Ribbon for IP and Optical

- Ribbon acquired ECI Telecom in March, 2020

- Full line of Optical, Ethernet, and IP platforms
  - Pizza-boxes to multi-terabit, full-rack systems
  - Automated network management

- Help service providers and electric utilities
  - Residential broadband backhaul networks
  - Mobile broadband backhaul networks
  - Wavelength services and optical networks
  - Carrier Ethernet services networks

Big Carrier Capabilities
Small Carrier Packages

Headquartered in the US

Customers in over **140 countries**[1]
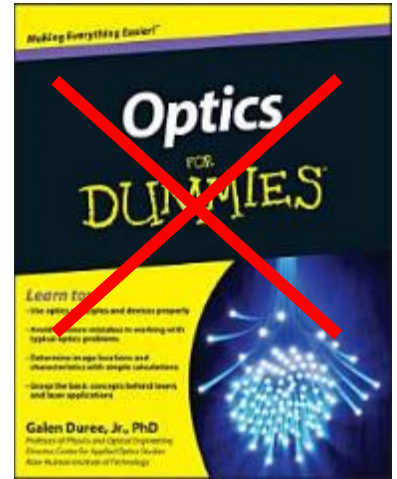
Over **4,000** employees globally[1]

1000+ Patents Worldwide

[1]*Combined FYE 2018 data of Ribbon and ECI.*

Nasdaq: [RBBN]

No one is dumb…. Just maybe unfamiliar…

- What can optical networks do for me?

- What are the major piece parts and vocabulary?

- What do I have to think about when I deploy?

- Any cool stuff on the market I should be aware of?

What Can an Optical Network Do for Me?

- Increase <u>capacity</u> without deploying more fiber cable
  - 100G large capacity to >10Tb/s huge capacity on <u>one</u> fiber pair

Site A   Site B

- Increase <u>distance</u> without deploying lots of electronics
  - > 80km to 100's of km's to 1000's of km's
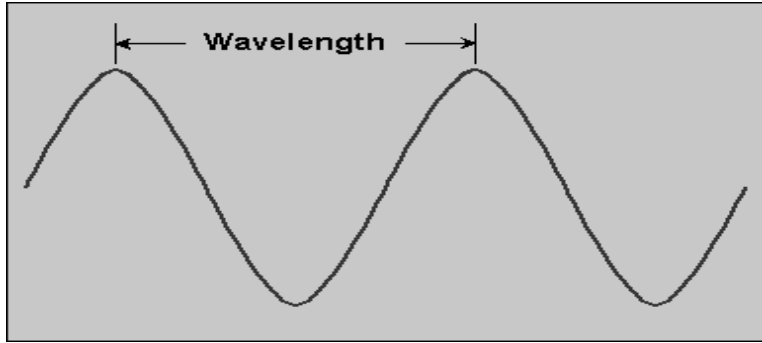
Site A   Site B
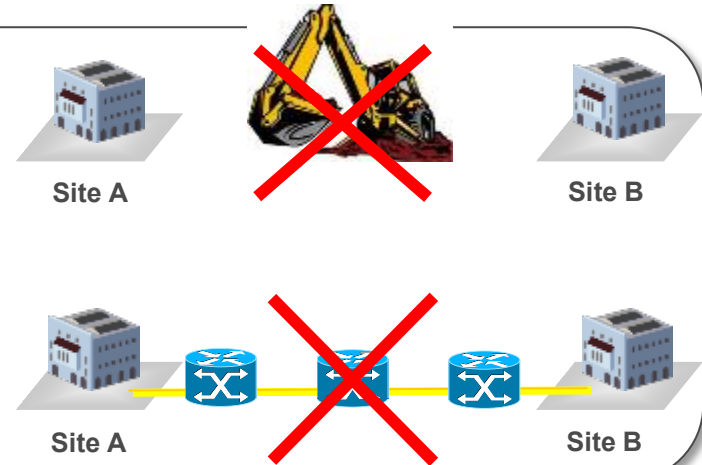
- Protect my traffic
- Encrypt my traffic
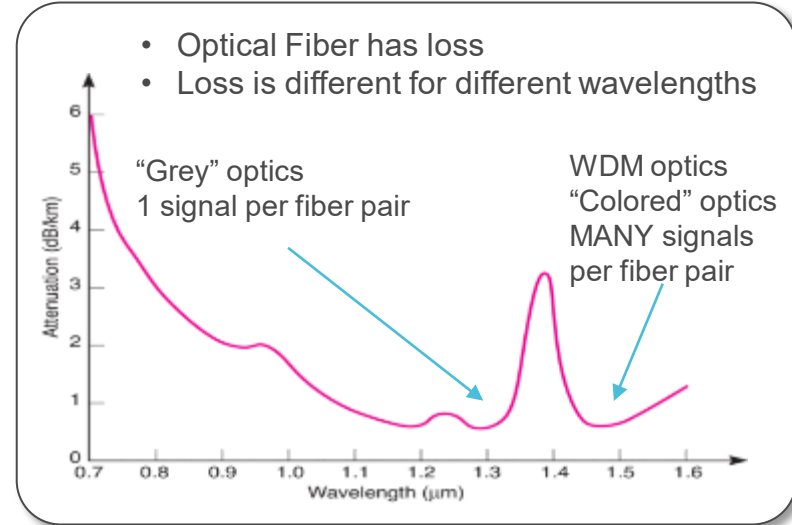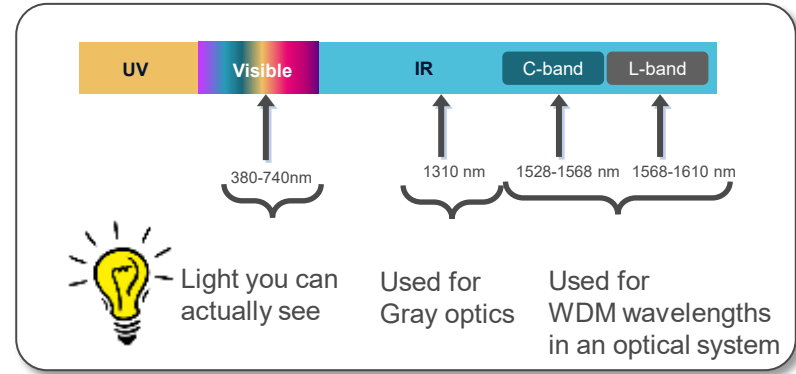- Rearrange my traffic
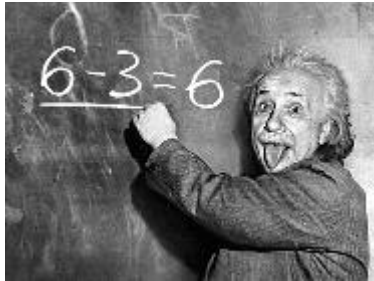
Only optical does this

