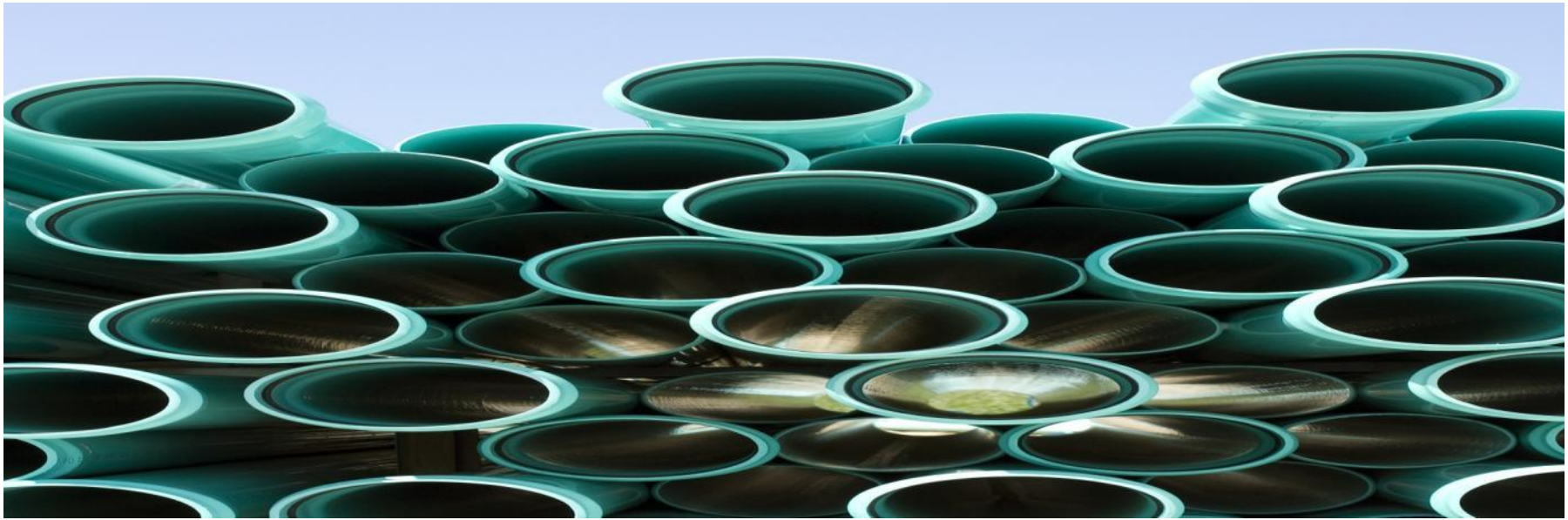
WEL-COME



INTRODUCTION TO VARIOUS TRANSPORT TECHNOLOGIES

Please contact me, this slide set had significant verbal presentation with it.

Alastair JOHNSON

alastair.johnson@alcatel-lucent.com

September 2011

Alcatel·Lucent

INTRODUCTION
WHO I AM

- I work for Alcatel-Lucent USA
  - Senior Product Line Manager for 7750SR, IP/MPLS Routers
  - Previously Consulting Architect, APAC
- Not an expert on all things covered in this tutorial
- But we make a lot of these products, so I'll give it a go

- This is not an exhaustive tutorial – simply too much to cover
- Please ask questions! Interactivity is good!

AGENDA

1. Introduction
2. CWDM
3. DWDM
4. Ethernet
5. xDSL
6. xPON
7. Putting it together
8. Future

INTRODUCTION
WHAT IS LIGHT?

Slide courtesy of Jonny Martin

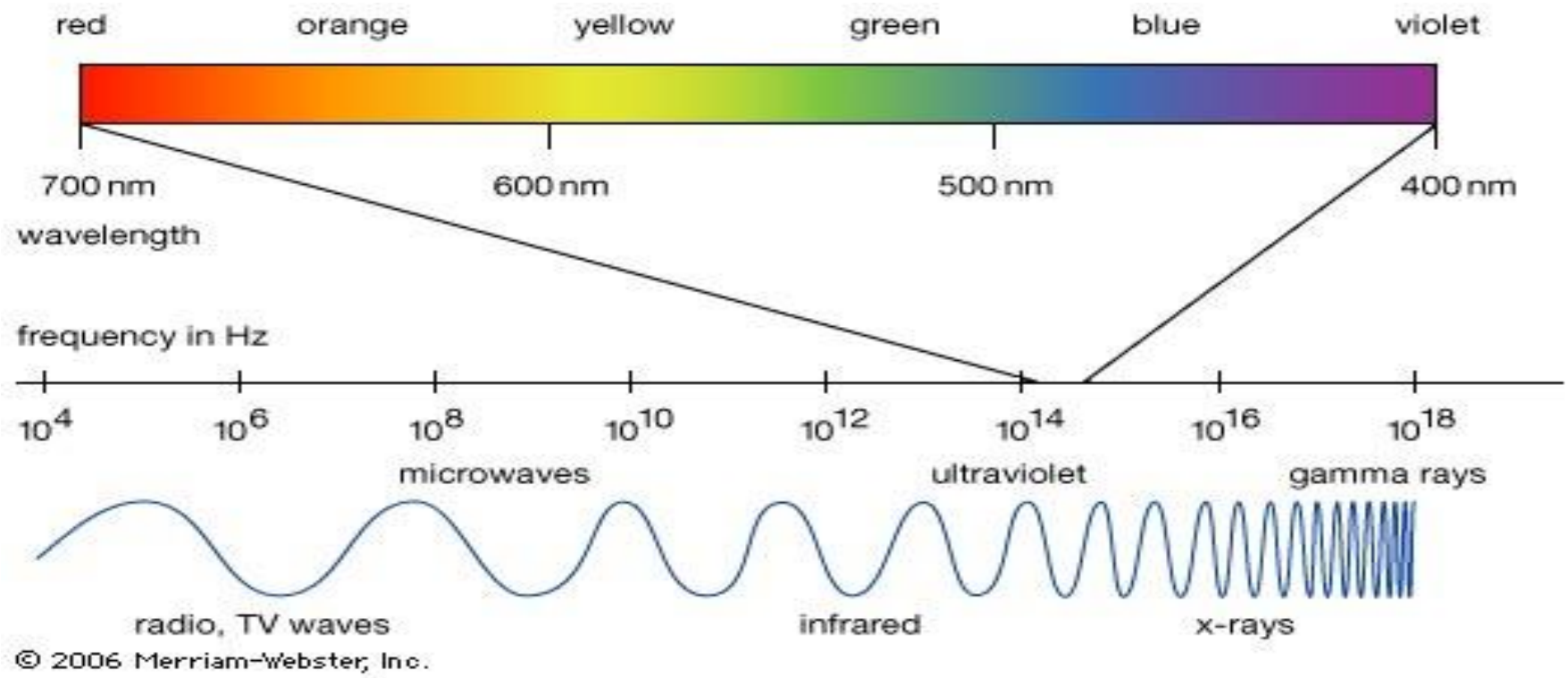
- Electromagnetic radiation
  - Requires no medium through which to transport it's energy
  - Covers a large spectrum all the way from subsonic - audible - RF - visible - x-ray and gamma rays
- Sometimes behaves like a wave, sometimes like a particle
- Waves have a wavelength and corresponding frequency

$$\text{frequency} = \frac{c}{\lambda}$$

$$\lambda = \frac{c}{\text{frequency}}$$

INTRODUCTION
ELECTROMAGNETIC SPECTRUM

Slide courtesy of Jonny Martin



INTRODUCTION
WHAT IS LIGHT?

Slide courtesy of Jonny Martin

- 'Low' frequency signals referred to by their frequency in Hertz.
  - Hz (cycles per second)
- 'High' frequency signals referred to by their wavelength in metres.
  - Visible light and above
  - Nanometre nm (10e-9 metre - one millionth of a millimeter
  - Red light ~700nm
  - Purple light ~400nm

Slide courtesy of Jonny Martin

INTRODUCTION
A LITTLE BIT OF MATHS...

- Decibels - logarithmic measurement scale
  - A ratio between two values, NOT an absolute measurement
- Light strength measured in dBm
  - Ratio with a reference level of 1mw

$$L_{\mathrm{dB}} = 10 \log_{10} \left(\frac{P_1}{P_0} \right)$$

- Makes calculations easy
  - For light we can add and subtract dB loss from dBm values
    - 20dBm - 10dB = +10dBm
    - The loss (or gain if +ve) is simply a ratio, thus has no specific unit

INTRODUCTION

A LITTLE BIT OF MATHS...

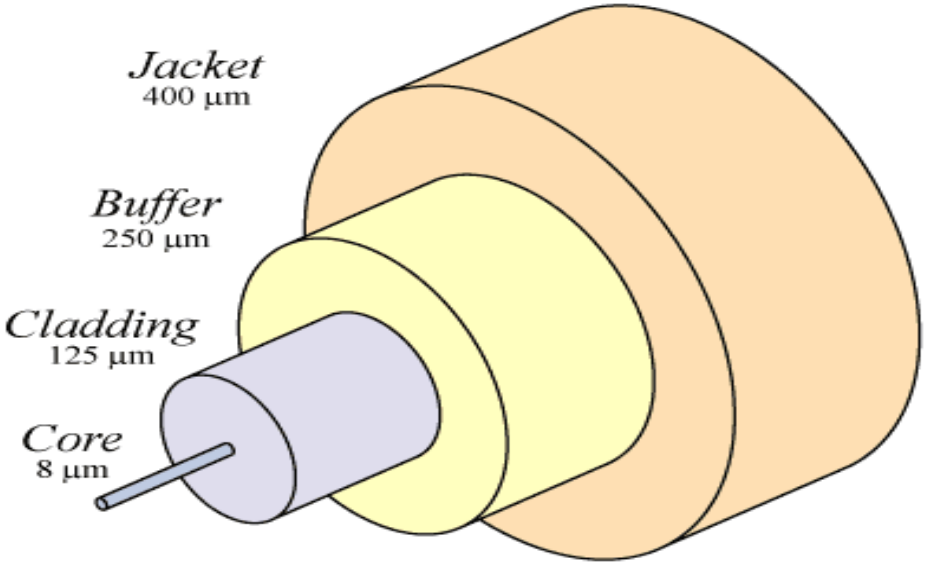
Slide courtesy of Jonny Martin

- Light amplifiers provide a +ve dB change
- Anything impeding or **attenuating** a light signal causes a -ve dB change
- This forms the basis of calculating optical budgets

Slide courtesy of Jonny Martin

INTRODUCTION
FIBRE OPTIC CABLE

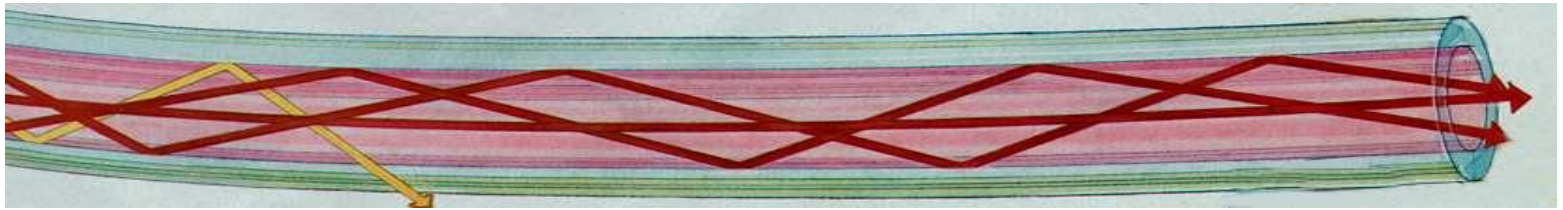
- A glass core of fibre with a cladding around the outside with a **lower index of refraction**.
- This causes **total internal reflection**



INTRODUCTION
TOTAL INTERNAL REFLECTION

Slide courtesy of Jonny Martin

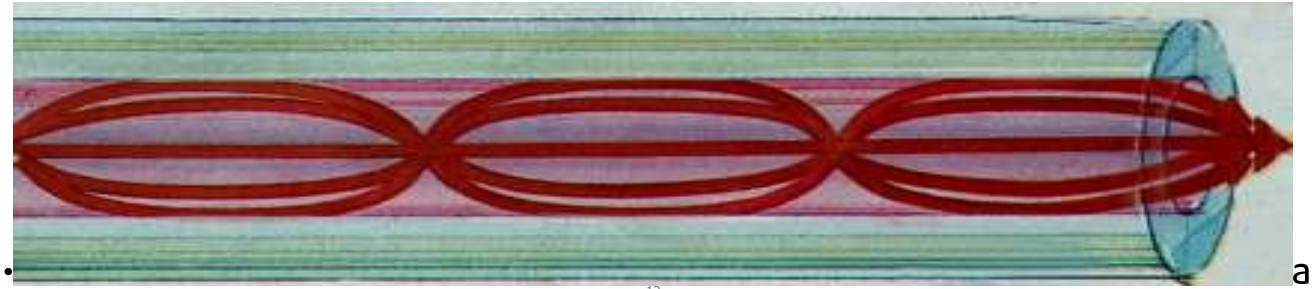
- Confines light within the fibre
- Light rays reflect back into the core if the hit the cladding at a shallow angle
- Any rays exceeding a critical angle escape from the fibre



INTRODUCTION
MULTIMODE FIBRE

Slide courtesy of Jonny Martin

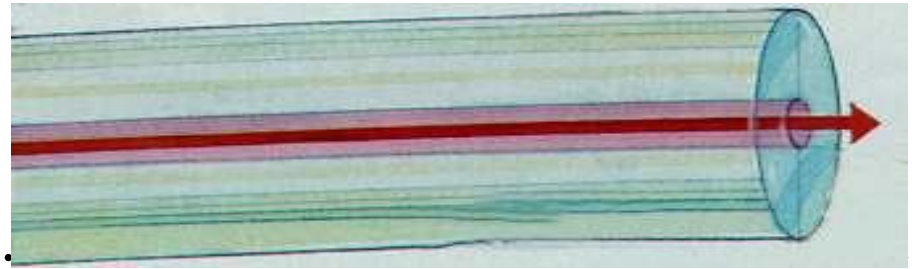
- Core diameter of 50 - 100 microns
  - typical values of 50, 62.5, 100 microns
- Generally used for runs <2Km
  - Gig and 10Gig require runs < 200m
- Light takes multiple paths through fibre resulting in signal degradation



