

Fiber Drivers in Today's Media-Rich Communications

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Fiber-Optics Technology

It can be considered our saviour for meeting the needs in the age of information due to its potentially 'limitless' capabilities to access information at our finger tips: when we need it, where we need it, and in whatever format we need it...

Today's Talk

- **Fiber Optics: An Overview**
- **Optical Networks**
- **Last-Mile Access: PON Technologies**
- **Conclusion**

Fiber-Optics: Overview

The information superhighway owes its very existence to fiber optics.

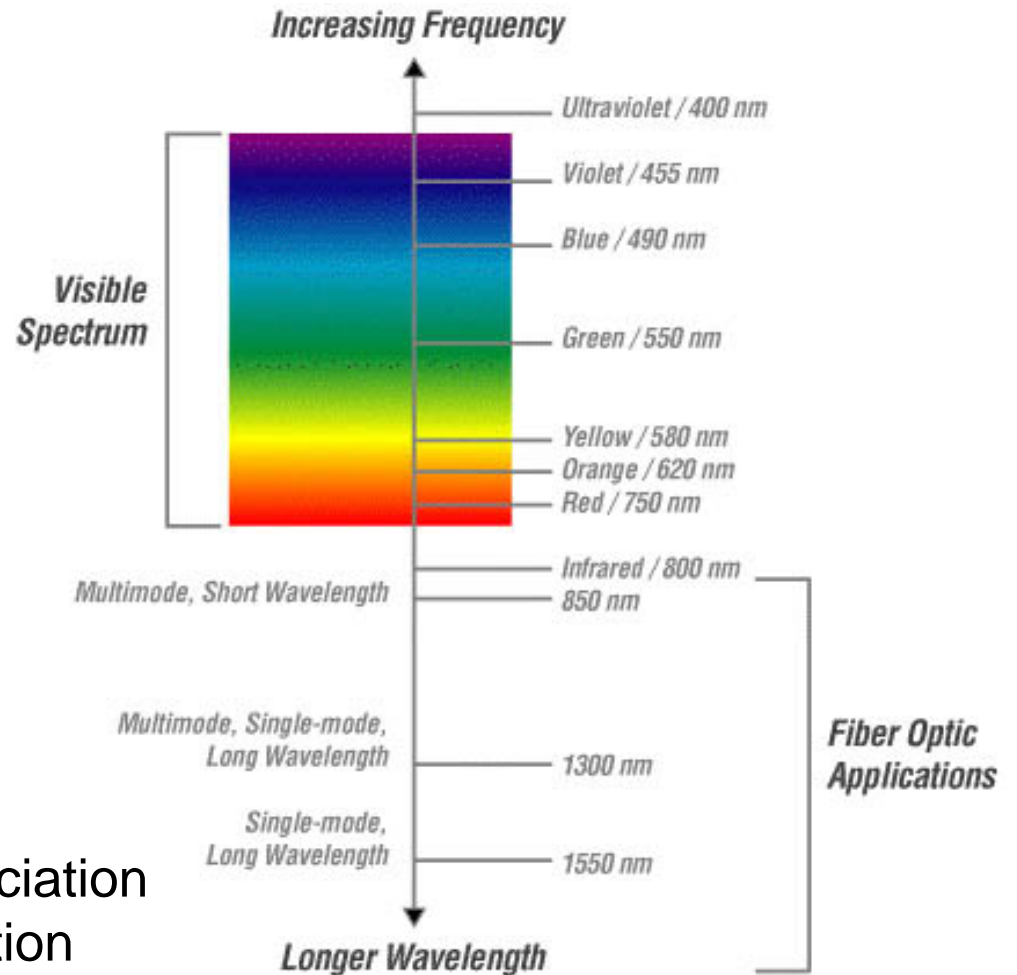
History

- The earliest attempts to communicate via light (e.g., smoke signals) undoubtedly go back thousands of years...
- 1966: Theorized that ultrapure and ultrathin filaments of glass could be a 'revolutionary communications pipeline.'
[Dr. C. Kao (高錕, the father of Fiber Optical Communications) of ITT]
- 1970: Succeeded in developing a glass fiber with attenuation at less than 20 dB/km, which implies the technological availability to produce and use optical fibers in (long-distance) communications.
[Drs. R. Maurer, D. Keck and P. Schultz of Corning Glassworks]
- 1970: first laser diode (light source)
[Bell Labs]
- Late 1970's: fiber networks started to deploy and use in telecom.
[US, Japan, England, ...]
- 1990's: Took Off...

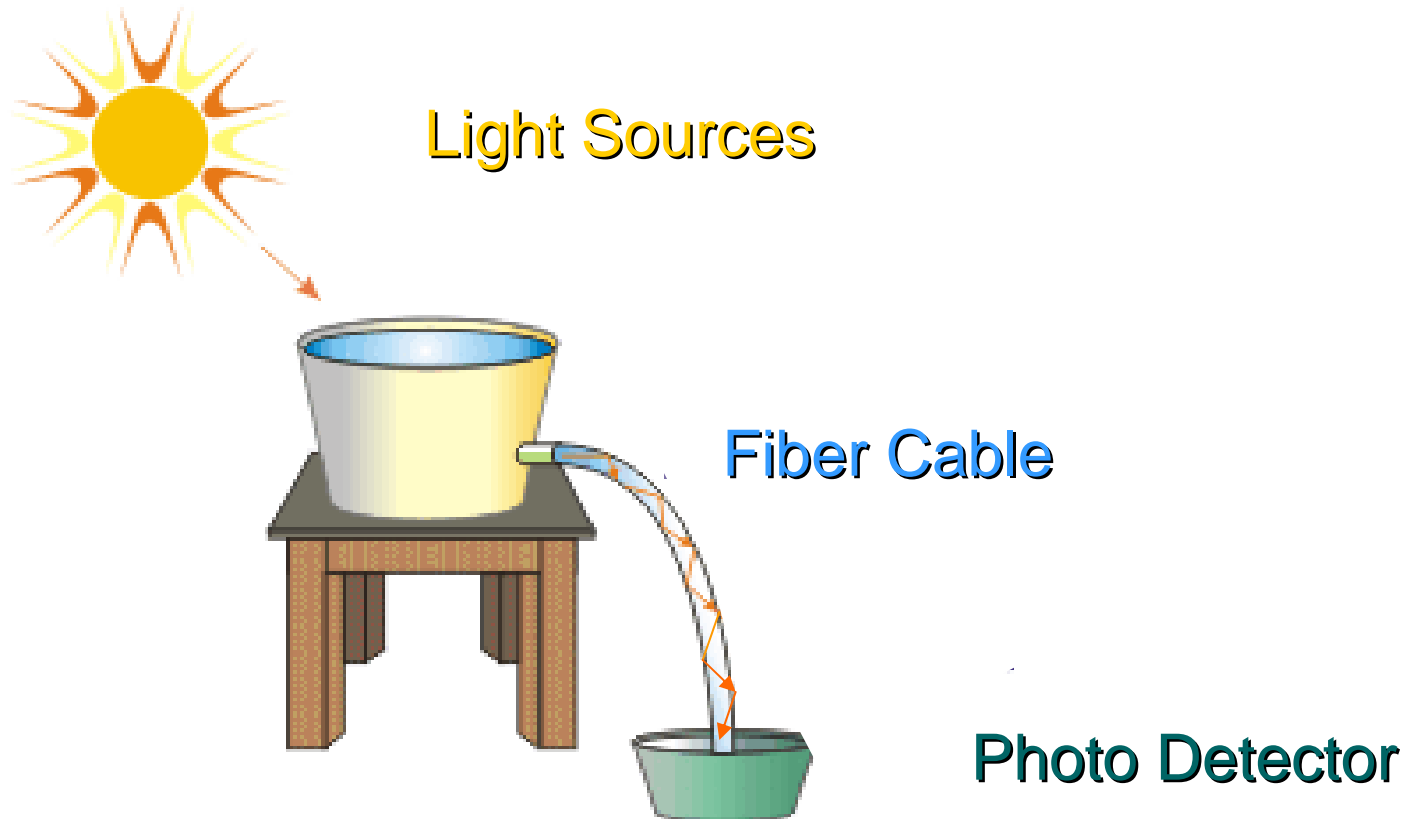
Characteristics

- Wavelength - a measure of the width of the waves being transmitted
- Three wavelengths supported
[EIA/TIA Standards]

EIA: Electronic Industries Association
TIA: Telecom Industry Association



Components



[This Picture] Source: www.MrFiber.com

Light Sources

■ Two Categories

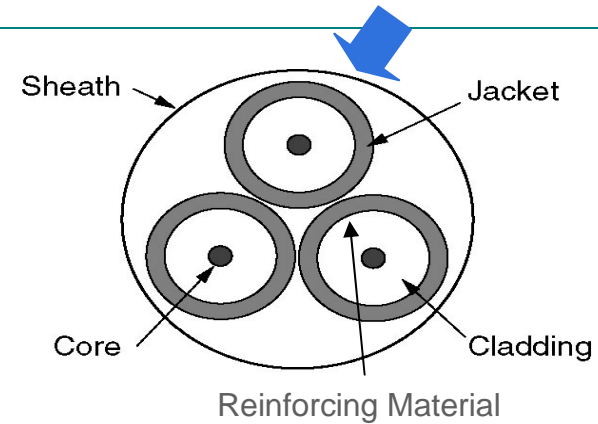
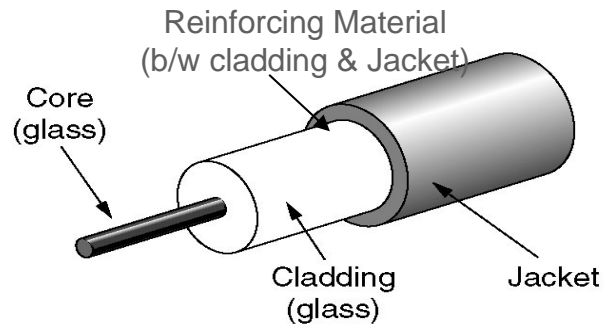
- Light-Emitting Diodes
- Semiconductor Laser Diodes

