Wavelength-Enhanced Passive Optical Networks with Extended Reach

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Thanks to Han Hyub Lee, Xiang Zhou, and Pete Magill

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I. TDM-PON Overview

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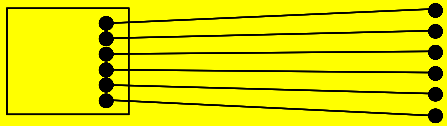
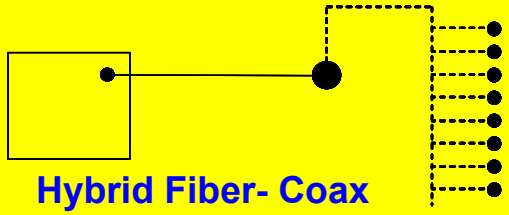
Broadband Access Architectures



- Secure
- Costly

Single star

- entrenched BB access
- Triple-play today

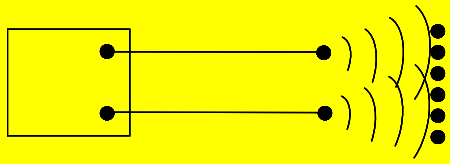


Hybrid Fiber- Coax

- More economical than single star for long fiber runs

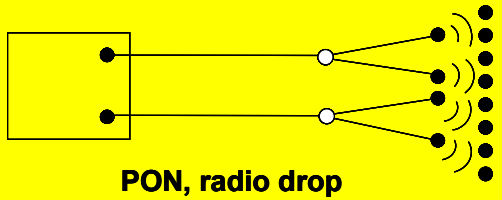
Active double star

BB Access with Fixed Wireless Drops



Single star, radio drop

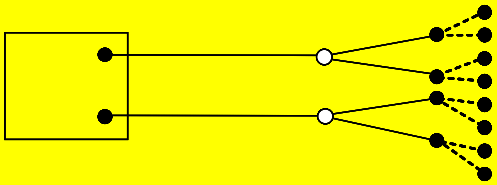
- Low cost drop
- Make the business Case at lower take rates



PON, radio drop

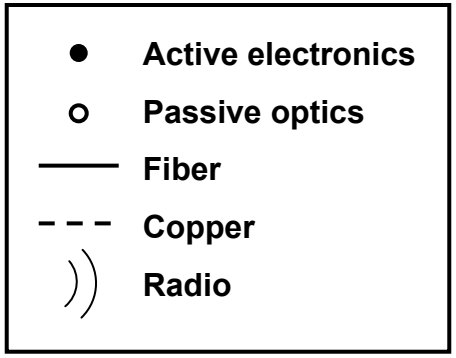
- No actives in field
- Reduced maintenance and operations

Passive Optical Network (Fiber to the Home)



- Lower cost per sub than FTTH
- Less BW than FTTH

Fiber to the node (or Fiber to the curb)



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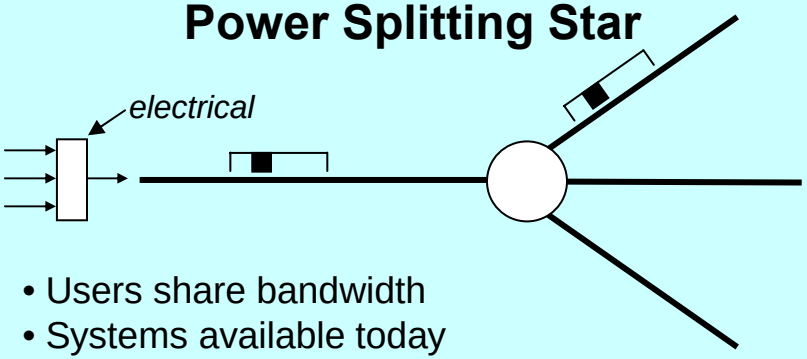
Passive Optical Network Types

(PONs: no actives or powering in outside plant)

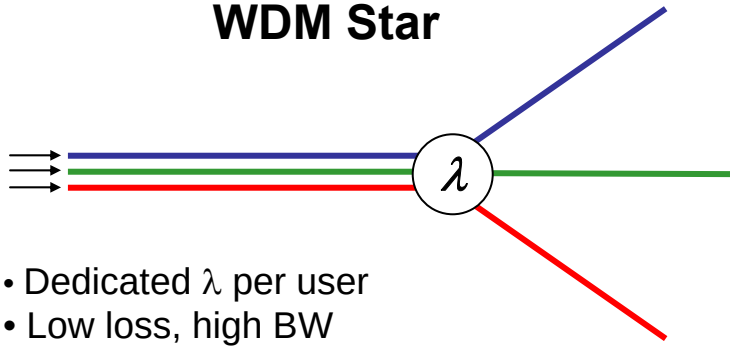
Power Splitting Star



- Users share bandwidth
- Systems available today
- Cheap optics

(e.g. ITU G.983)

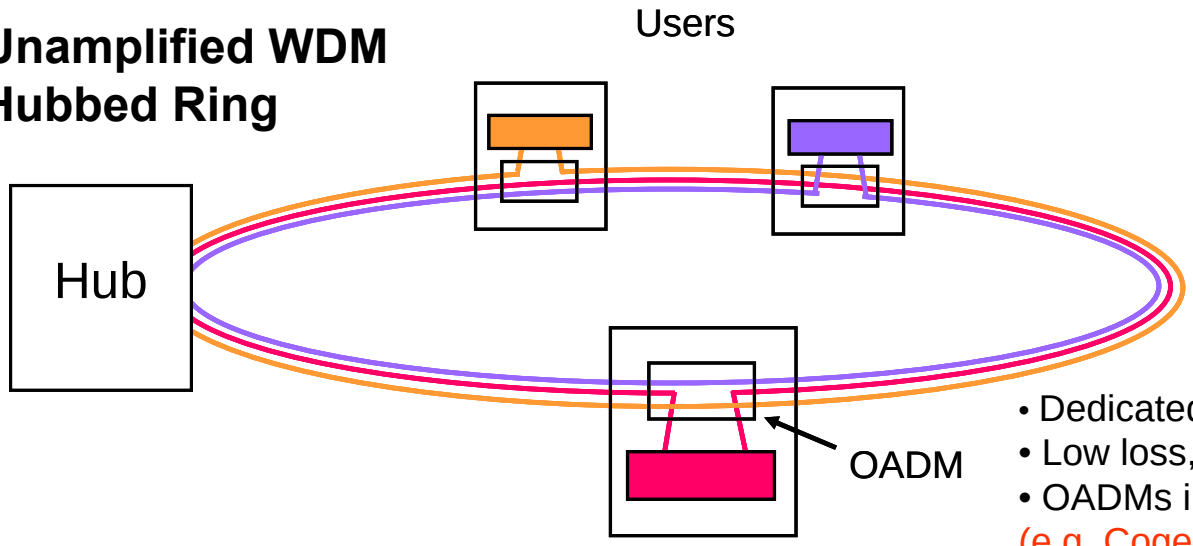
WDM Star



- Dedicated λ per user
- Low loss, high BW
- More expensive than power splitting

(e.g. CWDM for business, DWDM w/ Colorless ONTs, etc)

