15-441 Computer Networks

Lecture 4

Layered Architecture

Physical Layer

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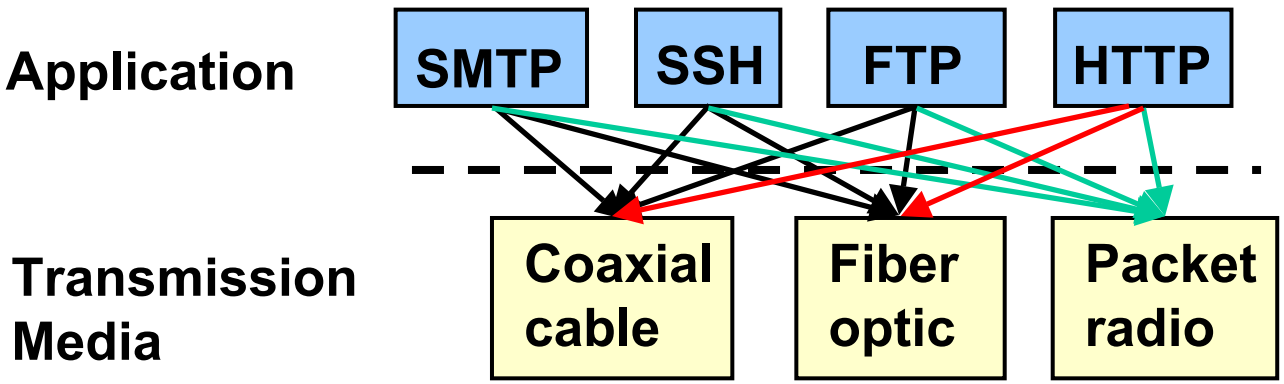
Review of Last Lecture

- **Many types of networks**
- **Switching architectures**
- **Other concepts**
  - Timing graph
  - Conversion among transmission rate (bps), time (second), distance (meter)

Organizing Network Functionality

- **Many kinds of networking functionality**
  - e.g., encoding, framing, routing, addressing, reliability, etc.
- **How should they be organized?**
- **How should they interact?**
- **Layering is one answer to these questions**

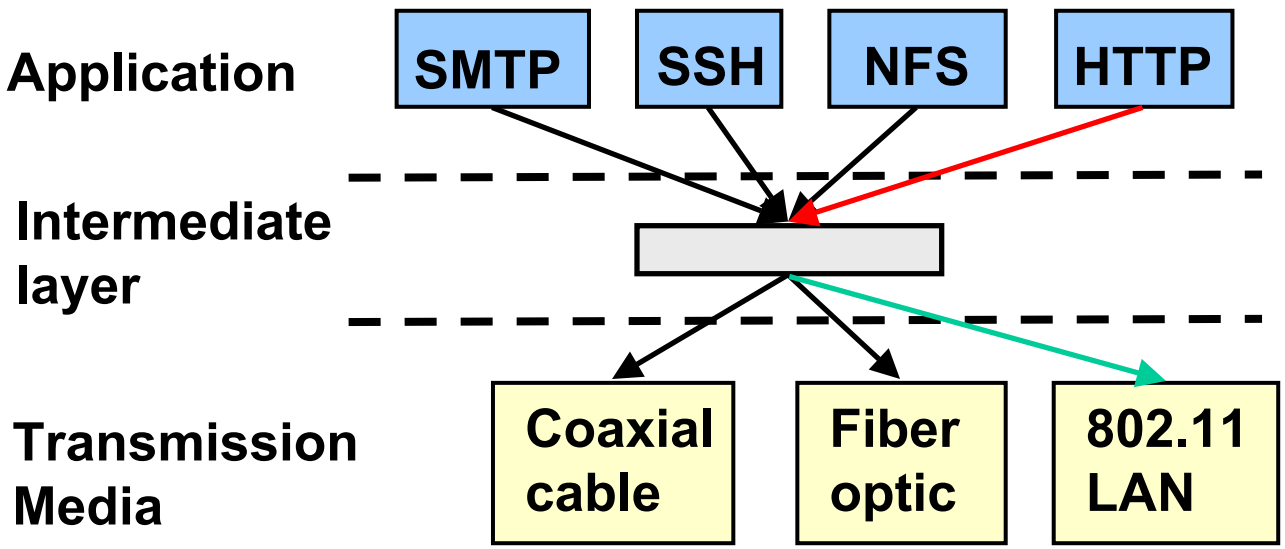
Networking Application



- **new application has to interface to all existing media**
  - adding new application requires O(m) work, m = number of media
- **new media requires all existing applications be modified**
  - adding new media requires O(a) work, a = number of applications
- **total work in system O(ma) → eventually too much work to add apps/media**
- **Application end points may not be on the same media!**

One Level of In-Direction

- **Solution: introduce an intermediate layer that provides a single abstraction for various network technologies**
  - O(1) work to add app/media
  - variation on “add another level of indirection”

