FSAN Highlights & NG-PON2 Standards Update

FSAN and IEEE NG-EPON/1904 ANWG Joint Session

hosted by CableLabs

February 4, 2015

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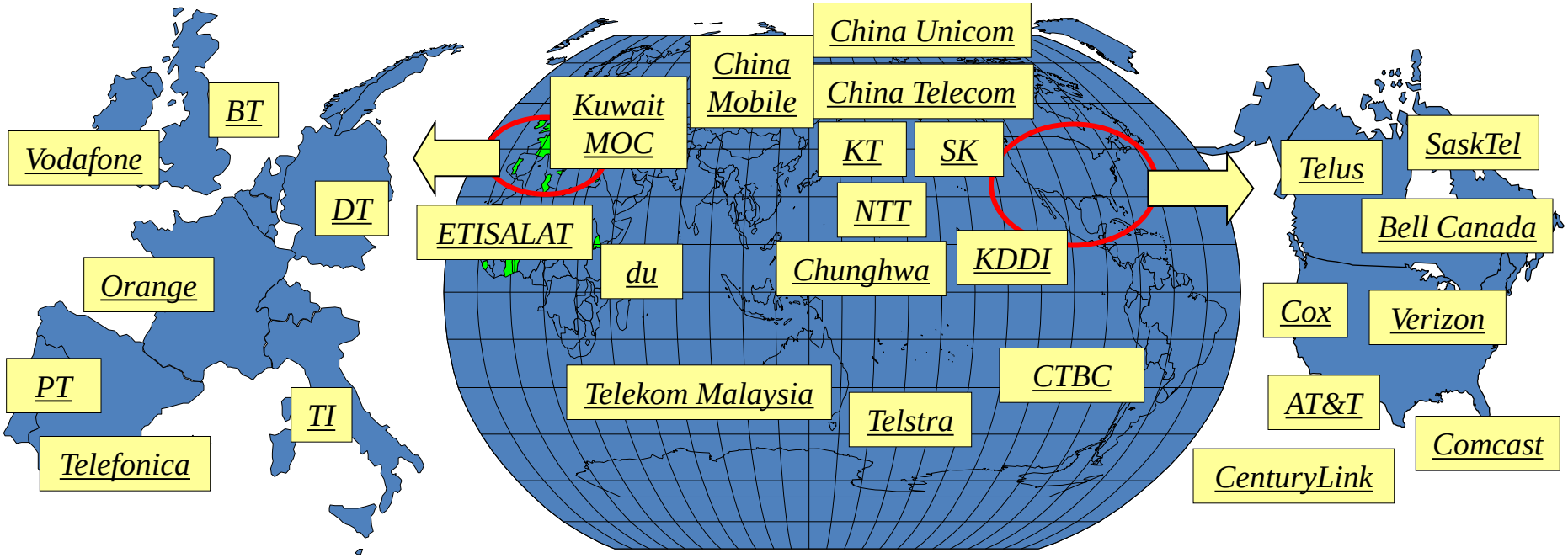
FSAN
Full Service Access Network

Guided by global operator community



- FSAN (Full Service Access Network) is an industry interest group
  - Global operator adoption leads to higher volumes and lower costs for all
  - Facilitate standards development for new, fibre-based access systems
  - Resultant standards enable future-proof broadband access networks
- Activities support ITU-T standardization
  - Develop operator standards requirements
  - Identify, assess, evaluate technical solutions
  - Publish findings/recommendations in White Papers, press releases, and technical articles
  - Individual FSAN member companies contribute results into the ITU-T Study Group 15

Industry ecosystem well represented

81 member companies

44 Vendors

- *Chip*
- *Component*
- *System*

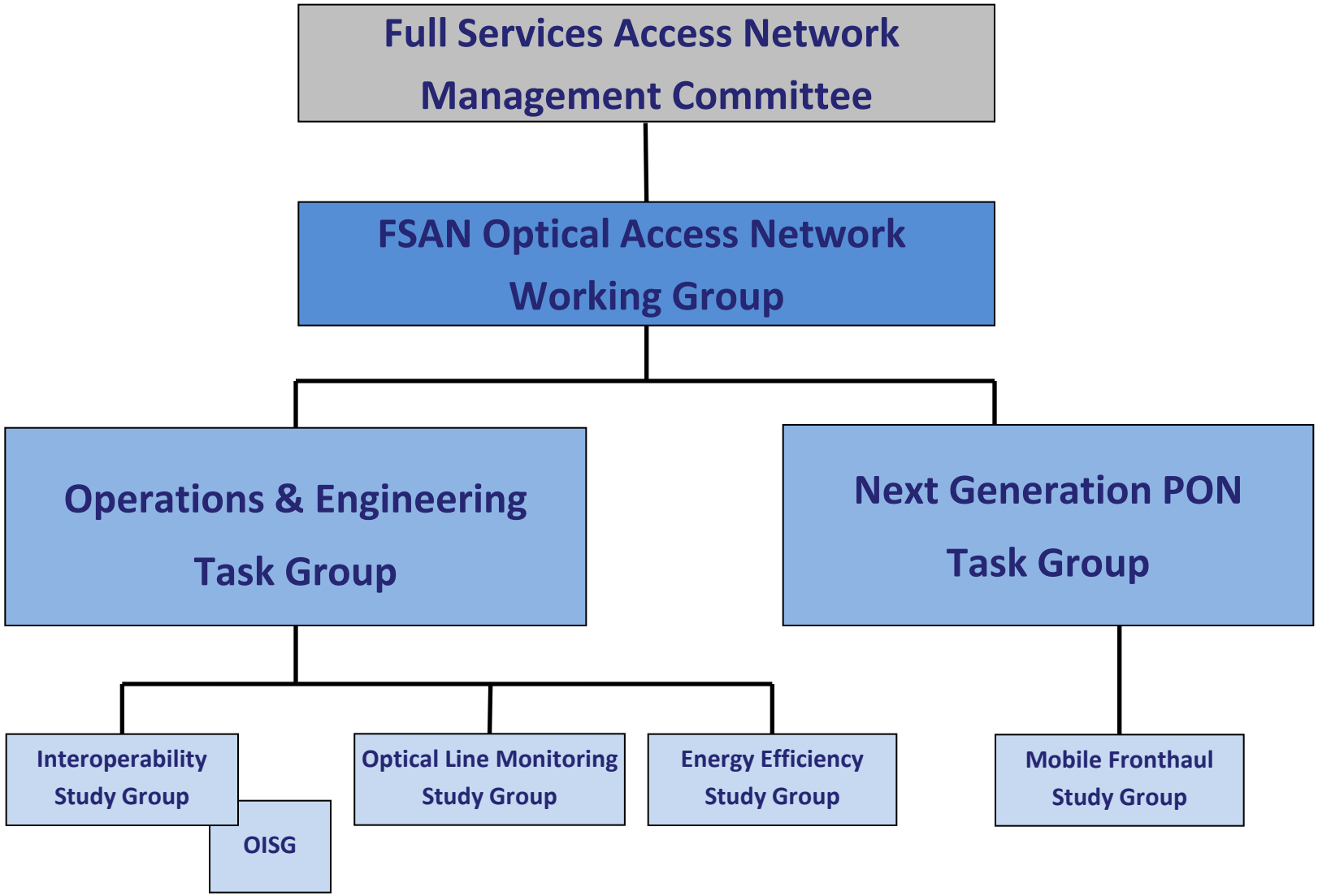
8 ITLs

29 Operators

Vendors	Vendors	Observer/ITL	FSAN OAN Operators
Adtran	iPhotonix	ETRI	AT&T
ADVA	Kaiam Europe (Gemfire)	ICL/ITRI	Bell Canada
Alcatel-Lucent	Lantiq	Iometrix	British Telecom
Alphion	LS Cable	LAN	Centurylink
ALU-Shanghai Bell	MACOM (Mindspeed)	MT2	China Mobile
Broadcom	Marvell	NTT-AT	China Telecom
Calix	Microsemi (Zarlink)	RITT	China Unicom
Cambridge	Mitsubishi	Univ. New Hampshire	Chunghwa Telecom
Cisco	NEC		Comcast
ClariPhy	NeoPhotonics		Cox
Comtrend	OFS Fitel		CTBC
Coriant	OKI		Deutsche Telekom
Cortina	Optical Zonu		du
ECI Telecom	Photop (Aegis)		ETISALAT
Ericsson	PMC Sierra		KDDI
Ericsson-LG	Semtech (Gennum)		Korea Telecom
Fiberhome	TECOM		Kuwait MOC
Finisar	Tellabs		NTT
Fujitsu	Tellion		Orange
Hisense-Ligent	T&W		Portugal Telecom
Hitachi	Zhone		SaskTel
Huawei	ZTE		SK Telecom/SK Broadband
			Telecom Italia
			Telefonica
			Telekom Malaysia
			Telstra
			Telus
			Verizon
			Vodafone