Unamplified WDM Hubbed Ring



- Dedicated λ per user
- Low loss, high BW
- OADMs in Multiple locations

(e.g. Cogent's CWDM FTTB network)

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TDM PON Standards

APON, BPON (ITU G.983.1 to G.983.8 ratified from 1998 to 2003)

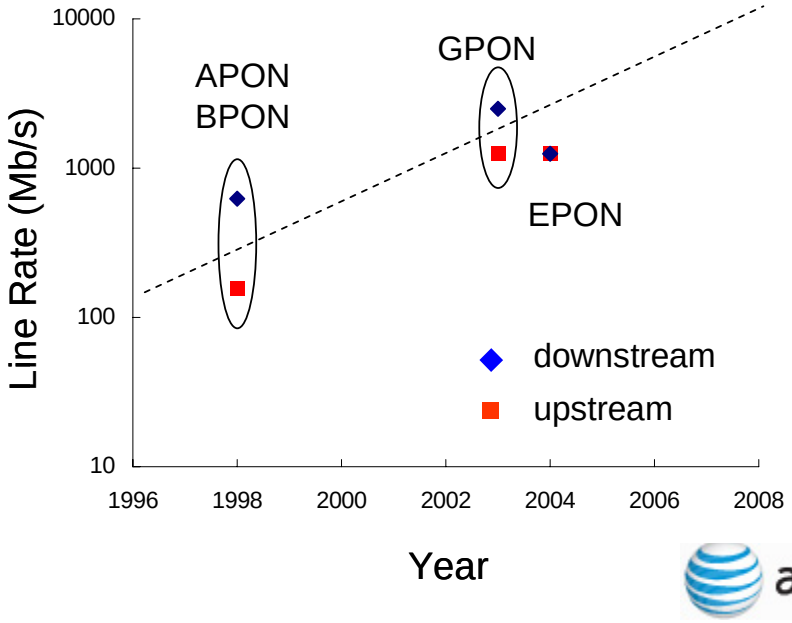
- 622 Mb/s downstream, 155 Mb/s upstream
- 20 km logical reach
- layer 2 protocol: ATM

GPON (ITU G.984.1 to G.984.4 ratified from 2003 to 2004)

- 2.5 Gb/s downstream, 1.25 Gb/s upstream
- 60 km logical reach, 20 km differential logical reach, up to 1:128 split
- Layer 2 protocol: Ethernet over GEM (generic encapsulation method)
- Improved bandwidth efficiency (92% downstream)

EPON (IEEE 802.3ah ratified 2004)

- 1.25 Gb/s downstream, 1.25 Gb/s upstream
- 20 km logical reach
- Layer 2 protocol: Ethernet
- Takes advantage of Ethernet cost structure
- Lower bandwidth efficiency (72% downstream)



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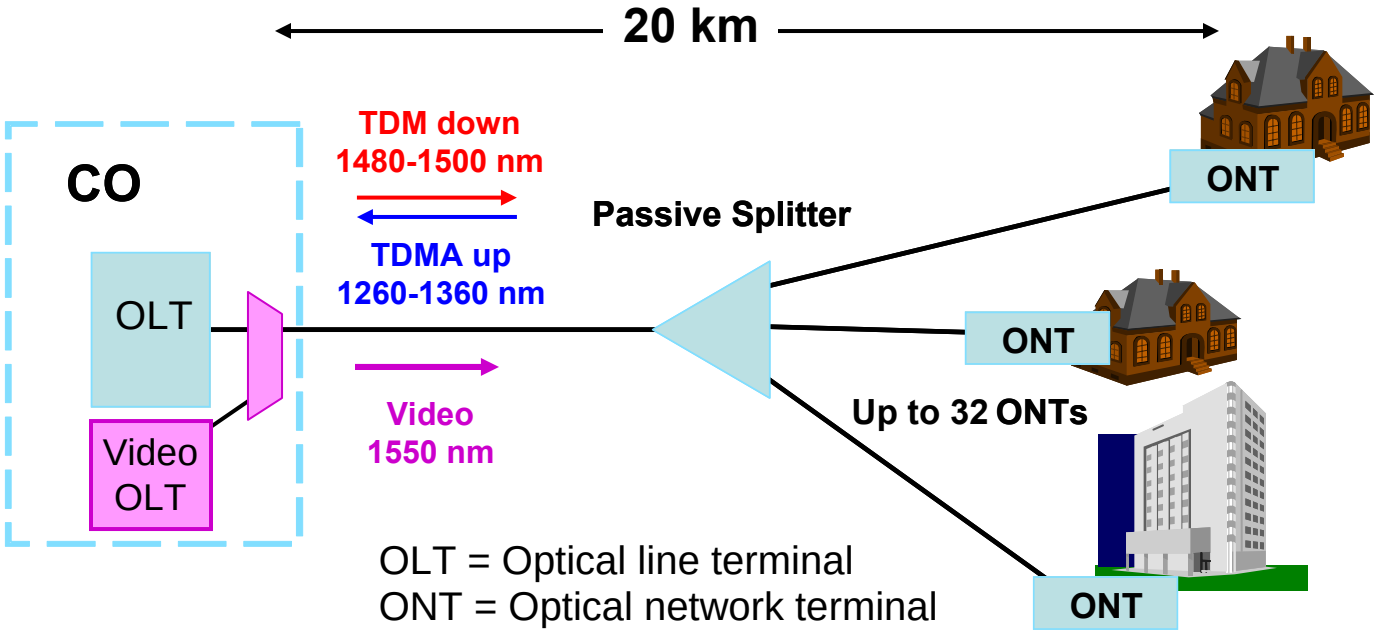
GPON is FTTH Network of Choice in N. America

