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Beyond 10G PON

Rishabh Sandhir, RVP and Kade Kincannon, SSE

August 2024

What Are the Options Beyond 10G-PON?

10G PON NOW

XGS
10GEPON
NGPON2

- All have a User Data Throughput of about ~8.5G
- NGPON2 would need “channel bonding” to exceed ~8.5G

25G PON

25GS-PON MSA GROUP
Consortium

- Combines 50G EPON & XGS
- Small Ecosystem
- Low System & ASIC Participation
- Low Operator Interest
- Low Volumes Likely
- ~21G

50G-PON

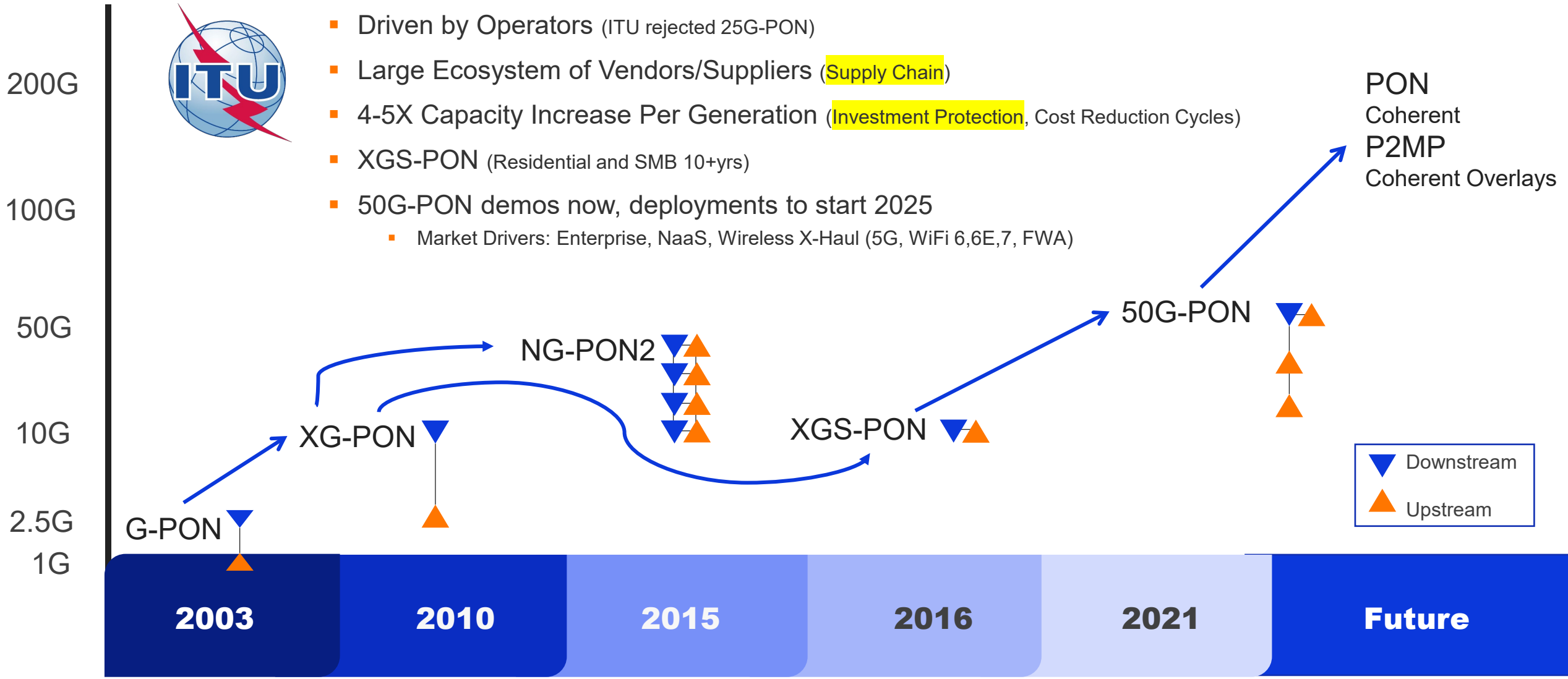
ITU

- 50G PON is an Approved ITU-T Standard!!!
- Embraced by a Majority of the PON Ecosystem
- Leverages the GPON and XGS Lineage
- 50G x 25G and 50G x 50G
- PON Slicing
- Large Ecosystem Developing
- Large Operator Interest
- Large Volumes Likely (China)
- ~42G

