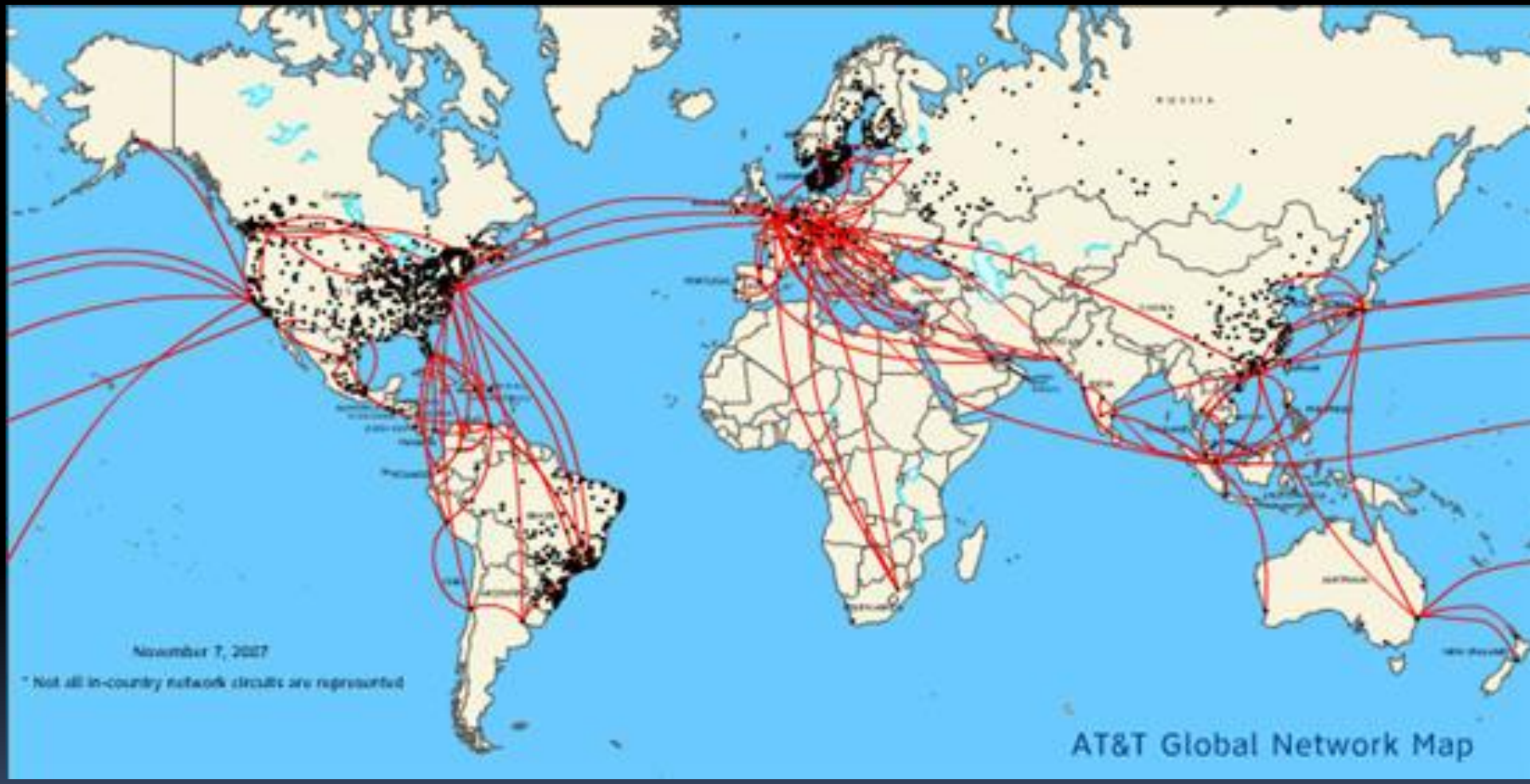
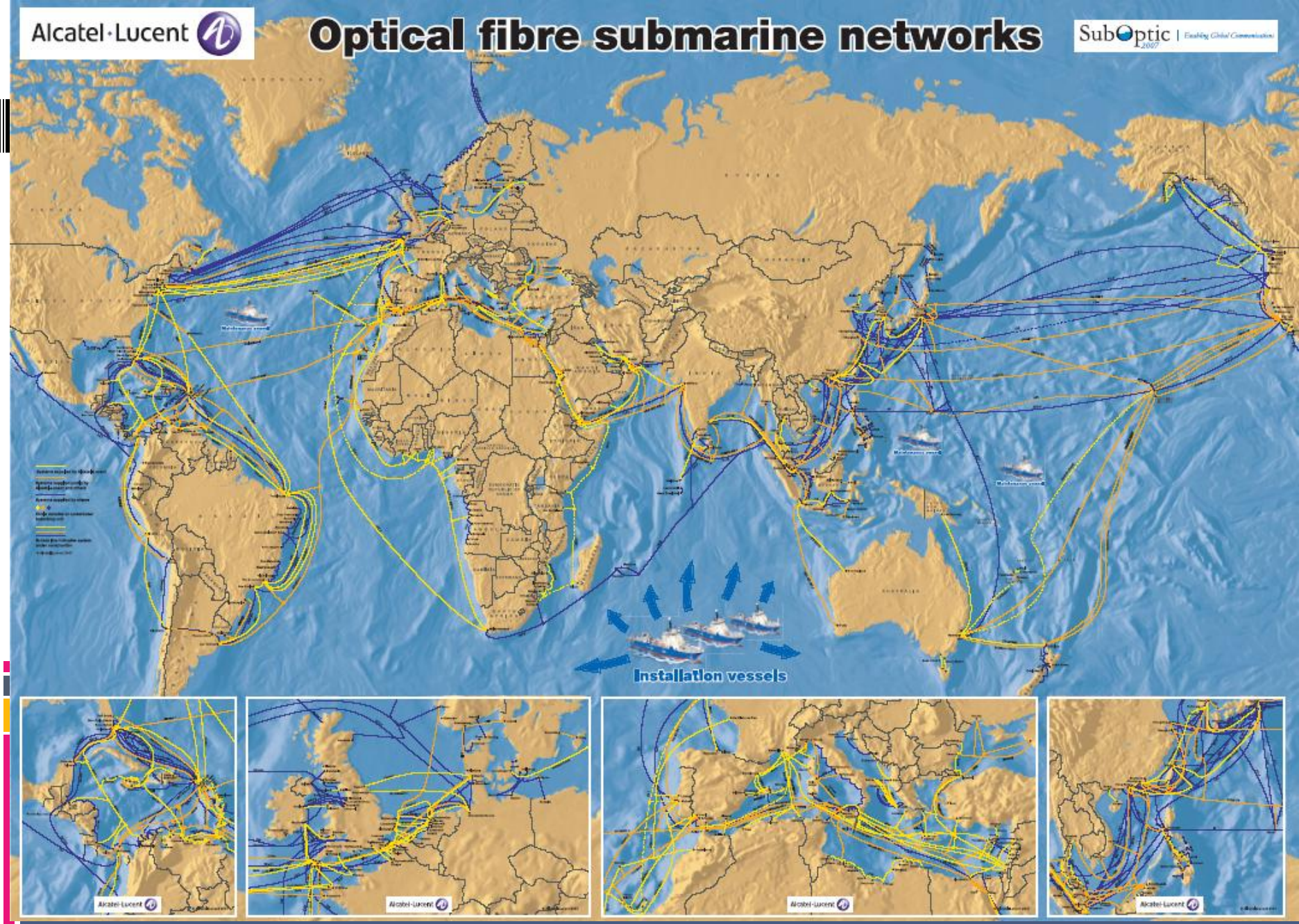
ECE 6323

OPTICAL COMMUNICATION NETWORK: INTRODUCTION (P. 2)

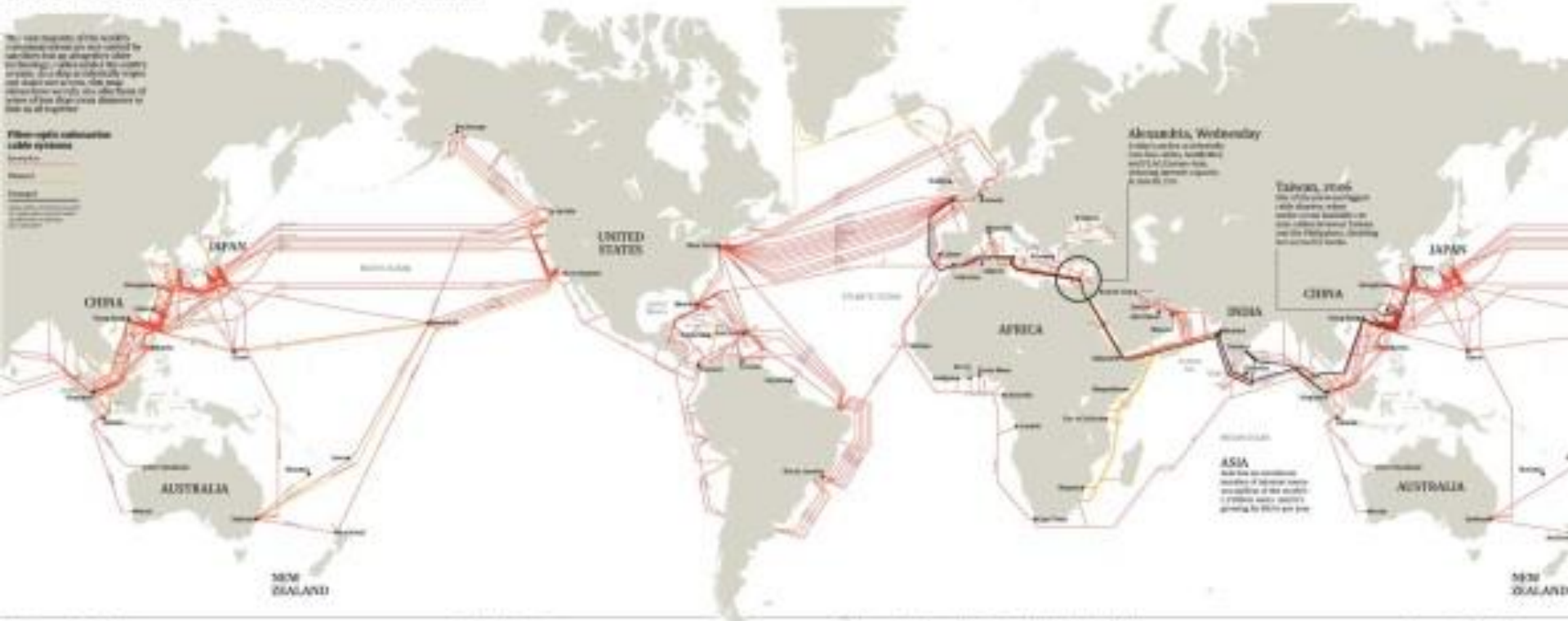
Outline

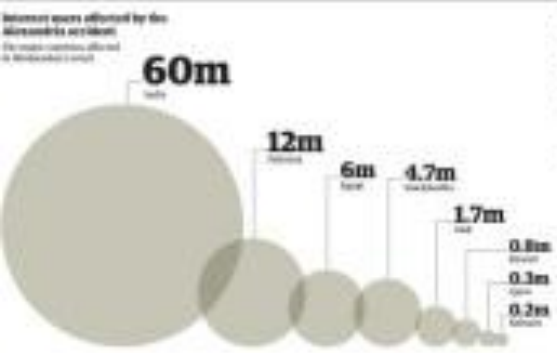
- Introduction
- Telecom/datacom network concept
- Optical network concepts and architecture
  - Overview
  - Layers and protocol
  - (D)WDM network and wavelength routing
  - Optical switching
- Optical network deployment
  - Global
  - Fiber to the premise (home, business,…)
- Summary

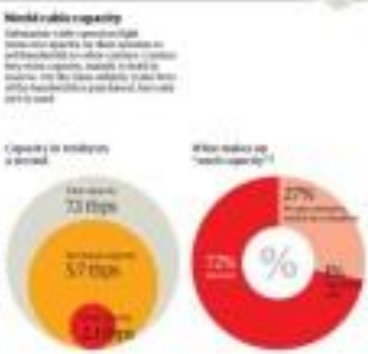

November 7, 2007
* Not all in-country network circuits are represented
AT&T Global Network Map

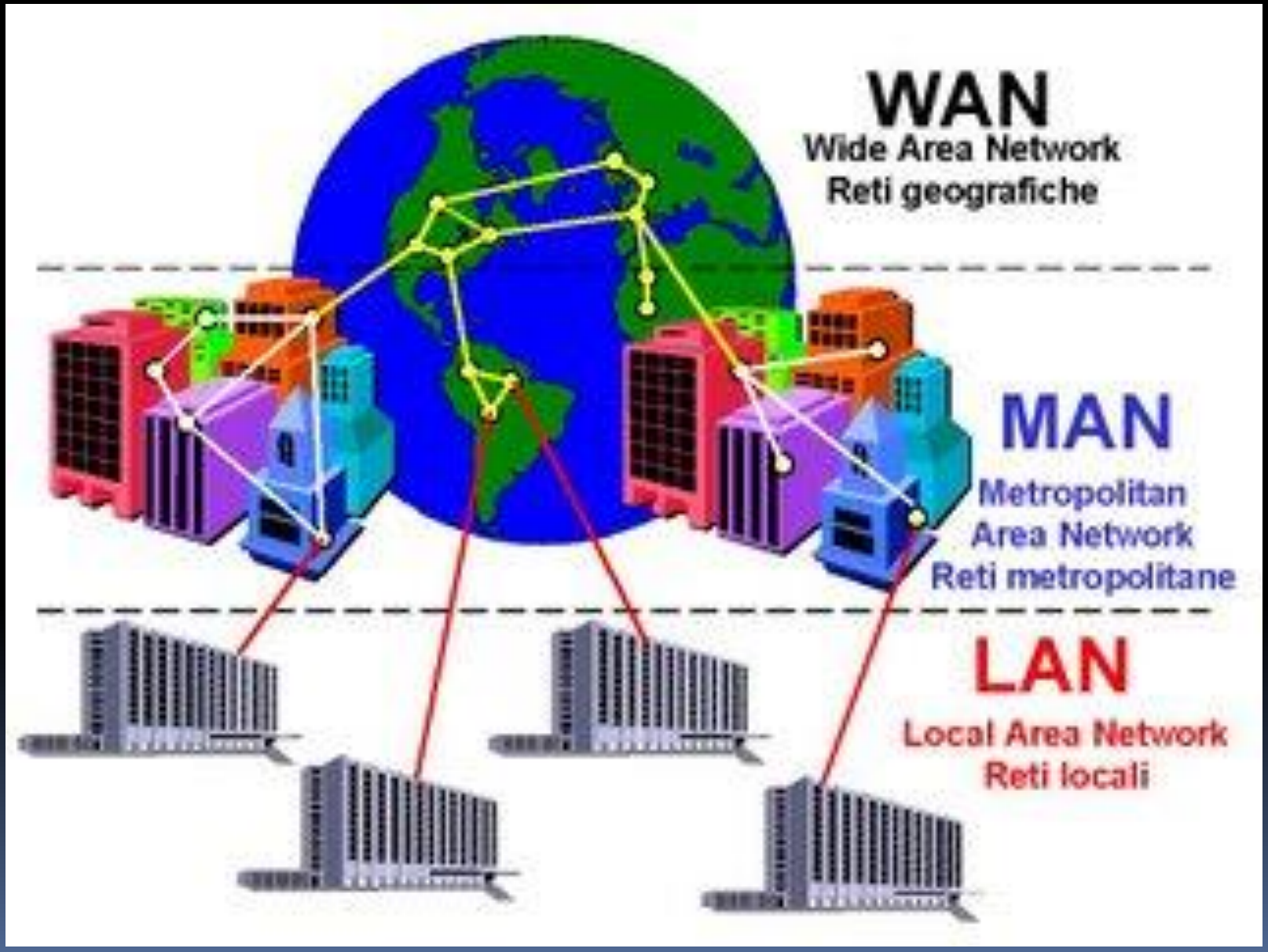

Alcatel·Lucent
Optical fibre submarine networks
SubOptic 2007
Installation vessels

The internet's undersea world








WAN
Wide Area Network
Reti geografiche
MAN
Metropolitan
Area Network
Reti metropolitane
LAN
Local Area Network
Reti locali

THE FIRST (LAST) MILE: FIBER TO THE HOME (FTTH) AND FTTX

Recent news

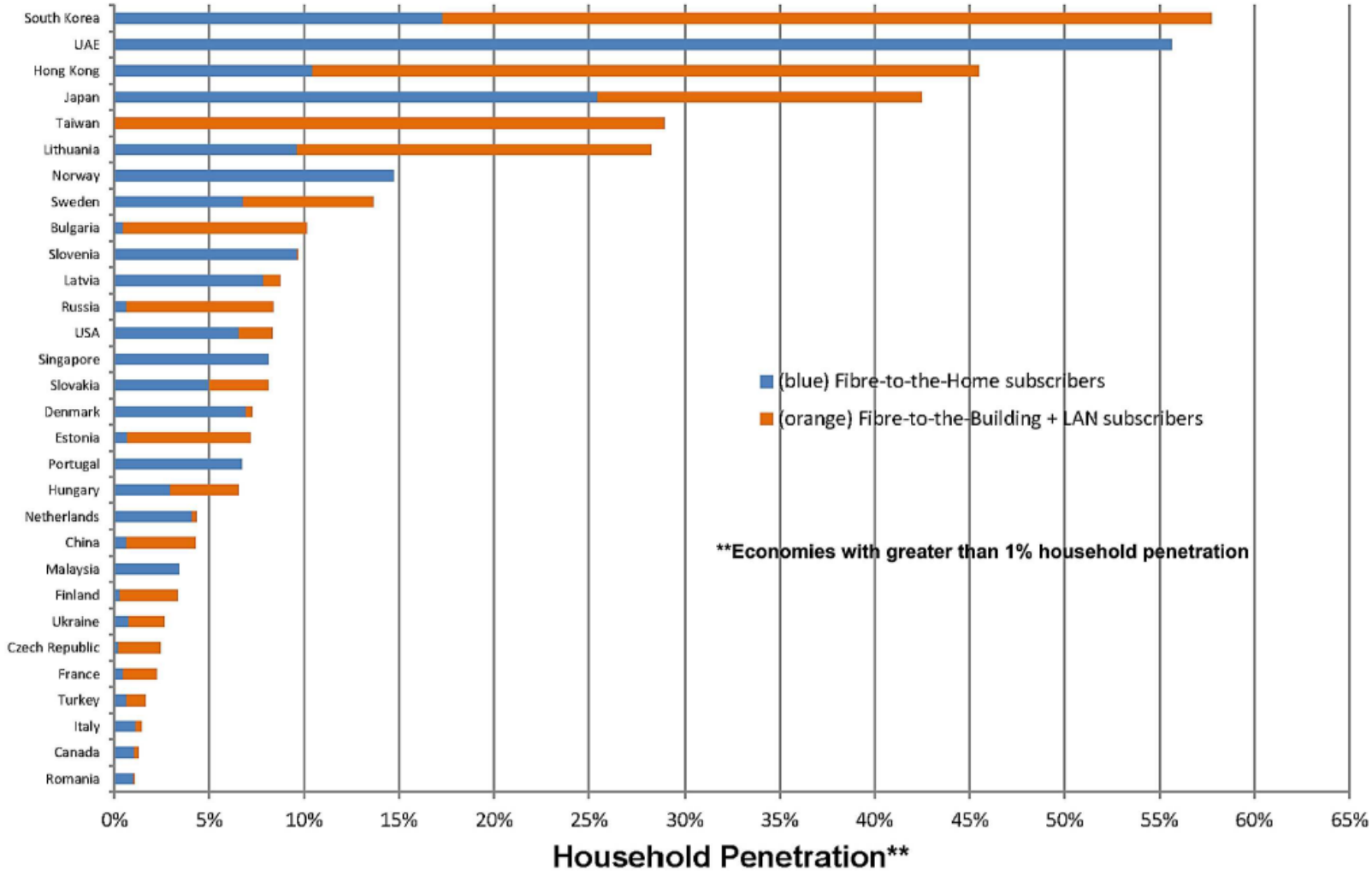
http://www.cnet.com/news/at-t-to-take-gigabit-broadband-to-21-new-metro-areas/

http://www.pcworld.com/article/2146381/atandt-lays-out-plan-for-gigabit-internet-dominance-setting-up-google-fiber-showdown.html

The First Mile - Outline

- Introduction: the first/last mile bottleneck
- Evolution of FTTH considerations
- Network architecture and standards
- Enabling technologies
- The future: applications

Economies* with the Highest Penetration of Fibre-to-the-Home/Building + LAN



December 2011 Ranking
Source: Fibre-to-the-Home Council
February 2012

*Economies with at least 200,000 households

The First Mile - Outline

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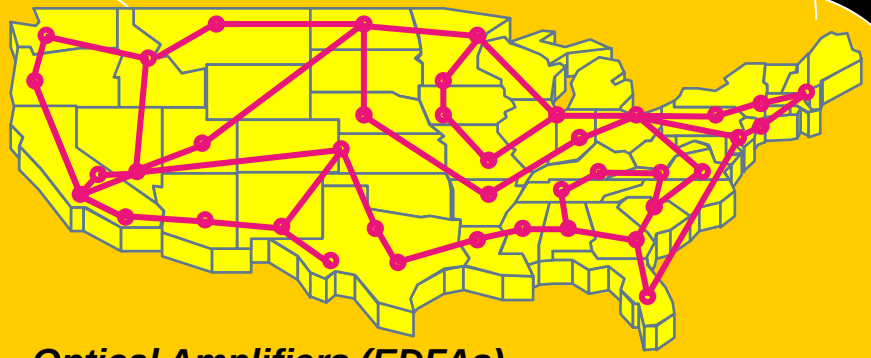
Access: Bottleneck & Brokers of Bandwidth

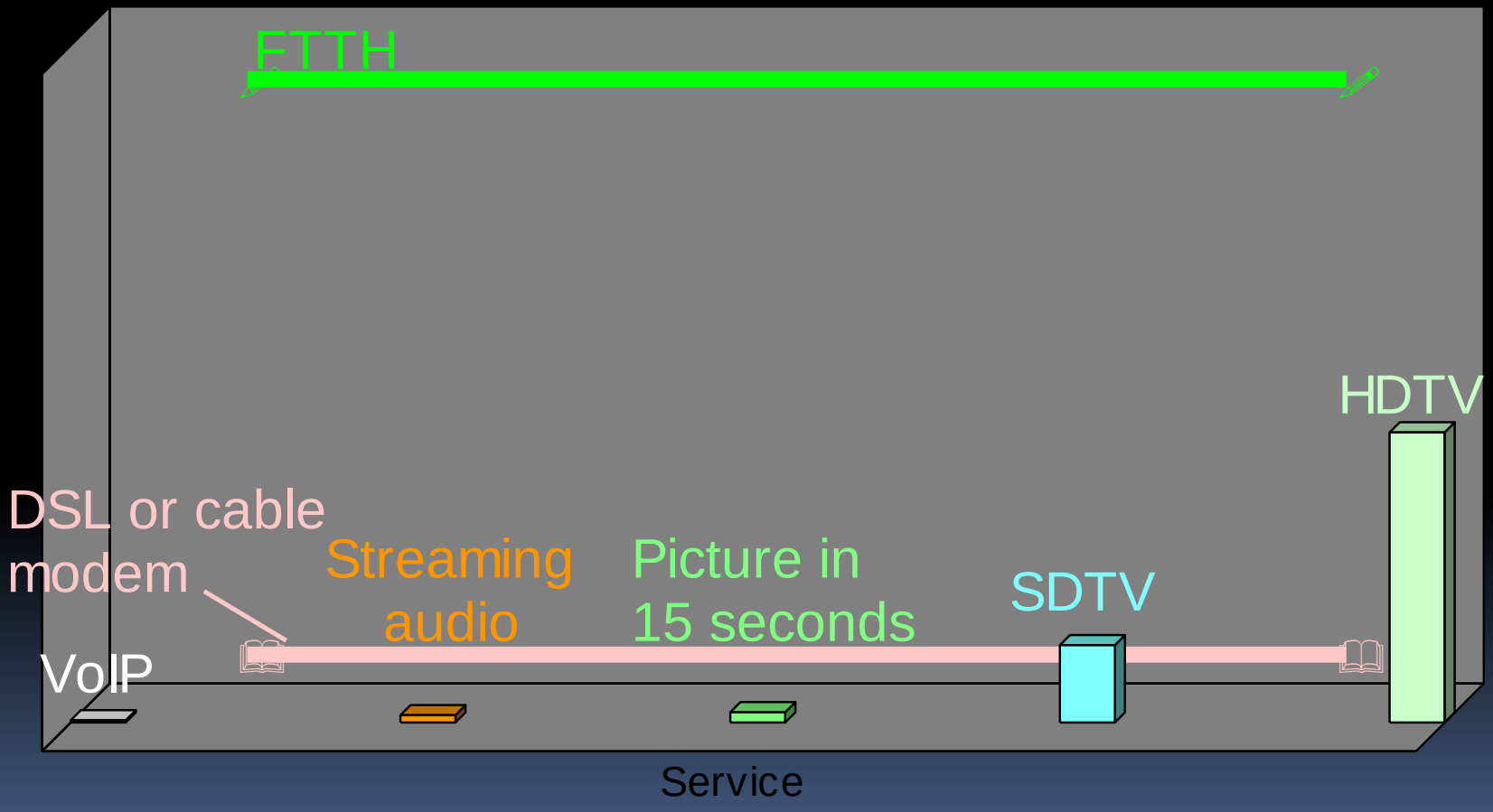


Optical Amplifiers (EDFAs)
DWDM (4, 8, 16, 40, 80, 96, 128, 256,…)
C + L band
100-50-25 GHz
S Band
Raman Amps
New Modulation Techniques