- **Natural migration from BPON:** Supports legacy TDM svcs, Ethernet, IP
- **Video is essential:** Delivered over IP (IPTV) or over a separate optical band as conventional analog subcarriers (Enhancement Band as per BPON, G.983.3)
- **Reach:** Class B+ (28-dB) link budget allows 1:32 split with 20 km reach (1:128 split, 60 km logical reach permitted by standard but not practical today)



Wavelength-Enhanced Passive Optical Networks with Extended Reach

II. PON Evolution Beyond Current GPON (EPON)

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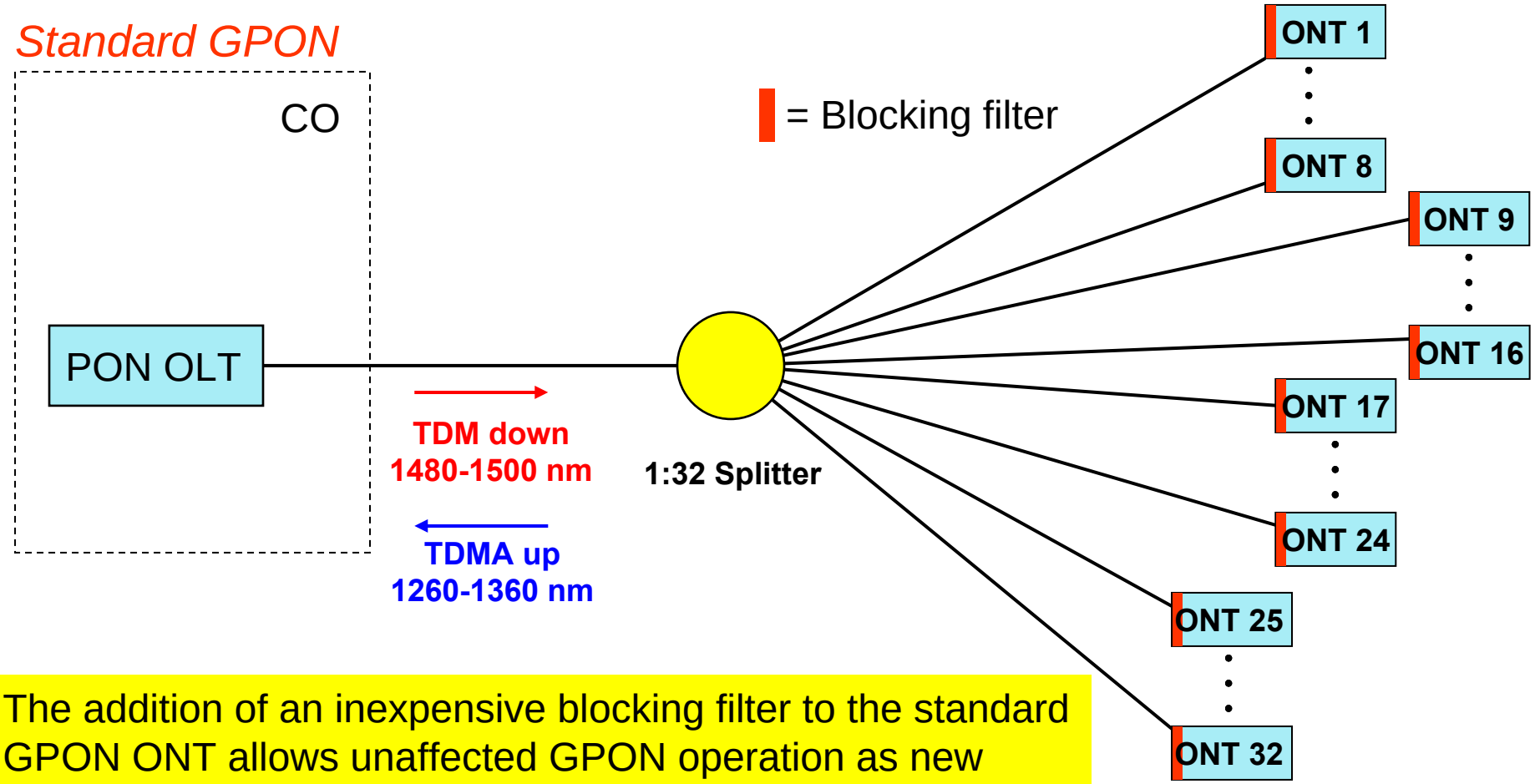
ONT Blocking Filters Permit λ Upgrades



The addition of an inexpensive blocking filter to the standard GPON ONT allows unaffected GPON operation as new wavelengths (future services) are added for some users