as of Nov 2014

FSAN structure



Standards development and interop

Late 1990s

APON/BPON
1.24 Gb/s DS, 622 Mb/s US
G.983 Series

2003/2004

GPON
2.48 Gb/s DS, 1.24 Gb/s US
G.984 Series

2009/2010

XG-PON1
10 Gb/s DS, 2.48 Gb/s US
G.987 Series, G.988

2014/2015

NG-PON2
40 Gb/s DS, 10 Gb/s US
G.989 Series

FSAN
Full Service Access Network

Requirements

ITU International Telecommunication Union

Standards

Interoperability

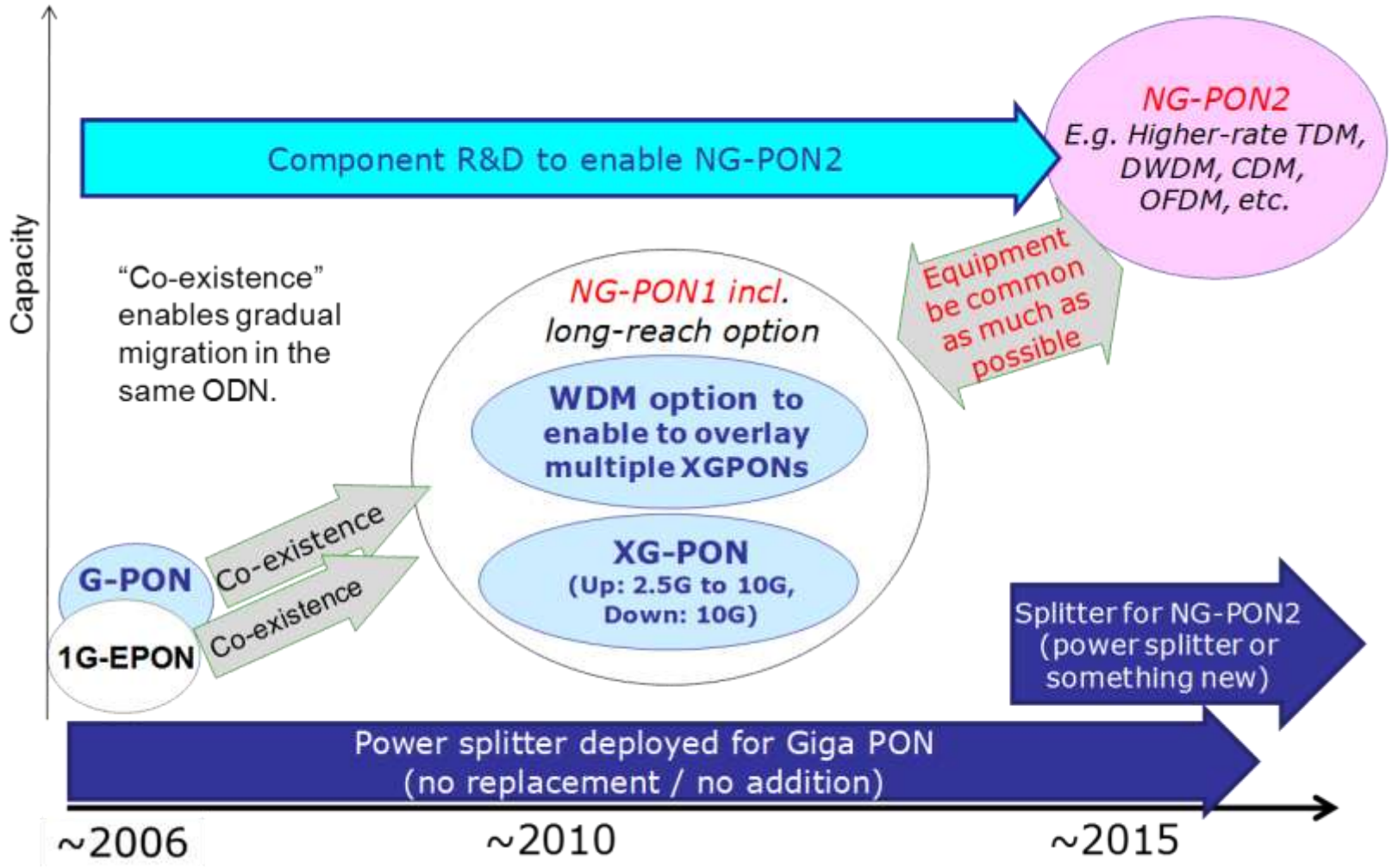
broadband forum

Interop Testing

Factors driving new standards

- **Need to improve cost/performance**
- **Consolidate service platforms to drive down TCO and/or WLC**
- **Increasing competition on "Speed"**
- **Address new application spaces**

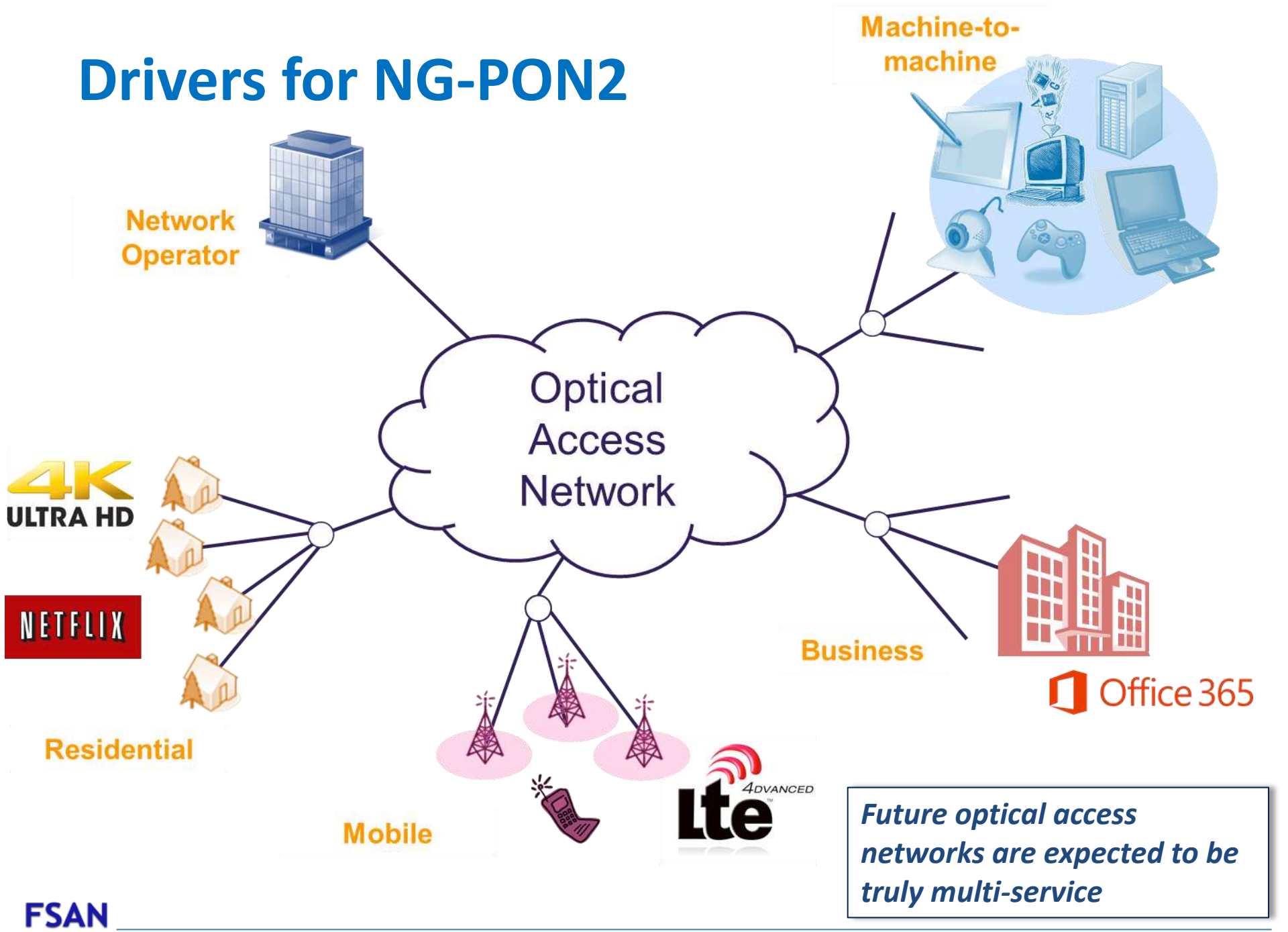
FSAN Roadmap



NG-PON2 Project in FSAN

- FSAN initiated the NG-PON2 project in 2010
- Started with initial workshops concerning the technology options
- FSAN Operators then developed a White Paper concerning their requirements for NG-PON2
- Followed by a Technology White Paper that proposed various NG-PON2 systems capable of meeting these requirements
- Through a process of requirements refinement to identify the “must haves”, system technologies were systematically set aside
- Continual checking throughout that we had sufficient understanding of both the technologies and requirements