INTRODUCTION
SINGLEMODE FIBRE

Slide courtesy of Jonny Martin

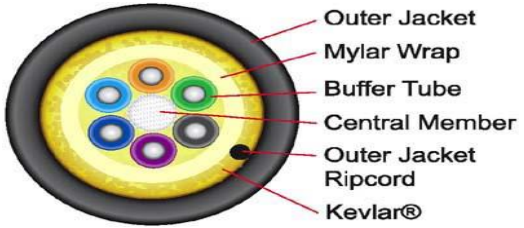
- Narrow core of around 8 microns
- Smaller change in refractive index between core and cladding
- Light travels mostly parallel to the axis of the fibre
  - Little pulse dispersion
  - Less attenuation

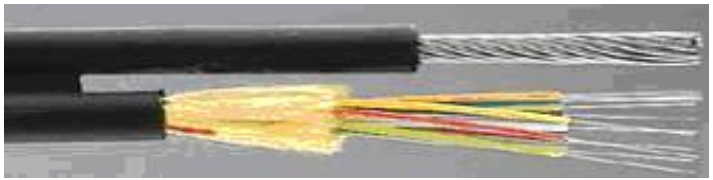


INTRODUCTION
FIBRE CABLE TYPES

Slide courtesy of Jonny Martin

- Loose tube
  - Typically used for outside runs
- Tight Buffer
  - Typically used for indoor runs
- Armoured, aerial, composite cables also available

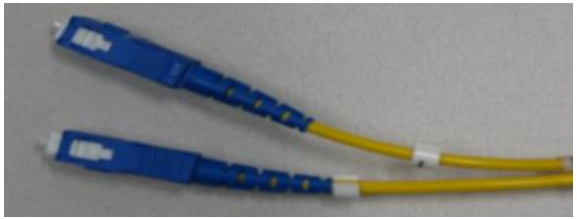




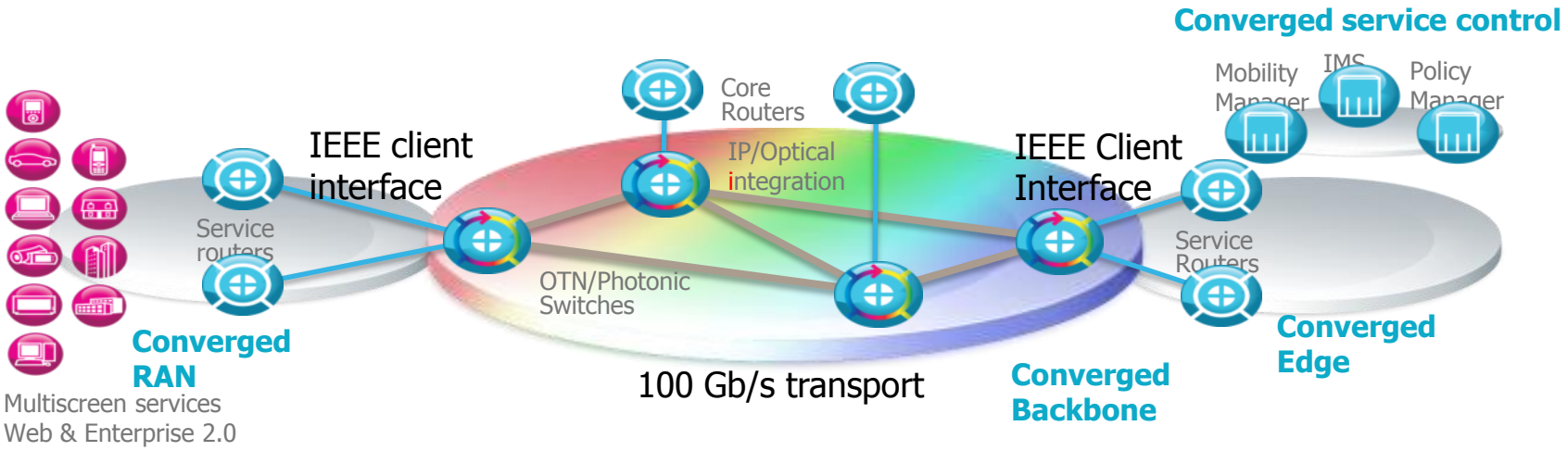
INTRODUCTION
COMMON CONNECTORS

Slide courtesy of Jonny Martin

- LC
- SC
- MT-RJ
- ST
- Many available with an angled ferrule
  - Less reflections at patch points



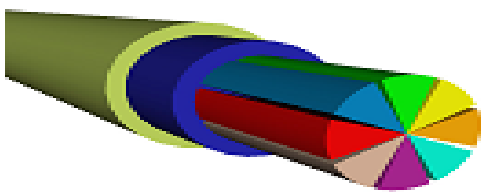
INTRODUCTION
STANDARDIZATION LANDSCAPE

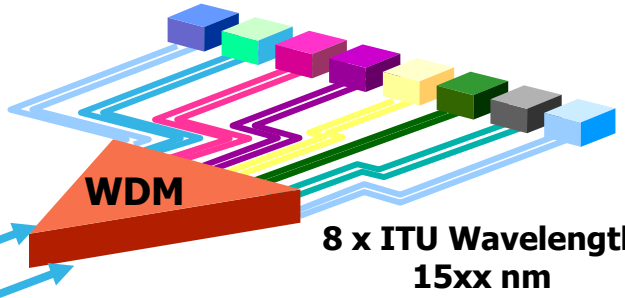


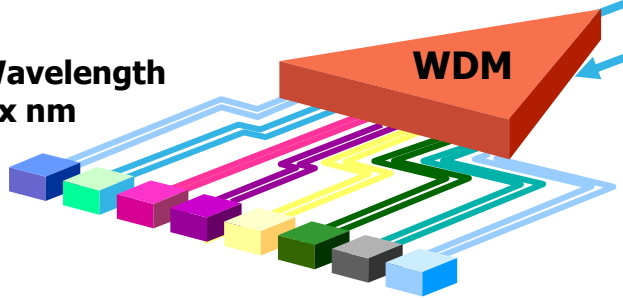
IEEE ITU OIF OPTICAL INTERNETWORKING FORUM

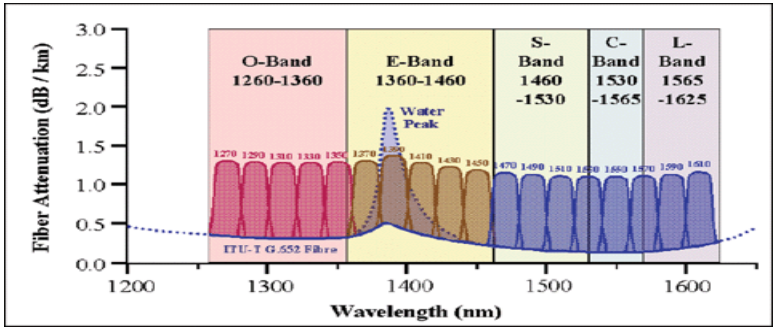
CWDM
COARSE WAVELENGTH DIVISION MULTIPLEXING

CWDM TECHNOLOGY



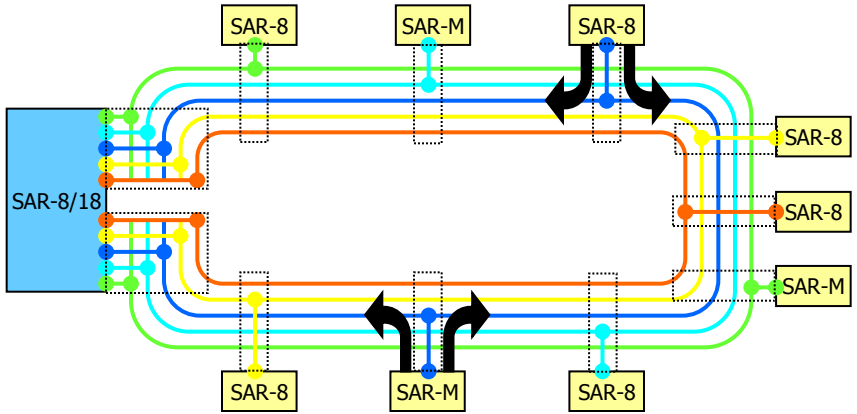






CWDM

- Optical power budget, based on the CWDM transceiver, fiber type/distance, OADM attenuation, etc.
- Optical ring or linear chain
- Eight colors
- Variety of deployment models
  - Colored optics (SFP/XFP/etc)
  - Passive circulators
  - "Active" combiners



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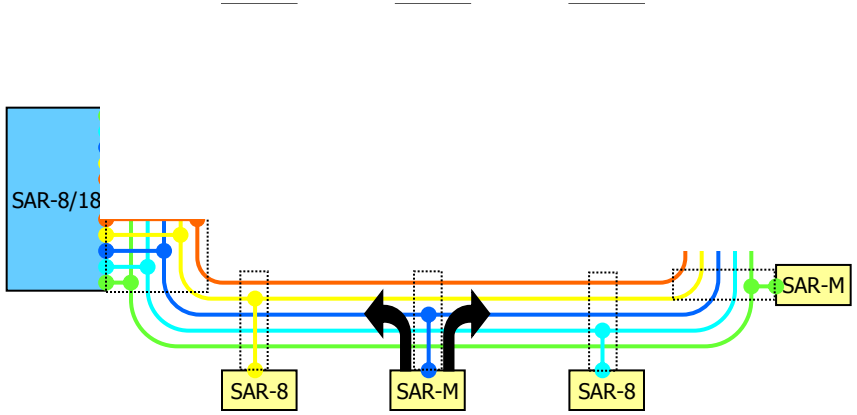
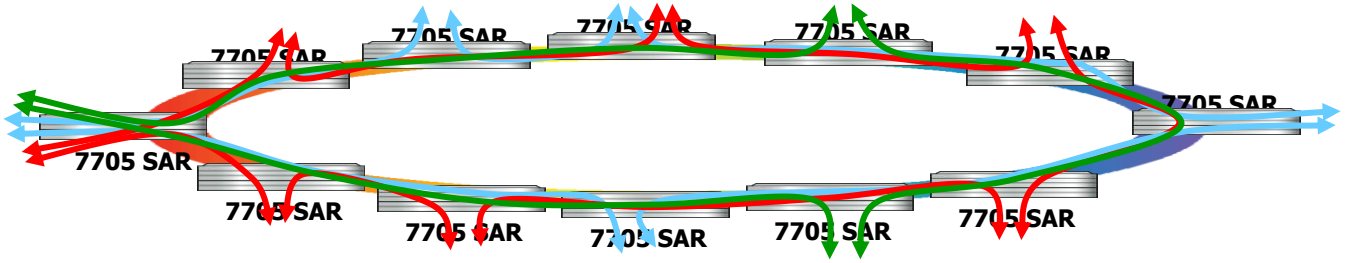
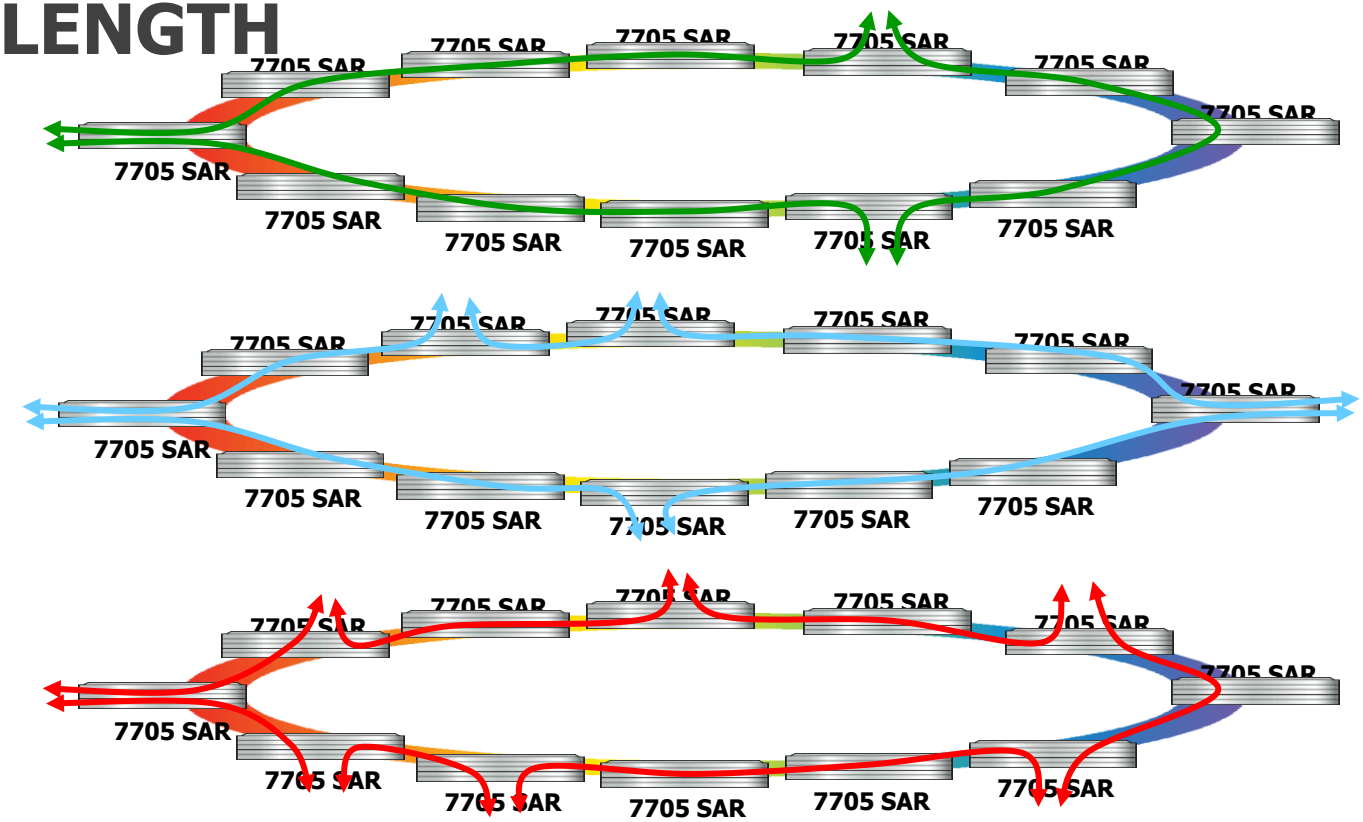


