Fiber-Optic Communication Systems An Introduction

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Why Optical Communications?

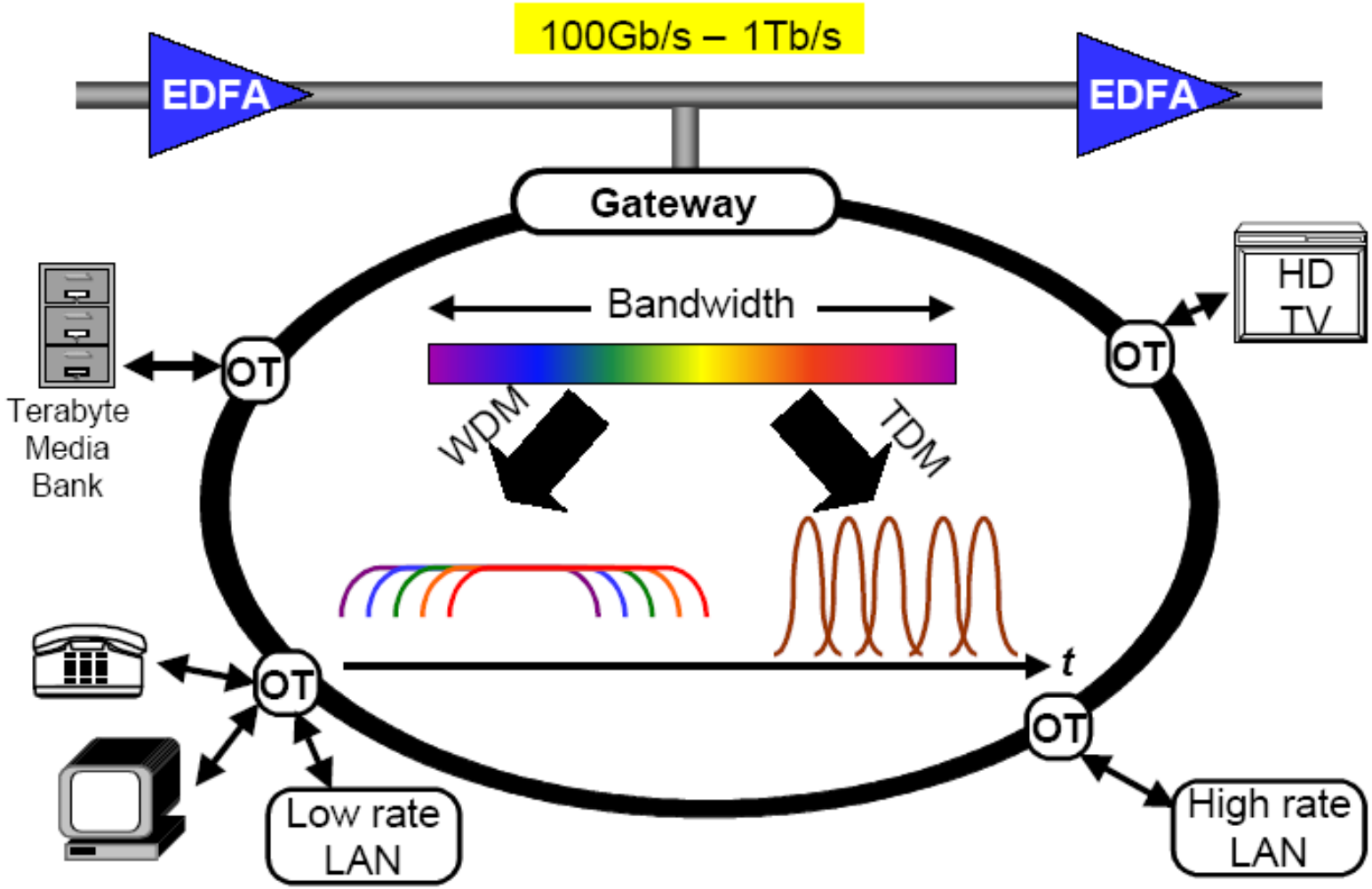
- Optical Fiber is the backbone of the modern communication networks
- The Optical Fiber Carries:
  - Almost all long distance phone calls
  - Most Internet traffic (Dial-up, DSL or Cable)
  - Most Television channels (Cable or DSL)
  - Most LAN, WAN and much more
- One fiber can carry up to 6.4 Tb/s (10^{12} b/s) or 100 million conversations simultaneously

Multimedia over Fiber

- Fiber carries various media
  - Voice (SONET/Telephony) - The largest traffic
  - Video (TV) over
    - Hybrid Fiber Coaxial (HFC) or
    - Fiber-Twisted Pair/Digital Subscriber Loops (DSL)
  - Data – Internet traffic
  - These three are called the 'Triple Play'

Information revolution wouldn't have happened without the Optical Fiber

Introduction



Why **Optical** Communications?

Lowest Attenuation: 0.2 dB/km at 1.55 μm band resulting in 100s of km links without repeaters (very useful in under-see communication)

Highest Bandwidth of any communication channel: Single Mode Fiber (SMF) offers the lowest dispersion → highest bit rate → rich content (broadband multimedia)

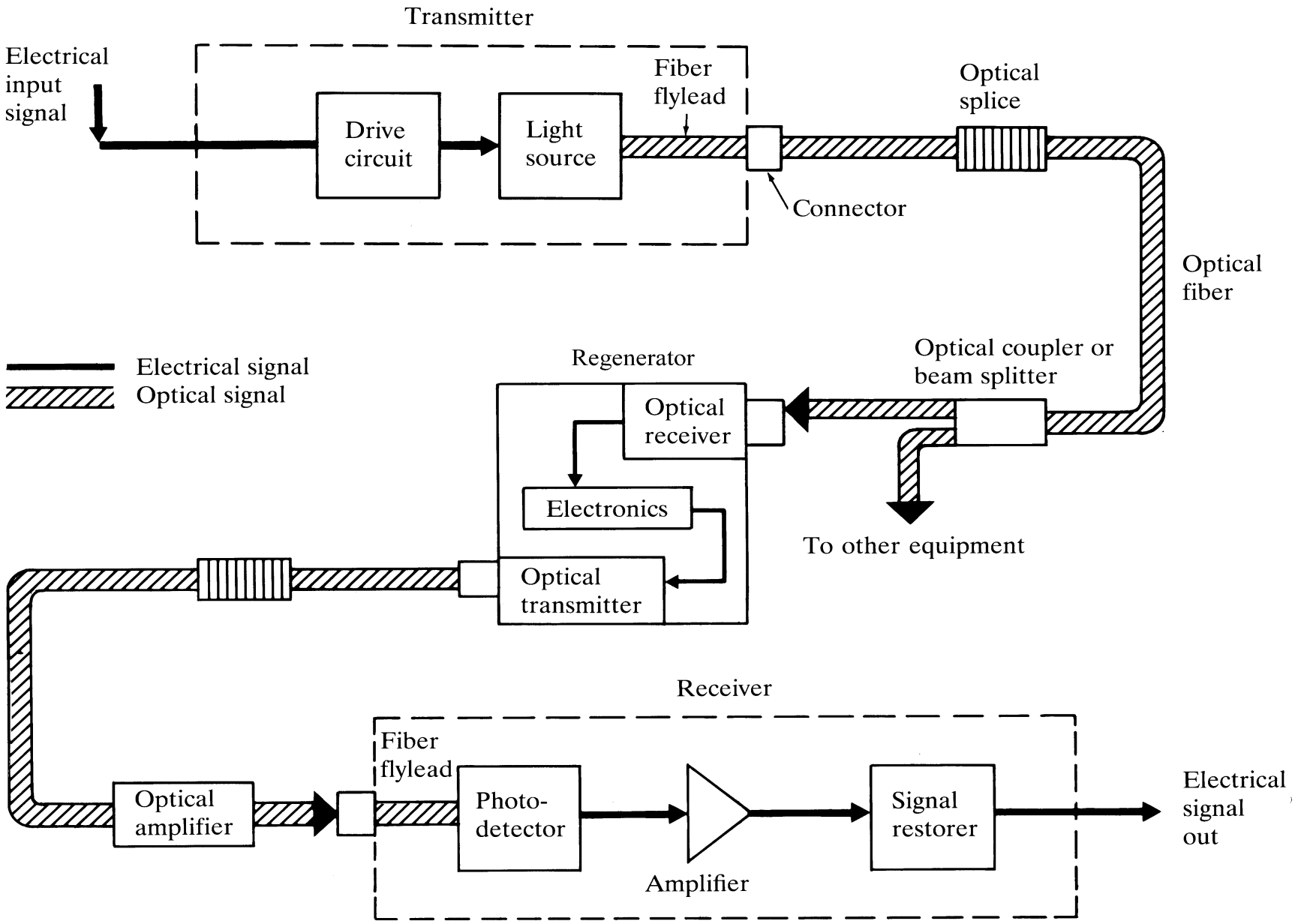
Upgradability: Via Wavelength Division Multiplexing (WDM)

Low Cost: Fiber is made of Silica (earth), much low cost than copper

Why OPTICOM for you?