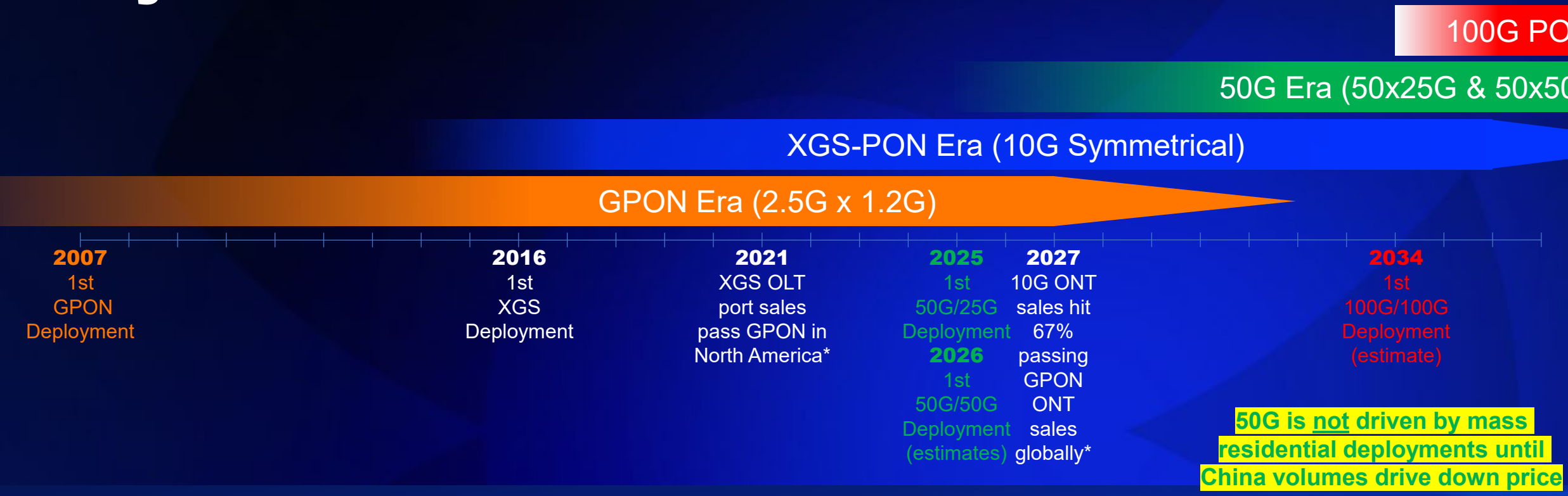
Every Generation PON Standard has Increased Capacity by at Least 4 Times!!!

ITU-T PON Standards Evolution

- Driven by Operators (ITU rejected 25G-PON)
- Large Ecosystem of Vendors/Suppliers (Supply Chain)
- 4-5X Capacity Increase Per Generation (Investment Protection, Cost Reduction Cycles)
- XGS-PON (Residential and SMB 10+yrs)
- 50G-PON demos now, deployments to start 2025
  - Market Drivers: Enterprise, NaaS, Wireless X-Haul (5G, WiFi 6,6E,7, FWA)



Key Market Inflection Points



- About ~10 years between next generation PON deployments (trend is ~9 years 2007, 2016 & 2025)
- About ~20 years for yearly PON port & ONT sales of the next generation PON to surpass the previous
- For about ~25 years of PON Standards there has always been a 4X-5X Capacity Increase to Next Gen.
- This enabled FTTH PON Operators as well as the Ecosystem to maximize their investments

* Source: Omdia research

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50G PON and PON Slicing are Game Changers

Highest Capacity at Lowest Cost per Bit

PON capacity supporting high sub count, service tiers and traffic growth rates

More Revenue Streams & Higher ARPUs

Business, Mobile Offload, Mobile Xhaul, Transport, and Billboard Speed Wars

Sustainable Solution with Lower OpEx

High-capacity per port using less space and power per Gigabit

50G PON as Access & Aggregation Layer

50G as an Aggregation Layer is an alternative to optical Ethernet

PON Slicing - ITU-T Supplement 74 PON

Programmability of slices of capacity, QoS, and latency for groups of subscribers

ITU-T 50G PON

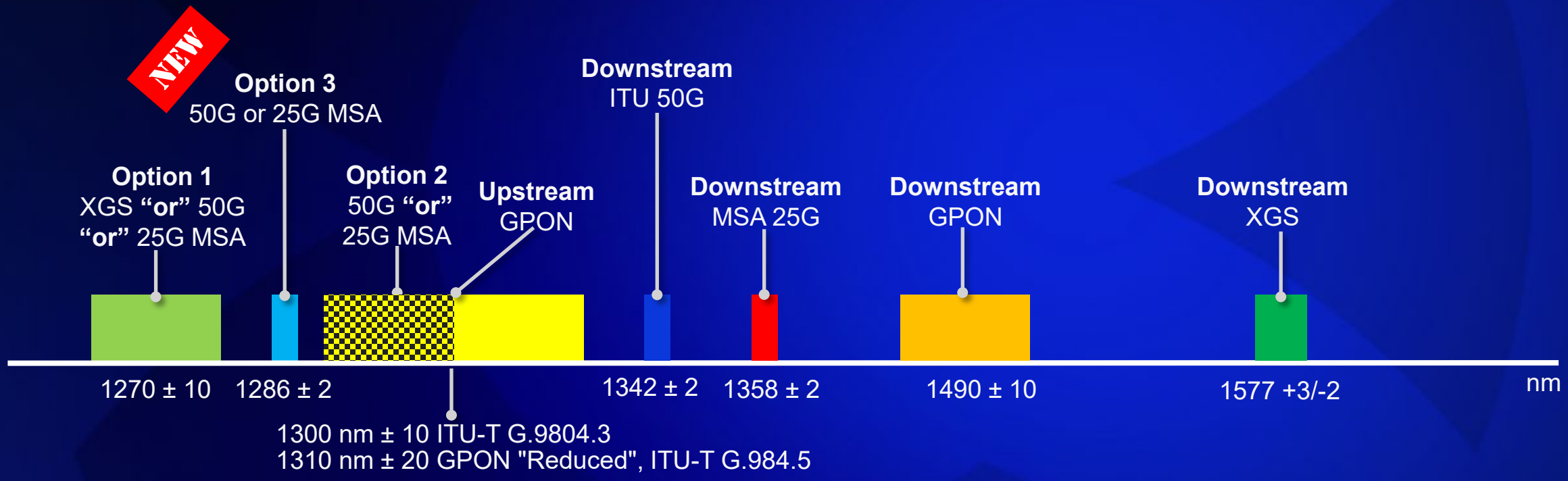
G.9804 Higher Speed Passive Optical Networks (HSP)

