Future Technologies for the Mass Market Residential Access Network

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Agenda

- Bandwidth Trends
- Future Copper Access Technologies
- Near term PON Technologies
- Long term PON Technology Possibilities (TDM, TWDM & WDM-PON)
- Building a Future-Proof Network
- Conclusions

1 Bandwidth Trends

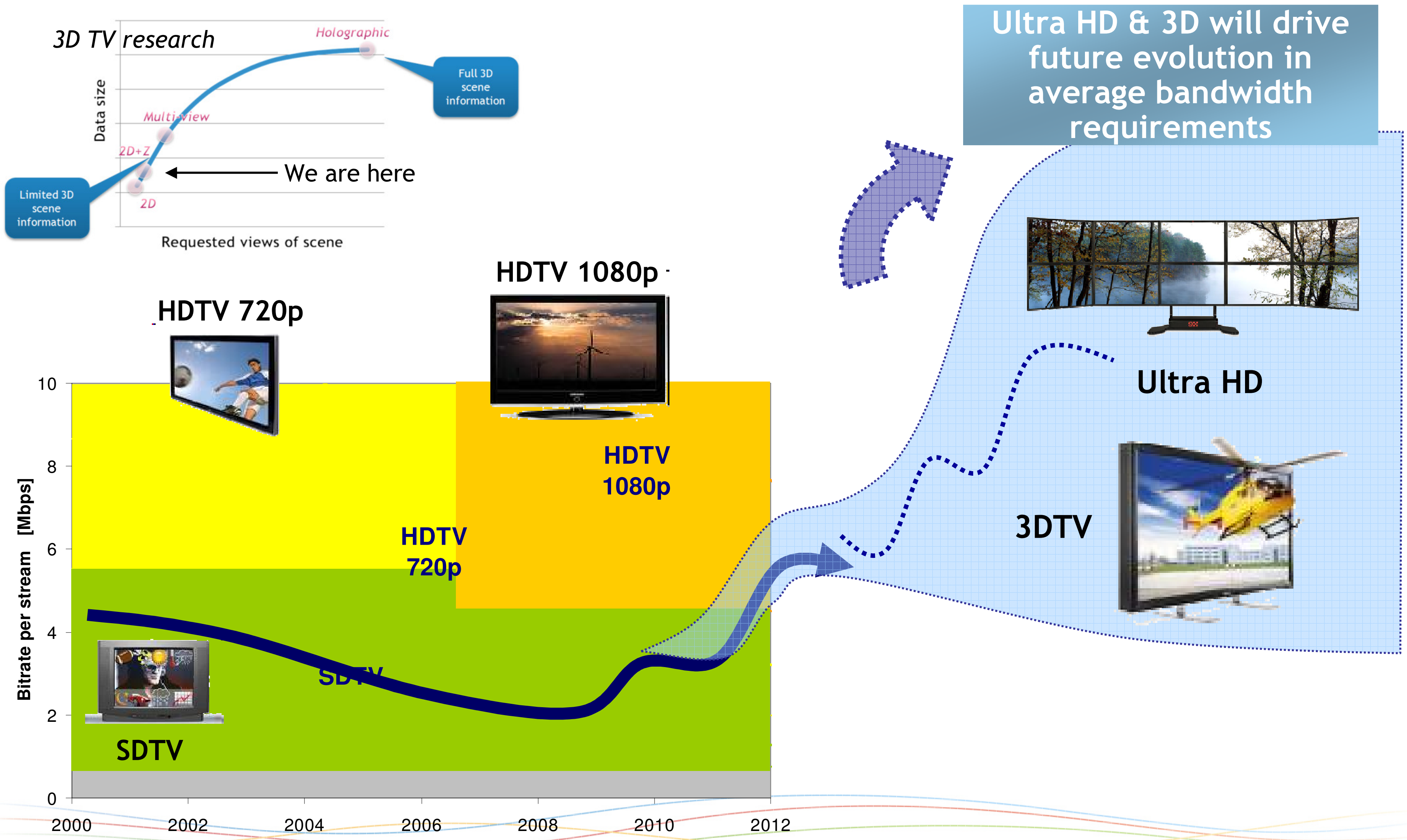
Changing Traffic Characteristics

- Increasing bit rates driven by the growth in video
  - Higher Quality Video
  - More Simultaneous Video Streams

- Transitioning from primarily multicast to primarily unicast
  - Network PVR
    - Pause Live TV, Time Shift TV
  - Video on Demand
  - OTT Video and other Internet Traffic

Bandwidth Trends:

1. Evolution in screen size will continue to drive BW need



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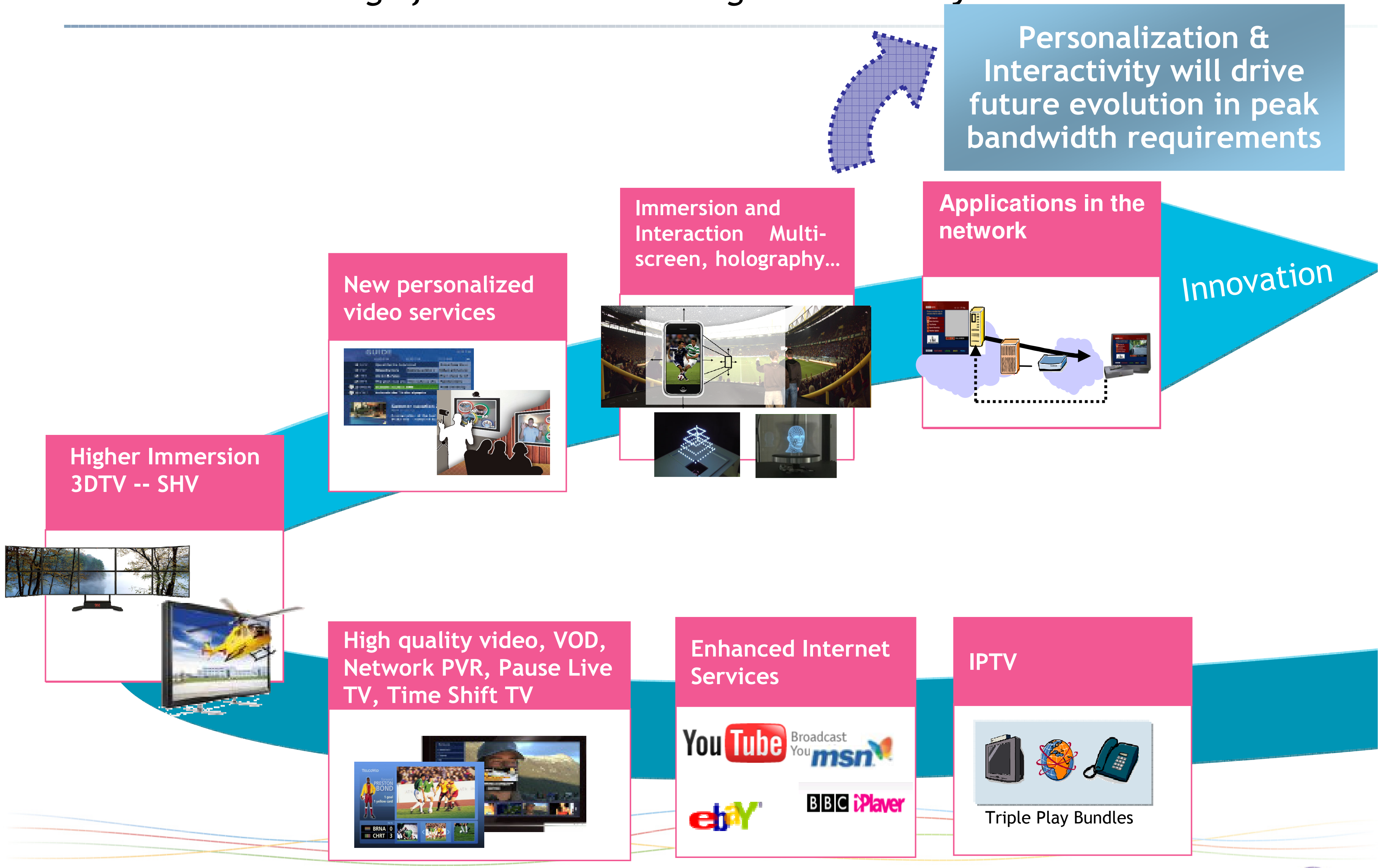
Bandwidth Trends:

2. Evolution in usage from multicast to high interactivity



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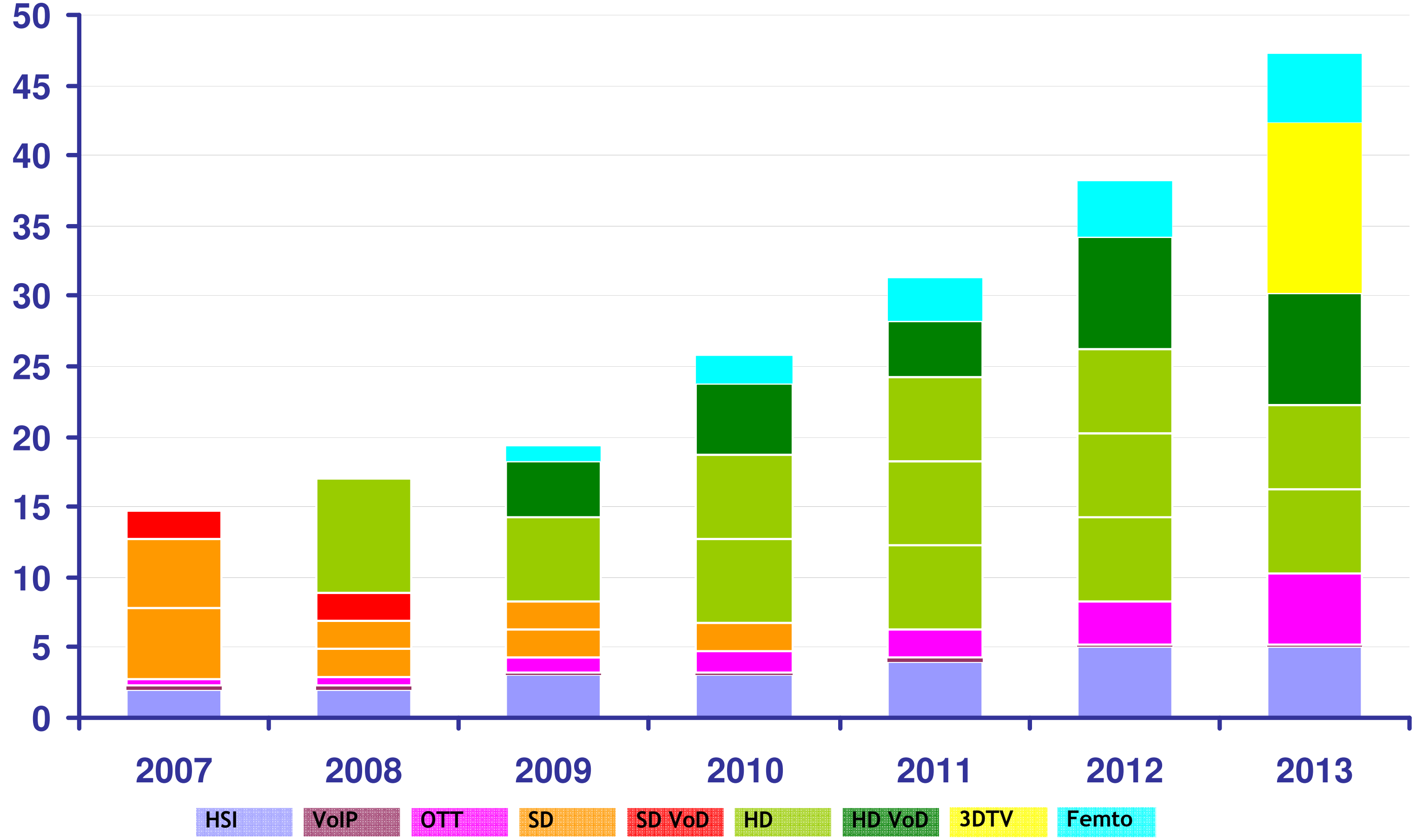
Bandwidth Trends

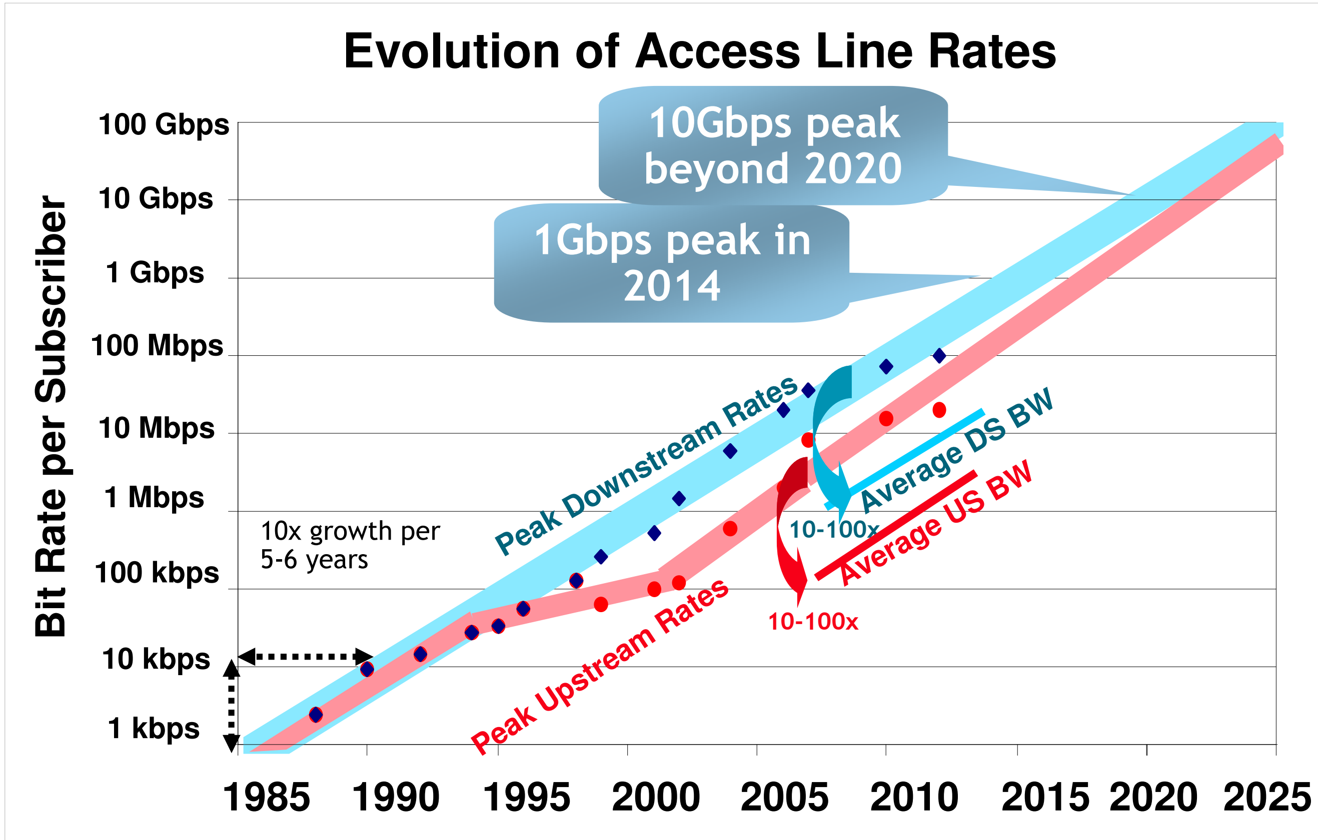
3. *Continued and Rapid Growth in Bandwidth* ***Consumption***

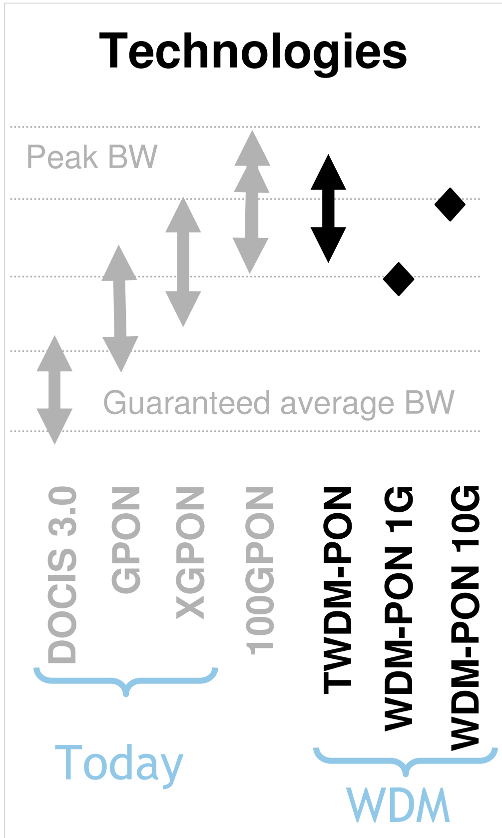


sources: FTTH Council, operators, Alcatel-Lucent

Bandwidth consumption growing by 20% a year
From 25 Mb/s in 2010 to >50 Mb/s by 2015

Bandwidth Trends
4. 50% CAGR in Offered Data Rates





Plenty of bandwidth in existing and planned PON technologies (GPON, XGPON) to carry through to 2020.