- Most of you will eventually work in Information and Communications Technology (ICT) area
  - 138,000 ICT engineers hired in US in 2006 compared to 14000 in biomedical
  - (http://www.bls.gov/oco/ocos027.htm)
- Canada produces 40% of the worlds optoelectronic products (Nortel, JDS Uniphase, Quebec Photonic Cluster…)

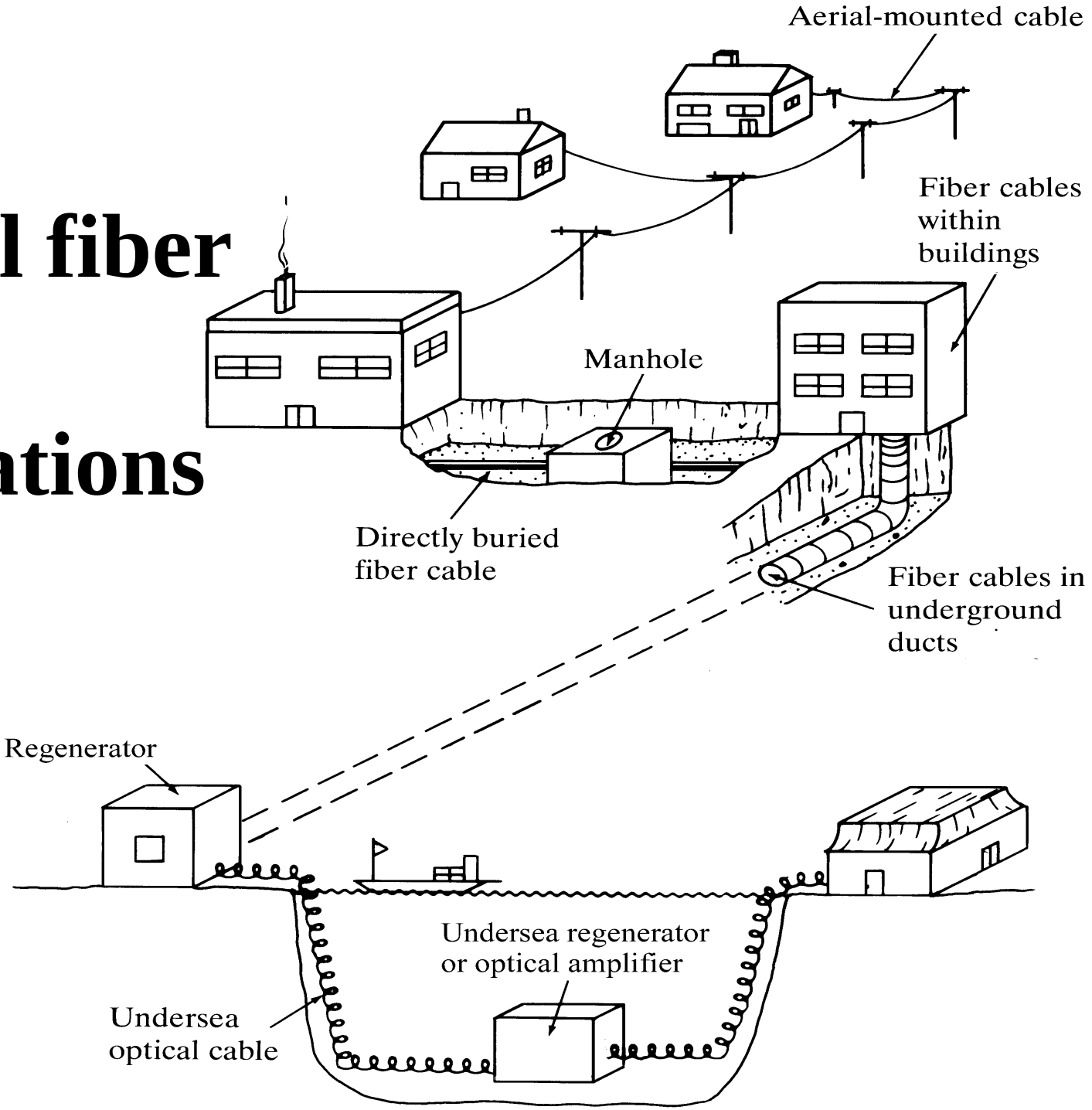
Elements of OPTICOM System



Elements of OPTICOM System

- The Fiber – that carries the light
  - Single Mode Fiber (only one EM mode exists), offers the highest bit rate, most widely used
  - Multi Mode Fiber (multiple EM modes exist), hence higher dispersion (due to multiple modes) cheaper than SMF, used in local area networks
  - Step Index Fiber – two distinct refractive indices
  - Graded Index Fiber – gradual change in refractive index

Optical fiber cable installations



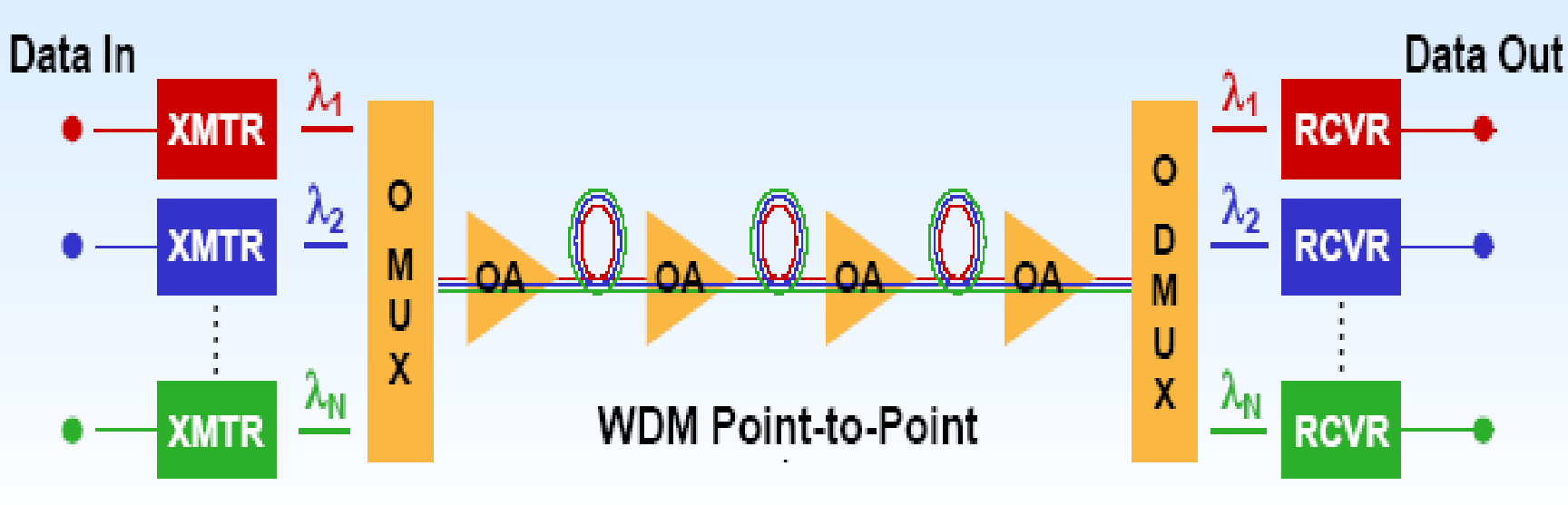
Elements of OPTICOM System

- Optical Transmitter converts the electrical information to optical format (E/O)
  - Light Emitting Diode (LED): cheap, robust and used with MMF in short range applications
    - Surface emitting and edge emitting LED
  - LASER Diode: high performance and more power, used with SMF in high speed links
    - Distributed Feedback (DFB) Laser – high performance single mode laser
    - Fabry-Perrot (FP) lasers – low performance multimode laser