Idea for long-haul and high speed transmission

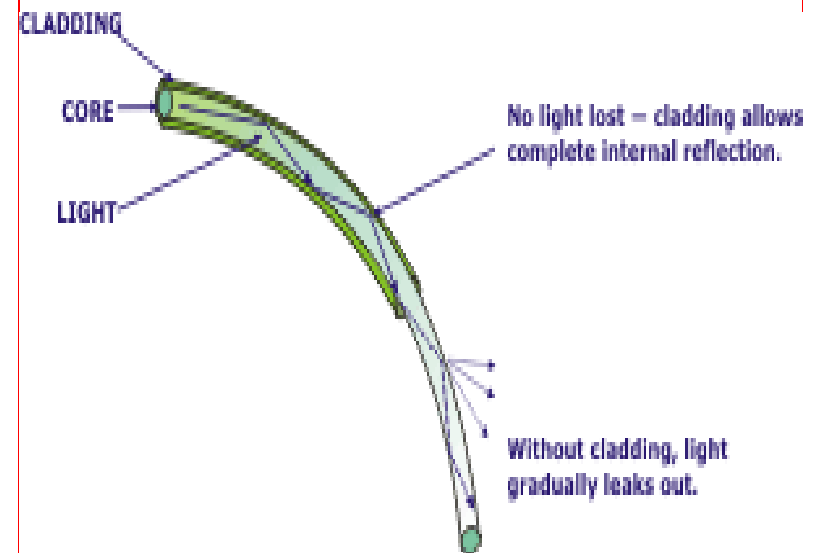
Item	LED	Semiconductor laser
Data rate	Low	High
Fiber type	Multimode	Multimode or single mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

Fiber Cable

Up to 500 fiber cables can be bundled inside 1 sheath

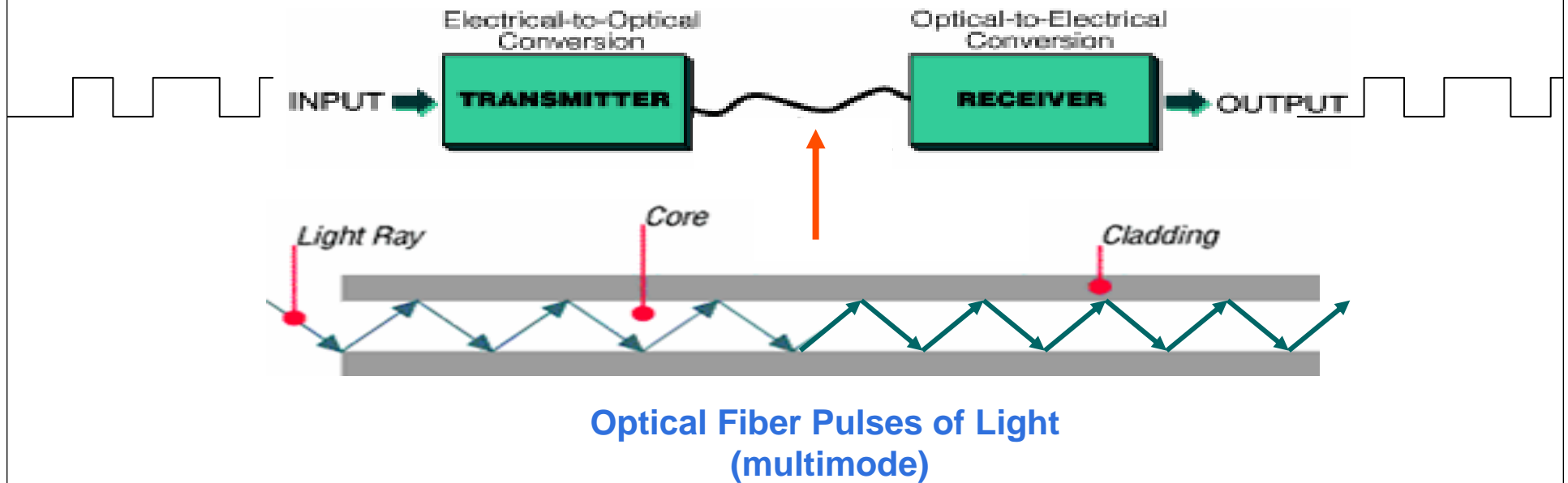
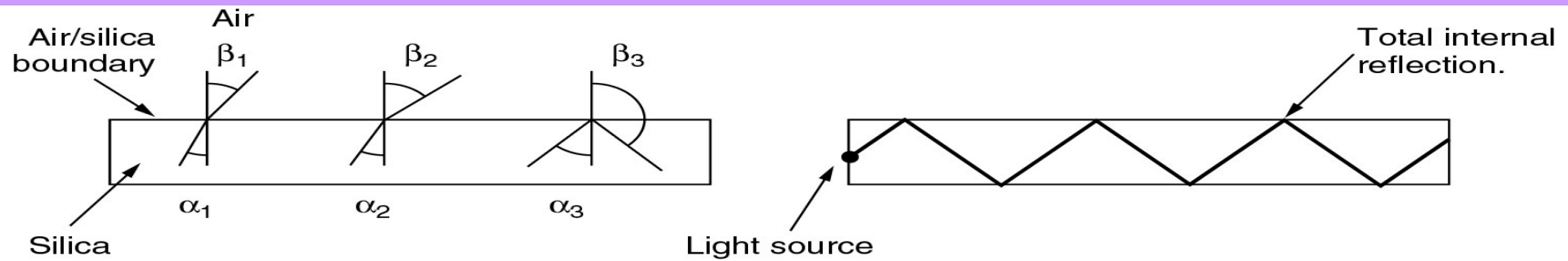


- [Core] to transmit the light the innermost region of the fiber
- [Cladding] to prevent the light from leaking by reflecting the light within the boundaries
- [Coating] to ensures the fiber not to bend to the point of breaking
- [Strengthening Fibers] (hard enough) to prevent other intrusions
- [Cable Jacket] to cover the strengthen fibers



[This Picture] Source: www.MrFiber.com

Fiber-Optic Transmission [Principle]

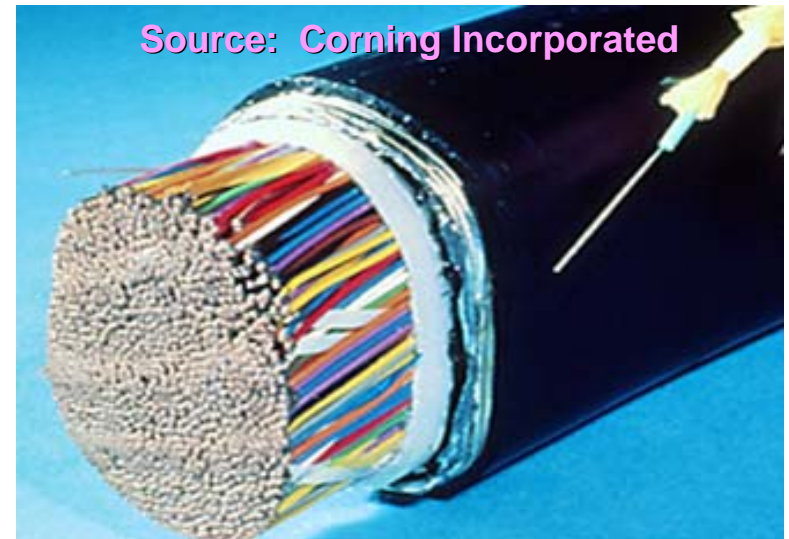


Fiber Optics Promises

The potential 'limitless' transmission capacity and the low attenuation of an optical fiber are of its major features...

Fiber versus Copper

- A single copper pair is capable of carrying six phone calls
- A single fiber pair is capable of carrying over 2.5 million simultaneous phone calls [64 channels X 2.5Gbps]
- 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



Transmission Capacity: Limitless?

- In electrical engineering and computer science, **information capacity** is the tightest upper bound on the amount of information being reliably transmitted over a communications channel.

■ Information Capacity for Single Fiber*

Can Exceed **100 Tbps** [$1T = 10^{12}$]

- Propagation Nonlinearity
- Typical Dense Wavelength Division Multiplexing
- With Coherent Detection

(*) P. P. Mitra & J. B. Stark, “*Nonlinear limits to the information capacity of optical fiber communications,*” *Nature*, vol. 411, pp. 1027 – 1030, June 2001.

■ 100 Tbps: How Fast?

Think about downloading the **entire Library of Congress** which is often used as the yardstick for the measure of all human knowledge ...

56Kbps:	81.500	years
10Gbps:	2.350	hours
100Gbps:	14.100	minutes
1Tbps:	1.410	minutes
100Tbps:	0.846	seconds

Optical Channels [in use*]

Optical Carrier (OC-x)	Synchronous Transport Mode (STM-x)	Line Rate (Mbit/s)
OC-3	STM-1	155.52
OC-12	STM-4	622.08
OC-48	STM-16	2488.32 (2.5G)
OC-192	STM-64	9953.28 (10G)
OC-768	STM-256	39813.12 (40G)

Standardized Transmission Line Rates

(*) Fiber Channel with Capacity 100 Gbps was Demonstrated in the Lab but not yet available for deployment.

Signal Attenuation

■ What's That?

- reduction in intensity of a light beam with respect to length traveled
 - a natural consequence of signal transmission over long distance
 - the biggest issue in fiber-optic communications
- also: transmission loss / propagation loss

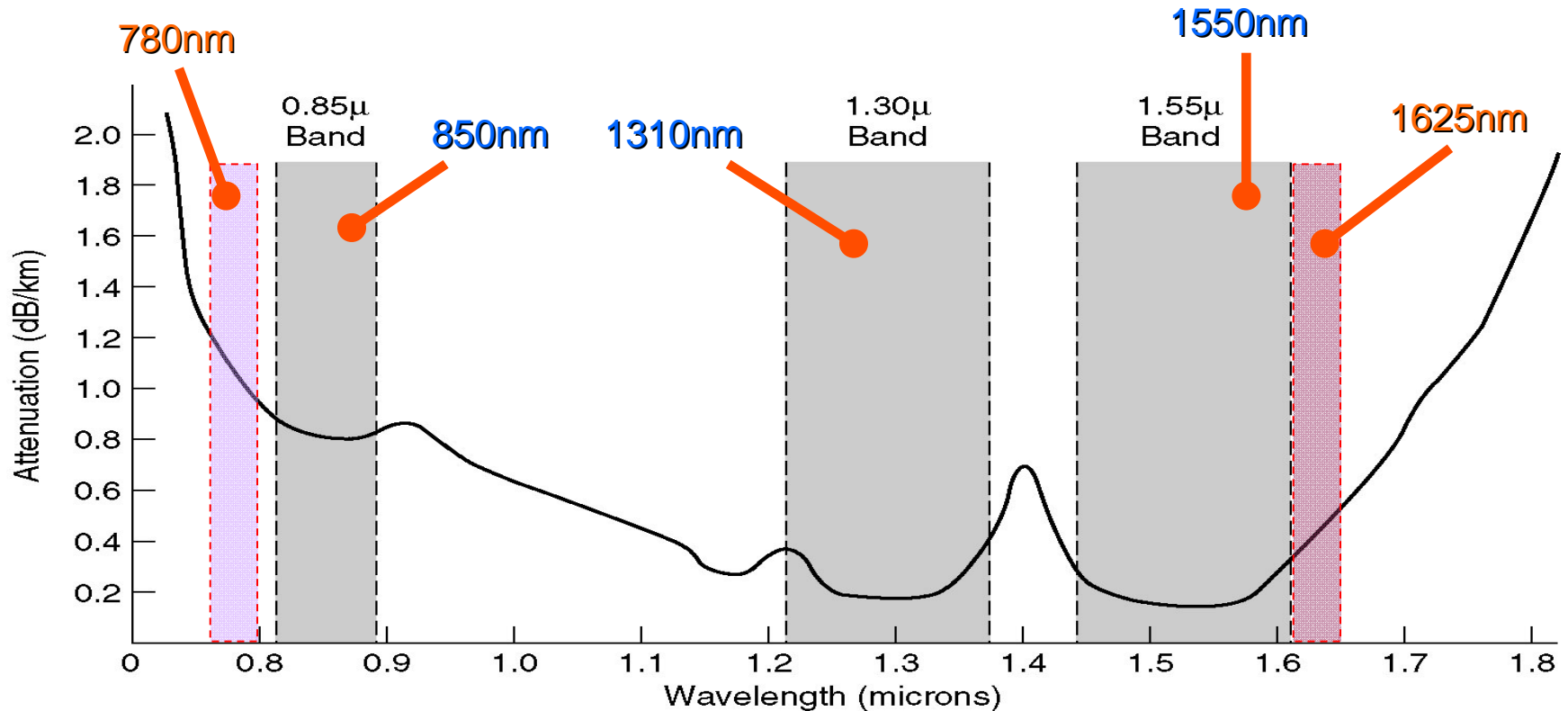
■ Measurement Unit

decibel per kilometer (dB/km)

