Sharing Direct Fiber Channels Between Protection and Enterprise Applications Using Wavelength Division Multiplexing

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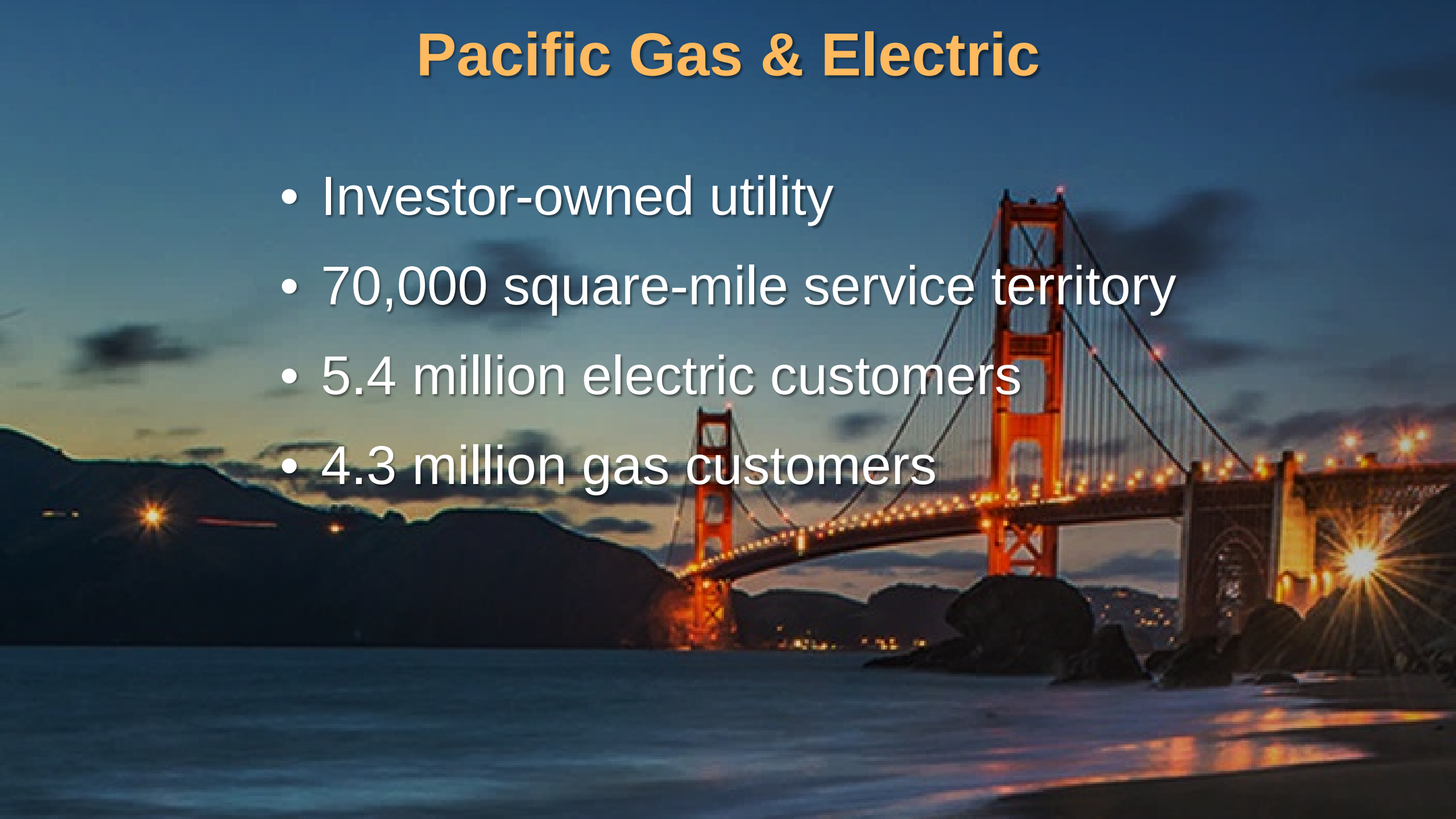


- Investor-owned utility
- 70,000 square-mile service territory
- 5.4 million electric customers
- 4.3 million gas customers