Elements of OPTICOM System

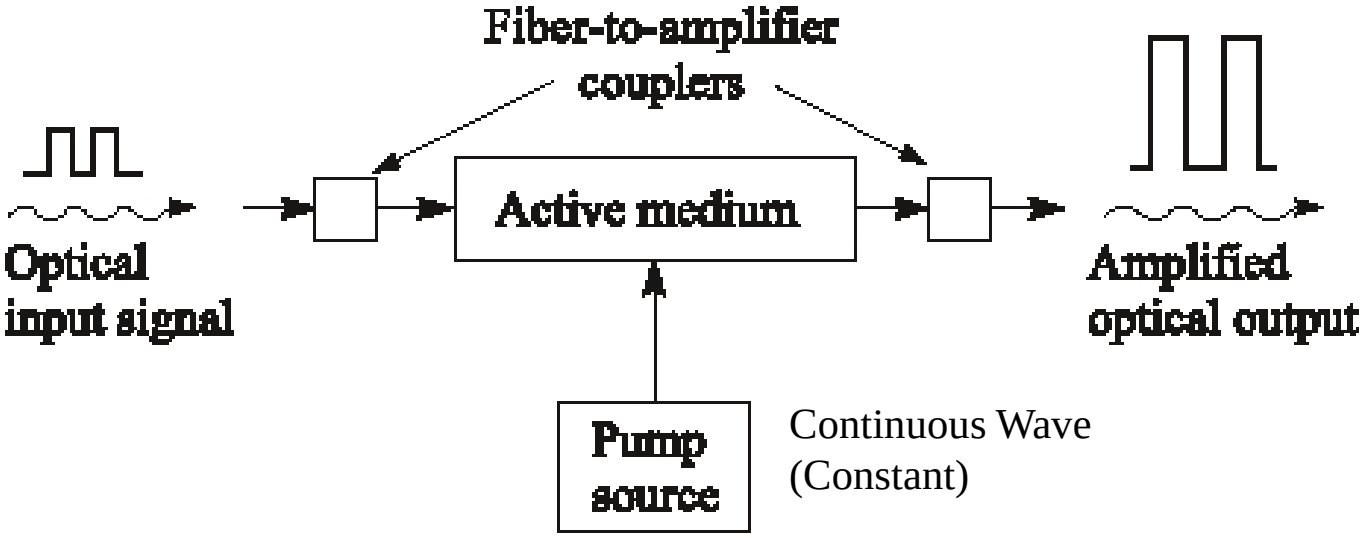
- Optical Receiver converts the optical signal into appropriate electrical format (E/O)
  - PIN Photo Diode: Low performance, no internal gain, low cost, widely used
  - Avalanche Photo Diode (APD): High performance with internal (avalanche) gain
- Repeater: receives weak light signal, cleans-up, amplifies and retransmits (O/E/O)
- Optical Amplifier: Amplifies light in fiber without O/E/O

Wavelength Division Multiplexing



- Fiber has the capability to transmit hundreds of wavelengths
- Cost effective only in long haul links in the past
- With low cost Coarse WDM (CWDM) equipment this is possible even in the access front
- Once the fiber is in place, additional wavelength can be launched at both ends by replacing transceivers

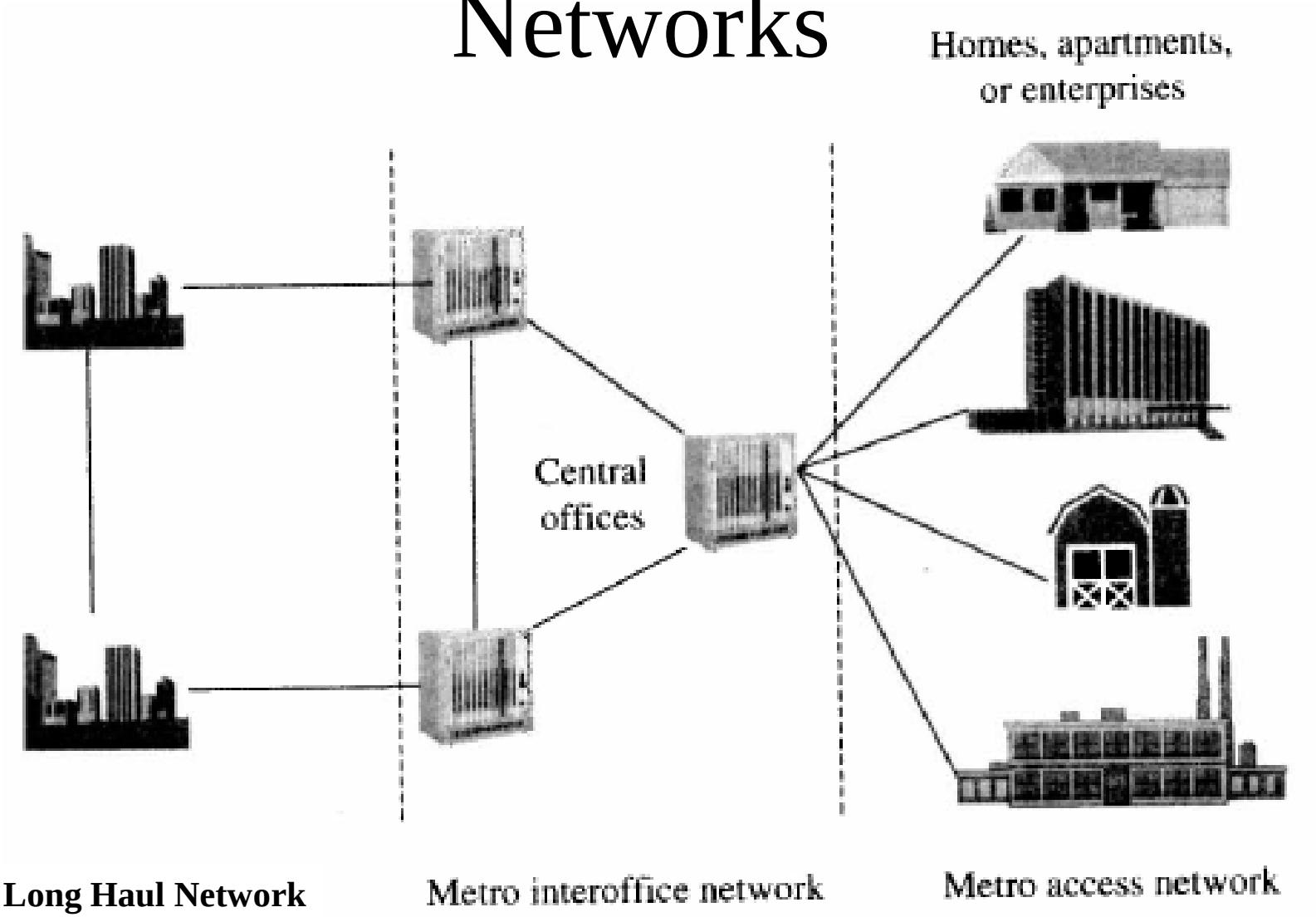
Optical Amplifier & EDFA



- An optical amplifier amplifies the light signal without converting to electrical
- Very useful is WDM systems
- Erbium Doped Fiber Amplifier (EDFA) works in 1550 nm band