Optical does this in **uniquely** valuable ways

Only Optical Solves <u>Capacity</u> and <u>Distance</u> Challenges

ribbon   ECI THE ELASTIC NETWORK
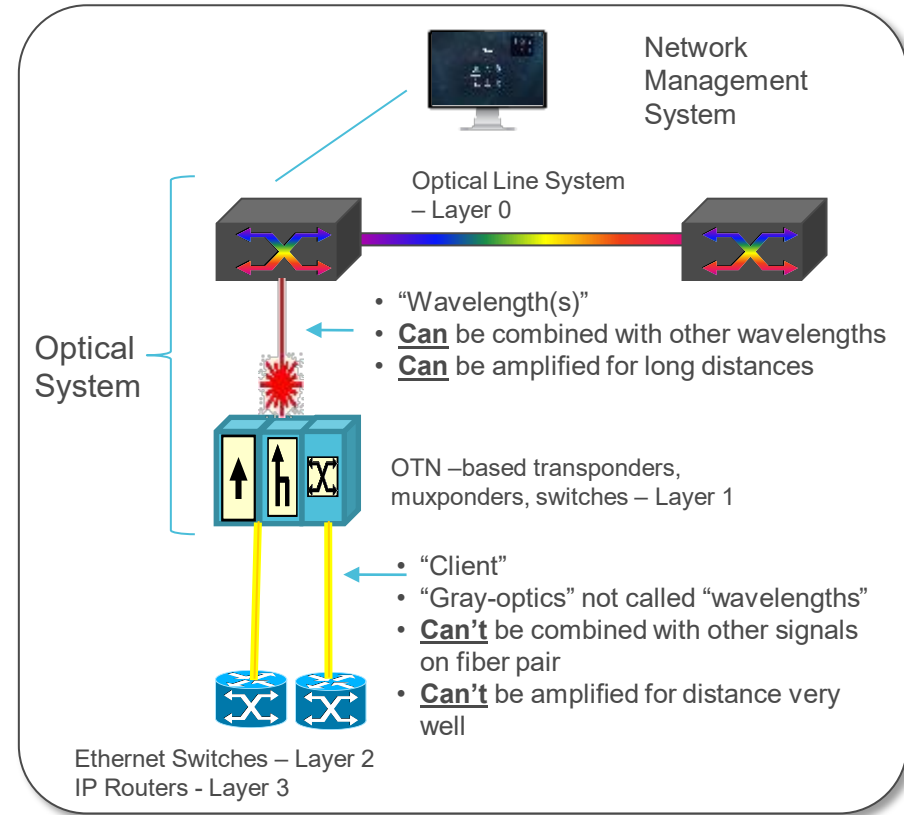
A couple basics…

Wavelength

- Light exists as electromagnetic waves
- Different colors of light have different wavelengths
- The wavelengths have a distance measured in nanometers (nm)

6-3=6

UV	Visible	IR	C-band	L-band

380-740nm — Light you can actually see

1310 nm — Used for Gray optics

1528-1568 nm / 1568-1610 nm — Used for WDM wavelengths in an optical system

- Optical Fiber has loss
- Loss is different for different wavelengths

"Grey" optics
1 signal per fiber pair

WDM optics
"Colored" optics
MANY signals
per fiber pair

Attenuation (dB/km) vs Wavelength (μm)

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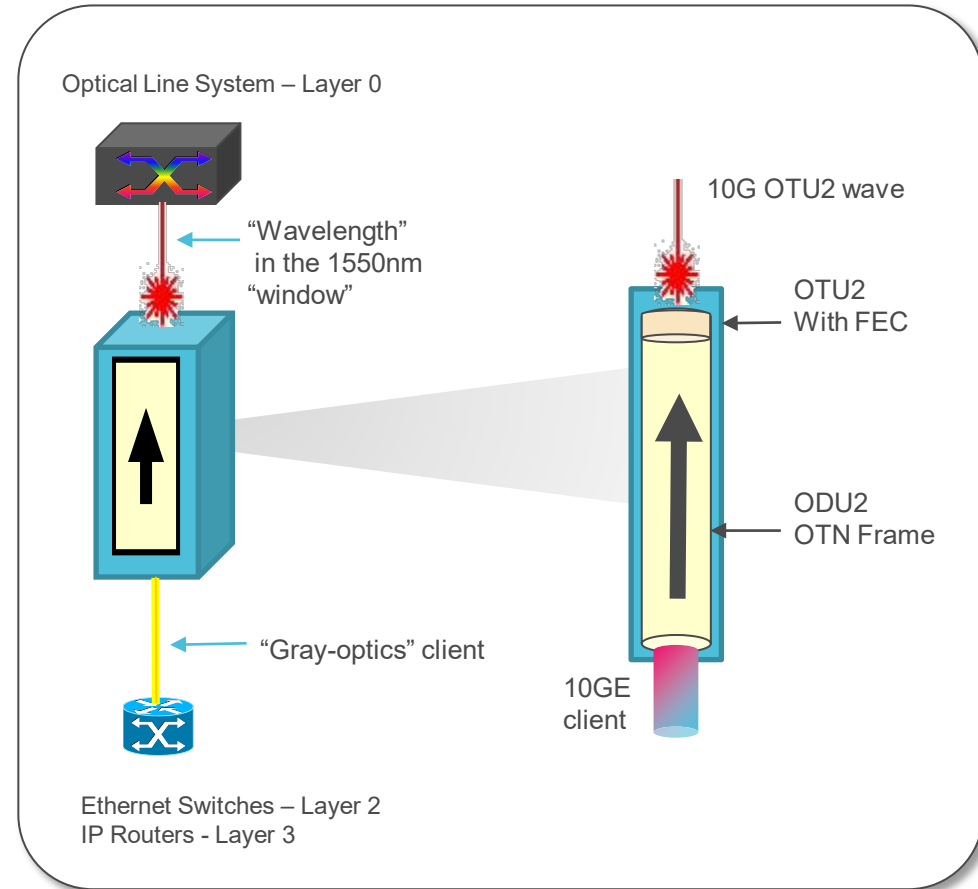# What are the Key Pieces of an Optical System?

- Optical line system
  - Photonic (optical) – "colors" not "bits"
  - Manipulates "wavelengths" (optical channels)
  - Delivers capacity and distance
  - Analog
- Transponders/muxponders/OTN switches
  - Electronic – "bits"
  - Creates "wavelengths"
    - Adapts gray optics interfaces (like Ethernet)
  - Can mux/groom (or not) lower speed traffic into a wave
  - Manipulates OTN containers
  - Feeds the line system
  - Digital
- Management system
  - GUI, point and click
  - Helps you sleep at night…

Network Management System

Optical Line System – Layer 0

Optical System

- "Wavelength(s)"
- **Can** be combined with other wavelengths
- **Can** be amplified for long distances

OTN –based transponders, muxponders, switches – Layer 1

- "Client"
- "Gray-optics" not called "wavelengths"
- **Can't** be combined with other signals on fiber pair
- **Can't** be amplified for distance very well

Ethernet Switches – Layer 2
IP Routers - Layer 3

Optical Line System, OTN Transponders/muxponders/switches, Management
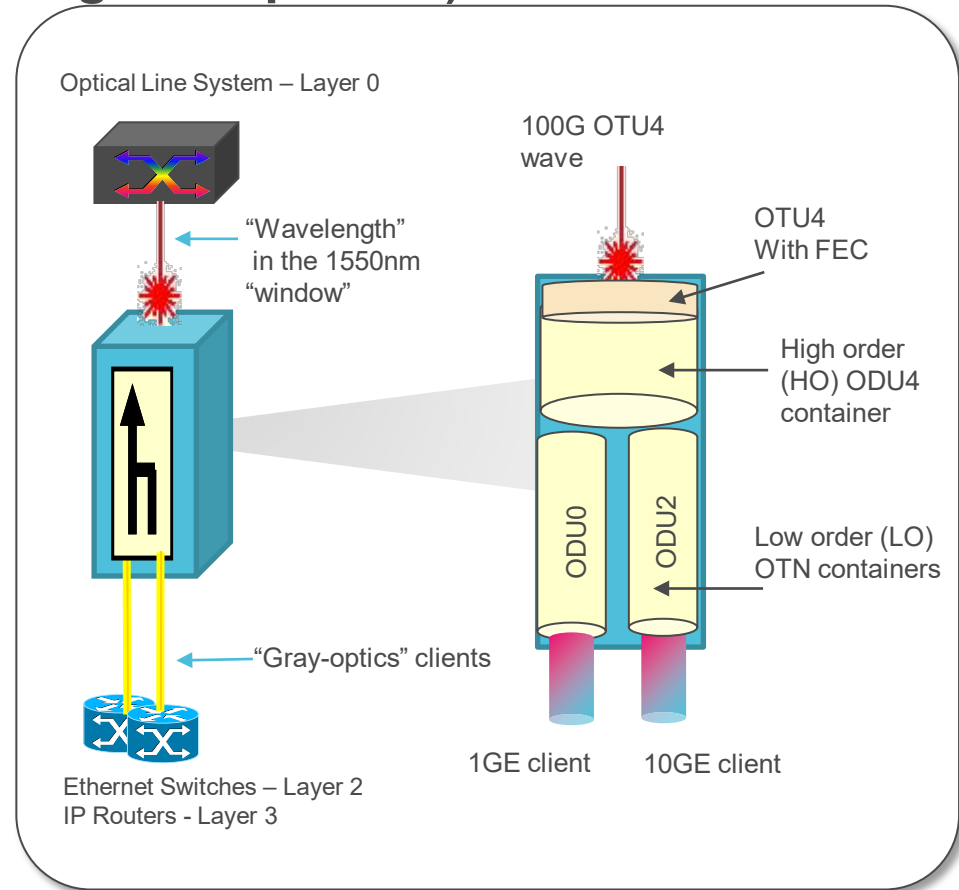
What is a Transponder?