PG&E Motivations

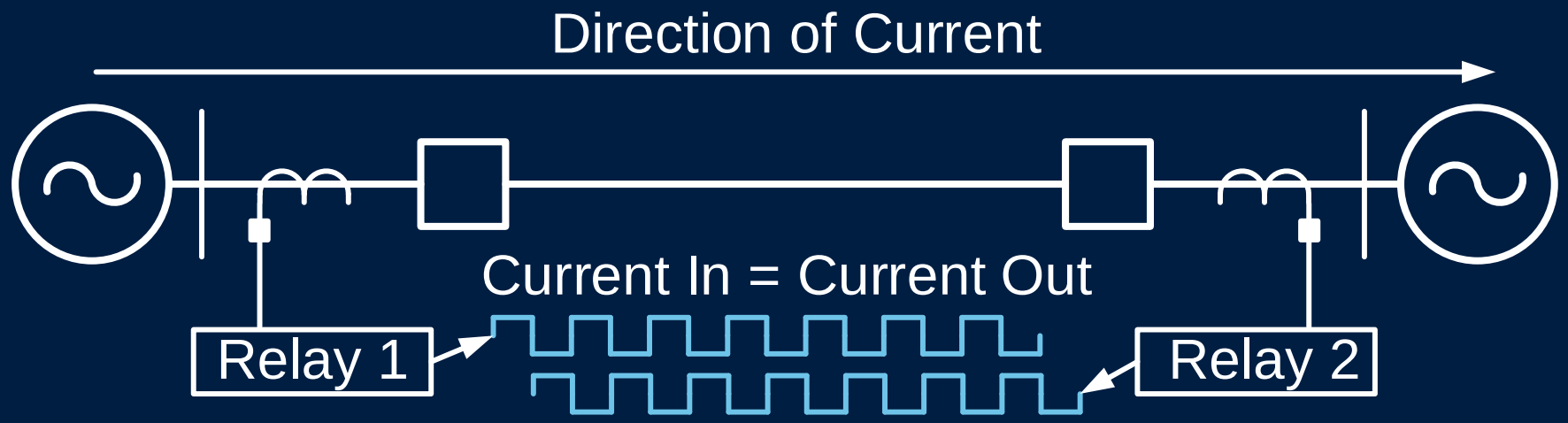
- Constant work to improve system reliability
- Openness to latest technological advancements
- Careful selection process
- Communications as a key part of every evaluation
- Communications technology laboratory in San Ramon, California

PG&E Communications Network

- Company-wide Optical Transport Network (OTN)
- Substations serving as network nodes
- 61 nodes in service
- North-side extension with additional 10 nodes
- Central management
- Extra capacity available

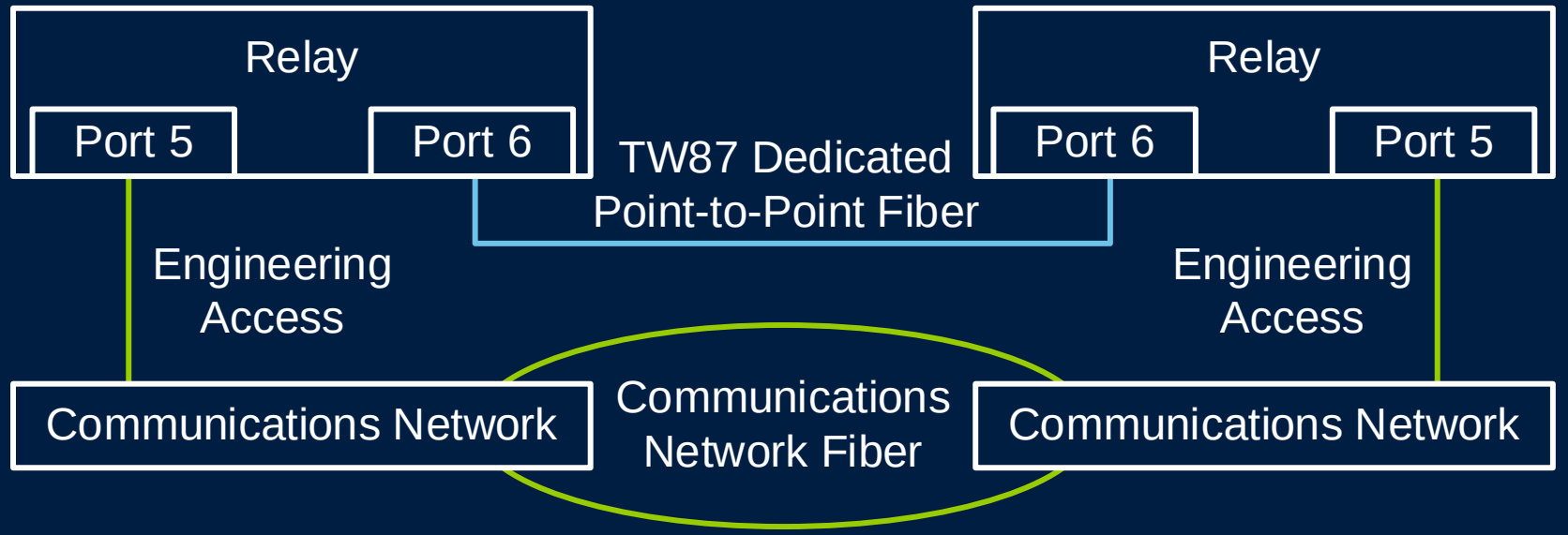
Communications-Based Protection

- Protection assumes limited communications and is optimized for legacy communications technologies
- 64 kbps digital voice channels are still popular
- Higher-speed packet-based communications slowly gaining hold