All alternative solutions must prove in on economic basis

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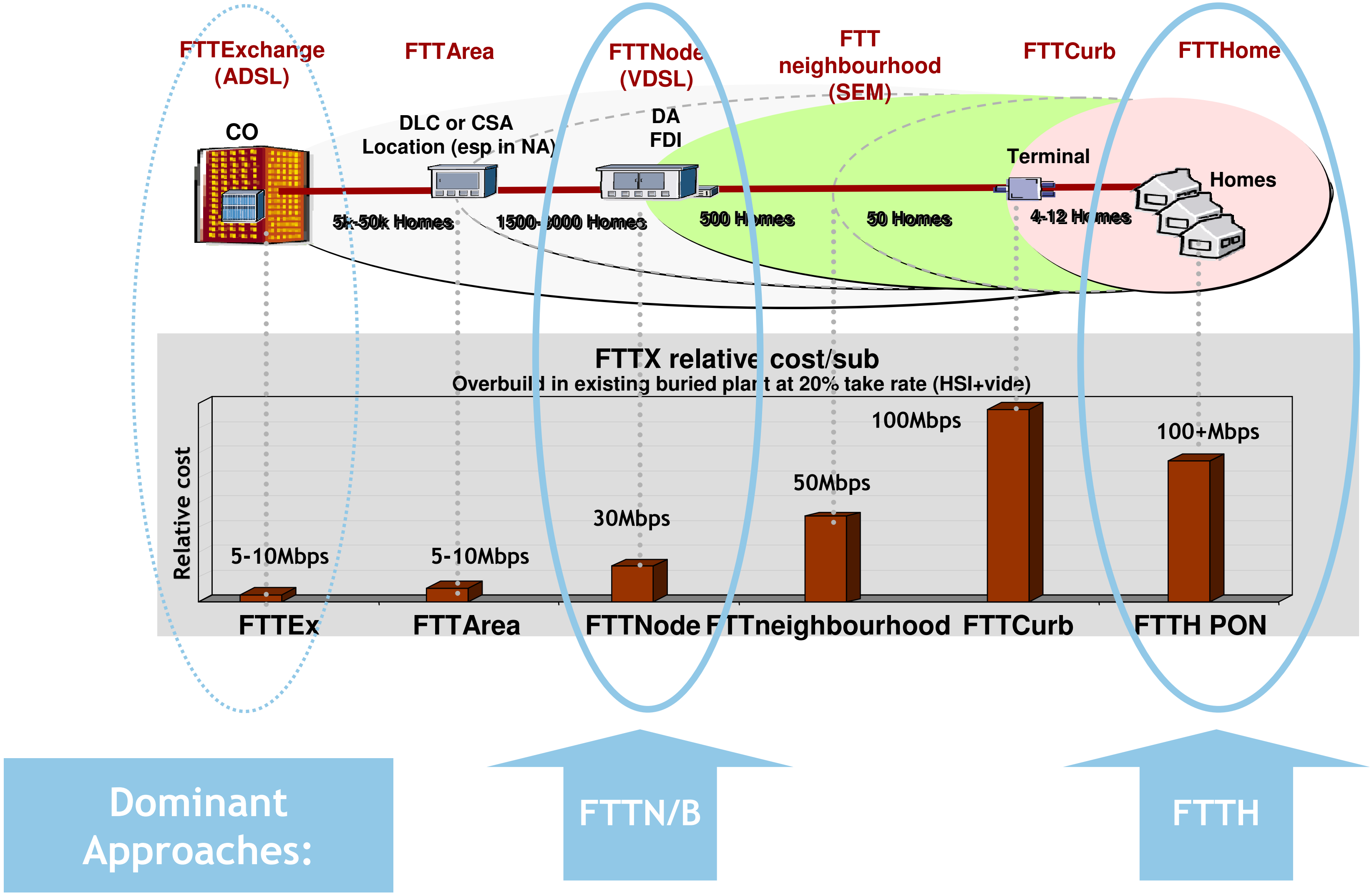
2 Future Copper Access Technologies

Current Operator Strategies
Economics of Different Alternatives



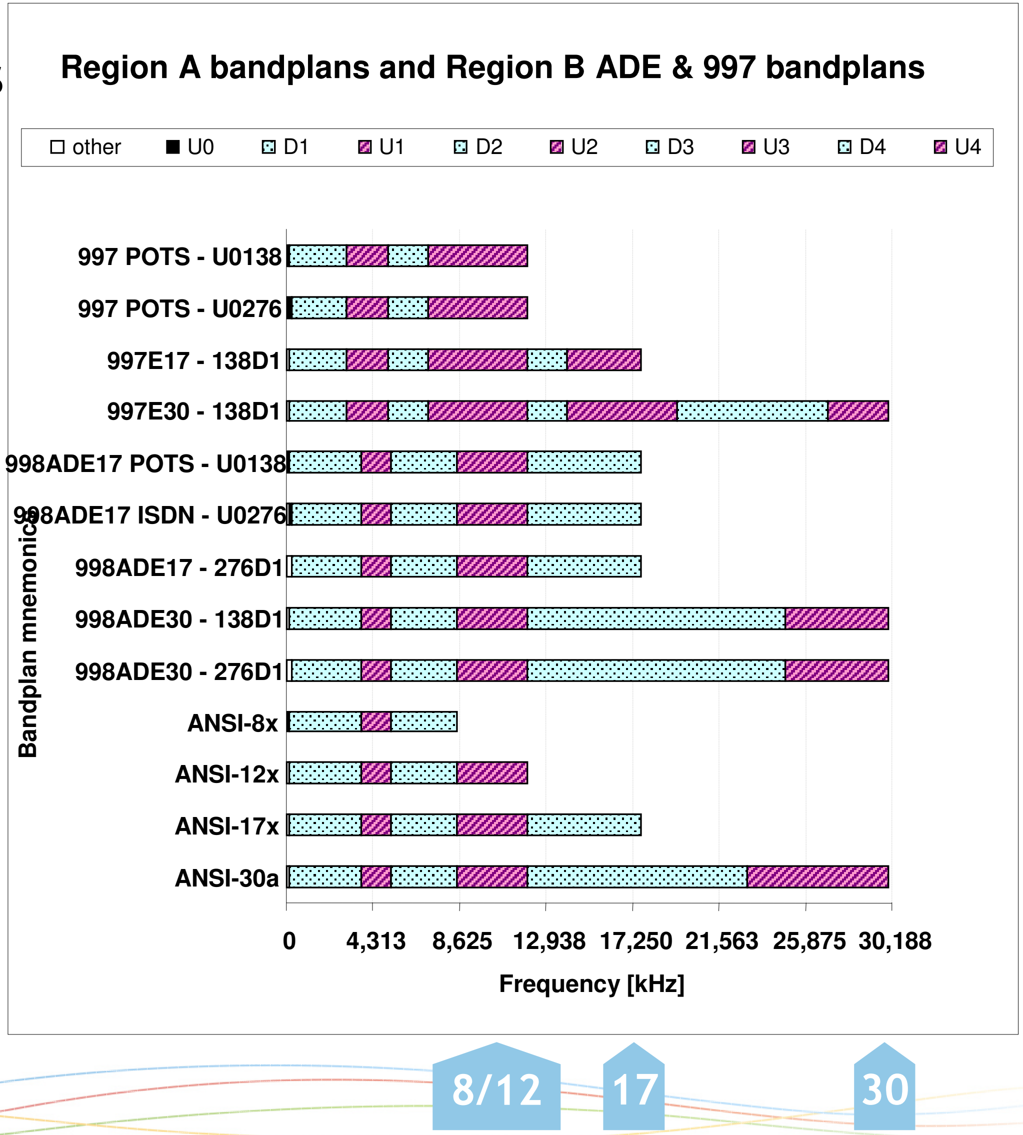
Economics based on 2005 study, R.Heron

A combination of existing capabilities and emerging innovations will allow service providers to take xDSL to the next level(s)

What More Can We Do With VDSL?

1 Increase VDSL Spectrum Bands

- Additional spectrum gives extra bandwidth
- However, higher frequencies are sensitive to loop length
- Band plans exist with slightly different mix between up/down



VDSL @ 17MHz gives additional BW at a usable distance of 300-800m.

VDSL @ 30MHz requires much shorter loops (<300m)

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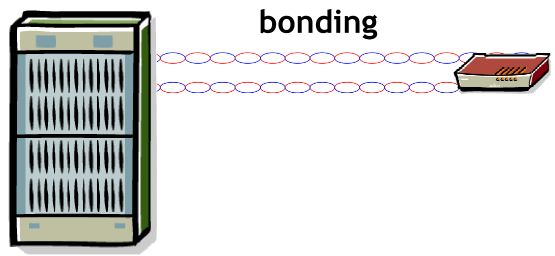
What More Can We Do With VDSL?

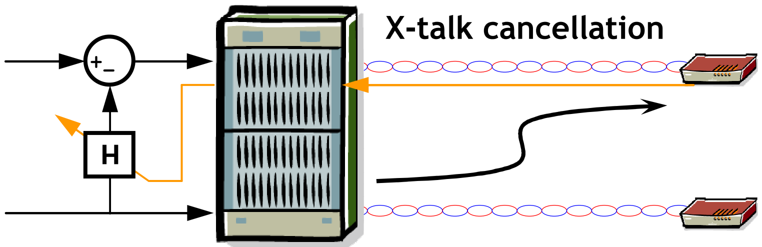
2 Bonding

- Delivers VDSL over 2 pairs
- Almost doubles the BW (1.9x)
- But increases the cross talk distortion in the access bundle



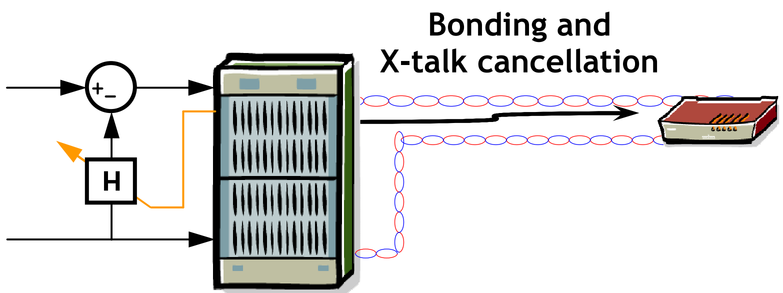
3 Vectoring

- Eliminate cross talk by modifying signal with “pre-compensated crosstalk signal”
- Need to sample transmission ‘channels’, evaluate crosstalk, calculate ‘inverse’ function and then apply to each line, in concert
- All the lines in the bundle should be generated jointly (i.e. common LT)



2 + 3 Bonding + Vectoring

- Vectoring mitigates the cross talk impacts of bonding

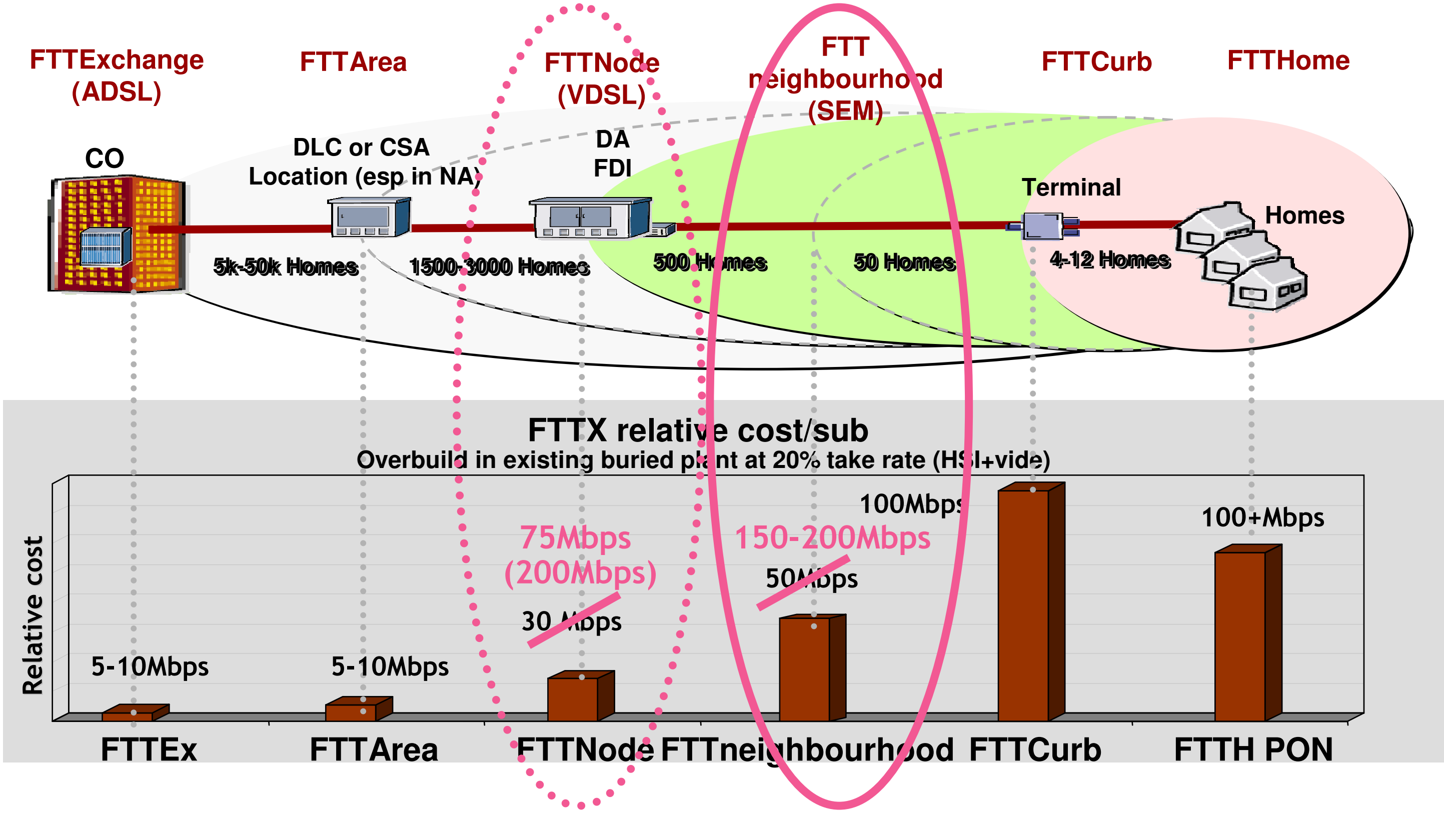


At **1km**, could increase from **30Mpbs** to **75Mbps** with vectoring & bonding

At **500m**, could increase from **50Mpbs** to **150Mbps** with vectoring & bonding

What More Can We Do With VDSL?