Brief Intro on Telecom Networks

Basics of Communication Networks

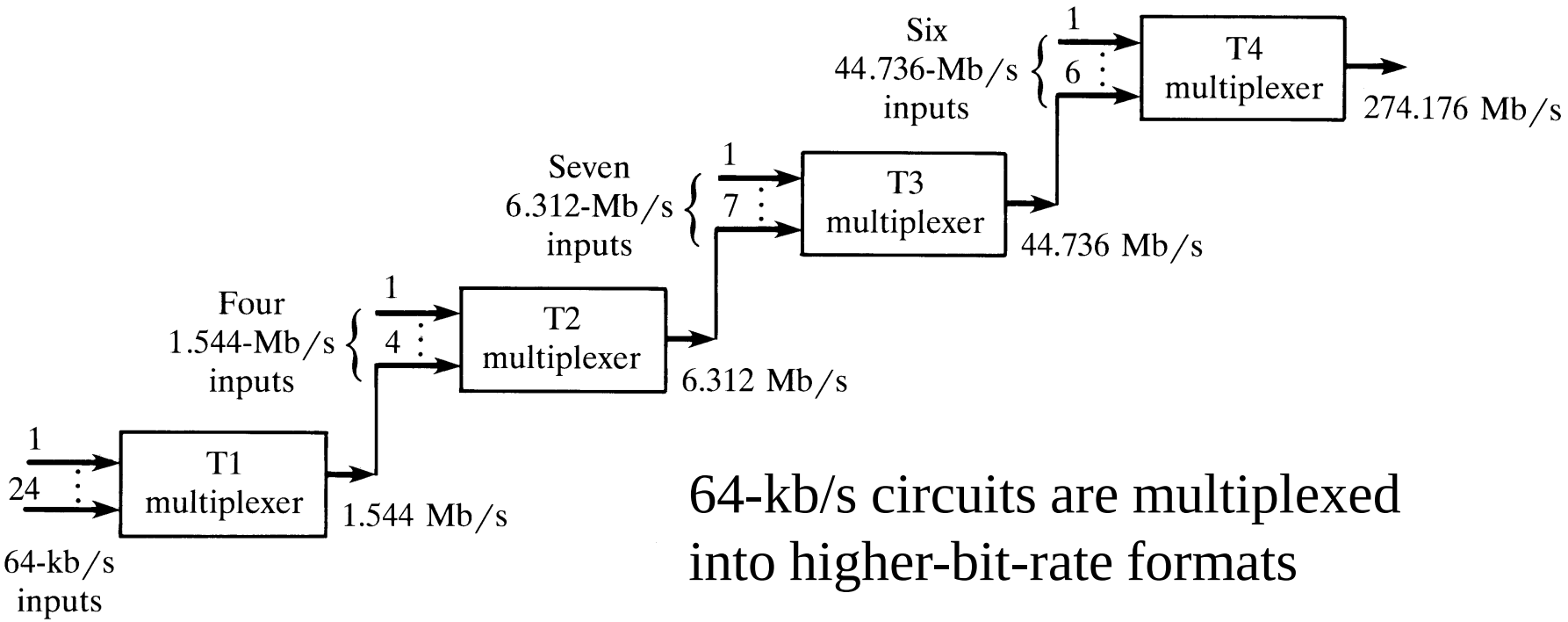


Brief History of Networks

Copper Telecom Networks:

- 4 kHz analog voice local loop (between customers and central office – access end) still in Bell Telephone lines & 56k modems
- Digital interoffice trunks using DS-1 (D*igital* S*ignal Type* 1)
- A voice signal digitized at a sampling rate of 8 kHz → 8 bits/samples is DS-0 (64 kb/s)
- Carried on a single twisted copper-wire pair
- Required repeaters every 2 km to compensate for attenuation

Digital Transmission Hierarchy (DTH)



64-kb/s circuits are multiplexed into higher-bit-rate formats

Called Telephony or T-Networks

This is Copper network

First Generation Fiber Optic Systems

Purpose:

- Eliminate repeaters in T-1 systems used in inter-office trunk lines

Technology:

- 0.8 μm GaAs semiconductor lasers
- Multimode silica fibers

Limitations:

- **Fiber attenuation**
- Intermodal dispersion

Deployed since 1974

Second Generation Systems

Opportunity:

- Development of low-attenuation fiber (removal of H2O and other impurities)
- Eliminate repeaters in long-distance lines

Technology:

- 1.3 μm multi-mode semiconductor lasers
- Single-mode, low-attenuation silica fibers
- DS-3 signal: 28 multiplexed DS-1 signals carried at 44.736 Mbits/s

Limitation:

- **Fiber attenuation** (repeater spacing $\approx$ 6 km)

Deployed since 1978

Third Generation Systems

Opportunity:

- Deregulation of long-distance market

Technology:

- 1.55 μm single-mode semiconductor lasers
- Single-mode, low-attenuation silica fibers
- OC-48 signal: 810 multiplexed 64-kb/s voice channels carried at 2.488 Gbits/s

Limitations:

- **Fiber attenuation** (repeater spacing $\approx$ 40 km)
- **Fiber dispersion**

Deployed since 1982

Fourth Generation Systems

Opportunity:

- Development of erbium-doped fiber amplifiers (EDFA)

Technology (deployment began in 1994):

- 1.55 μm single-mode, narrow-band semiconductor lasers
- Single-mode, low-attenuation, dispersion-shifted silica fibers
- Wavelength-division multiplexing of 2.5 Gb/s or 10 Gb/s signals

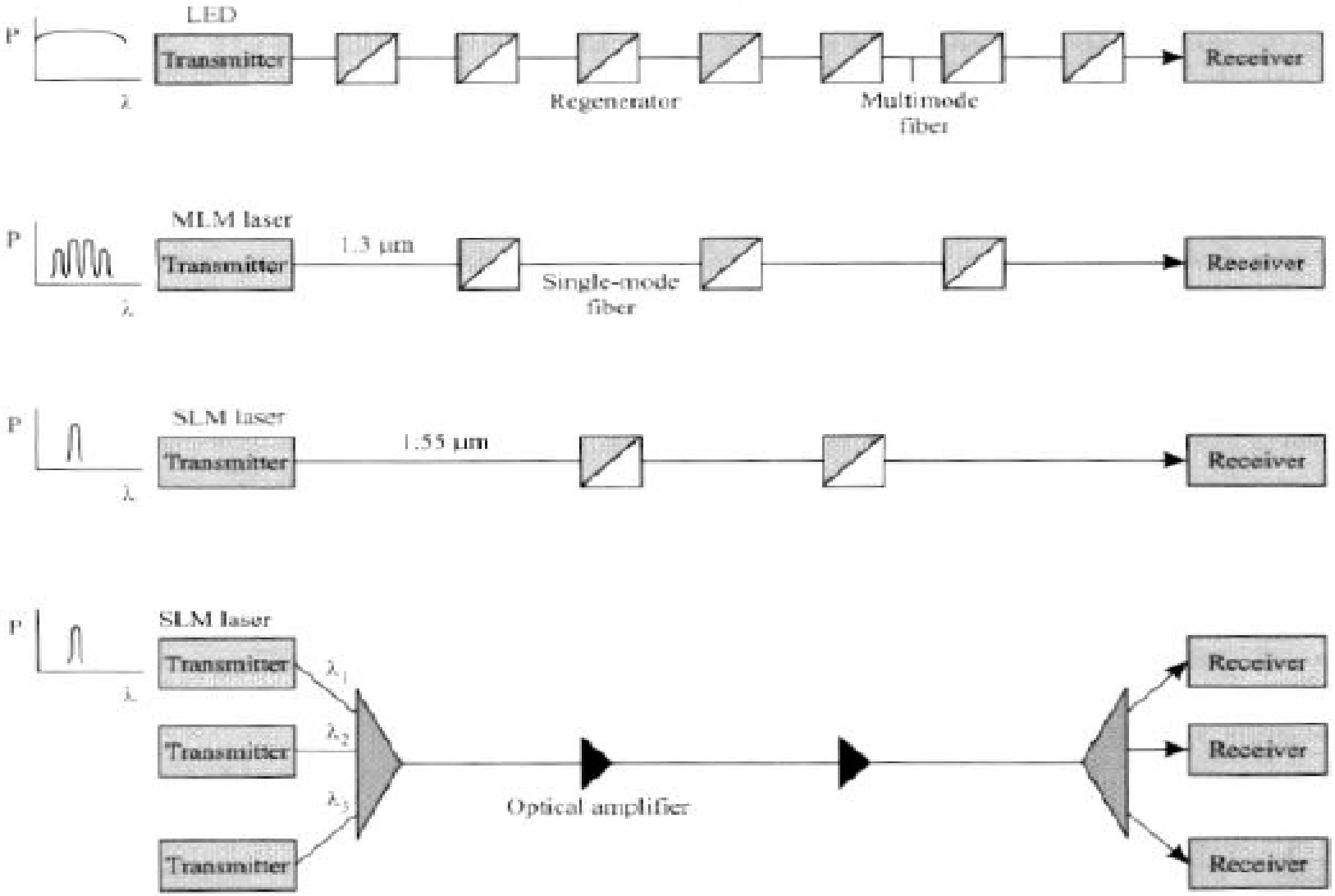
Nonlinear effects limit the following system parameters:

- Signal launch power
- Propagation distance without regeneration/re-clocking
- WDM channel separation
- Maximum number of WDM channels per fiber

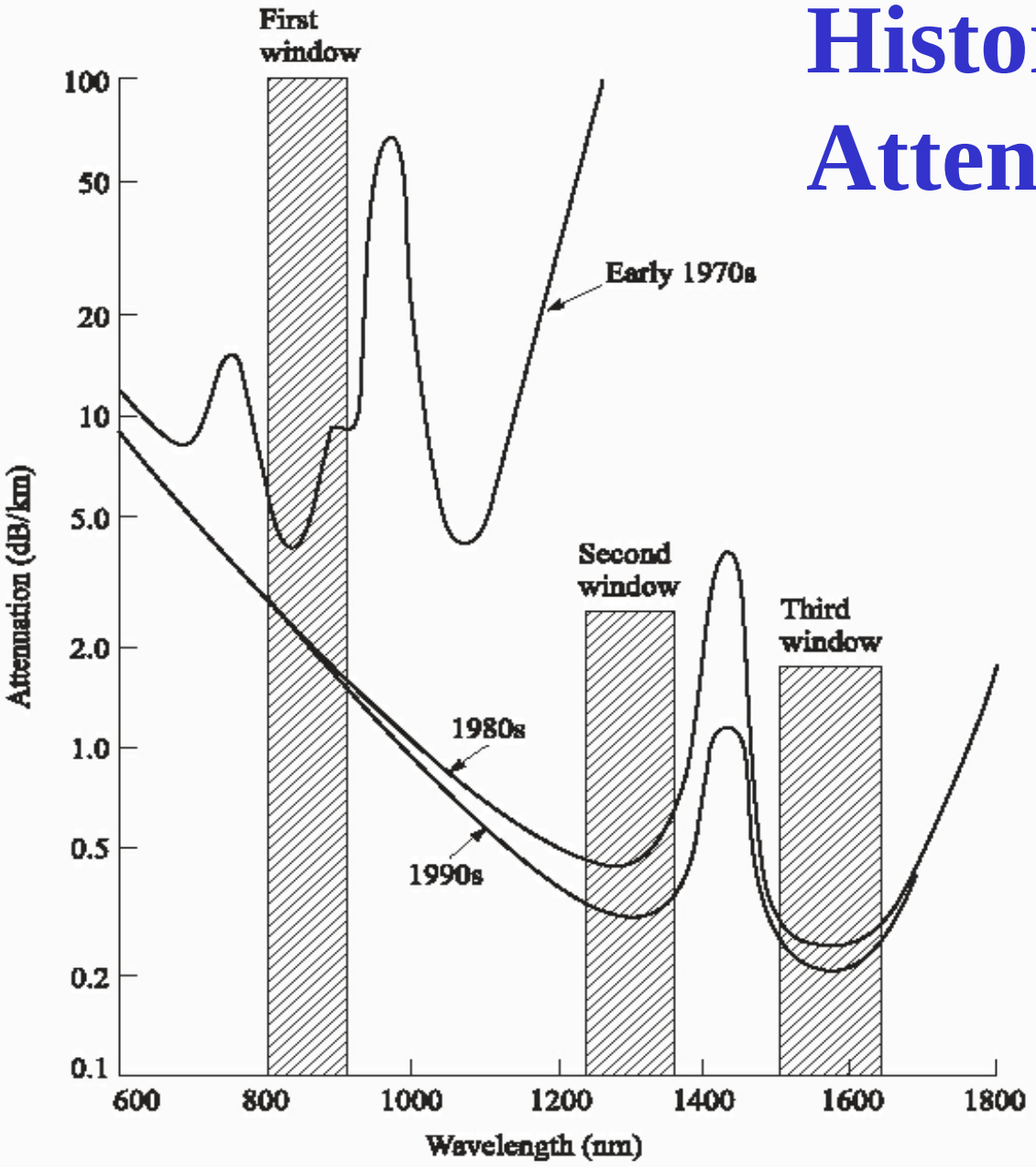
Polarization-mode dispersion limits the following parameters:

- Propagation distance without regeneration/re-clocking

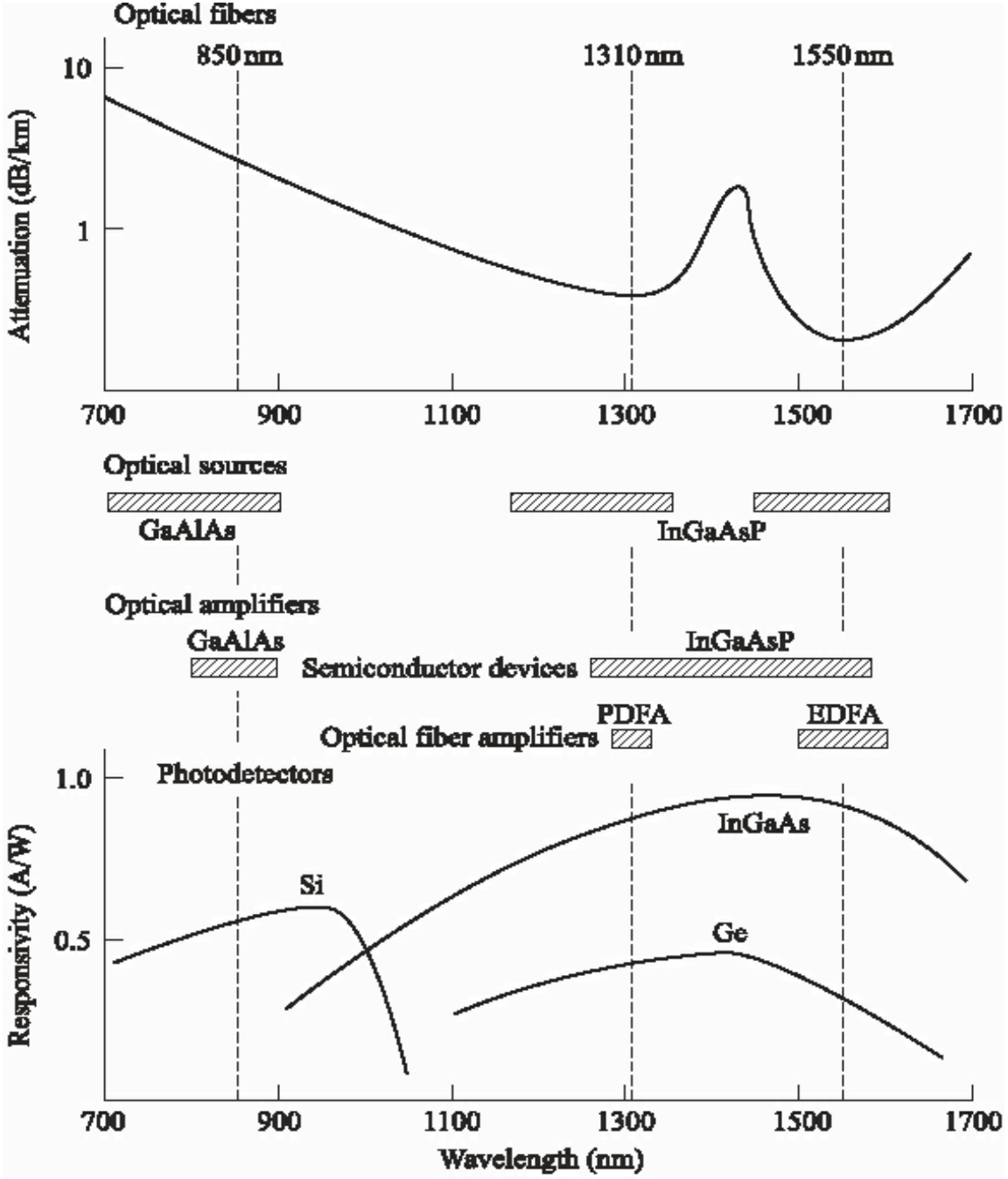
Evolution of Optical Networks



History of Attenuation



Three Windows based on Wavelength



Fiber Network Topologies

	Who Uses it?	Span (km)	Bit Rate (bps)	Multi-plexing	Fiber	Laser	Receiver
Core / LongHaul	Phone Company, Gov't(s)	~10^3	~10^{11} (100's of Gbps)	DWDM/ TDM	SMF/ DCF	EML/ DFB	APD
Metro / Regional	Phone Company, Big Business	~10^2	~10^{10} (10's of Gbps)	DWDM/CWDM/TDM	SMF/ LWPF	DFB	APD/ PIN
Access / LocalLoop	Small Business, Consumer	~10	~10^9 (56kbps-1Gbps)	TDM/ SCM/	SMF/ MMF	DFB/ FP	PIN

Core - Combination of switching centers and transmission systems connecting switching centers.