Drivers for NG-PON2



Future optical access networks are expected to be truly multi-service

High Level Target Requirements for NG-PON2

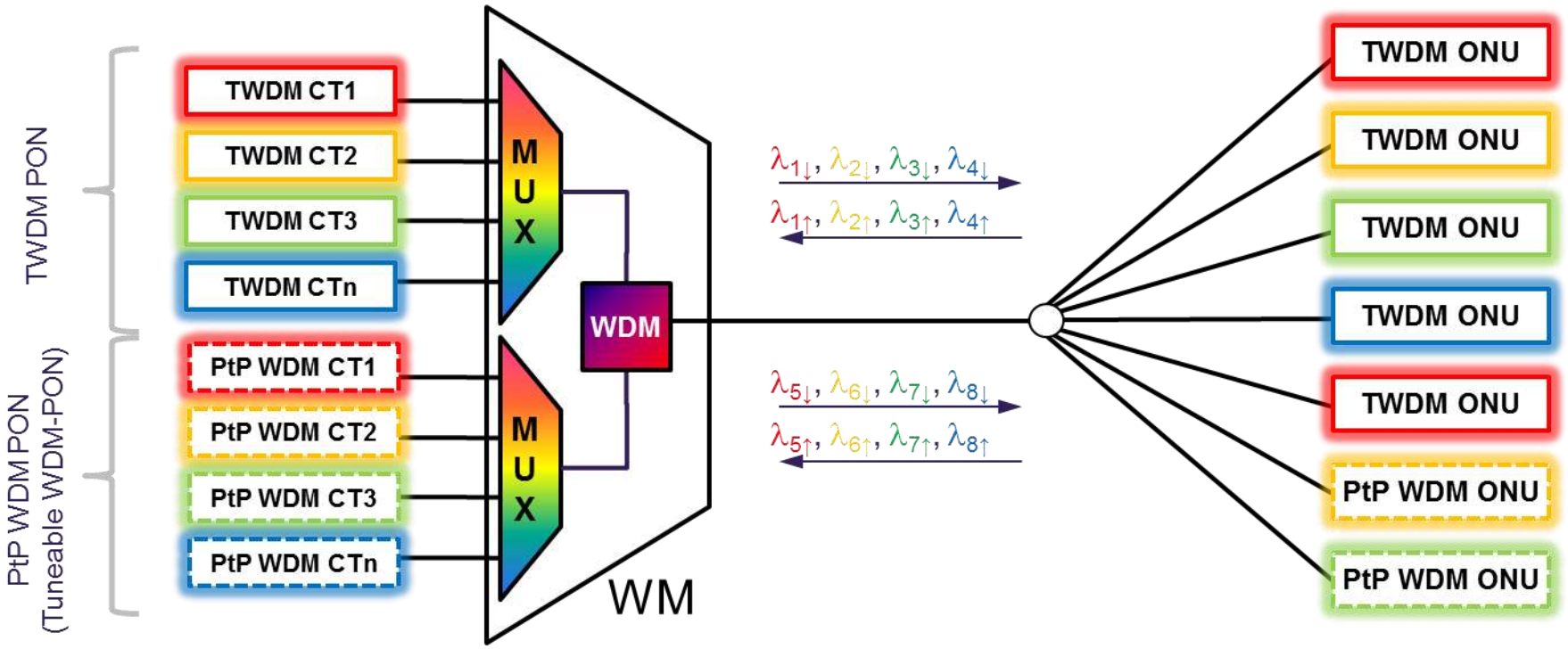
- Increased aggregate capacity per OLT PON port (e.g. ≥ 40 Gbit/s)
- Downstream 1Gbit/s and upstream 0.5 to 1Gbit/s sustainable bandwidth on any ONU
- Support ≥ 64 ONUs per port (256 ONUs or more also of interest)
- Compatible with legacy PON infrastructure (> 40 km reach)
- 40 km differential reach
- Smooth Migration
  - Legacy PON co-existence (G-PON and/or XG-PON1)
  - Smooth migration from a legacy PON on a per ONU basis
- Support for multiple applications on the same ODN (e.g. residential + business + backhaul)
- Embedded Test & Diagnostic capabilities
- Capable of reaching 60 km (preferably passive)
- Support of PON resilience, including dual parenting

Selected NG-PON2 Technologies

- TWDM-PON selected as the primary technology solution for NG-PON2 (in April 2012)
- With PtP WDM overlay channels
  - Many proposals concluded that the mobile fronthaul application was very challenging with TDMA-PON and easier to handle using dedicated wavelength channels
- Decision based on considerations of system cost, technology maturity, loss budget, complexity and power consumption.
- TWDM-PON does not excel in any one performance metric but provides a good balance of attributes for mass market residential broadband applications. It offers good performance with reasonable cost, using components mature enough to meet the NG-PON2 timescales.
- With the technology studies and consensus as a basis, NG-PON2 began ITU-T standardisation in 2012
  - First recommendation (G.989.1) defined the system Requirements; drawing extensively from the FSAN Operator White Paper
  - Consented in September 2012

So…. what is NG-PON2?

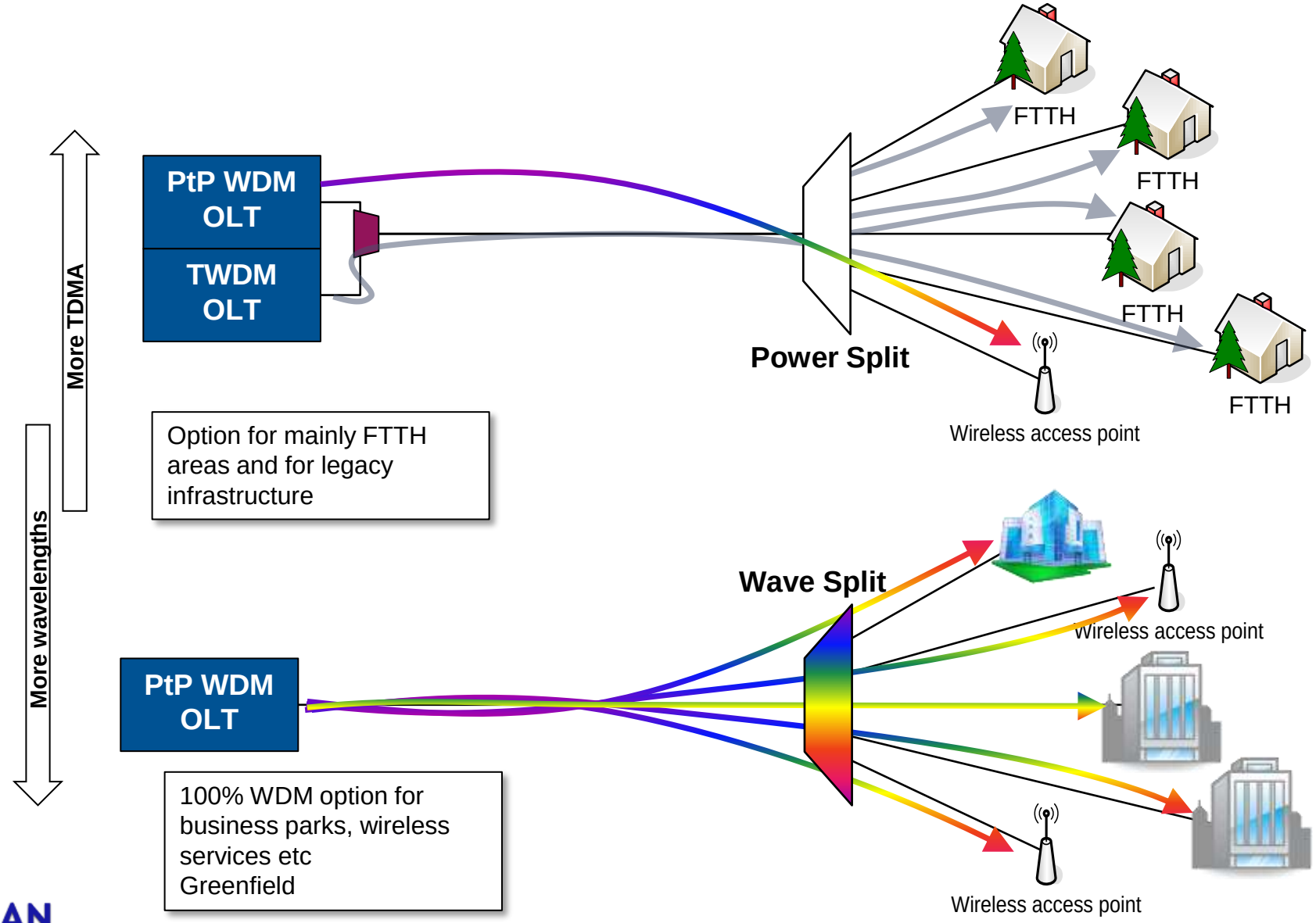
CT = Channel Termination
WM = Wavelength Multiplexer