4 Shortening the Loop Lengths



Economics based on 2005 study, R.Heron

Further evolution of FTTN towards:

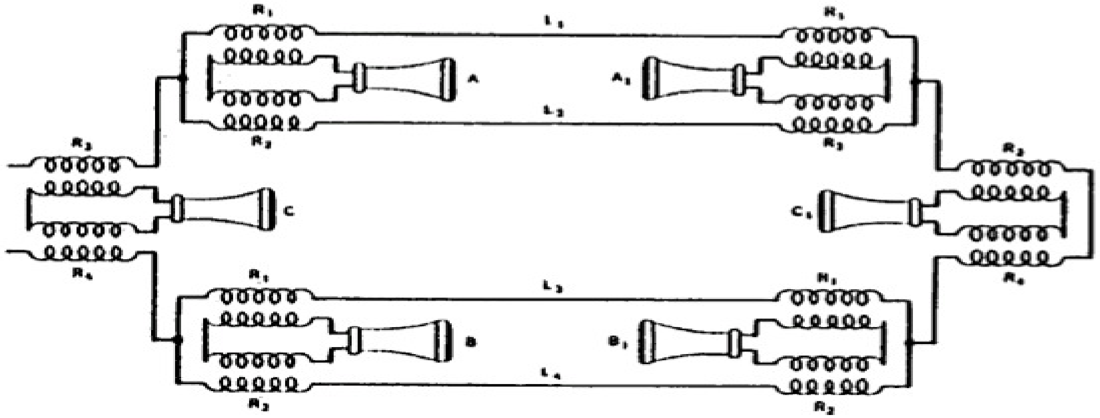
FTTNeighbourhood

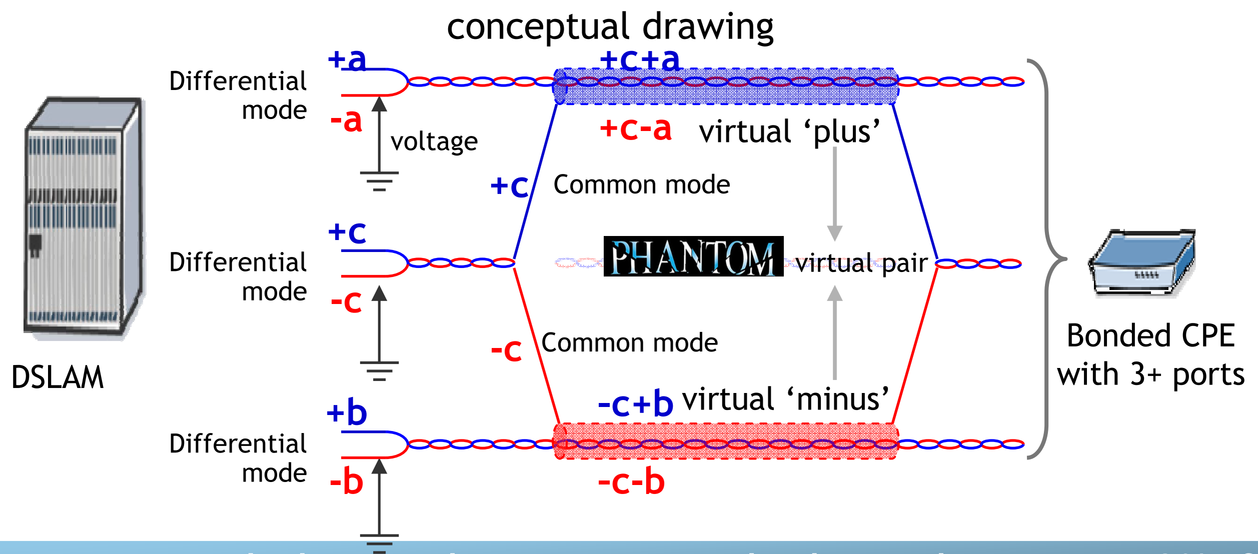
Can achieve 150-200Mbps using bonding and vectoring

But, there's more…

What More Can We Do With VDSL?

5 Phantom pairs!!!





- 1882: First proposal by F. Jacob, based on Wheatstone bridge arrangement.
- 1886: J.J. Carty proposed transformers in place of resistors (shown here).
- 2010: Alcatel-Lucent adapting the concept for broadband rate gains and demonstrating its viability for use with VDSL2 and Vectoring

Phantom mode boosts bit rate on a dual pair by up to 50% if combined with vectoring. Work in progress – deployment models under investigation.

300Mbps over 2 pairs @ 400m

Bell Labs "Phantom mode" Demonstration

300Mbps in 5 steps

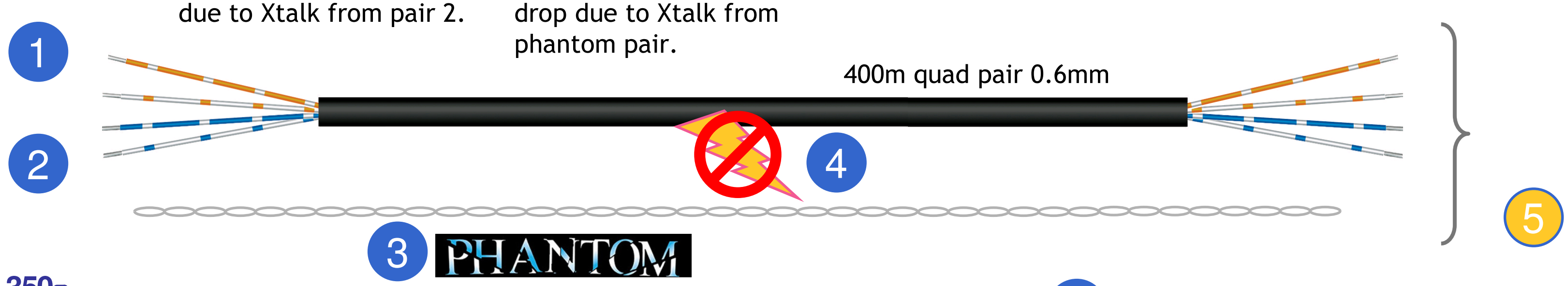
Start with a 1st twisted pair – good for about 100Mbps.

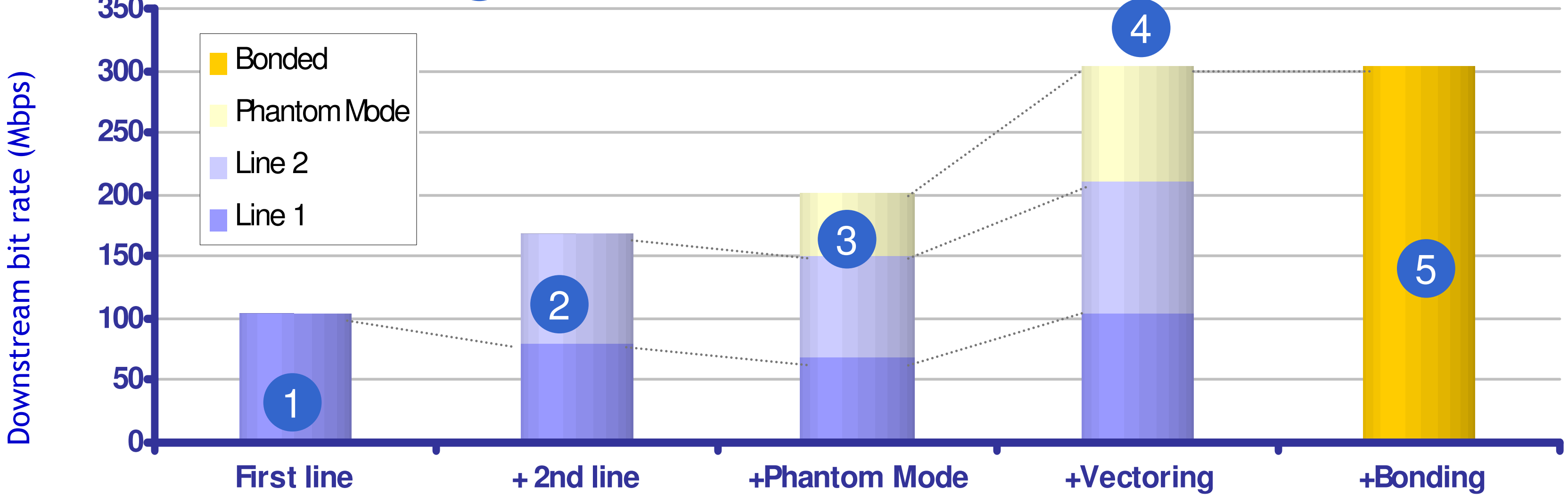
Add a 2nd twisted pair – good for another 80Mbps.
Bit rate on pair 1 drops due to Xtalk from pair 2.

Create a 3rd virtual pair or 'phantom mode' pair – another 50Mbps.
BUT: bit rates on pairs 1 & 2 drop due to Xtalk from phantom pair.

Apply vectoring (crosstalk cancelation) to boost bit rate by approx 50%.

Bond the 3 links (2 physical pairs + phantom mode) creating one big 300Mbps pipe.





Industry-first demonstration of 300Mbps@400m over 2 pairs
Innovative combination of phantom mode + vectoring

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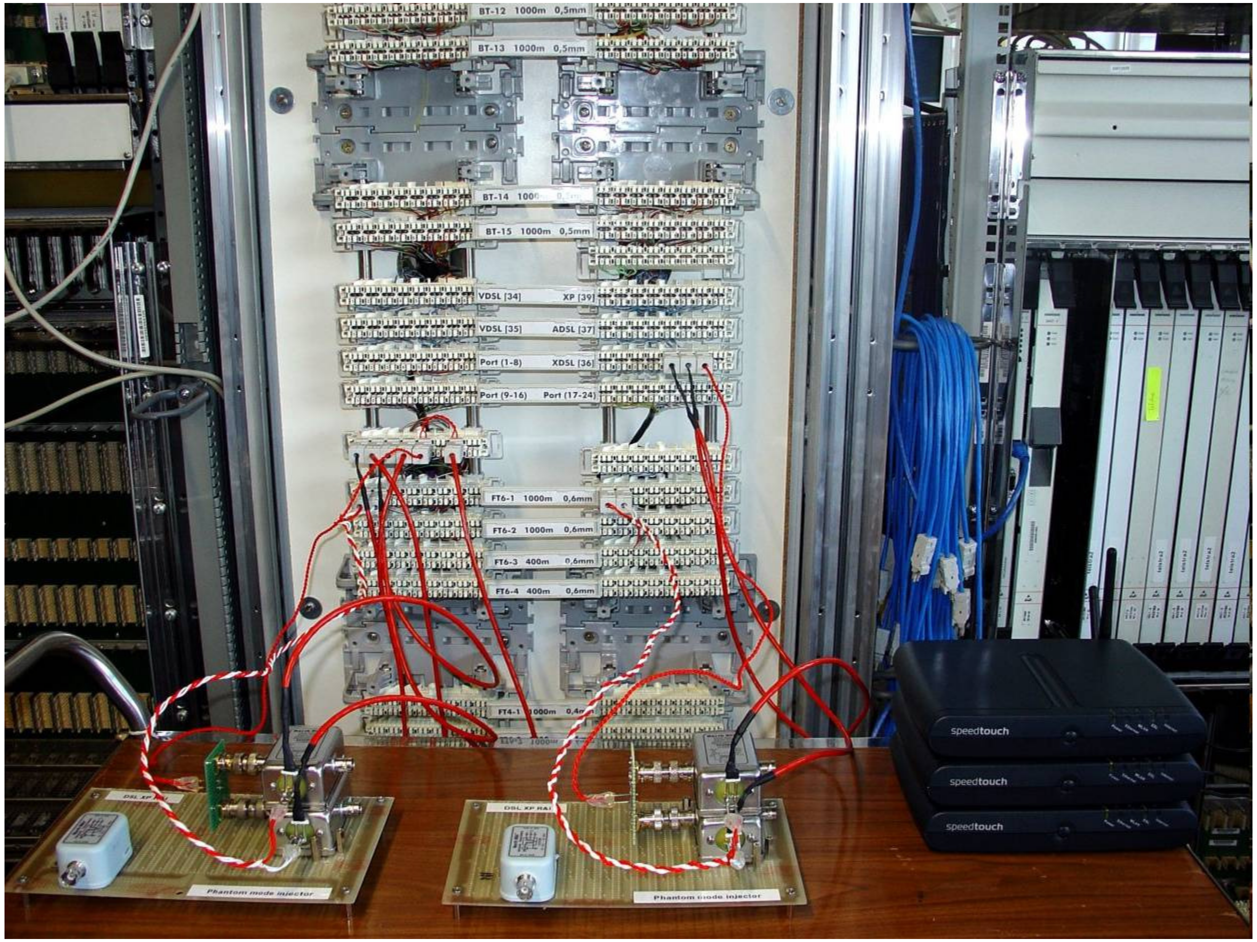
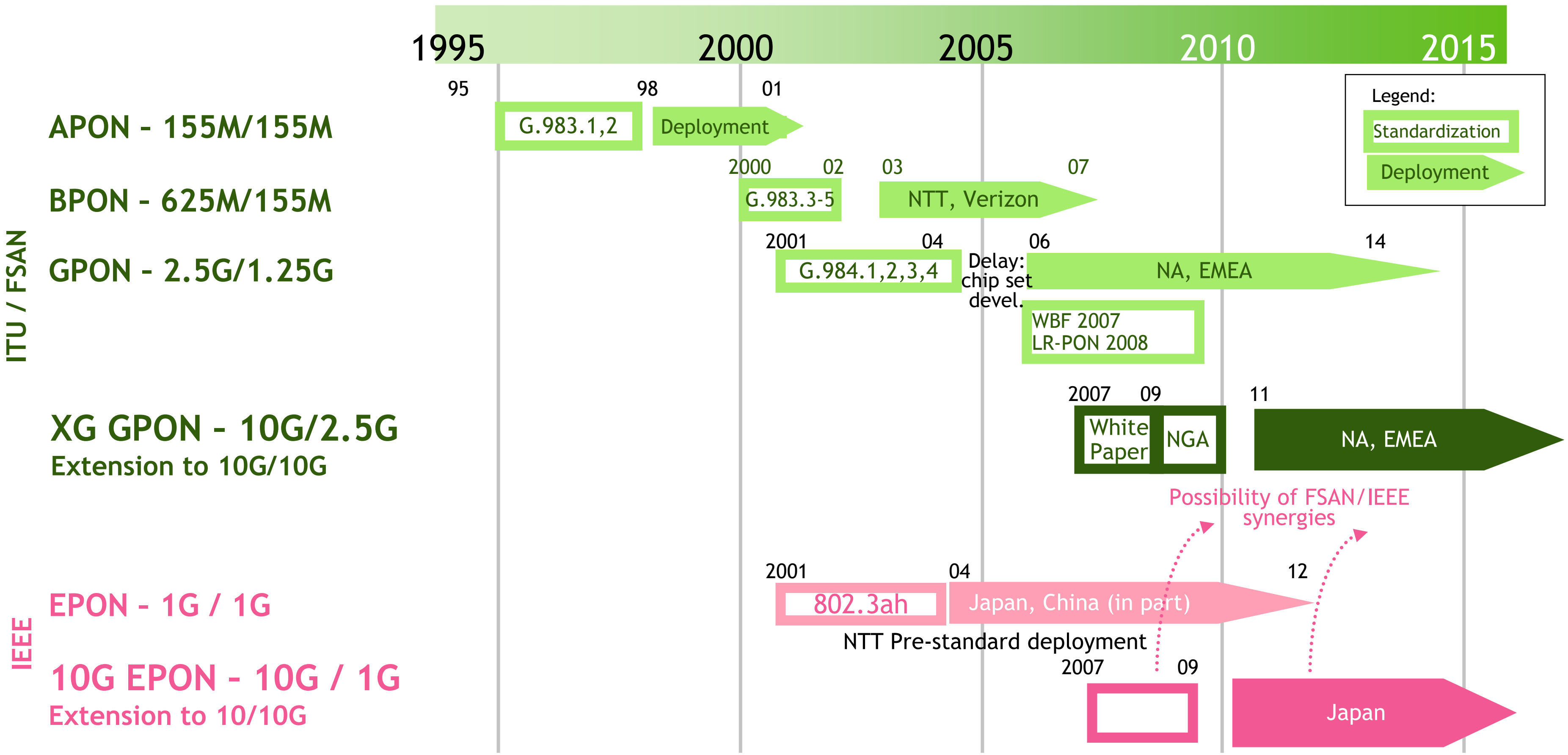
Phantom Mode Demonstration