Access- that part of the network which connects subscribers to their immediate service providers

LWPF : Low-Water-Peak Fiber, DCF : Dispersion Compensating Fiber, EML : Externally modulated (DFB) laser

Synchronous Optical Networks

- SONET is the TDM optical network standard for North America (called SDH in the rest of the world)
- We focus on the physical layer
- STS-1, Synchronous Transport Signal consists of 810 bytes over 125 us
- 27 bytes carry overhead information
- Remaining 783 bytes: Synchronous Payload Envelope

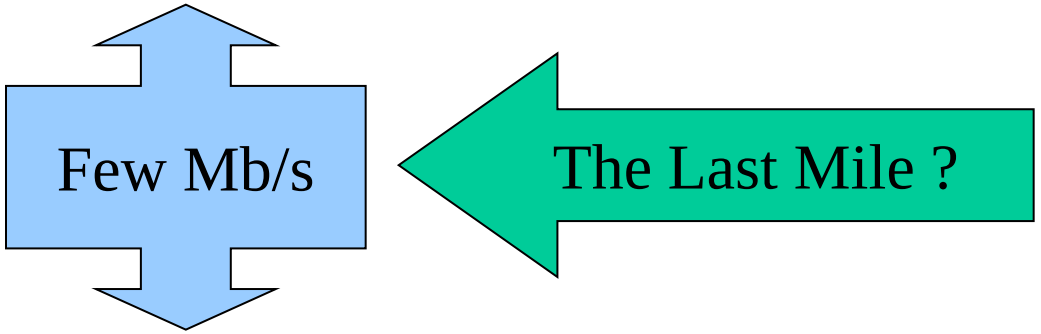
SONET/SDH Bit Rates

SONET	Bit Rate (Mbps)	SDH
OC-1	51.84	-
OC-3	155.52	STM-1
OC-12	622.08	STM-4
OC-24	1244.16	STM-8
OC-48	2488.32	STM-16
OC-96	4976.64	STM-32
OC-192	9953.28	STM-64

Last Mile Bottle Neck and Access Networks

Infinite Bandwidth Backbone

Optical Fiber Networks → A few (Gb/s)



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Virtually infinite demand end user