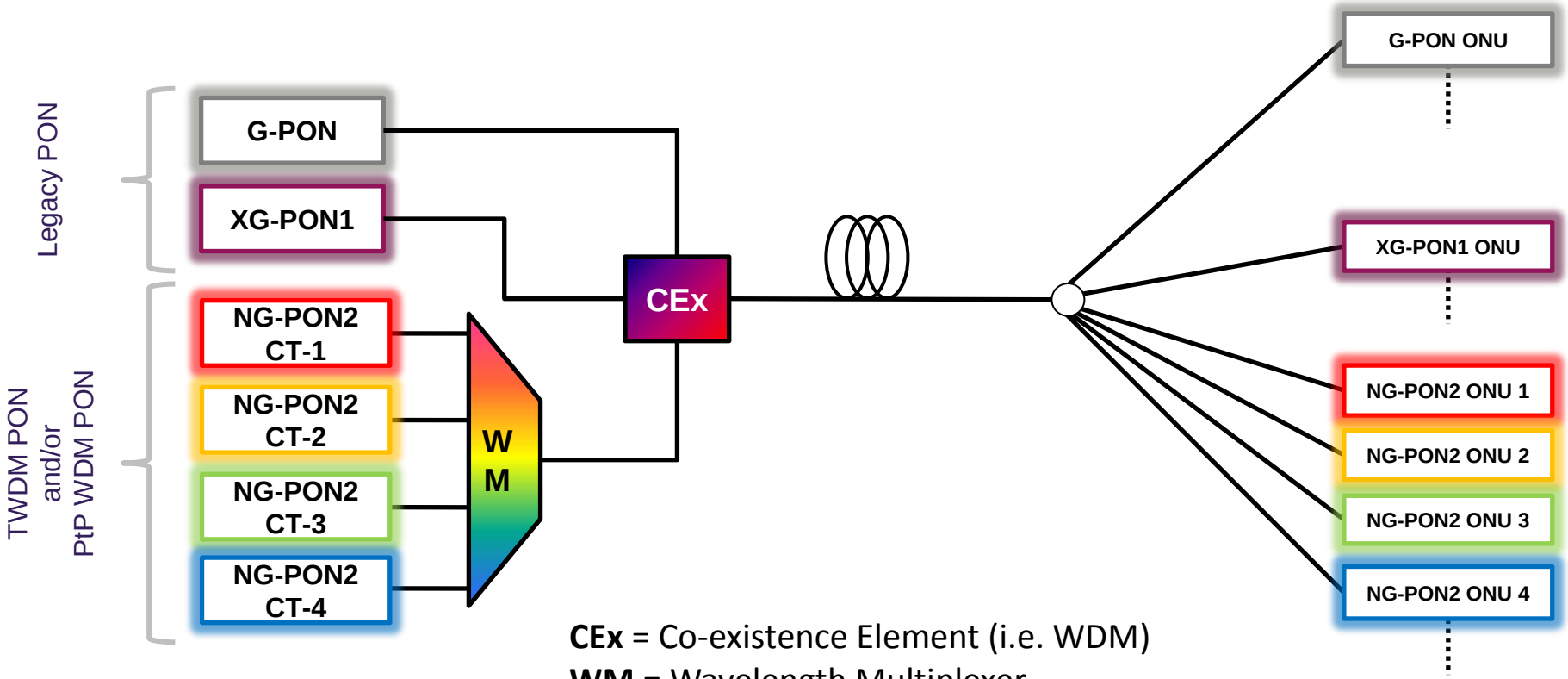
NG-PON2 = 40 Gigabit Capable Multi-Wavelength PON System

- Ch. # ⇨ Base = 1 – 4 TWDM (TDM/WDM) and Option = up to 8
  - PtP WDM (Ch# 8)
- TWDM Ch. Rates ⇨ Base = 10/2.5G and Options =10/10G and 2.5/2.5G
  - PtP WDM Ch. Rates ⇨ 1G, 2.5G and 10G classes
- ONUs are colourless and can tune to any assigned Channel

Flexible deployment options



Co-existence

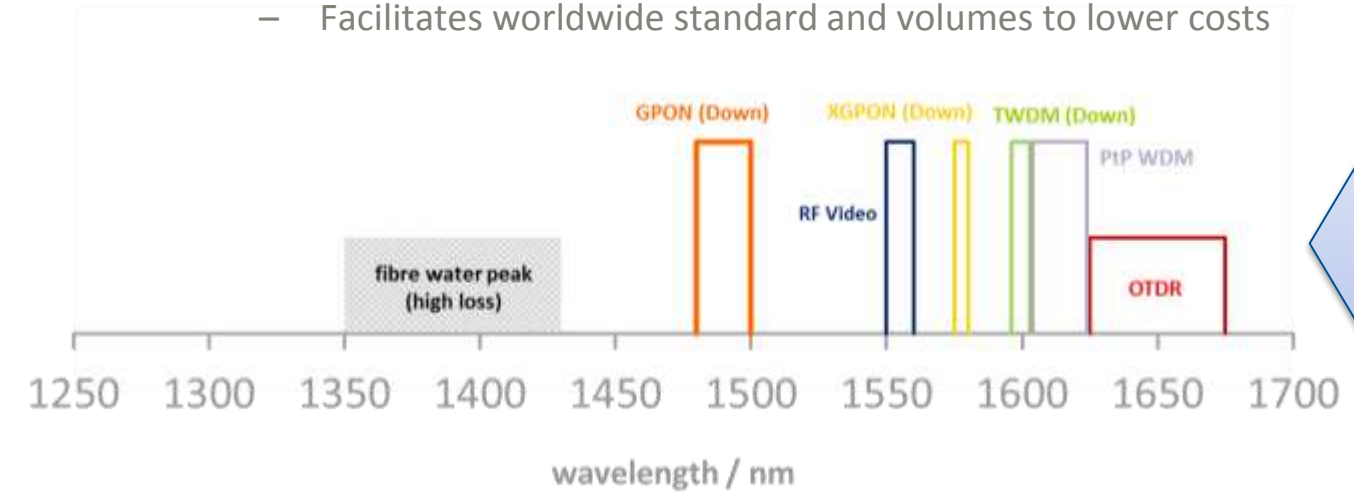


CEx = Co-existence Element (i.e. WDM)
WM = Wavelength Multiplexer

Co-existence with RF Video Overlay at 1555nm is accommodated by the wavelength plan but may need methods to compensate for Raman crosstalk that can impact lower frequency RF channels.
Due to the variety of RF Video implementations this will require joint engineering between the system vendor and network operator