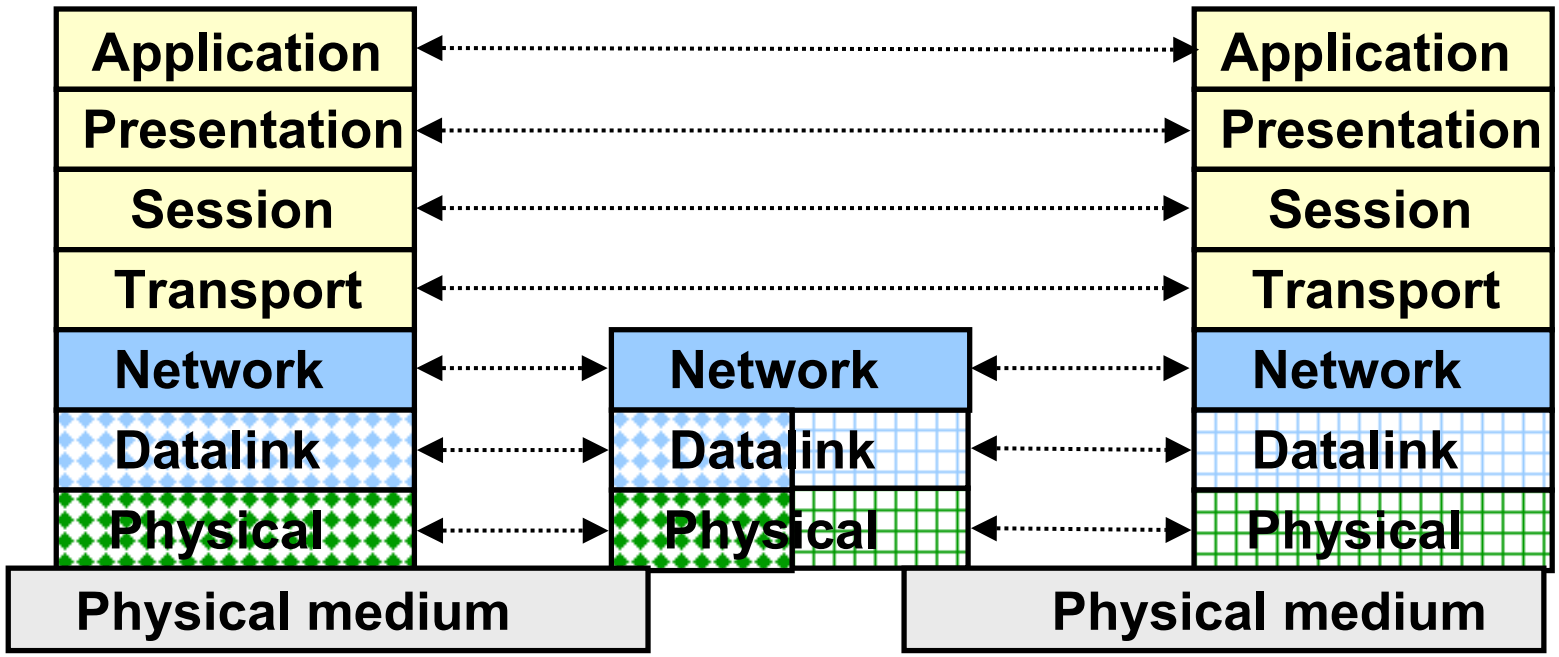


ISO OSI Reference Model

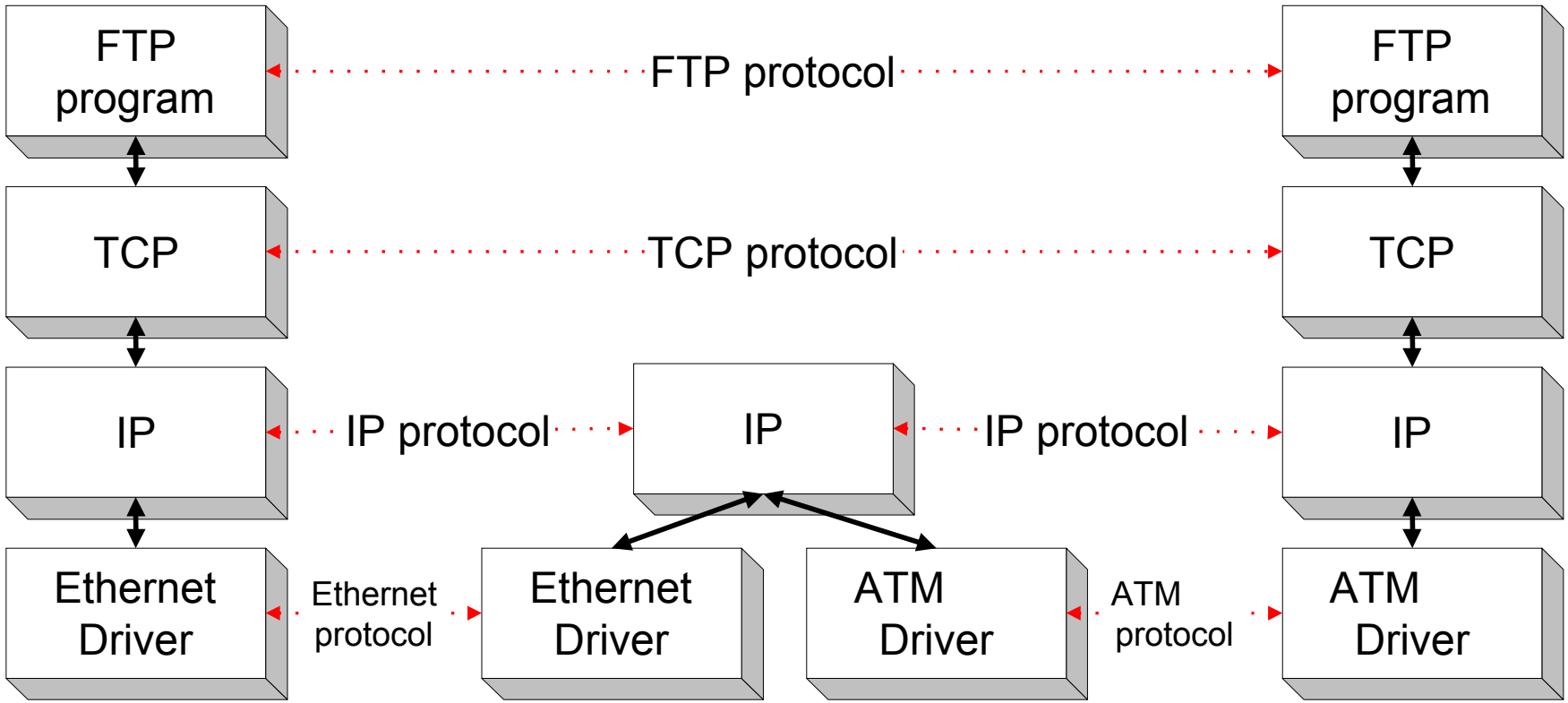
- **ISO – International Standard Organization**
- **OSI – Open System Interconnection**
- **Goal: a general open standard**
  - allow vendors to enter the market by using their own implementation and protocols