- <u>Single</u> client port
- <u>Single</u> wave port
- Rate of client and network port are roughly the <u>same</u>
- No "grooming"
- **3** functions
  - Terminates client
  - Transparently wraps the client signal in an OTN frame (electronics)
    - Adds 'forward error correction' (FEC) to achieve distance
    - Does <u>not</u> touch Ethernet VLANs or IP packets
  - Transmits the OTN-wrapped client on the correct "wavelength"
- Wavelength is now ready to join its other wavelength friends on the line system
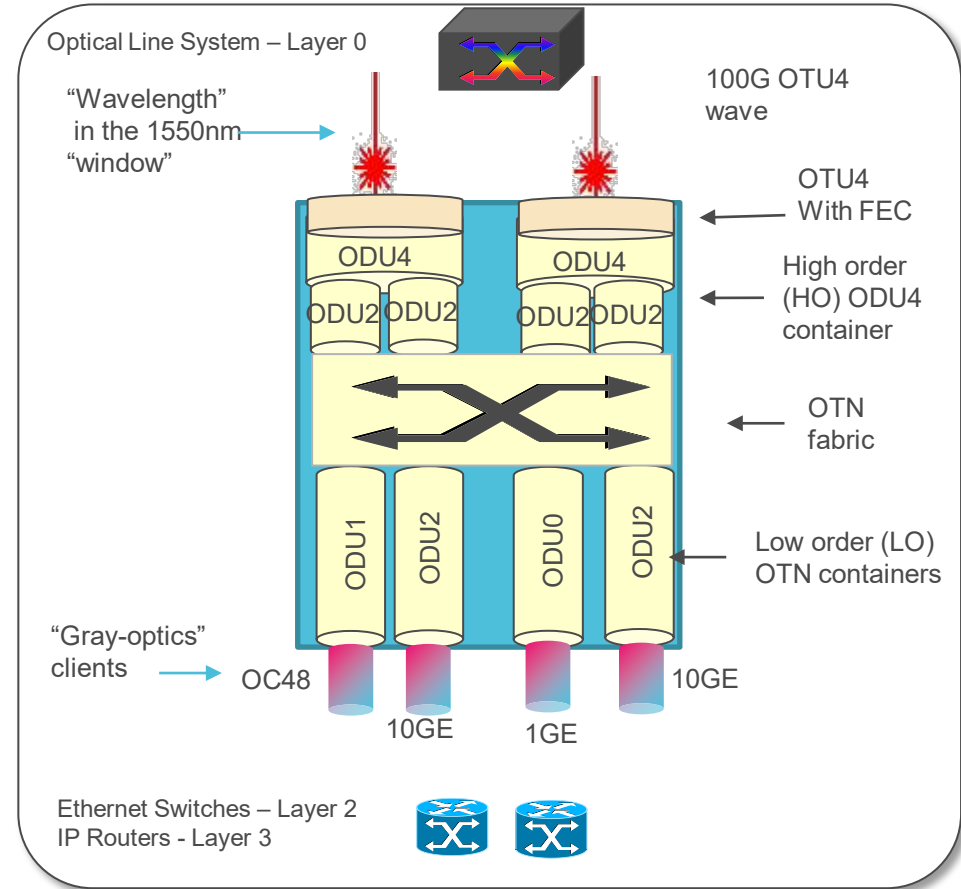
Optical Line System – Layer 0

"Wavelength" in the 1550nm "window"

10G OTU2 wave

OTU2 With FEC

ODU2 OTN Frame

"Gray-optics" client

10GE client

Ethernet Switches – Layer 2
IP Routers - Layer 3

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What is a Muxponder? (Multiplexing Transponder)

- <u>Many</u> lower-speed client ports
- <u>Single</u> higher-speed wave port
- Saves wavelengths
- **4** functions
  - Terminates client optics
  - Transparently wraps each client signal in its own OTN container (electronics)
    - Does <u>not</u> touch Ethernet VLANs or IP packets
  - Multiplexes **many** low-order OTN containers into **one** bigger high-order OTN container
    - Adds 'forward error correction' to achieve distance
  - Transmits the high-order OTN container on the correct "wavelength"
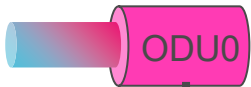- Wavelength is now ready to join its other wavelength friends on the line system

Optical Line System – Layer 0

100G OTU4 wave

"Wavelength" in the 1550nm "window"

OTU4 With FEC

High order (HO) ODU4 container

ODU0

ODU2

Low order (LO) OTN containers

"Gray-optics" clients

Ethernet Switches – Layer 2
IP Routers - Layer 3

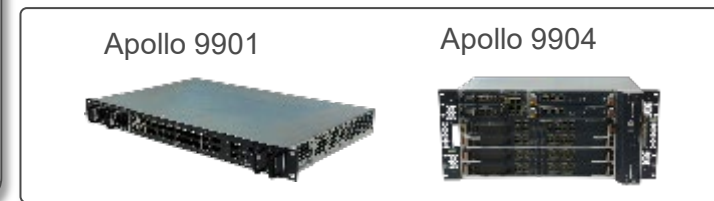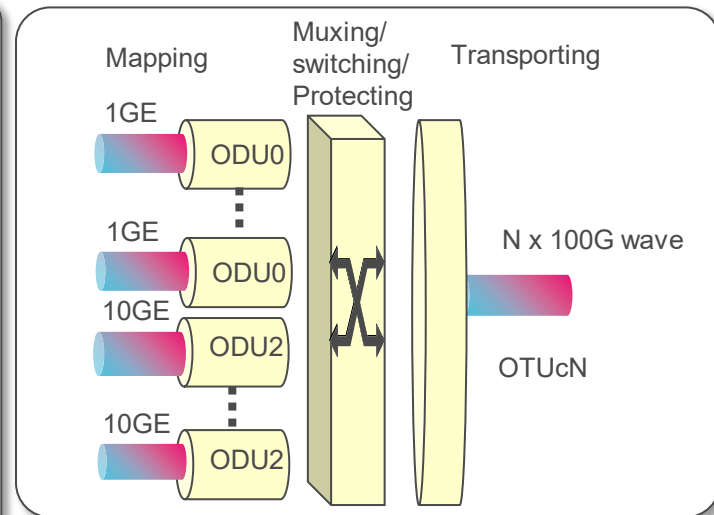1GE client

10GE client

What is OTN Switching?

- Ability to groom across
  - Many lower-speed client ports
  - Many wavelength ports
- Save wavelengths – more protection options
- **5** functions
  - Terminates client optics
  - Transparently wraps each client signal in its own OTN container
    - Does not touch Ethernet VLANs or IP packets
  - Rearranges OTN containers "any to any"
  - ODU cross-connecting – hairpinning, passthrough, add/drop
  - Transmits the OTN containers on the correct "wavelength"
- Wavelengths are now filled with clients as you want them


Optical Line System – Layer 0

"Wavelength" in the 1550nm "window"

100G OTU4 wave

OTU4 With FEC

High order (HO) ODU4 container

ODU4   ODU4
ODU2 ODU2   ODU2 ODU2

OTN fabric

ODU1 ODU2   ODU0 ODU2

Low order (LO) OTN containers

"Gray-optics" clients

OC48   10GE   1GE   10GE

Ethernet Switches – Layer 2
IP Routers - Layer 3

OTN Containers

Any type of client signal: Ethernet, SONET, Fiber Channel, etc.