■ Signal Attenuation Computation

$$\text{Attenuation(dB)} = 10 \times \log_{10} \left(\frac{\text{Output Intensity(W)}}{\text{Input Intensity(W)}} \right)$$

Most Common Peak Wavelengths



1 micron meter = 10^{-6} meter; 1 nanometer (nm) = 10^{-9} meter

■ 1st Window

- 850nm Region
- used initially - support for the original LED and detector tech

■ 2nd Window

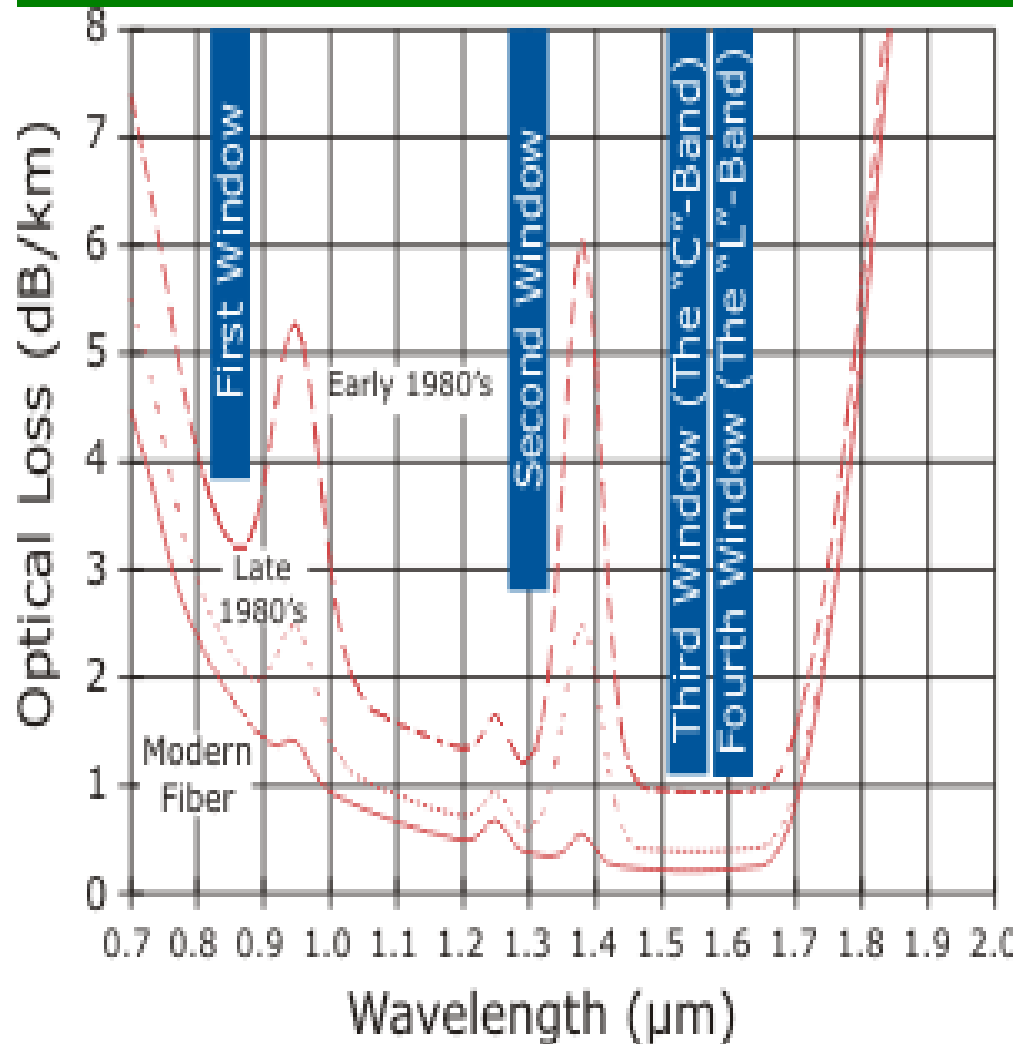
- 1310nm Region
- popular currently – dramatically lower loss and lower dispersion

■ 3rd Window

- 1550nm Region
- can avoid repeaters (performance and cost increase as wavelength increases)

■ 4th Window ...

Signal Attenuations for Windows 1 ~ 3



Window	Atten.	Signal Lost (per km)
	20.0 dB/km	99.00%
1 st : 850nm		
Early 1980's	3.3 dB/km	53.23%
Late 1980's	2.0 dB/km	36.90%
Modern Fiber	1.4 dB/km	27.56%
2 nd : 1310nm		
Early 1980's	1.2 dB/km	24.14%
Late 1980's	0.7 dB/km	14.88%
Modern Fiber	0.5 dB/km	10.88%
3 rd &4 th : 1550nm		
Early 1980's	1.0 dB/km	20.57%
Late 1980's	0.45 dB/km	9.84%
Modern Fiber	0.2 dB/km	4.50%

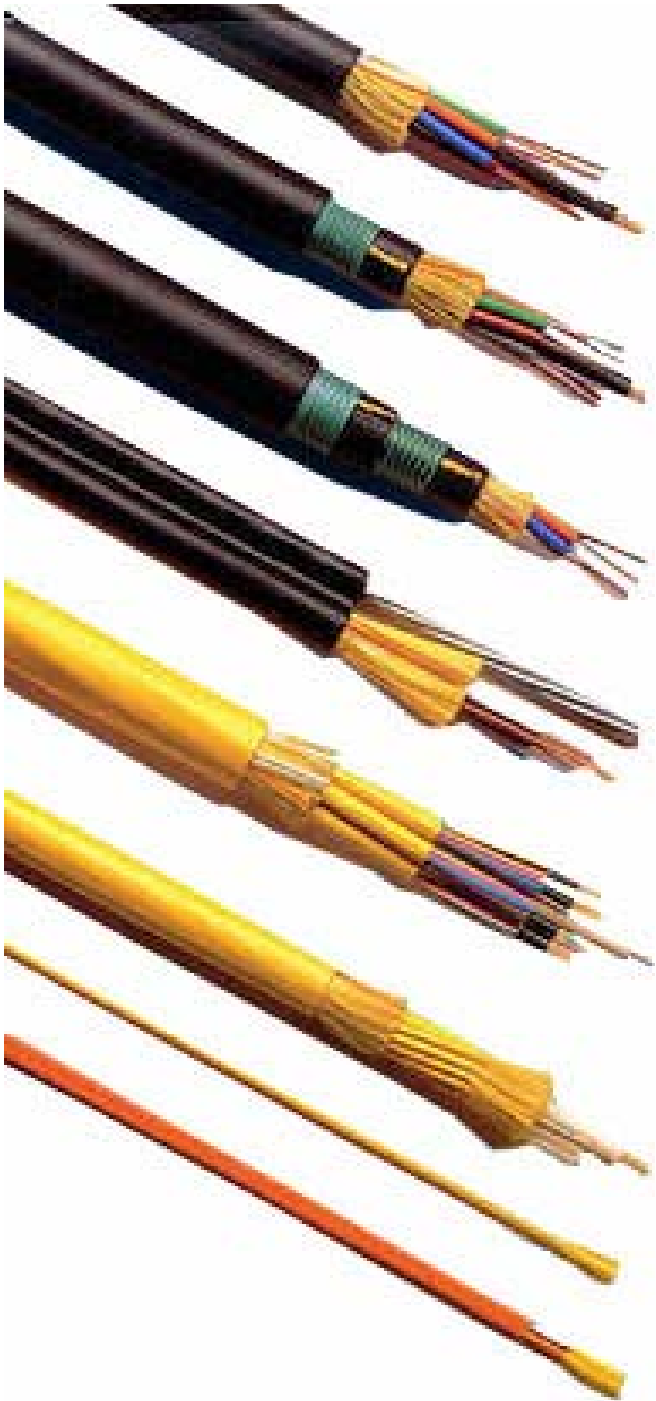
Categories of Optical Fibers

Determined by mode and index:

- **Mode: single / multi**
- **Index: stepped / graded**

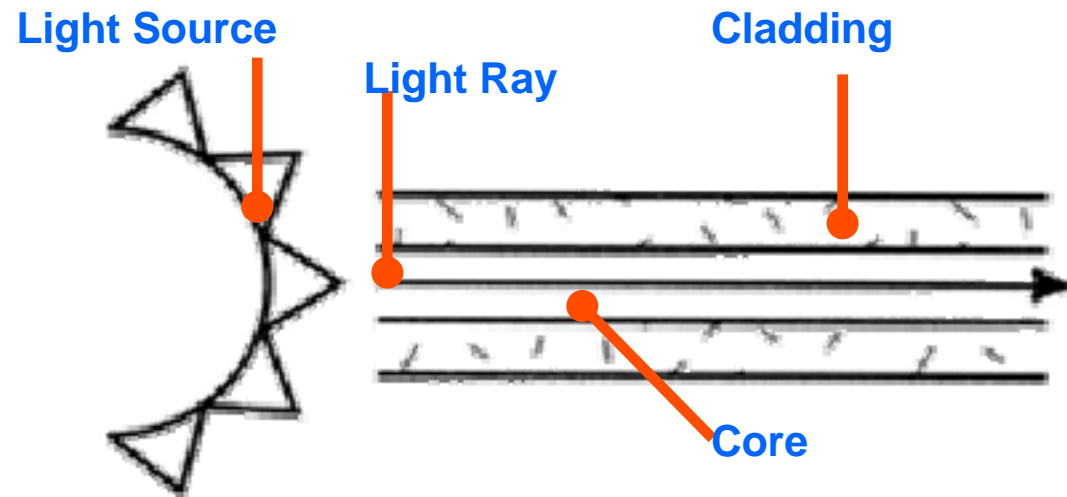
Three types of fibers

- **Single-mode step index**
- **Multimode graded index**
- **Multimode step index**