Using Modified Production VSDL2 Line Card To Demonstrate Phantom Gains

3 Near term *PON* Technologies

10G PON is an Evolution of TDM PON Technologies



FSAN & IEEE synergies:
Same learning curve, economies of scale for 10G EPON and 10G GPON optics.
…a few differences…

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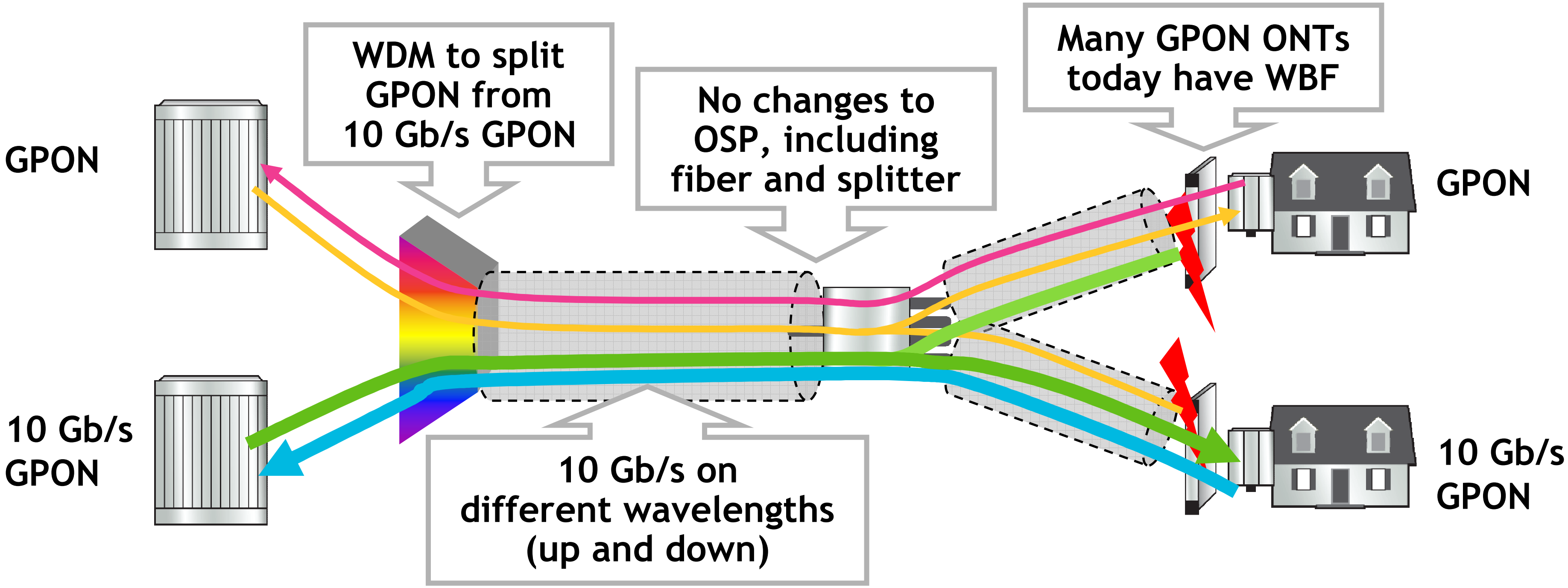
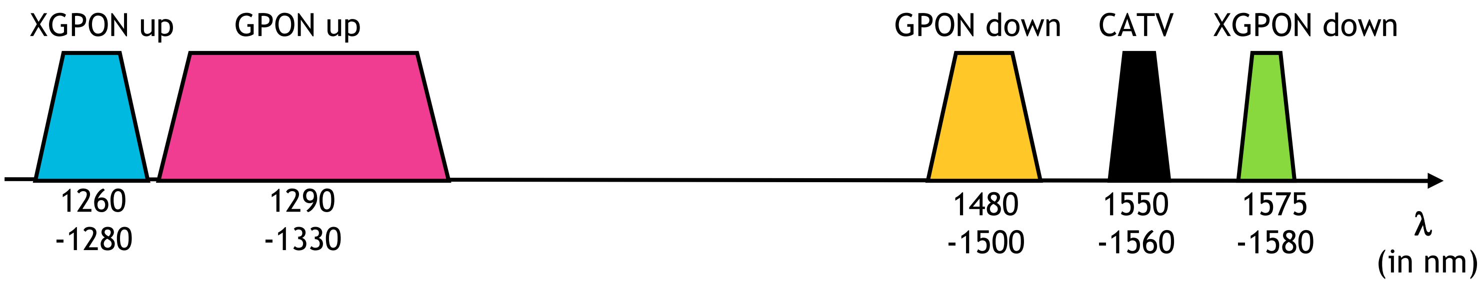
No fork-lift upgrade for 10G GPON

Wavelength overlay in both uplink and downlink





No stranded investments: GPON OLT, ONT and OSP can be reused

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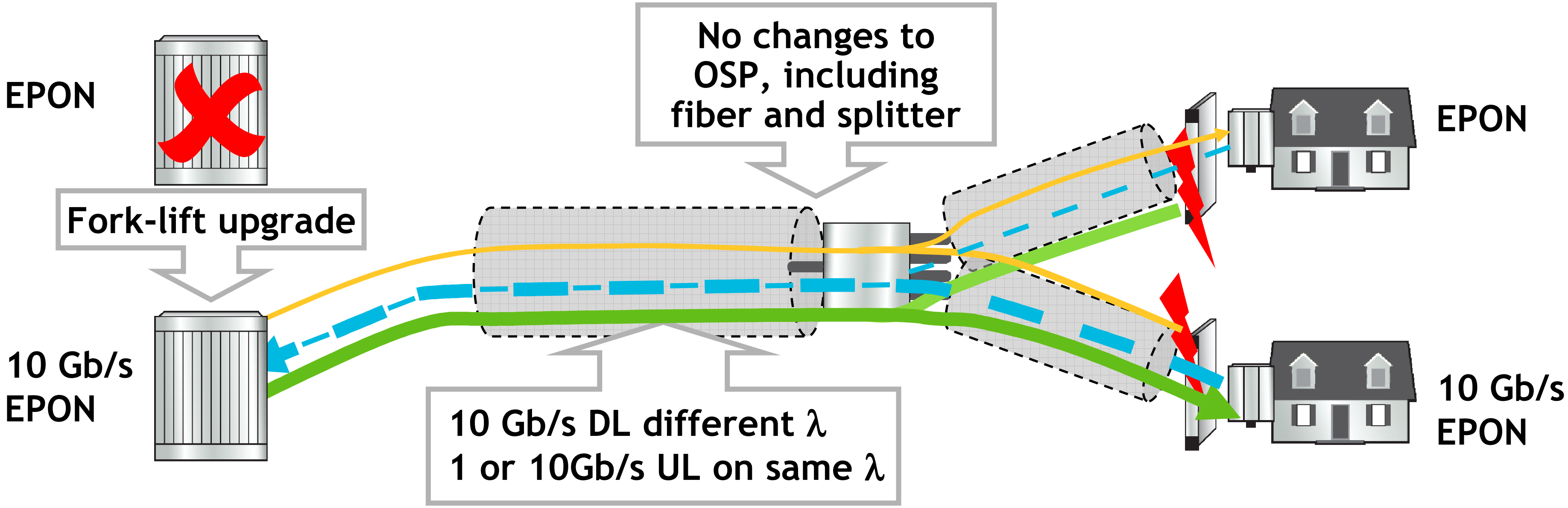
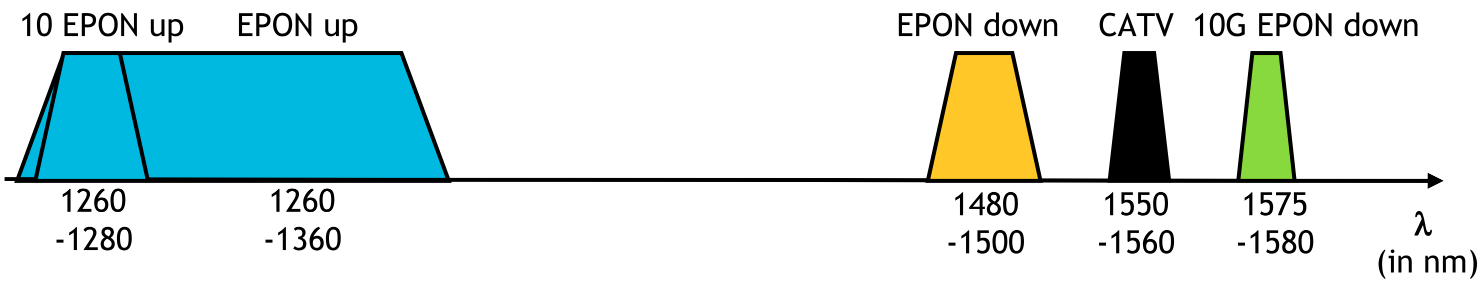
Forklift upgrade for 10G EPON

Wavelength overlay in downlink, TDM in uplink





Stranded investment: EPON OLT has to be replaced. Or overlay network

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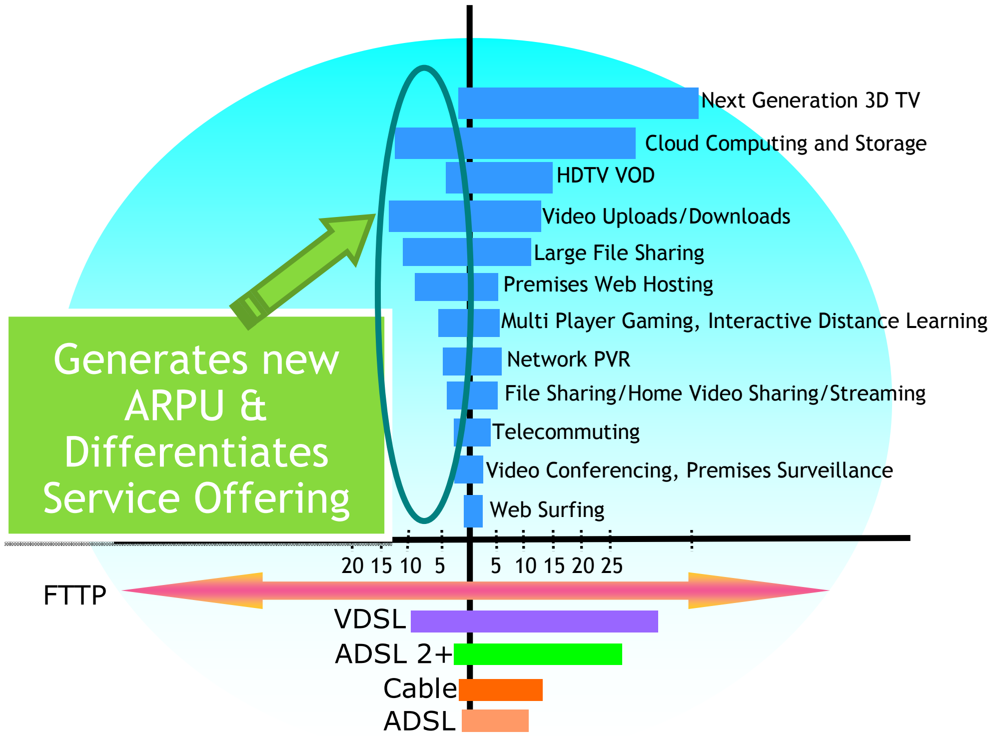
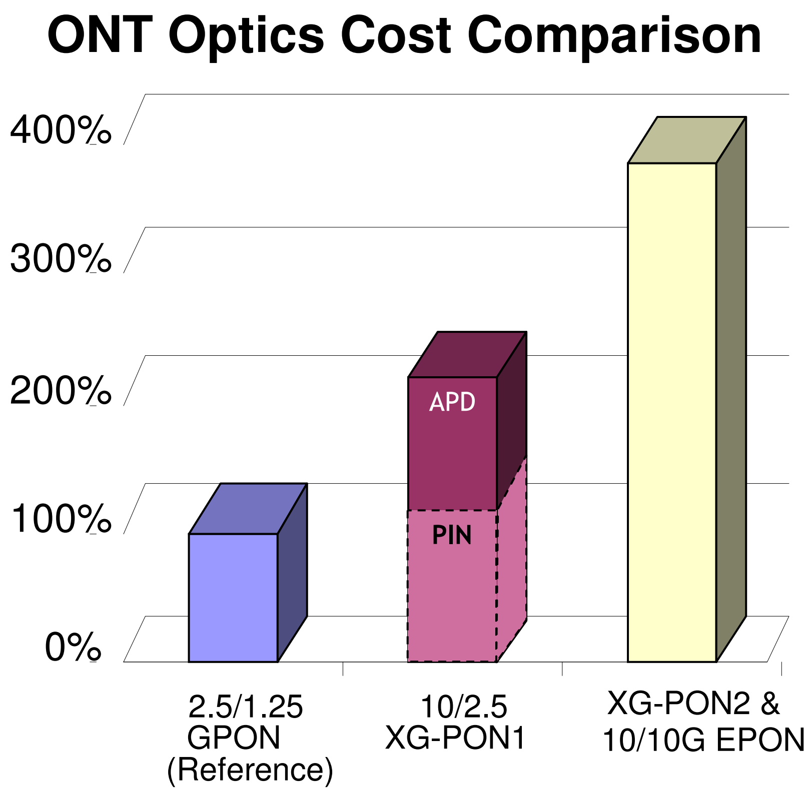
Optimum uplink capacity

Is the 10G/1G IEEE scheme or 2.5Gbps FSAN scheme optimal?