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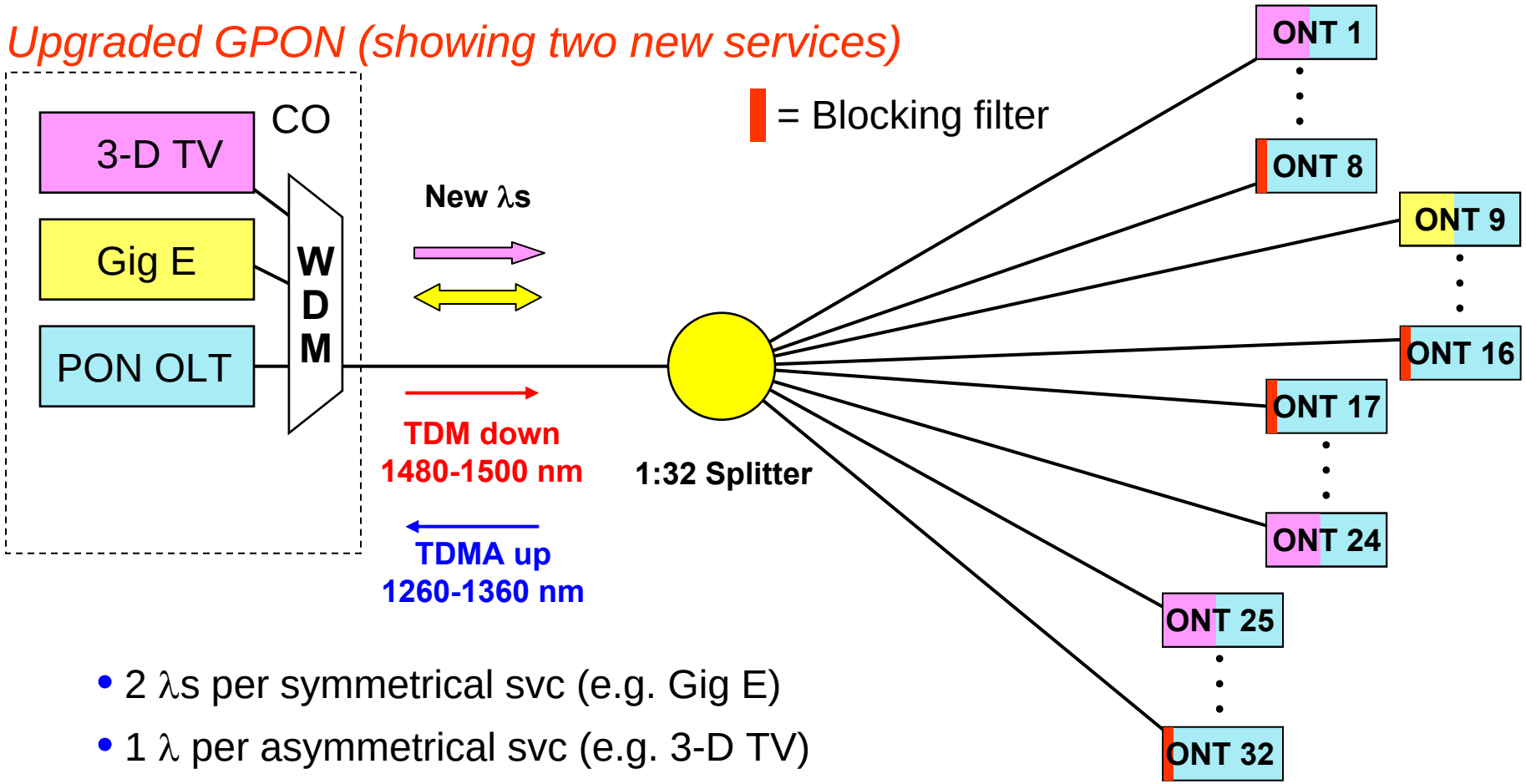
ONT Blocking Filters Permit λ Upgrades

C+L-band blocking filter will likely be standardized by ITU-T later this year



- 2 λs per symmetrical svc (e.g. Gig E)
- 1 λ per asymmetrical svc (e.g. 3-D TV)
- Only upgrade ONTs requiring new service

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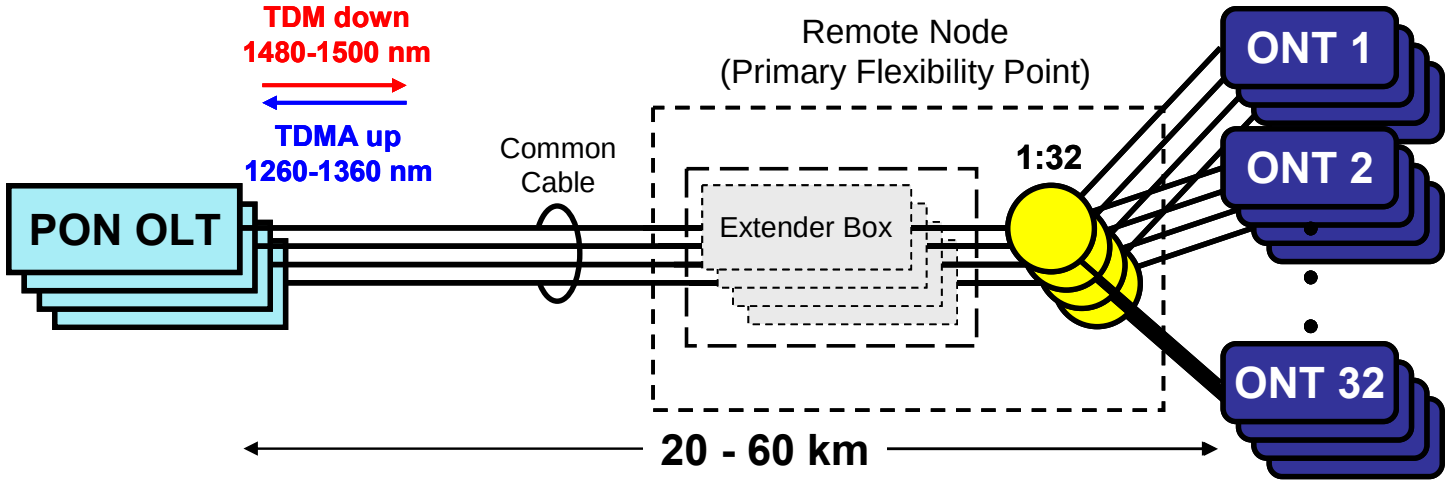
TDM PONs with Extended Reach / Split

I. Tactical use of a TDM PON "Extender Box"



- Extend current generation GPON (within 60 km logical limit)
  - 40 km would likely be sufficient given current placement of AT&T COs
- Use extender box only for those GPONs that would otherwise require remote OLT
  - Extender box has cost advantages (capex and opex) over powered remote OLT
- Consider OEO or optical amp-based "extender box"
- One extender box circuit per PON minimizes change to GPON architecture
  - No additional wavelength or electronic muxing (thus minimizing changes to OSS)