EXAMPLE OF THREE WAVELENGTHS OVER ONE RING

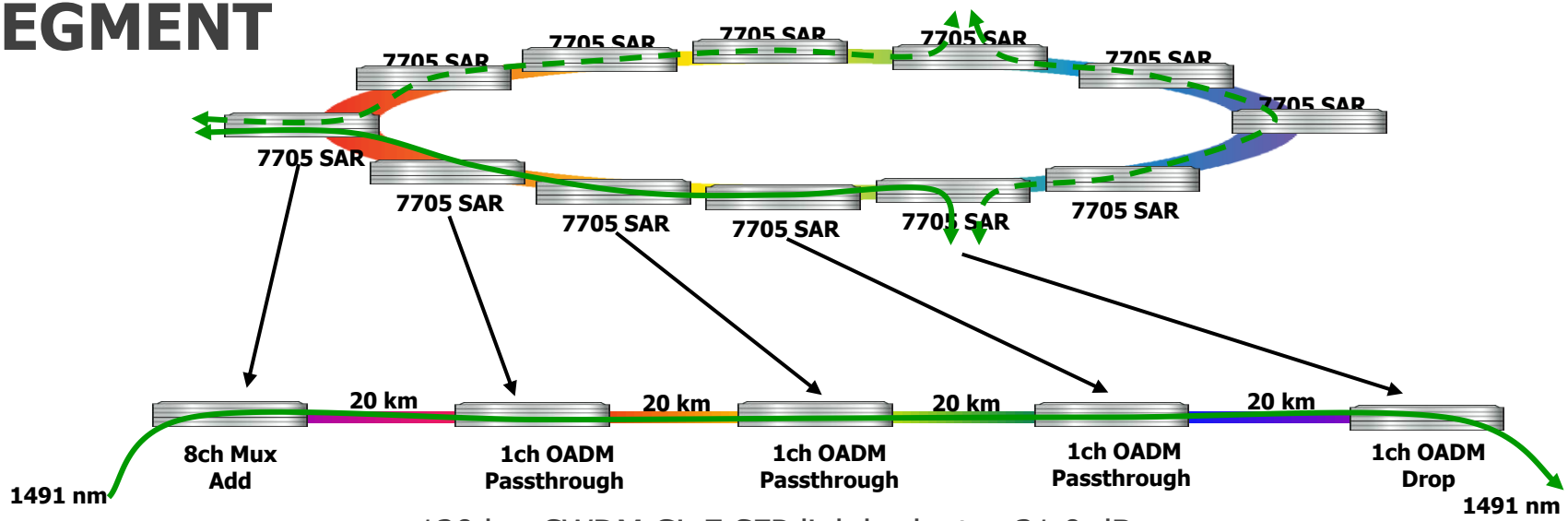


Wavelength multiplexing of three colors in the ring topology

EXAMPLE OF RING DECOMPOSED TO EACH WAVELENGTH



EXAMPLE OPTICAL LOSS CALCULATION FOR ONE SEGMENT



- 120 km CWDM GigE SFP link budget = 31.0 dB
- Maximum optical losses for 1491 nm: 8ch Mux add = 1.2 dB, 1ch OADM express = 1.1 dB, 1ch OADM drop = 0.9 dB
- Fiber loss: 0.25 dB/km → 20 km has 5 dB loss
- Total loss for this segment = 1.2 + 5 + 1.1 + 5 + 1.1 + 5 + 1.1 + 5 + 0.9 = 25.4
- Margin remaining = 31.0 – 25.4 = 5.6 dB

CWDM

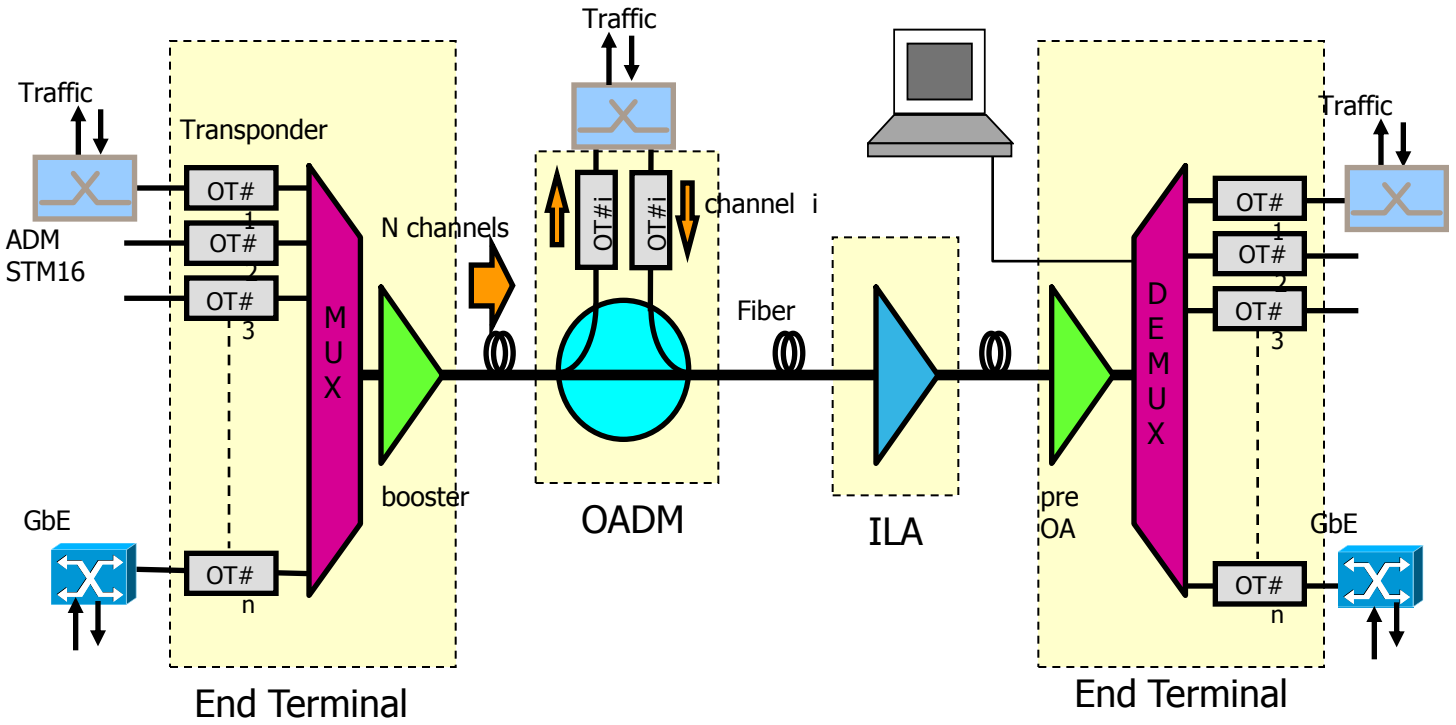
- Simple and inexpensive technology
- Allows up to 800% increase in capacity on your fiber
- Well supported by equipment vendors and third party optics vendors
- Fairly simple to deploy
  - If you meet the optical budget needs, and have circulators/combiners available, away you go
- Emerging in other technologies
  - 10GBASE-LX4
  - 40GBASE-LR4
  - 100GBASE-LR4/SR10

CWDM
WHAT'S IT USED FOR?

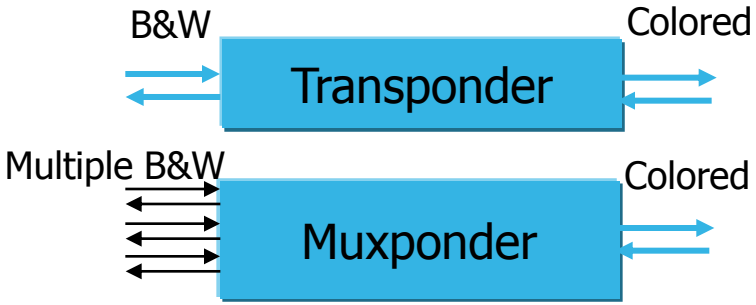
- Expanding the amount of services carried on a single fiber
  - Reducing your fiber lease requirements
  - Reducing your fiber consumption on a bundle
  - Optimizing interconnects (metro, floor-to-floor, within datacenter, etc)
- Typically
  - In a metro/building/short-haul environment
  - Between network elements owned and managed by an operator
  - Occasionally to a customer
- Very useful for carrying GE or 10GE services

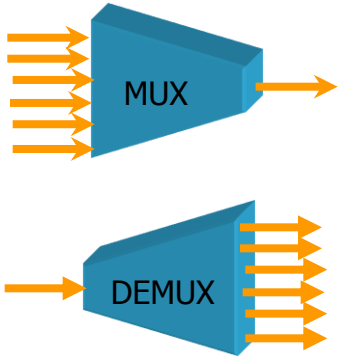
DWDM
DENSE WAVELENGTH DIVISION MULTIPLEXING

DWDM TOPOLOGY

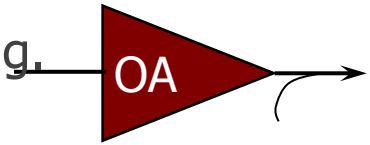


KEY COMPONENTS OF DWDM SYSTEM

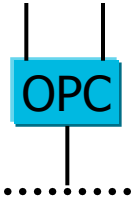




- Transponders take black and white interfaces from equipment (e.g. router) and transport as wavelength services, e.g. 10GE to 10G.
- Muxponders aggregate traffic into a single wavelength, e.g. 10xGE to 10G, 4x10GE to 40G, etc.

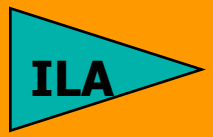


OSC (Optics Supervisory Channel)



TYPICAL DWDM CONFIGURATIONS

- **Line Terminal Configuration**
  - Add/Drop all the lambdas



- **In Line Amplifier**
  - in the DWDM line to compensate the loss of the power for all the lambdas due the fiber loss
  - No lambda add/drop

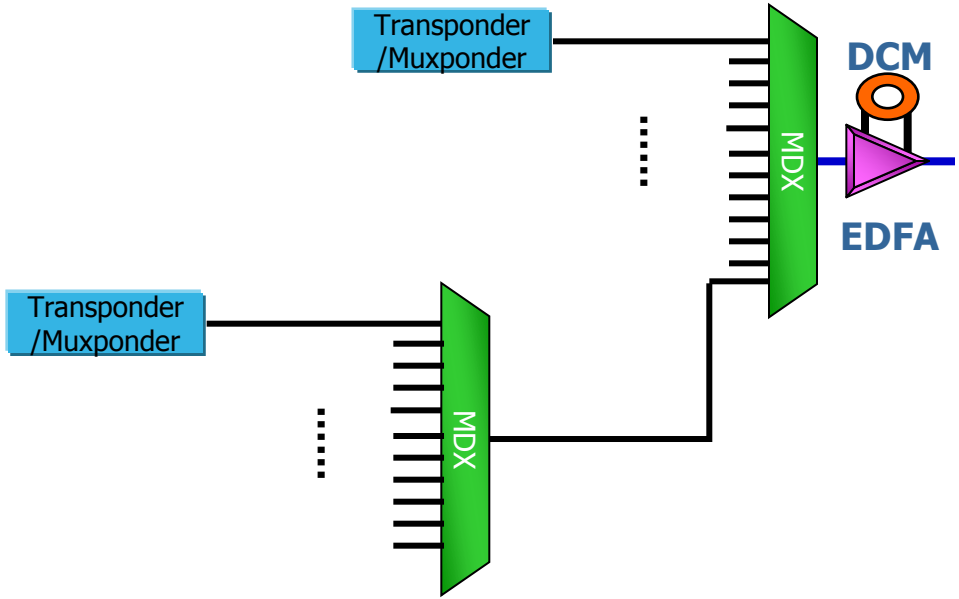
- **Back to back hub terminal configuration**
  - with 2 LT configuration in same NE
  - For add/drop and 3R regeneration functions

- **Optical OADM**
  - In a DWDM ring or linear network
  - To provide lambda Add/Drop and pass-through

- **Programmable Gain Equalization**
  - In the DWDM line to flatten the power level across the lambdas to compensate the discrepancy between the different lambdas after passing multiple DWDM spans and amplifiers