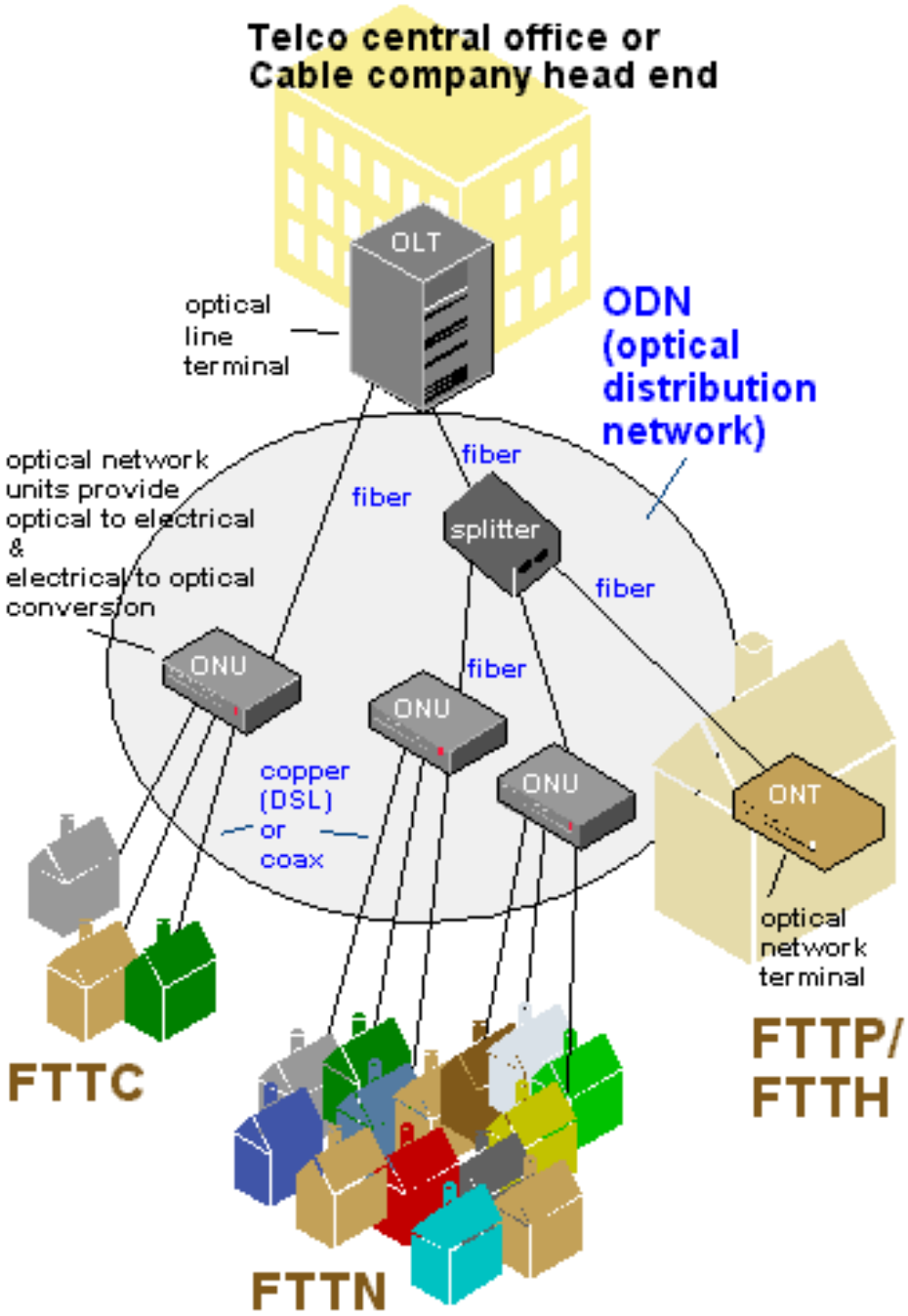
Fiber in the Access End

Passive Optical Networks (PON) – No active elements or O/E conversion

Fibre-Coaxial (analog) or DSL (digital) fibre-copper systems

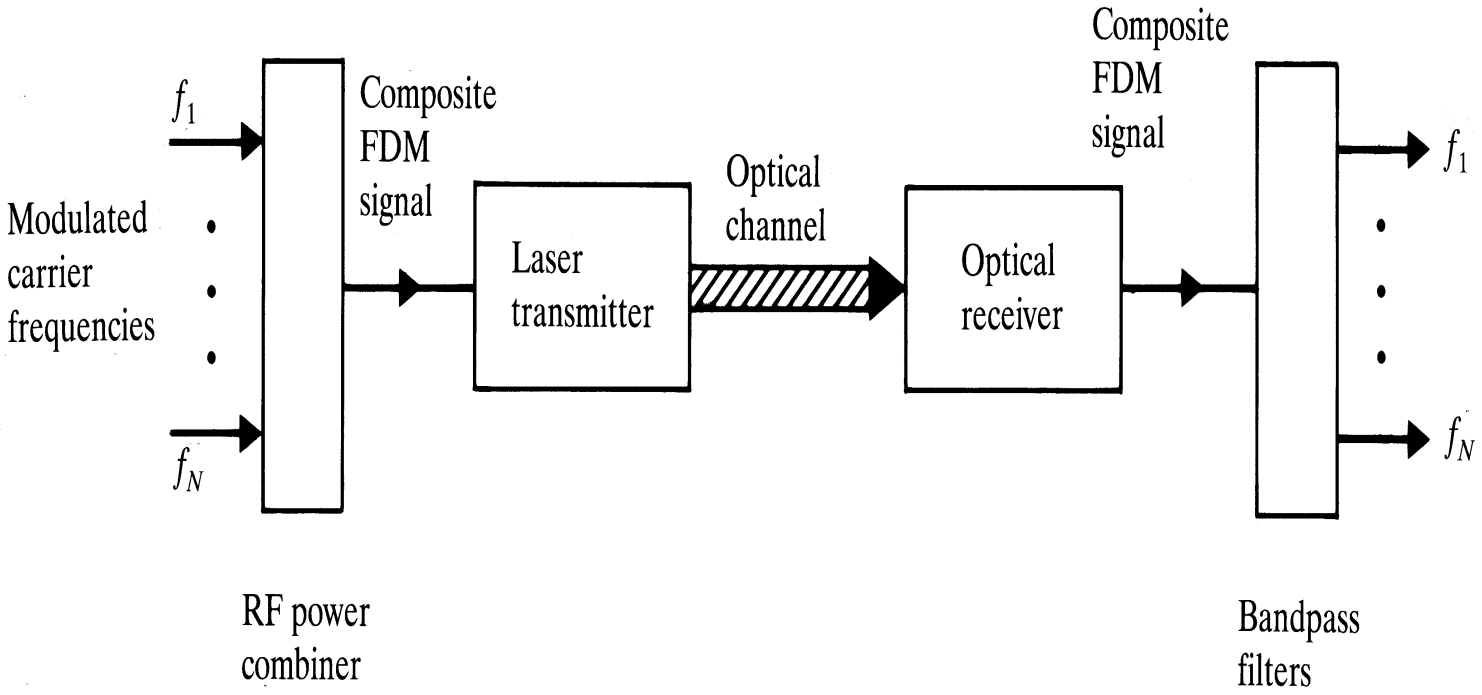
Radio over fibre (Fibre-Wireless) Systems

Currently Drives the Market

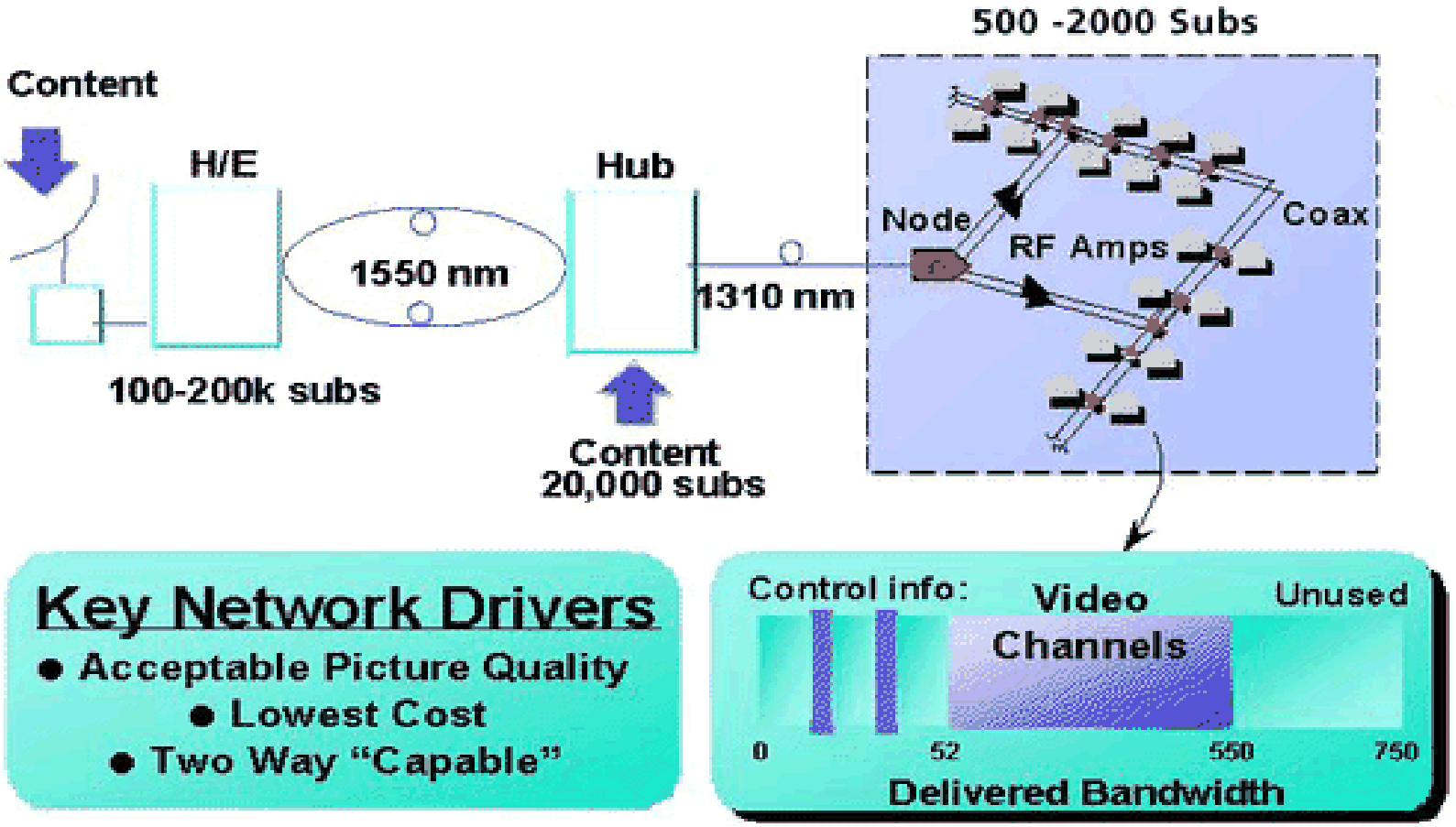


Analog Systems:
Sub Carrier Multiplexing (SCM)

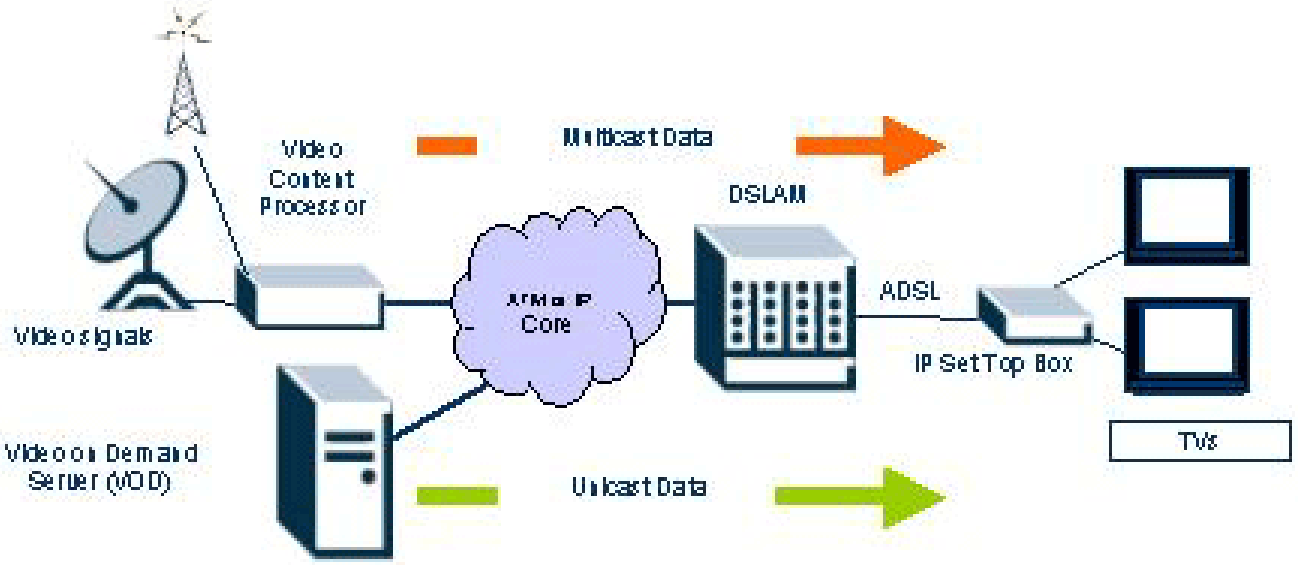
- Several RF carriers are frequency division multiplexed over single fiber
- Each RF Carrier is an independent communication channel
  - Ex: CATV System