New World
TW87 Dedicated Fiber Communications

- 3 phase voltages and 3 phase currents
- 145 Mbps stream payload
- Sampling at 1 MHz with 18-bit resolution
- 1 Gbps Ethernet physical layer



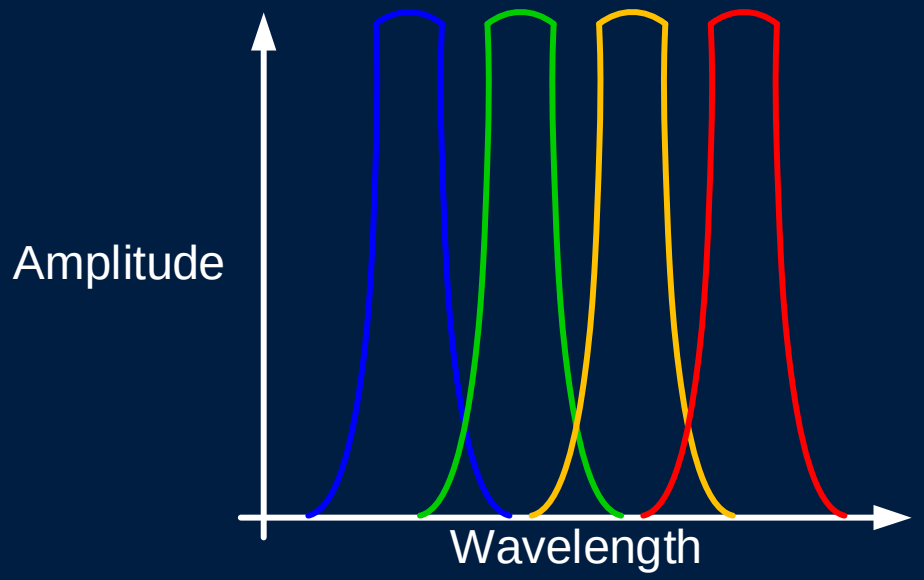
TW87 Link Requirements

- 1 Gbps Ethernet physical layer
- Industry-standard SFP module-based fiber interface
- Low latency (<3 ms)
- Low frame jitter (<25 ns)
- No link asymmetry (<100 ns)
- No third-party traffic
- Constant link delay (no protected path switching)

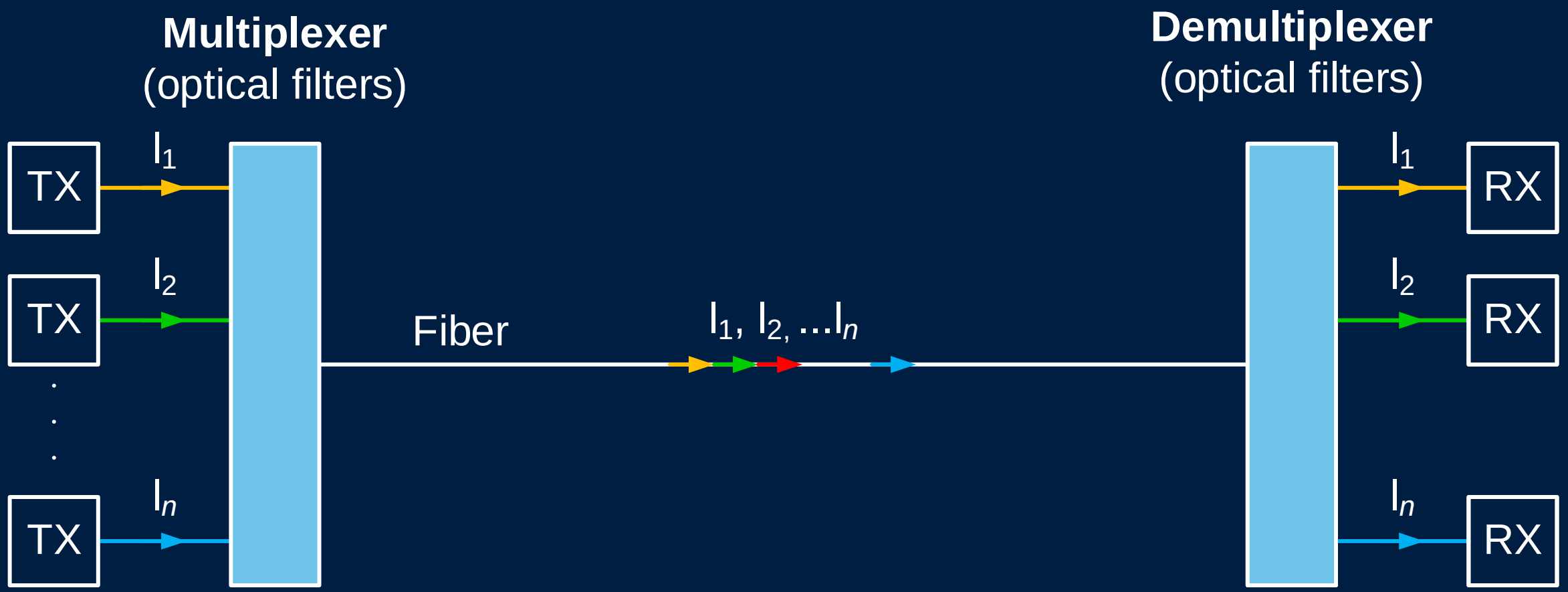
Point-to-Point Communications Link Options