LINE TERMINAL ARCHITECTURE

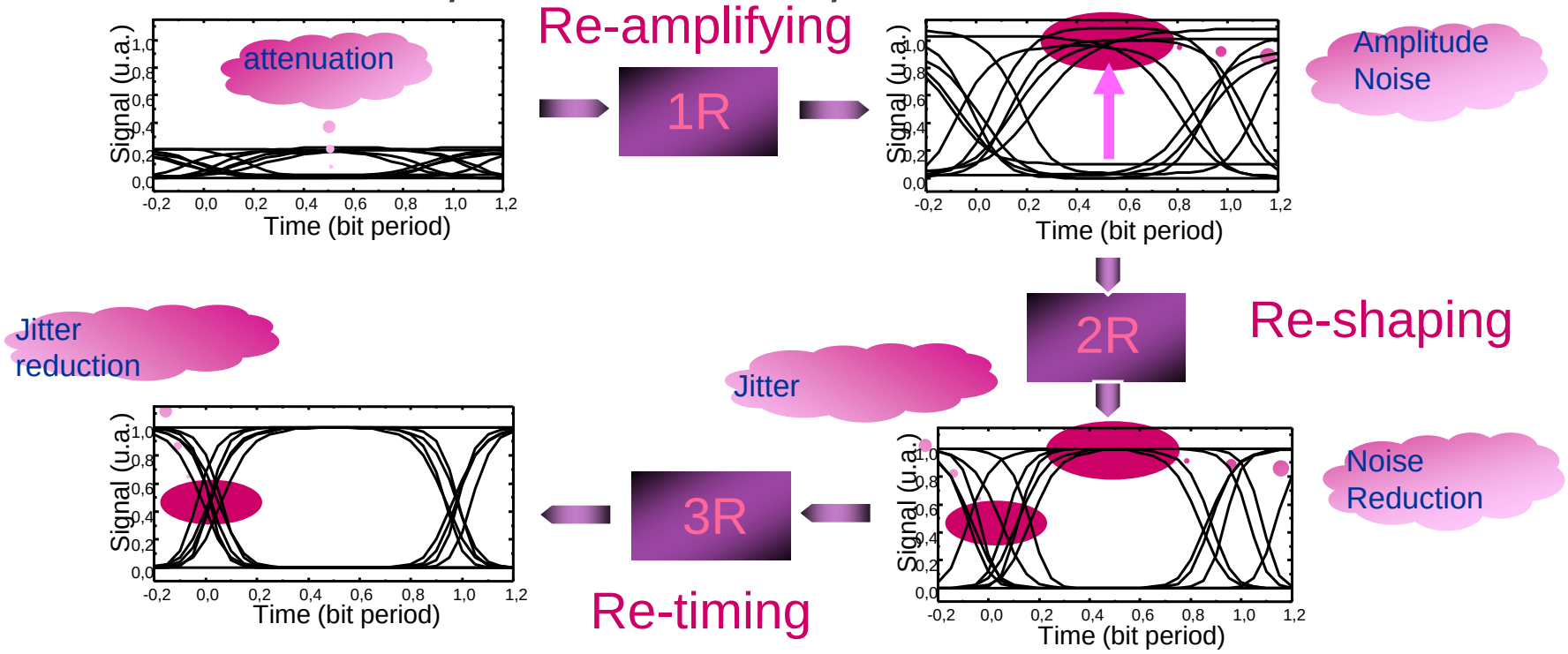
- Tx terminal architecture:



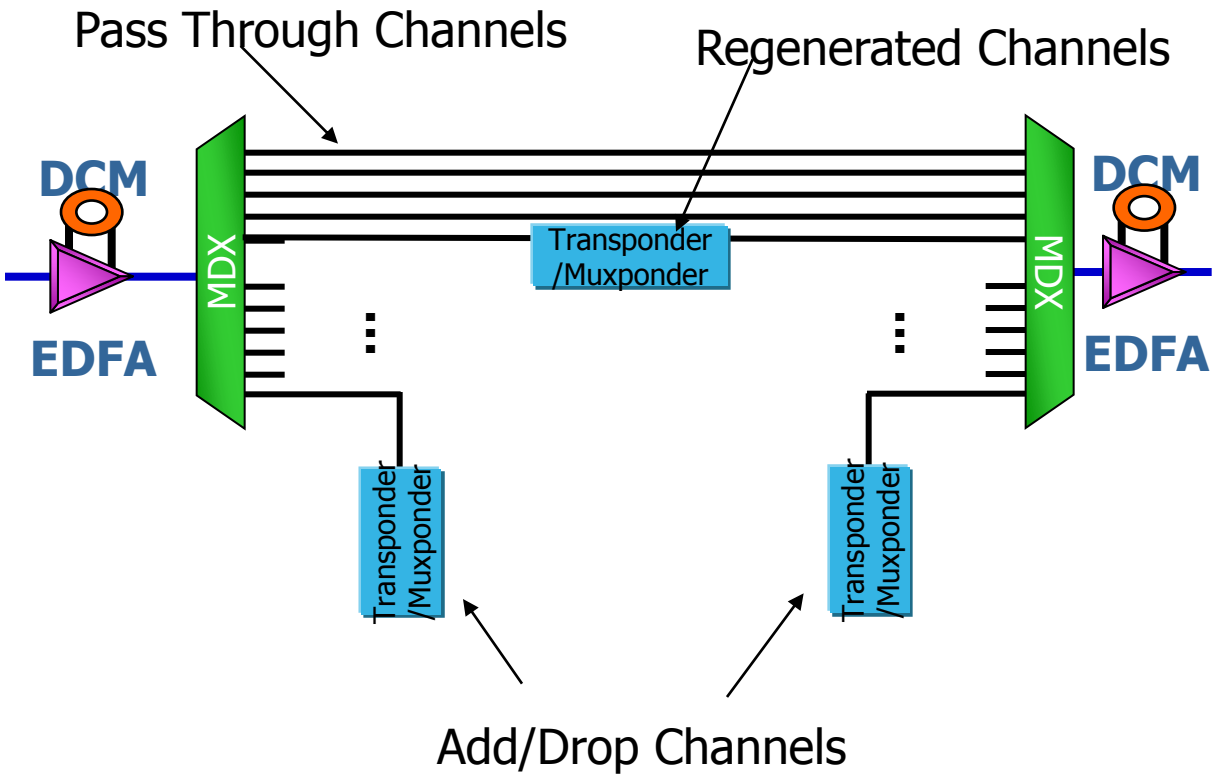
EDFA - Erbium Doped Fiber Amplifier

DWDM REGENERATION

RE-AMPLIFYING, RE-SHAPING, RE-TIMING



OADM ARCHITECTURE



OEO
OPTICAL-ELECTRIC-OPTICAL

- Transponder-driven WDM requires a series of OEO conversions
- This is expensive and inefficient (especially when multiple transponders are needed)
- "Transponderless" or "Alien Wavelength" operation allows the client equipment to drive a transponder into the WDM system, removing a layer of OEO
  - 'Tunable' WDM interfaces on routers (1G, 10G, 40G)
  - Reduces/shifts cost between domains in your network
  - Tradeoffs between cost and latency benefits vs. span length and FEC requirements

DWDM

- Like CWDM, it carries multiple wavelengths on a single fiber – but many more wavelengths
  - 16, 32, 44, 88, 128 channels or more
- Transponder driven interfaces allows you to take simple optical (B&W) interfaces from your network equipment (routers, switches)
  - OEO conversion
  - Long haul transport (3R)
- Transponderless operation allows colored optical interfaces to be directly connected to the optical mux (and 3R system)
- Muxponder operation allows you to aggregate lower-rate services into higher-rate wavelengths on the transport system for efficiency

DWDM
WHAT'S IT USED FOR?

- Metro transport
  - Between fiber constrained POPs
  - E.g. two very large sites requiring large number of 10GE interfaces
- Long haul transport
  - Long haul spans (hundreds/thousands/tens of thousands of kilometers)
- "Wavelength Services"
  - Purchasing a wavelength on someone's DWDM system for haul between two locations

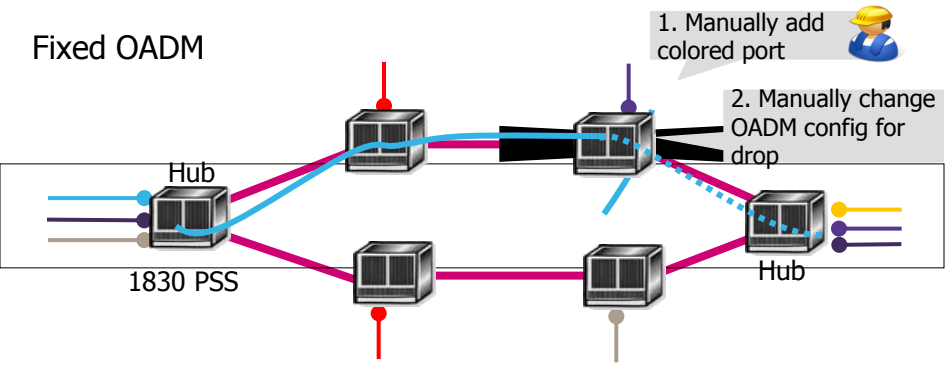
DWDM

- ROADM Reconfigurable Optical Add/Drop Multiplexing
  - Allows to remotely add/drop or passthrough any incoming channel.
  - Each add / drop port has access to one **fixed wavelength** only
- TROADM Tunable Reconfigurable Optical Add/Drop Multiplexing
  - Allows to remotely add/drop or passthrough any incoming channel.
  - Each add / drop port has access to **a subset or all wavelengths**

Building the F/R/T-OADM Value Proposition

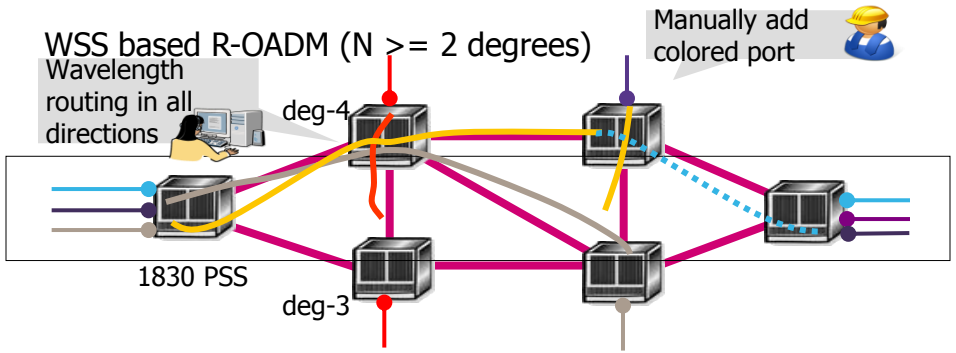
Full Tunability (Colorless Ports)

Fixed OADM



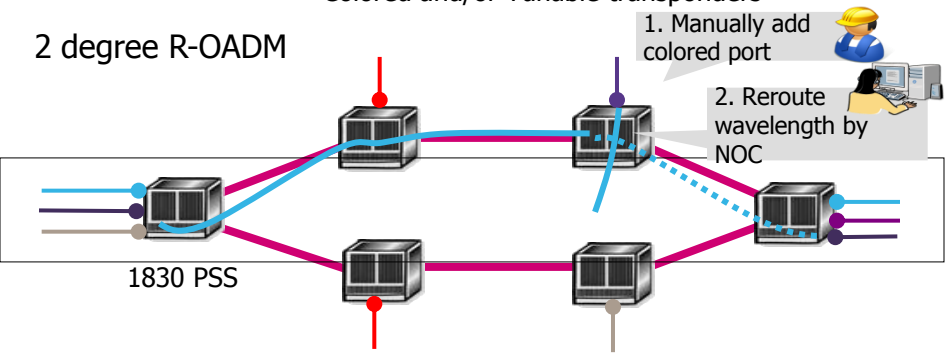
Fixed Filters only
Colored and/or Tunable transponders

WSS based R-OADM (N >= 2 degrees)



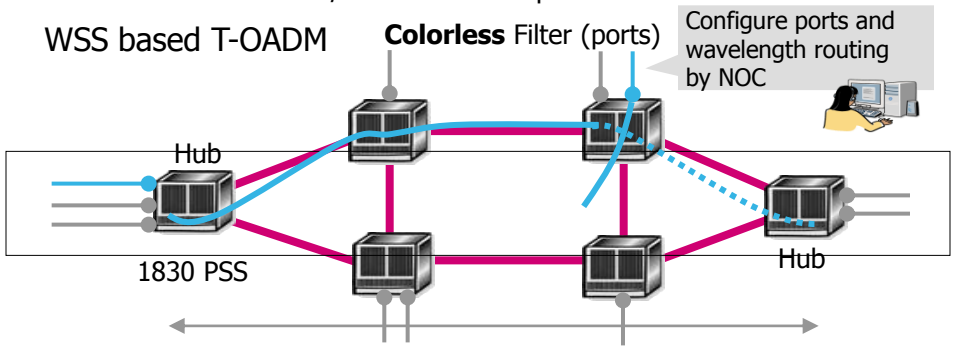
Combination of Reconfigurable and Fixed Filters
Colored and/or Tunable transponders

2 degree R-OADM



Combination of Reconfigurable and Fixed Filters
Colored and/or Tunable transponders

WSS based T-OADM



End-to-end service provisioning by NOC in minutes
Tunable Filters - Less equipment in non-Hub locations (Tunable Add/Drops)
Colored and/or Tunable Transponders

ETHERNET

ETHERNET

- Ethernet is the main transport technology that we use today
  - Cheap
  - Reliable
  - Widely available
  - Great bandwidth evolution
- Ethernet can be transported over many of the technologies we have and will talk about today

ETHERNET

- 1G
- 10G
- 40G
- 100G

- Every variation of interface type and optical parameters you can imagine

METRO ETHERNET

- IP/MPLS
- MPLS-TP
- Plain Ethernet (with spanning-tree)

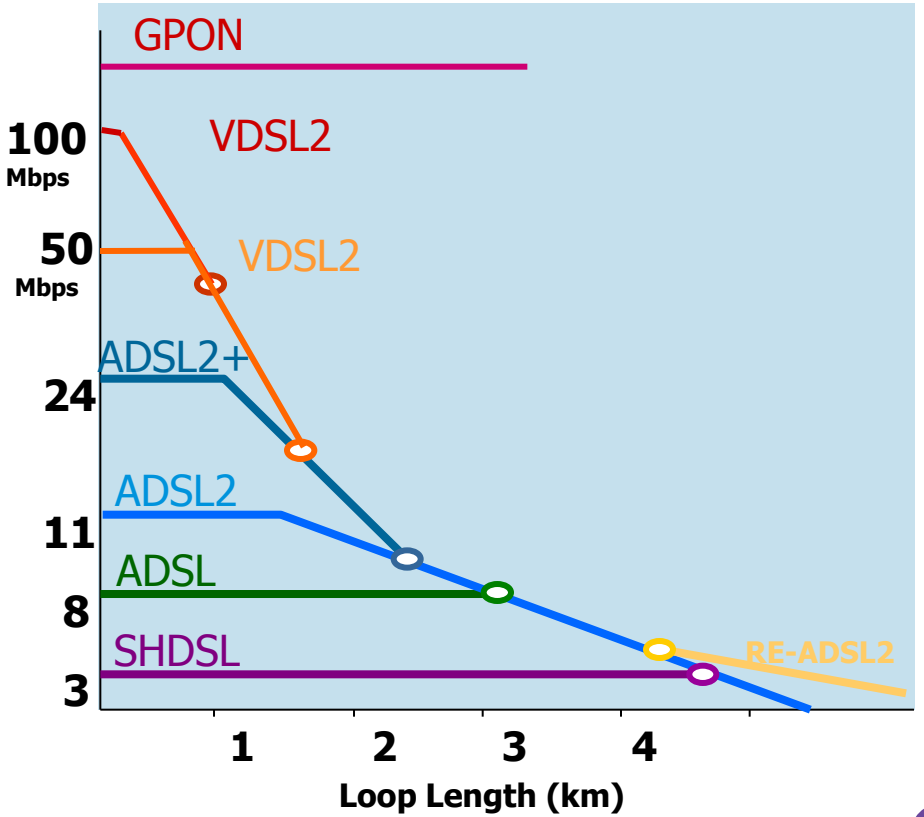
METRO ETHERNET
WHERE DO WE USE IT?