ISO OSI Reference Model

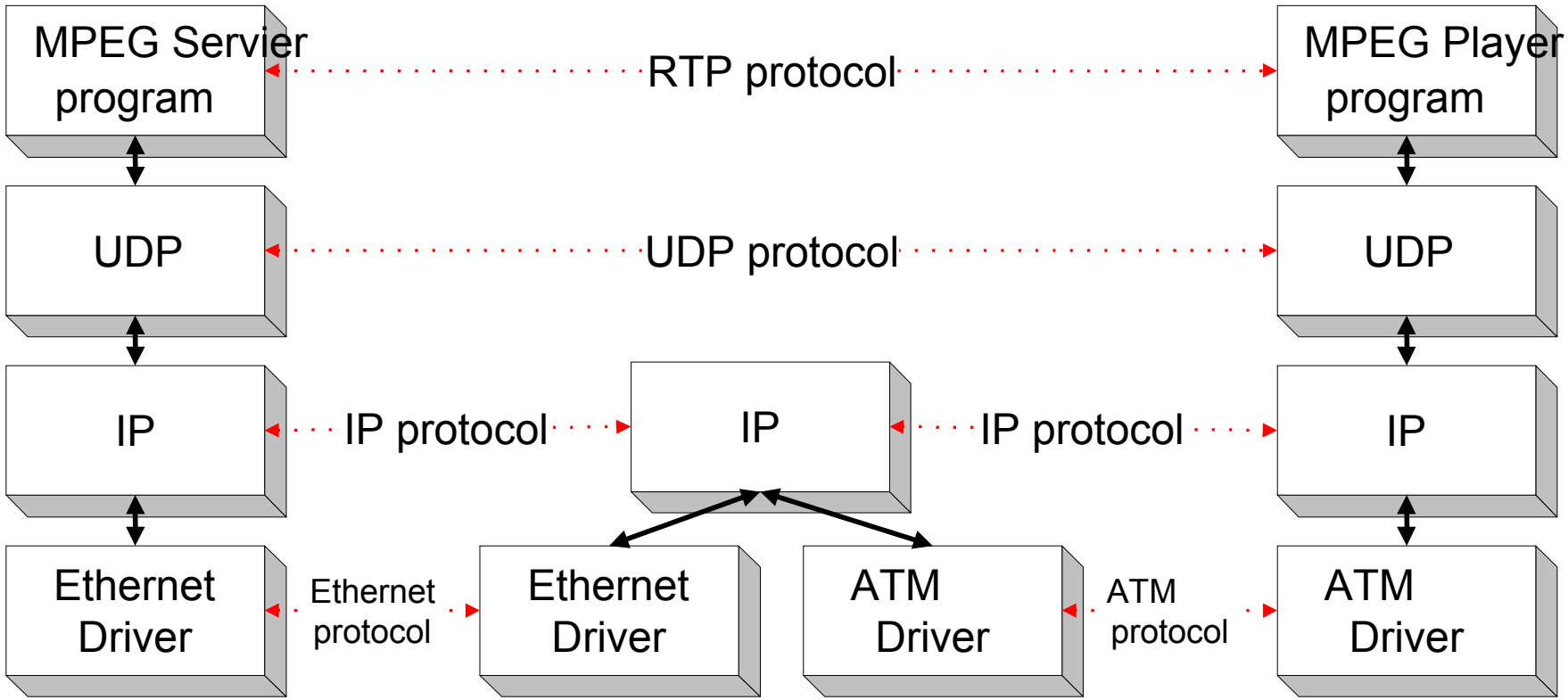
- **Seven layers**
  - Lower two layers are peer-to-peer
  - Network layer involves multiple switches
  - Next four layers are end-to-end



Internet Protocol Architecture



Internet Protocol Architecture



Key Concepts

- **Service – says what a layer does**
  - Ethernet: unreliable subnet unicast/multicast/broadcast datagram service
  - IP: unreliable end-to-end unicast datagram service
  - TCP: reliable end-to-end bi-directional byte stream service
  - UDP: what service do you use in your project?
- **Interface – says how to access the service**
  - E.g. socket interface
- **Protocol – says how is the service implemented**
  - a set of rules and formats that govern the communication between two peers
  - Syntax, semantics, timing