LAN

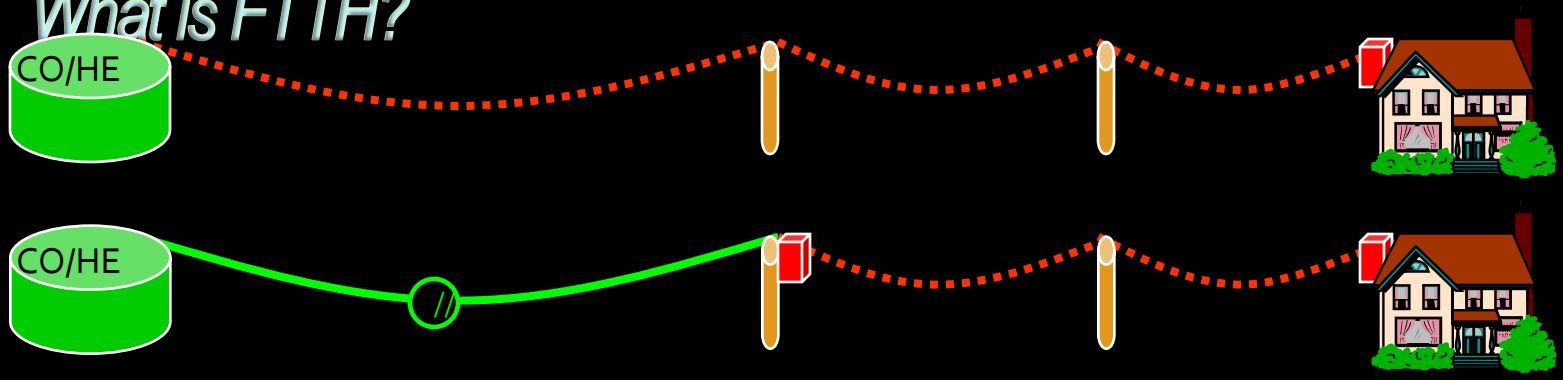
FTTH technical tutorial

Technical considerations - Speed



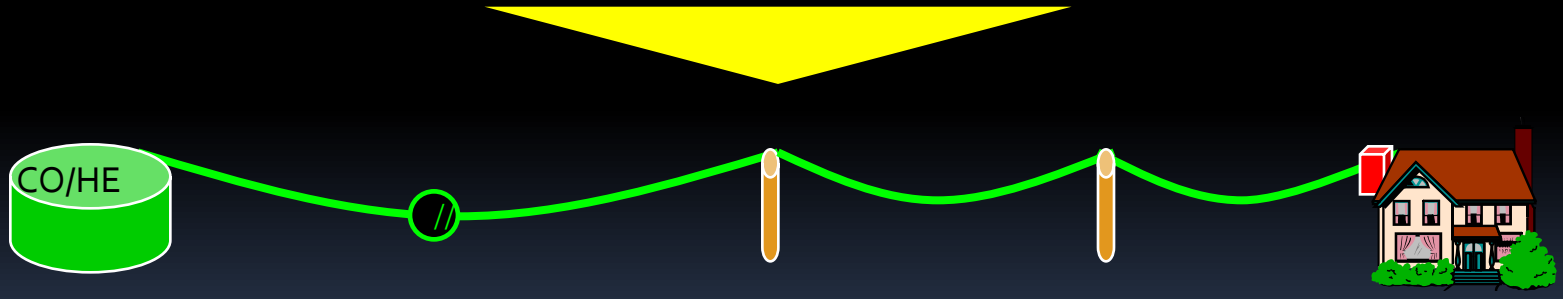
FTTH technical tutorial

What is FTTH?



Old networks, optimized for voice

24 kbps - 1.5 Mbps



Optical networks, optimized for voice, video and data

19 Mbps - 1 Gbps +

Note: network may be aerial or underground

What use is all that bandwidth?


MACNELLY Chicago Tribune
Bell Atlantic
TCI
Liberty
QVC
Paramount
BLOCKBUSTER
INFORMATION SUPERHIGHWAY
GREAT. SO NOW HOW DO WE ORDER A PIZZA?

Telecom market is redefining itself

Beyond voice – a fragmented market

The power of users

60 billion online searches conducted worldwide in August 2007

45% of US and European workers are away from their desk more than 20% of their time

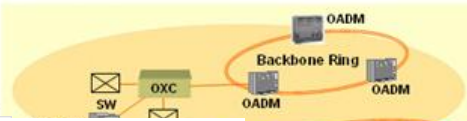
Over **8.6 million** articles and over 5.7 million registered contributors on Wikipedia globally

World of Warcraft, the subscription-based online game, has more than **10 million** players

Global digital music sales reached **$3 billion** in 2007, half of the revenues came from mobile

Over **3 billion** songs, 50 million TV episodes and 2 million Disney movies have been purchased and downloaded from iTunes

21st Century

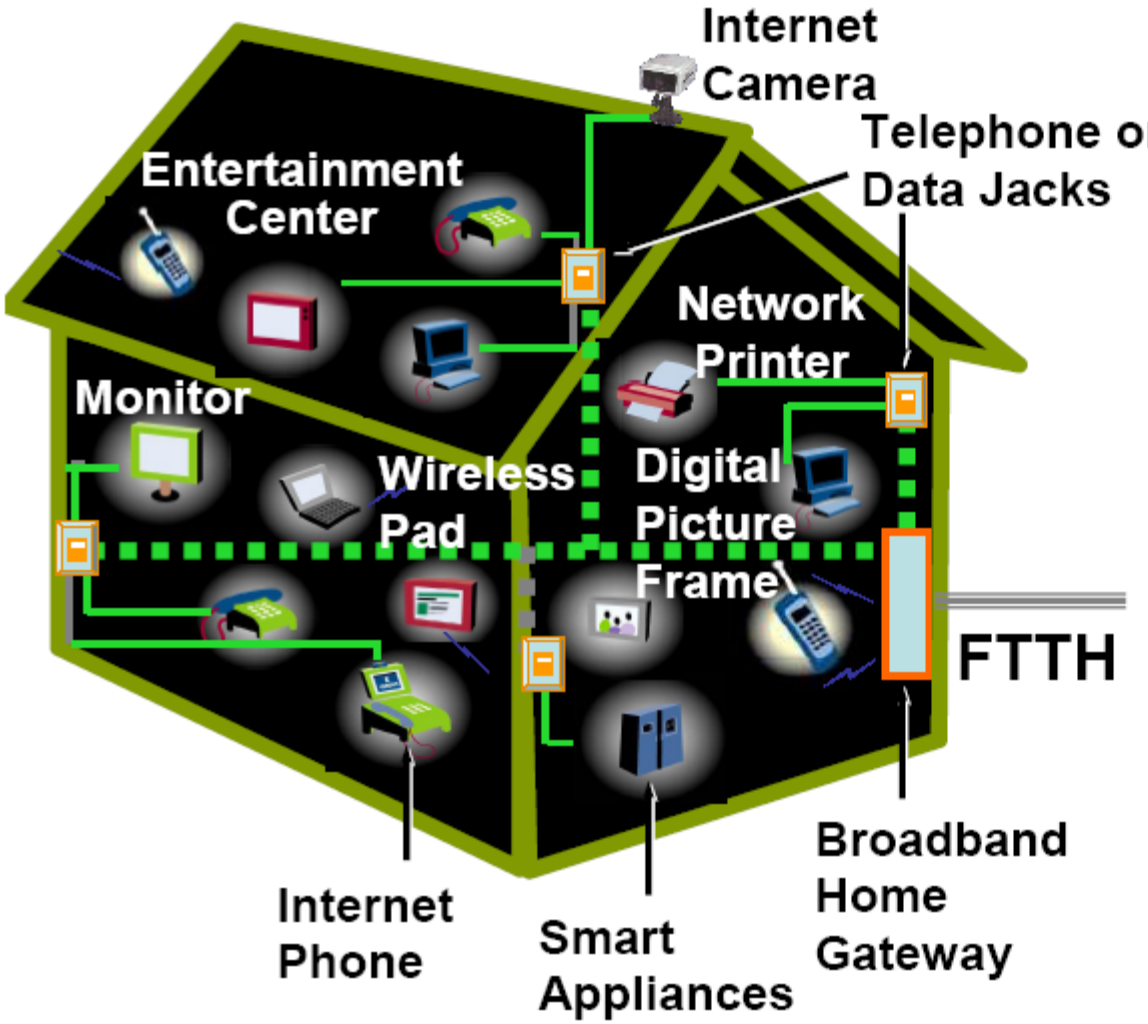


Connected Home Entertainment Ecosystem

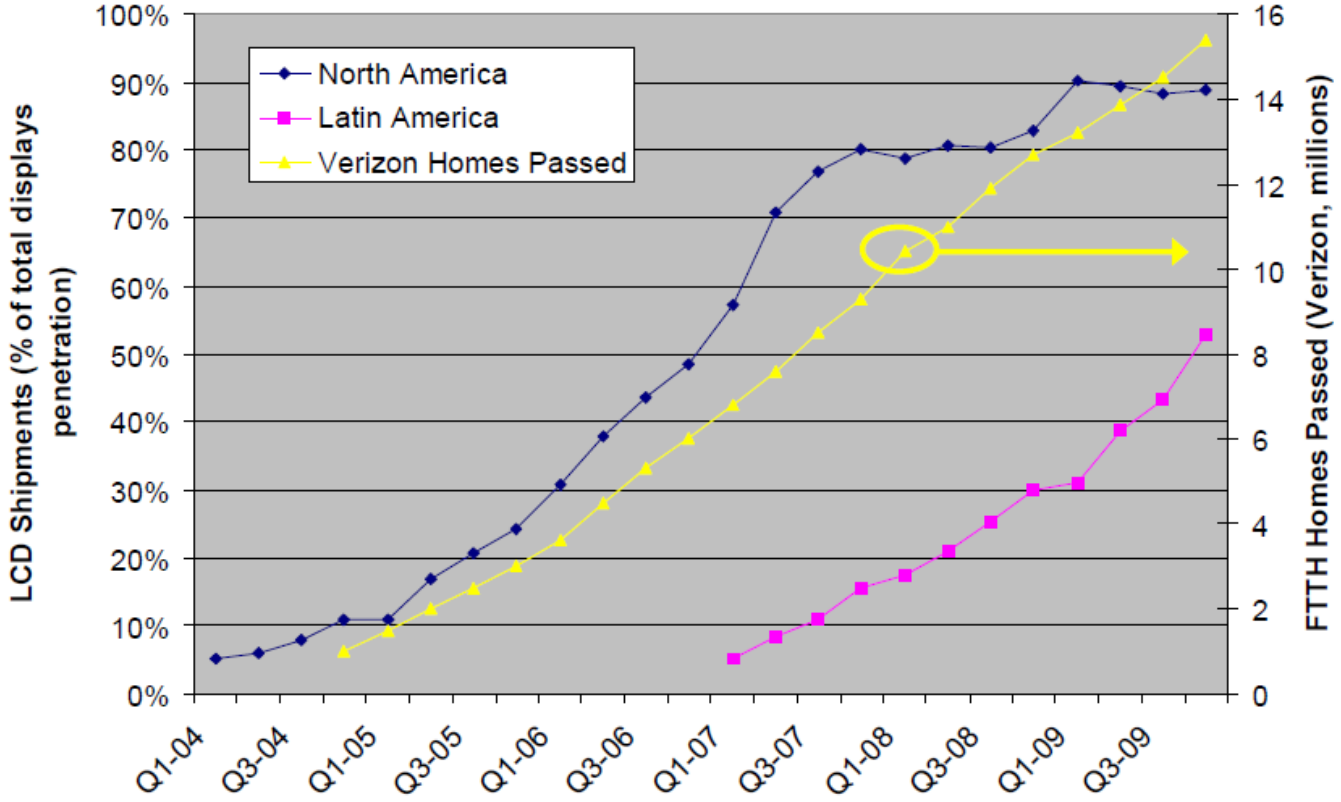
Source: Trends in Consumer Technology: Defining and Sizing the Market
© 2006 Parks Associates

Source: Michael Lebby – US-OIDA
Han Le & Assoc

What do you Need Broadband for?



LCD's and FTTH…a parallel



Source: *Paulo Dainese, Corning Optical Fiber*

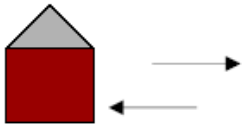
Larger Screens need Higher Definition

- 108 inch LCD 1080p HDTV now available - Larger screens under development
- Larger screens mean larger pixels and lower definition at the same distance
- Eventually Wall sized screens in multiple rooms of the home?

Video Applications Consume Bandwidth . . .

	2D Video Format	Applications	Mb/s Native per stream	Mb/s (compressed)	
				H.262 or MPEG-2	H.264 or MPEG-4
Today: Mature	Standard Definition (SD) 480p	DVD Digital Broadcast	249	4	2
Today: Mature	High Definition (HD) 720p	HD Broadcast	1,493	16	8
Today: Growing Fast	Very High Definition (VHD) 1080p	HD-DVD Blue Ray Videoconferencing Camcorders	2,986	32	16
2160p New Standards	Super HD	Large Screens	14,930	100	50
4320p	Ultra HD		59,720	400	200

Source: OFS Estimates from Industry Data



Multiple streams/downloads/uploads will need 100 Mb/s – 1 Gb/s per unit symmetrical

* New Standards: Nov 2005 ITU Recommendation J.601, Transport of Large Scale Digital Imagery (LSDI) applications

3D Display Technology – Can drive > 1 Gb/s per video stream

One example

- **Scientific and Engineering today. Entertainment in the Future.**
- **3D Volumetric Display with no moving parts**
- **16" x 12" x 4" display with larger sizes (50") possible**
- **20 LCD screens stacked, each with 1024 x 768 resolution, higher resolution possible.**
- **This example enables viewer perception of 608 depth levels**

Source: LightSpace Technologies Inc

FTTH technical tutorial

Technical considerations – Speed (IPTV Reference)

August 17, 2001:
MGM, Paramount Pictures, Sony Pictures, Warner Brothers, and Universal Studios unveiled plans for a joint venture that would allow computer users to download rental copies of feature films over the Internet.

December 9, 2002:
"Hollywood's Latest Flop"
Fortune Magazine
"The files are huge. At 952 Megabytes, Braveheart took just less than five hours to download using our DSL Line at home… in the same time we could have made 20 round trips to our neighborhood Blockbuster "

Estimated minimum time to acquire *Braveheart*

Technology	Minutes	Hours	Days
Modem 56 kb/s			2
ISDN 128 kb/s		20	
FedEx		12	
DSL 1 Mb/s		2.5	
Cable 2.5 Mb/s		1	
Blockbuster	45		
FTTH	0.4		

The First Mile - Outline

- Introduction: the first/last mile bottleneck
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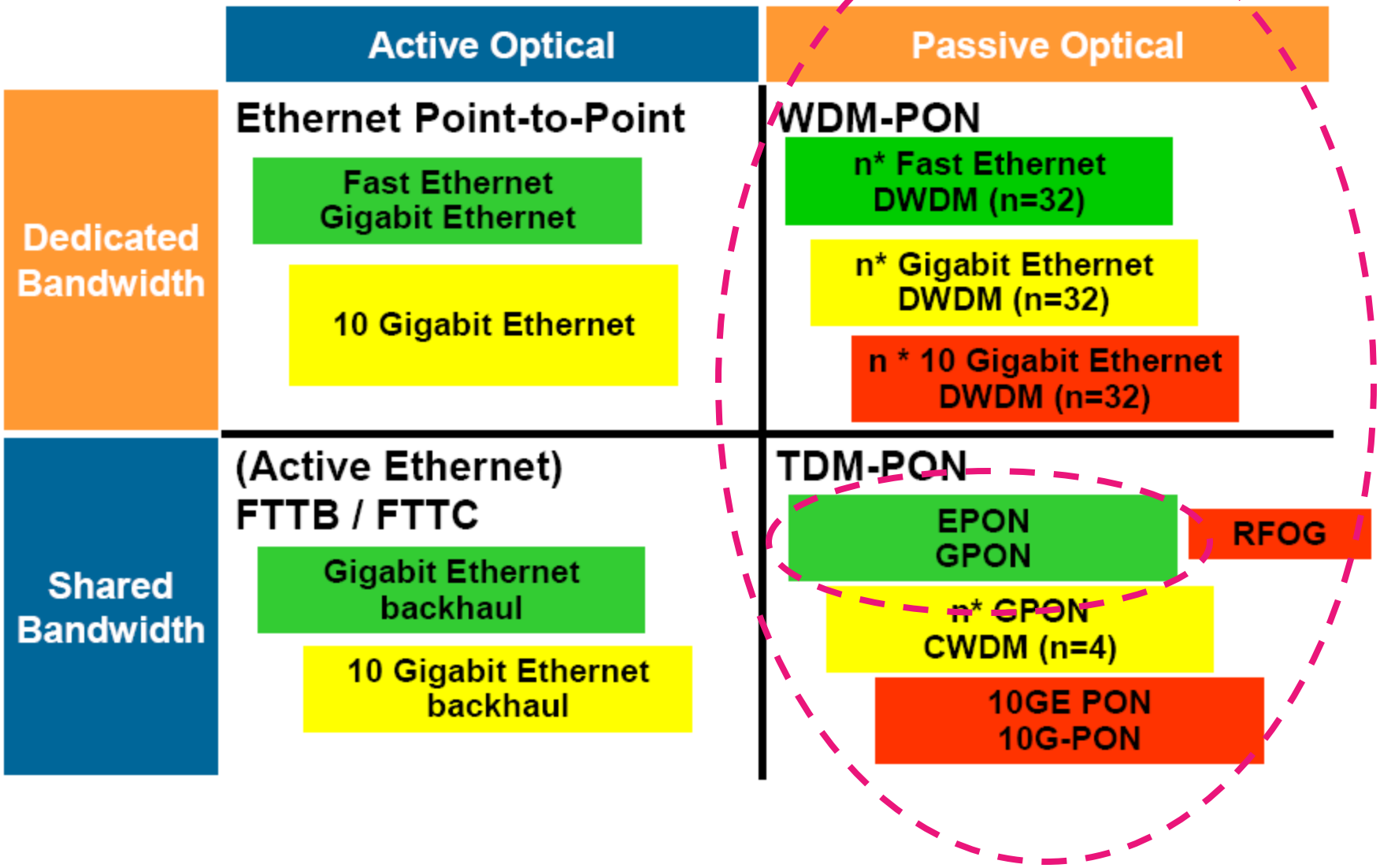
Service Requirements for Today &Tomorrow

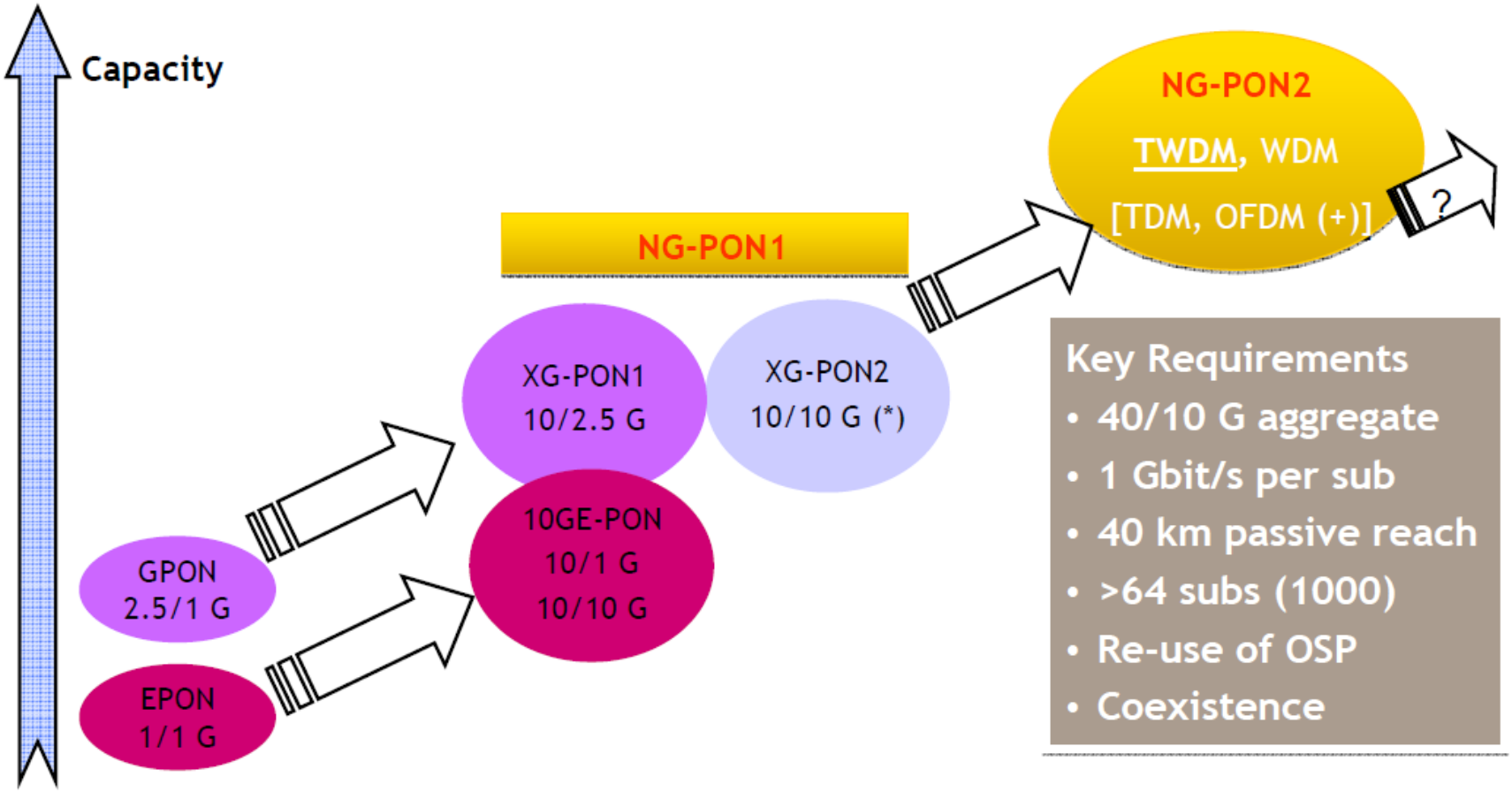
Application	Downstream	Upstream
Streaming Audio	128K - 384K	64K
Internet Access	256K - 1.5M	64K - 640K
Telecommuting	1.5M – 3M	1.5M – 3M
Standard Video Conferencing	384K - 1.5M	384K - 1.5M
Distance Learning	384K - 1.5M	384K - 1.5M
Personal Telepresence – HD	1.5M – 10M	1.5M – 10M
Interactive Video	1.5M - 6M	128K - 6M
Video on Demand	1M - 18M	64K - 640K
Multiple Digital TV	2M - 8M	64K - 640K
HDTV/IPTV	6-18M	64K
Gaming	2-20M	64K –20M

Technological evolution



PON Standardization Roadmap

Peter Vetter – Bell Labs, Alcatel-Lucent
ECOC, Amsterdam, September 18th, 2012



Key Requirements

- 40/10 G aggregate
- 1 Gbit/s per sub
- 40 km passive reach
- >64 subs (1000)
- Re-use of OSP
- Coexistence

Ref.: FSAN / ITU-T G.984
IEEE 802.3ah

G.987
802.3av

(*) Not a standard

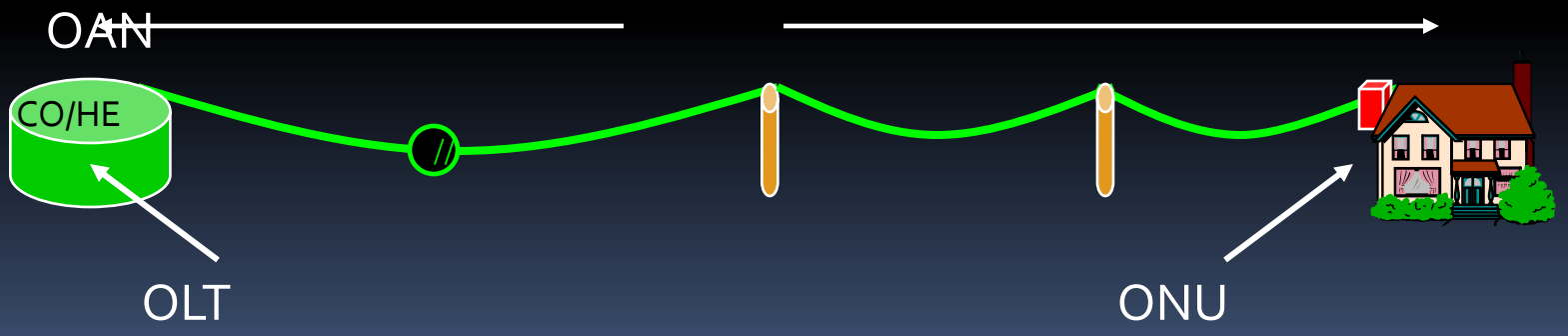
G.ngpon2
(+) No longer considered

OSP: Outside Plant

FTTH technical tutorial

What is FTTH?