- Everywhere!
- Customer access
- Network aggregation
- Core/Backbone

xDSL
DIGITAL SUBSCRIBER LINE

ADSL OVERVIEW

- ATM based
- Most prevalent xDSL variant today
- Wide CPE and DSLAM support

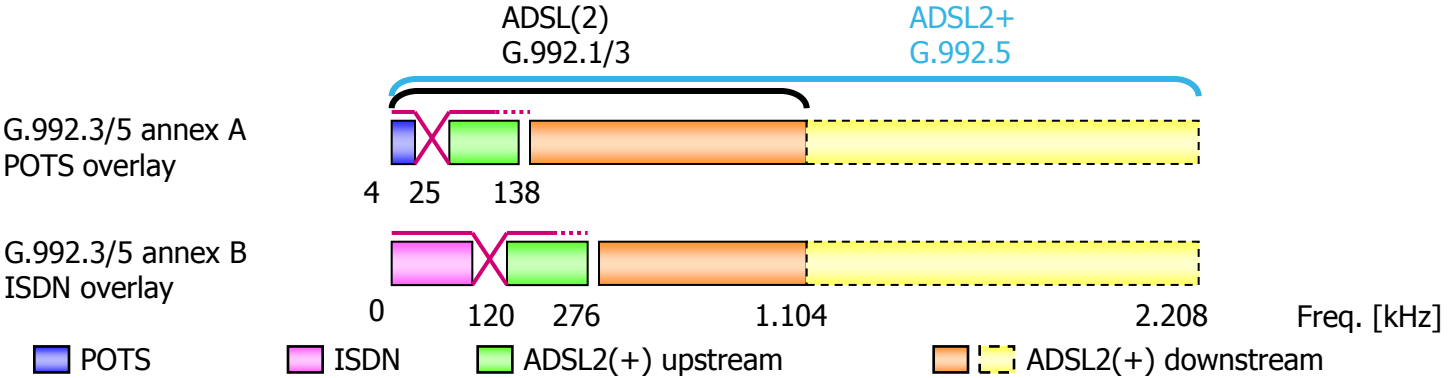


ITU DSL STANDARDS

OVERVIEW

ITU standards	Main Features	Main applications	Notes
G.992.1 ADSL (1999)	Coexistence with POTS/ISDN Up to 6.144 [Mbps] DS & 640 [kbps] US	High-Speed Internet	Unable to provide consistent performance over long distances
G.992.3 ADSL2 (2002)	Better performance Loop diagnostics Power management	High-Speed Internet	Annex L: reach extended ADSL2 Annex M: enhanced upstream
G.992.5 ADSL2+ (2003)	Downstream BW increase ▪ up to 24 [Mbps] DS Remote deployment	3-play (HSI + Video + VoIP)	Annex M: enhanced upstream PSD shaping for spectral compatibility in case of remote deployment
G.993.2 VDSL2 (2006)	Packet transport with 64/65B encapsulation (aka EFM mode) Up to 100 [Mbps] symmetrical over short loops (<150 [m])	3-play (HSI + Video + VoIP)	Multiple deployment scenarios: FTTEx, FTTN, FTTB New features for 3-play support ▪ INP, Virtual noise, …
G.991.2 E-SHDSL (2005)	Packet transport with 64/65B encapsulation (aka EFM mode) Up to 5,7 [Mbps] symmetrical over 1 copper pair	Business services: ▪ DSL Mobile backhaul	Multiple bonding scheme for boosting rate/reach: IMA, M-pair, EFM bonding No POTS/ISDN overlay

ADSL2plus BOOSTING DOWNSTREAM DATA RATE

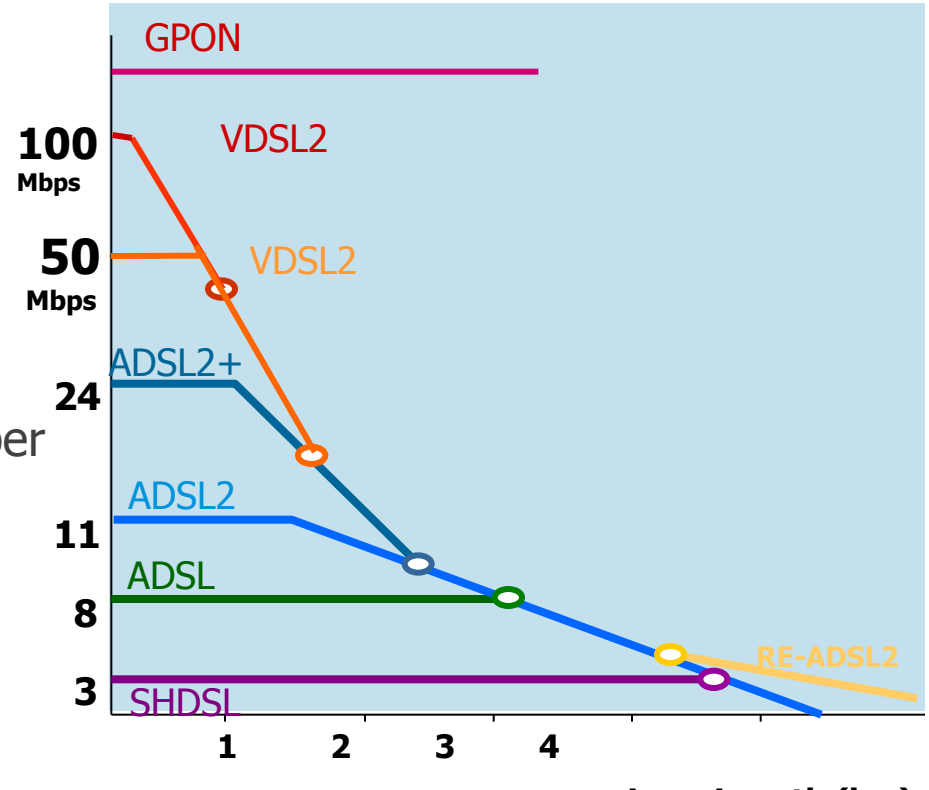


Recommendation	Mandatory downstream datarate	Standard architecture upper limit downstream datarate
ADSL (G.992.1)	6.144 Mbps	8 Mbps (15Mbps for optional S=1/2)
ADSL2 (G.992.3)	8 Mbps	15 Mbps
ADSL2+ (G.992.5)	16 Mbps	24,5 Mbps

ADSL2plus offers up to 24Mbps downstream

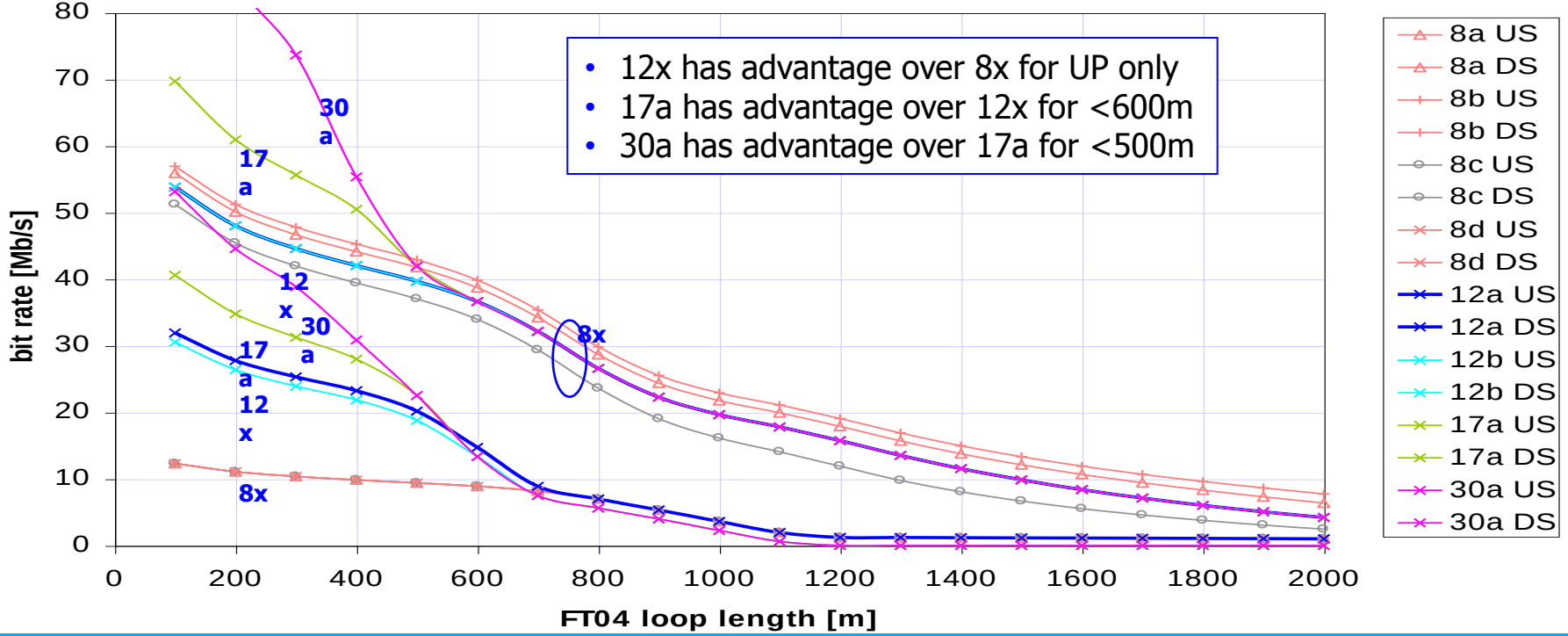
VDSL2 OVERVIEW

- Ethernet First Mile
- Direct Ethernet encapsulation
- ATM not required
- Greatly increased upstream
- Beginning of the last frontier for copper



SIMULATED bit rates.

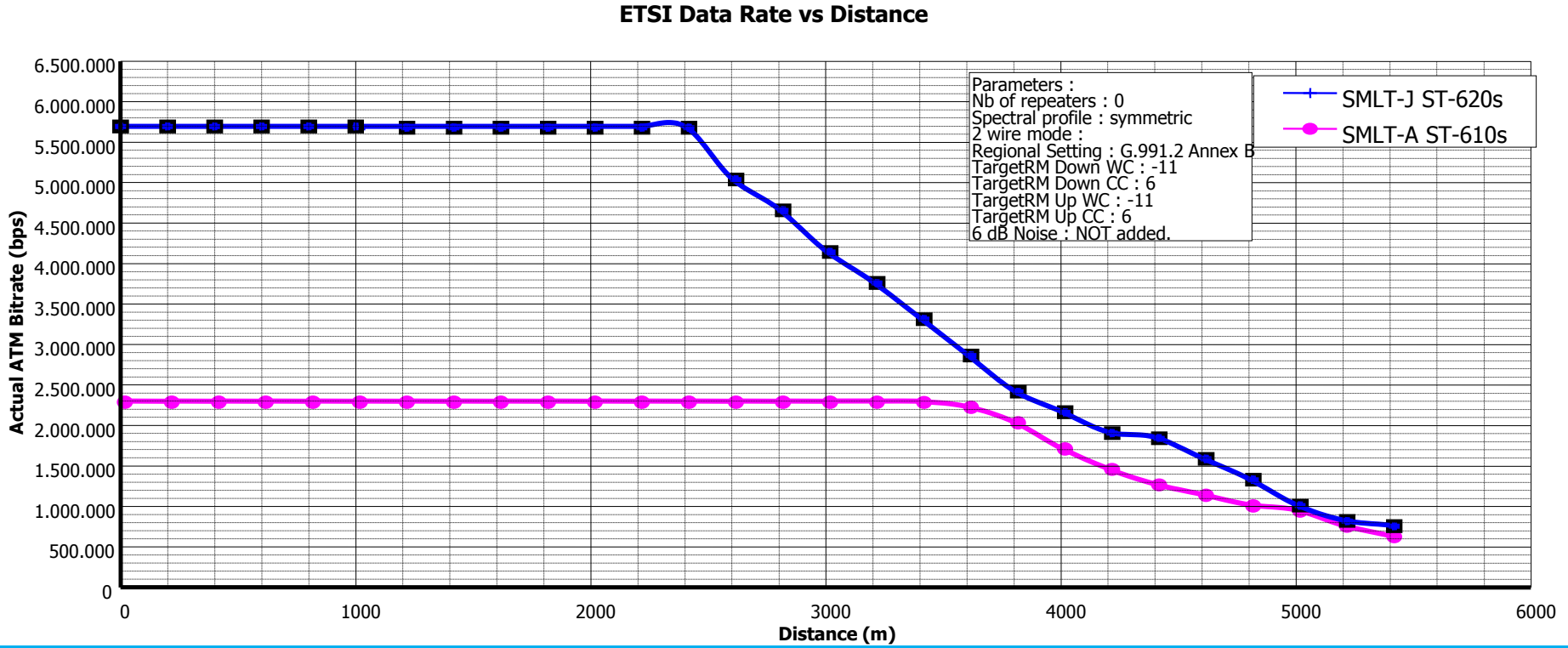
VDSL2 BIT RATES AS FUNCTION OF USED PROFILE



Shown bitrates are simulations that show the concept

VDSL2 performance is depending on many variables:
US0, UPBO, DPBO, cable type, bandplans, …

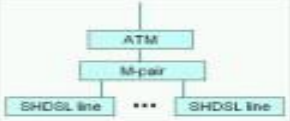
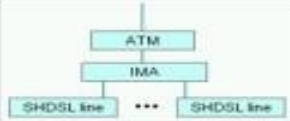
SHDSL



User data rate up to 5,7 [Mbps] over 1 pair

E-SHDSL TECHNOLOGY

SUPPORTED BONDING MECHANISMS

	M-pair mode	IMA Bonding	ATM Bonding	EFM Bonding
Specifications	ITU-T G.991.2	ATM Forum: Inverse Multiplexing for ATM (IMA) Specification Version 1.1	ITU-T G.998.1	ITU-T G.998.2
Transport Mode	ATM	ATM	ATM	EFM
Max. number of bonded lines as defined by standard	Up to 4 (M= 4)	Up to 32	Up to 32	Up to 32
Level of operation				
Upon failure of one pair	The whole group fails	The group won't be impacted	The group won't be impacted	The group won't be impacted
Data Rate distribution over the bonded lines	Same data rate	Same data rate	Disparate data rate	Same data rate

xDSL
HOW DO WE USE IT?