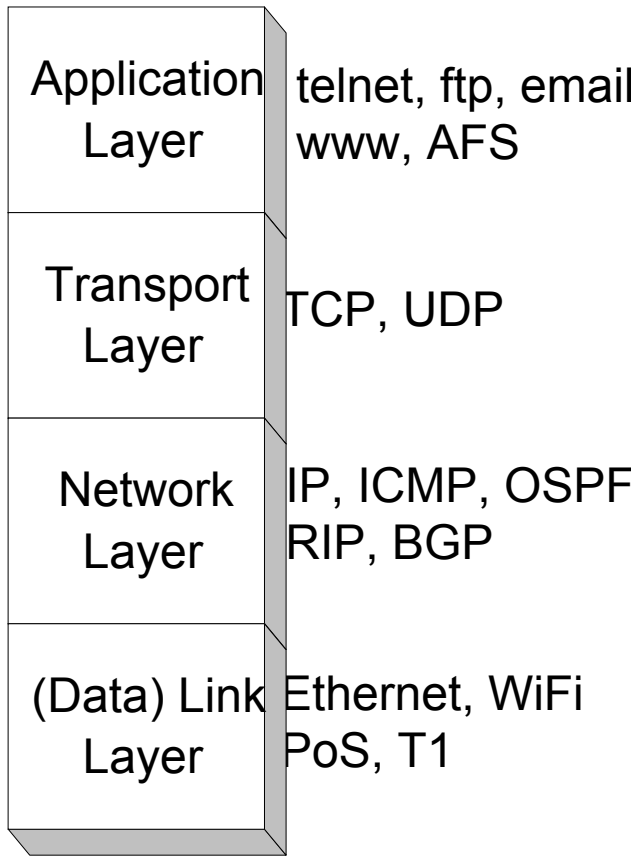
Functions of the Layers

- Service: Handles details of application programs.
- Functions:

- Service: Controls delivery of data between hosts.
- Functions: Connection establishment/termination, error control, flow control.

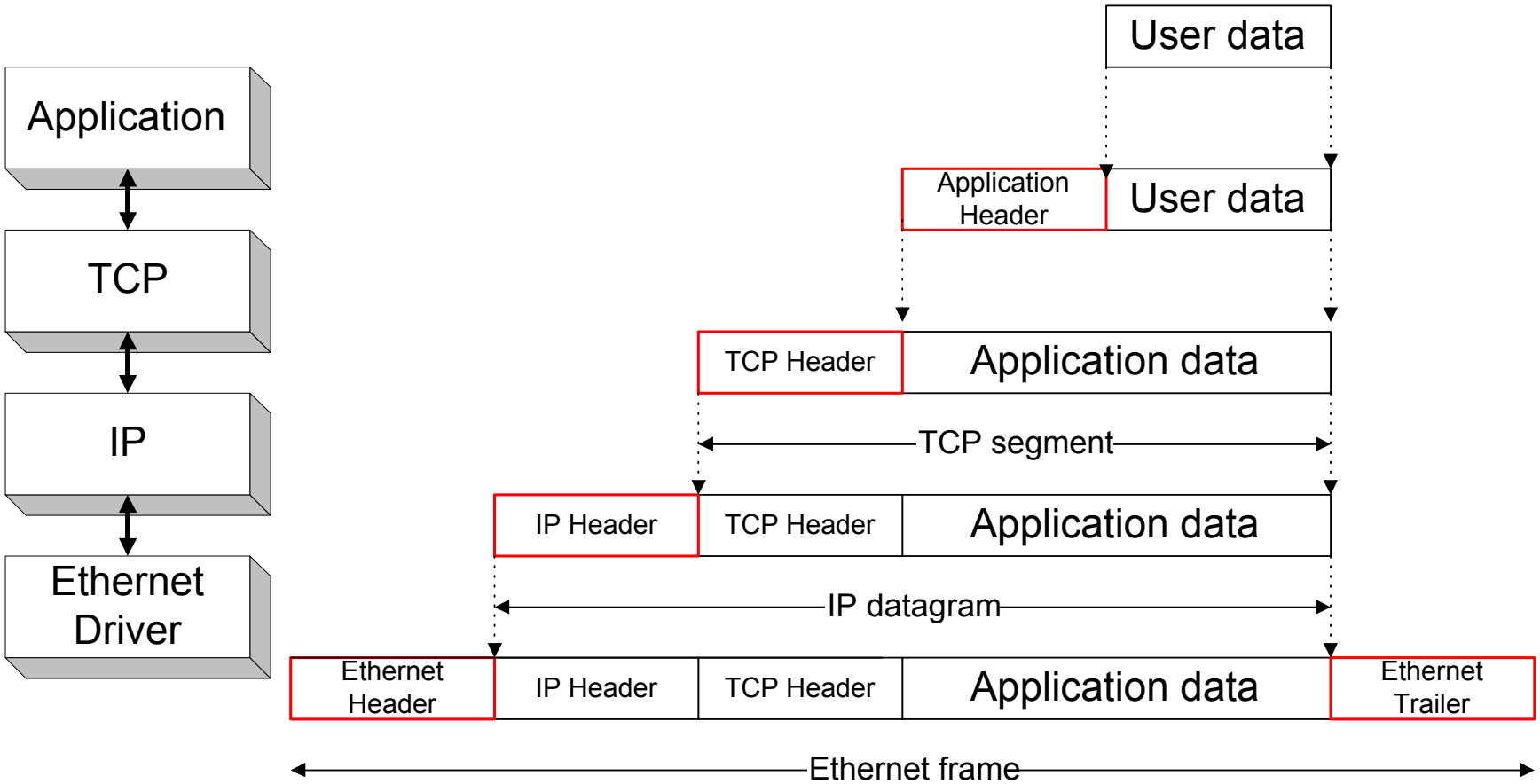
- Service: Moves packets inside the network.
- Functions: Routing, addressing, switching, congestion control.