- "An OAN in which the ONU is on or within the customer's premise. Although the first installed capacity of a FTTH network varies, the upgrade capacity of a FTTH network exceeds all other transmission media."
  - OAN: Optical Access Network
  - ONU: Optical Network Unit
  - OLT: Optical Line Termination



Source: www.ftthcouncil.org

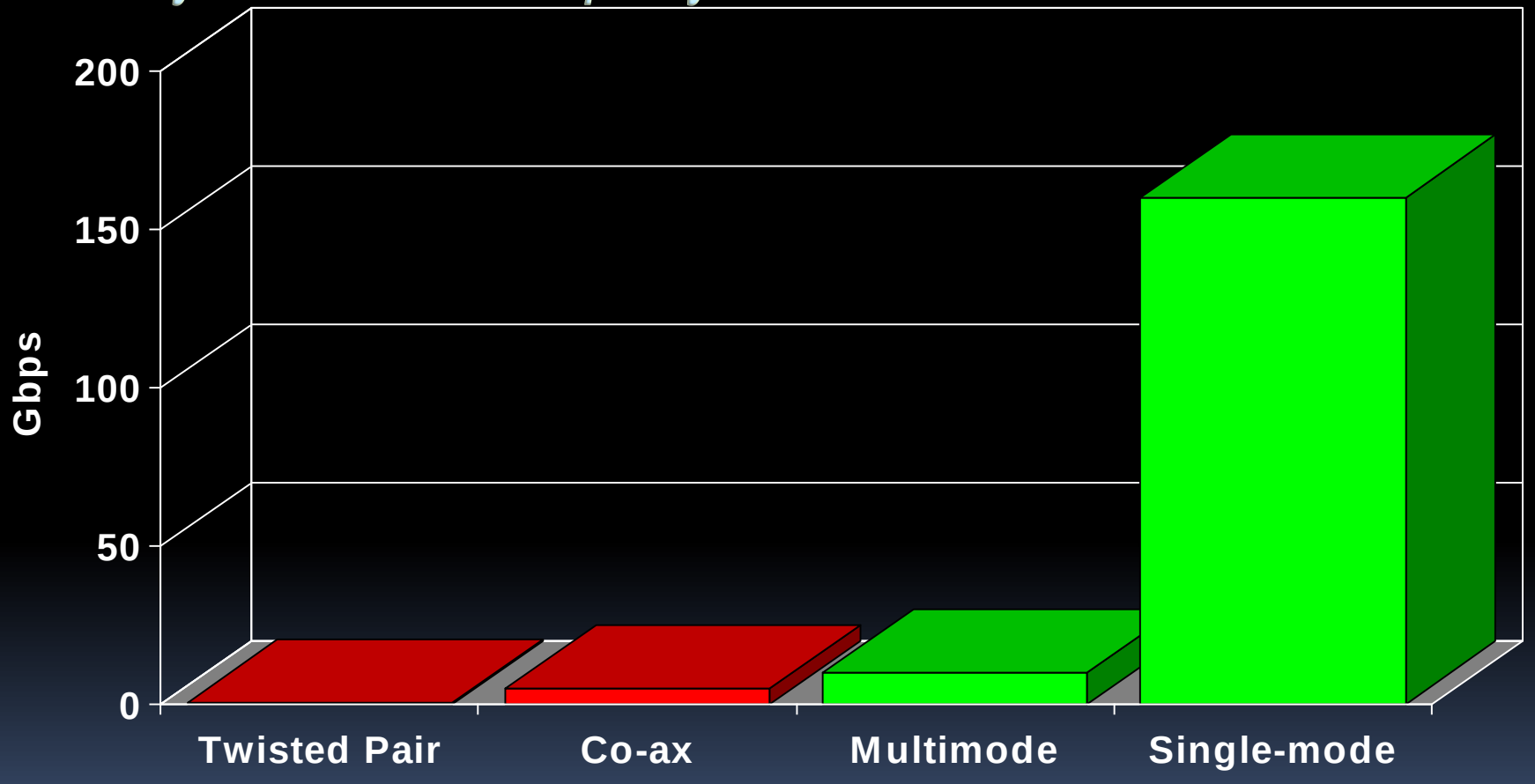
FTTH technical tutorial

Why FTTH?

- Enormous information carrying capacity
- Easily upgradeable
- Ease of installation
- Allows fully symmetric services
- Reduced operations and maintenance costs
- Benefits of optical fiber:
  - Very long distances
  - Strong, flexible, and reliable
  - Allows small diameter and light weight cables
  - Secure
  - Immune to electromagnetic interference (EMI)

FTTH technical tutorial

*Why FTTH? - more capacity**



* Typical system capability for 100 m link

Source: Corning Incorporated

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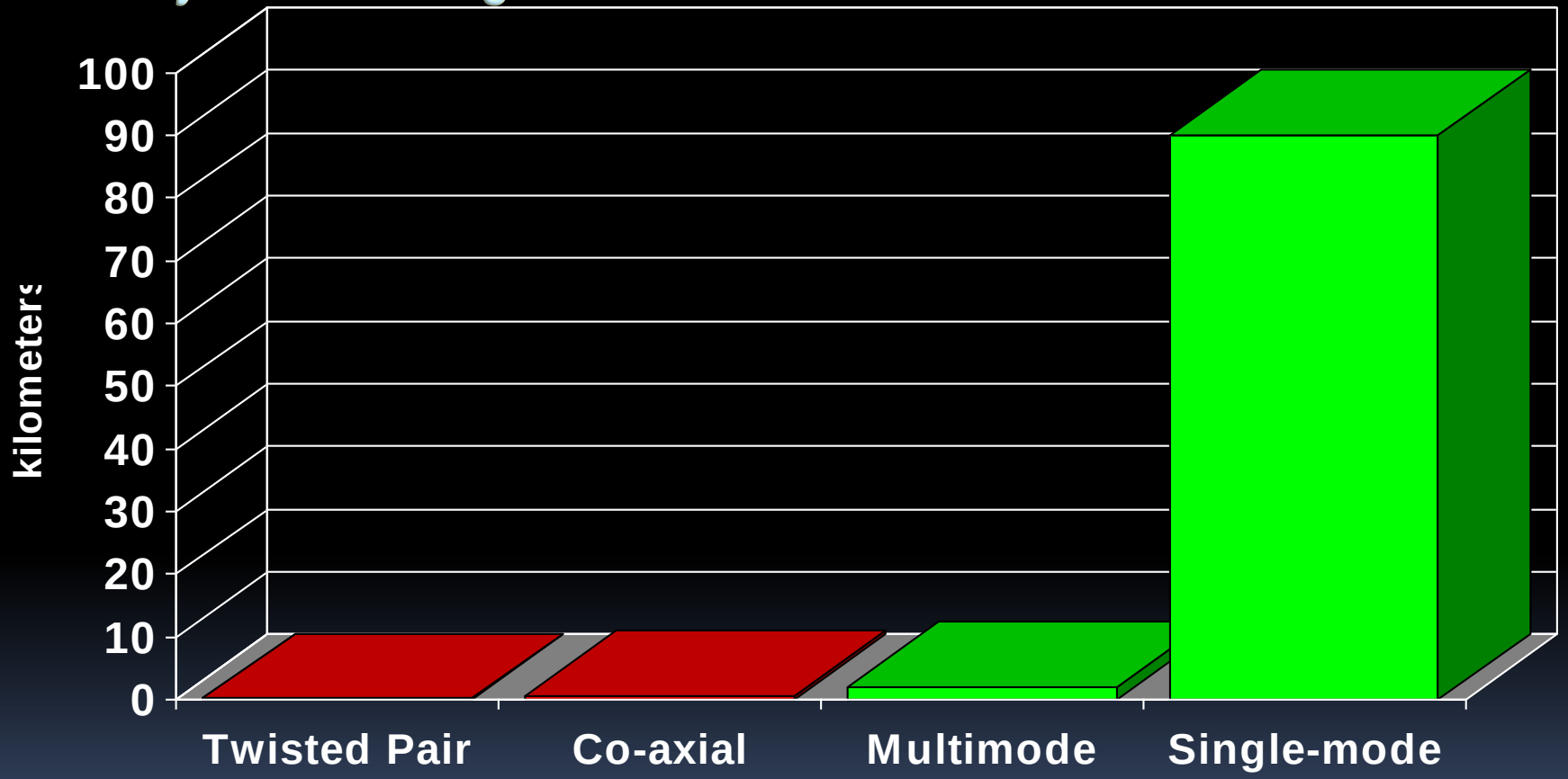
*Why FTTH? - longer distances**



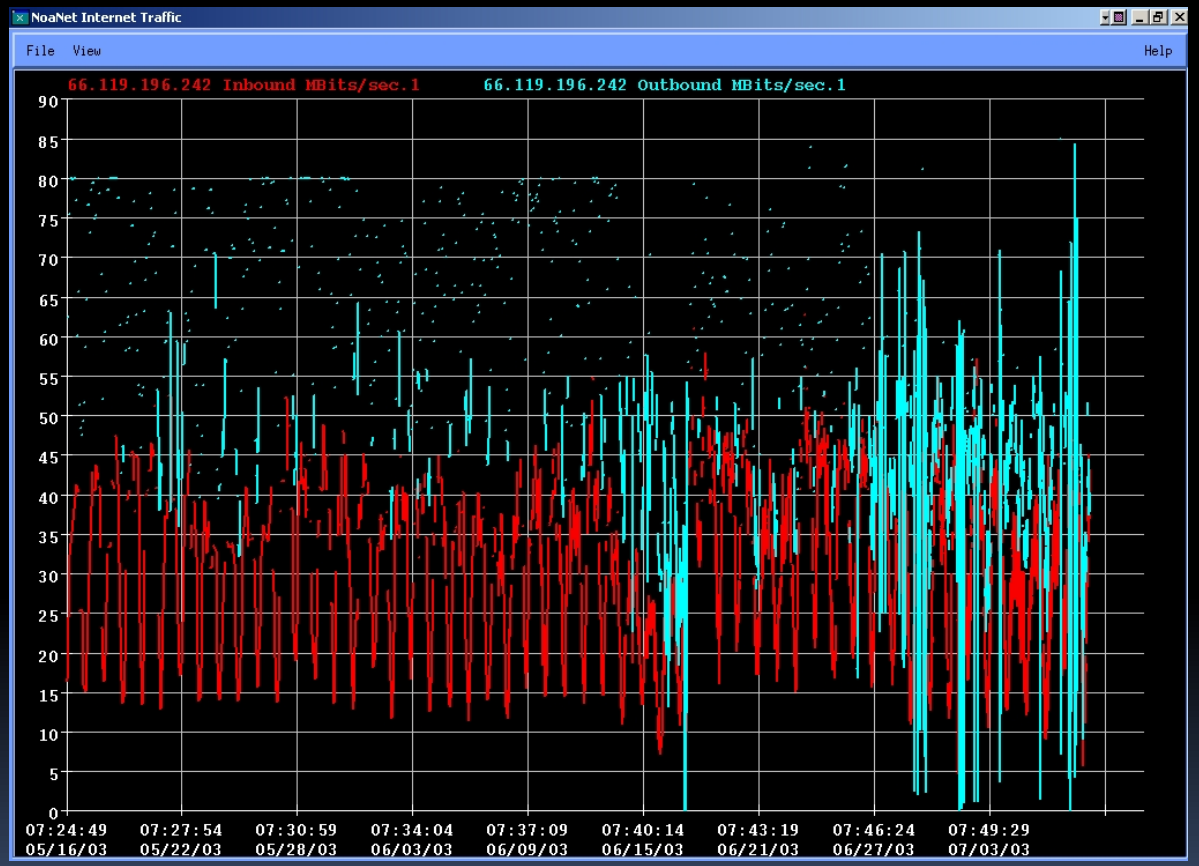
* Typical distance for 1 Gbps system capability

Source: Corning Incorporated

FTTH technical tutorial

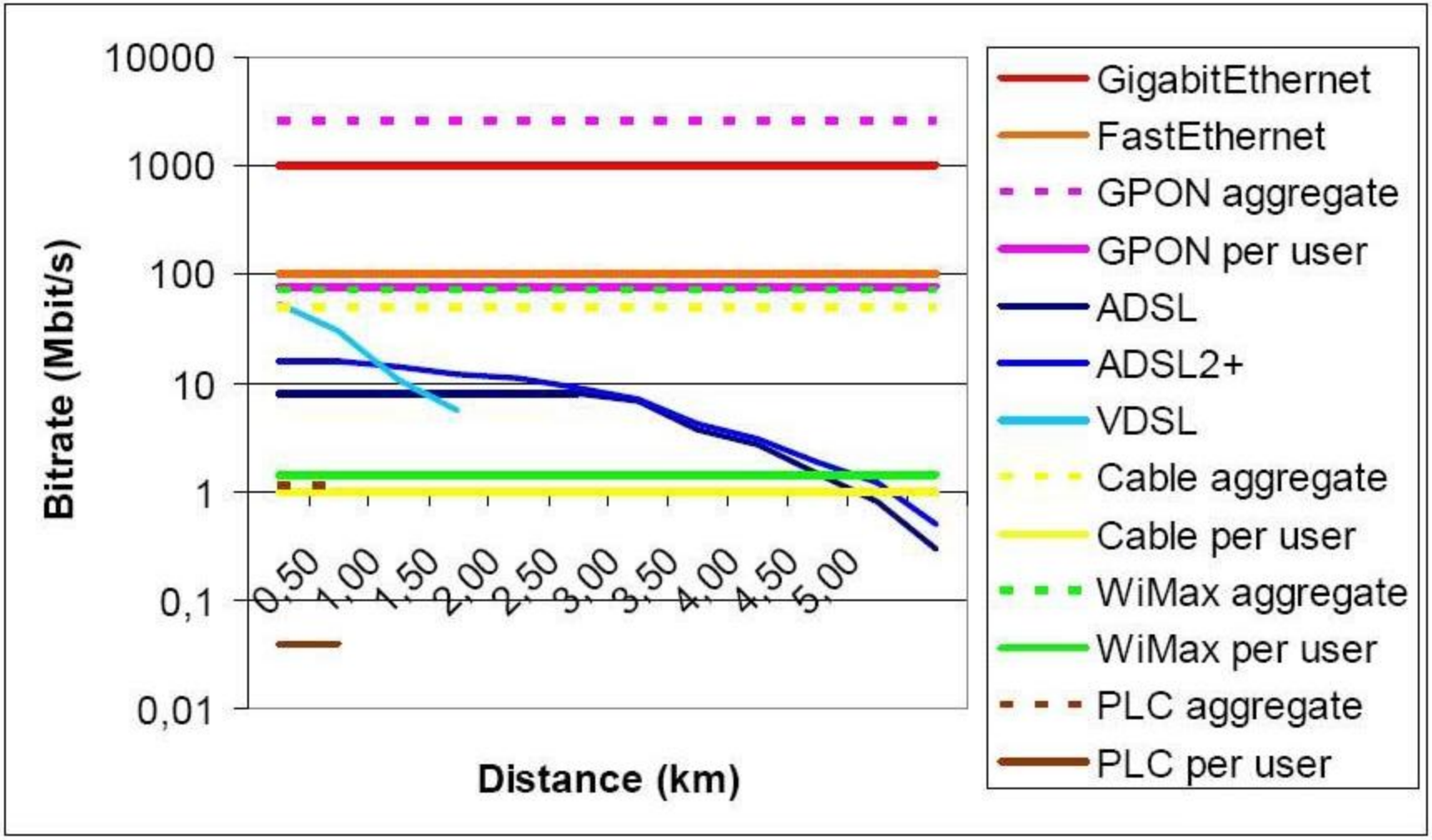
Why FTTH? - symmetric services

- Outbound Internet bursting to 80Mbps
- Inbound Internet (download) averaging about 35-40Mbps
- Upstream is consistently twice the download



Source: Grant County Public Utility District

Bitrate vs. Reach for Last Mile Technologies



FTTH technical tutorial

Architectures

- *Passive Optical Networks (PONs)*
  - Shares fiber optic strands for a portion of the networks distribution
  - Uses optical splitters to separate and aggregate the signal
  - Power required only at the ends
- *Active Node*
  - Subscribers have a dedicated fiber optic strand
  - Many use active (powered) nodes to manage signal distribution
- *Hybrid PONs*
  - Literal combination of an Active and a PON architecture

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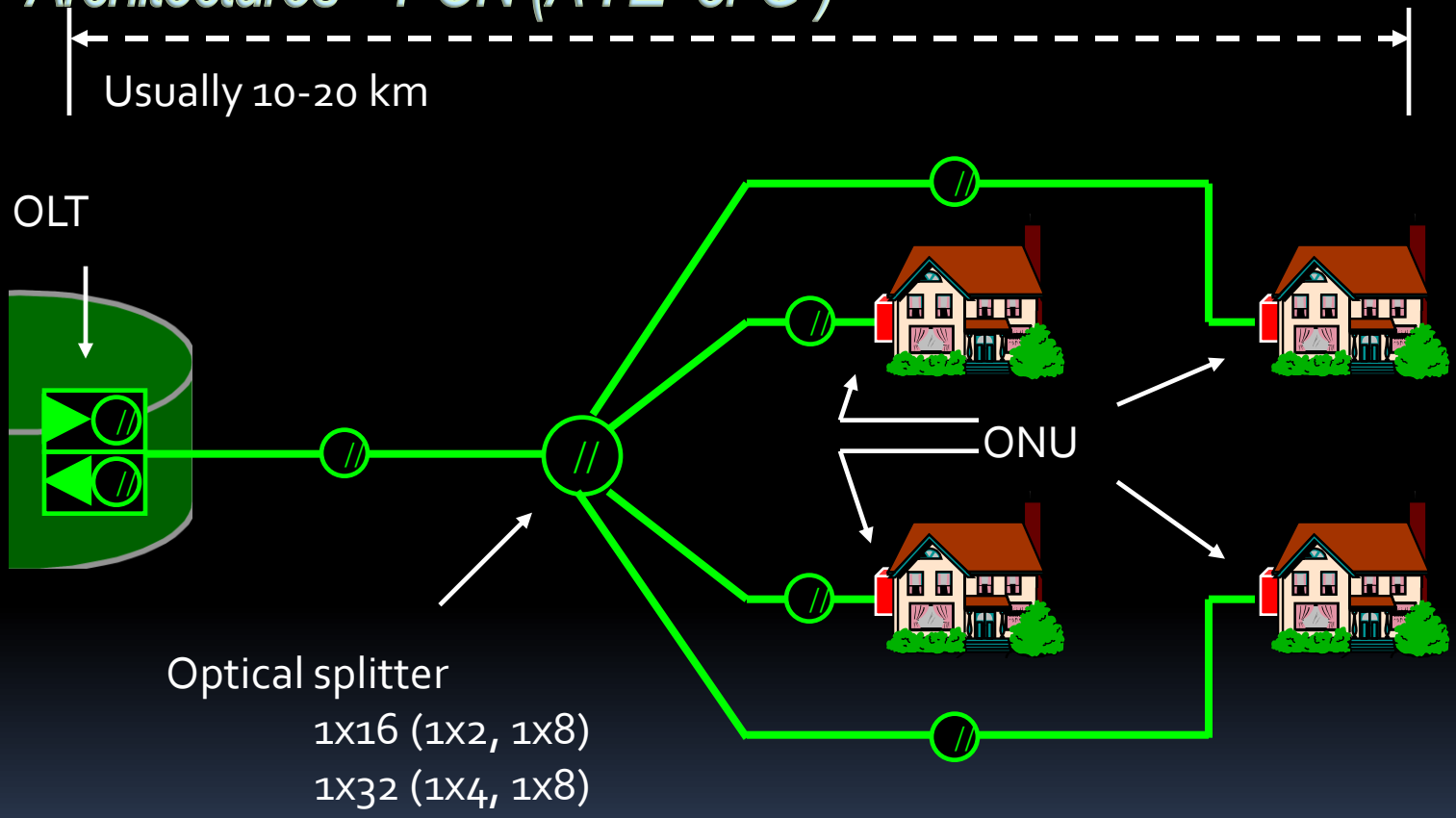
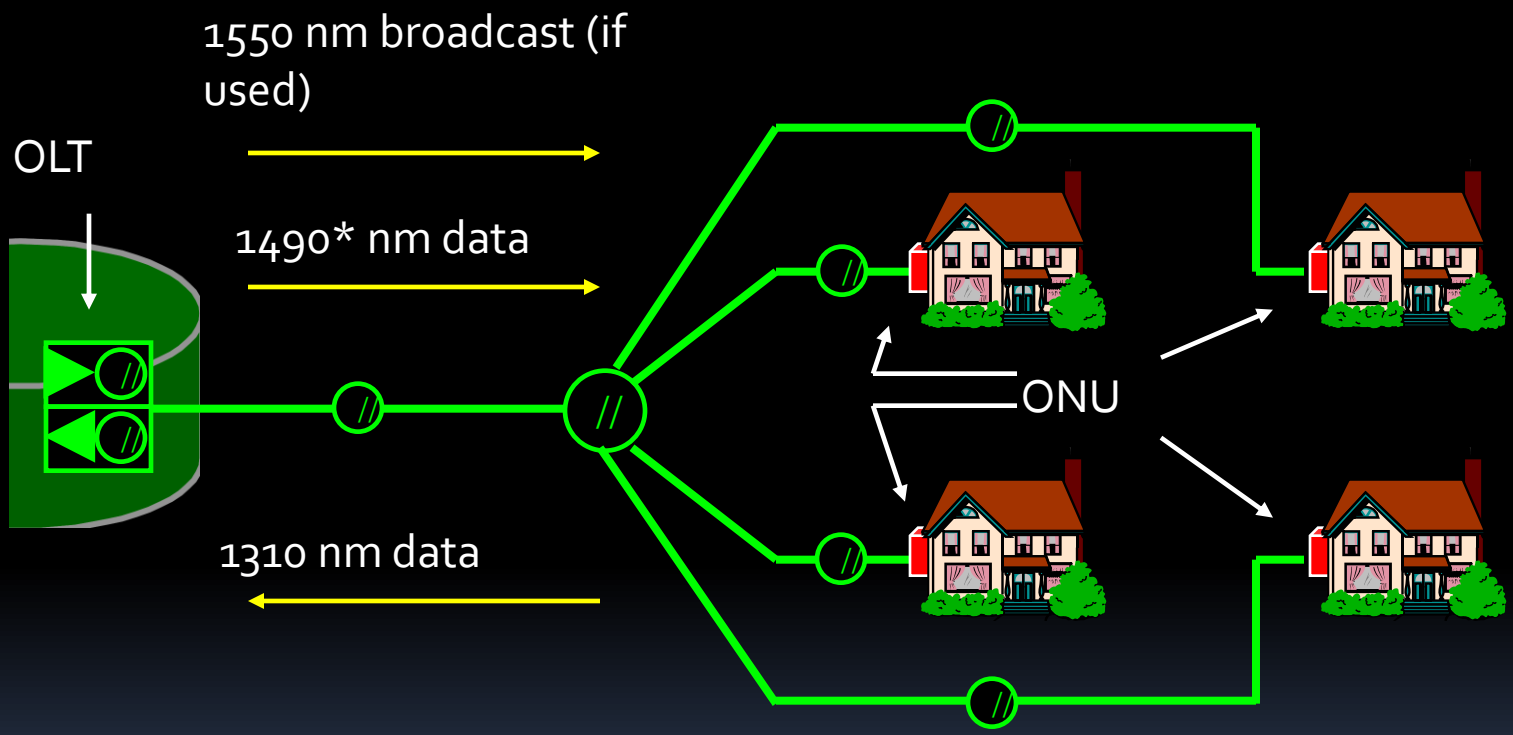
FTTH technical tutorial

Architectures – PON (A-. E- or G-)



FTTH technical tutorial

Architectures – PON (2) (A-. E- or G-)