- DSL, like Ethernet, is relatively inexpensive
- Has reasonable range on our existing copper plant
- Can be used for transporting Ethernet!
  - RFC1483/2684 bridging
  - PTM
- DSL becomes a powerful tool for connecting customers to the network over bridged Ethernet style services, via our DSLAMs
- ***It's not just for residential HSI!***

xPON
PASSIVE OPTICAL NETWORKING

GPON

Gigabit

Delivering downstream speeds up to 2.5Gbps downstream and 1.25 Gbps upstream per fiber (actual speed depends on splitting ratio)

(1Gbps = 1.000.000 Kbps)

Optical

Using light (wavelengths) to transmit data via lasers or LEDs

DSL = using electricity

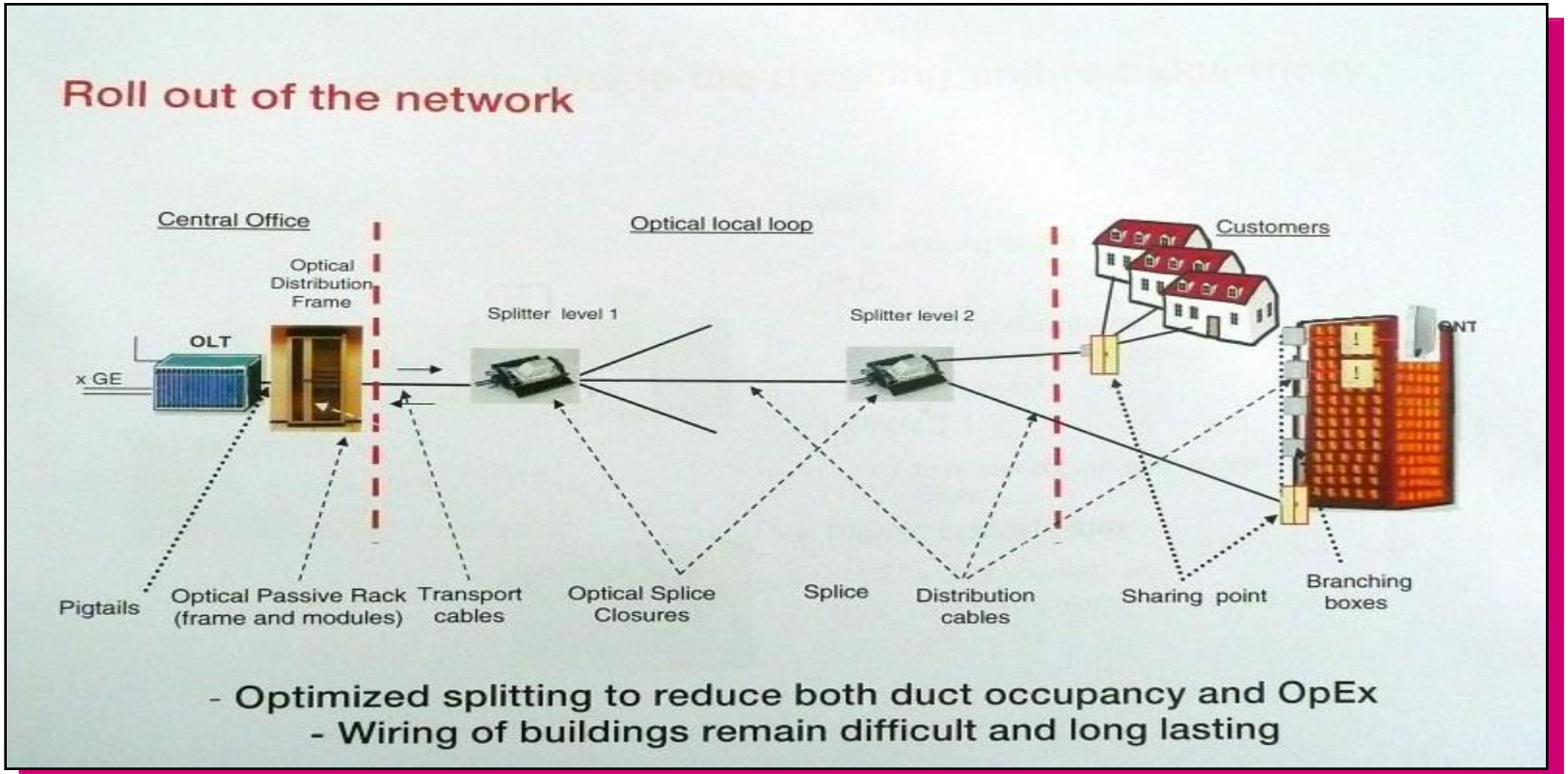
Passive

Only using passive components in the distribution network. Based on splitters to share the medium between different users (128). No amplifiers!

Network

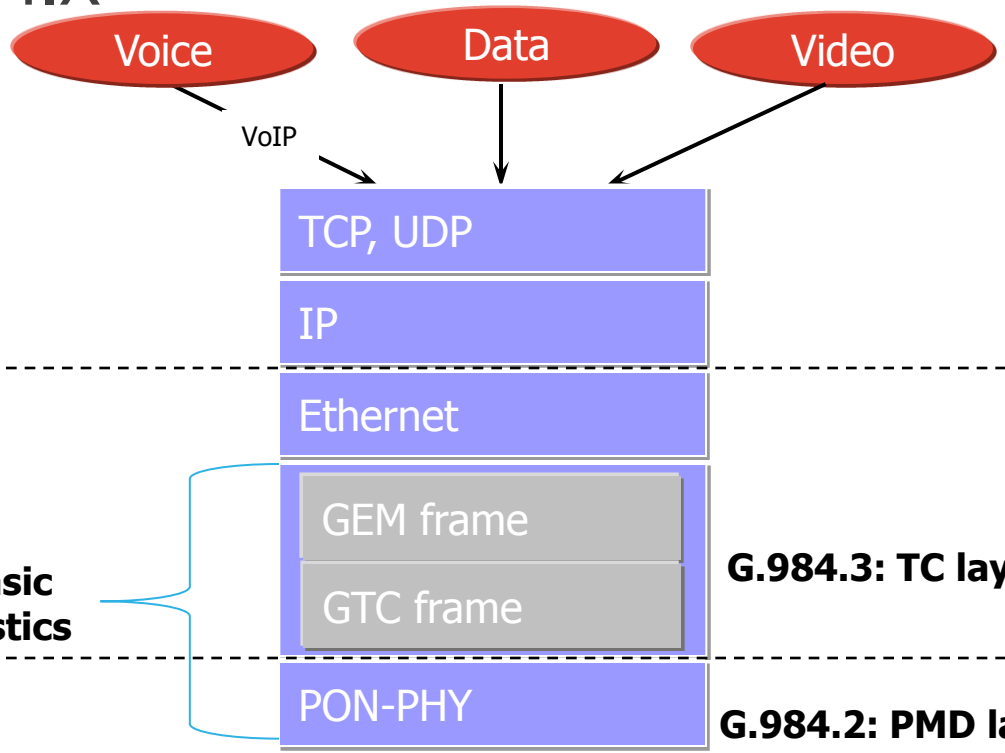
Using a star topology to connect the users to the central office

TOPOLOGY EXAMPLE



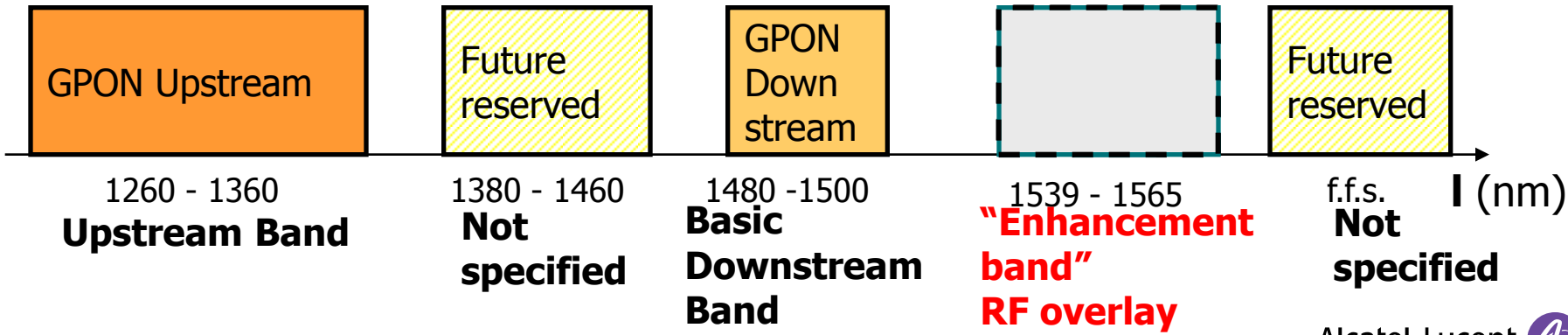
GPON STANDARDS

ITU-T G.984.X



GPON WAVELENGTH PLAN ITU G.984.2

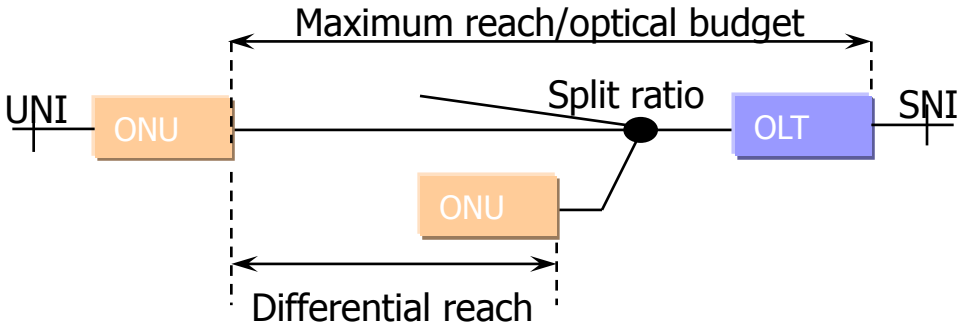
- For all standardised TD/TDMA PON technologies
  - Downstream (OLT -> ONTs) and Upstream (ONTs -> OLT) communication using separate wavelengths
  - 2.488 Gbit/s downstream, 1.244 Gbit/s upstream GPON
  - ITU-T wavelength plan for GPON :



GPON ITU-T 984.2 PMD SPECIFICATIONS

- Optics characteristics:

	OLT	ONT	
Mean Launched Power MIN	+1,5	+0,5	dBm
Mean Launched Power MAX	+5	+5	dBm
Minimum Sensitivity	-28	-27	dBm
Minimum Overload	-8	-8	dBm
Optical Penalty	0,5	0,5	dB

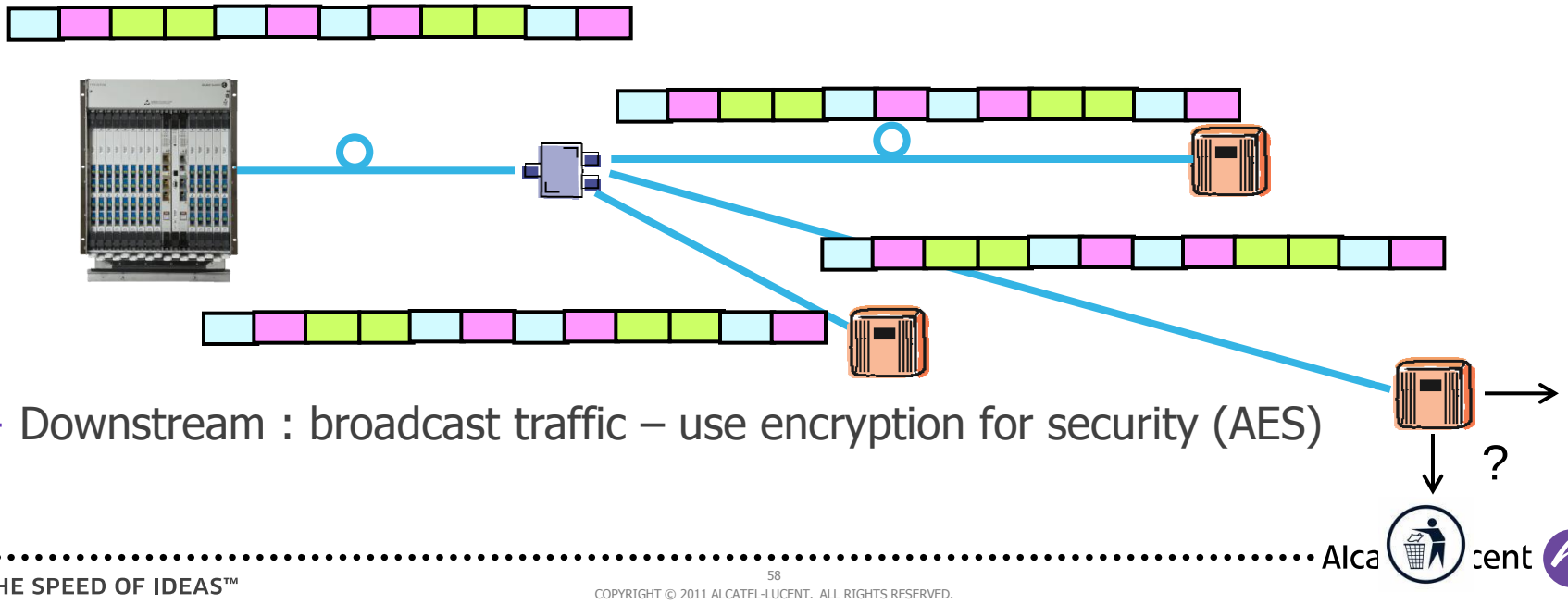


- ITU-T 652 Single Mode fiber
- 28 dB optical power budget (class B+)
- Design for BER < 10E-10