Standard	Approved Date	Status	Description
G.9802.1 (2021) Amendment 1 (02/23)	2023-02-22	In Force	Updated WDM-PON requirements
G.9804.1 (2019) Amendment 1 (08/21)	2021-08-06	In Force	Higher speed passive optical networks - Requirements
G.9804.2 (2021) Amendment 1 (02/23)	2023-02-22	In Force	Higher speed passive optical networks - Common transmission convergence layer specification
G.9804.3 (2021) Amendment 1 (02/23)	2023-02-22	In Force	50-Gigabit-capable passive optical networks (50G-PON): Physical media dependent (PMD) layer specification
G.9805 (2022) Amendment 1 (06/23)	2023-06-13	In Force	Coexistence of PON systems via upstream wavelength Option 3 50G Upstream N1 29 dB link budget without multi-PON reach ~20 km 32 split / ~14 km 64 split
Current ITU-T 50G Work Activities	• 50G Upstream C+ optics 32 dB budget supporting ~20km 64 split / ~10km 128 • Key Exchanges Minor updates for more clarity for interoperability purposes		

Source: https://www.itu.int/rec/T-REC-G/en

PON Wavelength Considerations

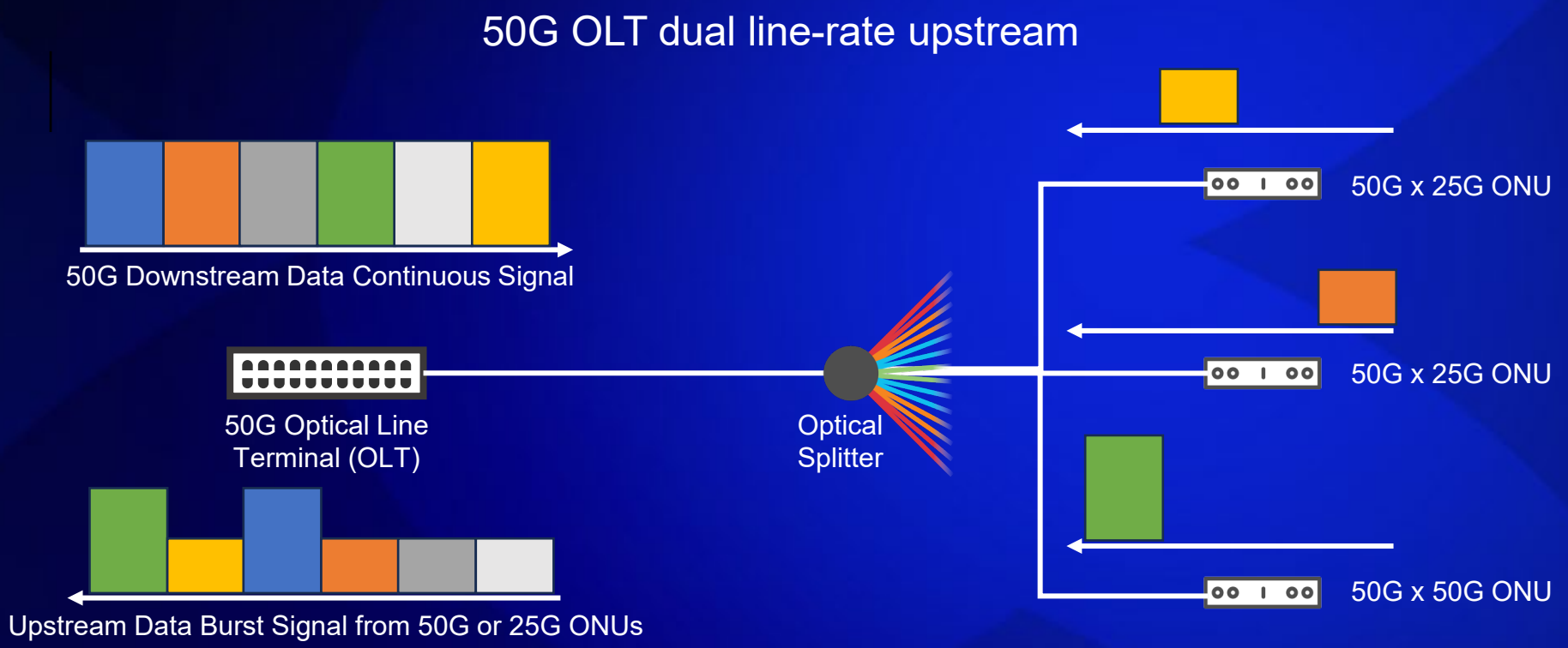
- **Both 25G PON & 50G PON defined upstream wavelengths previously assigned to GPON & XGS**
- **The Problem:** Many service providers have GPON and XGS-PON in use on the same fiber
- **New Upstream Wavelength Option 3** placed between GPON & XGS (last remaining wavelength)
- **Many service providers will have to choose 25G "or" 50G (<u>not 25G "and" 50G</u>)**