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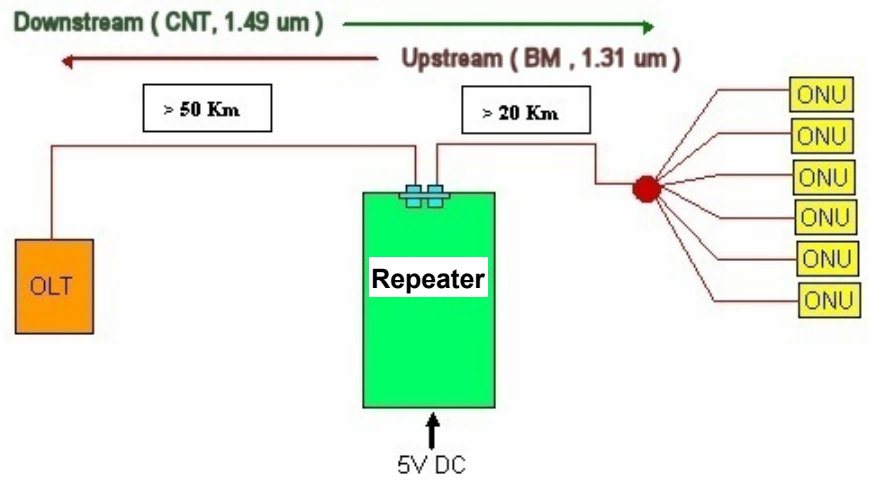
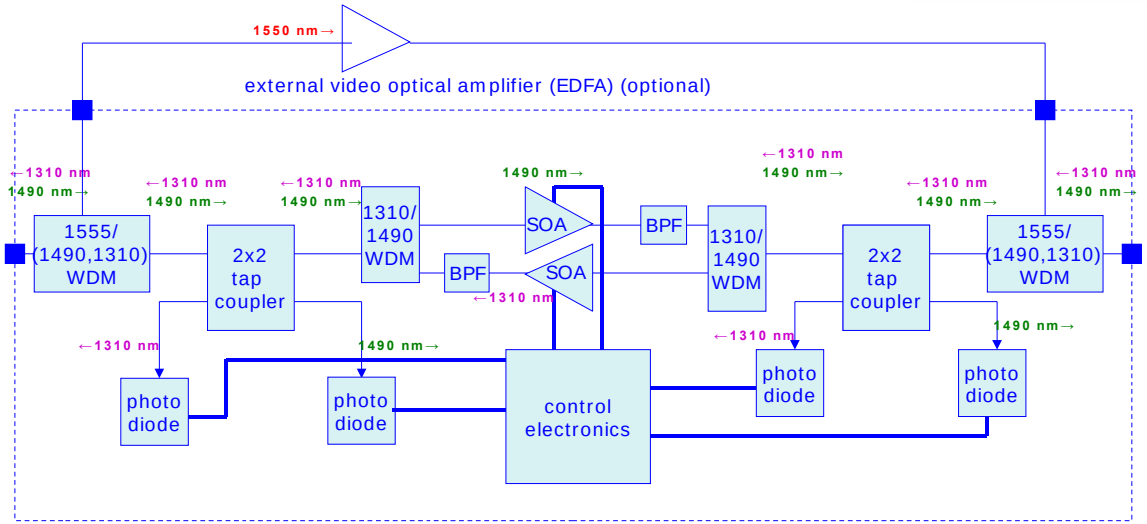
TDM PONs with Extended Reach / Split

I. Tactical use of a TDM PON "Extender Box"

OEO version: Zenko Technologies (Yusuke Ota)



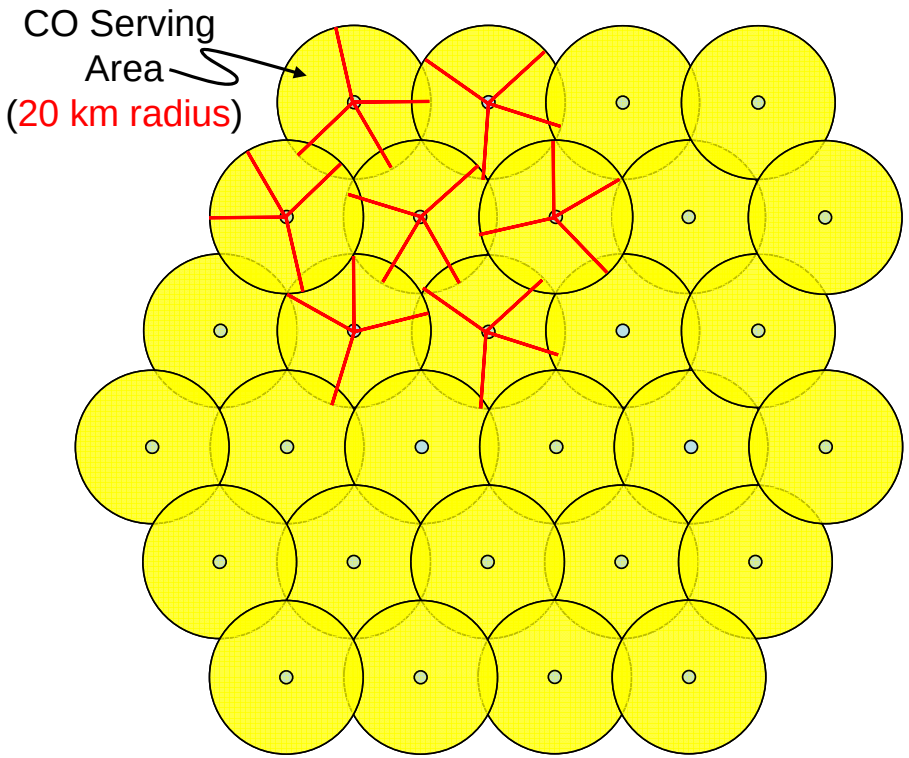
Optically-amplified version (SOAs): Alphion



TDM PONs with Extended Reach / Split

II. Strategic (long term) Use of Extender Box

BT's Long-Reach PON Strategy



○ **Central Office**

Red lines represent subset of individual PONs

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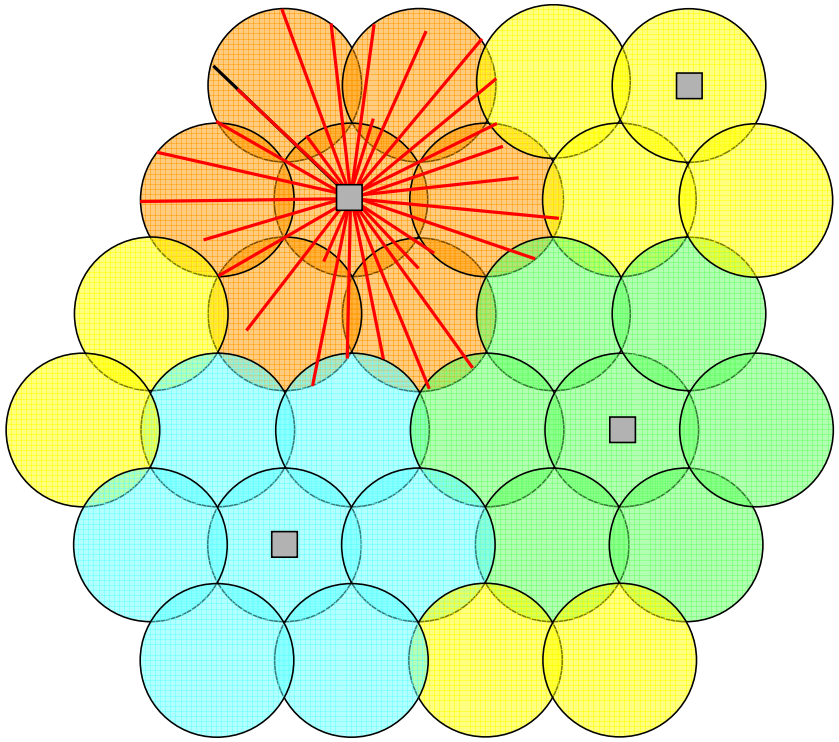
TDM PONs with Extended Reach / Split