Wavelength division multiplexing (different light colors) is a great way to share a fiber

Transport Technology	Acceptability	Comment
Single-mode fiber pair	Yes	Difficult to justify for sole use by protection
CWDM	Yes	
DWDM	Yes	
OTN	Yes	
SONET	No	Jitter
Ethernet	No	Jitter
MPLS	No	Jitter
SDN-based Ethernet	Sometimes	Affected by device construction and network setup



Wavelength Division Multiplexing (WDM)



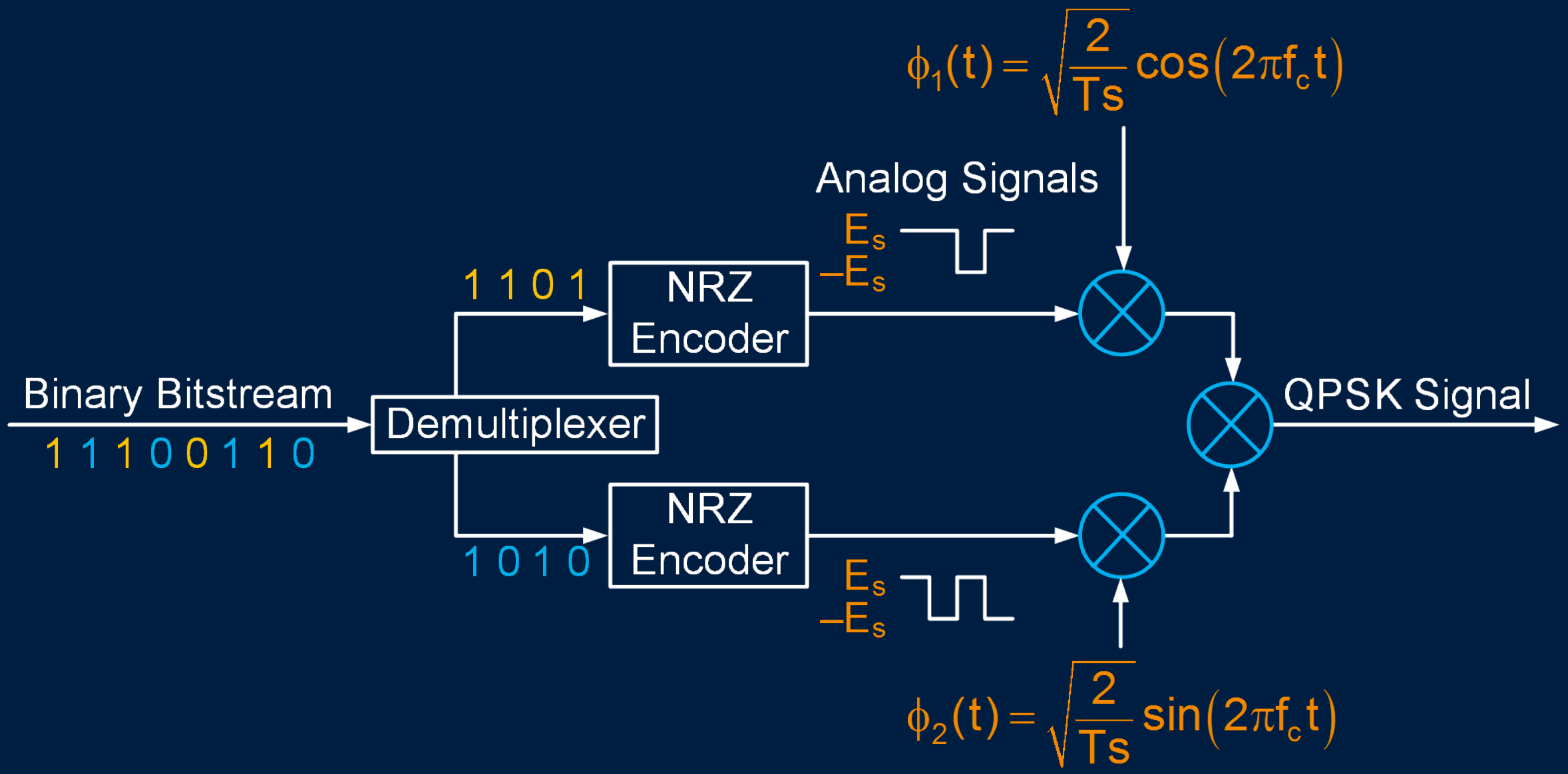
Fiber Capacity Today

- Capacity is affected by distance
- Optical amplifiers are used extensively

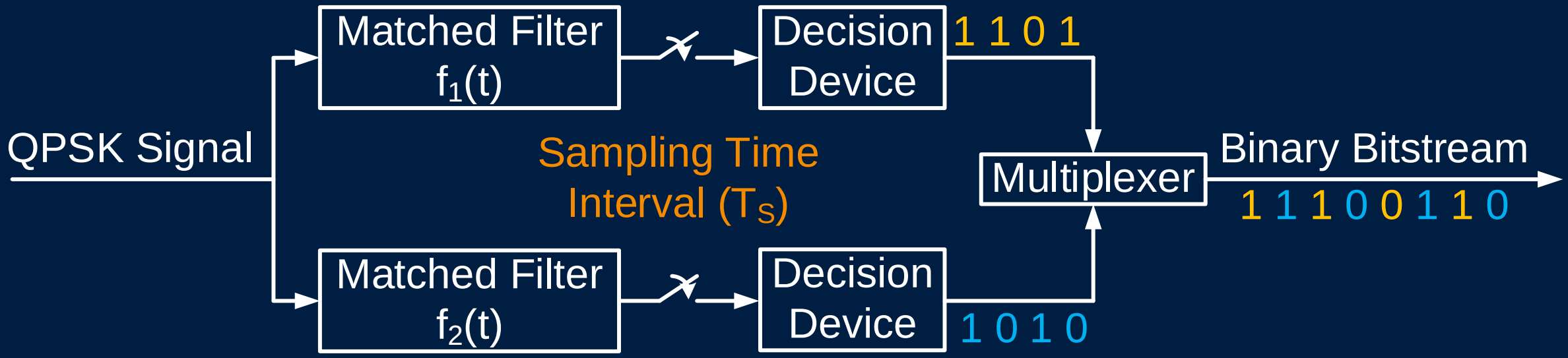
Capacity (Tbps)	Modulation	Typical Distance (km)
4 to 7	PM-BPSK	5,000
8 to 15	PM-QPSK	3,000
12 to 21	PM-8QAM	1,200
16 to 27	PM-16QAM	500

- Fiber can carry many optical wavelengths (88+)
- Advanced modulation schemes are required
- Capacity and distance records are broken daily

Conceptual Structure of a QPSK Transmitter



Conceptual Structure of a QPSK Receiver



Example: MAREA Submarine Cable

- Laid in September 2017
- 4,000 miles long (Virginia Beach to Bilbao, Spain)
- Designed with 160 Tbps capacity (8 fiber pairs, 20 Tbps per fiber)
- Cofinanced by Facebook, Microsoft, and Telxius
- Operational by end of 2018

Optical Transport Network

- Physical layer (Layer 1) optical transport
- Very high speeds (1, 10, 100 Gbps, and above)
- Many wavelengths (88+)
- Diverse tributaries (SONET, MPLS, and so on)
- Integrated optical plane (DWDM, amplification, reconfigurable add-drop, wavelength management)
- Scalability

OTN Multiplexing

- High speed helps multiplex many tributaries
- Flexible bit mapping preserves each tributary
- Tributaries never see each other