Recommend <u>not</u> using the last wavelength for 25GS-PON it does not meet the capacity needs

50G OLT Dual line-rate upstream receiver

- 50G OLT dual line-rate upstream receiver
- Enables compatibility of 50Gx50G “and” 50Gx25G ONUs on the same OLT port



Beyond 50G PON - ITU-T G.suppI.VHSP

- **Overview**
  - G.vhsp (Very High Speed PON) name given during study phase
  - PON transmission technologies above 50 Gb/s per wavelength
  - 100G PON (minimum) likely higher 250G PHY (200G) or 400G PON
- **Status Under Study and Timing 2025 with medium priority**
- **Proposal 1: 250G PHY rate usable 200G (2 x 100G service)**
- **Proposal 2: 100G Coherent (E.g., CableLabs)**
  - Pros: Long Distances and High Split Ratios
  - Cons: High cost & high-power module 20W+ (XGS 2W / 50G 3.5 - 5W)
- **Proposal 3: 100G Downstream PAM4 with IM-DD**
  - Pros: 100G downstream PAM4 likely supported in today's ODNs
  - Cons: 100G upstream PAM4 not likely possible

Symmetrical 100G+ Standards ~2027

Symmetrical 100G+ Deployments ~2030+

PON distance grow as "Coherent Optics" become part of the ecosystem

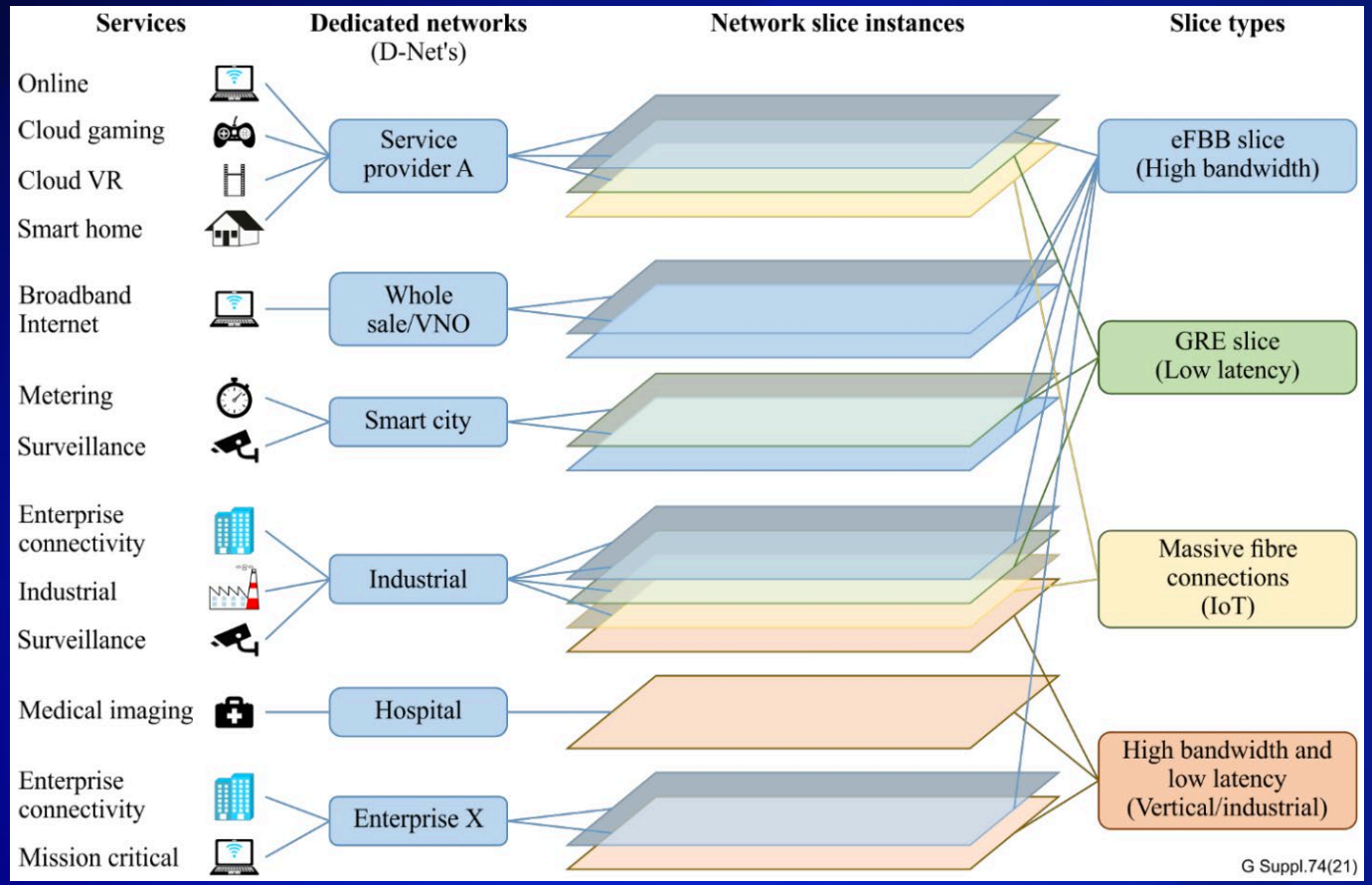
PON Slicing ITU-T - Series G Supplement 74

What is a PON Slicing?