Towards more symmetry…



…10G optics too expensive for ONTs



1G up is not sufficient, 10G up is too costly ⇒ 2.5 Gbps = a good compromise

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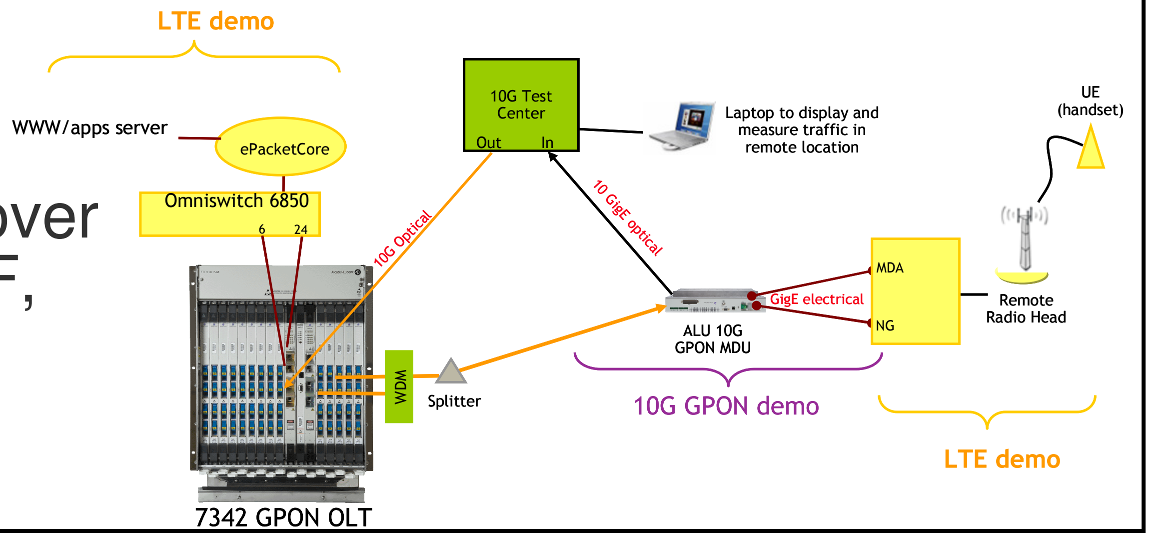
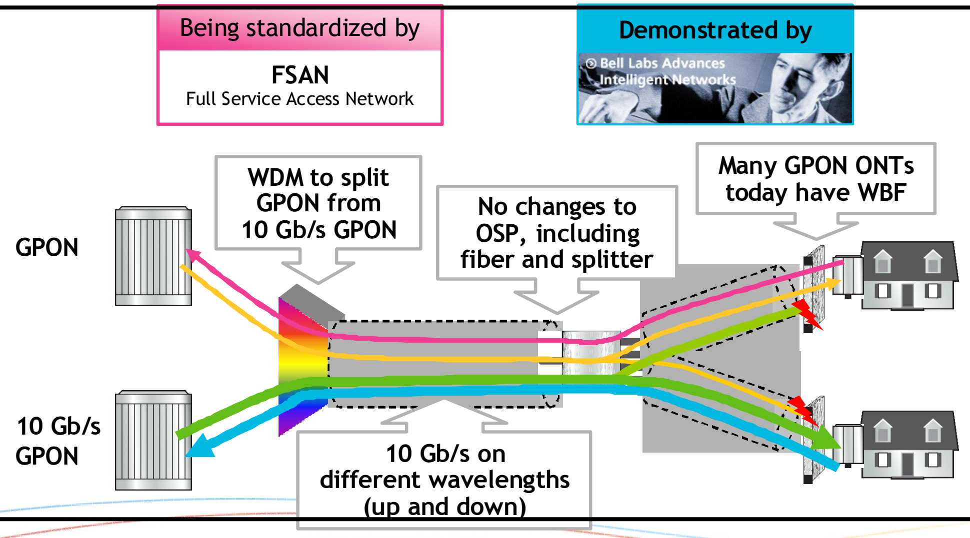
ALU 10G GPON Demos

- ALU Successfully Demonstrated LTE over 10G GPON at BBWF, Paris 9/2009



- ALU presented 10G/2.5G GPON coexistence with 2.5G/1.25G GPON at FTTH Council Sept. 09



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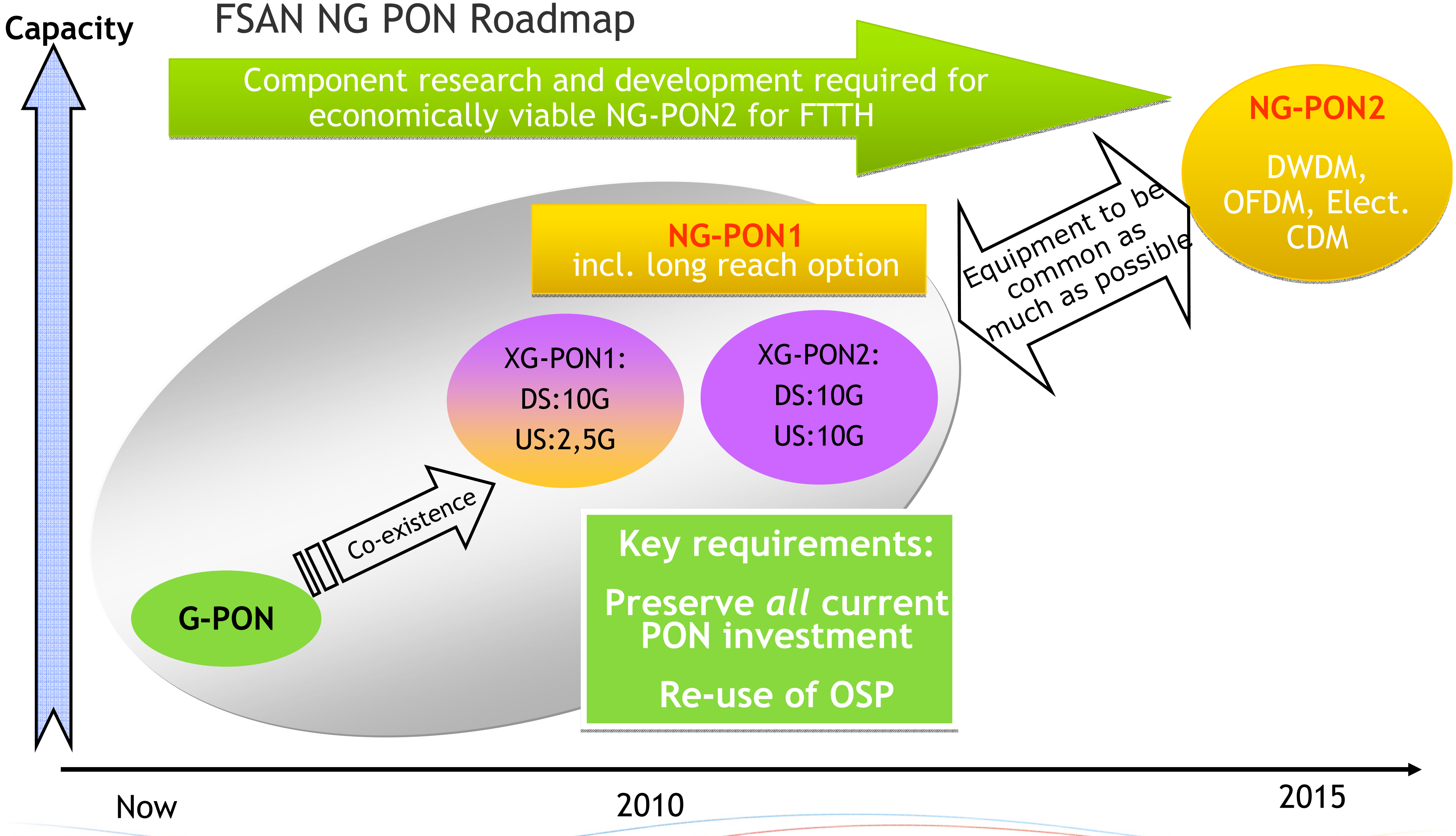
4

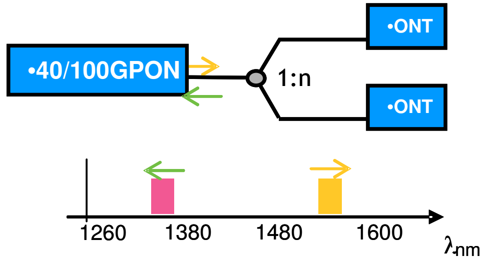
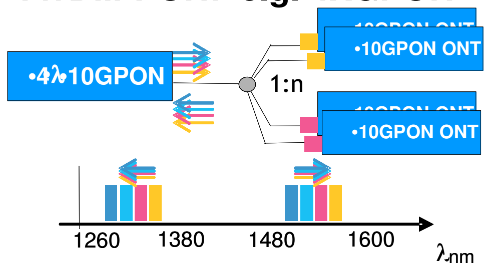
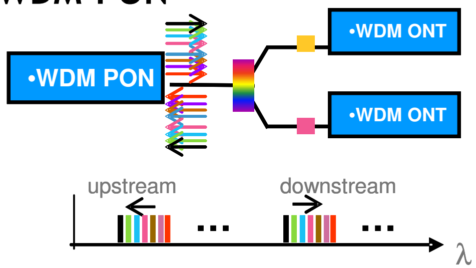
Long term PON Technology Possibilities

(NGPON2: TDM, TWDM & WDM-PON)

So, What's next?



So what's next?
…Categories of NGPON

<table>
<tr><th></th><th></th><th>Solution</th><th>Characteristic</th></tr>
<tr><td></td><td>Pure TDM PON</td><td>TDM-PON: 40-100G PON

</td><td>▪ Conceptually simple TDM
▪ Leverage existing colorless ODN
Progress is expected on TDM-PON, but it is not covered in this presentation.</td></tr>
<tr><td>FOCUS</td><td>TDM/WDM PON = TWDM PON</td><td>TWDM-PON: e.g. 4XGPON

</td><td>▪ Combines benefits of TDM (lower cost optics) with WDM (increased BW)
▪ Possible dynamic λ selection or λ unbundling</td></tr>
<tr><td>FOCUS</td><td>Pure WDM PON</td><td>WDM-PON

</td><td>▪ One wavelength per subscriber
▪ Improved optical power budget with AWG (Could also use power splitter)
▪ Has multiple OLT lasers. Needs colourless ONT
WDM-PON is a wonderful research topic. But we must consider some realities of residential access network.</td></tr>
</table>

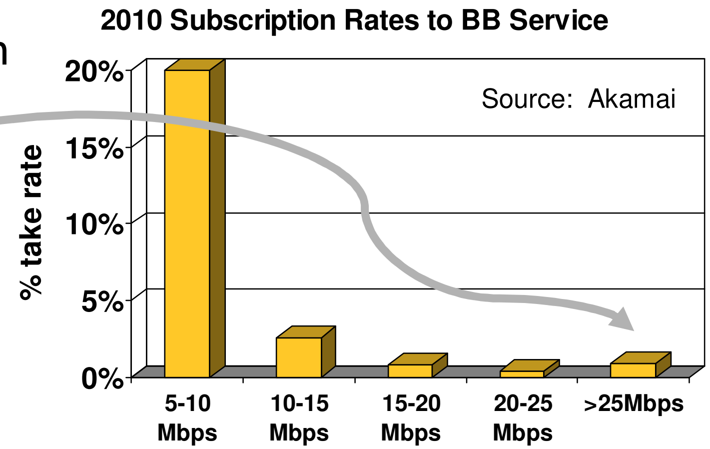
Potential motivations for WDM-PON in residential access *…Let's test them.*

1. • Bandwidth support
2. • Per-customer service flexibility and upgradeability
3. • Wavelength unbundling & open access
4. • Power reduction
5. • Space reduction
6. • CO consolidation (reach & redundancy)

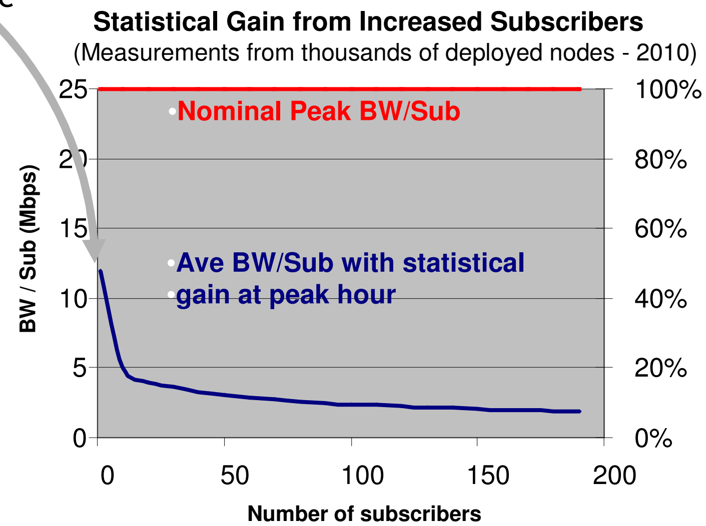
1 Bandwidth Support

The idea: *"Everyone needs 1 Gbps"* *It's true, we do, but…*

- Need the capability to burst at very high peak rates in leading edge deployments (e.g. Google Fiber, Korea, etc)
  - Need **100Mbps** today (a fraction of a %)
  - Need **1Gbps** in 2014
  - Need **10Gbps** beyond 2020
    - **> GPON & XGPON meet these needs today** (e.g. 1Gbps service in Hong Kong, Chatenugua,)



- The average traffic per user (between bursts) can be much lower
  - Agregated traffic is historically 1/10th to 1/100th of peak traffic
    - **> GPON and XGPON can leverage shared BW architectures**



- Upstream has always lagged behind downstream
  - Historically 10:1 (Down : Up)
  - Increasing symmetry towards 4:1, but still asymmetric
    - **> GPON and XGPON are tailored to this asymmetry**

Residential bandwidth is bursty and asymmetric.
WDM-PON doesn't offer anything special for this.