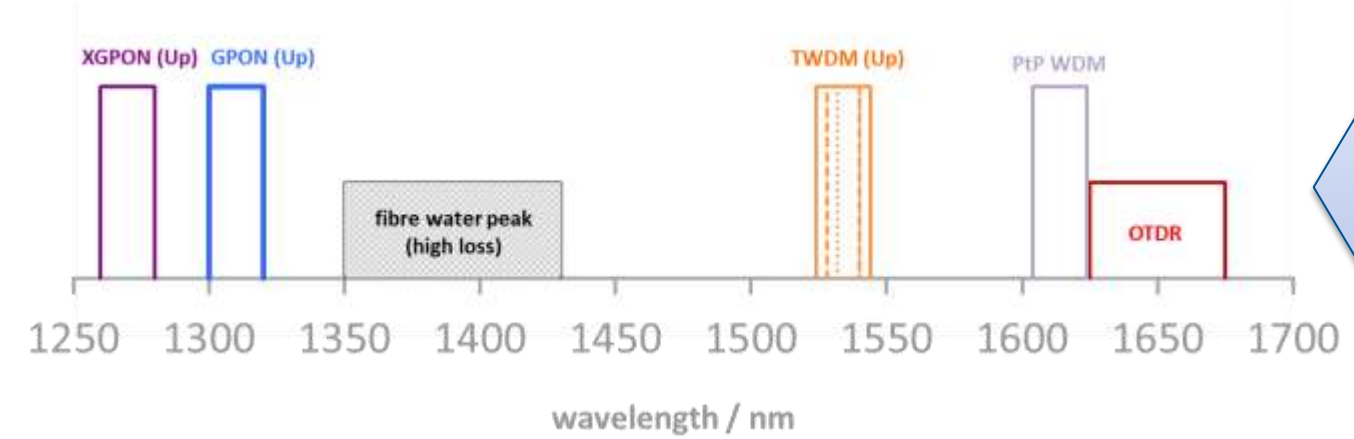
NG-PON2 Wavelength Plan

- Full co-existence with legacy ITU-T PONs (G-PON, XG-PON1) and RF video
- Enables a single Standard to meet the requirements of all FSAN Operators
  - Facilitates worldwide standard and volumes to lower costs



Downstream

The TWDM channels fit between XG-PON1 (DS) and OTDR (monitoring band). This enables simultaneous co-existence with legacy PON (G-PON and XG-PON1) and 1550nm RF video



Upstream

The TWDM channels work in the C-band above the WDM1r co-existence filter edge and below the 1550nm RF video band.
Use of C-band enables lower costs at the ONUs

Wavelength plans

- **TWDM**
  - DS : 1596-1603 nm
  - US : 1524-1544 nm (Wide)
    1528-1540 nm (Reduced)
    1532-1540 nm (Narrow)
  - Upstream wavelength options driven by differing capabilities of the ONU Tx to control it's wavelength
    - Wide band option is useable by a Wavelength Set approach to channel control where a DFB laser may drift over a wide range
    - Narrow band option may be most appropriate for temperature controlled lasers that can lock onto an assigned DWDM wavelength
- **PtP WDM**
  - US/DS : 1603-1625 nm (Shared Spectrum)
  - US/DS : 1524-1625 nm (Expanded Spectrum)
- Shared spectrum is the useable wavelength band considering the scenario of full co-existence with legacy PON systems
- Expanded Spectrum fully exploits the concepts of spectral flexibility in NG-PON2 by enabling bands not being used to be utilised by PtP WDM. This option may also be most beneficial in a Greenfield scenario with no legacy co-existence limitations

Line Rates

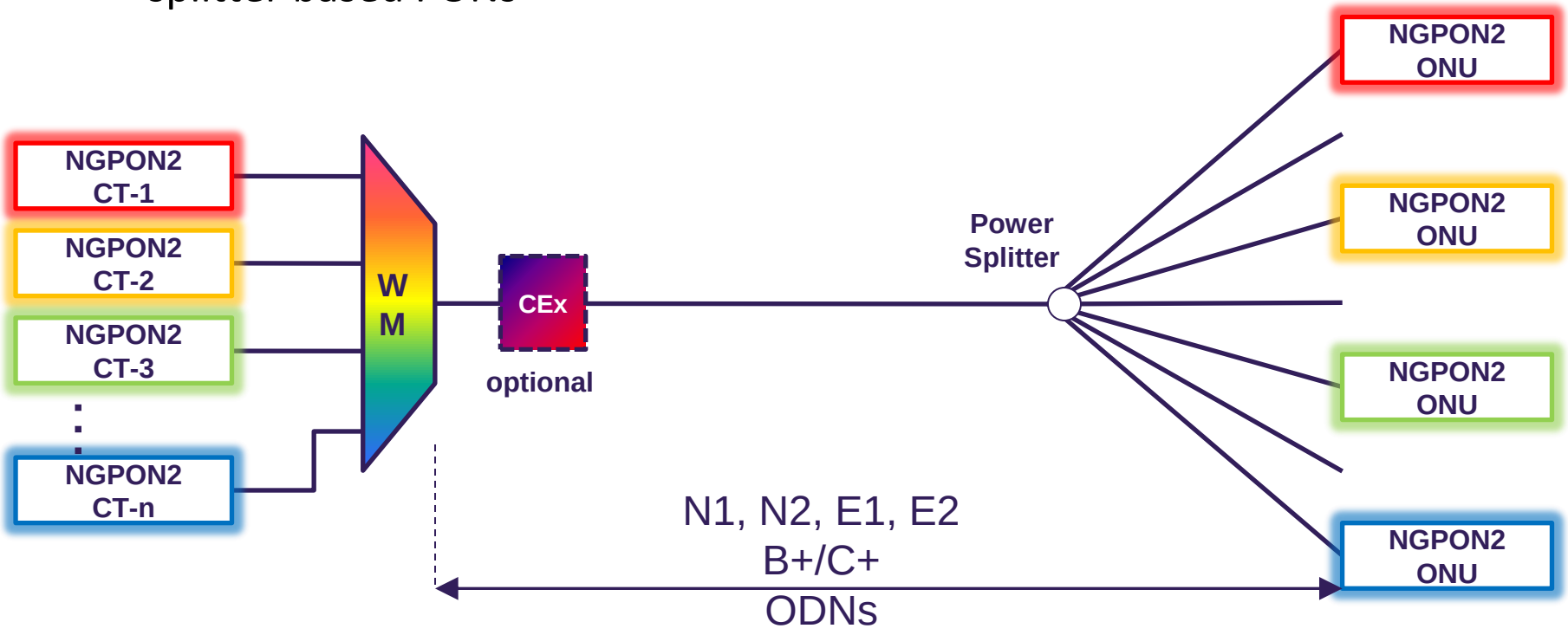
TWDM	Downstream line rate (Gbit/s)	Upstream line rate (Gbit/s)
Basic Rate	9.95328	2.48832
Rate Option 1	9.95328	9.95328
Rate Option 2	2.48832	2.48832

PtP WDM	Downstream/Upstream line rate (Gbit/s)
Class 1	1.2288 - 1.2500
Class 2	2.4576 - 2.6660
Class 3	9.8304 – 11.09
Class 4	6.144 (still under study)

Clients: Ethernet, CPRI, SDH/SONET, OTN

Compatibility with legacy ODN

- It is a fundamental requirement of NG-PON2 that it works over power splitter based PONs



- Furthermore, NG-PON2 is compatible with legacy loss budget classes i.e. B+ / C+ (G-PON) and N1 / N2 / E1 / E2 (XG-PON1)
- … and legacy differential losses (15dB) & differential reach (40km)