■ Single-Mode Fiber

“Single mode fiber”
single path through the fiber



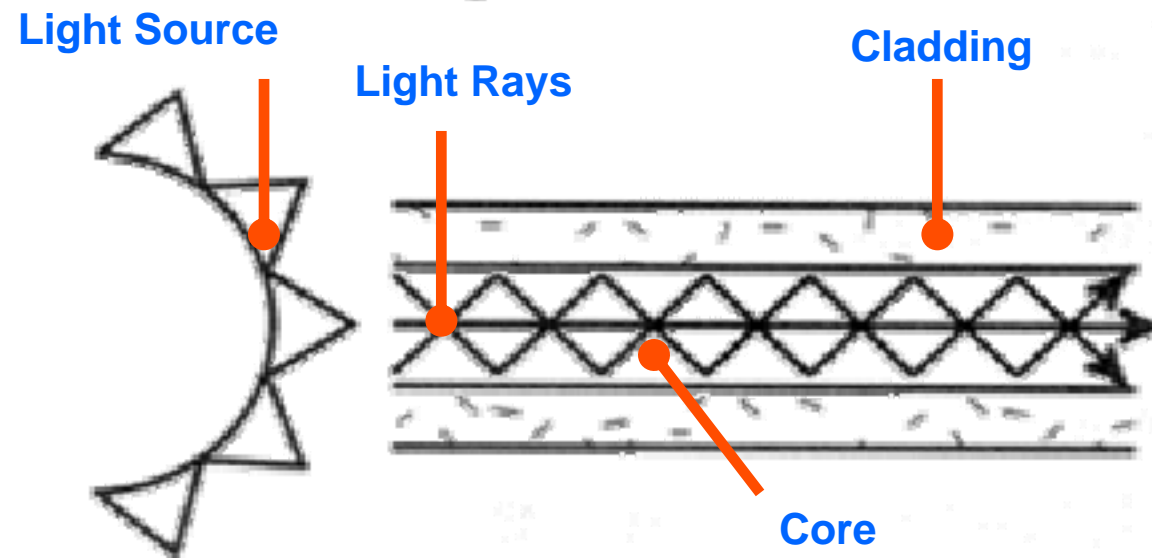


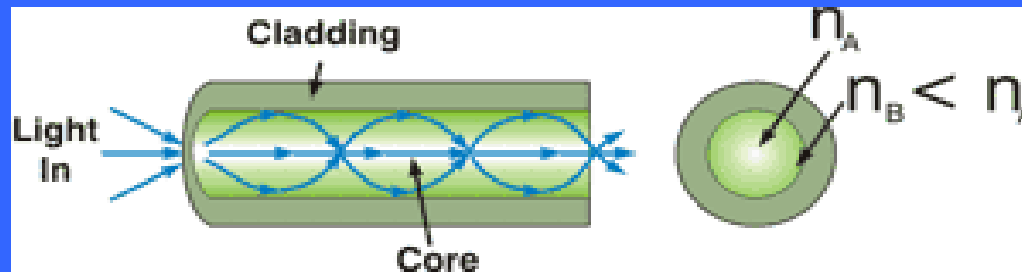
■ Single-Mode Fiber

- High-performance mode of fiber
- Core Diameter: 8 ~ 12 microns
 - low acceptance angle: one light path only
 - light travels parallel to central axis
- Low attenuation: as low as 0.2 dB/km
 - Very good signal quality over long distance
 - Ideal for ultra-/long haul (undersea; terrestrial)
(known repeater space: 500 miles)
- Wavelengths: 1300 ~ 1500 nm

■ Multi-Mode Fiber

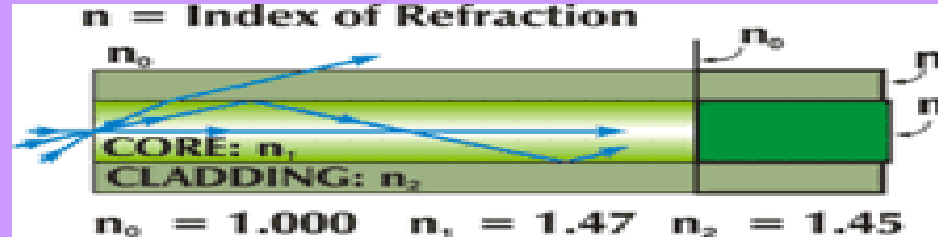
“Multimode fiber”
multiple paths through the fiber





■ Multimode Graded-Index Fiber

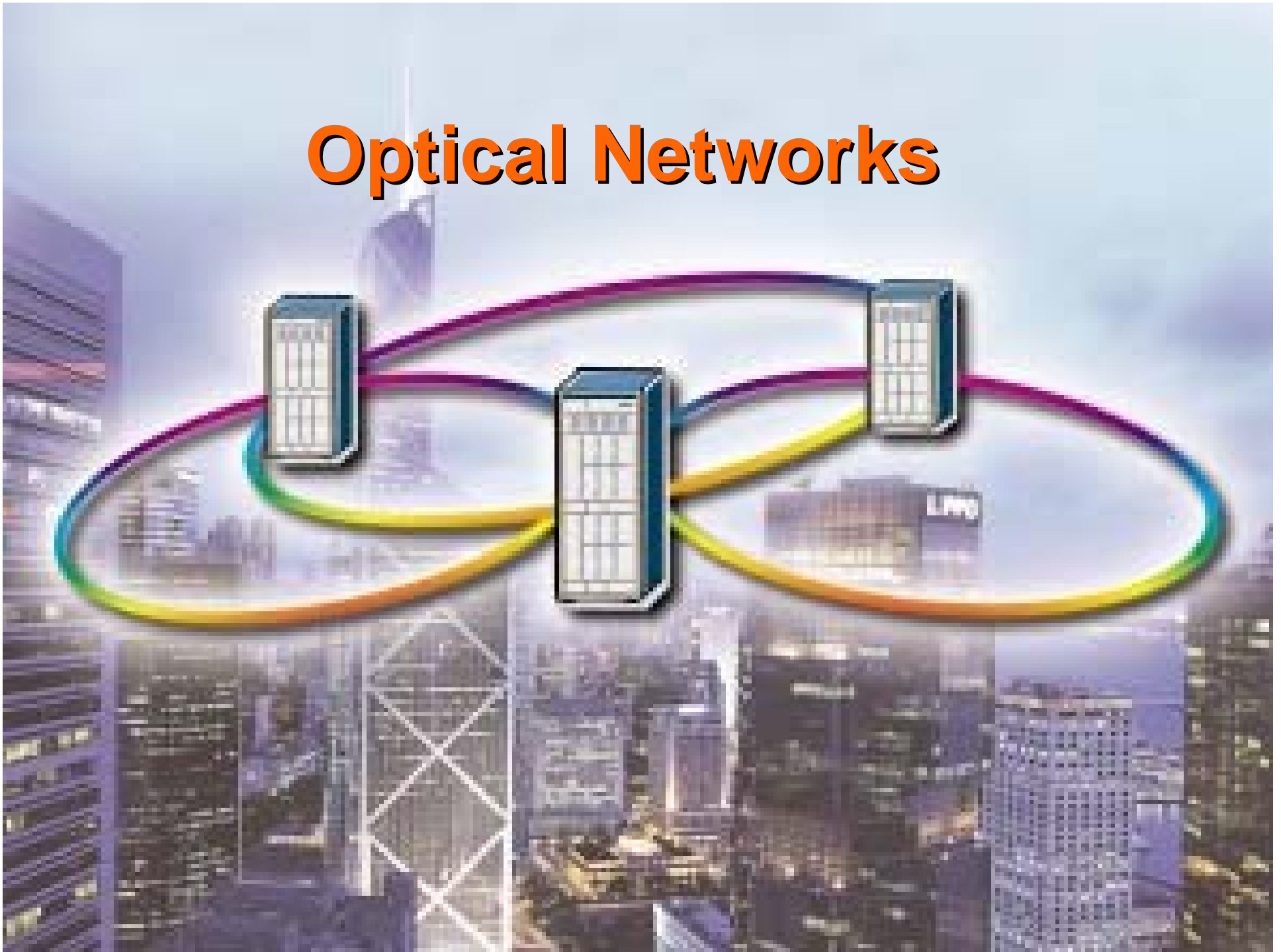
- Less signal distortion in multimode fibers
- Core Diameter: 50 ~ 62.5 microns
- Clear signal due to grading
- High attenuation due to thickness
 - Known repeater space: 10 ~ 40 miles
 - Ideal for short range communications
- Wavelength 850nm or 1300nm



~~Multimode Step-Index Fiber~~

- Sharp boundaries b/w core and cladding with clearly defined indices of refraction
- Very high attenuation: 2.5 dB/km
- Core Diameter: Large, can be 100 microns with high angle of acceptance
- High signal distortion
- Ideal for cameras and illumination
- **Unfit for communications**

Optical Networks



Optical Networks

■ Transport Network

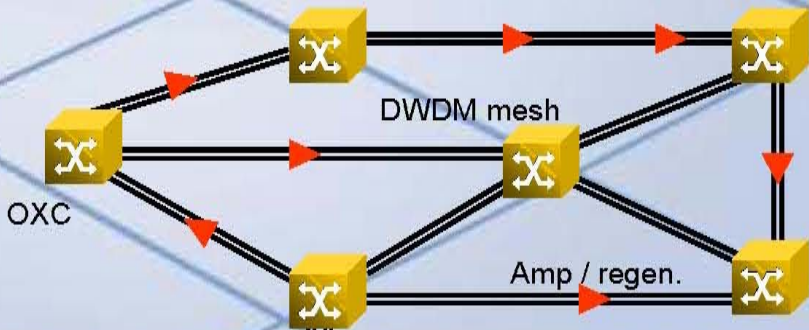
- Also: Backbone / Core Networks
- Split into two kinds of Sub-networks:
 - Ultra-/Long Haul: InterNational / Inter-City
 - Metropolitan/Metro Network: Intra-City

■ Metro Edge/Access Network

■ Last Mile Network

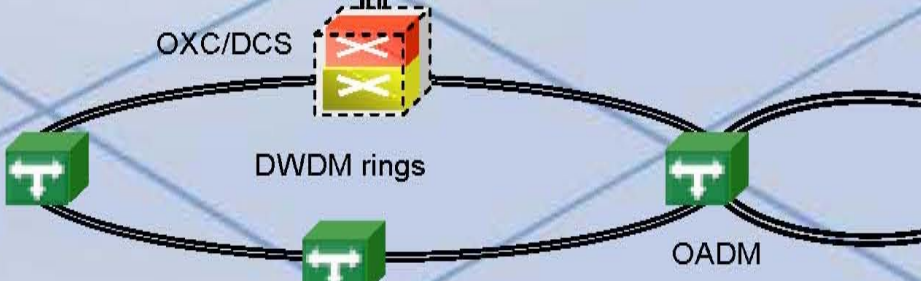
- Also: subscriber access network
local loop