- Allocating a portion of PON capacity to a group of users with each group having its own DBA.
- All DBAs are managed by hierarchical traffic scheduler.
- Slice groups could be based on flows across many ONUs that have a similar QoS profile or per groups of ONUs.

Benefits of PON Slicing

- Each slice and members in a slice can have configurable Bandwidth and Latency properties
- Any bandwidth unused above guaranteed may be shared with users within each slice and among all slices



ITU-T - Series G Supplement 74

50G PON has the Capacity to Enable ITU-T PON Slicing

Future End-to-End Network Slicing

CalixCloud®

Customizable programmability of end-to-end network slicing

- End-to-end Service Orchestration
- Networking Automation
- Proactive Network Monitoring
- Security & Policy Enforcement
- Usage Based Billing

Open Access / VNO / MNO

Enterprise

Carrier Wi-Fi

OLT System

Segment Routing	Hierarchical Scheduler / DBA	
Routing & VPN	User Plane (BNG UP)	PON Slice
		PON Slice
Traffic Engineering	Session Steering	PON Slice

OLT Channel Termination (CT)

50G PON Slicing

(Policy set per slice includes bandwidth and latency controlled Hierarchical Scheduler / DBA)

Network Slicing

IETF Segment Routing with TE for VPN service & SR Policy with SLA

PON Slicing

50G PON Slicing via ITU-T Supplement 74

Network Slicing Examples

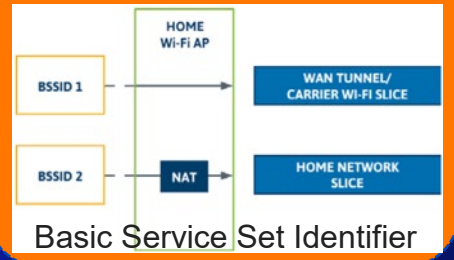
3rd Party Provider / Carrier Transport Services

Open Access
Carrier Transport
Mobile Xhaul
Open Mobile Offload

Enterprise

Medical
Education
Smart Cities
Industrial IoTs
Private Networks

Carrier Wi-Fi



Basic Service Set Identifier

Beyond 10G PON Drivers

What are the drivers beyond 10G-PON?

>10G PON

Business Services

Small / Medium / Large
CIR beyond XGS-PON
"True" 10G or 25G Service

Private Networks
PON Slicing (BW & latency) offerings for Groups of Subs

Aggregation Services

Wireless Access
Mobile Xhaul
Wi-Fi 7 Access Points

Distributed Access
Transport To/From
MDUs, Cabinets & Nodes

Residential Services

Service / Speed Tier
Billboard Speed Wars
Service Tier beyond XGS

Customer Traffic
Traffic + Service Tier beyond XGS
4K/8K Streams & Metaverse

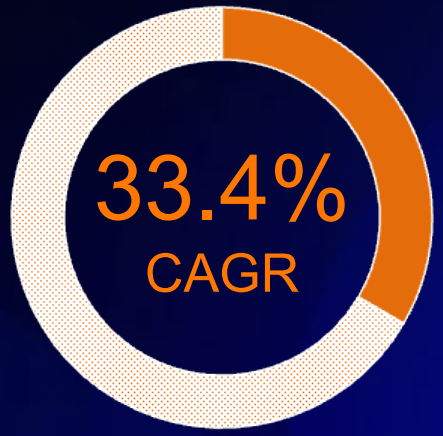
Services & PON Assessment

Segment	Service / Aggregation (per customer or per site)		Gbps	10G PON	25G PON	50G PON
Business Services	Business Max Service Tier and Peak Traffic		<8.5 Gbps	✓	✓	✓
	True 10G Services		10 Gbps	✗	✓	✓
	True 25G Services		25 Gbps	✗	✗	✓
Aggregation Services	Wi-Fi Access Point Transport	Wi-Fi 6 / Wi-Fi 6e Access Point Transport	9.6 Gbps	✗	✓	✓
		Wi-Fi 7 Access Point Transport	30 – 46 Gbps	✗	✗	✓
	5G Mid/Backhaul	Small Site (FR1 carrier)	2.0 Gbps	✓	✓	✓
		Small Site (FR2 carrier)	3.7 Gbps	✓	✓	✓
		Small Site (FR1 + FR2 carriers)	5.7 Gbps	✓	✓	✓
		Medium Site (FR1 + FR2 carriers)	15.2 Gbps	✗	✓	✓
		Large Site (FR1 + FR2 carriers)	36.8 Gbps	✗	✗	✓
	Transport	To/From MDU, Cabinet, & Node	10 – 40G	✗	✗	✓
Residential Services	Max Service Tier and Peak Traffic		<8.5 Gbps	✓	✓	✓
	Max Service Tier and Peak Traffic		>8.5 Gbps	✗	✓	✓