- Service: Reliable transfer of frames over a link.
- Functions: Synchronization, error control, flow contro

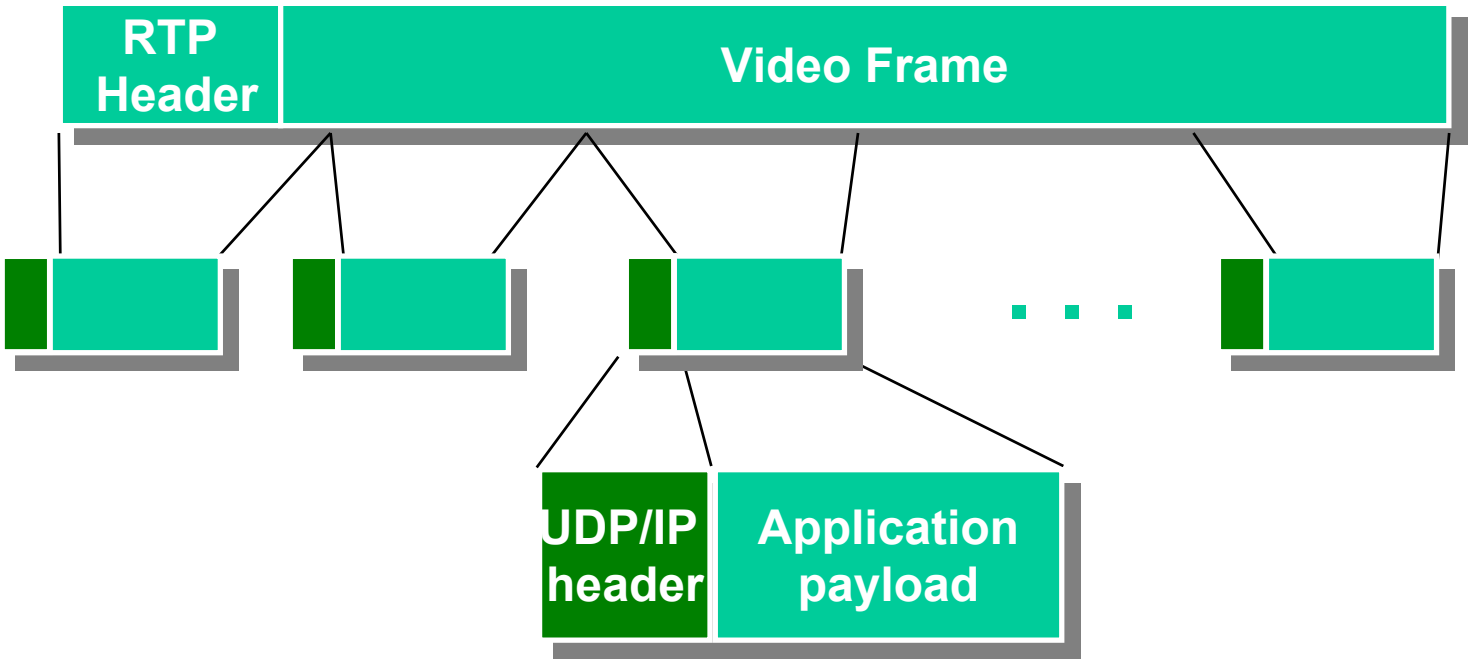


Encapsulation

- **As data is moving down the protocol stack, each protocol is adding layer-specific control information.**