- 30 km maximum reach
- 20 km differential reach
- Up to 1:128 optical split
- FEC – Forward Error Coding
- Latency < 1.5ms

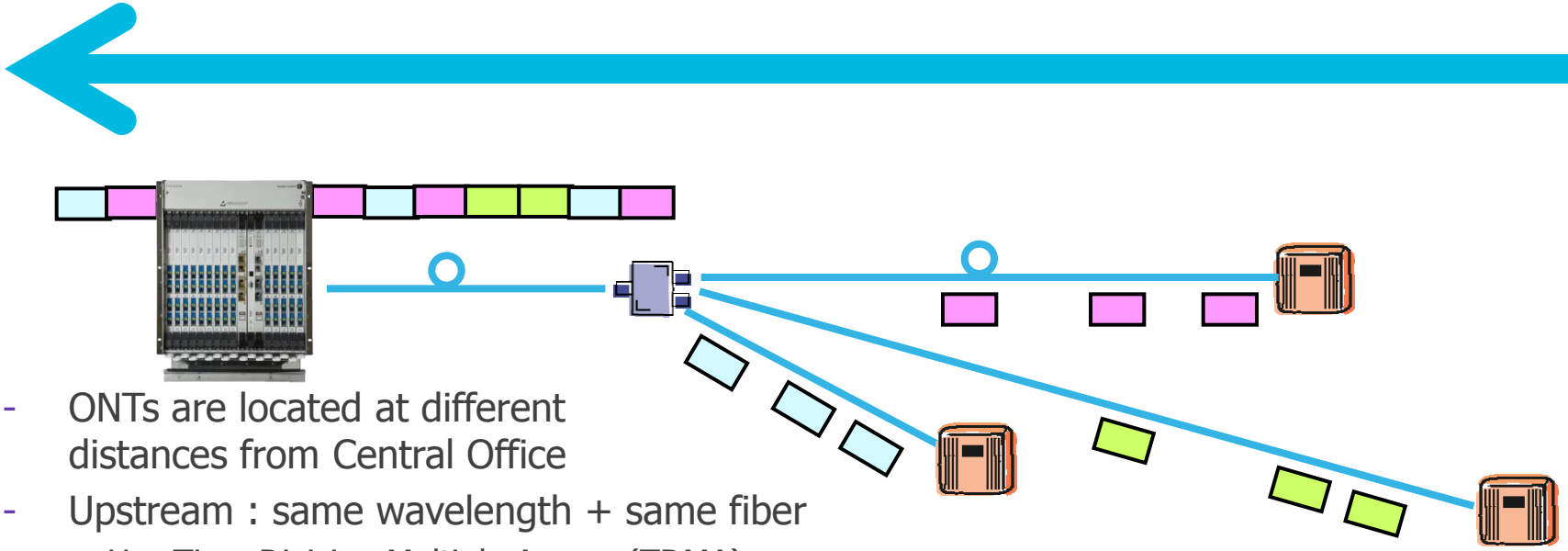
Data Transmission : DOWNSTREAM

- Standardized by ITU-T in G.984.x recommendation
- Communication between P-OLT and ONT



- Downstream : broadcast traffic – use encryption for security (AES)

Data Transmission : UPSTREAM



- ONTs are located at different distances from Central Office
- Upstream : same wavelength + same fiber
  - Use Time Division Multiple Access (TDMA)
- How ?
  1. Distance OLT – ONT has to be measured
  2. Timeslots are allocated according to distance
  3. ONTs only send upstream according to granted timeslot

OTHER PON TECHNOLOGIES

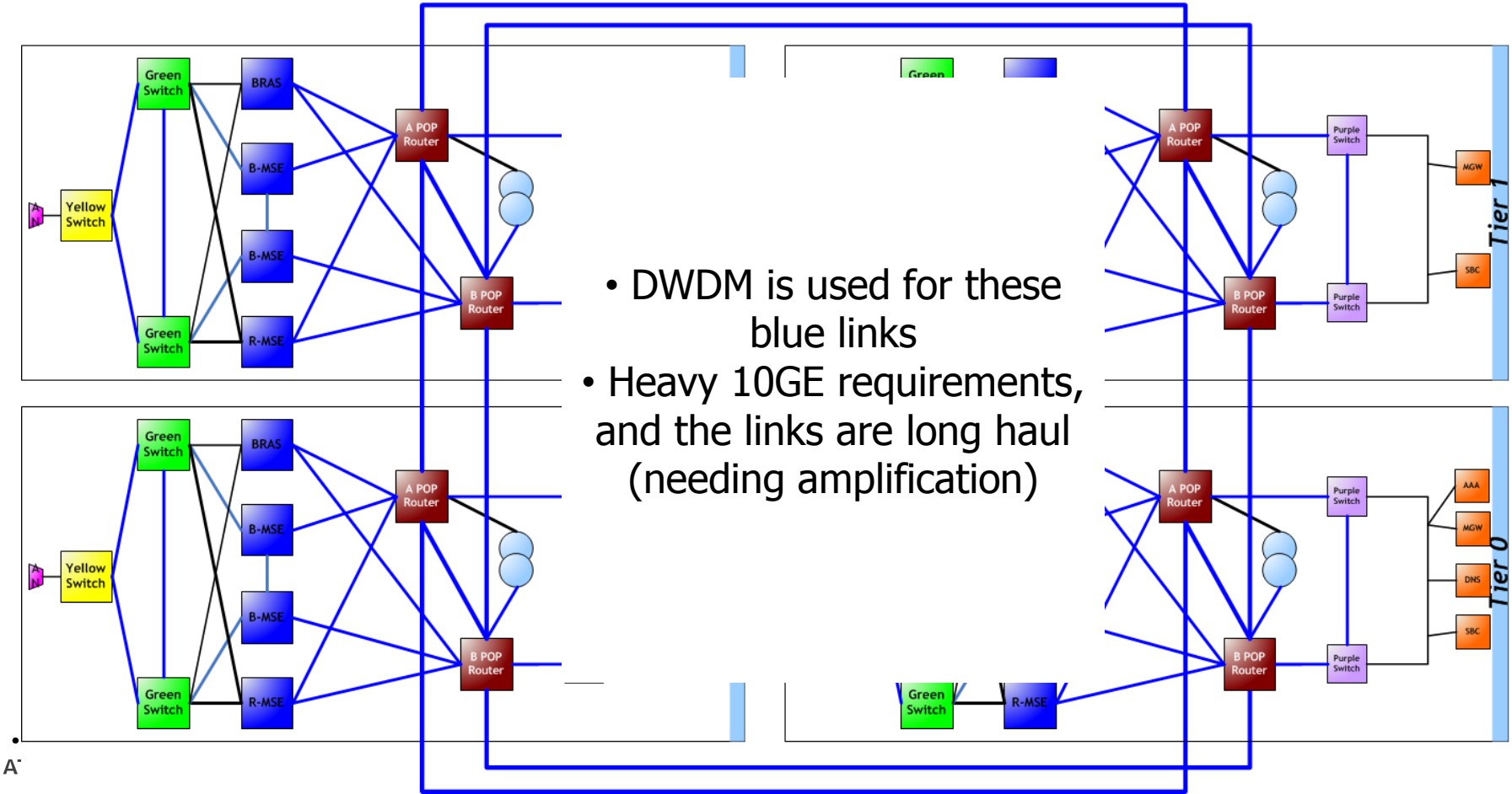
- 10G-PON
  - Based on GPON, at 10Gbps (ds) speeds
- EPON / 10G-EPON
  - Ethernet based, 1Gbps or 10Gbps
- BPON
- APON

xPON
HOW DO WE USE IT?

- Last mile access technology to businesses, homes, street signs, bus stops, mobile cell towers
- Delivers us Ethernet interfaces that are relatively transparent*
- High bit rates (up to 1Gbps possible per UNI)

PUTTING IT ALL TOGETHER
AN END-TO-END LOOK

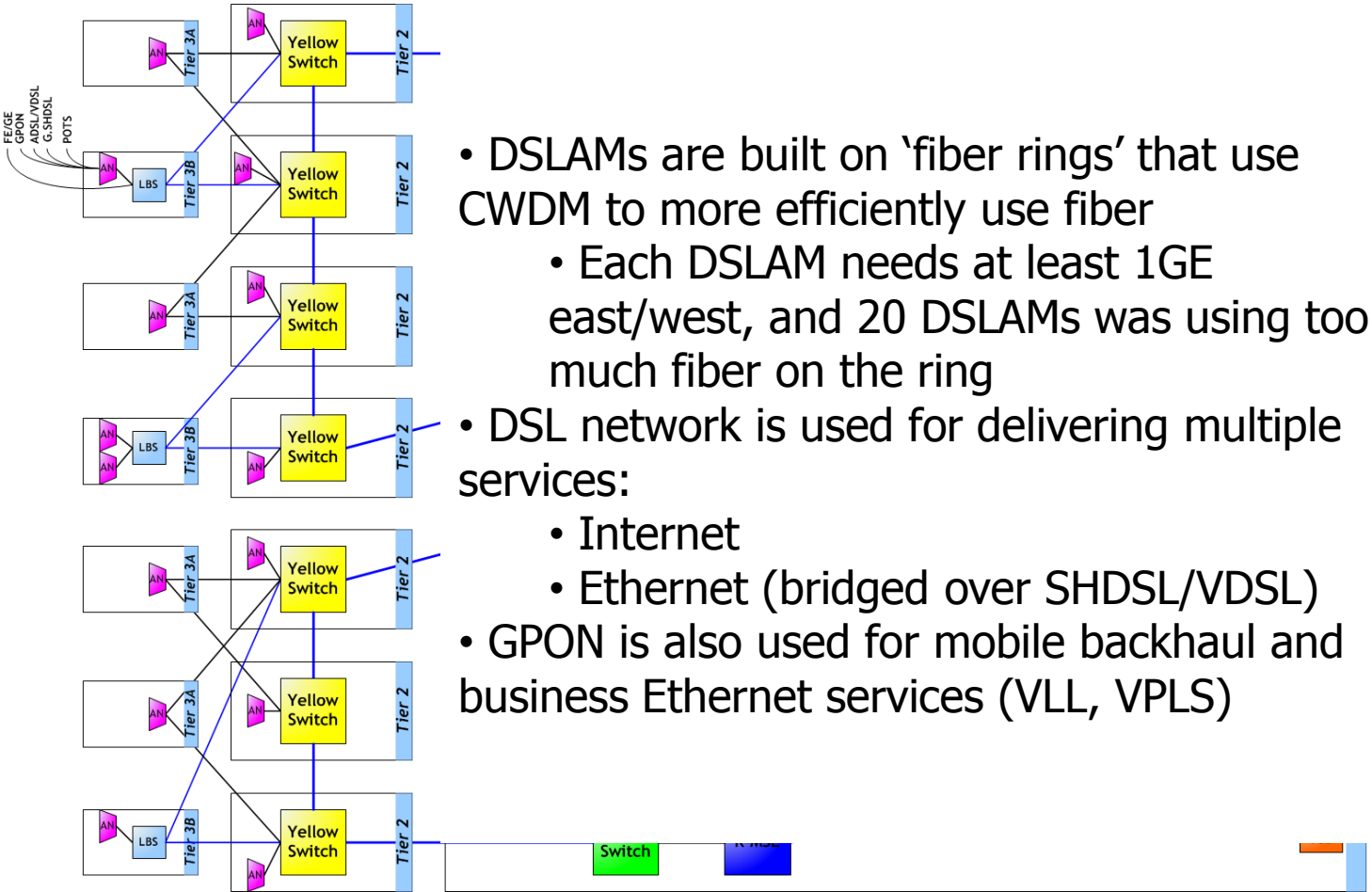
PUTTING IT ALL TOGETHER



- DWDM is used for these blue links
- Heavy 10GE requirements, and the links are long haul (needing amplification)

A-

PUTTING IT ALL TOGETHER



- DSLAMs are built on 'fiber rings' that use CWDM to more efficiently use fiber
  - Each DSLAM needs at least 1GE east/west, and 20 DSLAMs was using too much fiber on the ring
- DSL network is used for delivering multiple services:
  - Internet
  - Ethernet (bridged over SHDSL/VDSL)
- GPON is also used for mobile backhaul and business Ethernet services (VLL, VPLS)