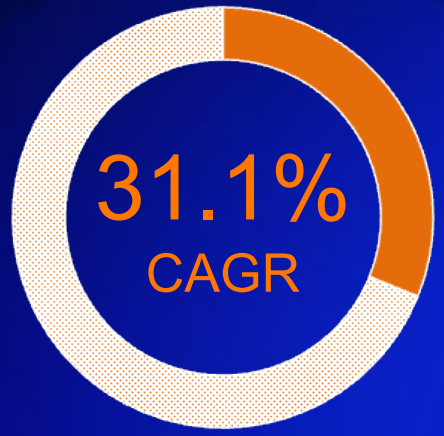
50G-PON enables convergence of all services to one network

Bandwidth per Subscriber Growth Rates

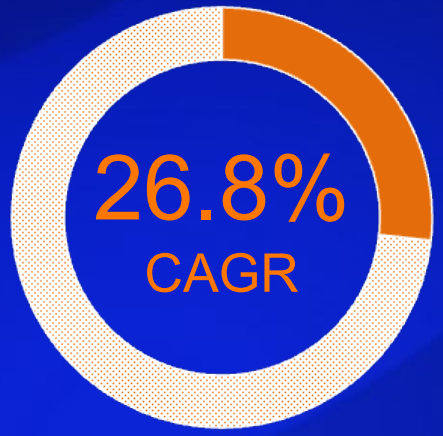
Downstream Traffic per Sub Compound Annual Growth Rate (CAGR)



For the Last 22 Years
From 2000 to 2022



For the Last 10 Years
From 2012 to 2022



For the Last 5 Years
From 2017 to 2022

Downstream Peak Period Average Bandwidth per Subscriber

20% CAGR Assumption

15000 2030

93000 2040

Peak Hours Traffic Growth Rates Vary Due to Application Adoption and Measurement Timeframe

Source: 6.176 Kbps per subscriber BHBD in the year 2000, "Bandwidth Monitoring Parameters for Capacity Management", page 3, "200 or 300 customers per DS-1", (used the average in this model), Dennis Cleary, NCTA 2000)
Source: 89 Kbps per subscriber BHBD in the year 2010, 233 Kbps in the year 2012, and 1070 Kbps in the year 2017, *"Traffic Engineering in a Fiber Deep Gigabit World"*, Ulm, et al., Cable-Tec Expo 2017
Source: 2.36 Mbps per subscriber BHBD in the year 2020 and 3.5 Mbps in the year 2022, *"Broadband Capacity Growth Models"*, Ulm, et al., Cable-Tec Expo 2022

Applications Driving Future Traffic CAGRs (1 of 2)

Streaming Impact (Downstream)

Important: With No Change in subscriber behavior streaming bandwidth may increase by 3 to 10 times

VR / AR Bandwidth (Downstream)

"By 2026, 25% of people will spend at least one hour per day in virtual shared spaces, thus driving enormous pressure on home Wi-Fi networks." (and access network)

Important: AR/VR are new behaviors using long duration streams (like movies) but at 16 to 200 times the bandwidth

Source: Streaming Media https://www.streamingmedia.com/Articles/ReadArticle.aspx?ArticleID=131687
Source: https://help.netflix.com/en/node/306
Source: WBA, https://wballiance.com/resource/wba-annual-industry-report-2023/
Source: Gartner, https://tinyurl.com/yb6g5lxr

Drivers for Continued Traffic CAGRs

Streaming Platform (Downstream)

Streaming Platform	SD (480) or HD (720p)	High Definition (HD) – 1080p	Ultra High Definition (UHD/4K)
Netflix[11]	3 Mbps	5 Mbps	15 Mbps
YouTube	3 Mbps	7 Mbps	15 Mbps
Hulu	1.5 Mbps	3 Mbps	8 Mbps
Amazon Prime Video	0.9 Mbps	3.5 Mbps	25 Mbps
Disney+	5 Mbps	10 Mbps	25 Mbps
HBO Max / MAX	5 Mbps	10 Mbps	25 Mbps
Apple TV+	1 Mbps	6 Mbps	25 Mbps
Paramount+	1.5 Mbps	3 Mbps	25 Mbps

8K Ultra HD 30 - 50 Mbps per Stream

Conferencing Platform (Down and Upstream)

Conferencing Platform	Quality	Upstream	Downstream
Zoom 1:1 Video Calling	SD Video	600 Kbps	600 Kbps
	720p HD	1.2 Mbps	1.2 Mbps
	1080p HD	3.8 Mbps	3.0 Mbps
	4K UHD	TBD	TBD
Zoom Group Video Calling	SD Video	1.0 Mbps	600 kbps
	720p HD	2.6 Mbps	1.8 Mbps
	1080p HD	3.8 Mbps	3.0 Mbps
	4K UHD	TBD	TBD

Virtual Reality Streams (Downstream)

ESTIMATE THROUGHPUT AND LATENCY FOR VR/AR TECHNOLOGIES

	VR Resolution	FPS	Equivalent Resolution	Maximum Throughput (Mbsp)	Maximum Streaming Latency (ms)	Maximum Interactive Latency
Early VR	1K X 1K	30	240p	25	40	10
Entry VR	2K X 2K	30	SD	100	30	10
Advanced VR	4K X 4K	60	HD	400	20	10
Extreme VR	8K X 8K	120	4K	1000-2350	10	10

Home Security Cloud Platforms (Upstream)