II. Strategic (long term) Use of Extender Box

BT's Long-Reach PON Strategy (see Davey and Payne, *ECOC'05*, paper WE2.1.3)



- Long-reach PONs (60 – 100 km max reach)
  - Eliminate majority of COs
    Saves on: powering,
    real estate
  - Avoids remoting OLT
- Possibly increase users per PON
- WDM or TDM muxing between OLT and Extender Box
  - Shares feeder fiber
  - Reduces fiber management issues

New Central Office

Red lines represent subset of individual PONs

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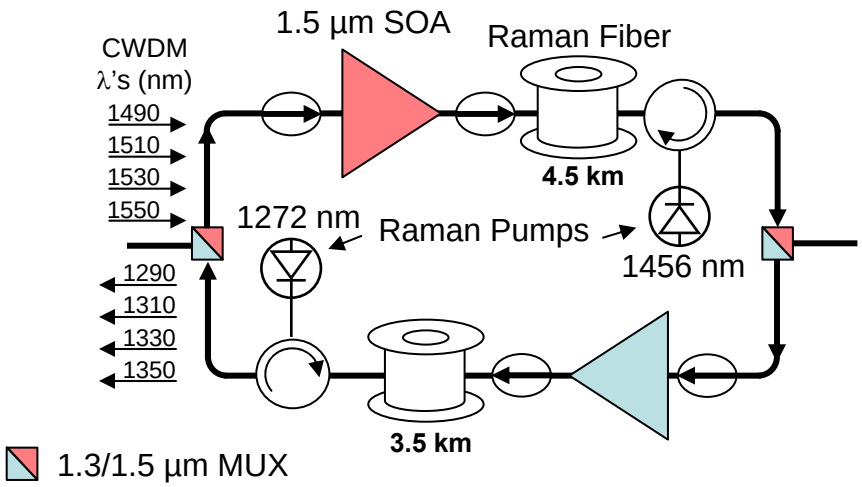
TDM PONs with Extended Reach / Split

II. Strategic (long term) Use of Extender Box

Bi-Directional Extender Box Based on Hybrid SOA-Raman Amplifiers



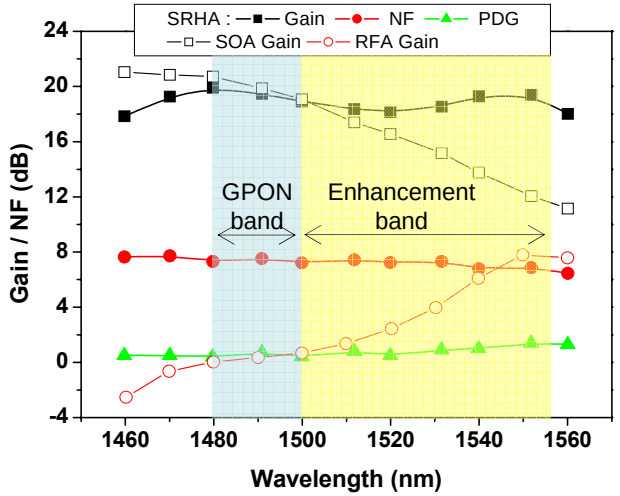
Downstream

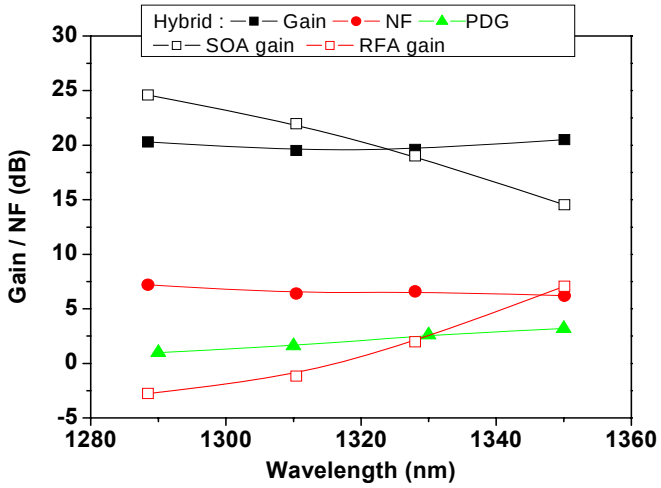
- 1500-nm SOA: 300mA
- 4.5-km Raman Fiber
- Raman pump: 247 mW@ 1456 nm