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2 Service flexibility & 3 Wavelength unbundling

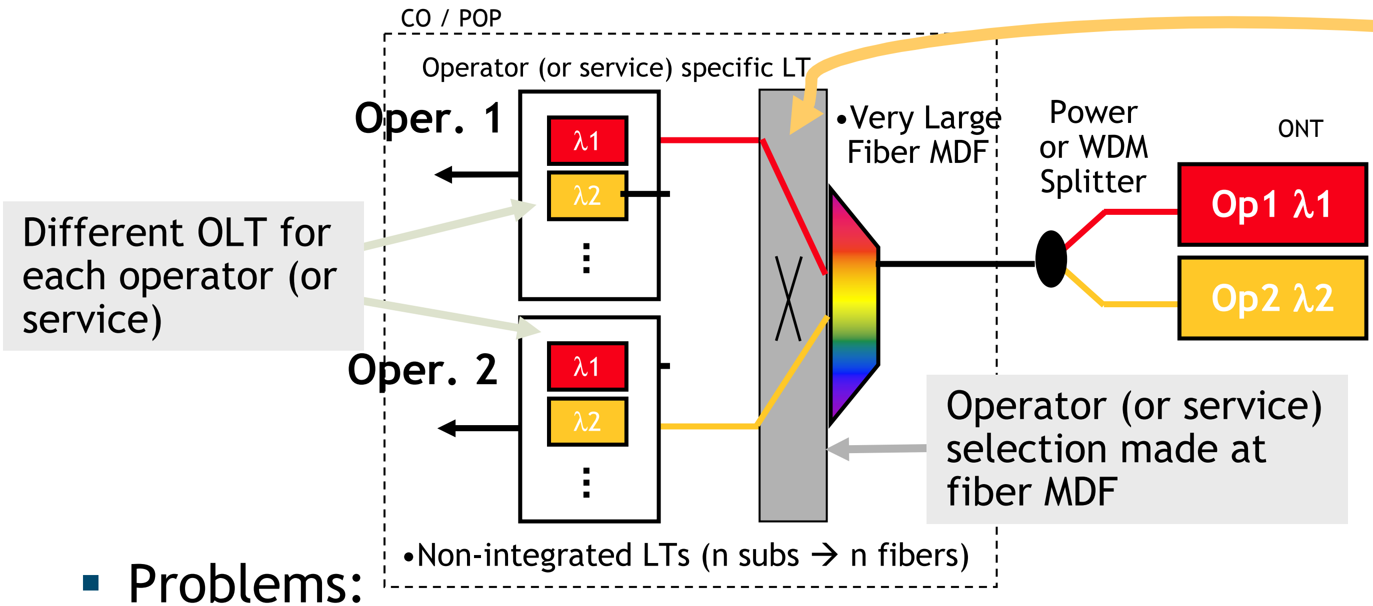
- The idea:
  - "WDM-PON should allow any service to be placed on any wavelength to any customer. Service migration should be smooth and easy!"

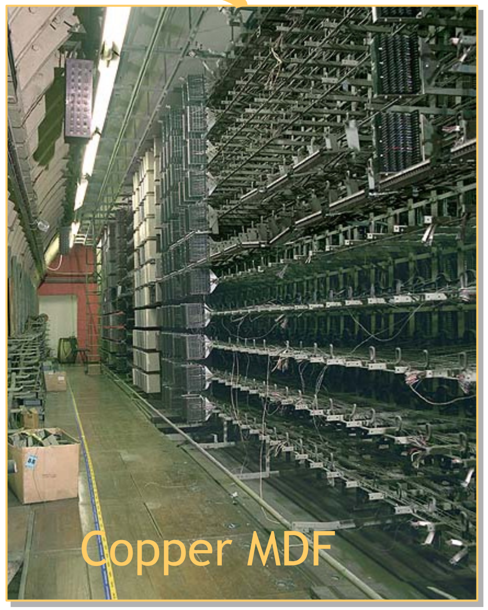
- The idea
  - "WDM-PON should allow operators to flexibility serve any customer using a different wavelength (the ideal 'open access')"

- Reality
  - To achieve this using WDM-PON, must fan out all the wavelengths in the CO and terminate each customer individually.

…not pretty, see illustration

2 Service flexibility & 3 Wavelength unbundling (illustrated)
…Trying to accomplish the dream using WDM-PON and λ fan-out



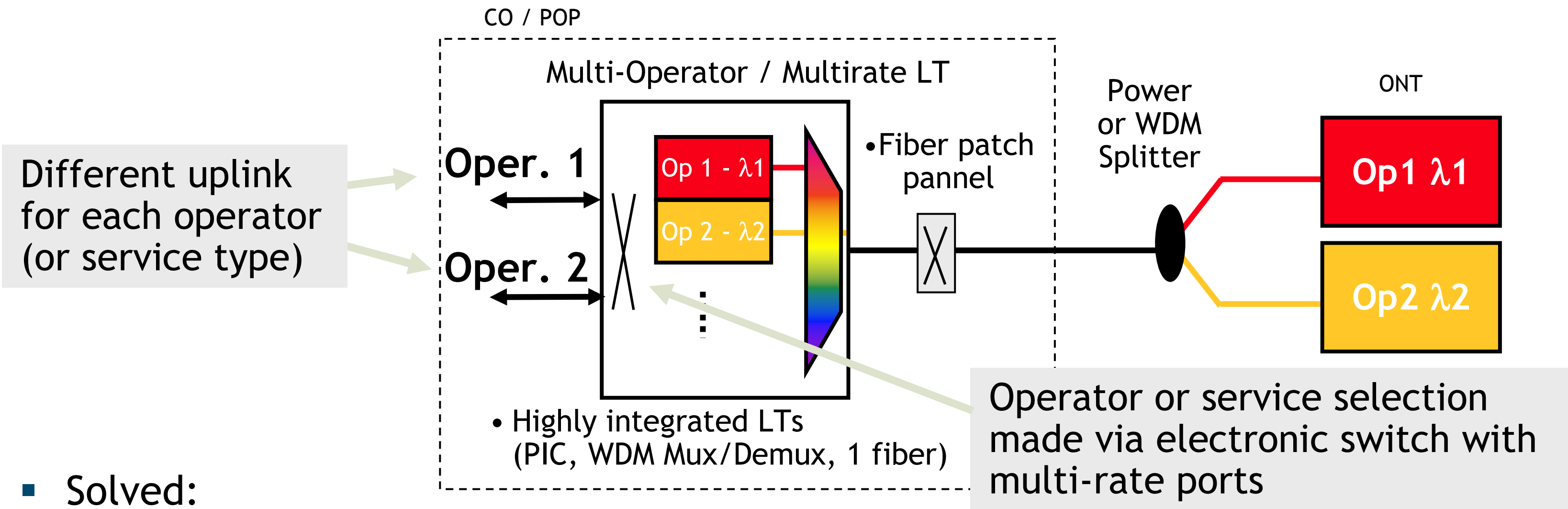


- Problems:
  - Requires huge fiber Main Distribution Frame in CO
    - EQUIVALENT TO THE OLD COPPER MDF!
  - Prevents PIC integration on the line card → High equipment cost

This dream is "possible" but is "impractical" and "expensive"
…ok for business but not appropriate for mass market residential access

→ so these are weak motivations for WDM-PON

2 Service flexibility & 3 Wavelength unbundling (illustrated)
…an alternative using WDM-PON and bit-stream unbundling

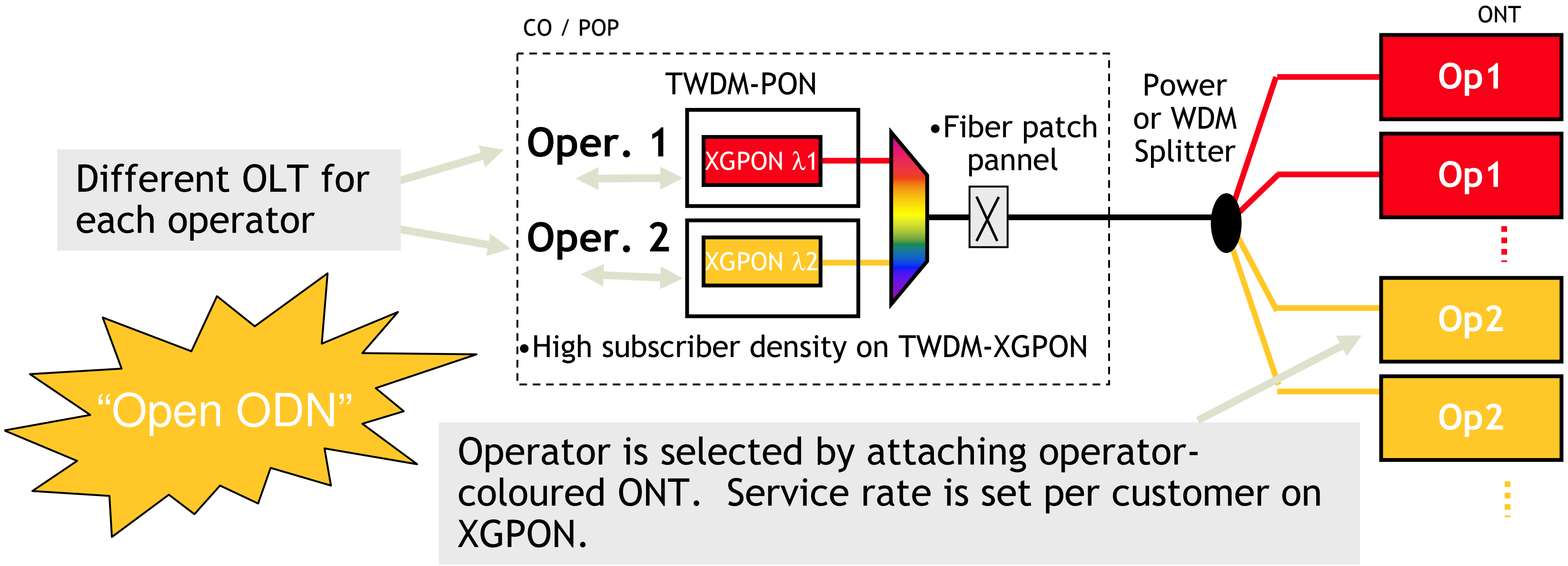


- Solved:
  - Very small fiber patch panel instead of MDF
  - Allows for PIC integration on the line card → lower equipment costs
- New problems:
  - Must over-design ports for the highest service rate
  - When capability of switch is exceeded, must up-grade

But wait!
…this is now identical to every other optical access: GPON, XGPON, GEPON, P2P, AE, etc.!!!

→ so this is still not a driver for WDM-PON

3 Wavelength unbundling
...one more alternative using TWDM-PON and l unbundling



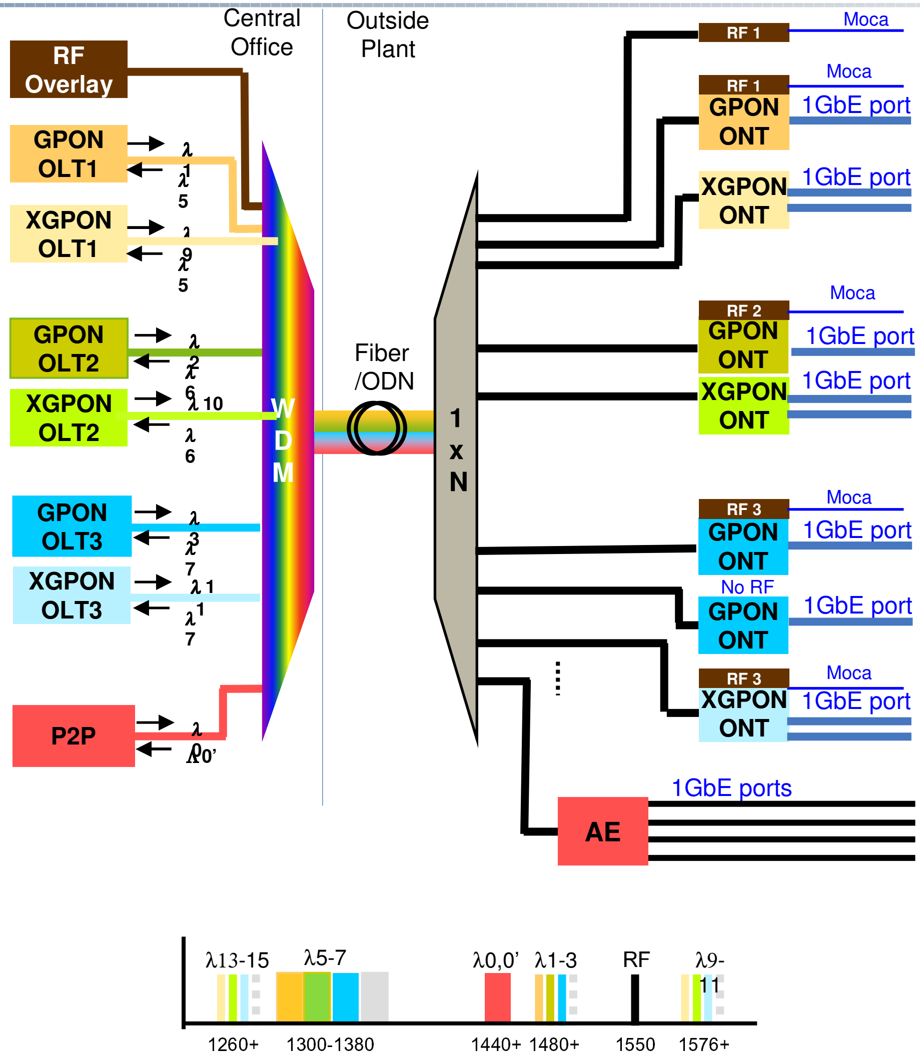
- Solved:
  - Very small fiber patch panel instead of MDF
  - Allows for normal GPON / XGPON optics integration → low equipment

This could be an attractive use of WDM in combination with TDM-PON

→ a potential driver for TWDM-PON

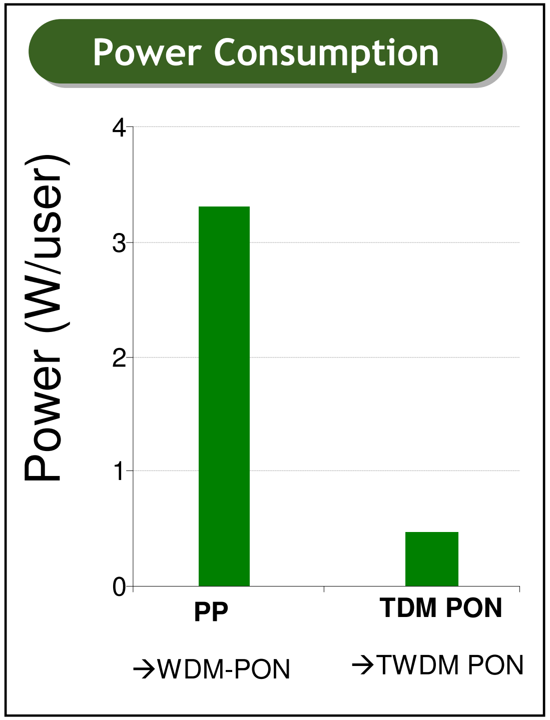
3

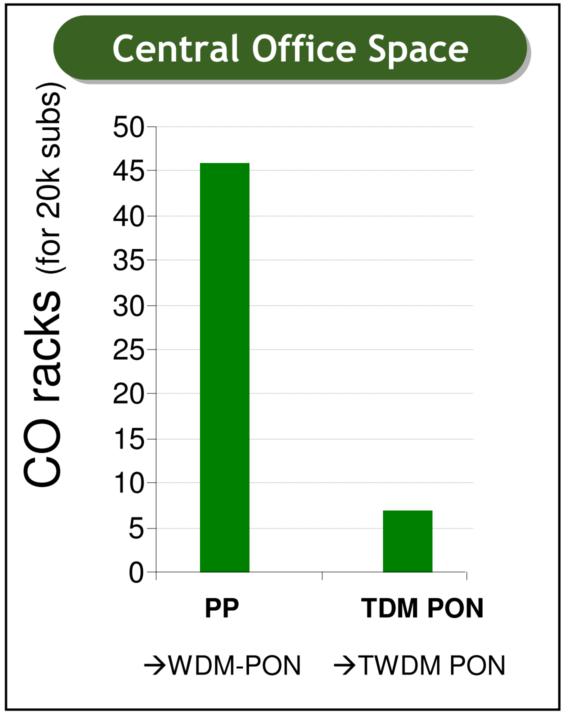
Example of “Open ODN” network



- Shared infrastructure investment
- TWDM-PON overlays:
  - Multiple GPONs
  - RF overlay
  - AE overlay
  - Multiple XGPONs