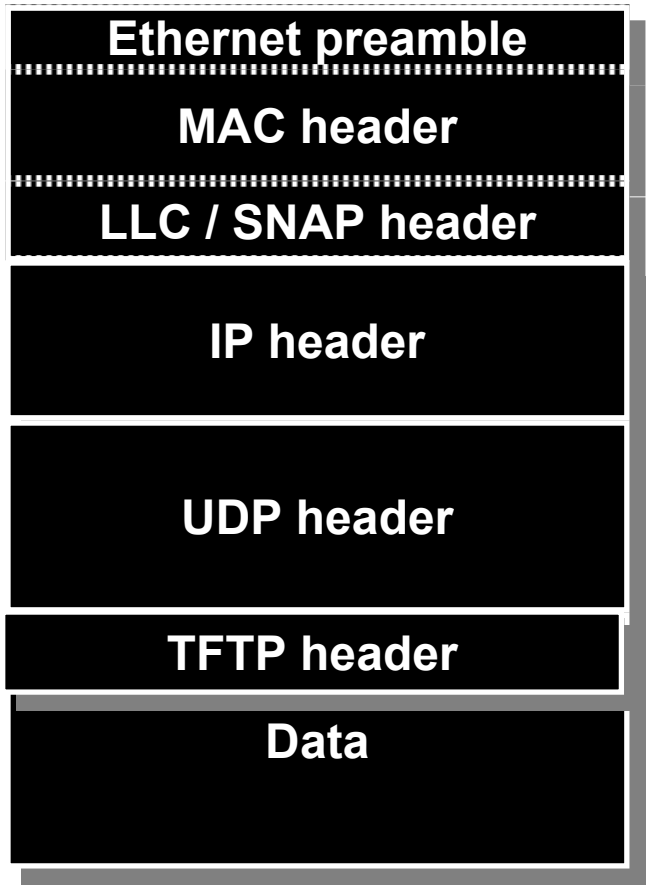


Example: Sending Video Over Internet



Application
Presentation
Session
Transport
Network
Data link
Physical

A TFTP UDP / IP / 802.3 Packet



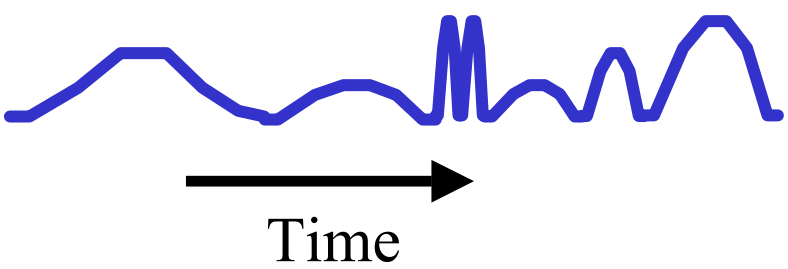
Physical Layer

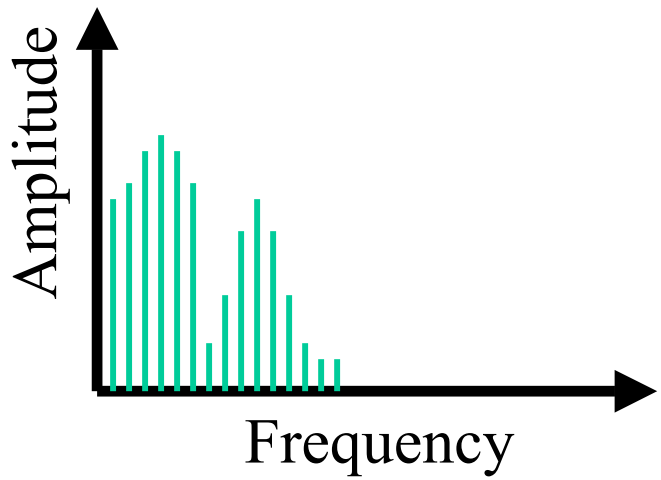
Historical Perspective

- **Independent developments of telecommunication network and local area data networks (LAN)**
- **Telecommunication network**
  - Analog signal with analog transmission
  - Digital transmission of voice over long distance
  - Long distance digital circuit for data transmission service
  - Access modem for data transmission
  - Introduction of optical transmission

Frequency, Bandwith of Signal

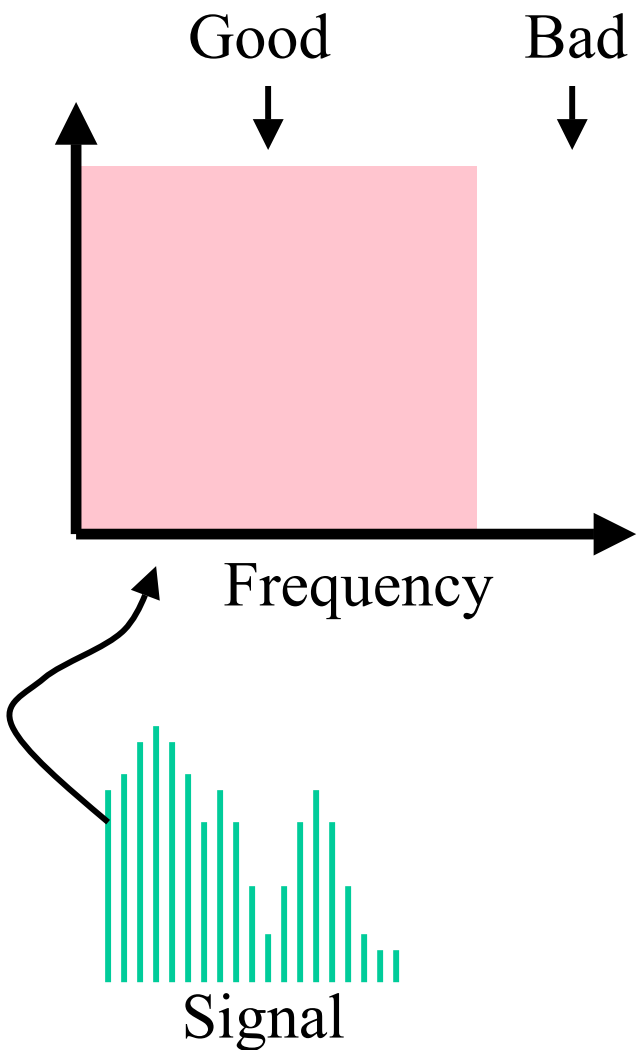
- **A signal can be viewed as a sum of sine waves of different strengths.**
  - Corresponds to energy at a certain frequency
- **Every signal has an equivalent representation in the frequency domain**
- **Frequency: how fast a period signal changes, measured in HZ**
- **Bandwidth: width of the frequency range**
  - E.g. human voice: 100~3300 HZ, with a bandwidth of 3200





Bandwidth of Transmission Channels

- **Every medium supports transmission in a certain frequency range.**
  - Outside this range, effects such as attenuation, .. degrade the signal too much
- **Transmission and receive hardware will try to maximize the useful bandwidth in this frequency band.**
  - Tradeoffs between cost, distance, bit rate
- **As technology improves, these parameters change, even for the same wire.**
  - Thanks to our EE friends