Client Port Type	ODU Container	Bit Rate
GE	ODU0	1.25Gb/s
OC48/STM-16	ODU1	2.5Gb/s
Various	ODUFlex	Nx 1.25Gb/s
10GE/OC-192/STM-64	ODU2/2e	10 Gb/s
40GE	ODU3	40Gb/s
100GE	ODU4	105Gb/s
200GE	ODUc2	210Gb/s
400GE	ODUc4	421Gb/s

1GE — ODU0

10GE — ODU Flex

10GE OC-192/ STM-64 — ODU2

100GE — ODU4

Mapping

Muxing/ switching/ Protecting

Transporting

1GE — ODU0

1GE — ODU0

10GE — ODU2

10GE — ODU2

N x 100G wave

OTUcN

Apollo 9901

Apollo 9904

What are the Functions of a Line System?

- Combining many waves together onto a single fiber to achieve <u>capacity</u>
  - Wavelength division multiplexing

- Manipulating wavelengths
  - Added/dropped/passed through/switched
  - Optical ADM
  - ROADM (Reconfigurable Optical Add/Drop Multiplexer)

- Taming the wild, nasty effects of analog transmission to achieve <u>distance</u>
 - Amplification
  - Dispersion compensation
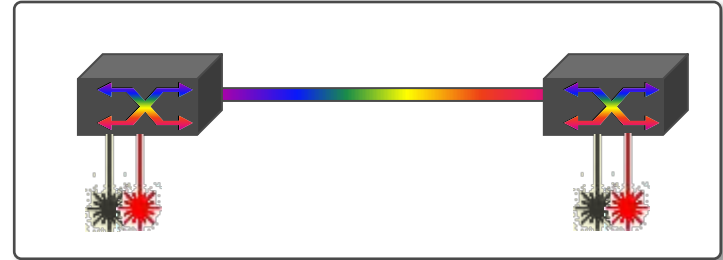
Combining Waves using Wavelength Division Multiplexing (WDM)

- DWDM – dense WDM
  - Up to 128 channels with 37.5GHz spacing of each channel
  - Channels can be up to 400G or greater
    - (may need wider spacing depending about how far you want to go)
  - Can be amplified for long distances
  - Started in long haul, penetrated metro, now in access

- CWDM – course WDM ("coarsewave")
  - Up to 18 channels (usually only up to 8)
  - 20nm wide spacing (2500GHz spacing)
  - Best for 2.5Gb/s and below channels
  - Limitations for amplification - distance limited to ~60km
  - Helps with capacity, but not distance
  - Decreasing use…

DWDM "Grids"

Each wavelength consumes spectrum in the C-Band
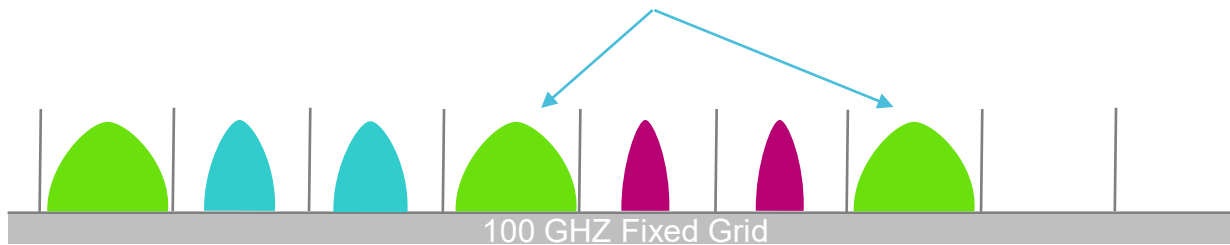
100 GHZ Fixed Grid

Fixed Grid
- 100GHz Spaced center-frequencies
- 100GHz wide channels
- 44 channels in C-band

50GHZ Fixed Grid

Fixed Grid
- 50GHz Spaced center-frequencies
- 50GHz wide channels
- 88/96 channels in C-band
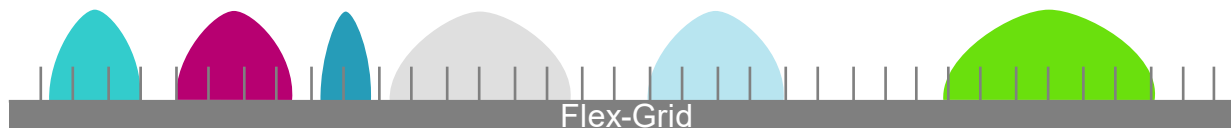
Flex-Grid

Flex-grid
- Center frequencies are at 6.25GHz increments
- Width of each channel is N x 12.5GHz

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What Determines How Much Spectrum I Use for Each Wavelength?

- 10G transponders/muxponders are simple
  - 10G waves typically use 50GHz or 100GHz spectral grid
  - Intensity modulation
  - Direct detection – presence of light = "1"; absence of light = "0"

- 100G+ transponders/muxponders are more flexible
  - "Multihaul" transponders/muxponders
  - Many "knobs" to turn
  - Tradeoffs for line rate and spectrum and distance
  - QAM modulation and coherent detection

- FlexGrid allows the line system to accommodate these trade-offs

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Transponder Options

Knobs to turn:

Baud Rate

25GBaud   140GBaud

Baud rate (symbols/second)
x Modulation (bits/symbol)
x 2 polarizations
_____
= Line rate (bits/second)

Modulation

8QAM   16QAM

QPSK   64QAM

64QAM
32QAM
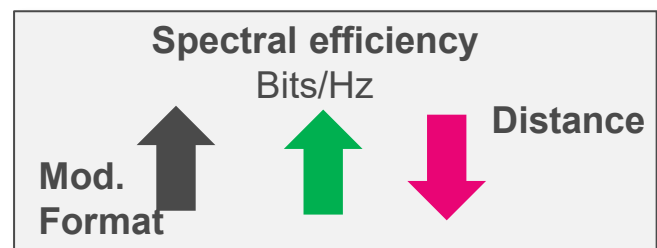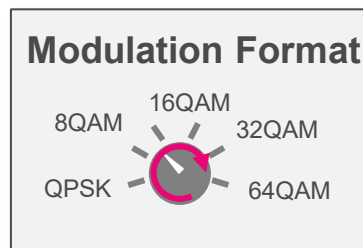16QAM
8QAM
QPSK

Bits/symbol

2 3 4 5 6
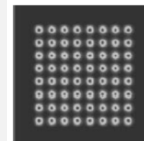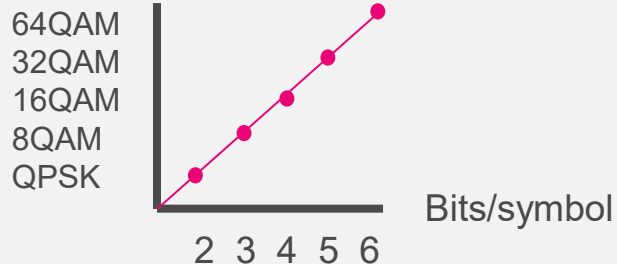
e.g., 64QAM constellation
= 6 bits/symbol