* Data may be transmitted at 1550 nm if not used for video

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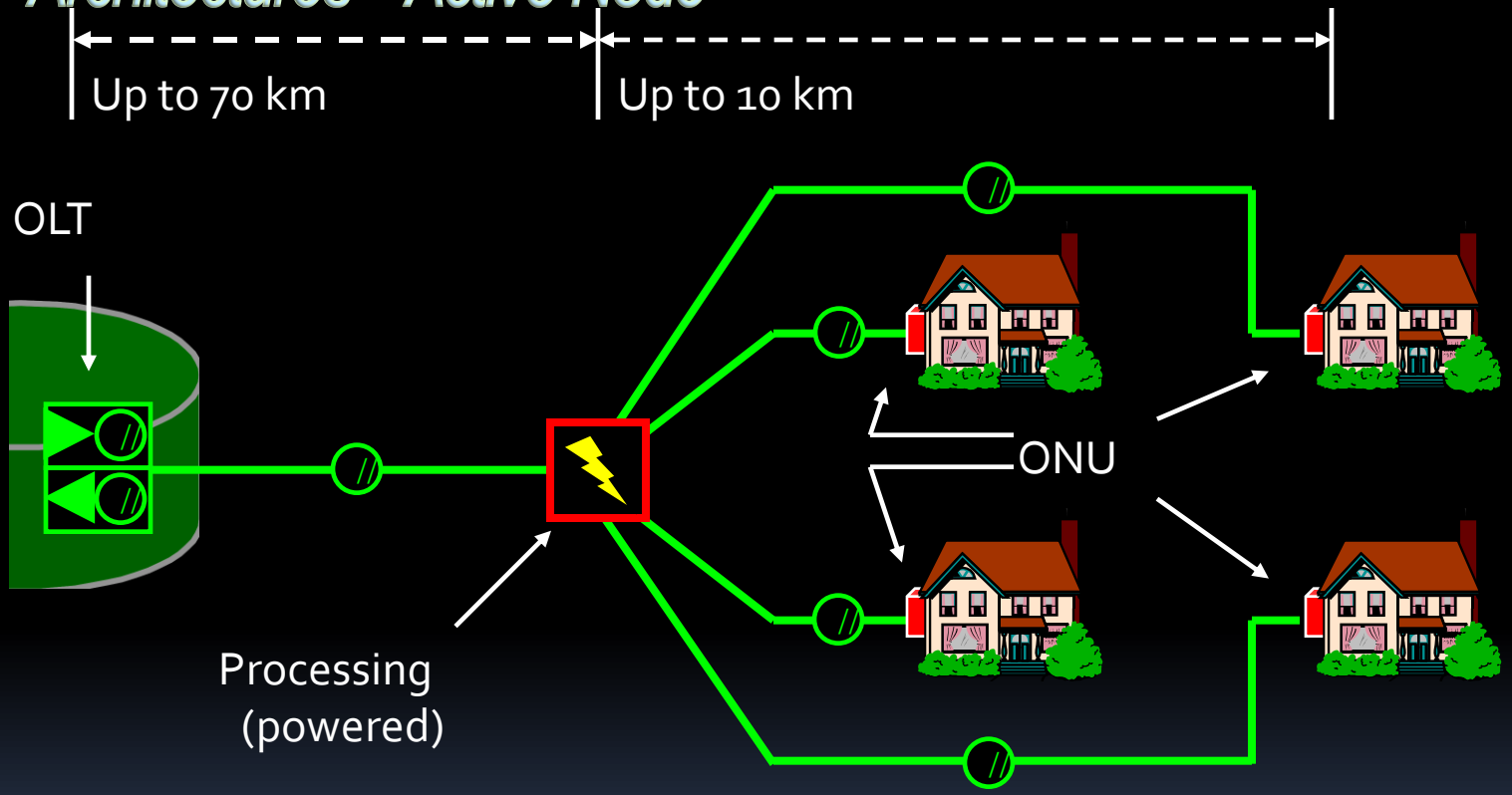
Architectures – Active Node



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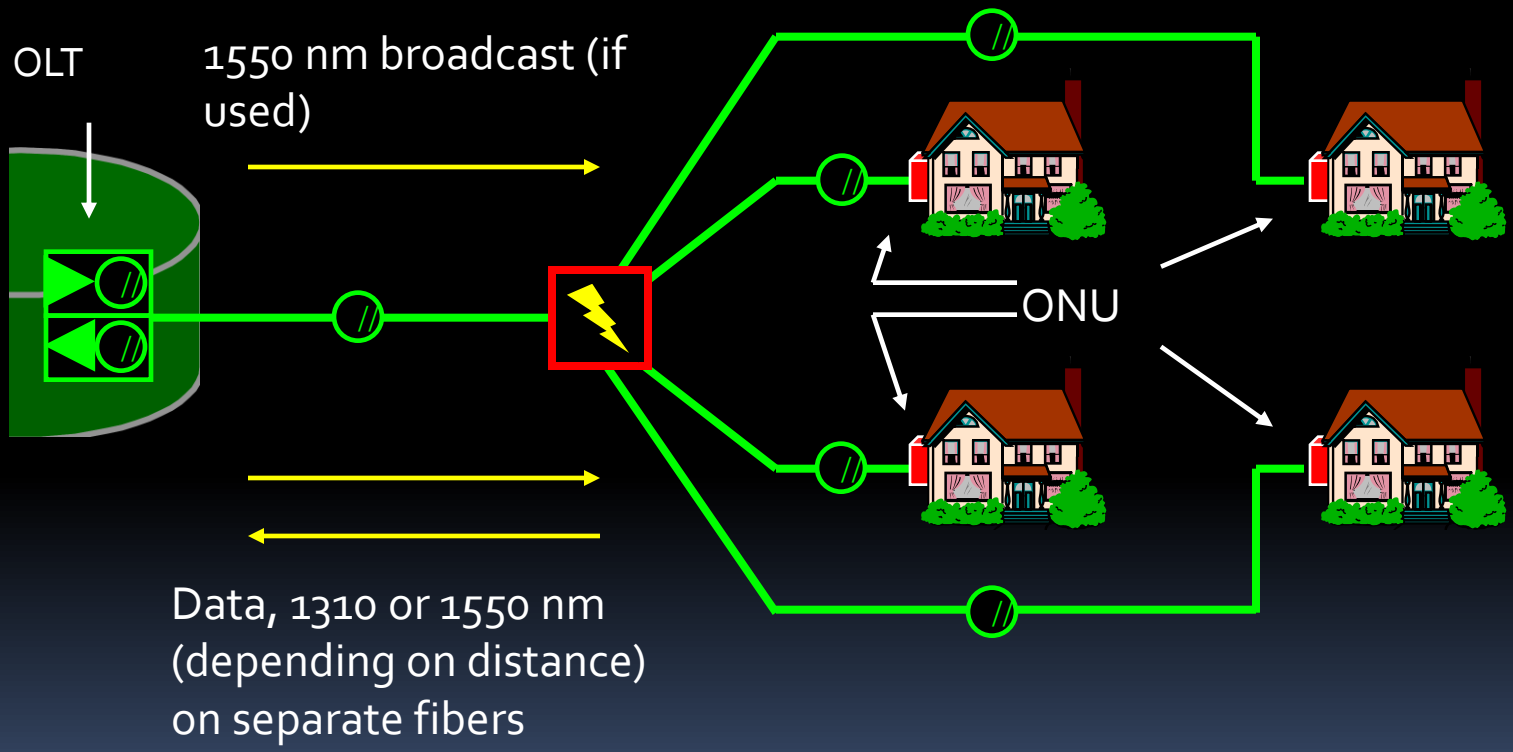
Architectures – Active Node (2)



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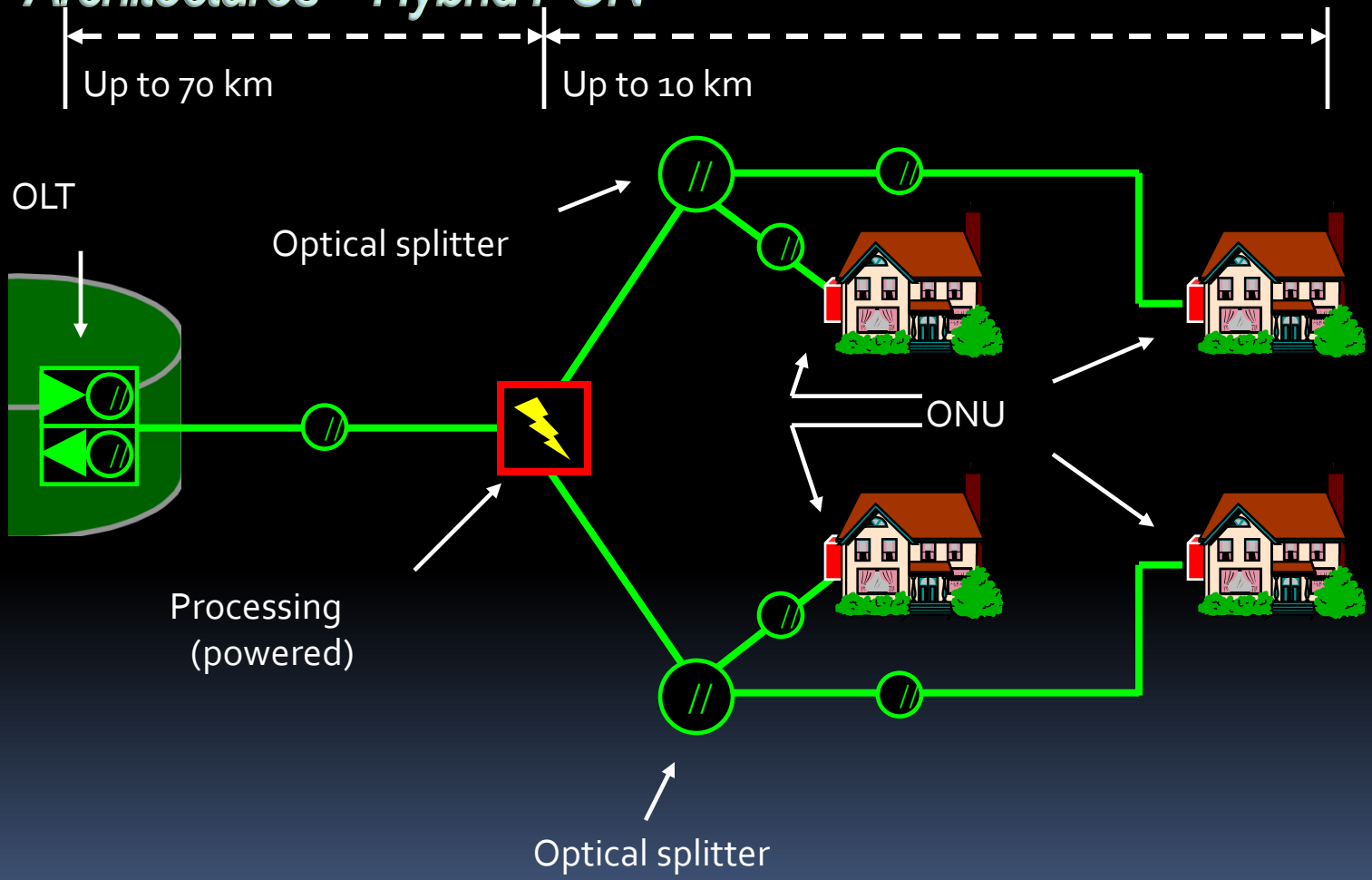
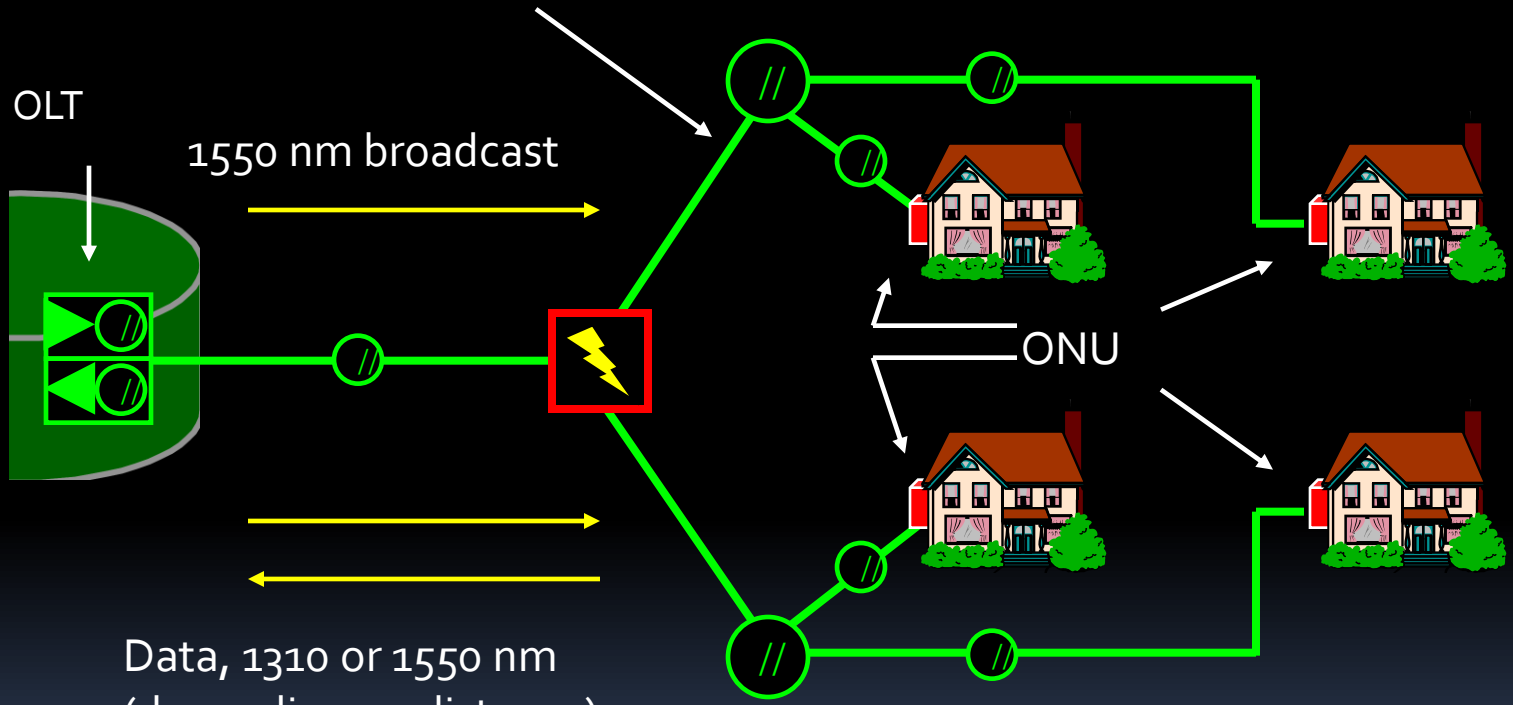
Architectures – Hybrid PON



FTTH technical tutorial

Architectures – Hybrid PON (2)

ngle fiber, 1550 broadcast, 1310 bidirectional data



Physics: Fiber Access Architectures

FTTH provides greater bandwidth capacity and transmission speeds.

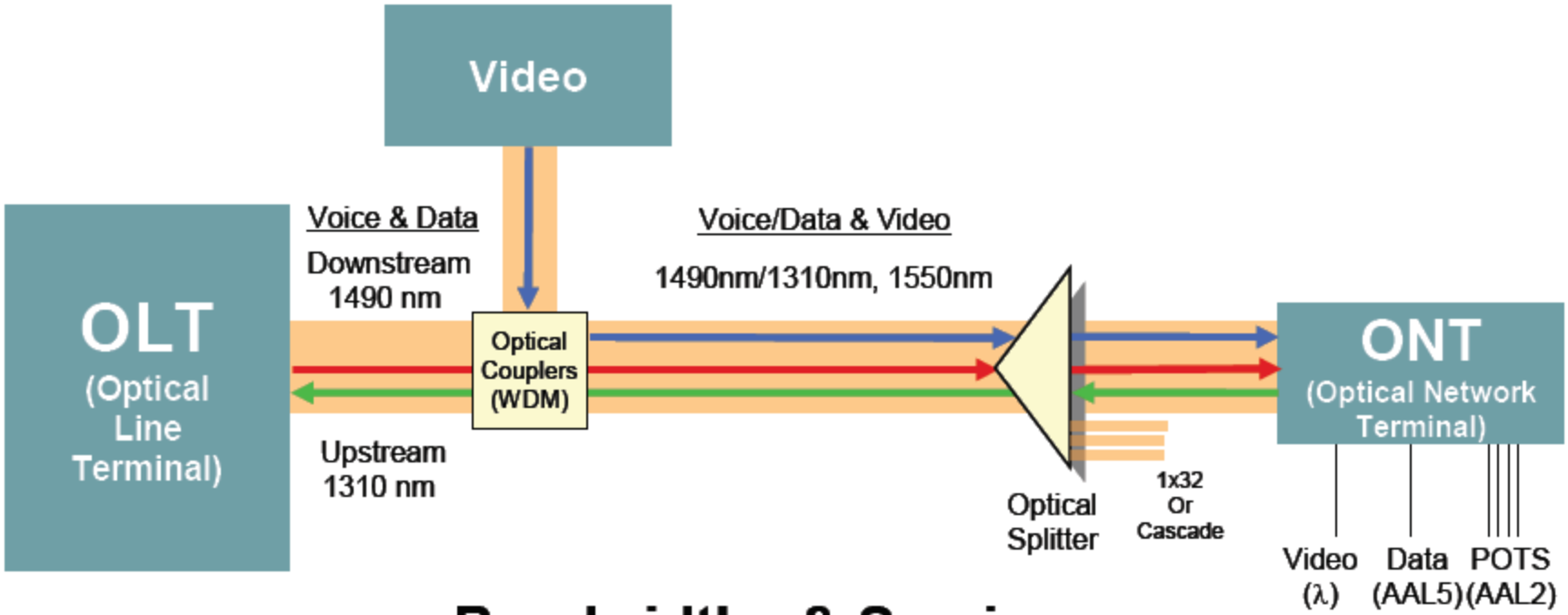
- APON – 622/155* Mbps (1:32 shared) - legacy
- BPON – 622/622* Mbps (1:32 shared) - legacy
- GPON – 2.5/1.2 Gbps to 2.5/2.5* Gbps (1:64 shared)
- EPON – 10/100* Mbps (1:32 shared)
- GE-PON - 1/1Gbps* (up to 1:128)
- 10G-EPON – 10/10Gbps & 10/1Gbps*
- P2P – 100/1000 Mbps (non-shared)
- WDM-PON – 1.2-10Gbps/1.2-10Gbps
- Hybrid – varies by vendor
- RFoG- RF over Fiber (rates: Spectrum Avail- DOCSIS)

** The upstream data rates are shared*

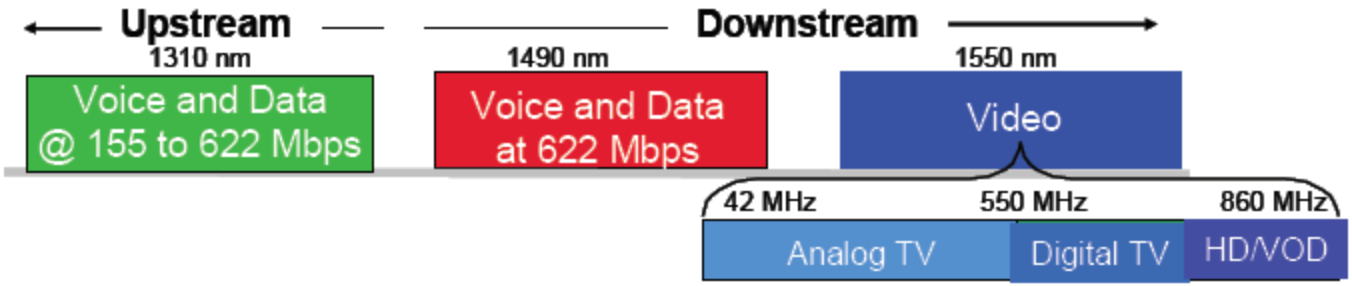
Standards References

- FTTx employs clearly defined and widely used standards for both P2P and PON including:
  - Full Service Access Network (FSAN)
  - **ITU-T** G.983 (BPON), G.984(GPON)
- Ethernet in the First Mile (EFM):
  - **IEEE** 802.3ah (Published Sept. 2004)

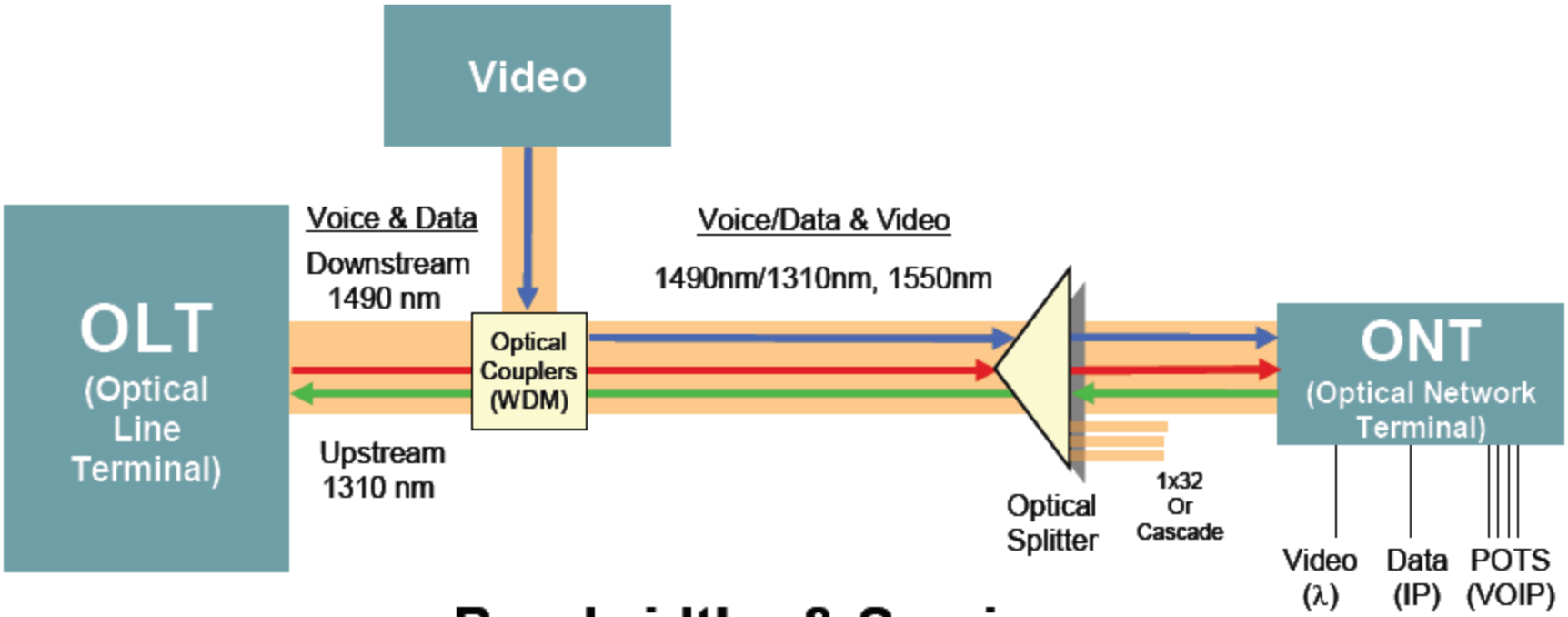
PON Architecture - FSAN Standard (ITU G.983)



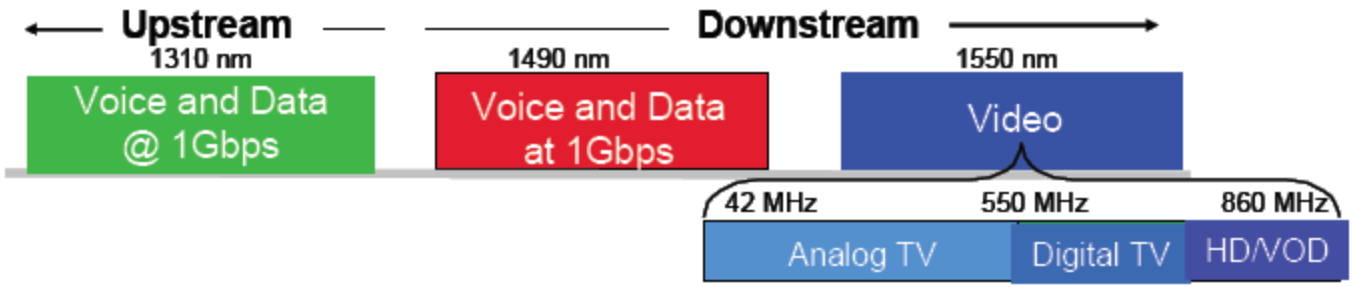
Bandwidths & Services



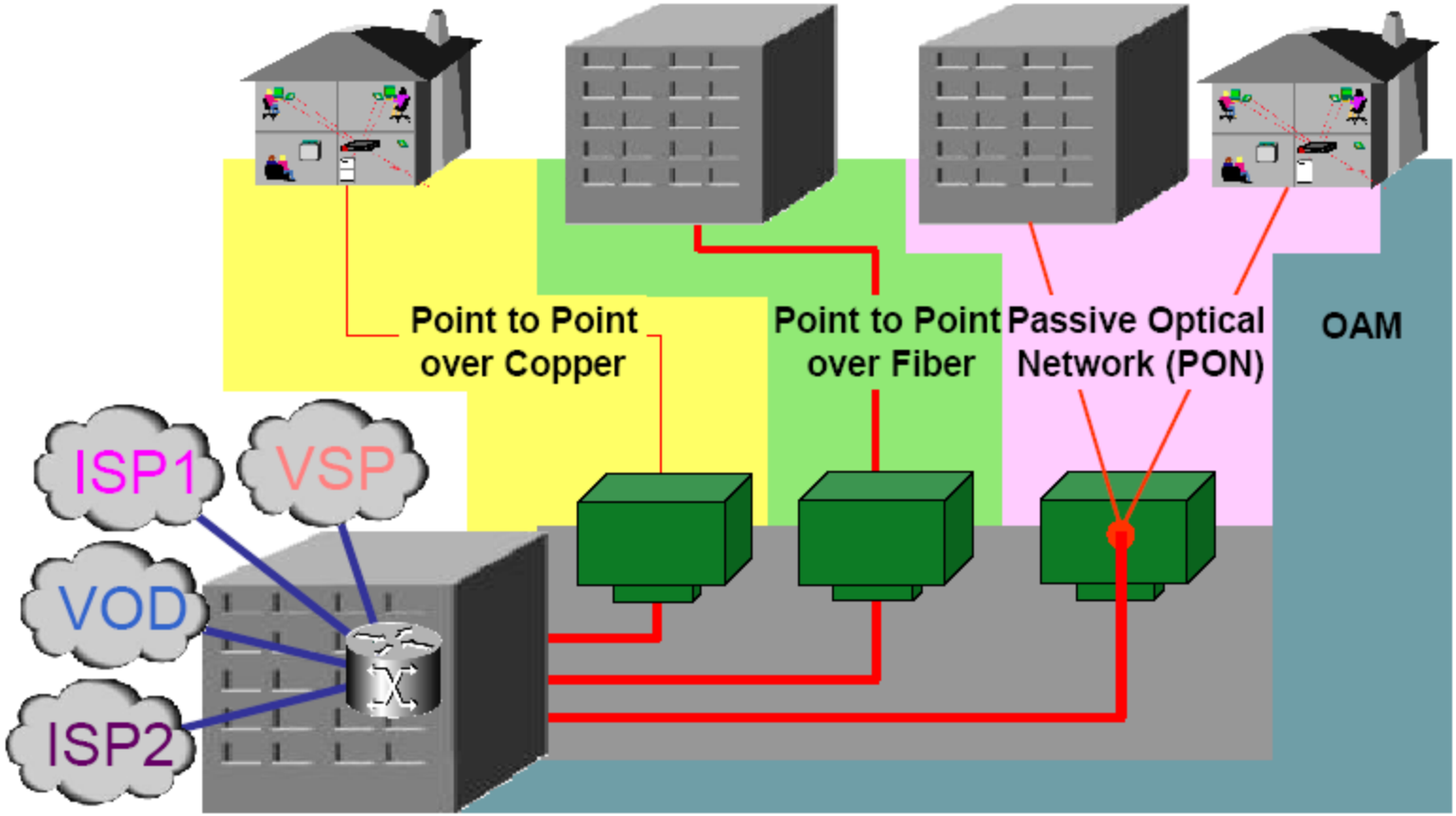
EPON Architecture - IEEE Standard (802.3ah)