Upstream

- 1300-nm SOA: 300mA
- 3.5-km Raman Fiber
- Raman pump: 310 mW@ 1272 nm

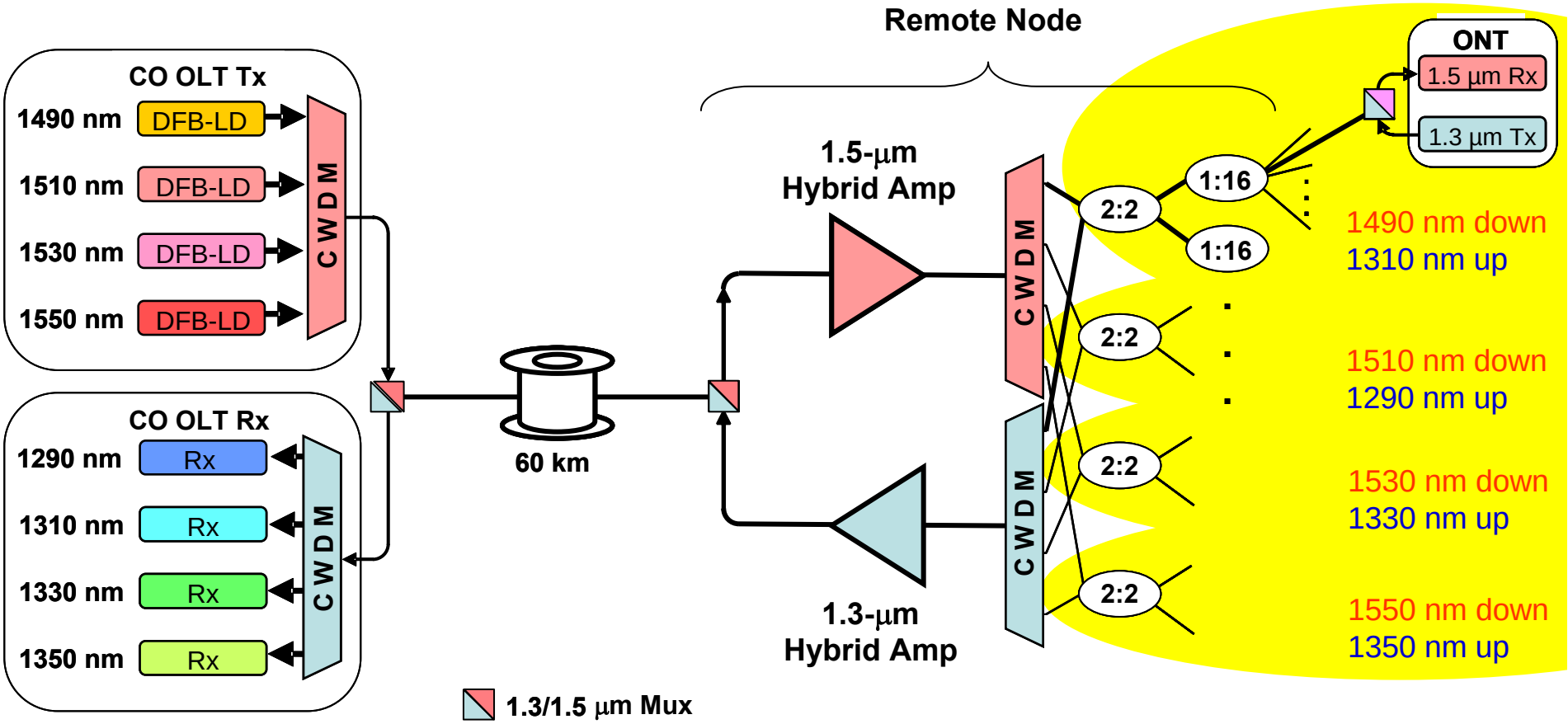
Downstream





Upstream

Experimental Set-Up



2.488 Gbps, 2^{31}-1 PRBS, Up and Down

Note: The erbium-doped fiber amplifier (EDFA) revolutionized optical communications with its capability of simultaneously amplifying a multiplicity of WDM channels. Due to low cost and high performance, it remains the only broadly deployed optical amplifier technology despite the fact that it has a limited optical bandwidth → **the hybrid amplifier may fill the niche for broadband (multi CWDM or DWDM) gain at any wavelength.**

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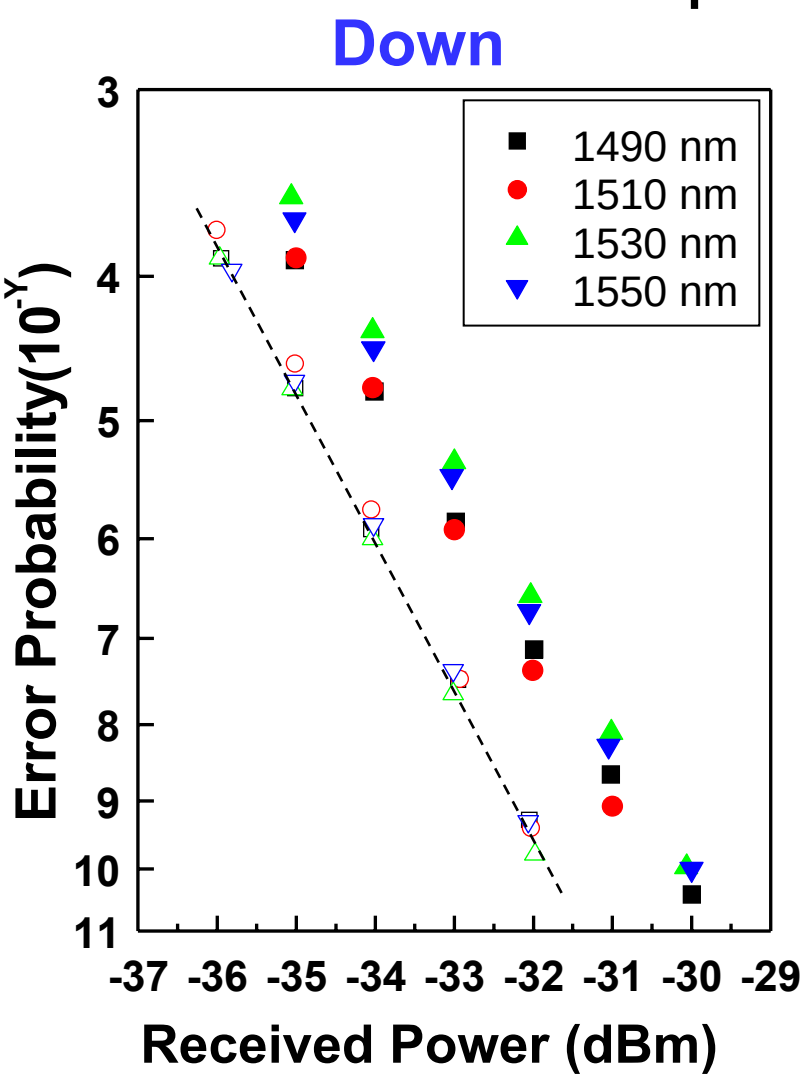
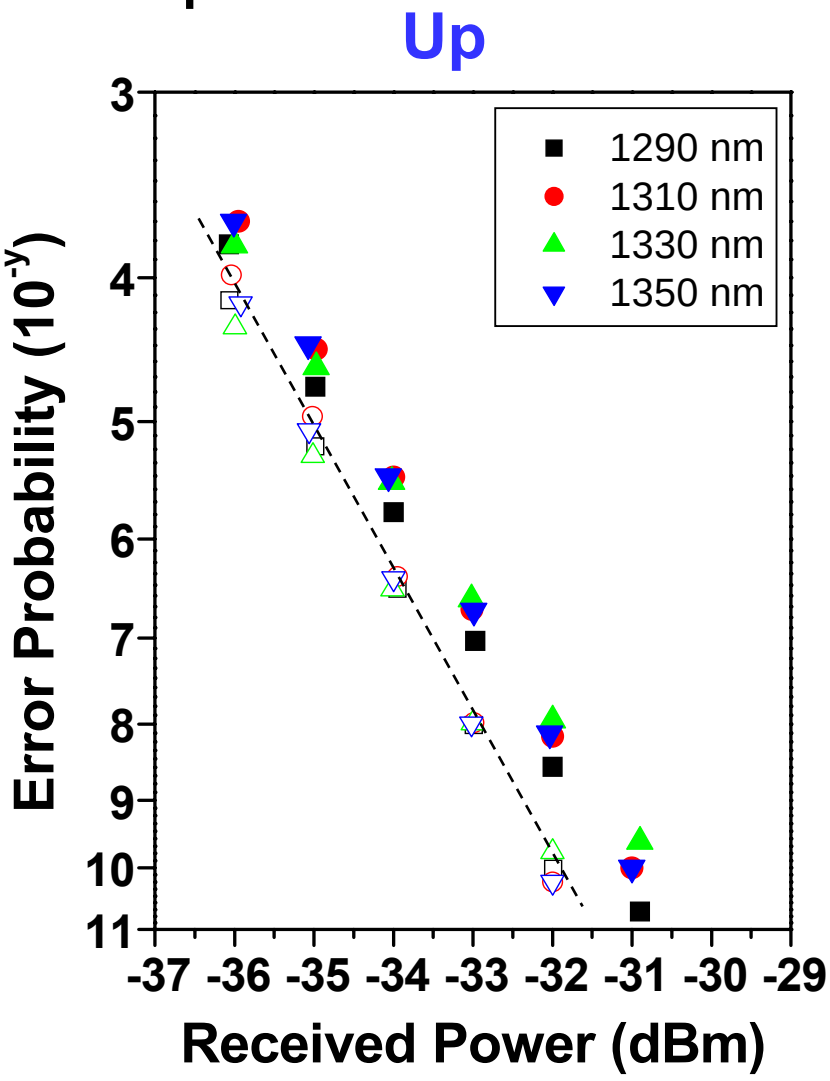
Experimental Results