Signal	Approximate Data Rate
ODU0	1.244 Gbps
ODU1	2.498 Gbps
ODU2	10.037 Gbps
ODU3	40.319 Gbps
ODU4	104.79 Gbps
ODUflex	Any configured rate

Dual Redundant OTN System Hardware

OTN Multiplexer Latency

- Forward error correction (FEC) increases latency
- FEC level is user selectable
- Direct optical system access (dedicated wavelength) has no additional latency

Line-Side FEC	Tributary Rate (GHz)	Line Rate (GHz)	Latency (µs)
None	1.25	10.709	17
RS FEC	1.25	10.709	23.5
EFEC	1.25	10.709	59
EFEC2	1.25	10.709	157

TW87 Link Test at PG&E

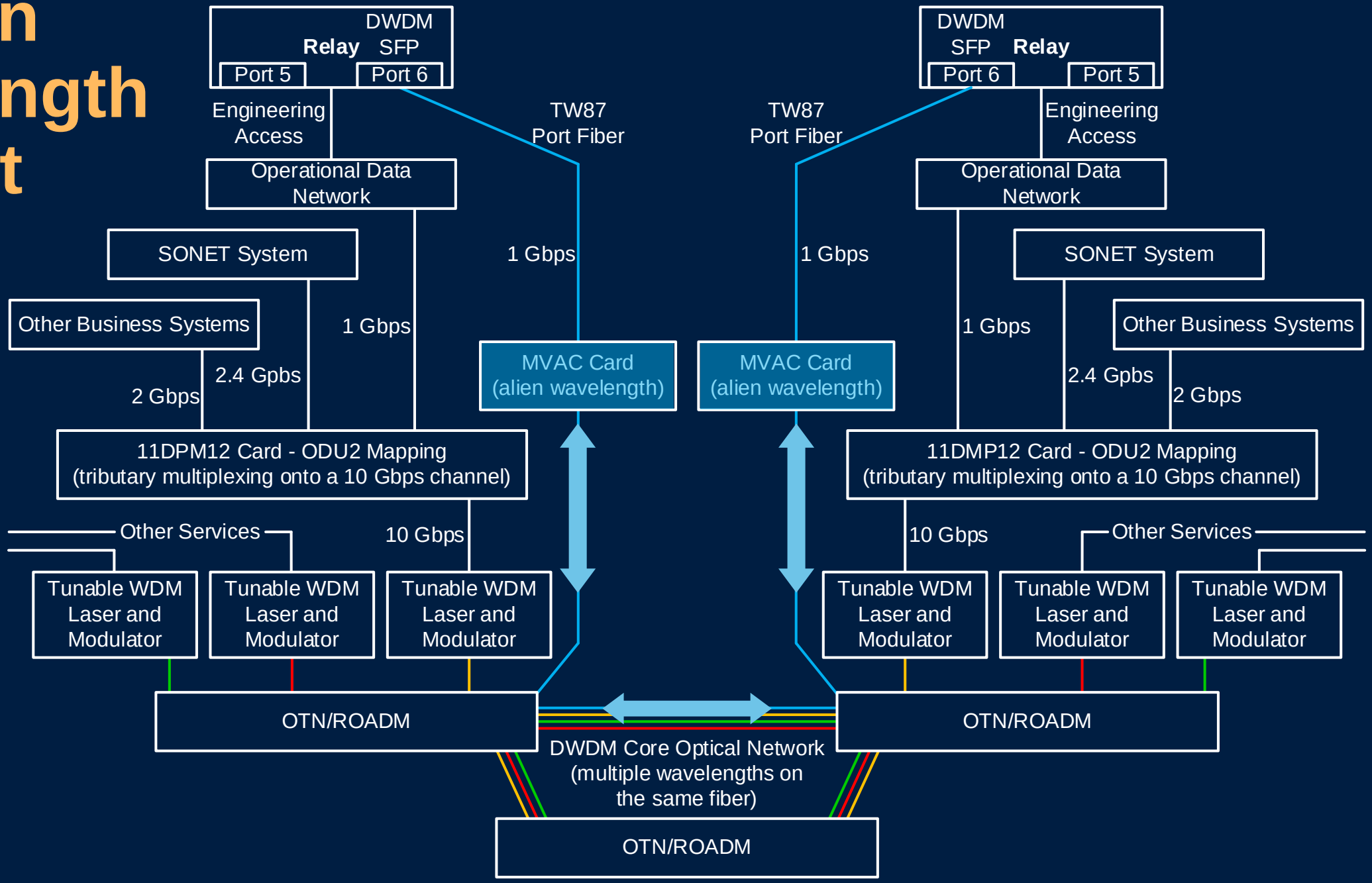
Test Goals

- Verify TW87 link compatibility with PG&E network
- Determine best interface method
- Introduce OTN capabilities to protection engineers