Example: "100"Gb/s line =
34GBaud x 2 bits / symbol x 2 polarizations

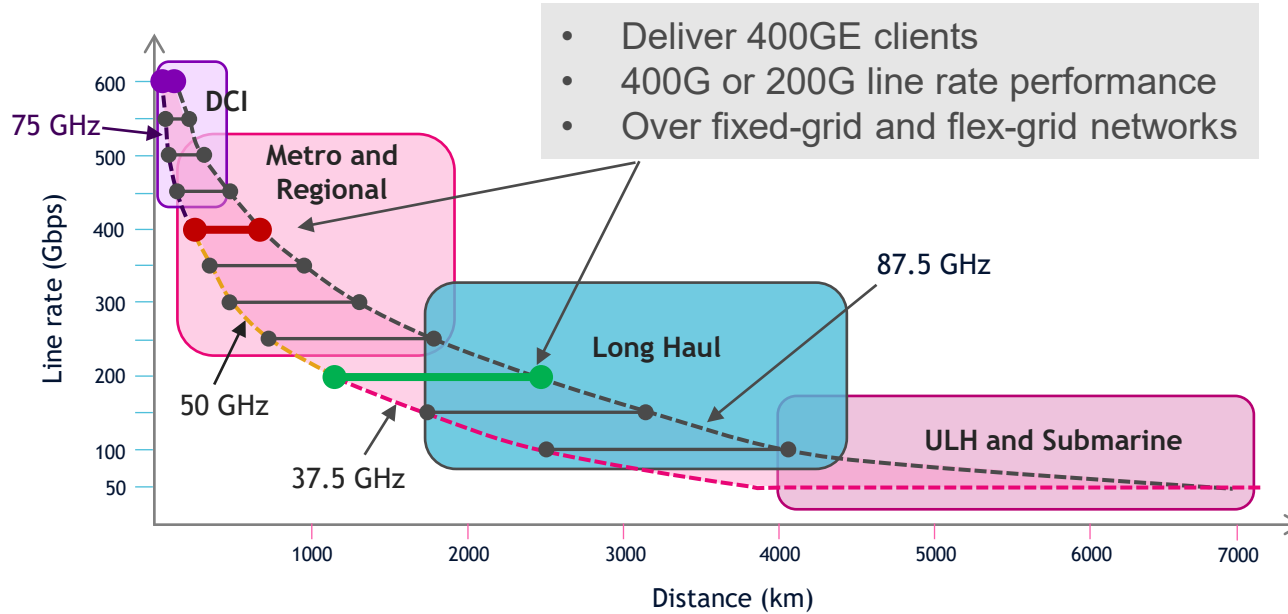ribbon   ECI THE ELASTIC NETWORK

No Free Lunch…

- Increasing **baud rate**
  - Improves transceiver efficiency (bits/device)
  - Increases spectrum required

- Increasing **modulation**
  - Improves spectral efficiency (bits/Hz)
  - Decreases distance
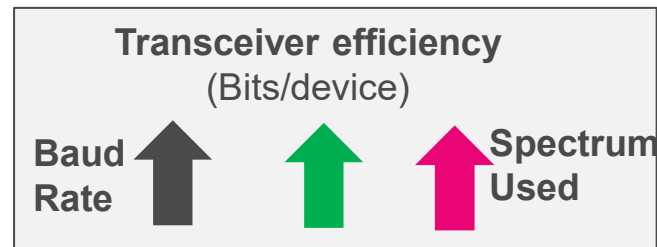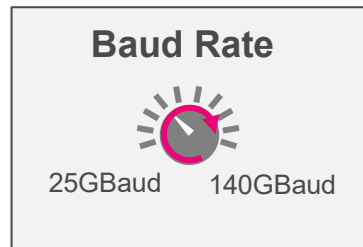
Fixed Baud Rate
x Fixed Modulations
_____
= Limitations

Baud Rate

25GBaud   140GBaud

Transceiver efficiency
(Bits/device)

Baud
Rate   **Spectrum
                         Used**

Modulation Format

8QAM   16QAM
        32QAM
QPSK   64QAM

Spectral efficiency
Bits/Hz

Mod.   **Distance**
Format

Service Provider World -
Needs Better Knobs and More Knobs

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Performance Optimized Transport –
3 better knobs

- Deliver 400GE clients
- 400G or 200G line rate performance
- Over fixed-grid and flex-grid networks

Adaptive Baud Rate

Low   High

Fractional QAM Mod.
(bits/symbol)

2.5 3 3.5 4
2   4.5
1.5   5.5
1   6

Line Rate Combo

2x200G   1x400G
1x200G   2x400G
2x100G   1x600G
1x100G   2x600G

Chart — Line rate (Gbps) vs Distance (km):

- 75 GHz
- 50 GHz
- 37.5 GHz
- 87.5 GHz
- DCI
- Metro and Regional
- Long Haul
- ULH and Submarine

Y-axis: Line rate (Gbps): 50, 100, 200, 300, 400, 500, 600
X-axis: Distance (km): 1000, 2000, 3000, 4000, 5000, 6000, 7000
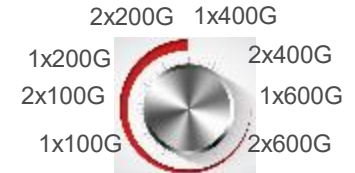
Satisfy Customer Demand in the Real World

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Manipulating Wavelengths…

- Point to point only
  - All waves going in Site A come out at Site B
  - Just mux many waves onto one fiber

- Fixed Optical Add/drop Multiplexers (FOADMs)
  - Cheap hardware, but requires truck roll and manual configuration at site B

- Reconfiguration Optical Add/drop Multiplexers (ROADMs)
  - "Static"
  - "Colorless" (C)
  - "Colorless-directionless" (CD)
  - "Colorless-directionless-contentionless" (CDC)
 - Automates wave manipulation to create larger networks
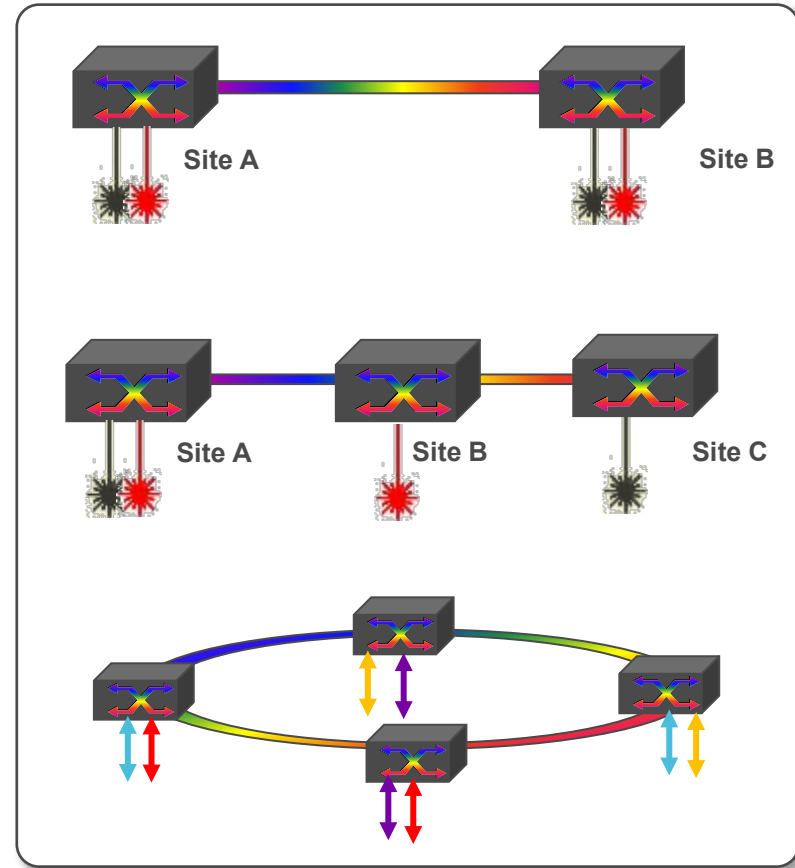
Brute Force Networking