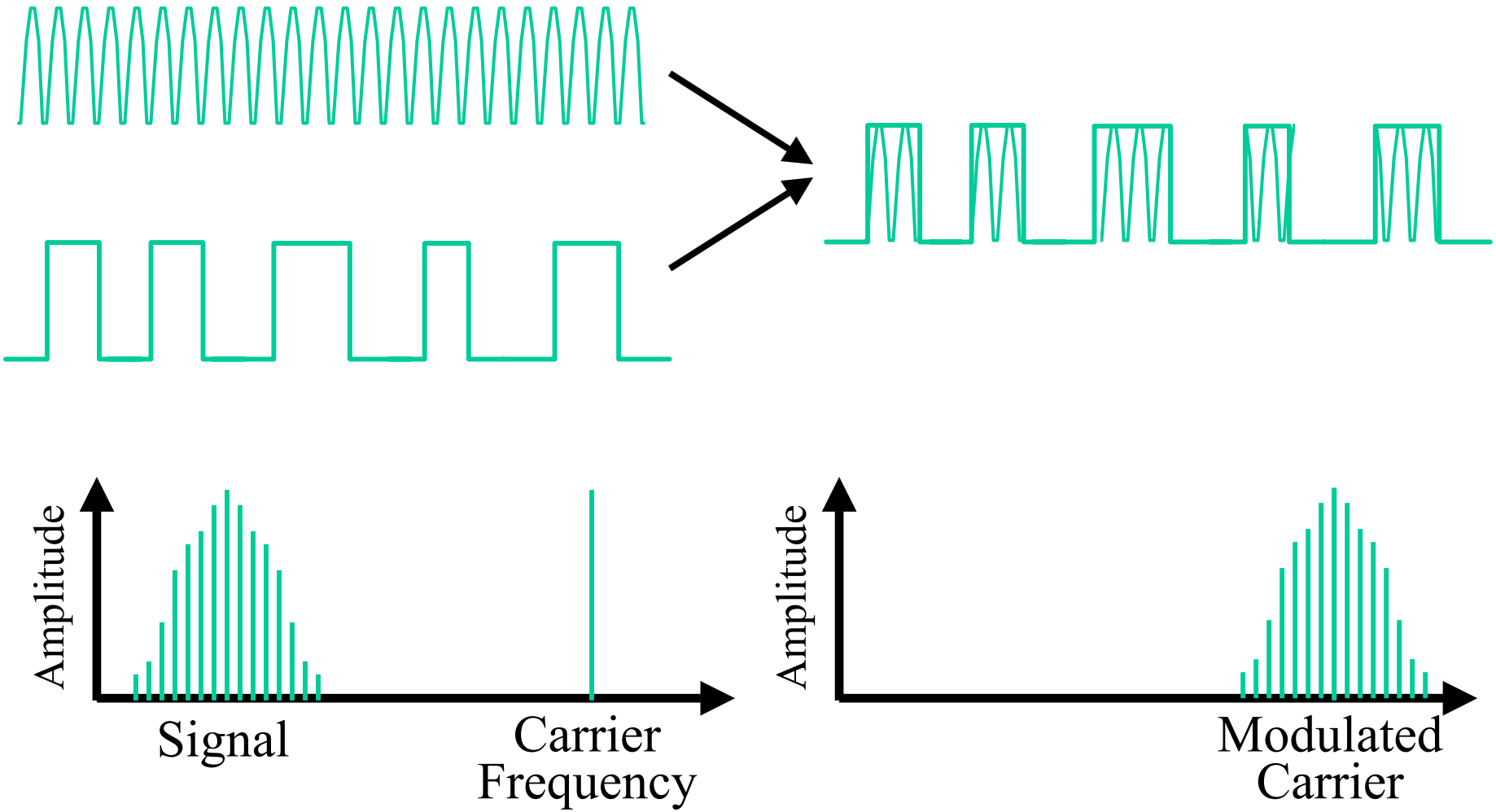
Multiplexing

- **Transmit multiple signals on the same channel**
  - Frequency Division Multiplexing
  - Time Division Multiplexing