Bandwidths & Services



IEEE 802.3ah – Ethernet in the First Mile



PON Standards

BPON – ITU G.983.3 – Published (FSAN group)

- 622 Mb/s or 155 Mb/s downstream. 155 Mb/s upstream.
- 20 KM reach ATM Protocol
- Up to 32 users share one fiber

GPON – ITU G.984.2 - Published

- 2.4 or 1.2 Gb/s downstream, 155 Mb/s, 622 Mb/s, 1.2 Gb/s, or 2.4 Gb/s upstream.
- 20 KM reach
- Can use ATM or Ethernet Protocol Up to 64 users share one fiber

PON Standards

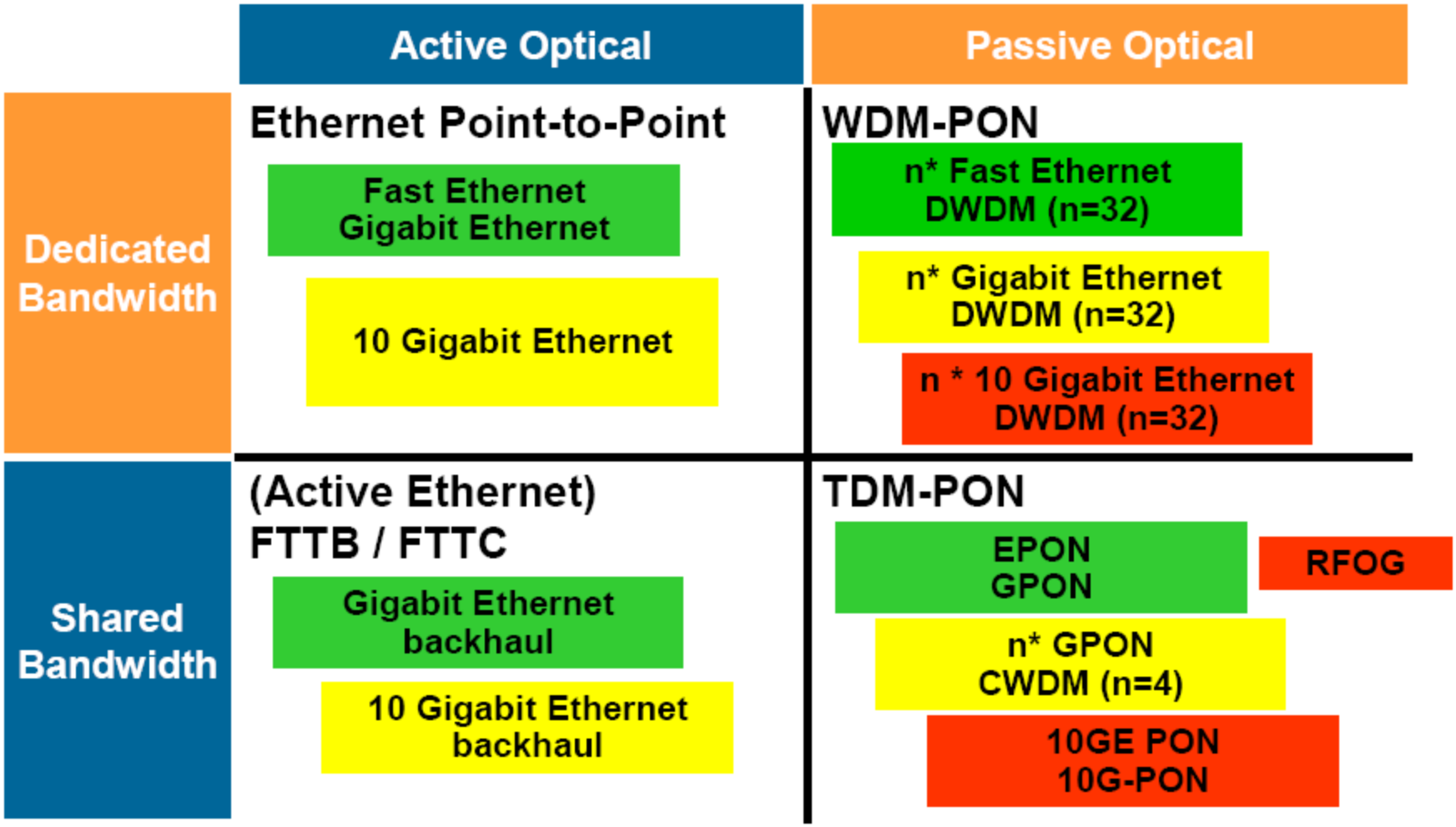
Ethernet - PON and Point to Point– IEEE 802.3ah, 2004

- EPON – 10/100/1000 Mb/s upstream and downstream, 16 – 32 users per PON
- Point to Point – 100 Mb/s and 1 Gb/s up to 20 KM distances

RFoG

- SCTE RFoG Specification is currently in development
- FTTH solution for traditional cable operators
- Method to deploy HFC services over fiber optics
  - DOCSIS VoIP and DOCSIS data
  - RF video (analog and digital QAMs)
  - Billing and operations support remain the same
  - Service provisioning is just like HFC
  - Supports switched digital video and existing VOD
  - Keep narrowcast service groups

Technological evolution

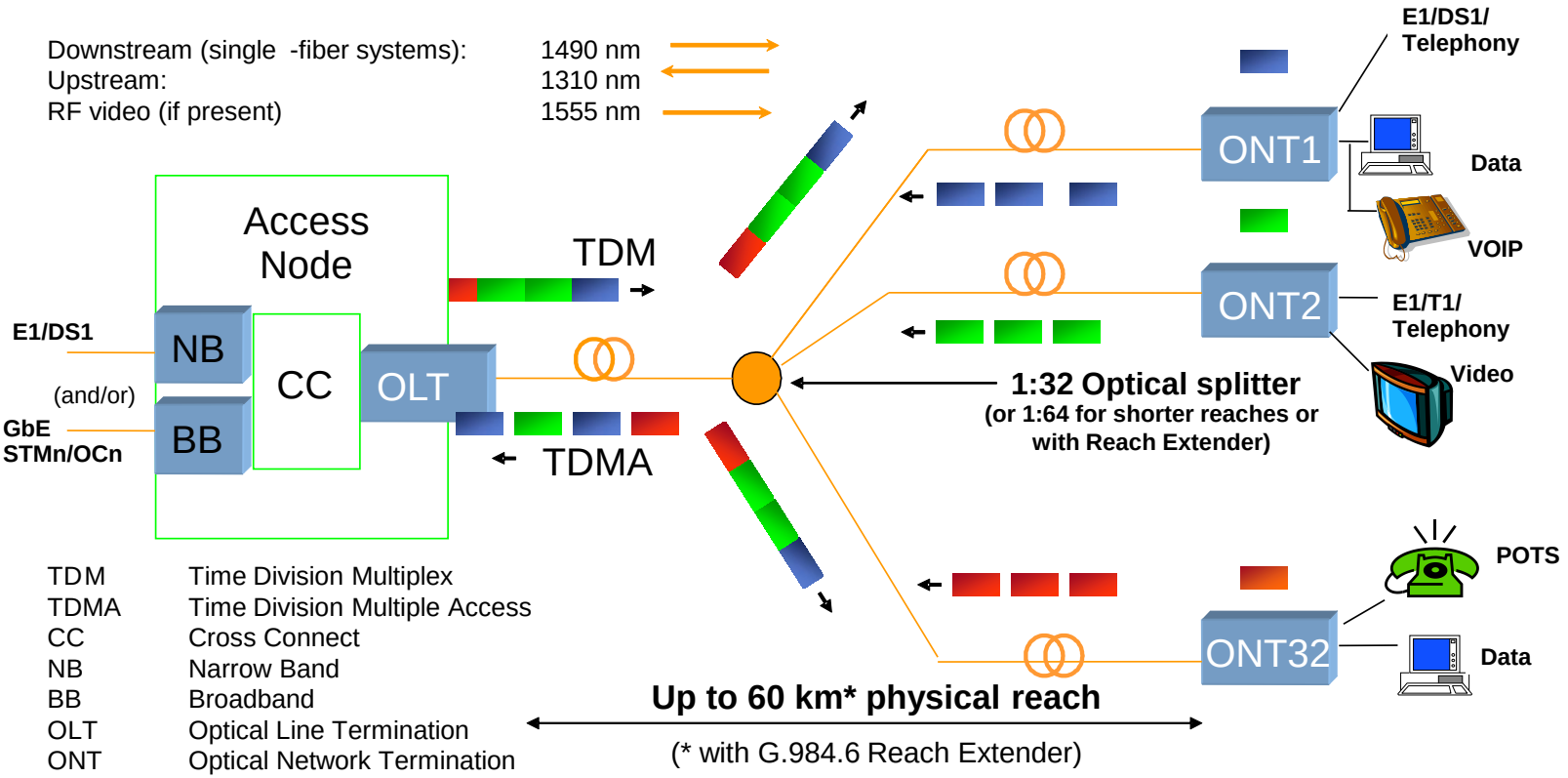


Example excerpted from

Rob Bond
Telcordia
rbond@telcordia.com

TDM PON Example

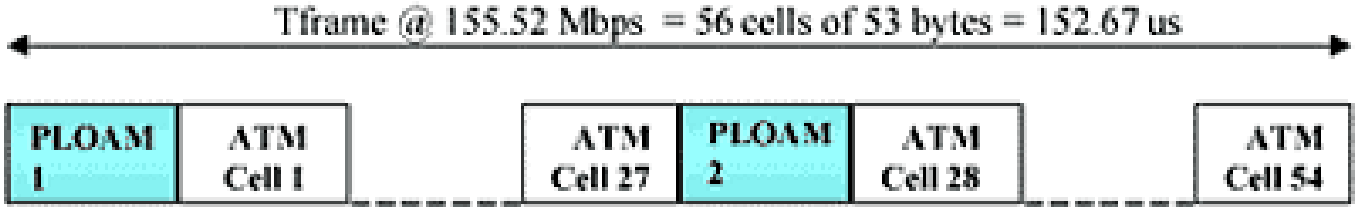
- **Downstream** – TDM transmission with multiple "listeners" (encryption to insure privacy)
- **Upstream** – TDMA transmission with upstream transmissions (bursts) scheduled to prevent overlap



PONs are (in some sense) like HFC systems – shared medium

Telcordia.

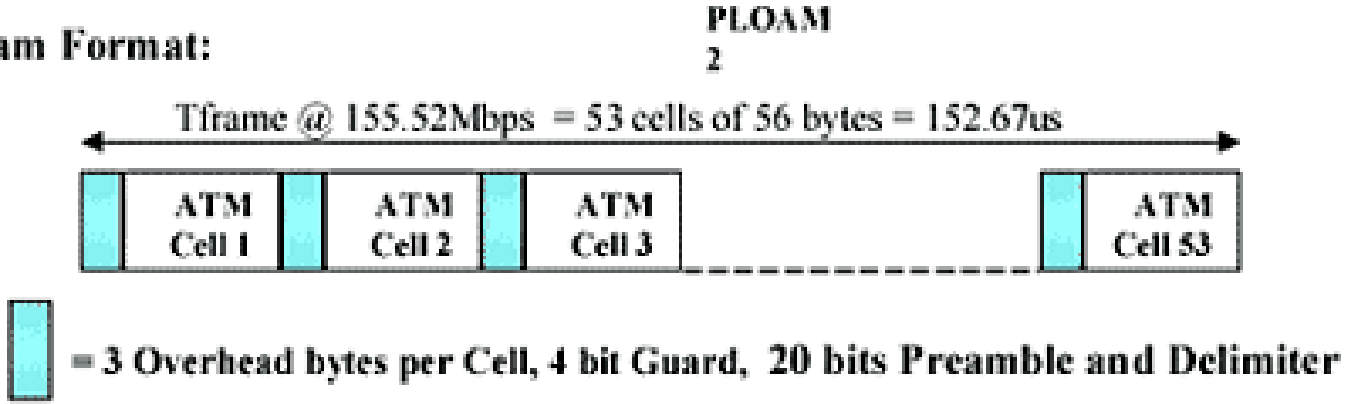
Downstream Format:



Capacity Downstream = 155.52 Mbps x 54/56 = 149.97 Mbps

PLOAM cells contain 53 Grants, 12 Message fields, Sync, CRC

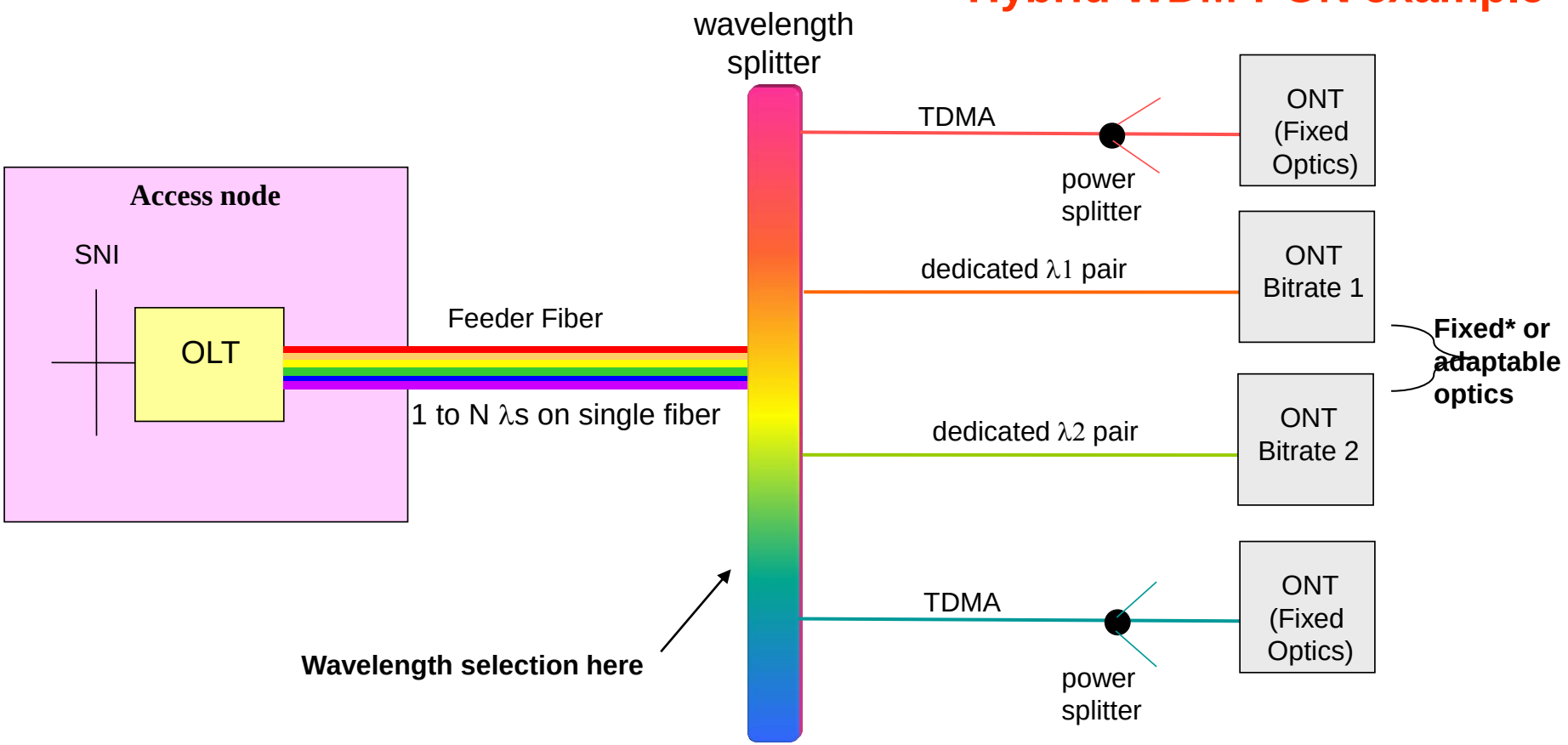
Upstream Format:



Capacity Upstream = 155.52 Mbps x 53/56 = 149.19 Mbps

Example of WDM-PON

Hybrid WDM-PON example



* "Fixed" optics might be a cost reduced version of convention DWDM long-haul optics
NOTE: Most believe adaptable optics will be required for a practical WDM-PON system

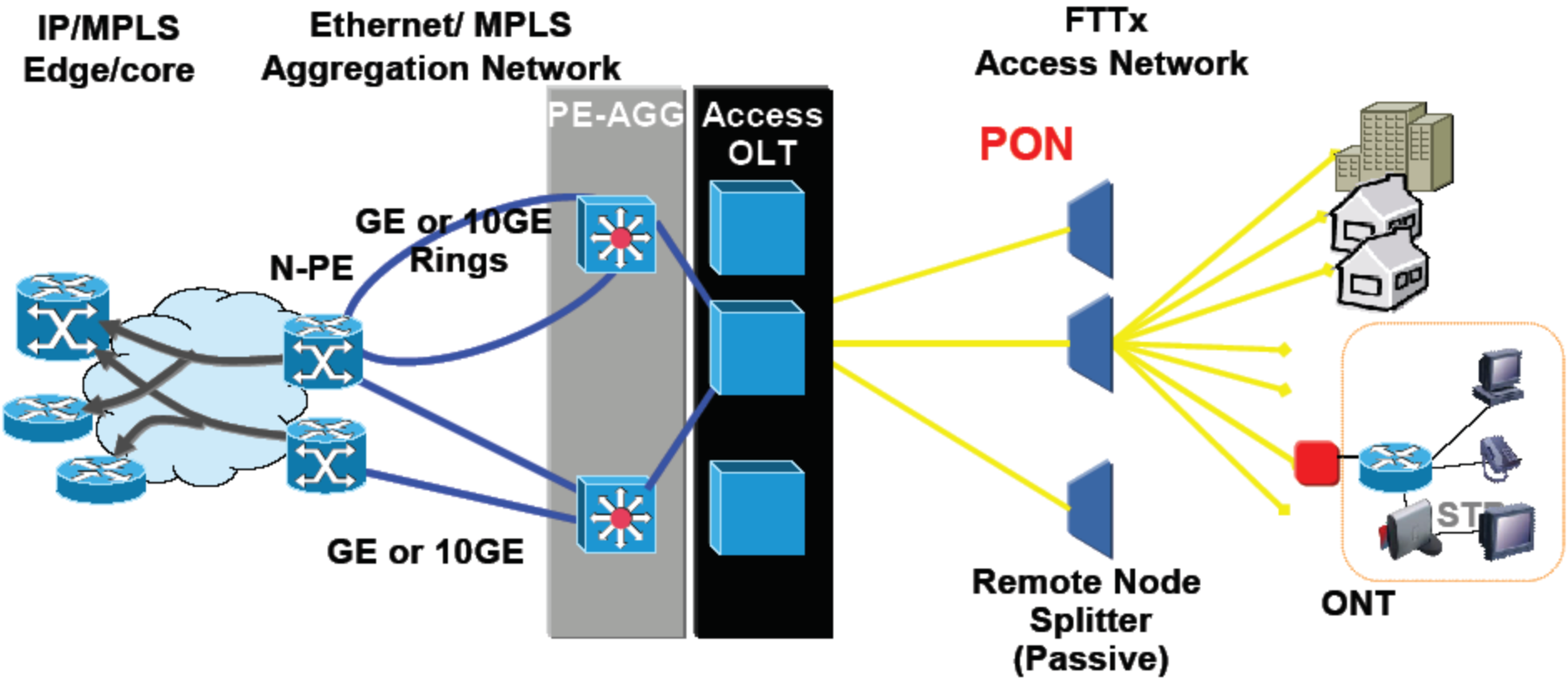
Colorless ONTs: Transmitter and Receiver front-end filter characteristics are wavelength adaptable

Telcordia

Today's PON Systems

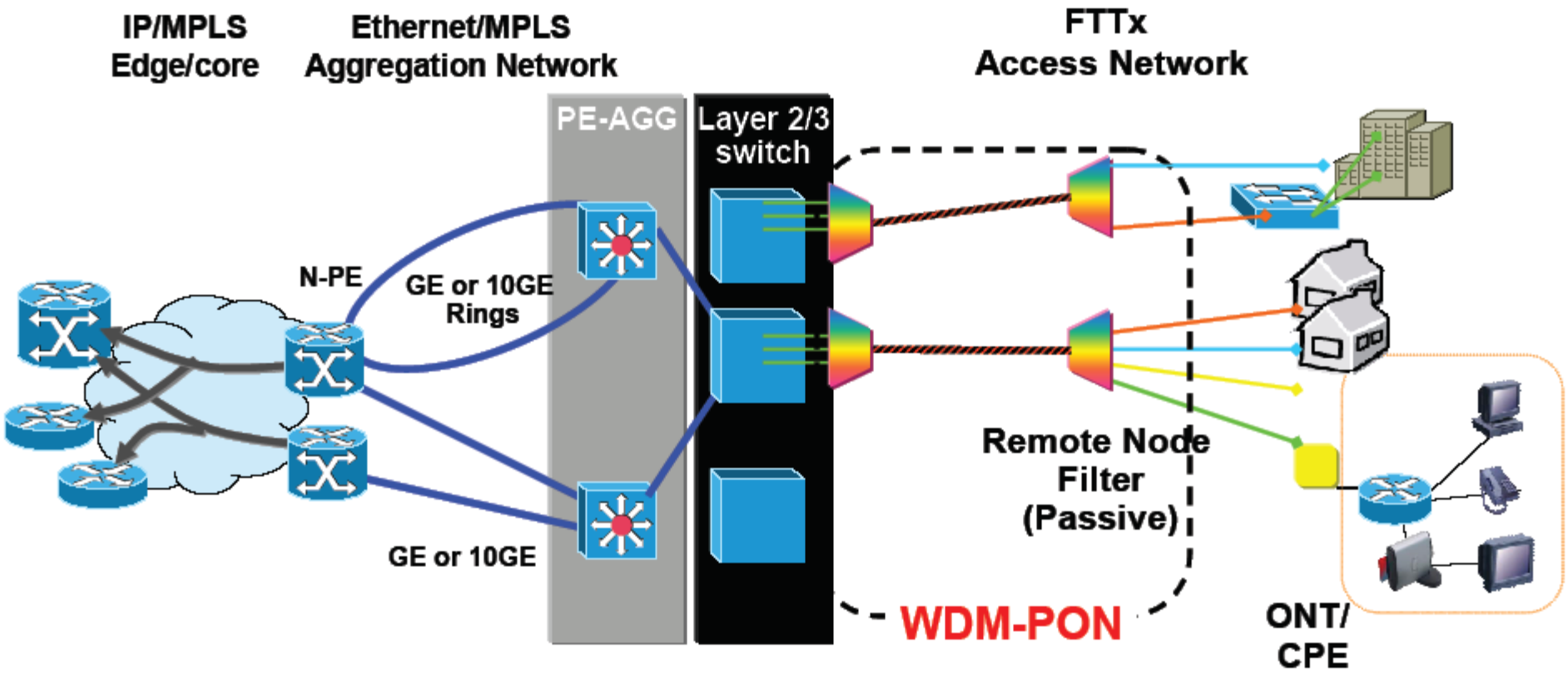
- **TDM-PONs Rule:** The vast majority of PON systems deployed today are TDM-based PON systems (i.e., B-PON, E-PON, and G-PON)
  - They almost exclusively operate on a single fiber, with WDM used to provide bi-directional transmission
  - A third wavelength in the downstream is sometimes used for broadcast video services (e.g., Verizon FiOS)
- **WDM-PON:** Very limited deploys, mainly in Korea
  - Costs of WDM-PON in delivering mass market dedicated wavelength services are still higher high relative to TDM-PON
  - WDM and hybrid WDM-PONs are expected to play a greater role in Next Generation (NG) PON systems (e.g., 5+ years) than today