Source: Dr. Nasir Ghani

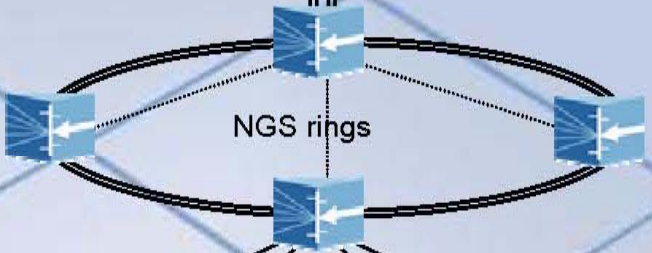
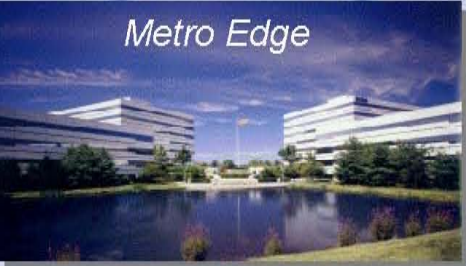


- 80-160 λ DWDM
- 2.5, 10, 40 Gb/s
- 1000+ km spans
- EDFA, Raman amp.
- FEC, disp. comp

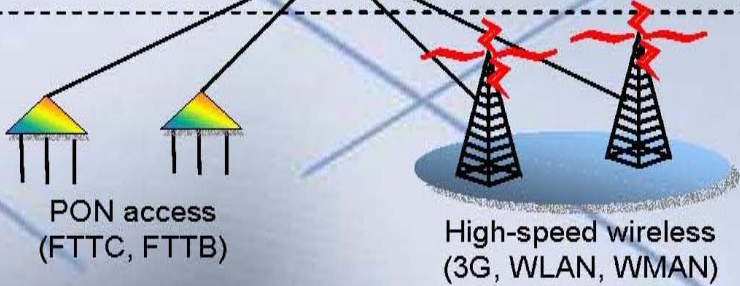
- 40-80 λ modularized
- 2.5, 10 Gb/s
- 50-500 km reach
- All-optical, EDFA



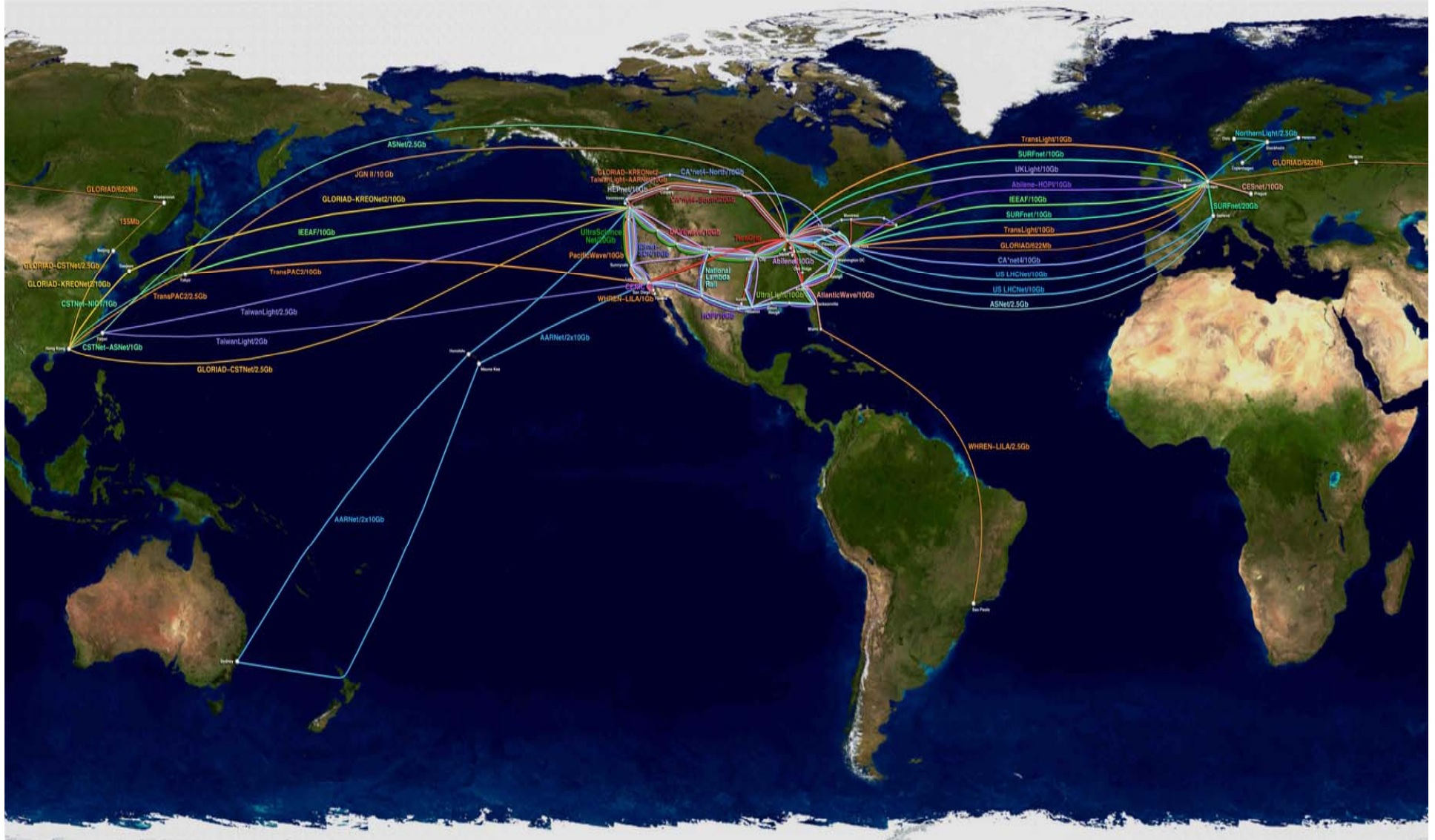
- Business loops, 10-100 km
- Service/tributary diversity
- Edge-grooming (NGS, RPR)
- Low-cost optics:
8/16 λ DWDM, CWDM



- PON (EPON, BPON)
- Multi-megabit (>20 Mbps)
- Hybrid wireless LAN/MAN



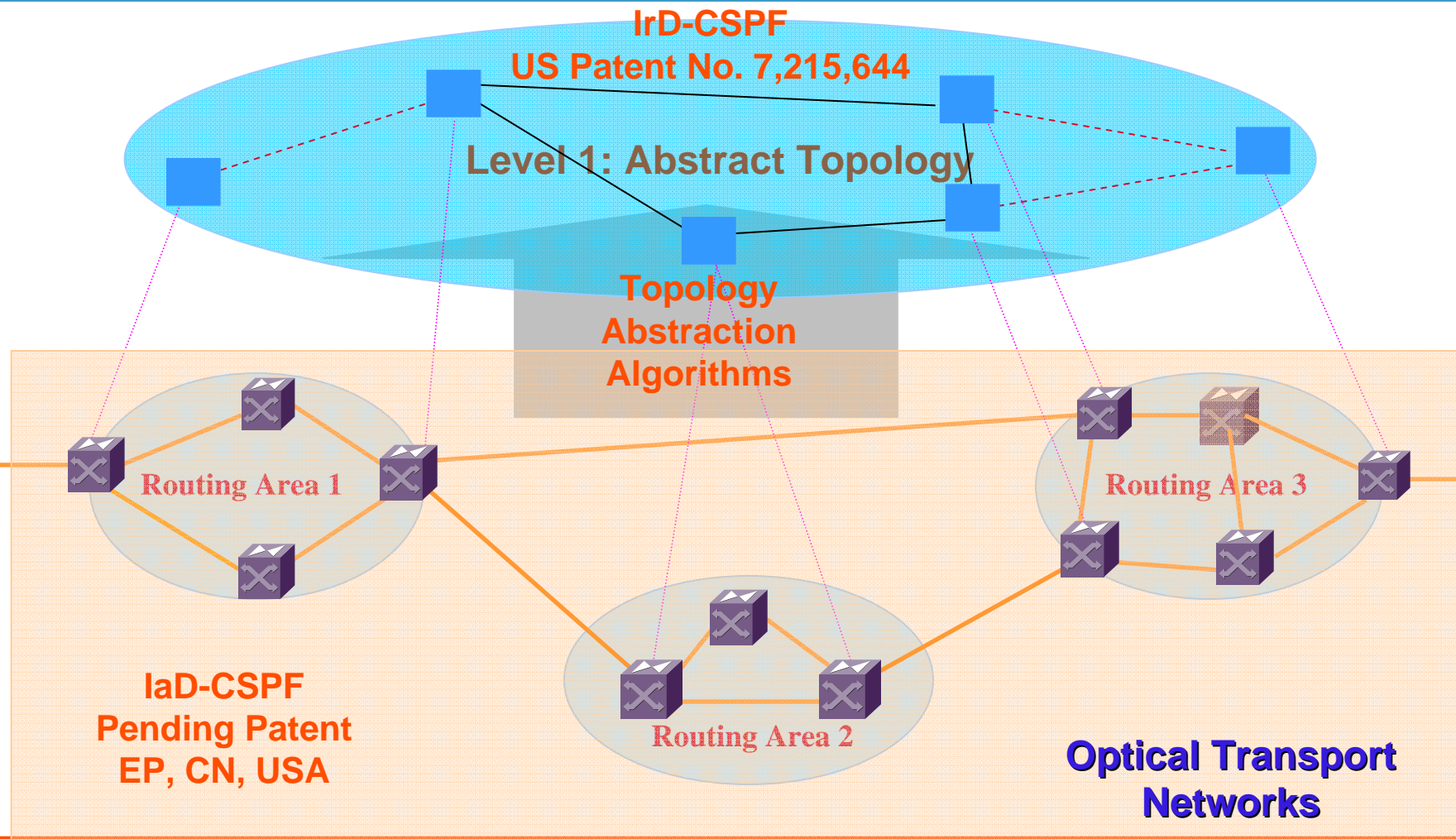
Global Lambda Integrated Facility World Map – August 2005



www.glif.is

Visualization courtesy of Bob Patterson, NCSA/University of Illinois at Urbana-Champaign.
Data compilation by Maxine Brown, University of Illinois at Chicago. Earth texture from NASA.