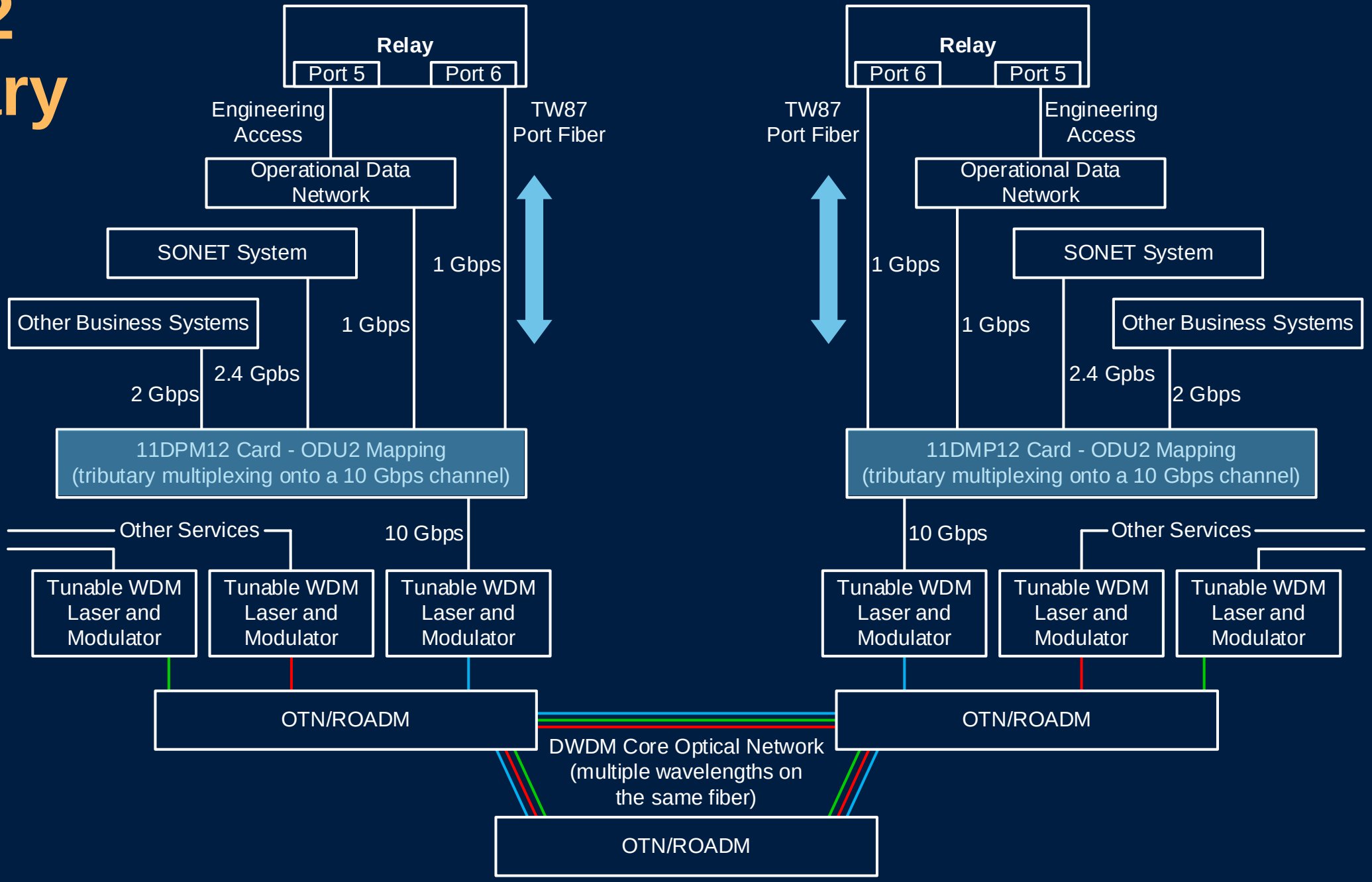
Test Scenarios

- Alien wavelength test
  - Uses dedicated wavelength
  - Is potentially wasteful (>100 Gbps resource)
- ODU2 tributary test
  - Is multiplexed with SONET, MPLS, and other services
  - Uses more modest 1 Gbps resource to transport 145 Mbps

Alien Wavelength Test



ODU2 Tributary Test



Test Results

- Latency is in line with error correction level used
- Jitter is below relay measurement limit

