC 2024

S1A

Large scale FOAs

- Three known use cases:
  - SOP sensing and coherent OTDR
    - Requires access to real life transmission fiber and a LOT of it
    - Long term data collection on different fibers from same cable, same direction
    - Metro behavior vs. ULH
    - Location matters – strong weather (electric storms vs. earthquakes)
  - openROADM type of environment
    - openROADM API and MSA is well defined but link control and timing of power control isn't
    - Lab environment isn't sufficient to truly test 2-3 vendors of optical line systems when it comes to any kind of interop
    - Need 40+ to 100+ NEs to validate power stability under outrage and power failure conditions
    - Openconfig, IOWN etc – more interop standards to come
  - Interoperable OFEC, CFEC and OFEC-PCS formats
    - OIF studies show a huge 4-9dB interop penalties which are poorly understood
    - No studies over real-life CD or PDL
    - No studies over large sample of parts

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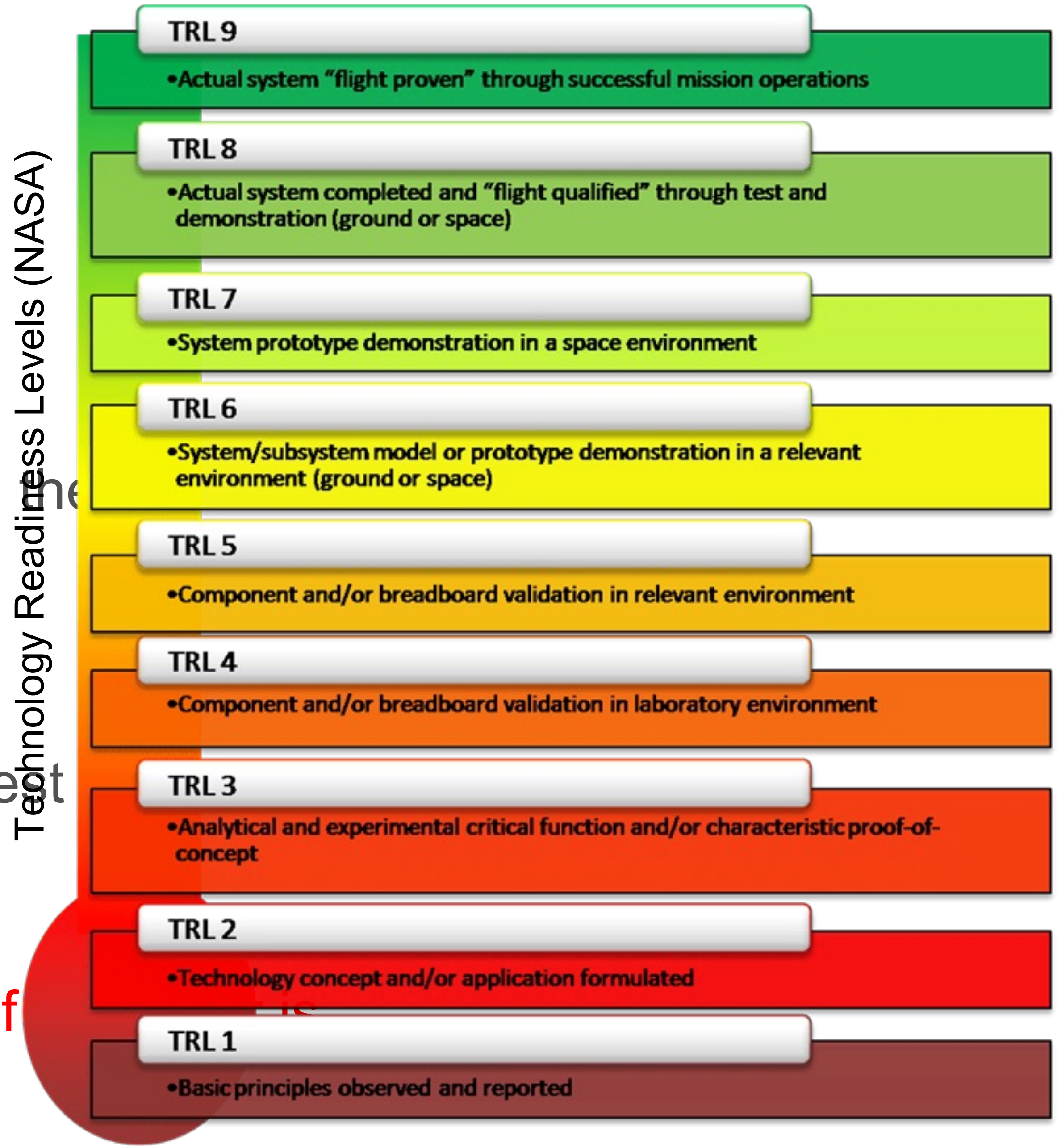
What is the role of field trial testbeds in comms R&I?

OFC 2024 – Workshop S1A – Real-life Testbed Innovation

24 March 2024, Jörg-Peter Elbers

Field trial testbeds – why?

- Demonstration, test and validation in operational environment
- Use of real channel characteristics and the temporal/statistical variations
- Capability to scale up and out (# of nodes & domains, geography)
- Opportunity for ML data generation & test applications



Replacing a lab fiber with a short strand of … not a field trial!

Some good use cases

Optical transmission

- *Margin assessment in fiber transmission (esp. under challenging conditions)*
- *Study of atmospheric turbulences & their compensation (e.g. ground-space links)*
- *Exploration of joint communication & sensing (fiber network as sensor)*
- *Stability investigations of quantum key distribution & entanglement schemes*

Network control & protocols

- *Verification of protocol performance and scalability in operational environment*
- *Investigation of new network protocols and their interoperability*

ML data generation & model tests

- *Collection of network performance and fault data sets*
- *Benchmark of models for performance optimization & trouble shooting*

Thank you

joerg-peter.elbers@adtran.com

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