1.5 um Amp + 1.3 um Amp + 60 km





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Summary

Potential enhancement strategies for TDM-PONs

A. Wavelength upgrades permitting increased capacity or additional services

B. Increased link budget for moderate extended reach / split

Hybrid amp suitable for non-erbium band amplification in access and metro enables A & B simultaneously

- Broad bandwidth (>80 nm)
- Reasonable and Bidirectional gain (> 18 dB in latest demonstration)
- Flexible design: flat gain in any band in optical fiber
- Four 60 km PONs sharing a common infrastructure

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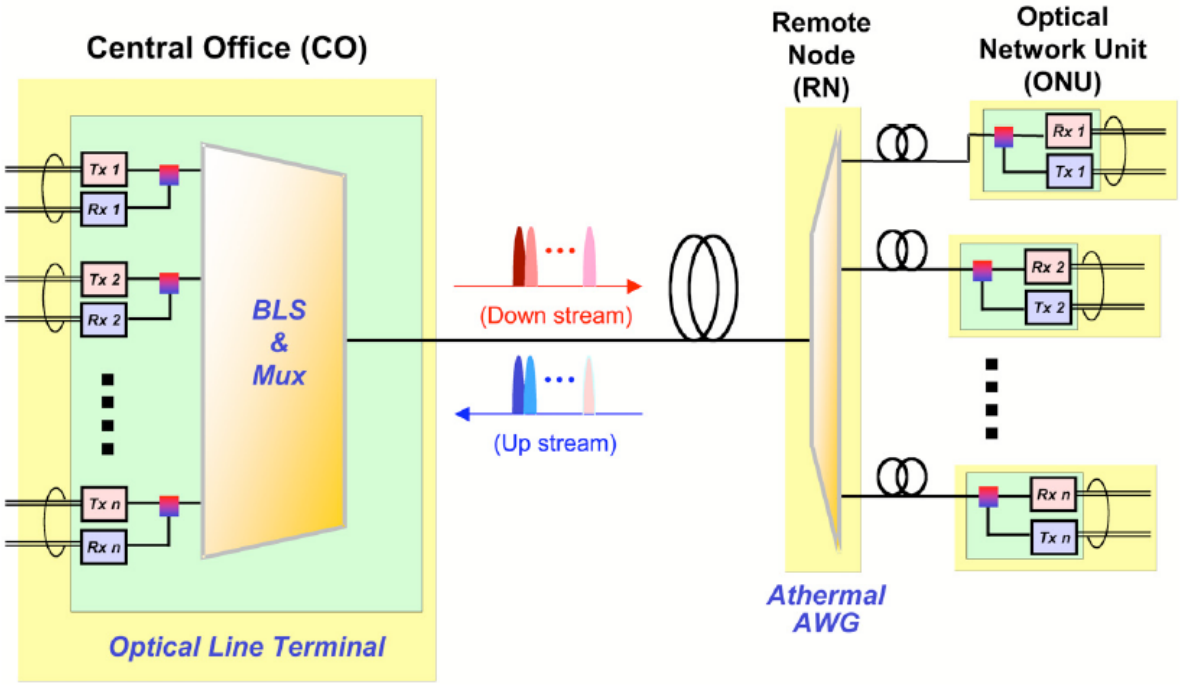
Backup Slides

DWDM PON with Colorless ONTs



Source: White paper by Novera Optics, Inc.

Impressive technological achievement

- Colorless ONTs
- Futureproof outside plant

But not ready for volume FTTP deployment (despite KT roll-out)

- BLS (Broadband Light Source) output power requirements
  - Cost per user
  - Polarization dependence
- Susceptibility to discrete and distributed reflections
- Channel amplitude variation
- Will low-cost DFBs be available by time real demand appears?

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