Home Security Platforms	Upstream
ADT (per camera)	1.5 Mbps
Arlo Ultra Series (per camera)	3.0 Mbps
Nest Cams and IQ Cams (per camera)	1.2 Mbps
Nest Dropcam (per camera)	2.0 Mbps
Ring Spotlight Cam (per camera)	2.0 Mbps
Vivint (per camera)	2.0 Mbps

Traffic Predictions and Max Service Tiers

Downstream Traffic with 20% Compound Annual Growth Rate (CAGR)

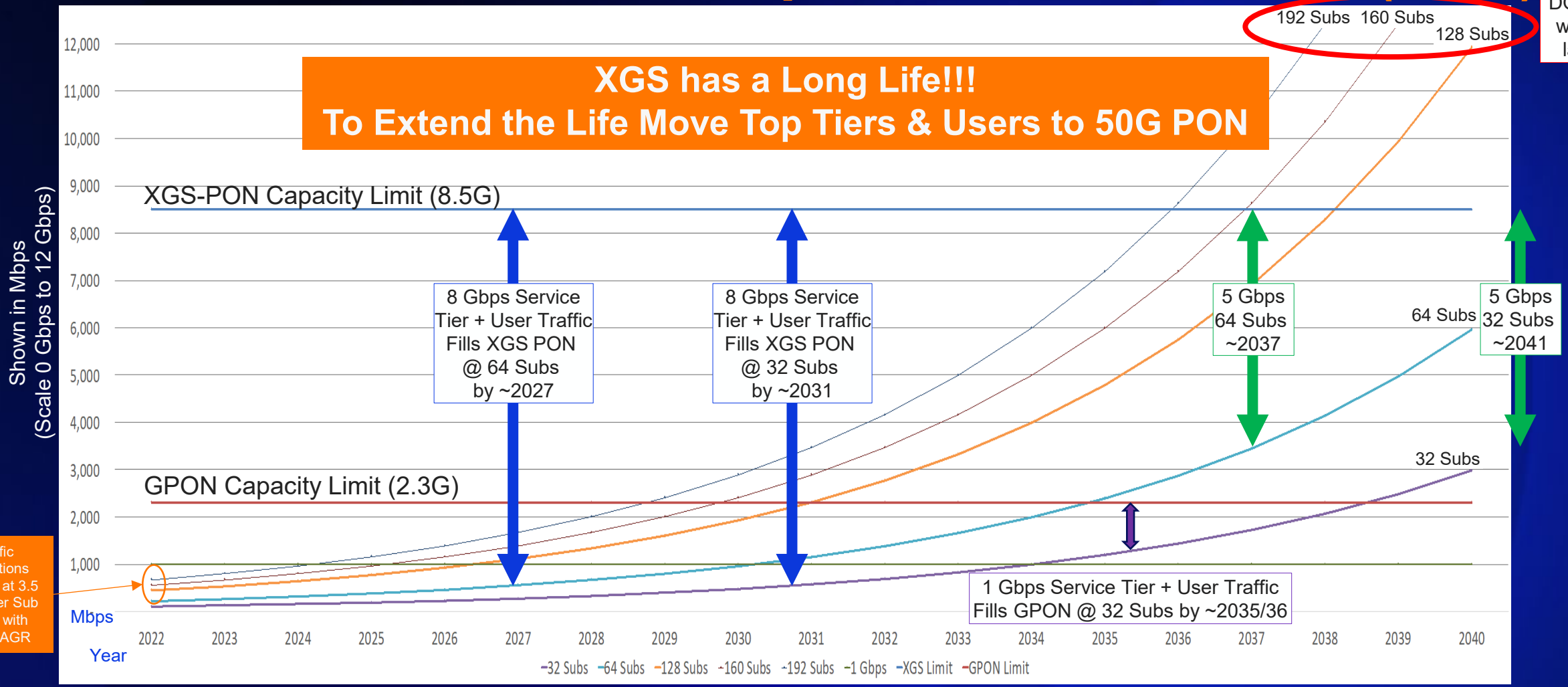


Image started with 3.5 Mbps per Subscriber during peak busy hours in 2022 and a projection of the 20% CAGR until 2040. (Subs per port could also mean service group used in DOCSIS)
FCC Speed Performance Metrics: https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-twelfth-report