Hierarchical Routing in Interconnected OTN

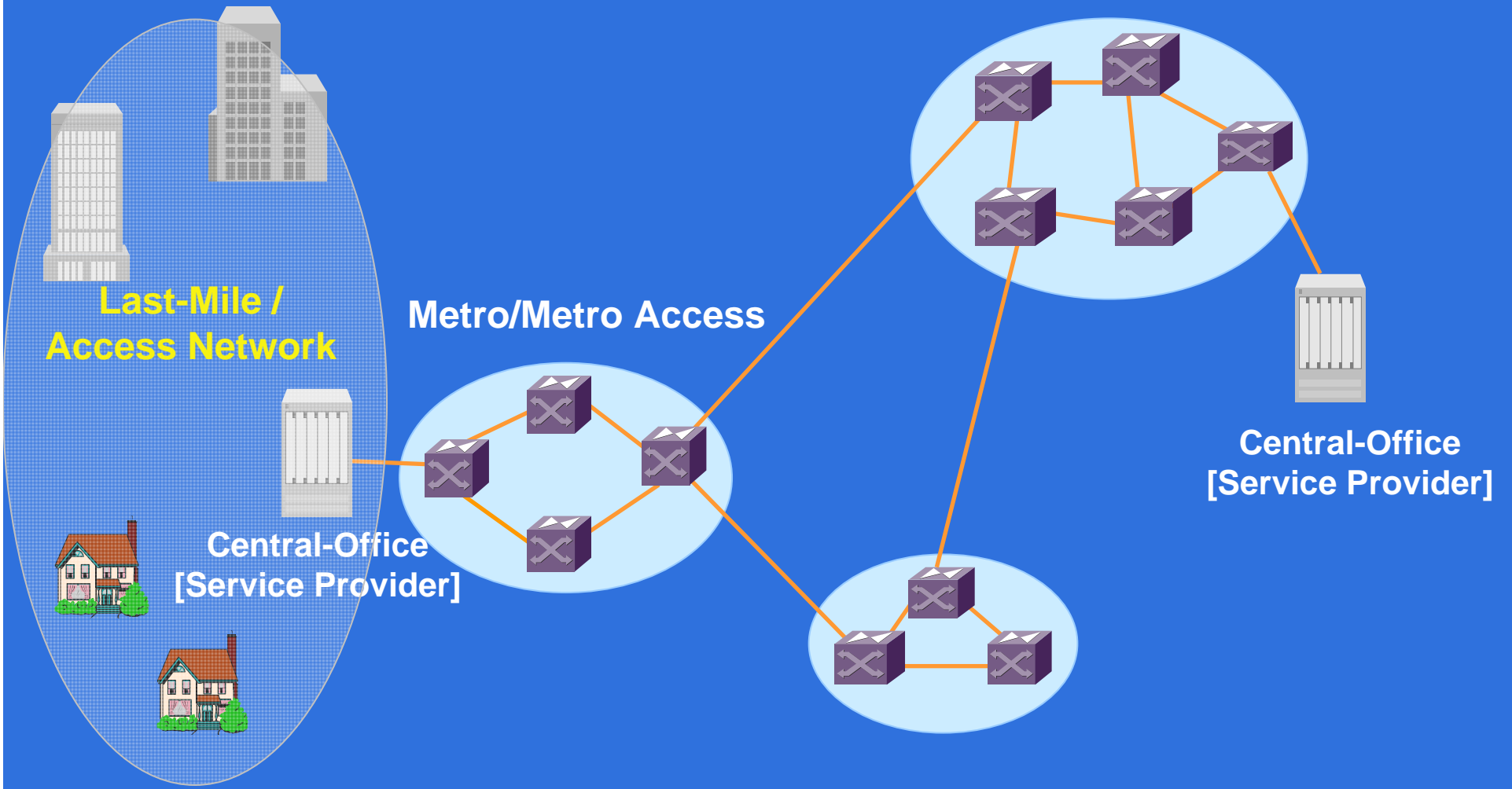




**Last-Mile Access:
Passive Optical Networks**



Last-Mile / Access Networks



Digital Home ...

■ High-Speed Internet & Apps

- Faster Downloading
- Instant MM Conferencing
- Online Collaborating
- Online Gaming



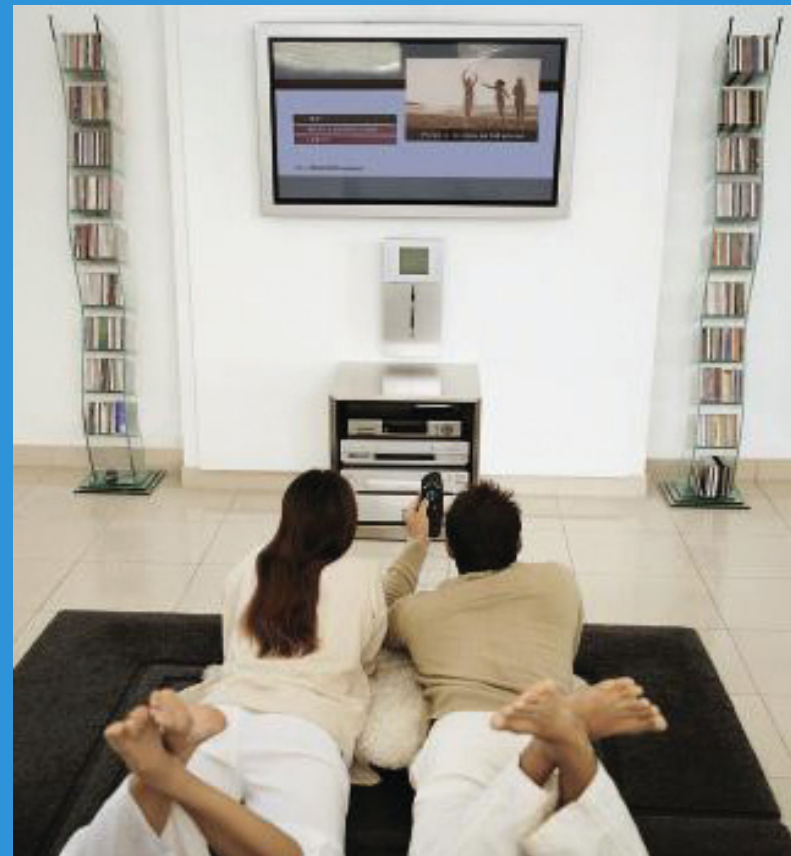
■ Cyber-Based, Real-Time Content & App Delivery

■ Triple Play

■ Video Surveillance

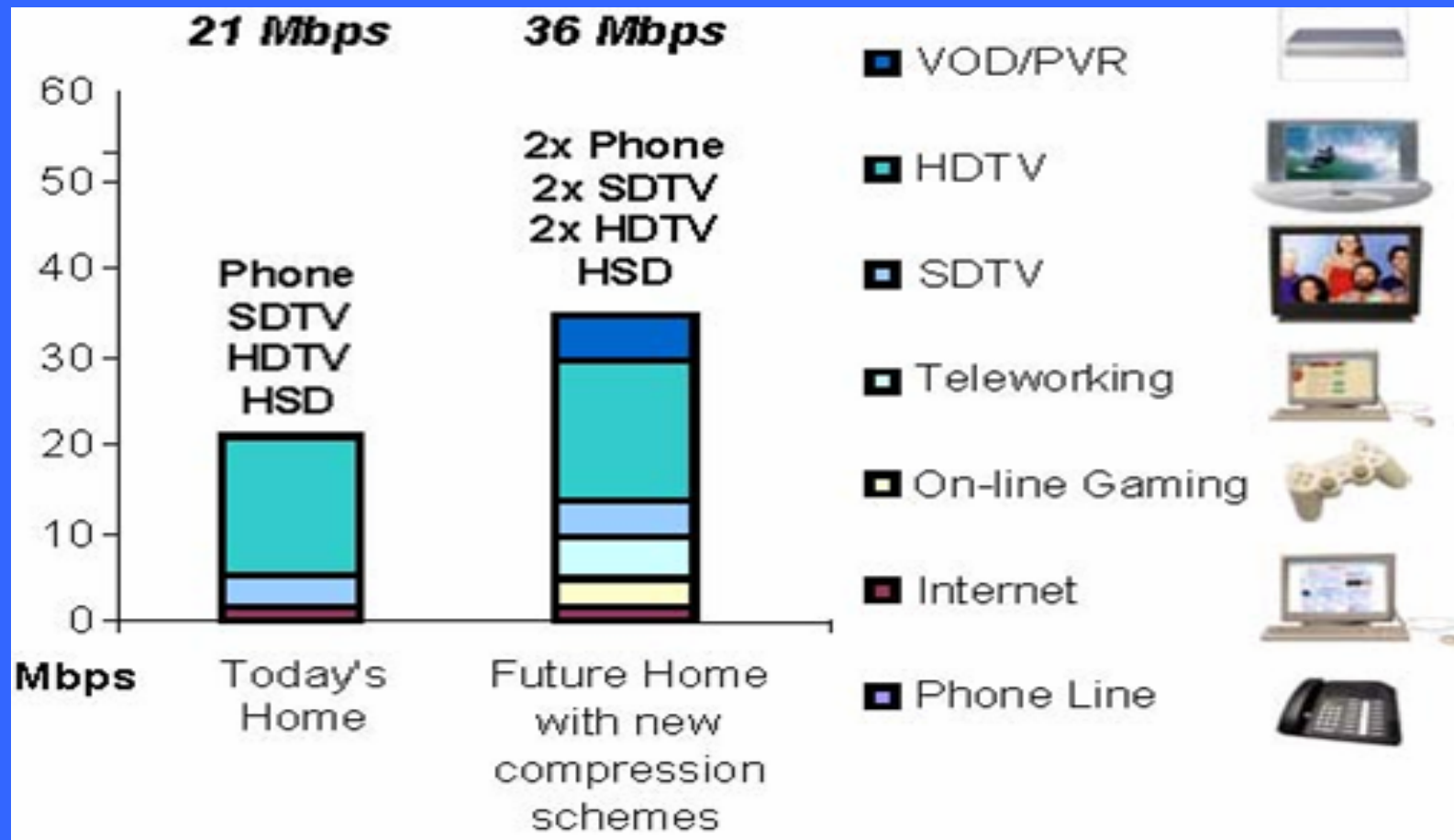
■ Bandwidth-Hungry Applications

- IPTV / HDTV / Interactive TV
- VoD (Video-on-Demand)