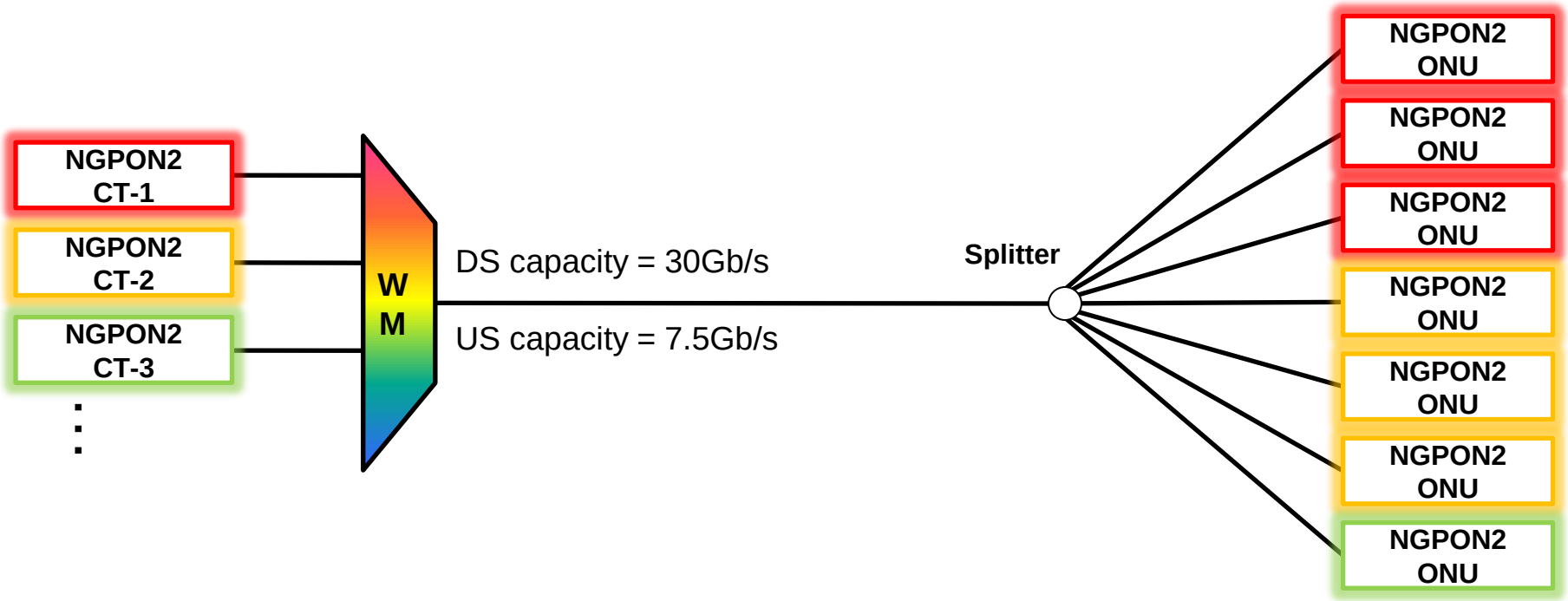
Optical Path Loss and Fibre Distance Classes

	Class N1	Class N2	Class E1	Class E2
Min Loss (dB)	14	16	18	20
Max Loss (dB)	29	31	33	35

Maximum differential optical path loss = 15 dB

Fibre distance class	Minimum (km)	Maximum (km)
DD20	0	20
DD40	0	40

Incremental Upgrade (Pay-as-you-Grow)



Incremental capacity can be added by provisioning additional NG-PON2 OLT channels. The ONUs are colourless and can tune to any NG-PON2 channel. This can also allow channel capacity management by redistributing ONUs across the available NG-PON2 channels

Classes of Tx/Rx Wavelength Channel Tuning Time

- Classes for the wavelength channel tuning time of the ONU Tx and Rx are defined
- These Classes open up various use cases for wavelength tunability e.g. dynamic wavelength assignment and advanced power saving
- The classes were broadly defined based on known wavelength tunable technologies
  - Class 1 components may include switched laser or filter arrays
  - Class 2 components may be based on electronically tuned lasers (DBR)
  - Class 3 components could be thermally tuned DFBs

Class 1	< 10 µs
Class 2	10 µs to 25 ms
Class 3	25 ms to 1 s

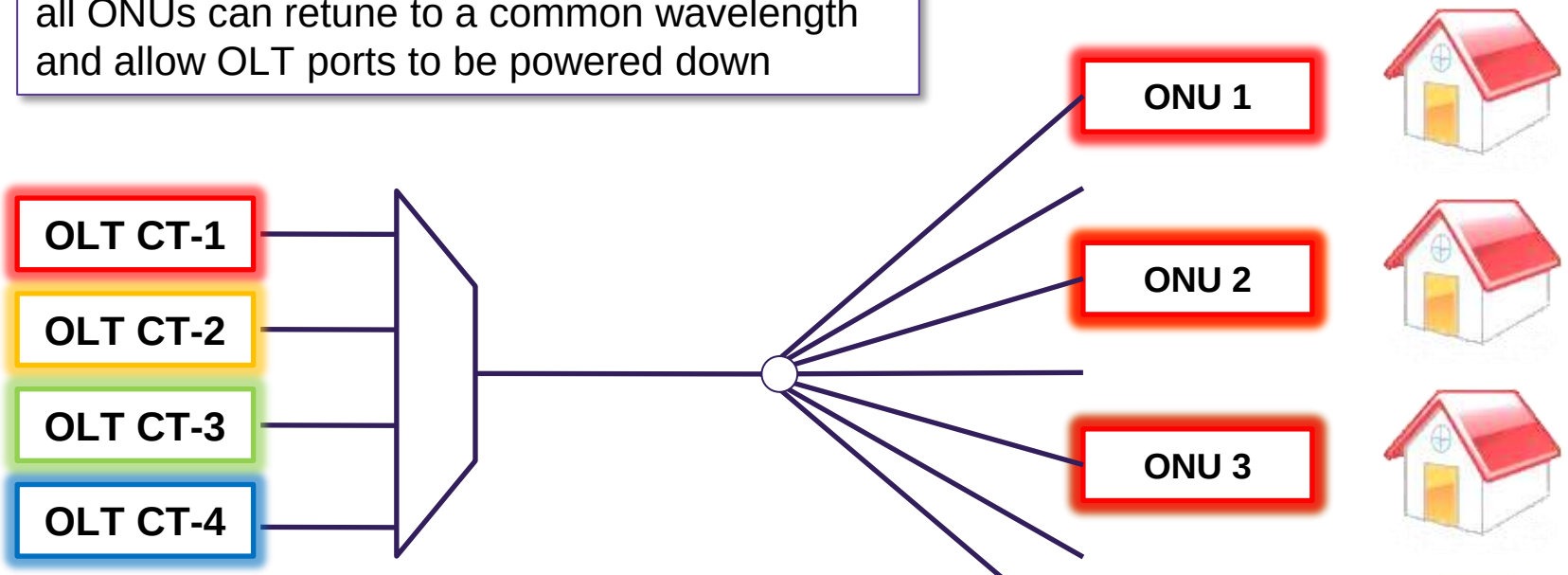
Use cases enabled by wavelength agility

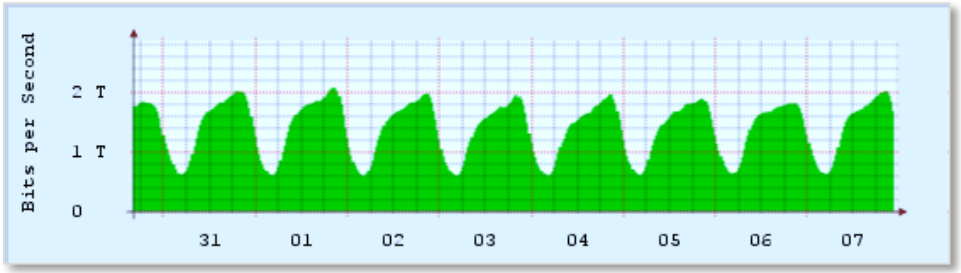
- TWDM PON allows enhanced network functionalities unavailable in previous generations of pure TDM PONs.
- Incremental bandwidth upgrade (pay-as-you-grow)
- Load balancing under for congested wavelength channels
- Selective OLT port sleep for power saving during low traffic periods
- Resilience against OLT transceiver failures through ONU retuning
- Fast, dynamic wavelength and timeslot assignment using DWBA (extra degree of freedom c.f. DBA today) to improve bandwidth utilisation efficiency