- Multiplex and demultiplex all waves at each site
- Use patch panel to manually patch through or add/drop at each site - flexible
- Heavy loss at each site for through waves
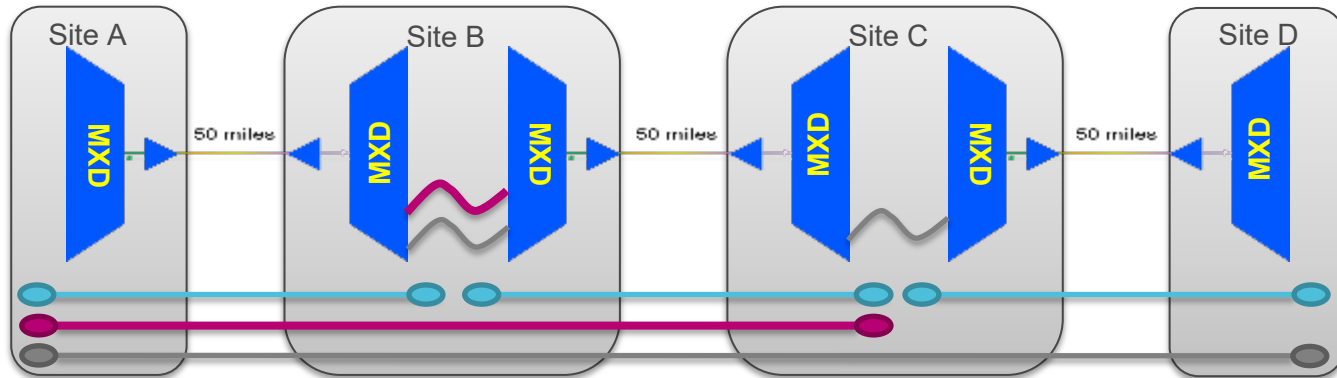
A Little Better – Fixed OADM units

- Add/drop <u>pre-determined</u> channels at intermediate sites

- Pass remaining channels through without demultiplexing - simpler

- Better performance (less loss) for through channels

- Less flexibility
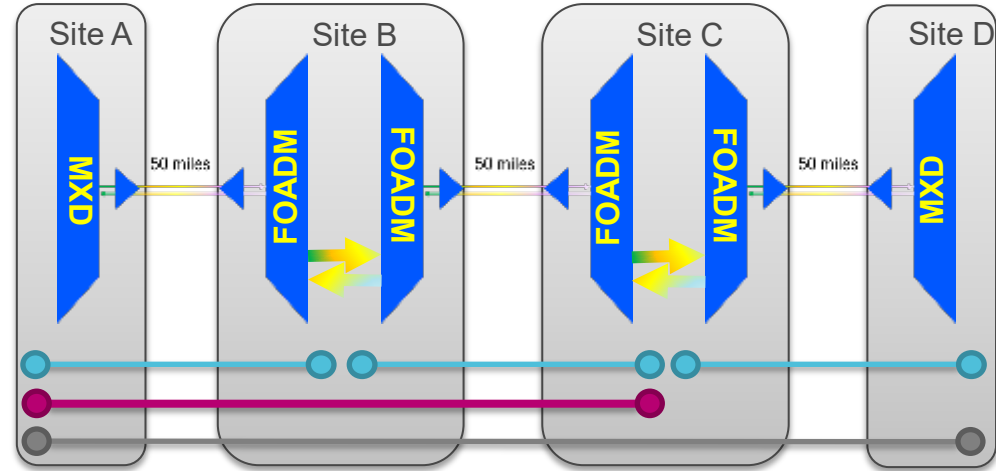
ROADM Networking – Where Networks are Trending

- Wavelength selective switch (WSS) devices at each ROADM node
- Add/drop/passthrough wavelengths via remote provisioning
- WSS devices offer many other benefits
  - Dynamically balance the power between all wavelengths sharing a fiber
  - Dynamically control the input power of incoming waves
  - Automated multi-degree sites – north/south/east/west
  - Reconfigure wavelength paths to avoid cable maintenance or to perform restoration
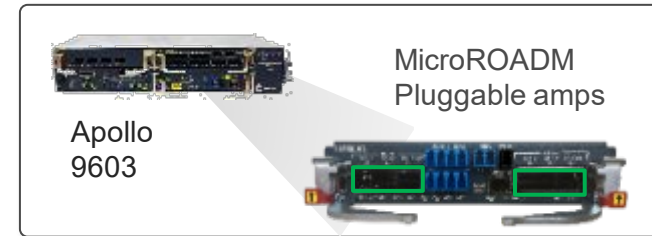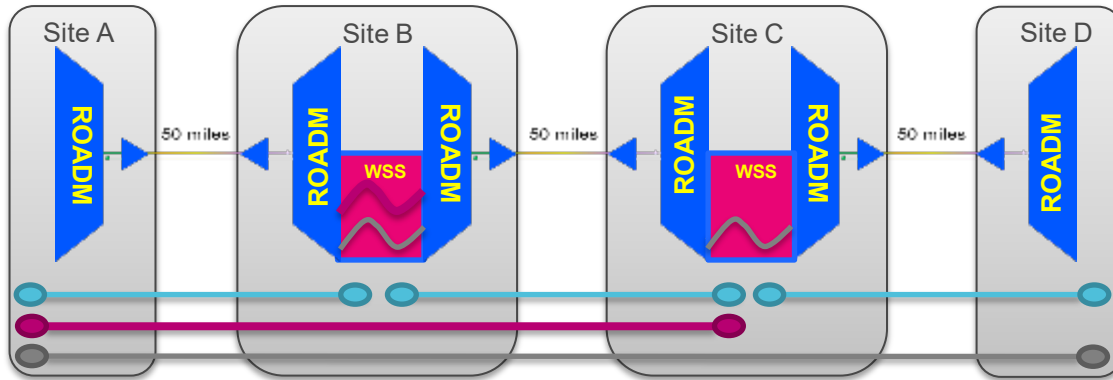
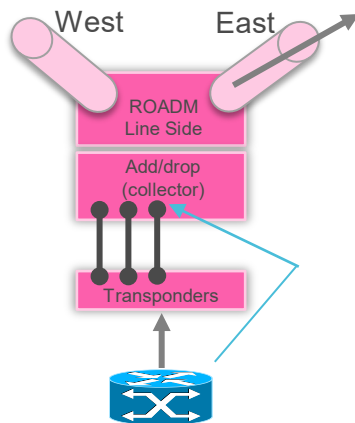# Different Types of ROADMs
(different types of add/drop hardware)

"Static" / "AWG"

West   East

ROADM
Line Side

Add/drop
(collector)

Transponders
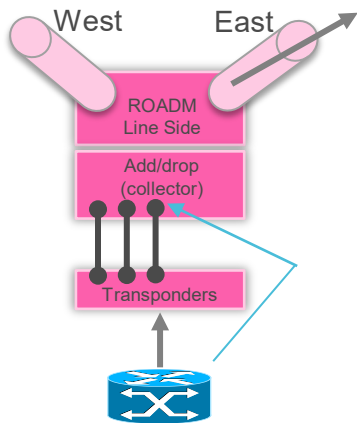
Port is tied to:
- Direction
- Color (wave #)

"Colorless" (C)

West   East

ROADM
Line Side

Add/drop
(collector)

Transponders

Port is tied to:
- Direction **only**
- **Pick any color**

Colorless /
Directionless (CD)

West   East

ROADM
Line Side

Add/drop
(collector)

Transponders
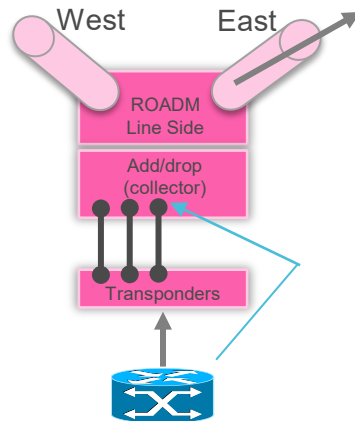
Port is tied to:
- Any direction
- Any color
- Only one drop port can occupy a color (drop side contention)

Colorless /
## Directionless /
Contentionless (CDC)

West   East

ROADM
Line Side

Add/drop
(collector)

Transponders
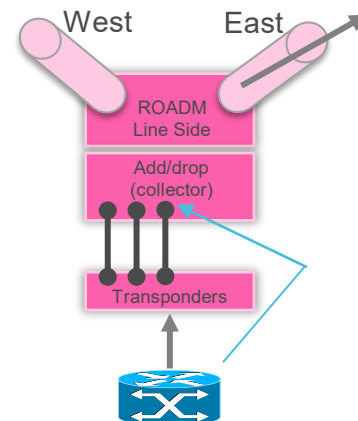
Port is tied to:
- Any direction
- Any color
- Many ports can occupy a color (eliminates drop side contention)

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It's Analog - What Can Possibly Go Wrong???