FTTH Technologies PON



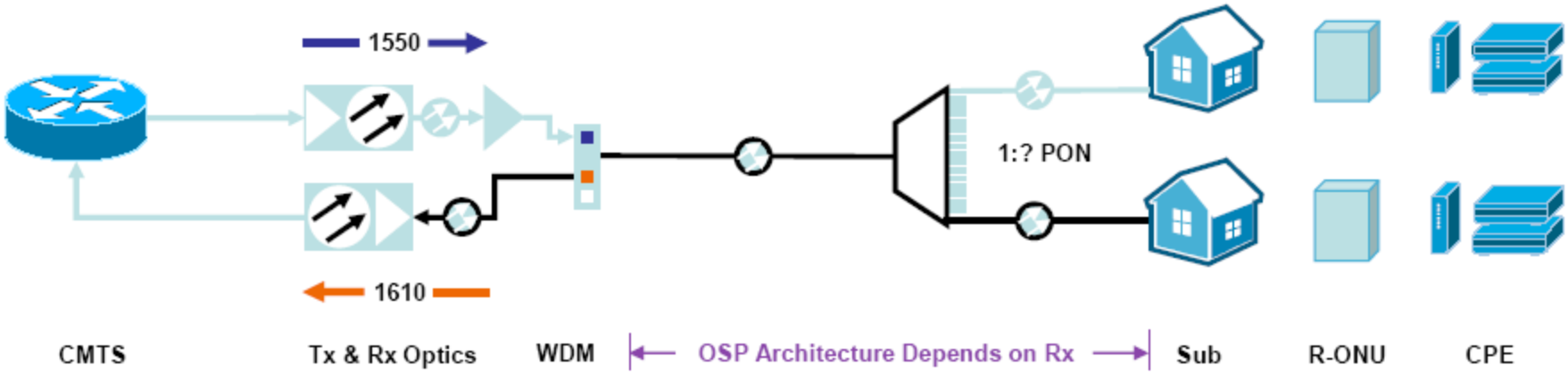
- Shared fiber from OLT to the remote node splitter
- Lower duct space requirements/ cost of lease

FTTH Technologies WDM-PON



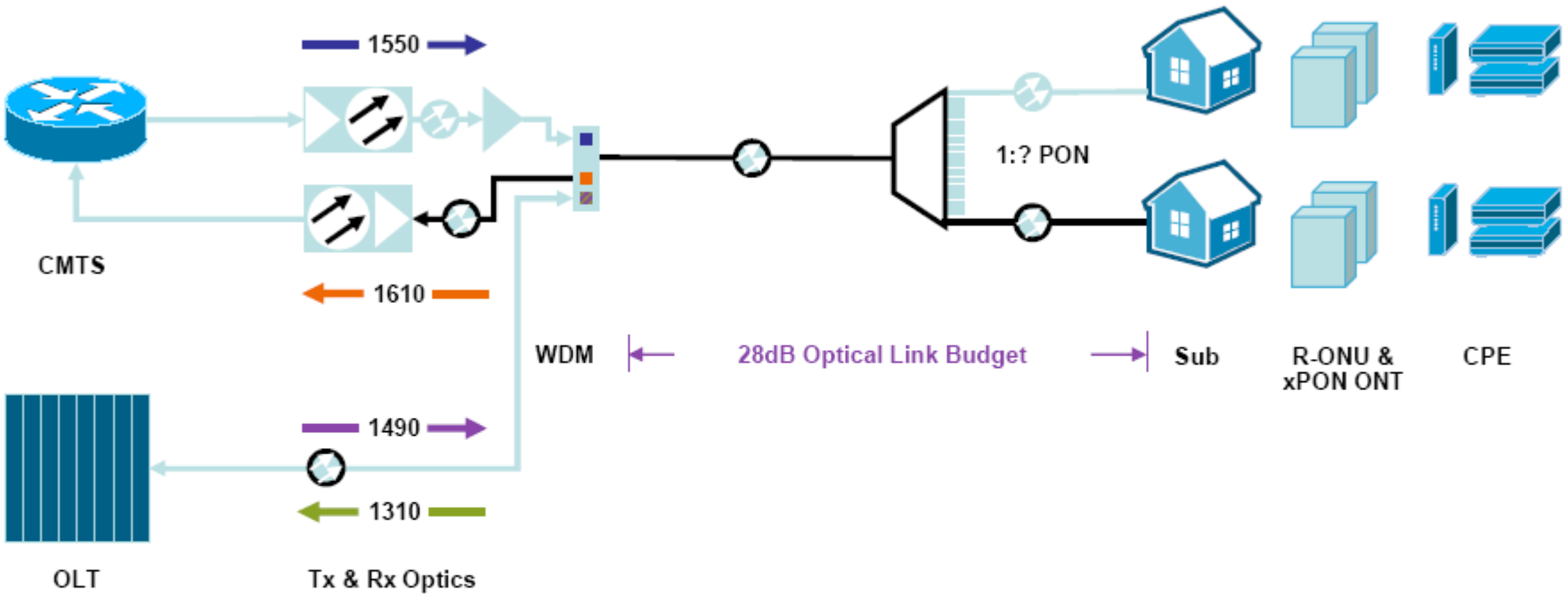
Single feeder fiber from CO to remote node – duct space needs similar to GPON

FTTH Technologies RFoG



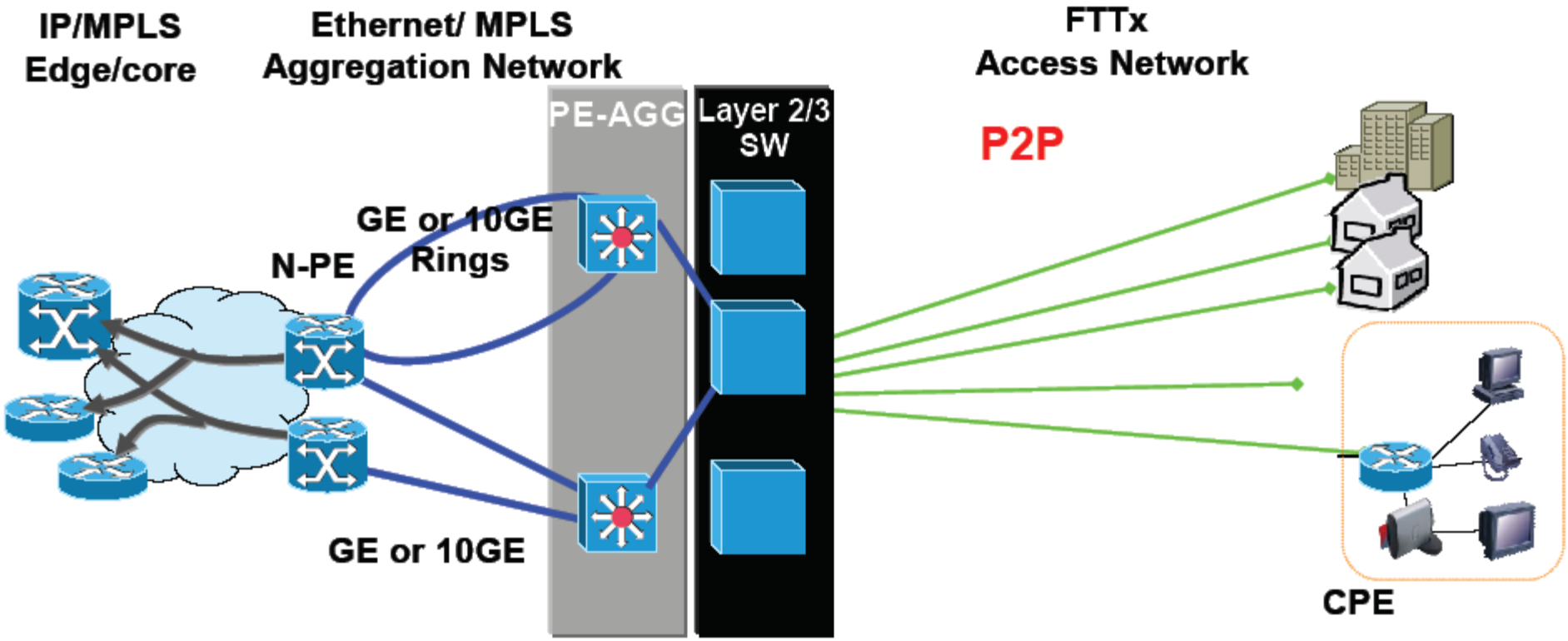
- RFoG is architecturally **agnostic**
  - PON version – all electronics in HE or Hub (similar to B/GE/GPON)
  - Hybrid PON version – actives in the field (short PONs)
- Three main splitting strategies
  - Home run
  - Centralized
  - Distributed
- 28dB required to match existing and future xPONs

RFoG Migration Path?



- Achieving a 28dB link budget and using 1610nm for the return wavelength ensures RFoG has a migration path to another type of xPON solution

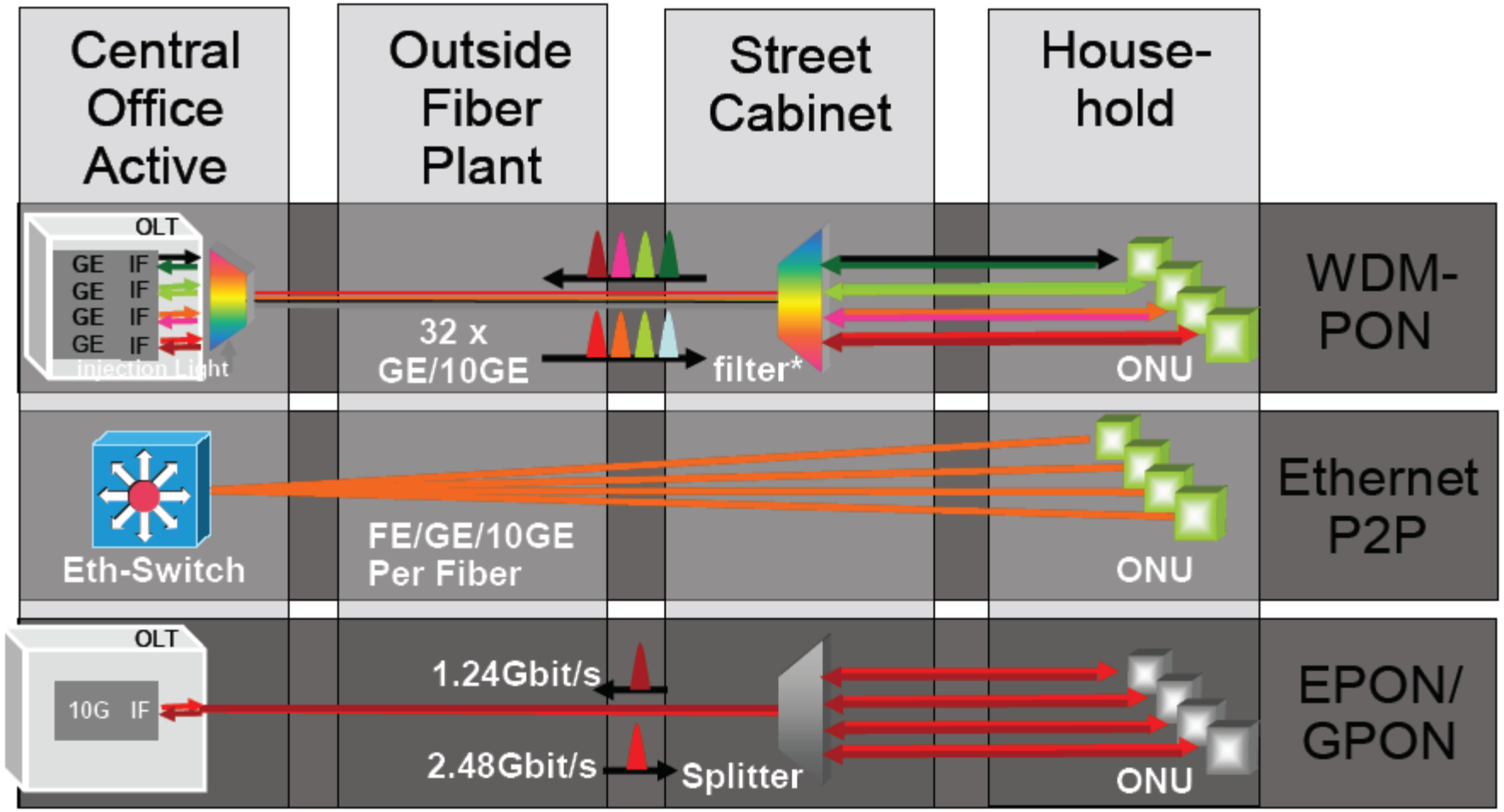
FTTH Technologies E-FTTH



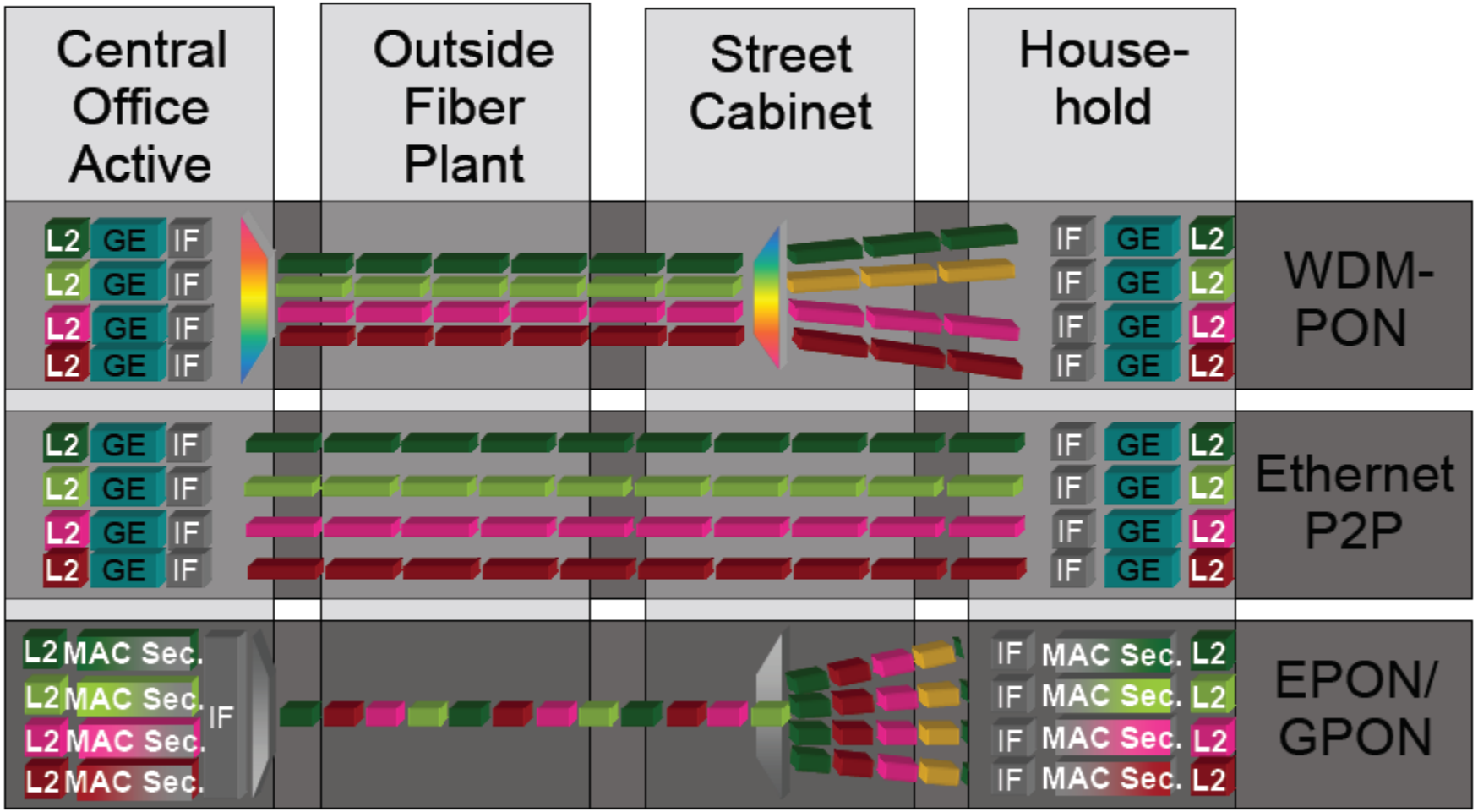
Future proof, with no bandwidth limit, higher security, flexibility & resiliency

However, needs one fiber per subscriber

Level 1: Connectivity



Level 2: MAC Layer Connectivity




Google fiber

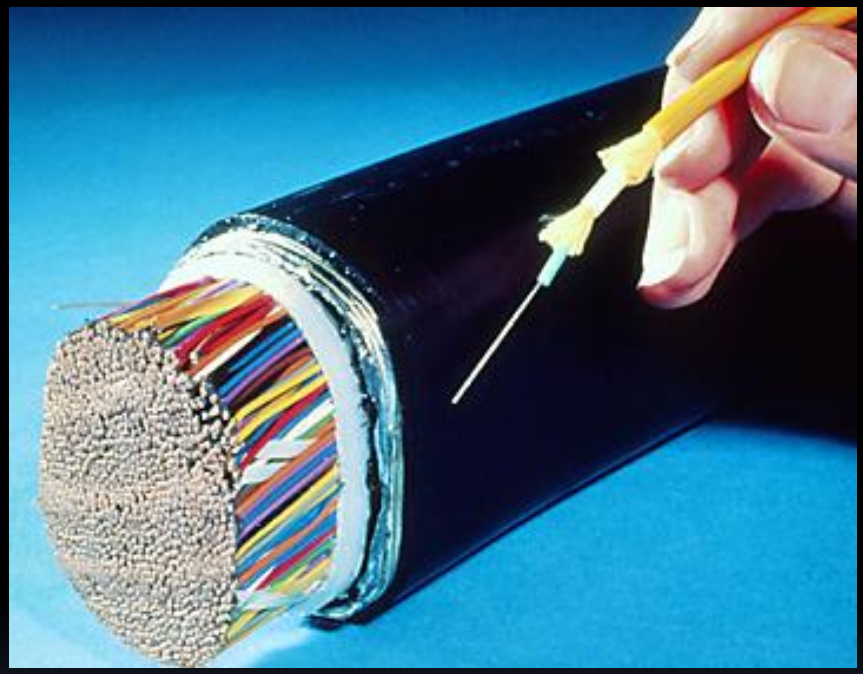
The First Mile - Outline

- Introduction: the first/last mile bottleneck
- Evolution of FTTH considerations
- Network architecture and standards
- Enabling technologies
- The future: applications

FTTH technical tutorial

Why FTTH? - fiber versus copper

- A single copper pair is capable of carrying 6 phone calls
- A single fiber pair is capable of carrying over 2.5 million simultaneous phone calls (64 channels at 2.5 Gb/s)
- A fiber optic cable with the same information-carrying capacity (bandwidth) as a comparable copper cable is less than 1% of both the size and weight



Source: Corning Incorporated

FTTH technical tutorial

Types of lasers used

- There are two laser technologies that are used for nearly all single mode communications applications
  - Fabry-Perot (F-P) lasers
    - Lower in cost, lower in power
    - Poorer wavelength stability
  - Distributed Feedback (DFB) lasers
    - Higher cost, higher power
    - Excellent wavelength stability
    - Excellent temperature stability
      - Internally modulated
        - Good for moderate powers and distances
      - Externally modulated
        - Ultimate today for quality in broadcast applications
- Vertical Cavity Surface Emitting Lasers (VCSELs)
  - Coming technology, promises lowest costs

FTTH technical tutorial

Types of lasers used

- Wavelengths used for Single Mode Fiber (long distances) communications
  - 1310 nm
    - Usually lowest cost lasers
    - Used for shorter broadcast runs and short to moderate data runs
  - 1550 nm
    - Can be amplified with relatively low-cost erbium doped fiber amplifiers (EDFAs)
    - Lasers are fabricated on a number of different wavelengths (about 1535 – 1600 nm) for wave division multiplexing (WDM) applications
    - Slightly lower fiber loss at 1550 nm
  - 1490 nm
    - Increasingly popular for downstream data in 3λ systems.
      - Cannot be amplified as easily
      - Somewhat higher device cost

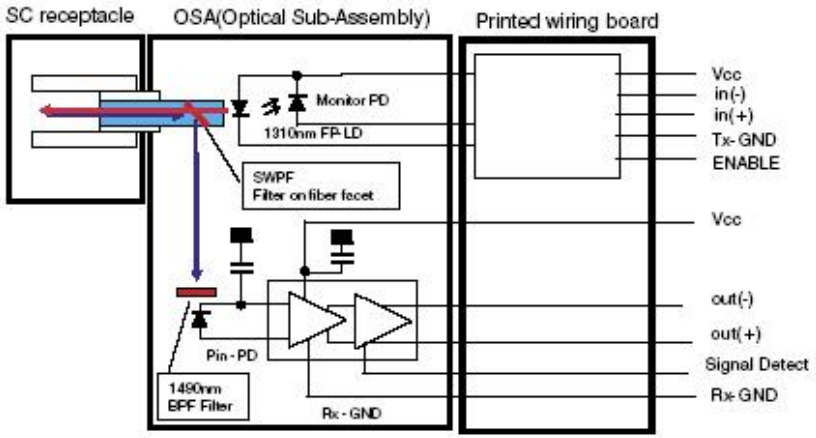


Figure 2 Block diagram of transceiver module for ONU.

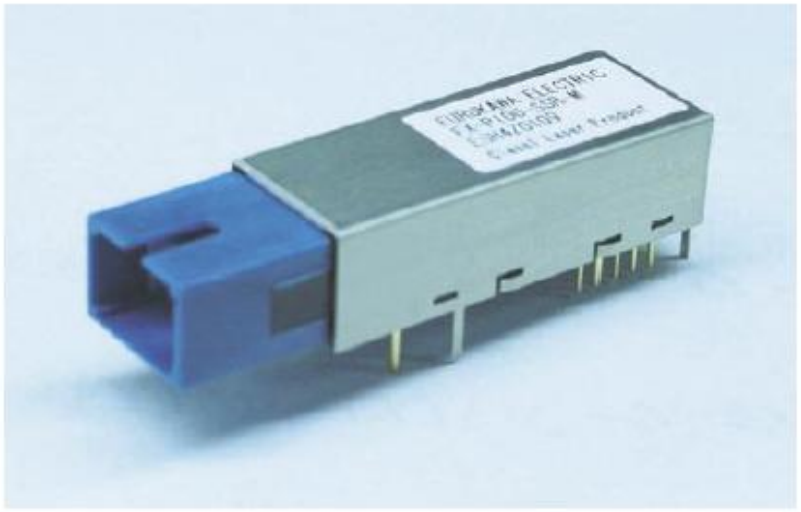


Figure 3 Photo of SFF transceiver module for ONU.

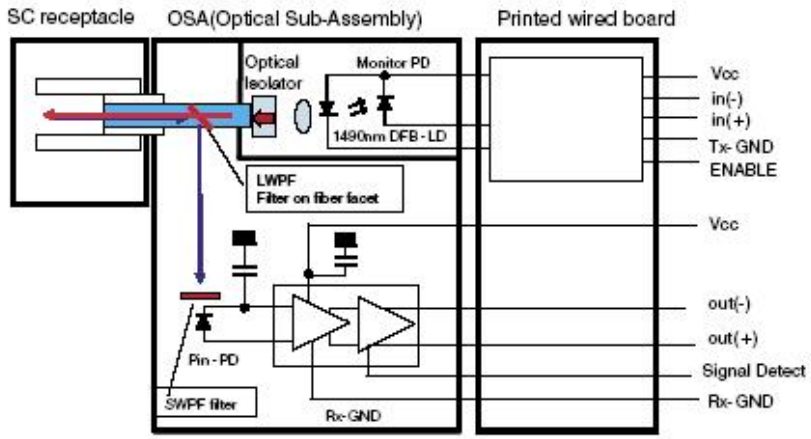


Figure 4 Block diagram of transceiver module for OLT.

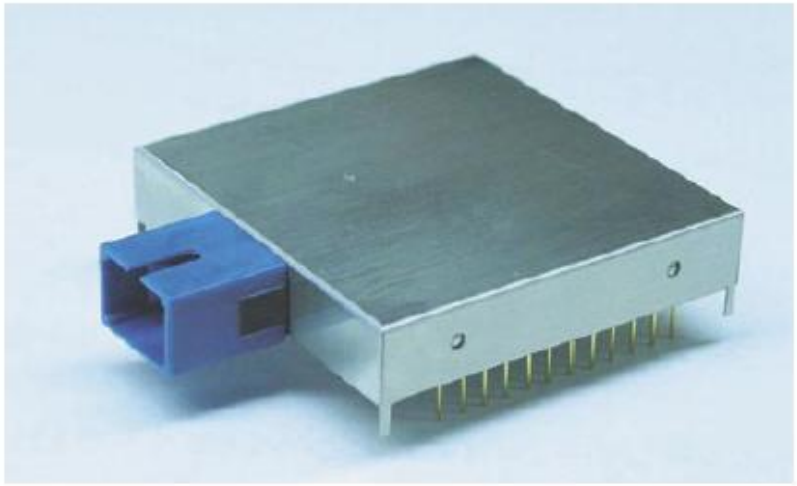


Figure 5 Photo of transceiver module for OLT.

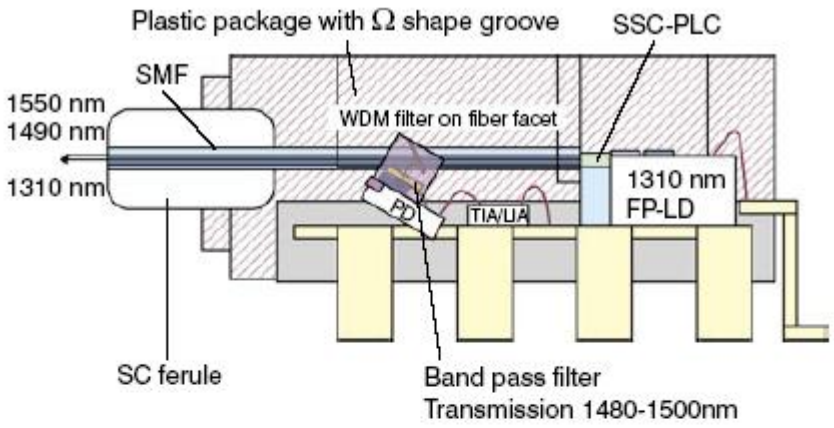


Figure 6 Structure of OSA for ONU transceiver.