4 Power savings & 5 space optimization



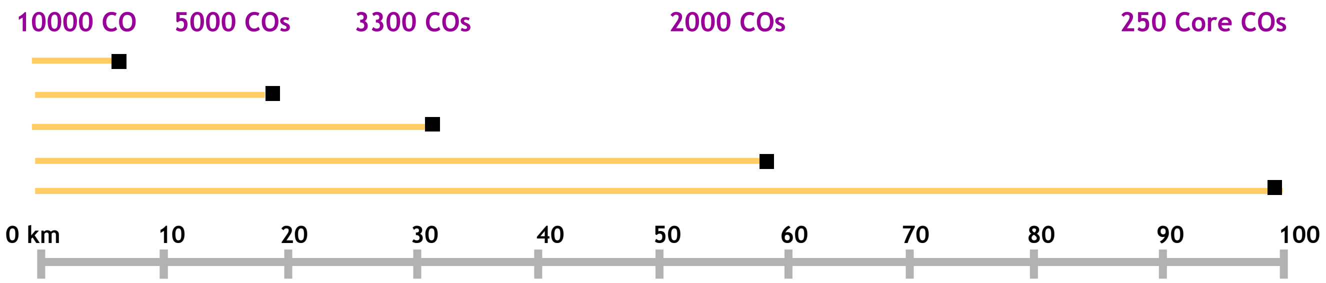


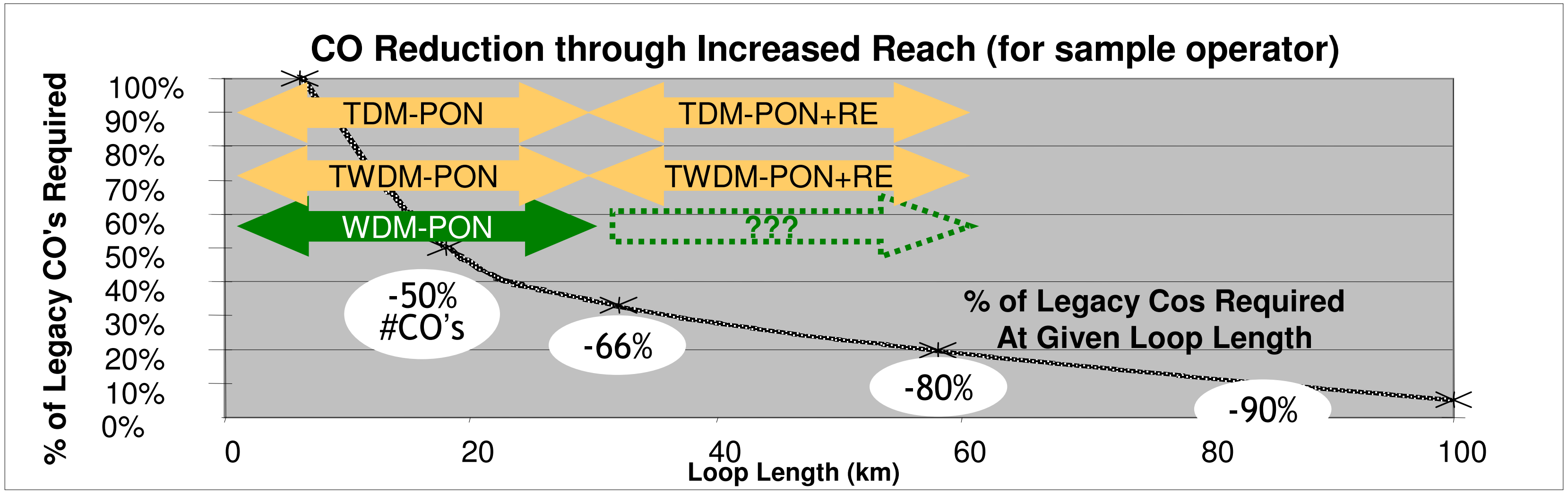
- Currently, both power and space are given by
  - WDM-PON
    = P2P + BB source in the CO
  - TWDM-PON
    = TDM-PON x nl

… hardly the winning argument for WDM-PON or TWDM-PON
More innovation required

Reach Extension, a possible motivation

Cos required for sample operator with extended reach:





Most of the gains are made with a reach of 20-30km using TDM or TWDM-PON. A passive WDM-PON solution that offers significantly more could be attractive …but there are diminishing returns

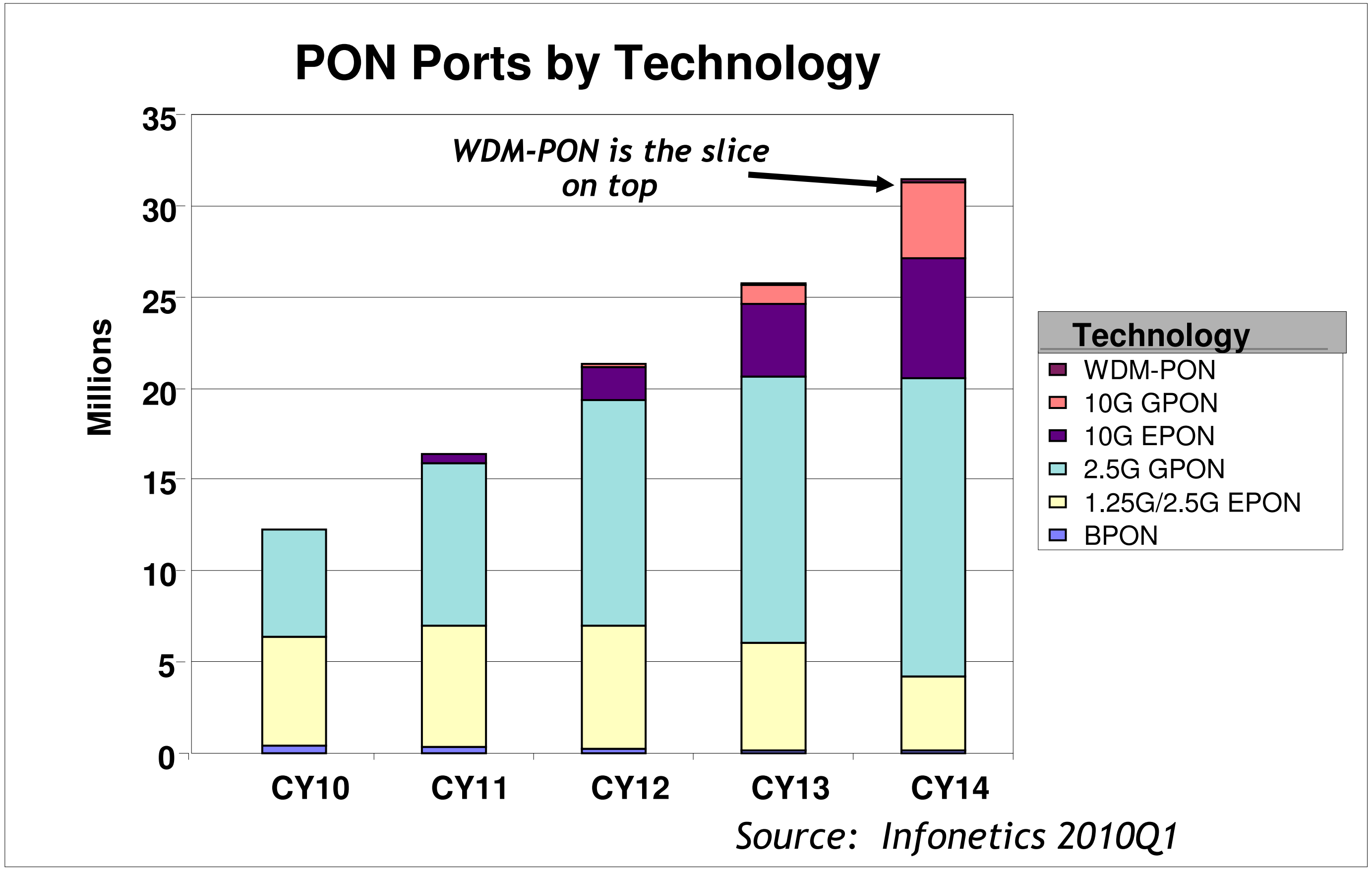
Summary of "Would-be" Motivations for WDM-PON in Residential access

	Motivation	WDM-PON for Res.	TWDM-PON for Res.	WDM-PON for Bus / Bkhl
1	Bandwidth support	? 10Gbps+	✓	✓
2	Per-customer service flexibility and upgradeability	X	✓	?
3	Wavelength unbundling & open ODN	X	✓	?
4	Power reduction	X	?	X
5	Space reduction	X	?	X
6	CO consolidation (reach & redundancy)	?	?	N/A

WDM-PON has challenges in the near term to address residential needs, HOWEVER, continued research will lead to break-throughs.

MEANWHILE, there may be applications for ***TWDM-PON*** in residential and ***WDM-PON*** in business access, wireless backhaul and FTTB.

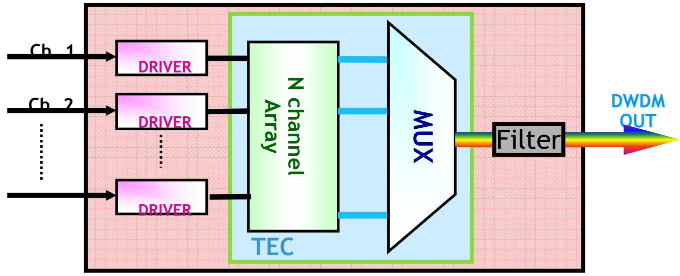
Forecast for BPON, EPON, GPON, 10GEPON, XGPON, …and WDM-PON



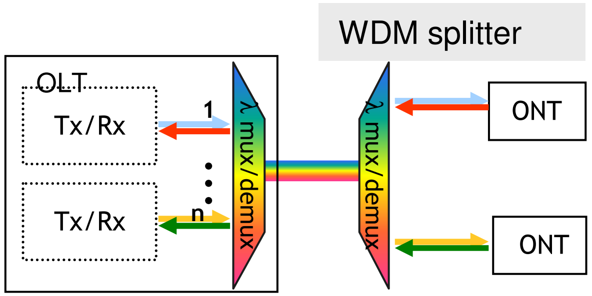
Well, it might be a while in coming,
But let's look at what it will take to make happen.

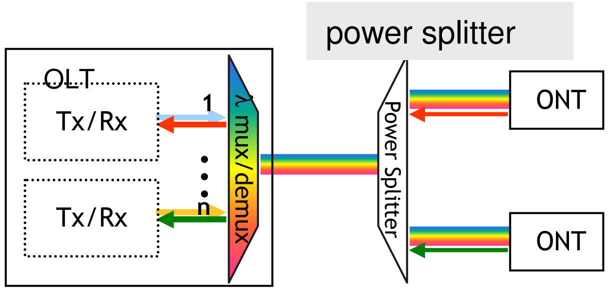
Technical Challenges and Enablers

- Component Integration in the CO
  - Requires photonic integration with single chip laser arrays and receiver arrays



- Filtering the Downstream Wavelength
  - 1. WDM splitter
    - A single wavelength is routed to each home
  - 2. Power splitter with filter at home
    - fixed filter in ONT or NID
    - tunable filter in ONT





The ideal WDM architecture should work with both WDM splitters and power splitters

Technical Challenges and Enablers

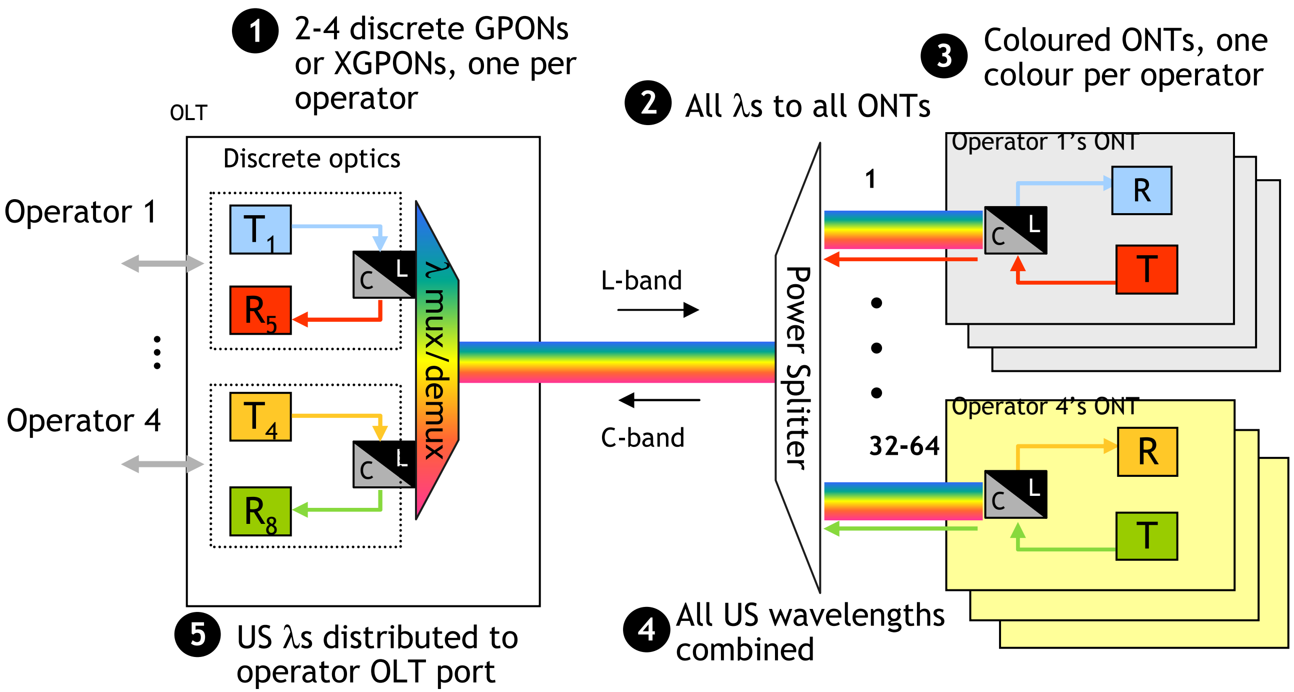
- Tuning the Upstream Wavelength (Colourless ONTs)
  - 1. Field swappable SFPs
    - May be ok for business or backhaul but not acceptable for res
  - 3. Traditional thermally tuned lasers
    - Expensive now but opportunity for the future
  - 4. Seeded Reflective SOAs or Fabry-Perot laser diodes
    - interesting but requires WDM splitters
  - 5. Mechanically tuned lasers
    - expensive and potentially unstable
  - 6. Selectable wavelengths
    - a possible alternative

The field for research is ripe

What will some of the solutions look like?
(6 architectures for TWDM-PON and WDM-PON)

1 *Operator-Coloured TWDM-PON* for "Open ODN" – λ unbundling

- Uses power splitter, all wavelengths to all homes
- Operators provide colour-specific ONTs to their customers
- Requires wavelength selection & standardization (CWDM, DWDM or MediumWDM)