- Optical attenuation (loss)
  - Wavelengths lose power
  - Receiver can't determine a "one" from a "zero"
  - OSNR (optical signal to noise ratio) becomes too low
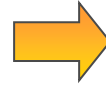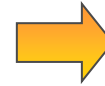
  ➜ Fix this with amplifiers

- Dispersion
  - Pulses of light spread out as they travel
  - Receiver cannot determine a one pulse from another

  ➜ Fix this with
  - Dispersion compensation 10G

- Non-linear effects
  - Wavelengths can trample on other wavelengths

  ➜ Overcome this with
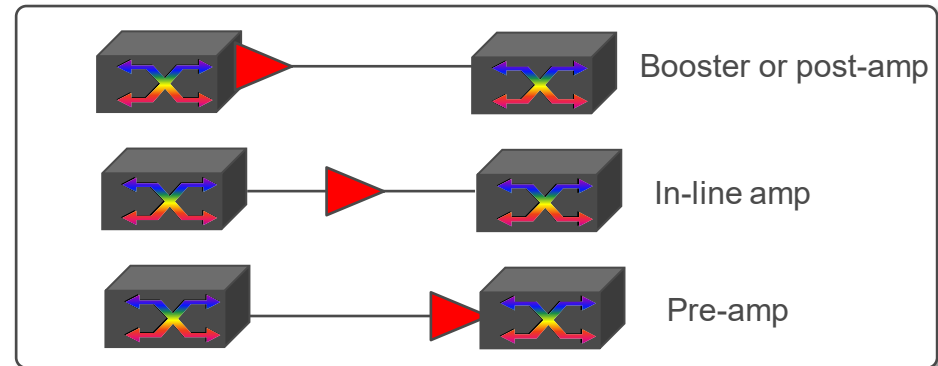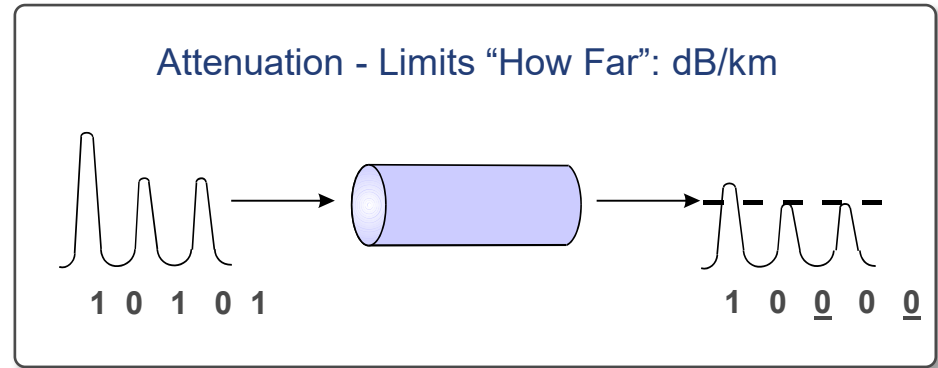 - Optical network design

- The fiber itself is damaged
  - Or a connector is broken…

  ➜ Fix this with
  - Armed guards and eternal vigilance
  React quickly or proactively with
  - Automated, network OTDR
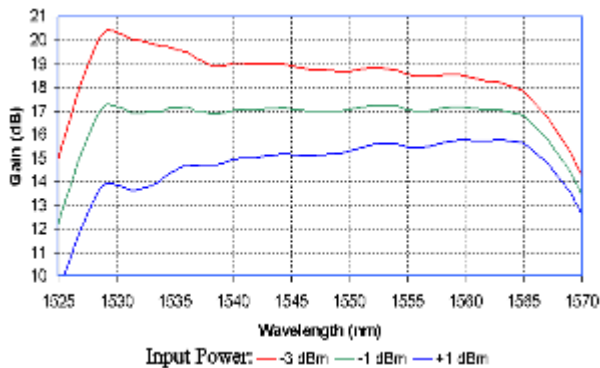
Attenuation (loss) Reduces Optical Power

- Losses from
  - fiber
  - WSS devices
  - mux/demux and filters
- Amplifiers (EDFAs*) boost the power
  - Of ALL** waves on the fiber!
  - Without terminating ANY of them!
  - Without electronically repeating each signal!
  - **Key to optical networking economics!**
  - Amps do not understand bits or wavelengths
  - Amps only understand optical power.
- Amps create noise
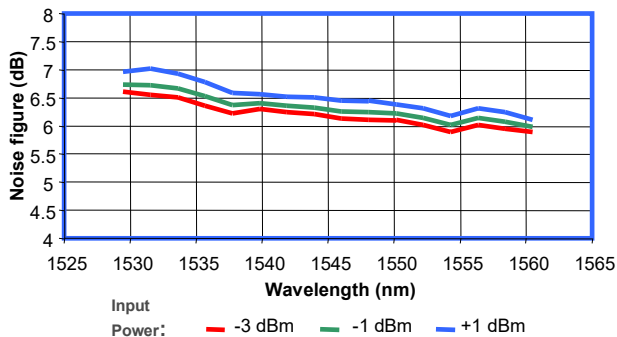 - Only so many amplifiers in the chain before the signal/noise ratio is ruined

**all waves together on fiber is called a "composite" signal

Attenuation - Limits "How Far": dB/km

1 0 1 0 1   1 0 <u>0</u> 0 <u>0</u>

Booster or post-amp

In-line amp

Pre-amp

*EDFA = Erbium Doped Fiber Amplifier
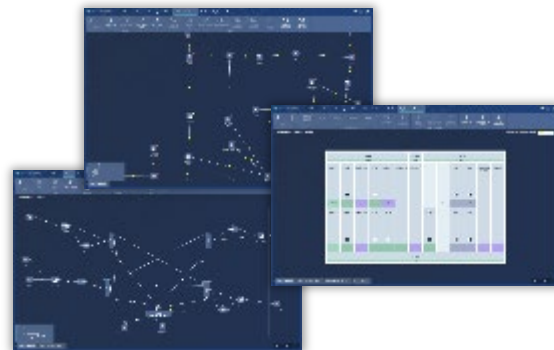
No Free Lunch in the Analog World