Hybrid/Fiber Coax (HFC) TV Networks



Digital Subscriber Loop



- DSL consists of fiber-twisted pair
- This is a digital fiber-copper link
- Multimedia (video and data) supported over voice
- At least 3.7 Mb/s streaming is needed for quality video
- Bit rate heavily depend on the length of the twisted pair link
- New techniques like very high rate DSL (VDSL) are tried
- Some new condominiums in Toronto have access to video over DSL

PON Flavours

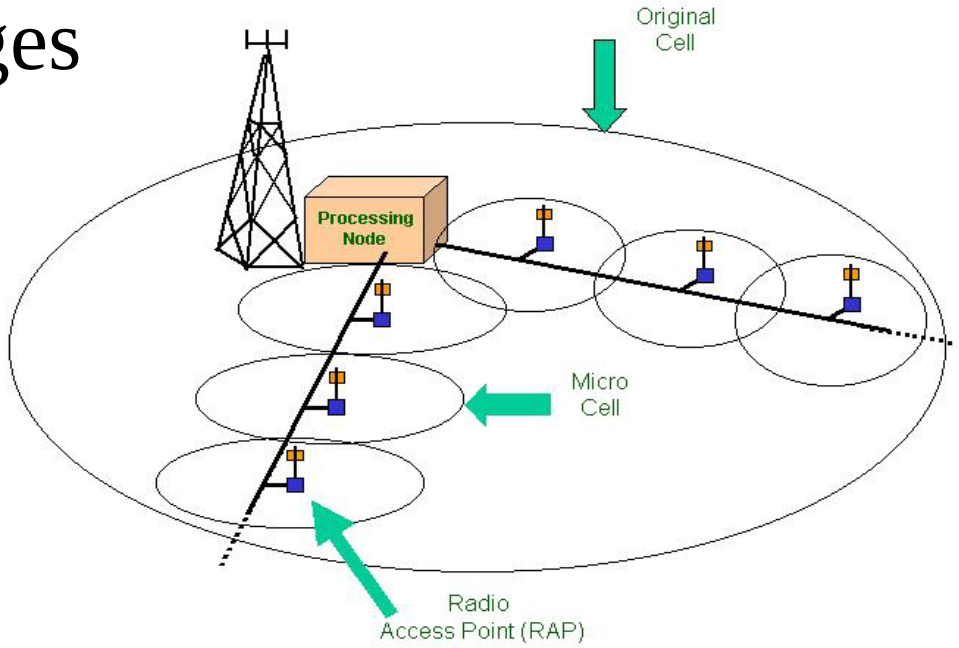
- APON/BPON: ATM/Broadband PON
  - Uses ATM as bearer protocol
  - 155 or 622 Mbps downstream, 155 upstream.
- EPON: Ethernet PON
  - Uses Ethernet frames for data transfer
  - 10G-EPON aims at reaching high data rates of 10 Gb/s
- GPON: Gigabit capable PON - successor of BPON
  - Enables the transmission of both ATM cells and Ethernet packets in the same transmission frame structure.
- WPON: WDM-PON
  - Support multiple wavelengths

PON Comparison

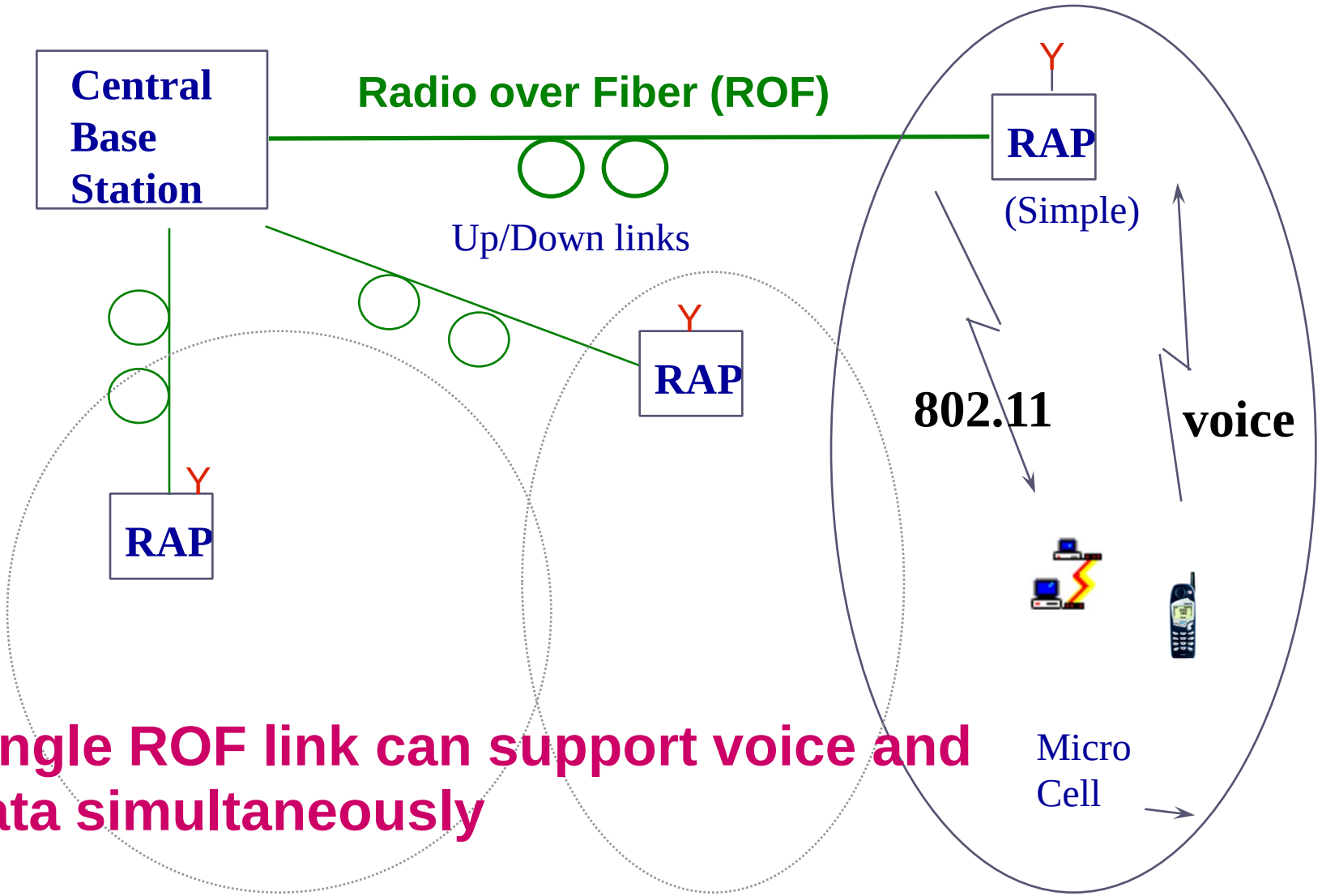
	Downstream	Upstream	Standard
APON	155 Mb/s 622 Mb/s	155 Mb/s 155 MB/s	ITU-T (FSAN)
BPON	155 Mb/s 622 Mb/s	155 Mb/s 622 MB/s	IEEE 802.3ah
EPON	10-1000 Mb/s	10-1000 Mb/s	ITU-T G.983 (FSAN)
GPON	1.244 Gb/s 2.488 Gb/s	155 Mb/s 622 Mb/s 1.244 Gb/s 2.488 Gb/s	ITU-T G.983 (FSAN – Full Services Access Network)

Radio over Fiber (ROF)

- RF signals are transmitted over fiber to provide broadband wireless access
- An emerging very hot area
- Many advantages



ROF for Fiber-Wireless Networks



Single ROF link can support voice and data simultaneously