- Application details depend on Tx/Rx Tuning Time Class

OLT Power Saving

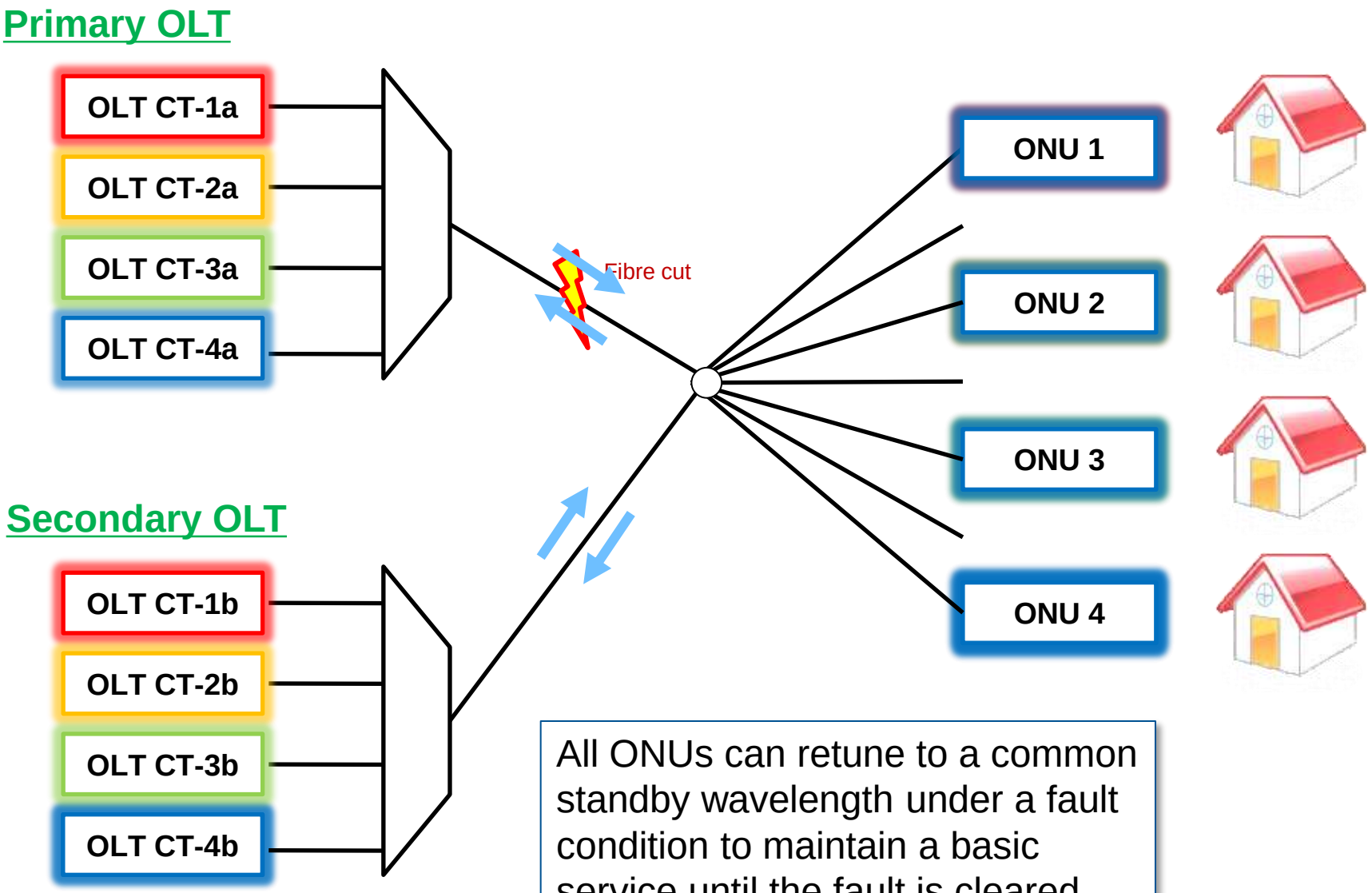
During times of low traffic load (e.g. overnight) all ONUs can retune to a common wavelength and allow OLT ports to be powered down





https://stats.linx.net/

Protection and Resilience for Service Restoration



All ONUs can retune to a common standby wavelength under a fault condition to maintain a basic service until the fault is cleared

Standards progress

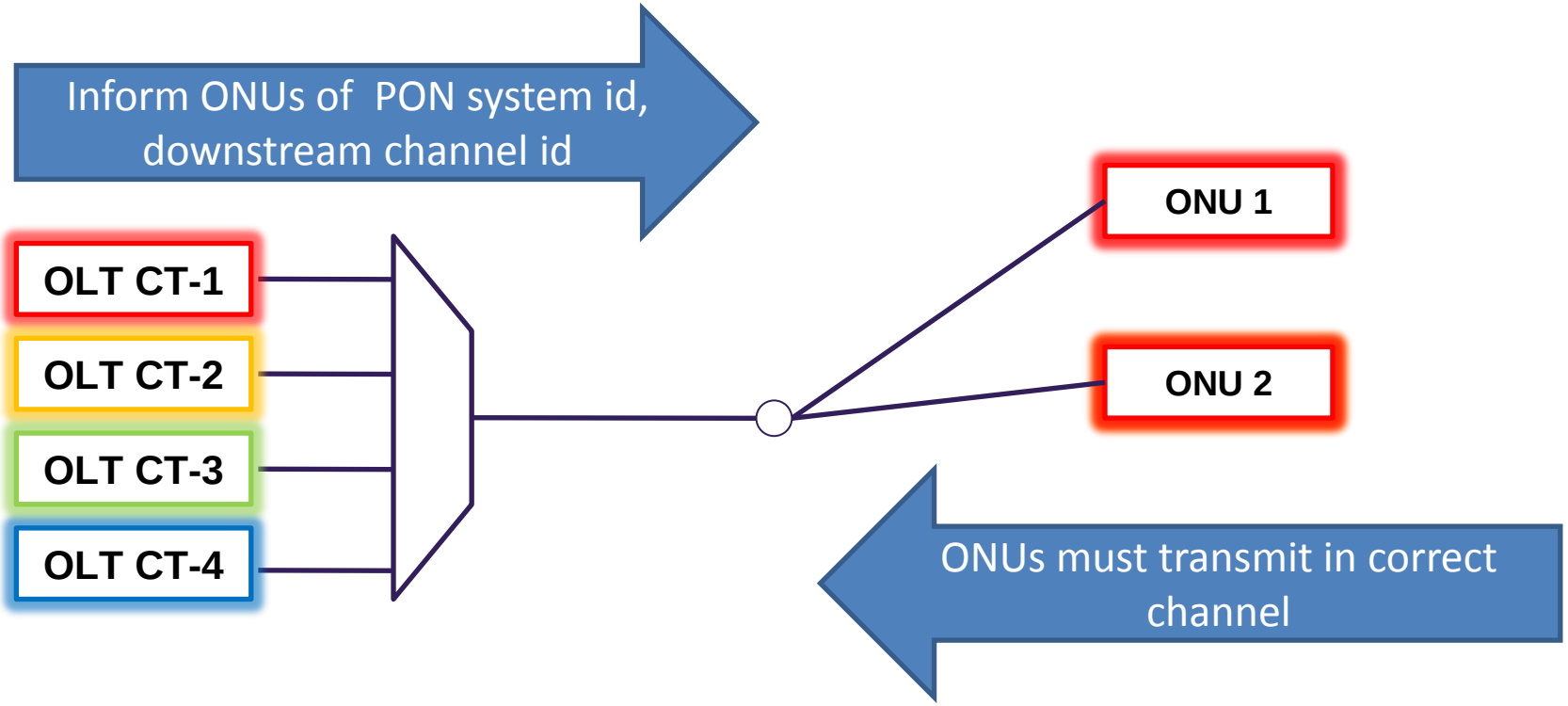
- Standardisation of NG-PON2 is proceeding rapidly in the ITU-T (considering the extra complexities involved)
- G.989.1 contains the general requirements for the NG-PON2 (approved and published)
- G.989.2 specifies parameters for the physical layer (approved Dec. 2014)
  - Wavelength plans
  - Optical loss budgets
  - Line rates
  - Modulation format
  - Wavelength channel parameters (spectral excursion, Tx SNR, etc)
  - ONU tuning time classes
- G.989.3 specifies transmission convergence (TC) layer protocols for NG-PON2 (consent targeted Jul. 2015)
- G.989 (no dot) contains the common definitions, acronyms, abbreviations, and conventions of the G.989 series of Recommendations (consent targeted Jul. 2015)

- FSAN and ITU-T (Q2/15) are working together to complete the G.989 series + any necessary OMCI changes to G.988

NG-PON2 transmission convergence layer

NG-PON2 has new capabilities that need protocol support

- Multiple wavelengths
- TWDM and point-to-point channels
- Start with a single channel, add more later
- Distributed OLT CTs can drive a single fibre