Source: Alcatel·Lucent 

Digital Home Forecast: Subscriber Bandwidth Demand

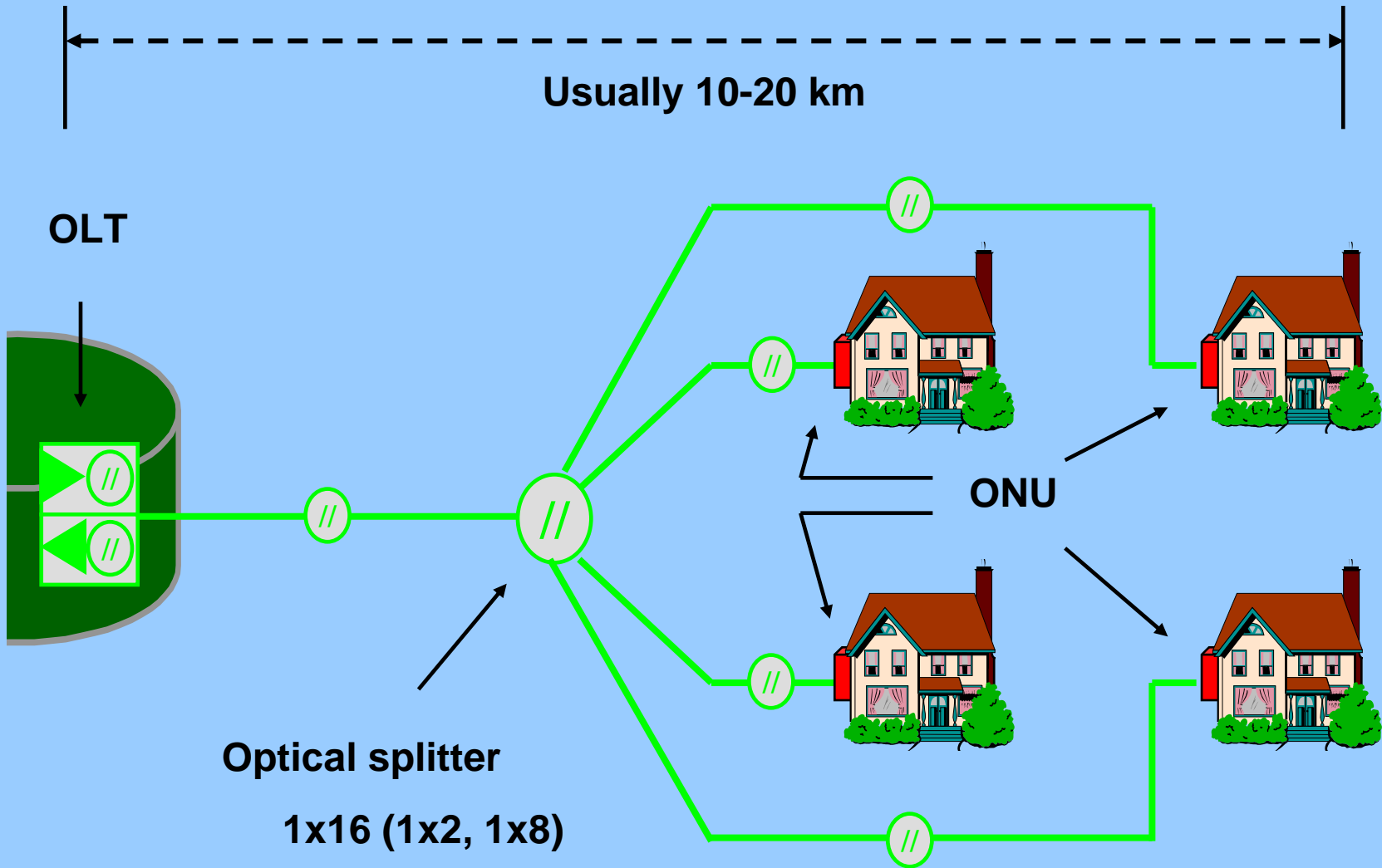


Source: Corning Cable System

PON Technologies

■ 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



Optical splitter

1x16 (1x2, 1x8)

1x32 (1x4, 1x8)

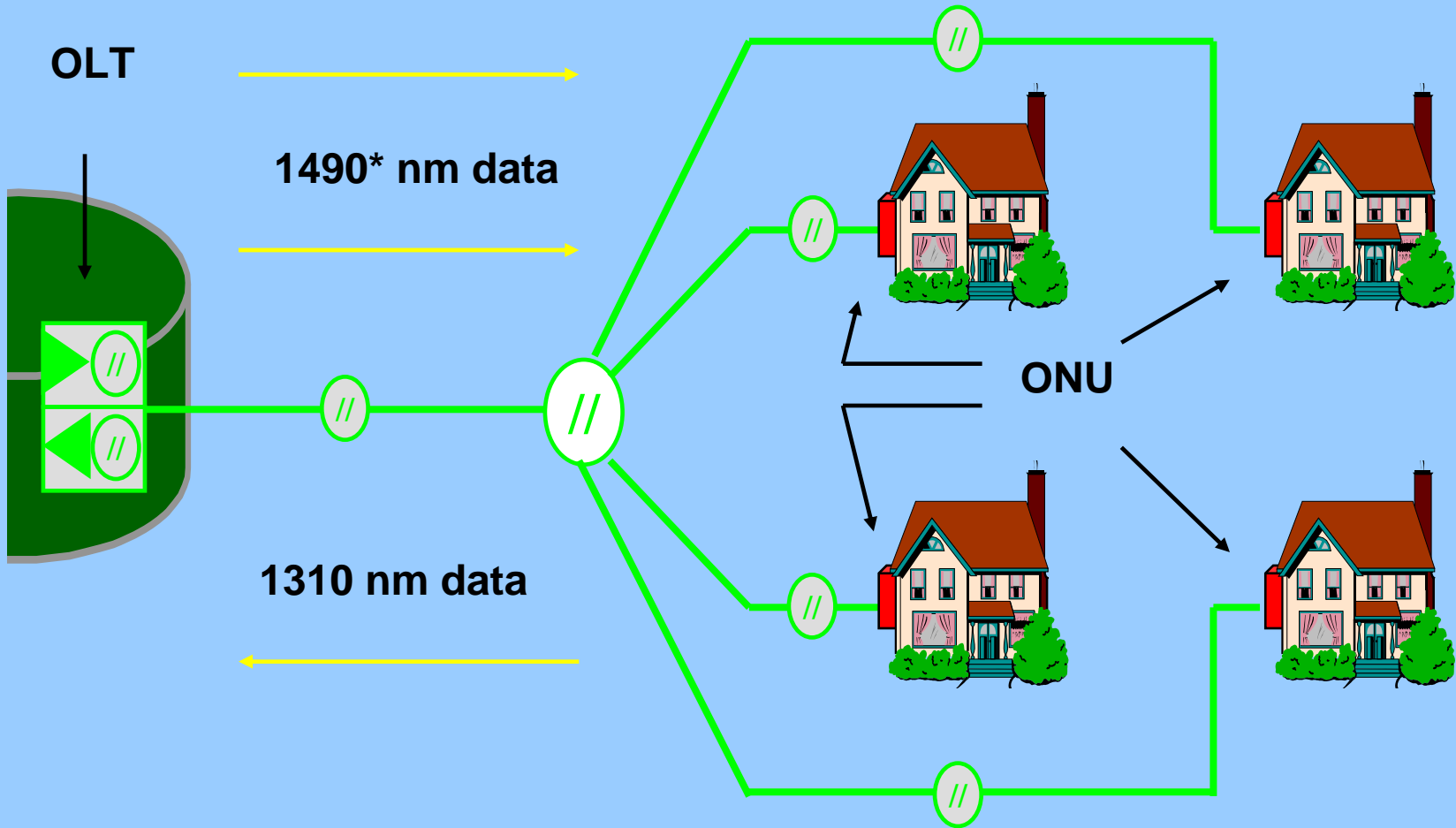
1X64 (1X16, 1X32)

OLT = Optical Line Terminal
ONU = Optical Network Unit



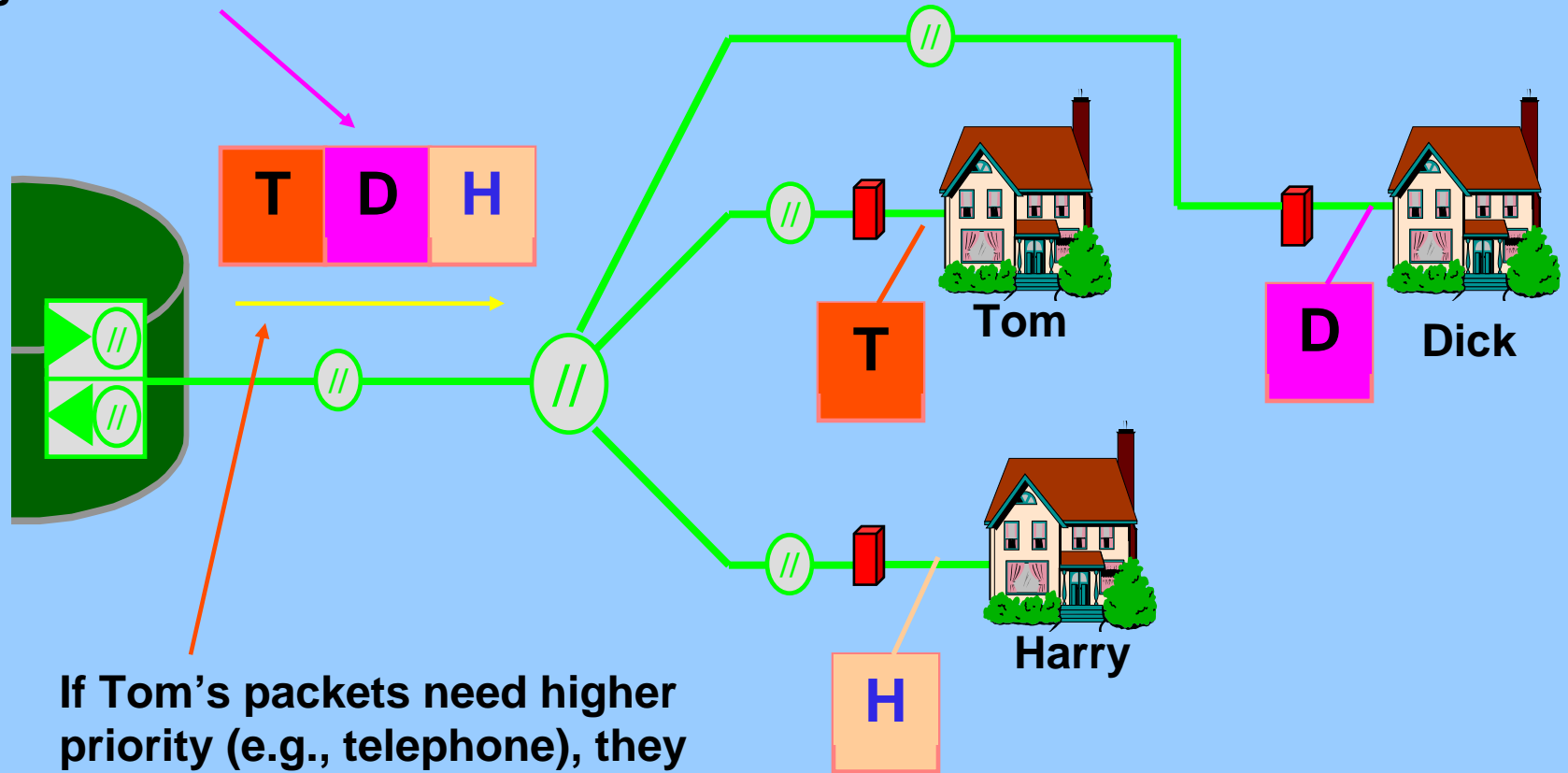
1550 nm broadcast
(if used)