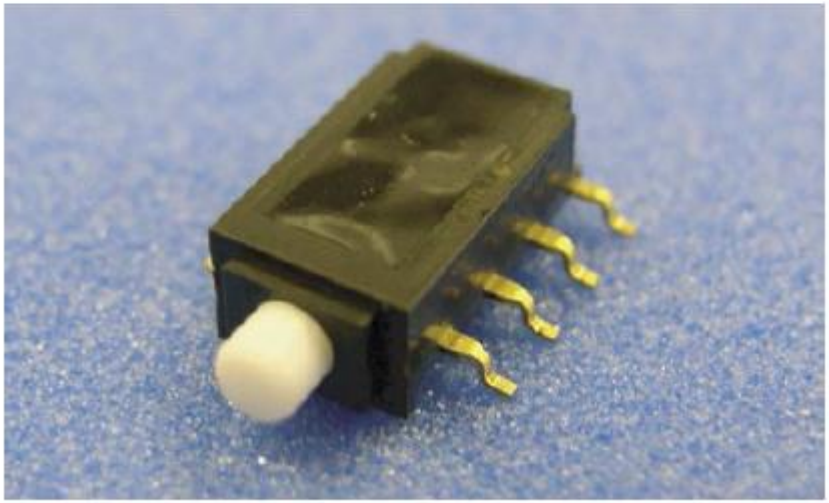


Figure 7 Photo of OSA for ONU transceiver.

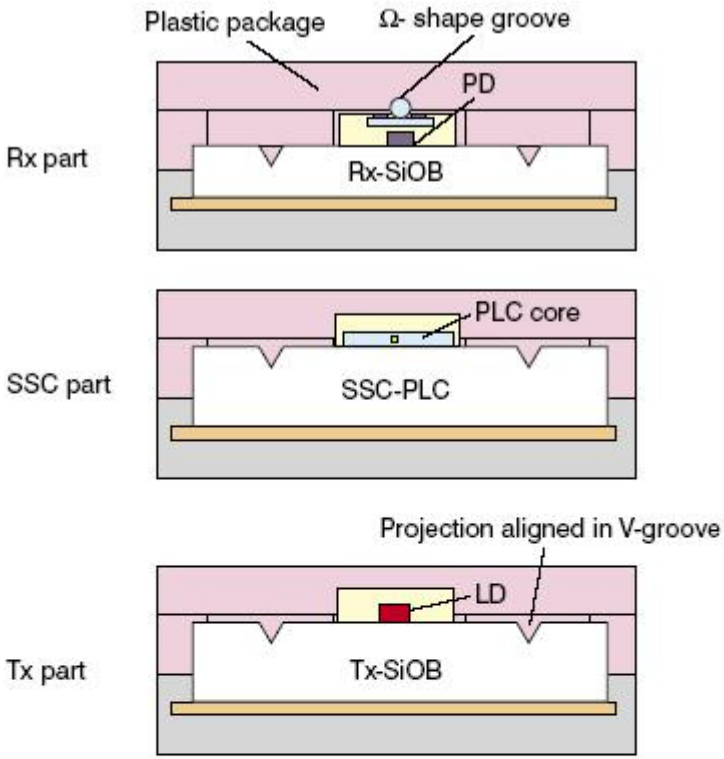


Figure 8 Cross-sections of OSA.

Figure 9 Cross-sections of V-groove alignment on silicon substrate (left) and omega groove of plastic mold (right).

Figure 10 WDM filter vapor-deposited on the facet of angle-polished fiber.

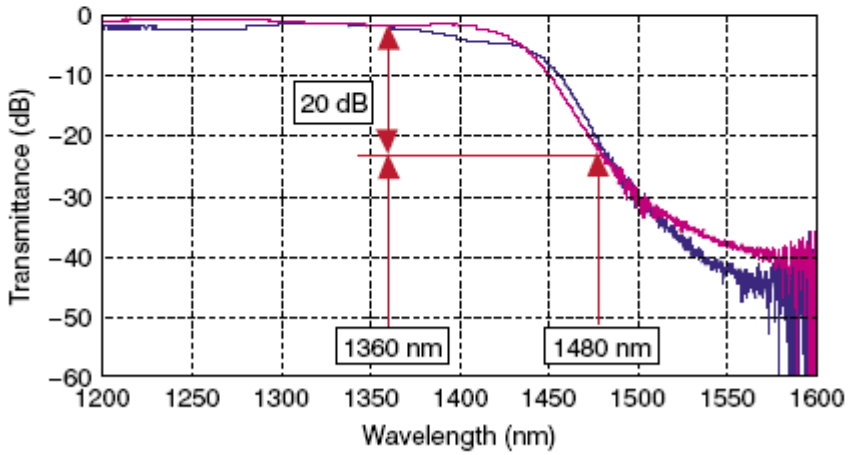


Figure 11 Characteristic of the short wavelength pass filter (SWPF) on a 30 °polished fiber facet.

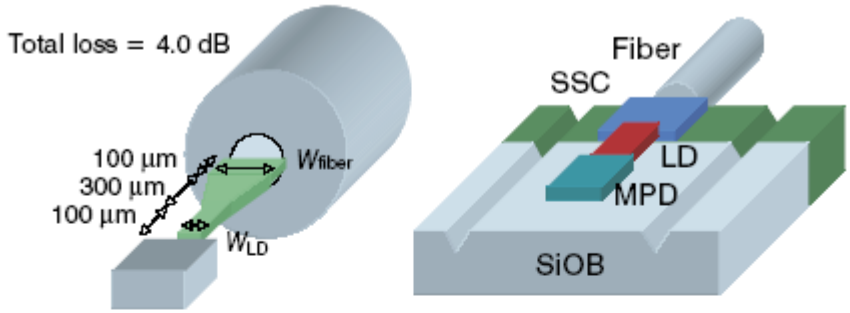


Figure 12 Structure of SSP-PLC.

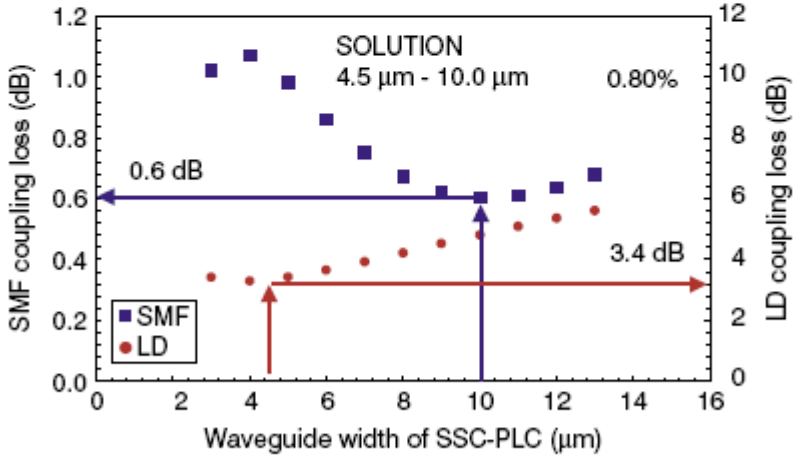


Figure 13 Calculated result of coupling loss between fiber and LD and SSC-PLC.

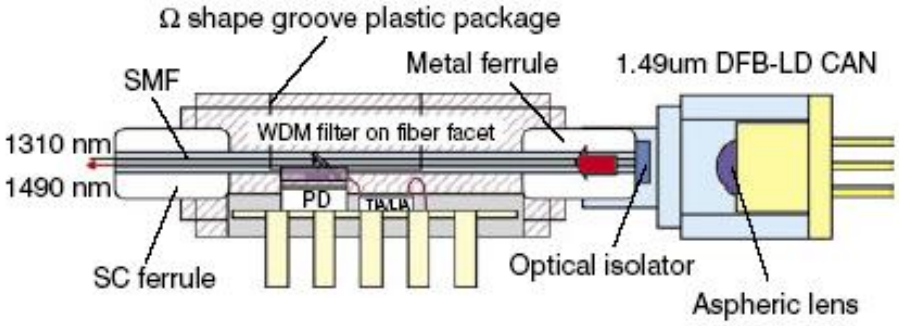


Figure 16 Schematic diagram of OSA for OLT transceiver.

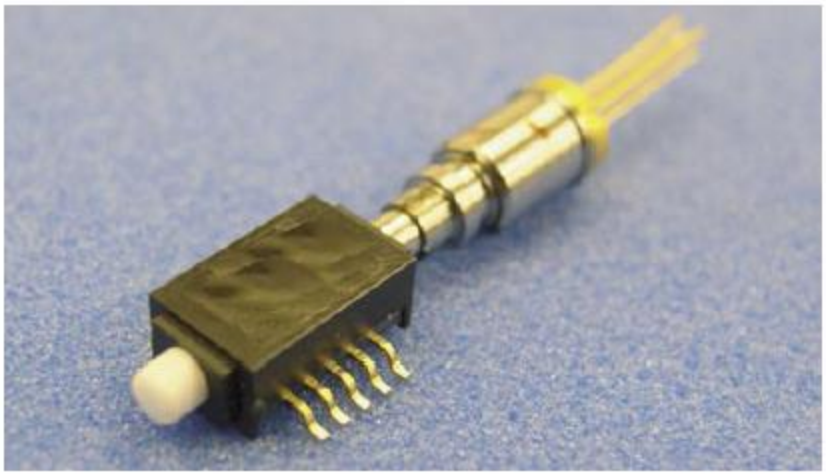


Figure 17 OSA for OLT transceiver.

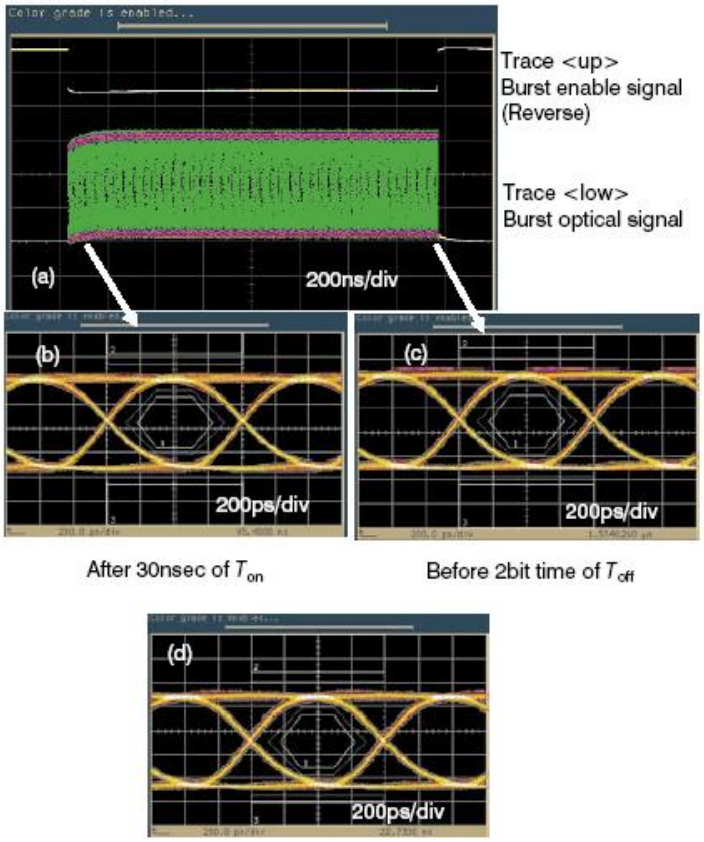


Figure 19 Eye diagram of ONU transceiver in burst mode operation.

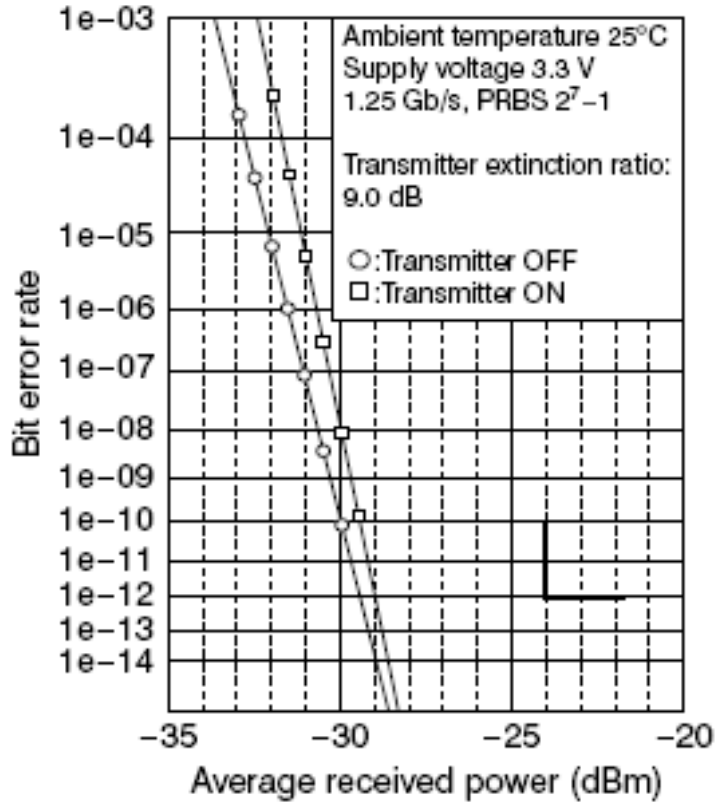


Figure 20 Bit error rate of ONU transceiver.

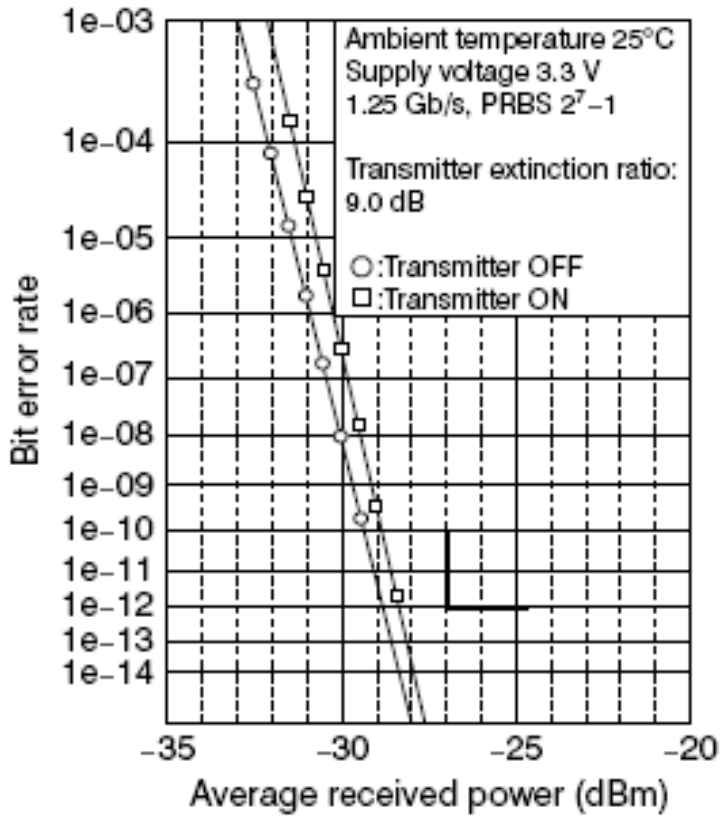


Figure 23 Bit error rate of OLT transceiver.

Fused or Fused Biconical Taper (FBT)

A fused coupler is a structure formed by the joining of two independent optical fibers (Figure 2). The claddings of the fibers are fused in a small region. FBT devices work as a result of an energy transfer by coupling proximity between optical fiber cores.

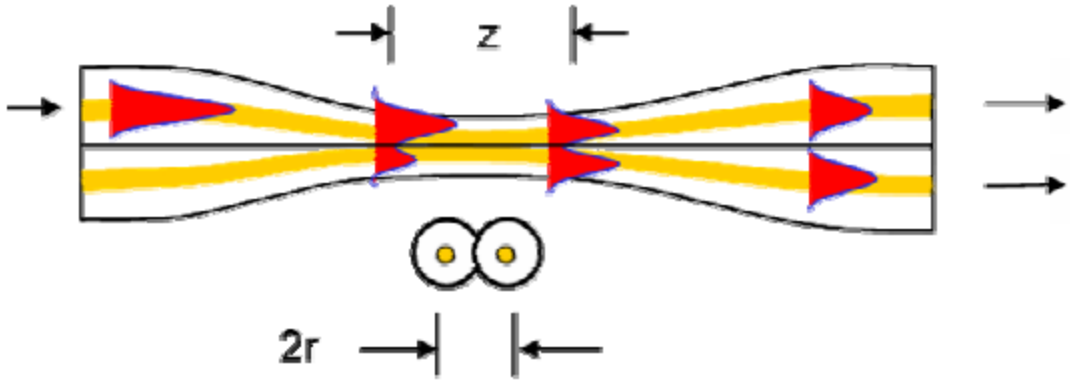
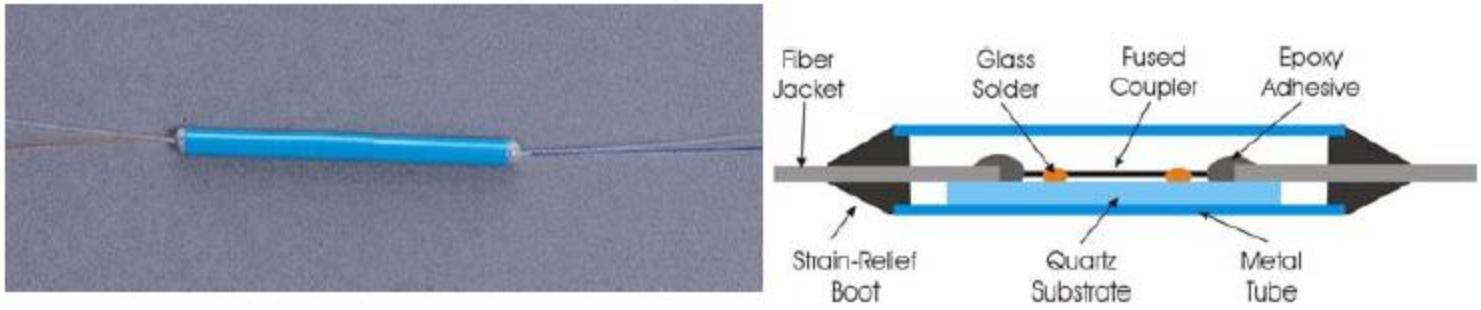


Figure 2: Fused coupler technology



Figures 3 and 4: FBT couplers

- Single window: 1310 **or** 1550 nm operating wavelength window (Figure 5)
- Single window, wavelength flattened coupler:
  1310 ± 40 **or** 1550 ± 40 nm wavelength window (Figure 6)
- Dual window or wideband: 1310 ± 40 **and** 1550 ± 40 nm (Figure 7)

Coupling Ratio vs. Wavelength

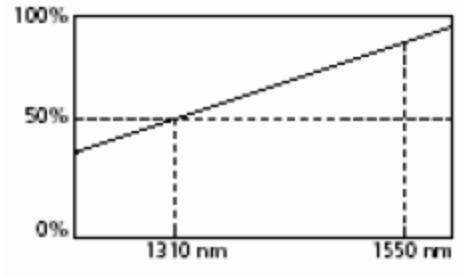


Figure 5
Single window coupler
(here for 1310nm)

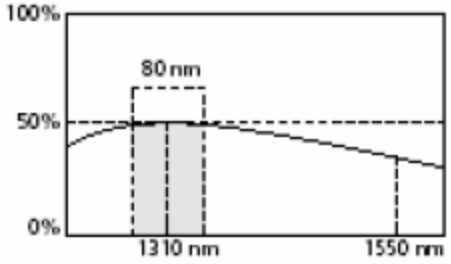


Figure 6
Single window wideband coupler
(here for 1310±40nm)

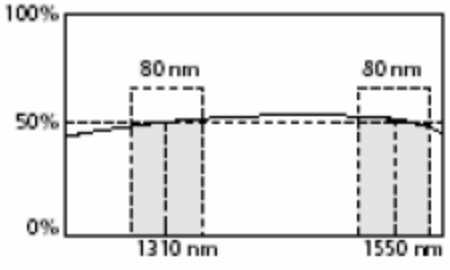


Figure 7
Dual window wideband coupler
1310±40 and 1550±40nm

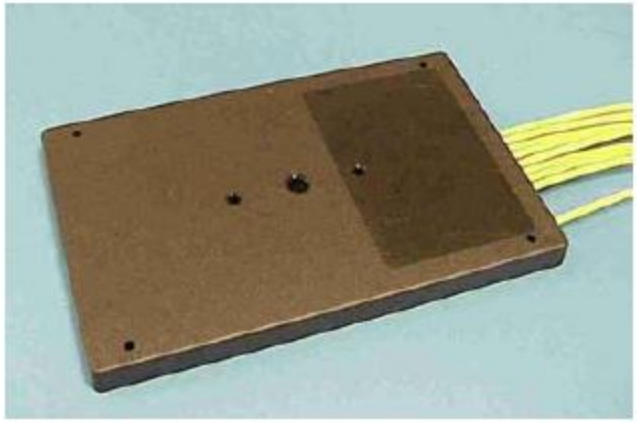


Figure 8

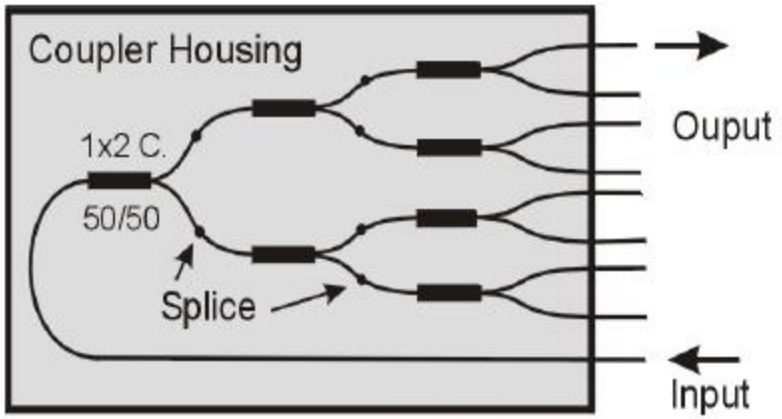


Figure 9

Planar Splitter or Planar Lightwave Circuit (PLC)

The second type of splitter is made up of a bulk integrated optical circuit assembled with an input and an output fiber array device. (Figure 10).

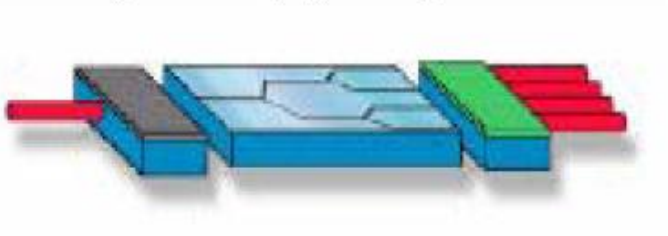


Figure 10: Planar splitter sub-assembling parts

The power split is achieved by a Y-junction (see Figure 11) fabricated inside the bulk material using photolithography techniques similar to the procedures used in the semiconductor industry.