New protocol functions

- Multiple wavelengths so protocol supports tuning
- New identities needed to distinguish system, wavelength channel
- PtP WDM and TWDM activation and management need new protocol
- Dealing with ONUs with uncalibrated lasers that must not be allowed to transmit in the wrong wavelength channel
- Distributed OLT channel terminations need inter-channel messaging for some procedures
- New rogue scenarios to be detected and mitigated

Tuning support and identities

Tuning supported by

- Revised ONU state machine covering activation and channel management
- PLOAM messages added to control tuning
- New ONU parameter for tuning time

Identities for multiple wavelengths and distributed OLT CTs

- Each downstream channel wavelength advertises channel information including channel number and an identity of the PON system that owns the channel
- OLT CT can feed back upstream channel identity to ONU
- ONU can feed back the downstream channel and system identity it is receiving to OLT CT
- Distributed OLT controls ONU ID uniqueness across all channels, PtP WDM and TWDM
- To not limit a potential future extension, the protocol has code space for 16 wavelengths even though the physical layer specifies up to 8

PtP WDM and TWDM activation and control

PtP WDM capability needs a means to exchange control and management messages

- NGPON2 supports a wide range of PtP WDM devices transparently, so a new channel is defined called auxiliary management and control channel (AMCC)
- Auxiliary management and control channel (AMCC) is used for activation and control of PtP WDM channels. Carries PLOAM messages.

For TWDM in a distributed OLT system, a very low power non-interfering transmit capability is useful for ONU activation if an ONU cannot guarantee to start transmitting the correct wavelength

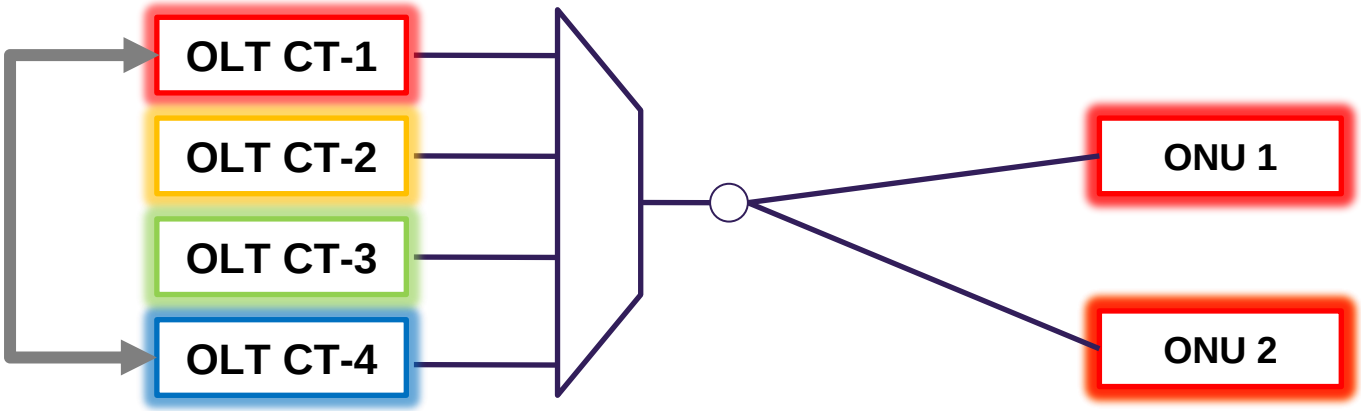
- Avoids having to synchronize quiet windows or use calibrated lasers
- ONU transmits at a level low enough to not interfere with working channels but detectable by the OLT. Information to be carried is minimal, for example the ONU serial number only (low capacity channel)

Handling uncalibrated ONUs

- NG-PON2 allows for the existence of different categories of ONU laser calibration
  - uncalibrated transmit at an initially unpredictable wavelength
  - loosely calibrated transmit with in a single channel band
  - calibrated transmit at correct upstream wavelength
- Allowing uncalibrated lasers aims to lower cost
- Protocol supports all laser types including dithering lasers that may drift

Inter-channel termination protocol

- OLT channel terminations are distributed so that some procedures require messages to be passed between OLT CTs
  - Synchronizing OLT CT Quiet Windows
  - ONU tuning
  - ONU activation
  - Parking orphaned ONUs
  - ONUs connected to the wrong ODN
  - Guided hand-off of ONUs Between OLT CTs
  - Rogue ONU Isolation

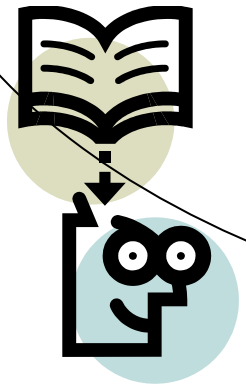


Rogue and protection scenarios

- ONU transmitter hops to wrong upstream channel
- ONU transmitter starts transmitting at wrong upstream wavelength
- OLT CT transmits in the wrong downstream wavelength channel
- Interference from co-existing devices, either faulty ones or due to spectral flexibility
- Distributed OLT channel terminations can be used for protection, requiring inter-channel termination co-ordination

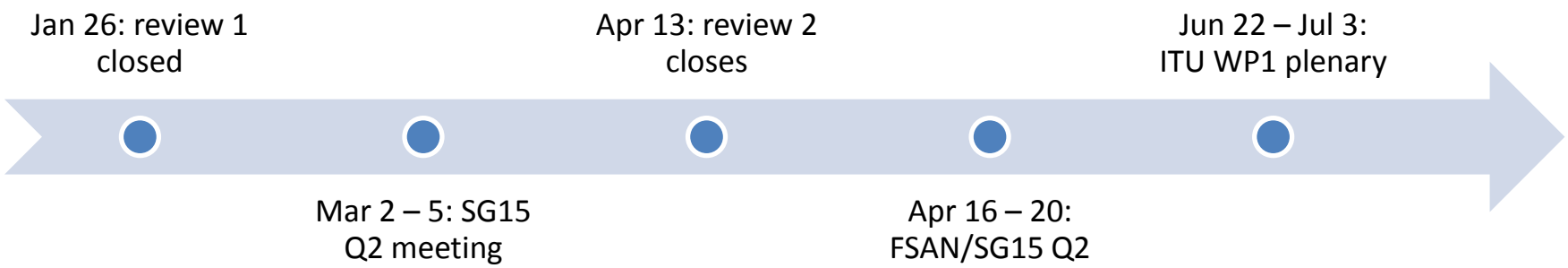
G.989.3 additions to G.987.3

- Activation cycle and activation state machine
- Silent start at the OLT
- TWDM channel management
- System protection
- Rogue behaviour
- Out of band management and control channel
- PtP WDM transmission convergence layer
- Tuning sequences
- Transcoded Framing with FEC and OAM for PtP WDM TC
- Protection Examples
- Appendix VI Inter OLT Channel Termination Protocol
- Appendix VII ONU ranging with consistent equalization delays across TWDM channels



Standards progress on G.989.3

- Editors: P. Dawes (VF), M. Jiang (CT), D. Khotimsky (VZ), K. Waters, (ALU), D. Zhang (ZTE)
- Original Q2 plan for consent at WP1 Plenary in December 2014 not met, but no big holes in the specification
- Timetable of informal last calls targeting Q2 consent in Jun/Jul 2015 SG15 Plenary Meeting
- First informal last call finished January 26th, editors and Q2 now working on resolving comments



G.989.3 Amd1 and other specs.

Protocol features are at different stages of maturity

- Core system features will form the basis of the first consented specification
- Non-core features needing further development will be added in amendments of G.989.3

Related specifications

- Rogue behaviour detection and mitigation to be described in a new G.Sup49
- Detailed specification of the inter-channel termination protocol is underway in the Broadband Forum

Background reading

- Here are some recent NG-PON2 papers that provide further background:
  - P. Chanclou et. al., “Network operator requirements for the next generation of optical access networks”, IEEE Network, vol. 26, no. 2, pp. 8–14, Mar. 2012.

    http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6172269

- Available as Early Access Articles through IEEE *Xplore*
  - D. Nesset, "NG-PON2 Technology and Standards", IEEE Journal of Lightwave Technology, 2015

    http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7005437
  - K. Asaka, "Consideration of Tunable Components for Next-Generation Passive Optical Network Stage 2 (NG-PON2)", IEEE Journal of Lightwave Technology, 2015

    http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7006659

THANKS