PUTTING IT ALL TOGETHER
AN END-TO-END LOOK

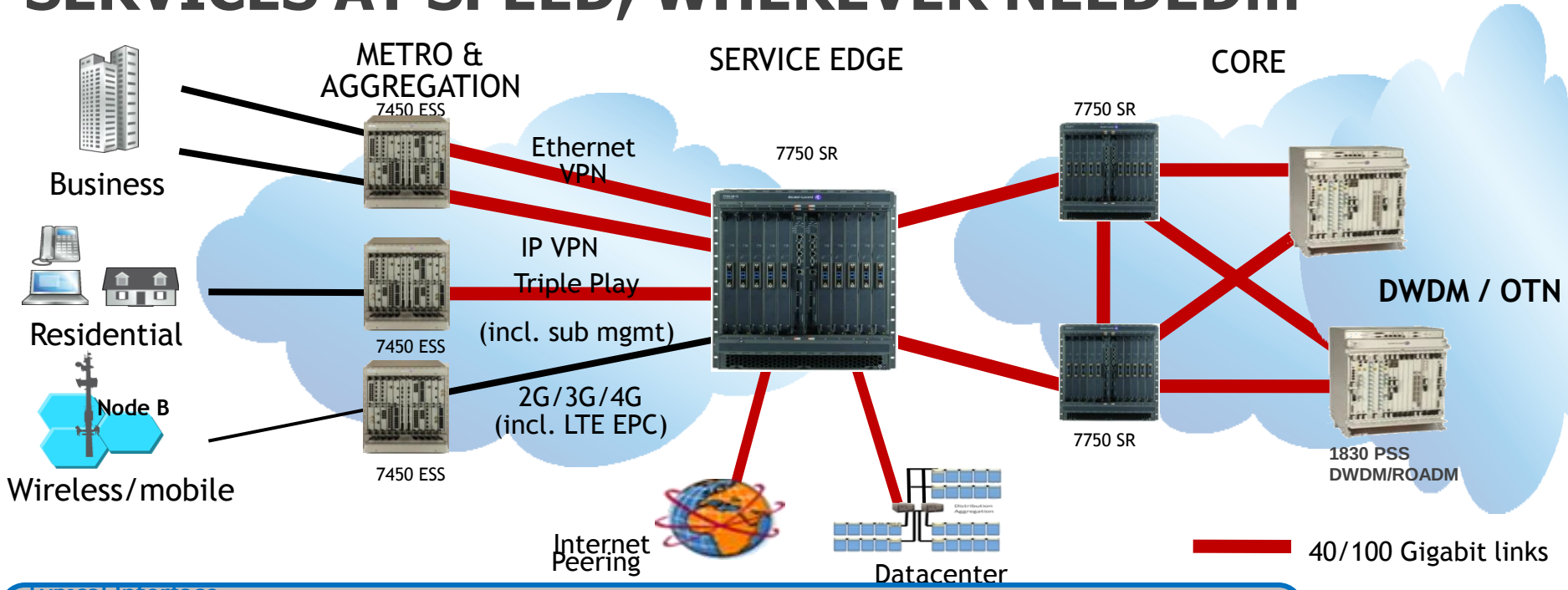
- Today's tool-kit of Ethernet based transport options are phenomenal
- Efficiently and inexpensively offer services over many technologies
- Higher and higher speeds are being demanded, and offered

FUTURE

FUTURE

- Everything points towards Ethernet and high speed transport
- Gigabit becoming the standard access rate for services, and higher bit rate demand, drives further increases in aggregation and core bandwidth
  - 40GE
  - 100GE
  - 400GE
  - 1TE
- Combination “smart IP” and “smart Optical” networks start to occur to manage traffic growth

SERVICES AT SPEED, WHEREVER NEEDED…



Typical Interface Capacity	Access	Metro	Edge	Core
2009	<1G	1G/10G	10G	10G/40G
2011+	1G/10G	10/40/100G	40/100G	100G

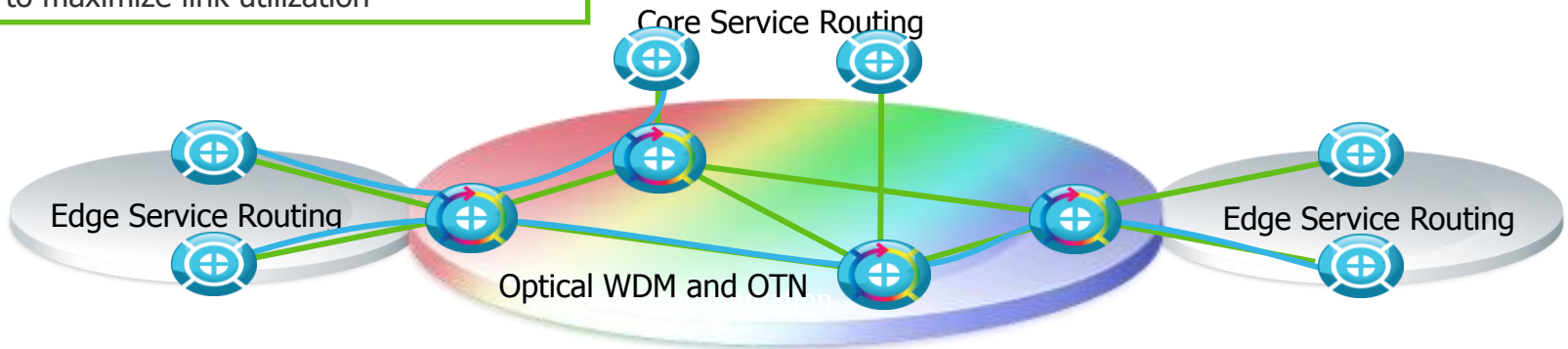
CBT

Data Plane Integration

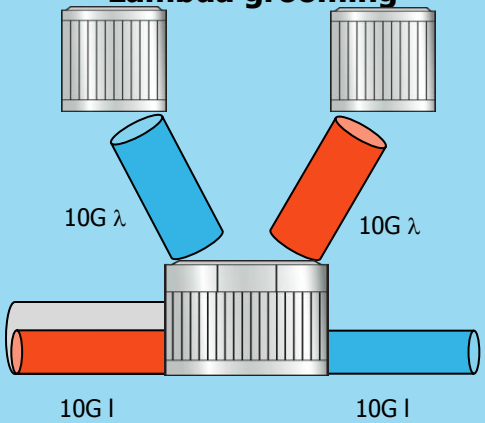
- 10/40/100G on Optics and IP
- Flexible grooming & IP shortcut options to maximize link utilization

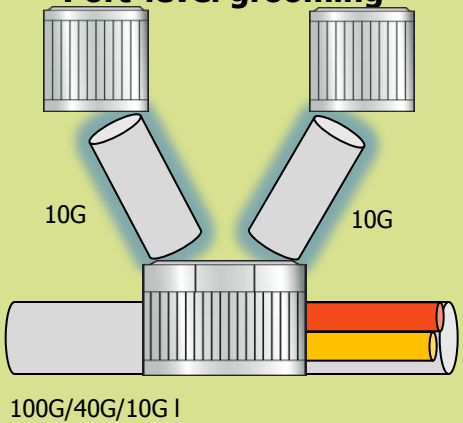
Control Plane Integration

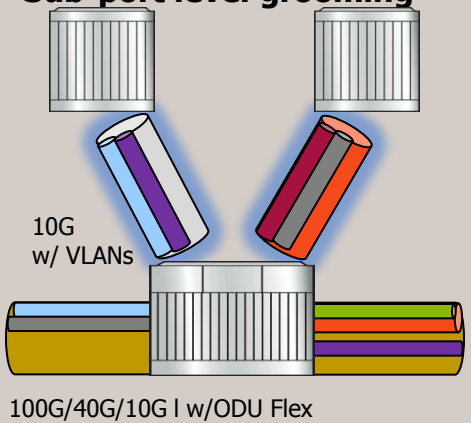
- Increased cross-layer visibility and resiliency, with improved resource efficiency



TRAFFIC GROOMING OPTIONS







Grooming model	Lambda grooming	Port-level grooming	Sub-port level grooming
Logical interfaces:	▪ None	▪ Router port	▪ VLANs within ports
Physical interfaces:	▪ Each port uses a λ	▪ Ports may be smaller than a λ	▪ Ports may be smaller than a λ
Granularity:	▪ Limited to the wavelength level, transport purely at photonic level	▪ Limited to the router port level, electrical & photonic processing	▪ Down to the VLAN or port level, electrical & photonic processing

hub & spoke:
Internet Access, VoD, Mobile Broadband

lower

Service type & distribution

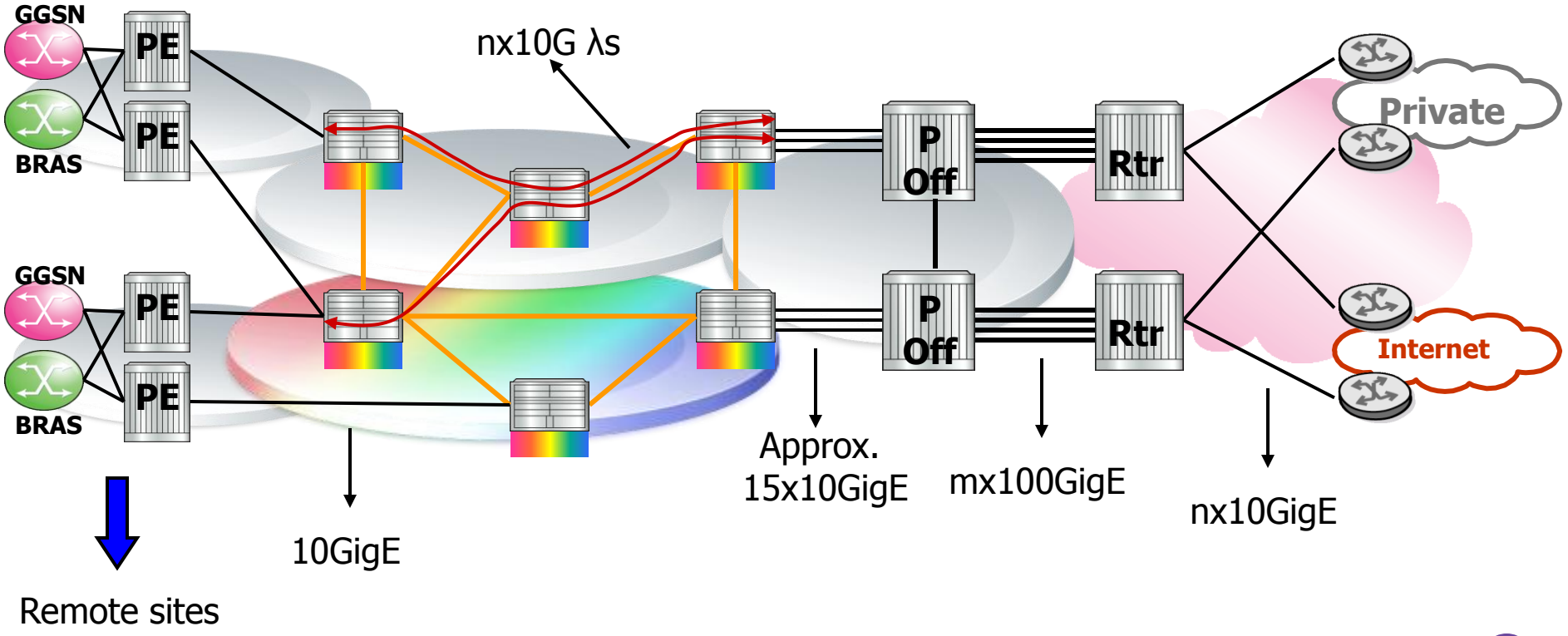
Grooming flexibility required

any to any:
Voice, Private Line

higher

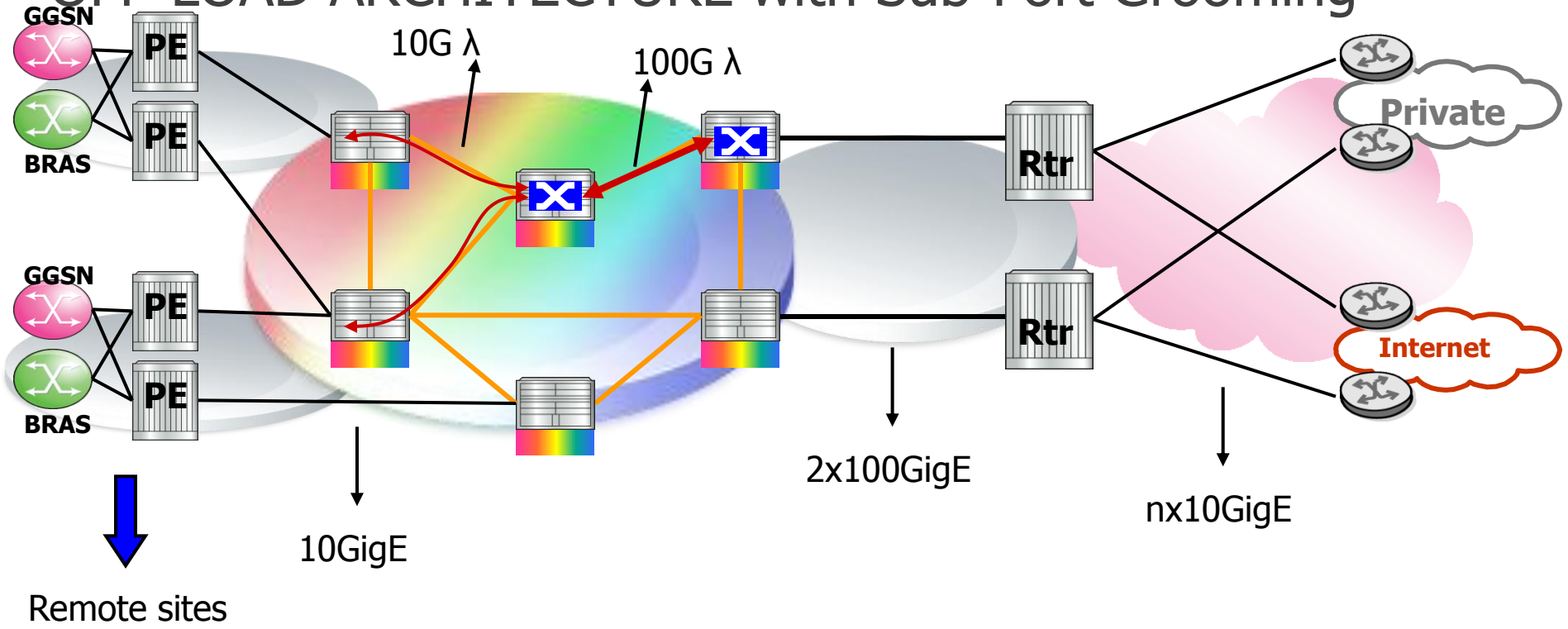
100 Gb/s END-TO-END

CURRENT INTERNET OFF-LOAD ARCHITECTURE



100 Gb/s END-TO-END

OFF-LOAD ARCHITECTURE with Sub-Port Grooming



AT THE SPEED OF IDEAS™

Alcatel·Lucent