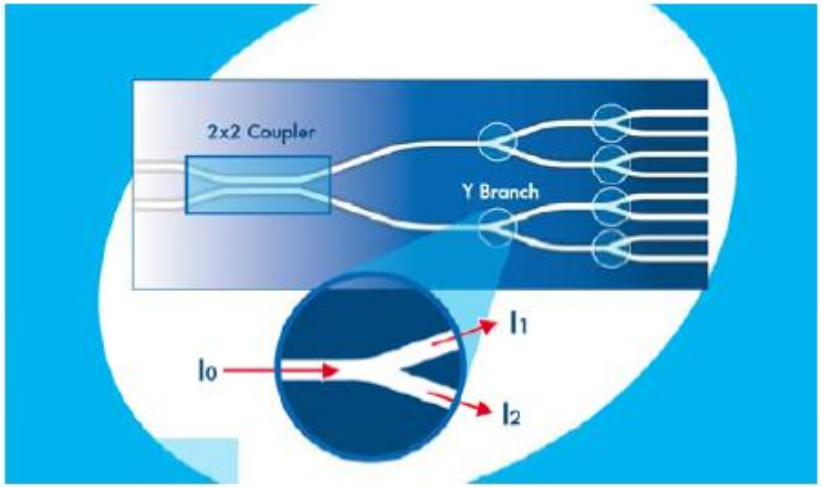


Figure 11: Planar splitter general design

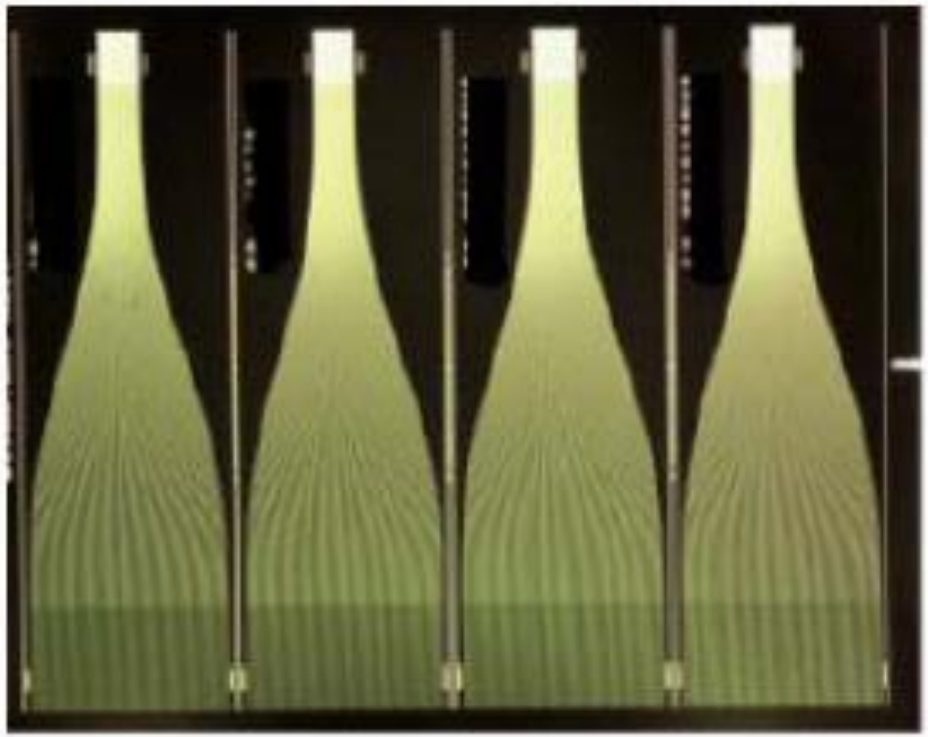


Figure 12: Photolithography mask

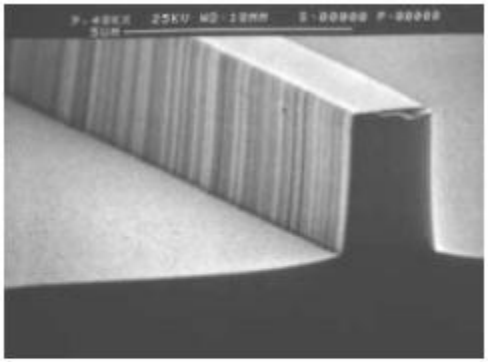


Figure 17:
REM picture of waveguide after upper cladding deposition

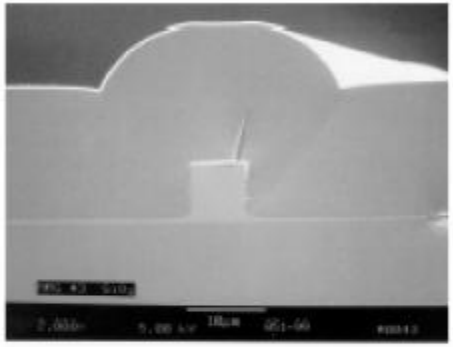


Figure 16:
REM picture of waveguide after mask lift off

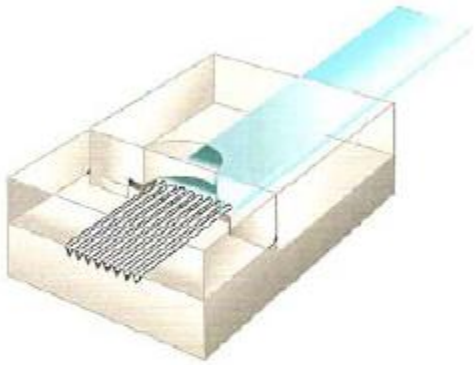
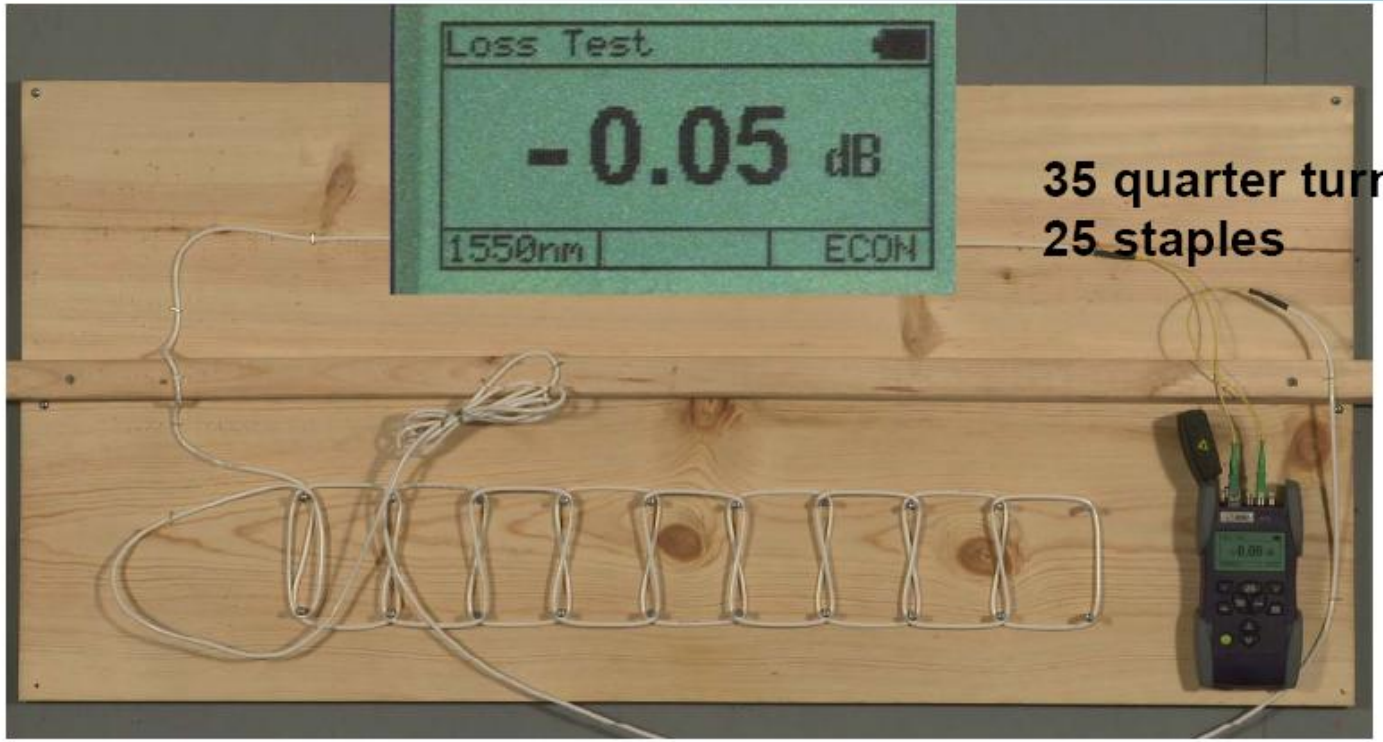


Figure 20: Fiber arrays

Figure 21: Packaged planar splitters

New Technology

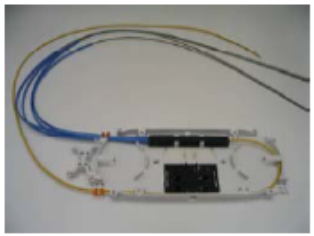
Bend Insensitive Fiber –
Enables fiber to reach inside homes and apartments



- Bend Capable Optical Cable - No Conduit or bend radius management required
- Can be stapled using traditional fast, low skill copper cable practice
- Up to 500 times lower bending loss than conventional fiber: 0.1 dB maximum loss at 5 mm radius single turn (1550 nm)
- Splicing/Connector mounting with Conventional Process

Key Cost Considerations for FTTH
Splitter Management

Centralized in Cabinets
- Typically Lowest cost for up to 50% take rate
- Enables efficient pay as grow CO electronics provisioning
- Some can provide modular and simplified upgrade path

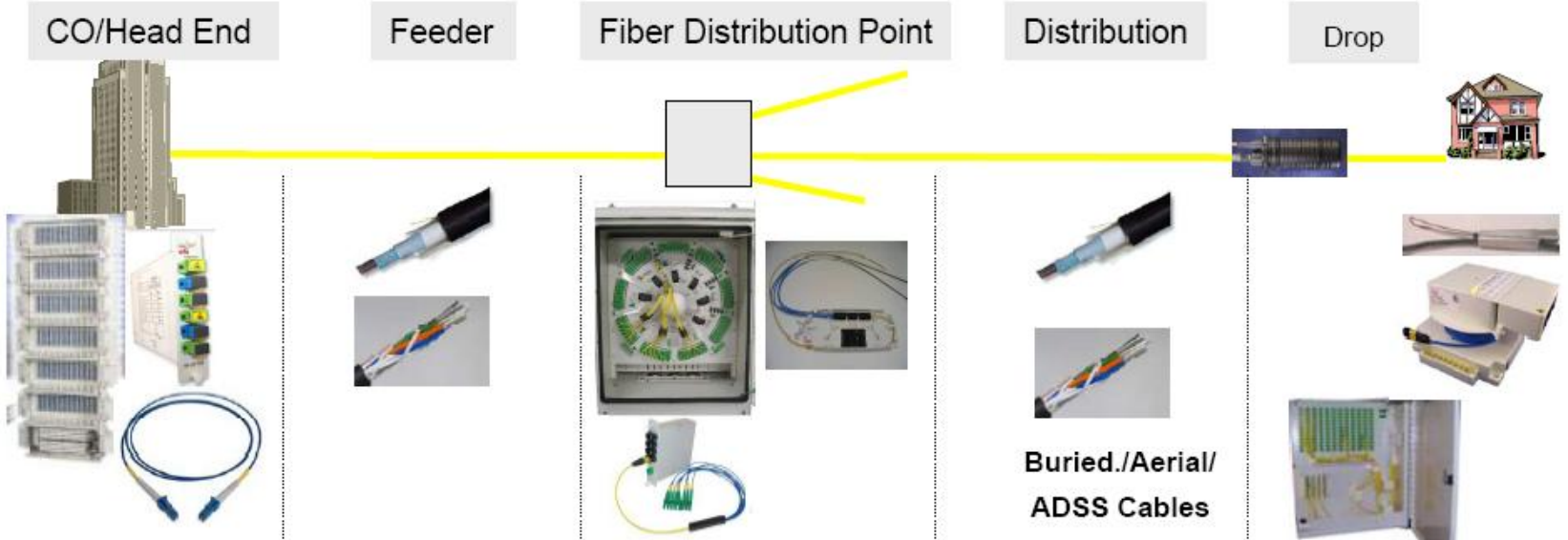


Distributed in closures
- Lowest cost for > 50% take rate, can save up to $100/HP
- Enables efficient pay as grow CO electronics provisioning

In the CO/Head End
- Typically lowest cost for < ~1 KM distances from CO/HE
- Enables efficient pay as grow CO electronics provisioning

Key Cost Considerations for FTTH

Pieces of the OSP Puzzle – Must work together for 40 years

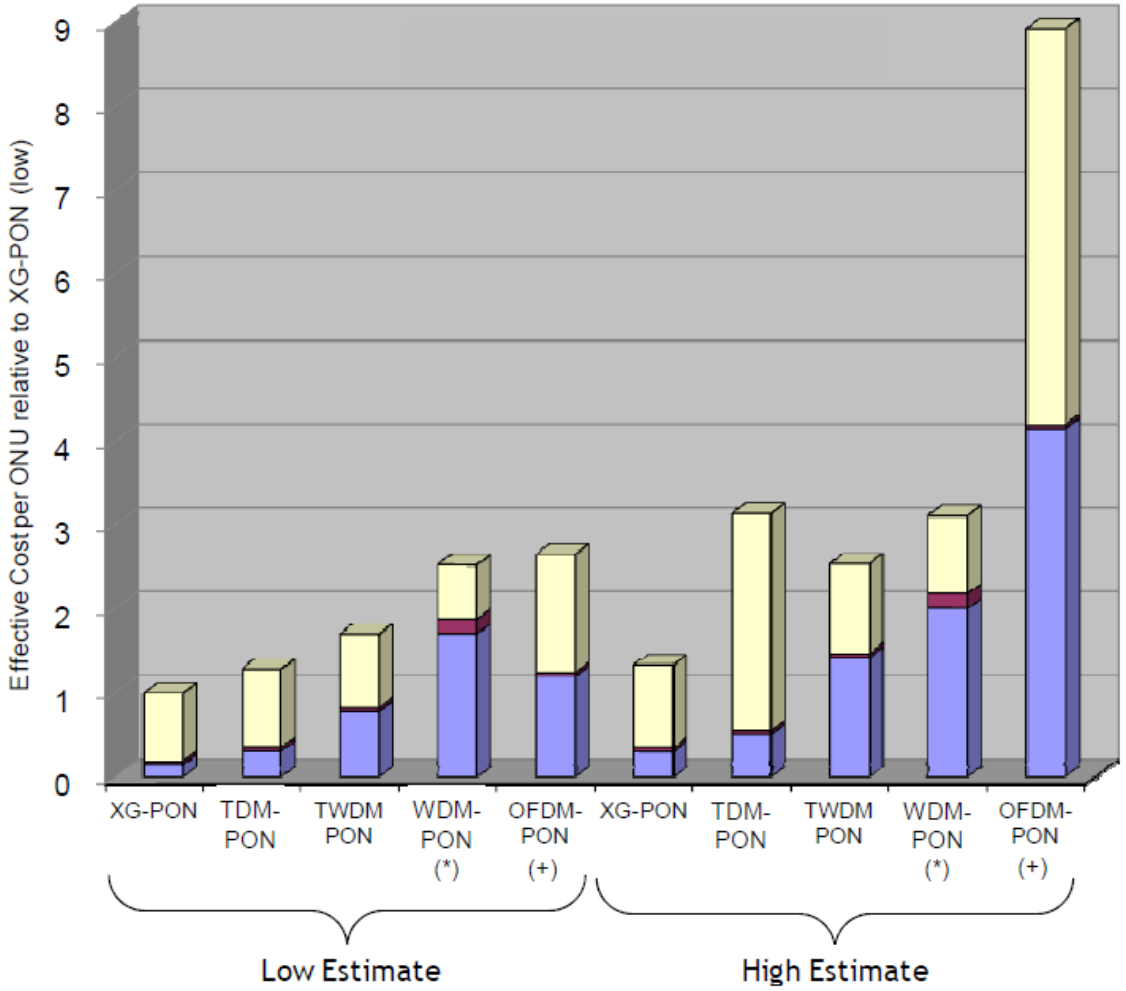


Bend Optimized, Low Loss Connectivity, indoor cable, video and splitter modules	Buried./Aerial/ ADSS /Micro Cables Dry Technology	Splitter Cabinets and Modules, Splitters in Closures Bend Optimized and Low Loss	Buried./Aerial/ ADSS /Micro Cables Dry Technology	Drop Cables MDU Plug and Play Systems

Full Spectrum, Low loss, Bend Optimized Optical Path

Cost comparison 40/10G NG-PON2 (year 2015)

Effective cost per subscriber (16 ONU connected per OLT)



Ref.: E. Harstead et al., Alcatel-Lucent

Larger uncertainties for higher risk technologies

ONU
OSP mux/demux
OLT

Volumes:
•OLT=10k
•ONU=100k

(*) Self-seeded PON used as example case
(+) Asymmetrical OFDM PON used as example case

Alcatel·Lucent

The First Mile - Outline

- Introduction: the first/last mile bottleneck
- Evolution of FTTH considerations
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- Enabling technologies
- The future: applications

Services Transformable Through FTTH

Few are new – all could be vastly improved with FTTH

- **Teleworking**
- **Telemedecine**
- **Entertainment**
- **Social Video**
- **Distance Learning**
- **Videophones**
- **Gaming**

Services Transformable Through FTTH
Video Telephony and Video Mail

Video Teleconferencing

- non-FTTH
  - 0.3 – 1 Mb/s upstream limits resolution and motion
- FTTH
  - 2 – 10 Mb/s upstream enables full HD resolution and motion
  - 100 – 1000 Mb/s for future higher definition and 3D video

Video mail becomes feasible

2 minute VHD 1080p video clip		Download	Upload
non-FTTH:	10 / 1	3 min	30 min
FTTH:	50/ 10	40 sec	3 min

Disney Oct 07

FIGURE 8: ONLINE BANKING THROUGH AN HD TELEVISION IN SOUTH KOREA[42]

Services Transformable Through FTTH
Teleworking

- Face time?
  - Videophone face time
    - Big Screen and in VHD
- Productivity solution
  - Videophone face time
  - Video conferencing
  - File sharing and e-mail at in-Office LAN Speeds

Source: VSGI

Data Rate (Mb/s typical)	Office Worker on LAN	Teleworker at home (HFC / DSL)
Downstream	100	10
Upstream	100	1

Teleworking - Transformable Through FTTH

Teleworking Benefits Projection USA	2006 Baseline	Fiber Enabled Projection
Teleworkers (%)	11.0%	35.0%
Teleworkers (M)	16.0	50.8
Avg days/week	1.6	2.6
Incemental over 2006 baseline		
Productivity Improvement/yr ($M)		$ 156,097
Fuel Savings/yr ($M)		$ 14,647
Business Travel savings/yr ($M)		$ 34,000
TOTAL ANNUAL BENEFIT ($M)		$ 204,744

- $4000 per teleworker annual benefit
- 2% increase in GDP

* Estimated and Projected

Additional Teleworking Benefits

- Greenhouse gas output reduced by about 56M tons/year
- Lower dependency on foreign oil imports by about 5%
- Fuel efficiency increases though reduced traffic
- Less road maintenance and construction
- Reduced office space requirements
- More flexibility and less stress

Health Care - Transformable Through FTTH

US Health Care Costs

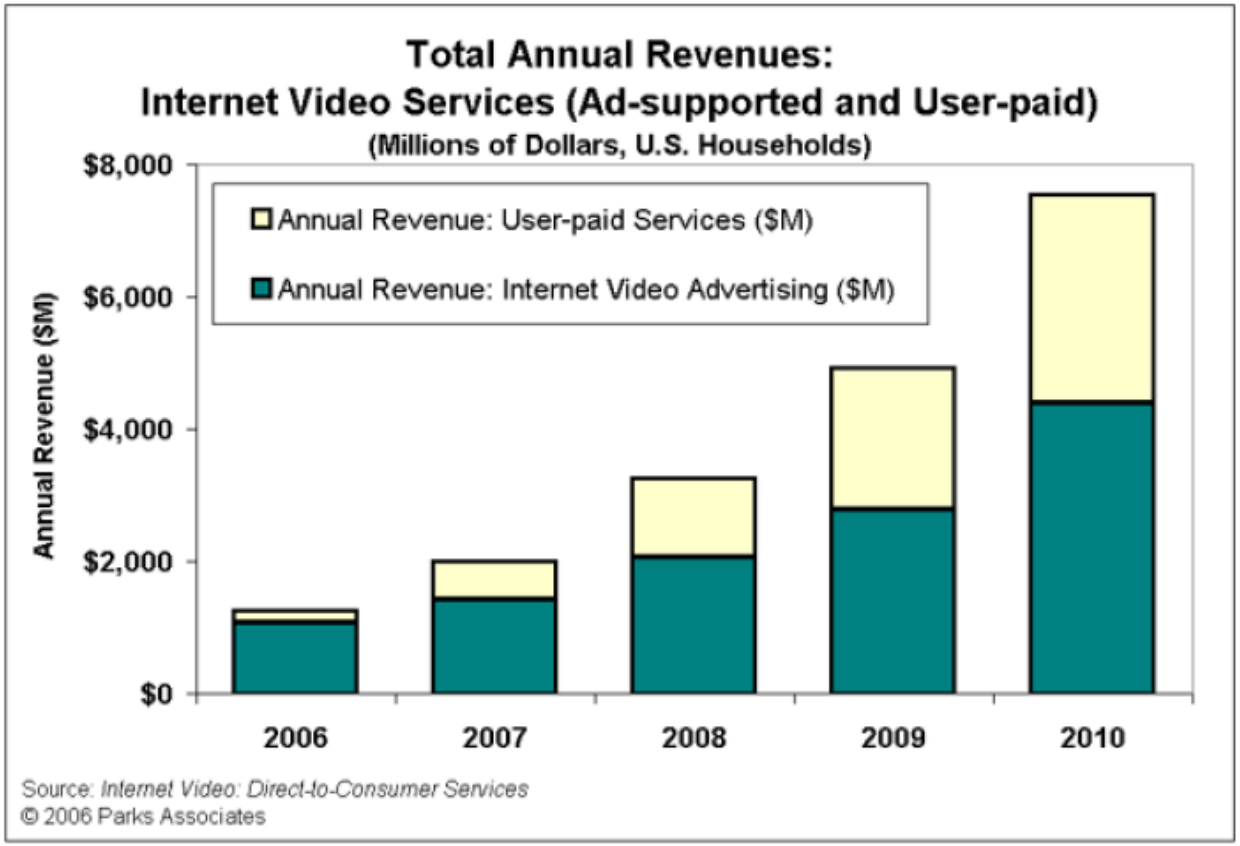
- $2 Trillion annually
- Growing 4%/yr above inflation

Videotelemedice $B hypothetical savings	2005 Expediture	10% Savings	Savings opportunities
Physician and Clinical	$ 420	$ 42	Virtual Dr appts at home
Nursing Home Care	$ 120	$ 12	At home monitoring vs institution
Home Health Care	$ 40	$ 4	Fewer visits from health practitioner
Total	$ 580	$ 58	

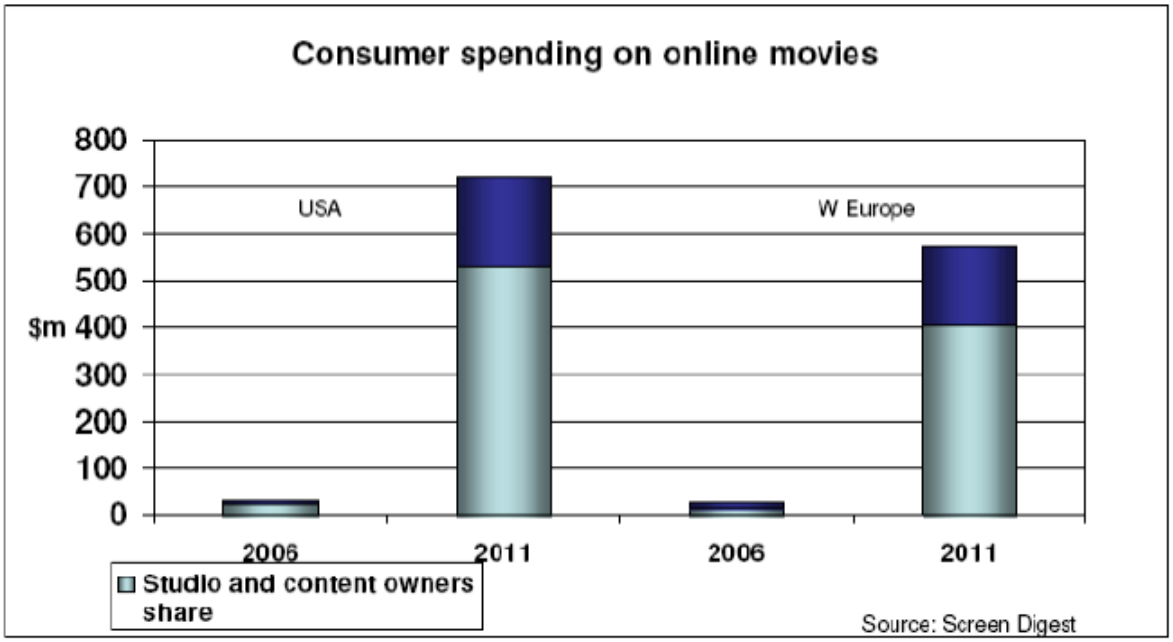
FTTH Bandwidth Enabled Telemedicine Tools

- VDH (1080p) videophone links, super fast file downloads/uploads
  - Health care practitioner to Patients
  - Remote diagnostics of large files (XRay. MRI, etc)

Services Transformable Through FTTH



Online Movies :
$35B market possible at FTTH Speeds?



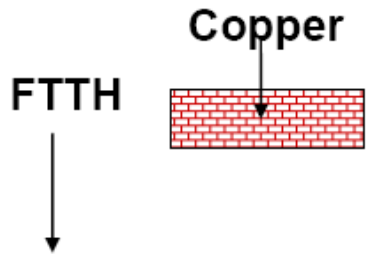
- In 2011 total of $1.3B for online movies
  - Only 4% share of $35B combined US and W. European Home Movie Markets
- FTTH bandwidths could dramatically grow online movie share.

Online Movie Distribution
Inhibitors and Enablers for growth

- **Lack of connectivity from PC to Large Monitors in the Home**
  - **Solutions: multi-room set-tops, in-home connectivity over existing cables, etc**

- **Online movie downloads currently bandwidth inhibited**

2 hour HD-DVD download time	Data Rate
- 480 minutes (8 hrs)	4 Mb/s
- 100 minutes (< 2 Hrs)	20 Mb/s
- 20 minutes	100 Mb/s
- 2 minutes	1,000 Mb/s



FTTH Benefits Summary

Improved Economy, Quality of Life, and Business Case

- Home Values increased $4,500 (RVA data)
  - Homebuyers already value FTTH with only 7% of homes passed
- Attract and retain businesses
  - Improved business efficiencies, sales, and marketing.
- Productivity and Quality of Life
  - The true "virtual office" and teleworking enabled by HD and later 3D video meetings and collaboration. Improved and lower cost education and health care
  - Distance learning
  - Distance medicine
  - Entertainment and video networking
- Greater revenue potential for the same cost as other options