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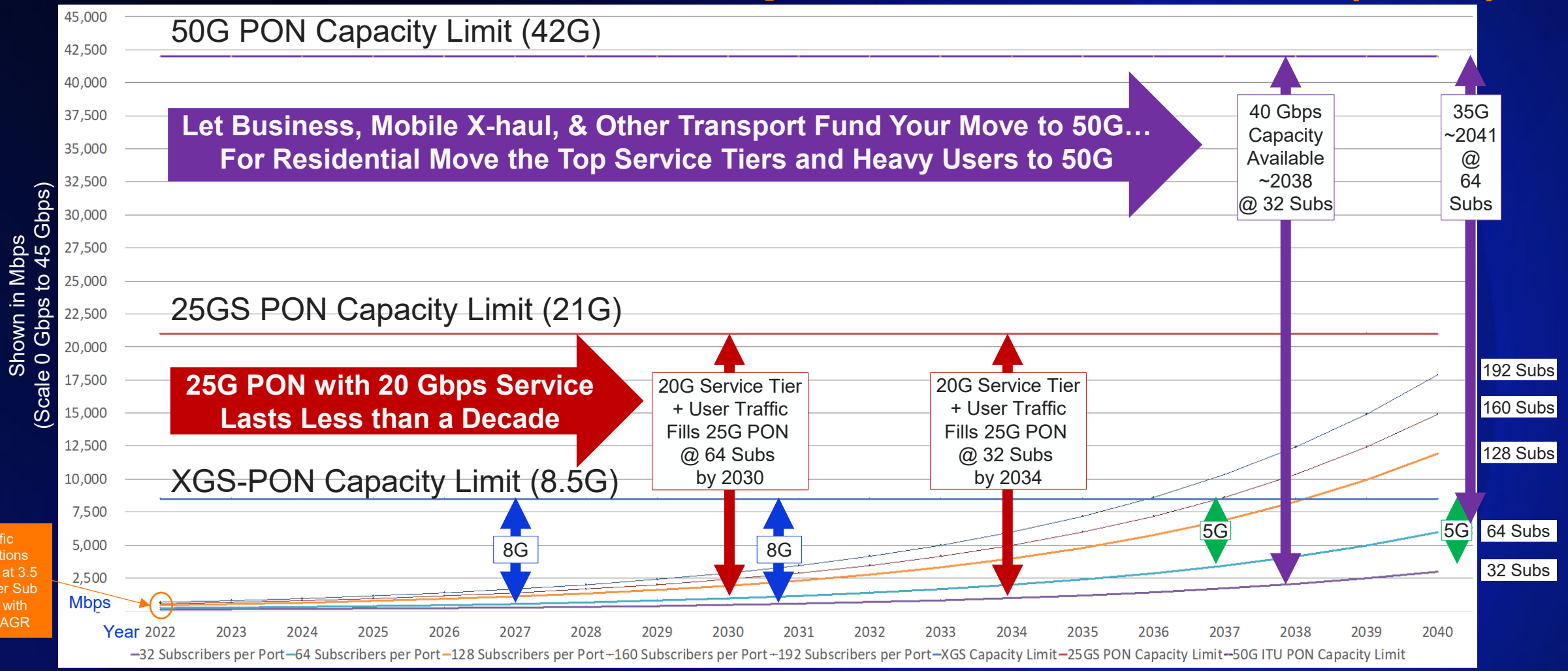

Traffic Projections Starting at 3.5 Mbps per Sub BHBD with 20% CAGR

50G PON: Reduces P2P Ethernet, Win the Billboard Speed Wars, and Extends the Life of XGS

Simplify. Excite. Grow.

Image started with 3.5 Mbps per Subscriber during peak busy hours in 2022 and a projection of the 20% CAGR until 2040. (Subs per port could also mean service group used in DOCSIS)
FCC Speed Performance Metrics: https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-twelfth-report

Reasons for 50G PON (Why not 25GS PON?)

1. ITU-T 50G PON is a Standard!
   - ITU-T G.9804 higher speed PON (HSP) (50G PON) is an approved standard that has worldwide support from the entire PON ecosystem
   - 25GS-PON Multi-Source Agreement (MSA) Group is not a standard development organization (SDO), like ITU-T and IEEE, and the ITU-T rejected 25 Gbit/s single channel PON.
   - 25G PON long-term viability is questionable due to low adoption interest from chip vendors, system vendors, and operators

2. ITU-T 50G PON has the Capacity!
   - Meets current “and” future use cases for business services (10 Gbit/s and 25 Gbit/s), Open RAN (O-RAN) Mobile Xhaul Backhaul and Midhaul, IEEE Wi-Fi 7 & 8 AP transport, aggregation layer functions, and future residential services, and 25G does not.
   - Service Tier and Traffic Growth Rates suggest that 50G PON will have a long useful life, while 25G may last a decade or less.

3. ITU-T 50G PON has better technology “and” economic flexibility!
   - 50G specifies single channel downstream and single channel upstream capable of operating at 50 Gbit/s, 25 Gbit/s, and 12.5 Gbit/s.
   - 50G specifies OLTs have a dual-rate receiver to support “both” 50x50 ONUs “and” 50x25 ONUs on the same OLT interface providing economic flexibility for BSPs to use “one” OLT interface and a choice of symmetric or asymmetric ONUs with likely different price points.

4. ITU-T 50G PON supports ITU-T PON slicing!
   - ITU-T supplement 74 PON slicing enables 50G PON to be programable into slices of capacity, QoS, and latency for groups of subscribers
   - PON slicing efficiency allows “unused” capacity above CIR to be shared by others in the slice, for other slices, and across the entire PON interface.
   - PON slicing is cost effective compared to optical Ethernet that dedicates wavelengths, ports, space, and power, even if little capacity is used.

Recommendations for using 50G PON + PON Slicing

- Use 50G PON Capacity and PON Slicing
  - Enables programmability of capacity slices, QoS, and latency for groups of subscribers (Open Access, Mobile Offload, Community Wi-Fi, Business Services, Xhaul, Aggregation Layer & Residential Services)
- Use 50G PON to Extend the Life of XGS
  - When XGS hits the capacity limit avoid moving to smaller splits ratios
  - Instead overlay 50G PON in the existing PON serving areas
  - Then move the Top Service Tiers and Heavy Users to 50G PON
- If GPON & XGS are in use, consider using the last wavelength for 50G PON
- PON technology should have a long life, so wait for 50G PON and skip 25G

Thank You