Amplifier **gain** changes with input power and frequency of each wavelength

Amplifier **noise** changes with input power and frequency of each wavelength

Network Planner™

Requires great network planning software
- Off-line while synchronized with the production network
- Optical design based-on traffic demands
  - What kind of amplifier?
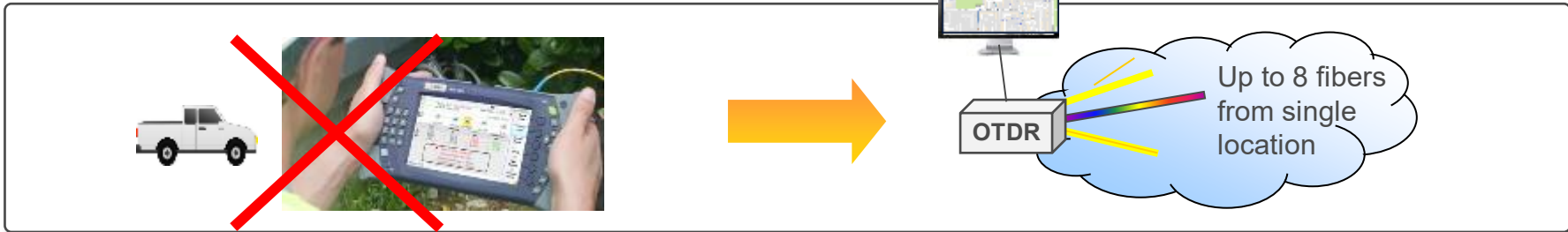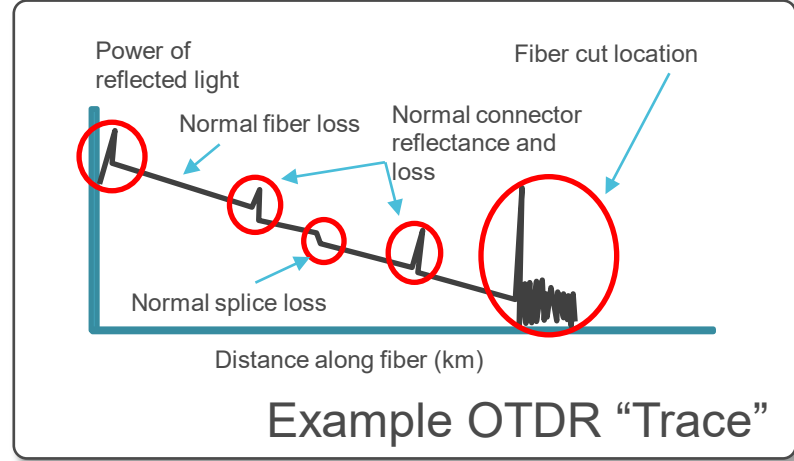 - Can my wavelengths reach the distance without electronics?

Dispersion – When Pulses Spread out Down the Fiber – 10G waves and below

- Leading edge of pulse travels faster than trailing edge
- Pulses bleed together - causes bit errors
- Applicable in 'direct detected' systems
  - 10G waves and below
- Largely eliminated in "coherent" systems
  - 100G and above
- Fix with Dispersion Compensating Fiber
  - In a dispersion compensation module (DCM)
  - Special fiber in the data path
  - Deployed at the receiver
  - That "undoes" the pulse spreading
  - Causes loss
- DCMs will worsen the performance of >100G waves that may come later
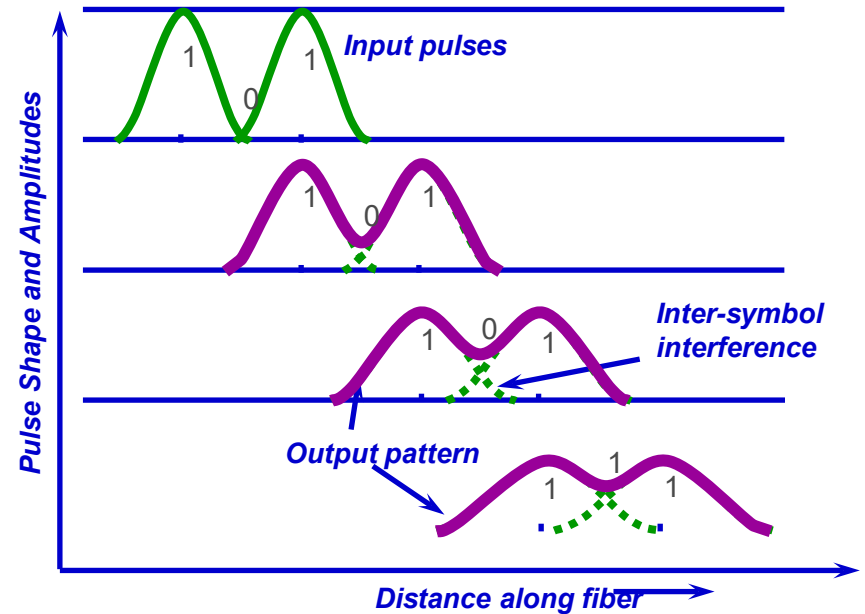
Network OTDR Helps you Predict and React to Fiber Failures

- Optical Time Domain Reflectometer is test equipment that finds fiber defects
- "Network OTDR" is an OTDR <u>deployed in</u> the existing fiber plant
- <u>In-service</u> alongside other equipment (from any vendor)
- Scans automatically multiple fibers at once for defects or cuts and raises alarms
- Enables fault location to within <u>meters</u>
- Dramatically reduces repair time and opex costs

Power of reflected light

Fiber cut location

Normal fiber loss

Normal connector reflectance and loss

Normal splice loss

Distance along fiber (km)

Example OTDR "Trace"

OTDR

Up to 8 fibers from single location

ribbon

ECI THE ELASTIC NETWORK

Technology, Design, and Deployment Considerations

- Things that impact distance…
  - Will I need to add sites and grow my network geographically?

- Things that impact capacity…
  - Will I be rolling out higher speed residential broadband?
  - Will I be offering mobile backhaul services for 5G?

- Things that impact operations…
  - Am I reducing my operational staff?
  - Am I trying to cover a larger geographical footprint?

What are Things that Help Me with Smaller Optical Networks

- Neptune™ Ethernet/IP platforms with "just right" optical additions
  - Amplifiers + WDM to extend capacity and distance for a low cost
- Apollo™ Micro-ROADM
  - Future-proofing benefits of FlexGrid
  - Automation benefits of ROADM
  - Pluggable amplifiers
  - Industry's smallest package
- Apollo 9901 and 9904 OTN Appliances
  - Switching for the price of muxing
- LightSOFT™ Network Management
  - Point and click GUI for Optical, Ethernet, and IP
  - Runs Network Planner™ software
- LightPULSE™ Network OTDR
  - Automatically find degradations before failures occur
  - Identify the location of failures to within minutes instantaneously

Neptune 1000 Series

Apollo 9603

MicroROADM
Pluggable amps

Apollo 9901

Apollo 9904
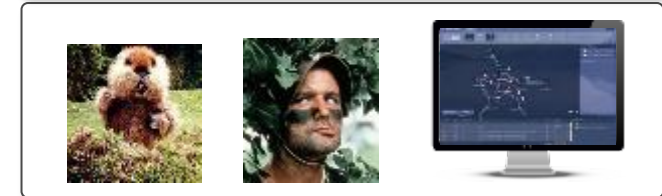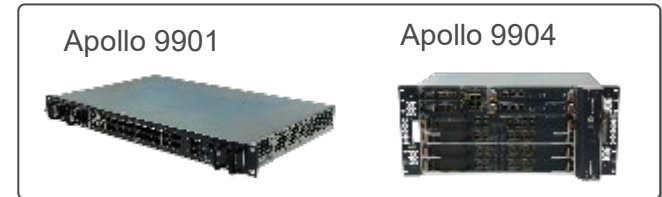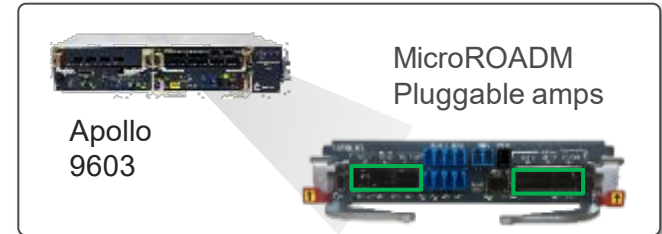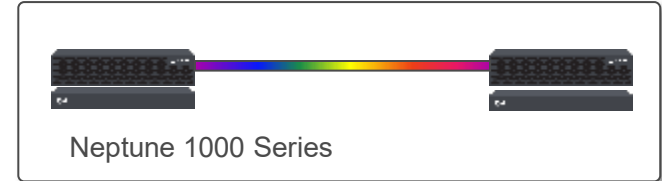
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ECI, Now Part of Ribbon

Thank you!!