OLT = Optical Line Terminal
ONU = Optical Network Unit



If Dick has paid for more bandwidth, he gets more

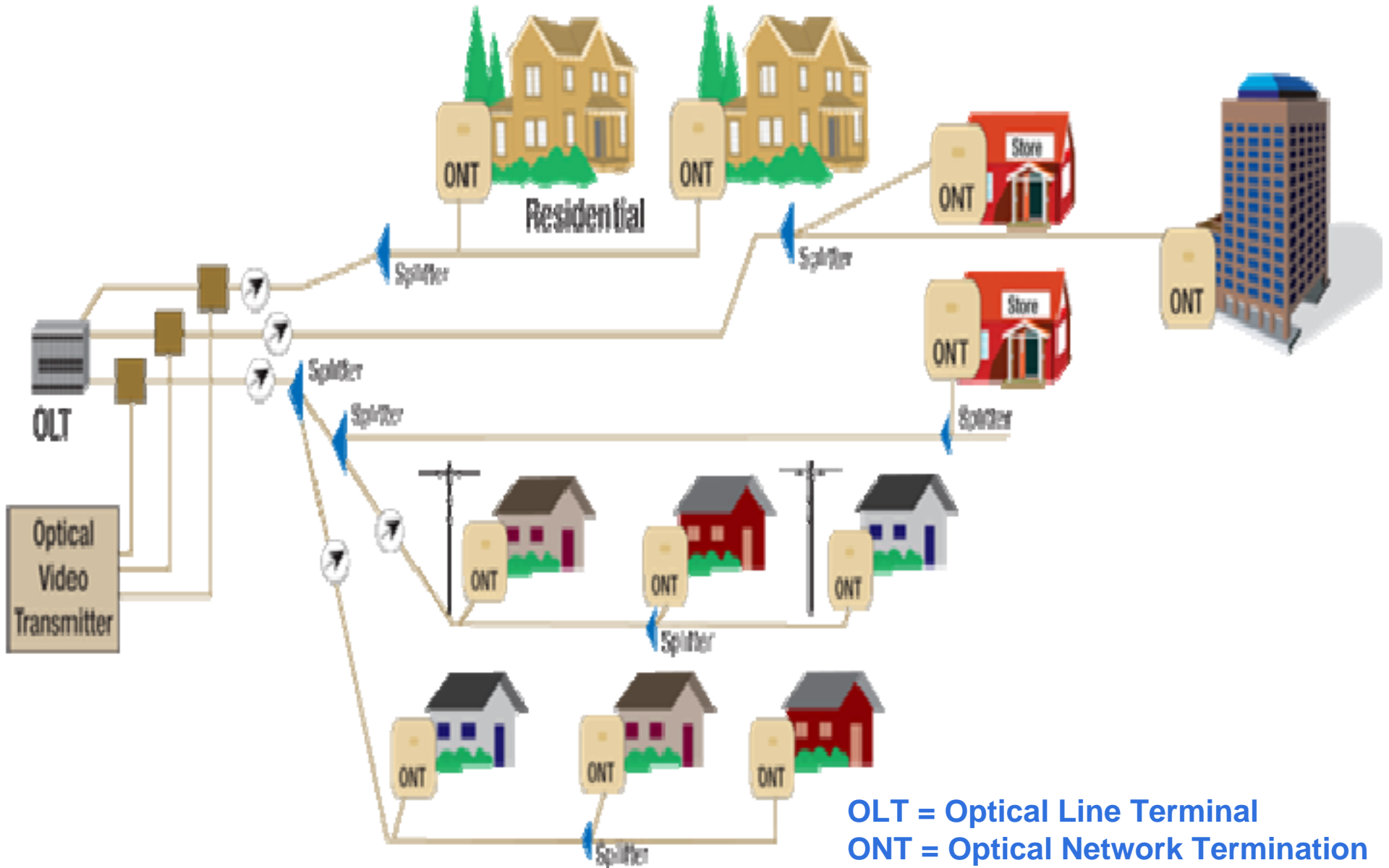
OLT = Optical Line Terminal
ONU = Optical Network Unit



If Tom's packets need higher priority (e.g., telephone), they go first

« All » Optical: FTTB & FTTH

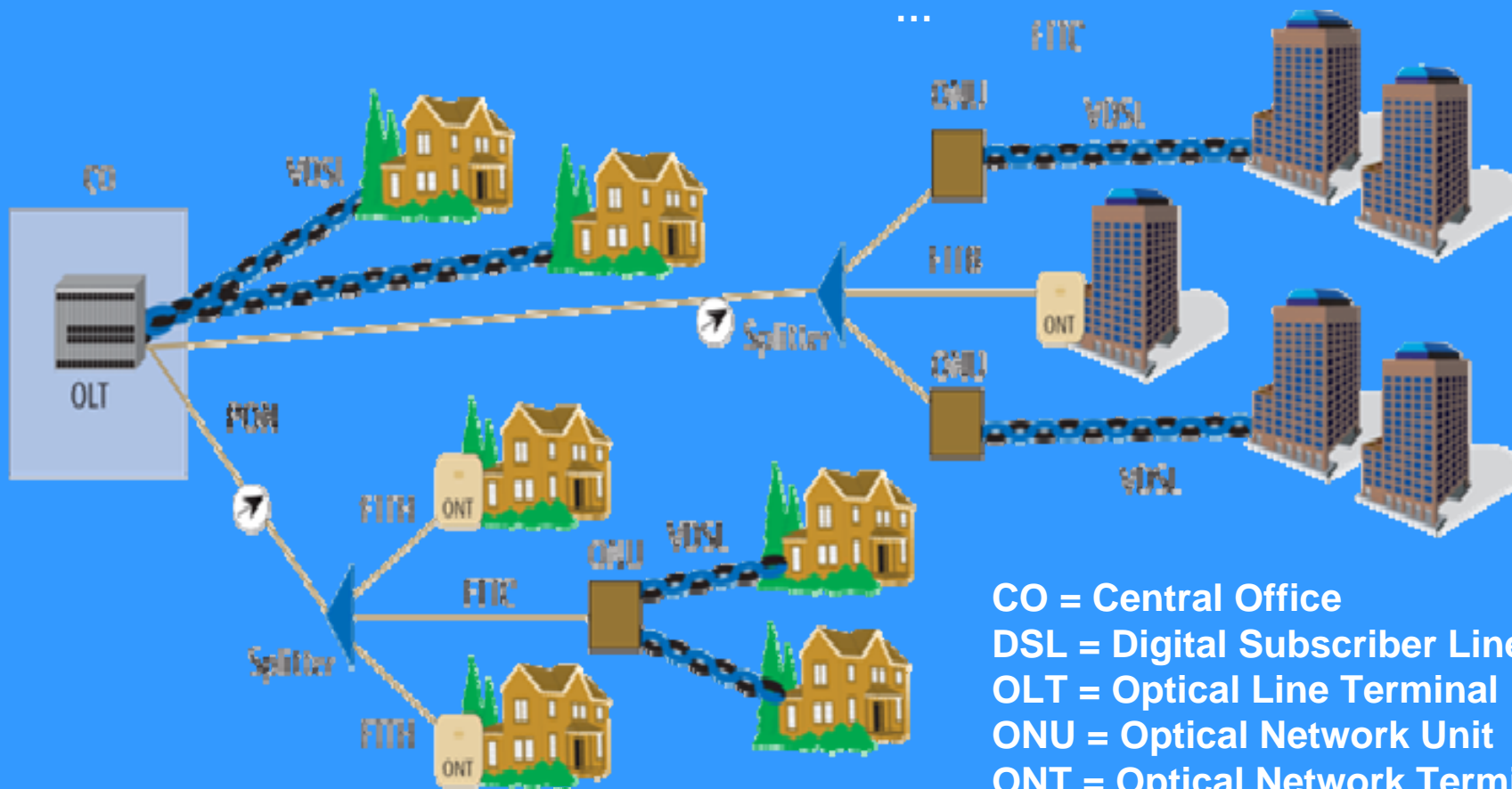
FTTB = Fiber-To-The-Building
FTTH = Fiber-To-The-Home



FTTx Variations

FTTB = Fiber-To-The-Building
FTTH = Fiber-To-The-Home
FTTC = Fiber-To-The-Curb

FTTN = Fiber-To-The-Node
FTTP = Fiber-To-The-Promise
FTTU = Fiber-To-The-Users,
...



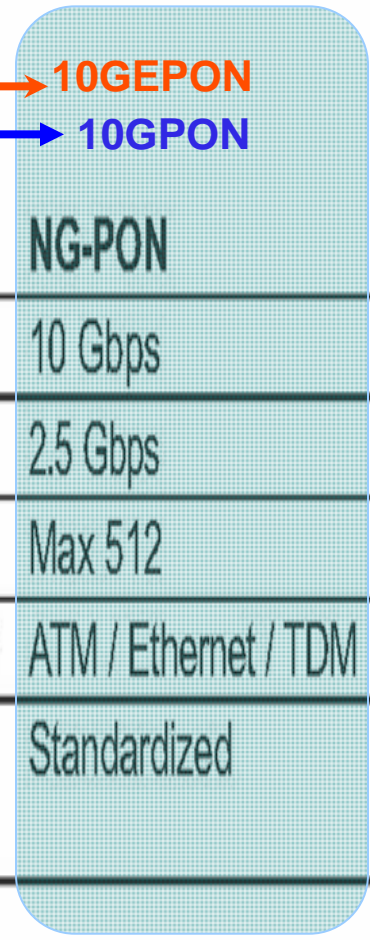
CO = Central Office
DSL = Digital Subscriber Line
OLT = Optical Line Terminal
ONU = Optical Network Unit
ONT = Optical Network Termination
PON = Passive Optical Network
VDSL = Very-high-bit-rate DSL

What's the Next?

PON technologies

	BPON	GEPON	GPON	NG-PON
DS bit rate	622 Mbps	1.2 Gbps	2.5 Gbps	10 Gbps
US bit rate	155 Mbps	1.2 Gbps	1.2 Gbps	2.5 Gbps
Splitting factor	32	Min 16	Max 64	Max 512
Payload	ATM cells	Ethernet	ATM / Ethernet / TDM	ATM / Ethernet / TDM
3 rd wavelength for cable TV overlay	Standardized	Non-standardized	Standardized	Standardized

10GEPON
10GPON



Conclusion

The main challenge is to turn the promise of fiber optics to reality to support the foreseeable bandwidth demands...