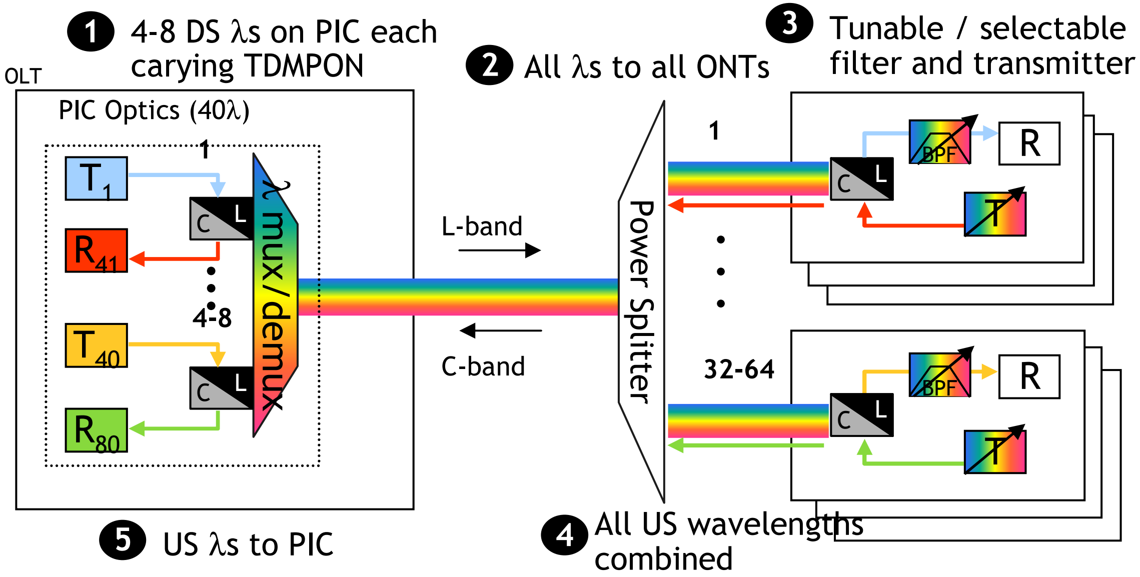
- 1-2.5Gbps per sub
- 2:1 asymmetry
- 32-64 sub/PON
- 20km reach (60km with RE)

Could be a cost-effective way of sharing infrastructure

2

Tunable TWDM-PON (a)
for bandwidth increase

- Each wavelength caries a TDM PON (e.g. 4 x XGPON)
- Use power splitters, all wavelengths to all homes
- Requires tunable or selectable filters and lasers in the ONT (needs innovation)
- Allows for dynamic bandwidth assignment and load balancing



- 10Gbps peak per sub
- 4:1 asymmetry
- 32-64 per PON
- 20km reach (60km with RE)

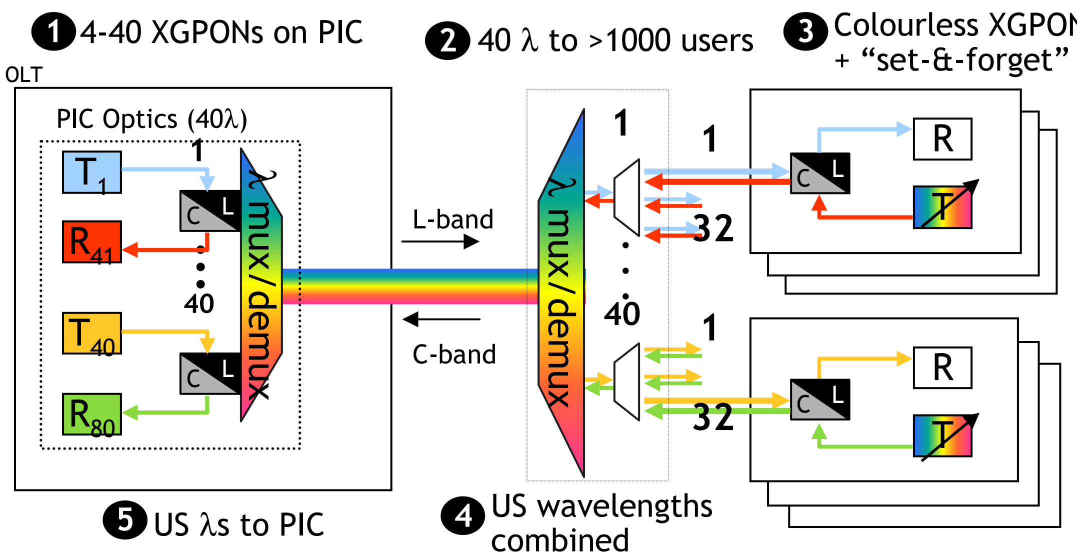
A long term possibility …if cost effective

Alcatel·Lucent

3

Tunable TWDM-PON (b) for CO consolidation

- Each wavelength caries a TDM PON, could be 40 x XGPON
- WDM splitter with cascaded power splitter allow for a massive fan-out to 1000s of users
- Requires tunable or selectable lasers in the ONT (needs innovation)
- Allows for significant fiber savings in feeder



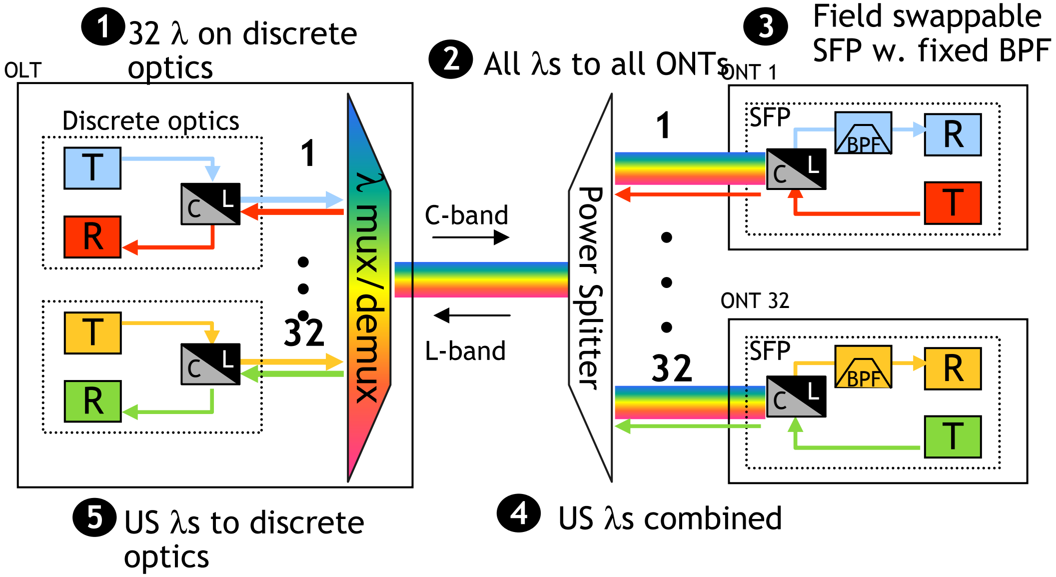
- •10Gbps peak per sub
- • 4:1 asymmetry
- **•1000s of subs / PON**
- •20km (60km with RE)

A long term possibility …if cost effective

4 *Field-Swappable WDM-PON*

for Business access & Wireless backhaul

- Uses power splitter, all wavelengths to all locations
- Each ONT has field swappable SFPs to select appropriate wavelength
  - Could be manageable for smaller volumes (i.e. not mass residential market)
- Allows for fiber Savings (vs P2P fiber)



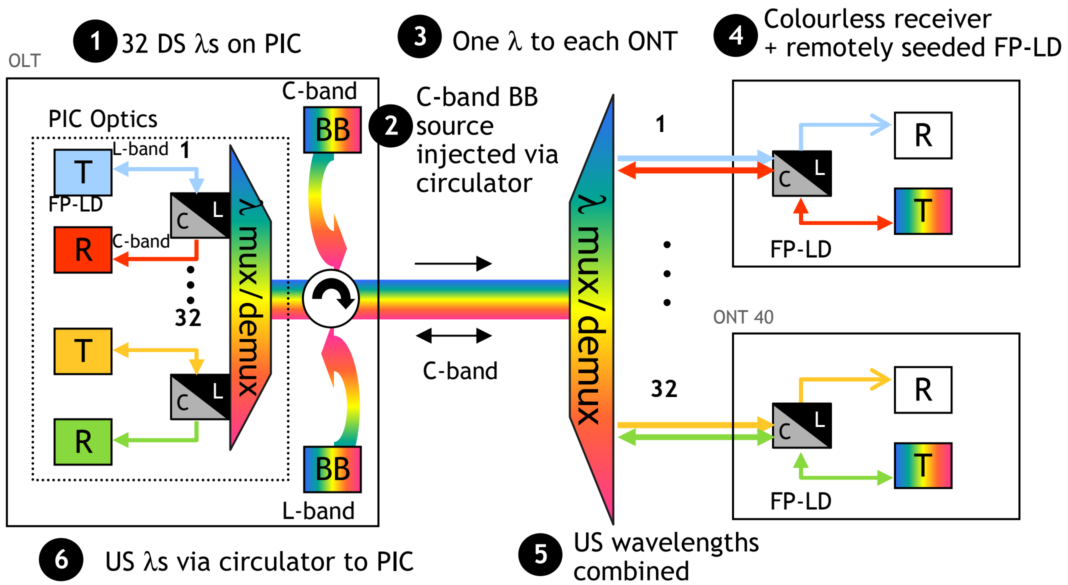
- 1 or 10Gbps peak per sub
- 1:1 symmetry
- 32 subs per PON
- **30km (with power splitter)**
- **60km (with wdm splitter)**

Could be an early application for WDM-PON

5 *Remotely-Seeded WDM-PON*

for Business access or Wireless backhaul

- ONTs (and OLTs) are seeded by a broadband source in the CO
- Requires a WDM splitter (cyclic AWG) to slice the BB source
  - Solution does not work on existing ODN with power splitters



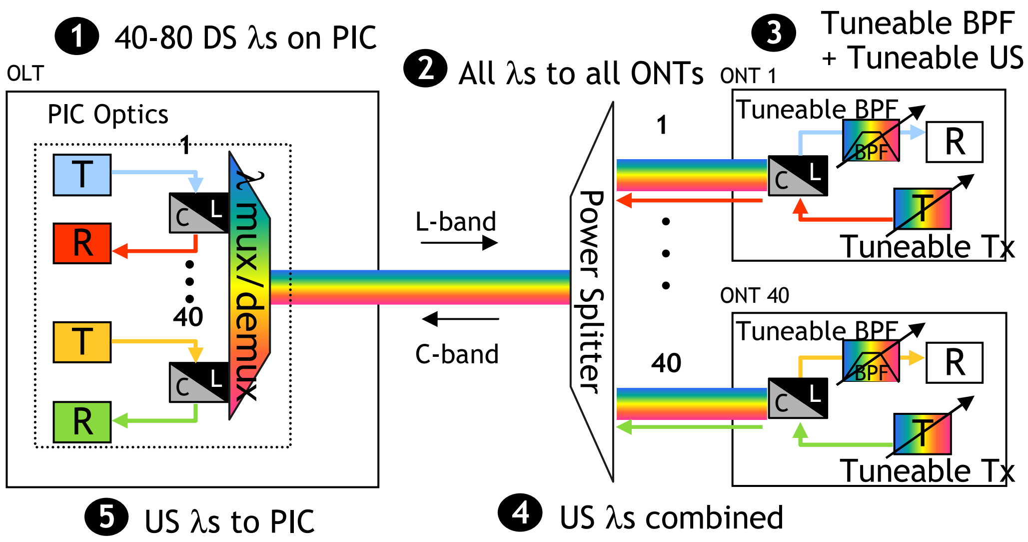
- 1 Gbps peak BW / sub
- **10G is Difficult**
- 1:1 symmetry
- 32 subs per PON
- 20 km reach

Could be an early application for WDM-PON ...if cost effective. Could also be a longer term solution for new res. deployment

6 *Tunable WDM-PON - THE LONG TERM GOAL*

for Mass Market bandwidth increase

- Can use Power splitters (as shown) or WDM splitters to get additional reach
- Wavelength selection is done via tunable or selectable filters and lasers in the ONT (requires innovation)
- Assume **10Gbps** is required in this time frame



- **10Gbps peak per sub**
- **1:1 symmetry**
- **40-80+ subs per PON**
- **30km (with power splitter)**
- **60km (with wdm splitter)**

Could be a long term role for WDM-PON …if cost effective

Comparison of 6 WDM Architectures

Application	**Short-term TWDM-PON** ▪λ unbundling (open ODN)	**Long-term TWDM-PON** ▪Residential BW (10G) ▪CO consolidation		**Early WDM-PON** ▪Business access (1 or 10G) ▪DSL and Wireless backhaul		**Long term WDM-PON** ▪Res. BW (10G) ▪CO consolid'tn
Architecture	1) Operator-Coloured TWDM-PON	2) Tunable TWDM-PON for BW with power splitter	3) Tunable TWDM-PON with hybrid splitter	4) Field-Swappable WDM-PON	5) Remotely-Seeded WDM-PON	6) Tunable WDM-PON
Advantages	▪"Open ODN" ▪Easy to implmnt	▪High settable BW	▪High Adjustabl BW ▪1000+ subs/PON	▪Less fiber (vs PP) ▪60 km passive	▪Known technology	▪10G symmetric ▪60 km passive
Challenges	▪Need λ standard	▪Need tunable T/R	▪Need tunable T	▪Coloured SFP	▪BB source ▪Reach & Rate	▪tunable T/R ▪PIC integration
Bit rate	▪1-2.5Gbps, 2:1	▪10Gbps 4:1	▪10Gbps, 4:1	▪1 or 10Gbps, 1:1	▪1 Gbps, 1:1 ▪10G is Difficult	▪10Gbps, 1:1
Subs / PON	▪32-64	▪32-64	▪1000s	▪32	▪32	▪40-80+
Reach	▪20km ▪60km with RE	▪20km ▪60km with RE	▪20km ▪60km with RE	▪30km (pwr) ▪60km (wdm)	▪20 km	▪30km (pwr) ▪60km (wdm)
Splitter	▪Power splitter	▪Both	▪Hybrid	▪Both	▪WDM-Only	▪Both

Must prove in relative to existing technologies

5 Building a Future-Proof Network

What is a Future-Proof Network?

- What is guaranteed to change
  - BW requirement of customer (100Mbps, 1G, 10G…)
  - Electronics at each end (APON, BPON, GPON, XGPON, WDM-PONs...)
  - Topology (P2P, TDM-PON, TWDM-PON, WDM-PON)
  - Splitter types (power splitters…pretty stable, WDM splitters with various λs)
  - Wavelengths used (2, 32, 40, 80, 100s of λs)

WDM-PON is NOT future-proof! ☺

- What will not change from one gen to the next:
  - **Fiber, ducts & fiber management points** (20-40 years)

Advice: Build fiber infrastructure to outlast the technology using fiber flexibility points!
Beyond that: Attempt to smooth evolution between technologies using l coexistence

In the mean time, use the lowest cost technology (GPON & XGPON are hard to beat)

What Material Last Longest?

…Here’s a hint from the ***Mohave Desert National Park Service***

i.e.:
Fiber Optics
= 1,000,000
year
investment

6 Conclusions

Summary & Conclusions

- Higher definition video and personalized interactive services continue to drive BW
  - Peak BW requirement of 1Gbps in 2014 and 10Gbps beyond 2020.
- Continued innovations in DSL will allow copper to deliver upwards of 200Mbps using vectoring, bonding and phantom mode
- GPON and XGPON have lots of bandwidth to meet residential needs for the coming 10 years.
- WDM-PON will not see an immediate application in mass residential applications, but there will be short term niche applications:
  - business access
  - DSL and wireless backhaul.
  - l unbundling & true service flexibility are not realistically achievable with WDM-PON
- Short term applications for TWDM-PON could include
  - “Open ODN” – λ sharing between operators
- Key topics for research in WDM include:
  - photonic integration
  - tunable/selectable receivers and transmitters
  - Cost remains key
- The long term target architecture for WDM-PON uses tunable/selectable transceivers
- The best preparation for the future is a flexible fiber infrastructure