Test	Error Correction	Measured Latency (µs)	Measured Jitter (ns)
Alien wavelength	None	1.6	< 8
ODU2	EFEC	60.8	< 8

Relay Design Opportunities

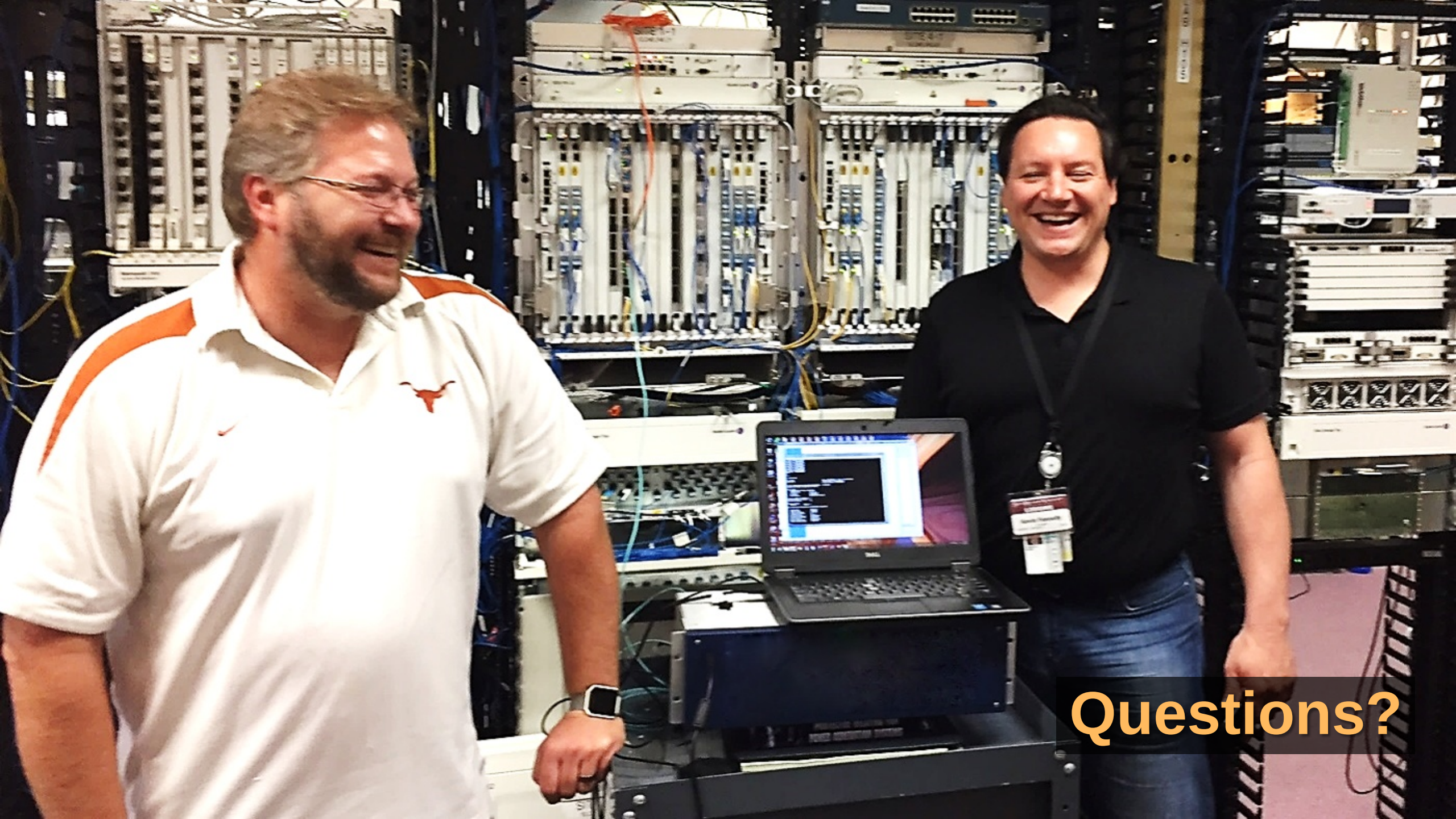
- Communications are omnipresent
- Digital communications are developing very fast
- Fiber capacity exceeds protection system needs by 5–9 orders of magnitude

Relay Design Opportunities

- What is the best way to use network communications?
- How should we build the next generation of relays to embrace network communications?

Relay Design Challenges

- Guaranteed network-wide time synchronization (IEEE 1588 PTP as a wide-area network service)
- Guaranteed frame delivery (quality of service)
- Maximum latency guarantees
- Mature network management tools
- Cybersecurity


Questions?