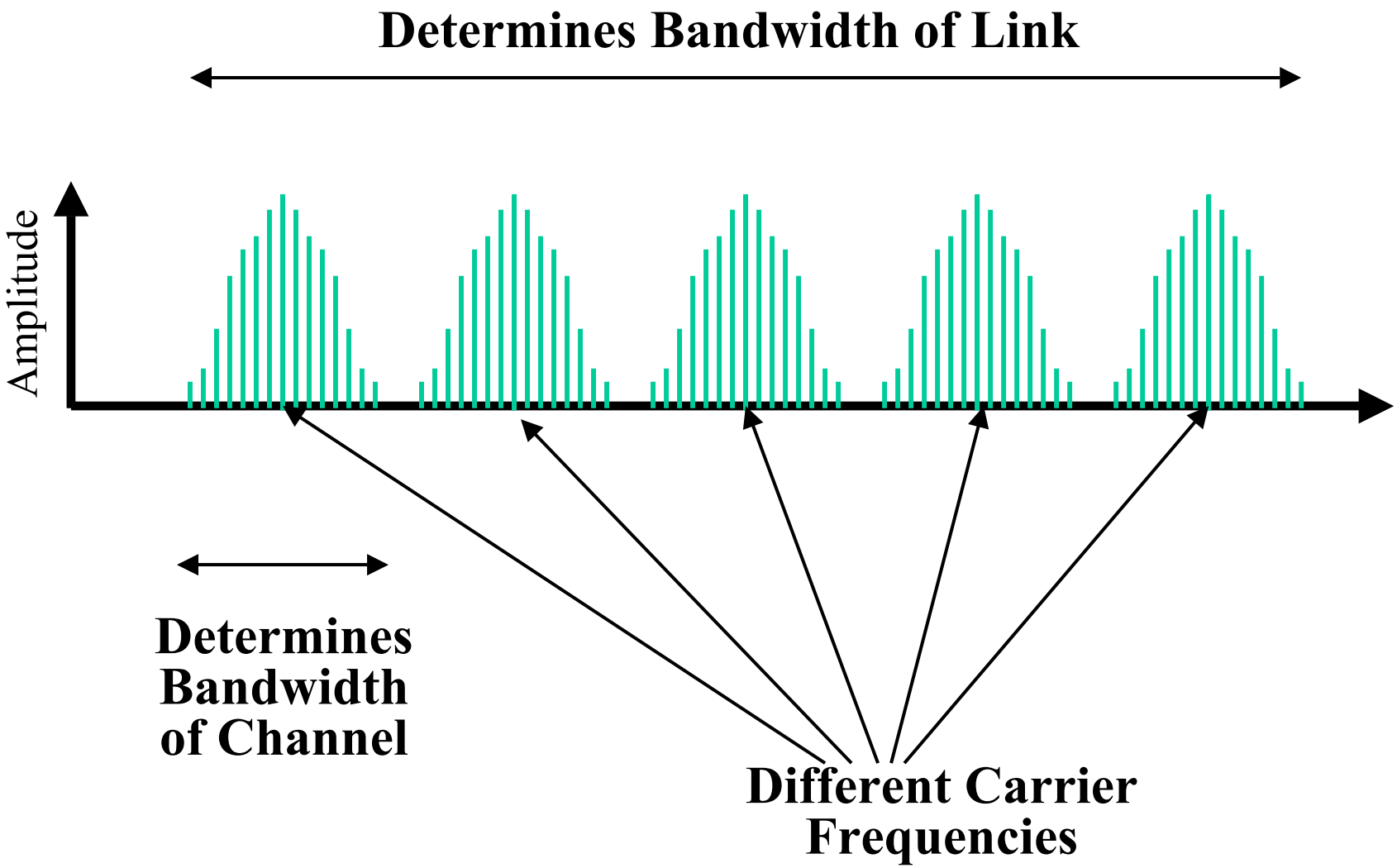
Baseband versus Carrier Modulation

- **Baseband modulation: send the "bare" signal.**
- **Carrier modulation: use the signal to modulate a higher frequency signal (carrier).**
  - Can be viewed as the product of the two signals
  - Corresponds to a shift in the frequency domain
- **Important for Frequency Division Multiplexing**

Amplitude Carrier Modulation



Frequency Division Multiplexing: Multiple Channels



Analog vs. Digital

- Used in different contexts

	Analog	Digital
Data (something has meaning)	Voice, Image	Text, computer message
Signal (encoded data)	Continuously varying wave	Sequence of 1's and 0's
Transmission	Propagation of waves	Propagation of 1's and 0's

Data Encoding: Mapping Data Into Signal

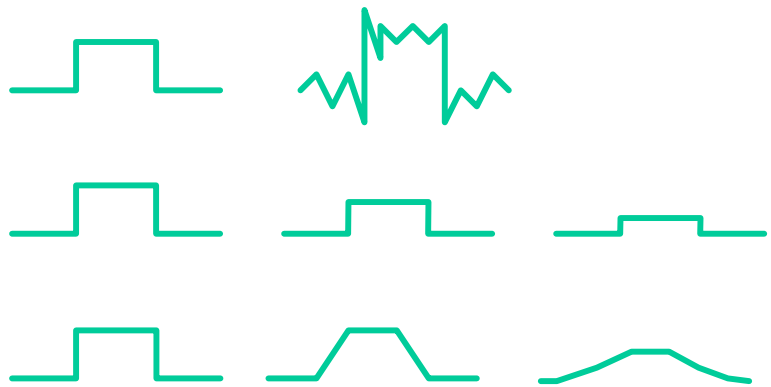
- **Analog data encoded in analog signal**
  - Radio,TV, telephone
- **Analog data encoded in digital signal**
  - Digital voice (PCM sampling)
- **Digital data encoded in digital signal**
  - Ethernet (Manchester)
  - FDDI (NRZ 4B/5B)

Analog vs. Digital Transmission

- **Digital transmission**
  - Interpret the signal as 1's and 0's
  - Use repeaters to reconstruct the signal
- **Analog transmission**
  - Do not interpret content
  - Use amplifiers to boost the strength of signal
- **Why digital transmission?**

Non-Ideal Channel

- **Noise: “random” energy is added to the signal.**
- **Attenuation: some of the energy in the signal leaks away.**
- **Dispersion: attenuation and propagation speed are frequency dependent.**
  - Changes the shape of the signal



Digitalization of Analog Voice

- **Two steps:**
  - Sample the voice signal at certain frequency
  - Quantize the sample
- **What should be the sampling frequency so that the original signal can be reconstructed losslessly?**
  - Nyquist's sampling theorem: 2H, where H is the bandwidth of the signal
- **PCM coding:**
  - 8000 HZ sampling
  - 7 or 8 bits encoding of each sample (lograithmically spaced)
  - 56 or 64 kbps

Digital Transmission/Multiplexing Hierarchy

- **North America**
  - T1/DS1: 24 voice channels plus 1 bit per sample
    - (24 x 8 + 1) x 8000 = 1.544 Mbps
  - T3/DS3: another D2 hierarchy that is rarely exposed
    - 7 x 4 x 1.544 = 44.736 Mbps
- **Europe has different standard**
  - E1, E3

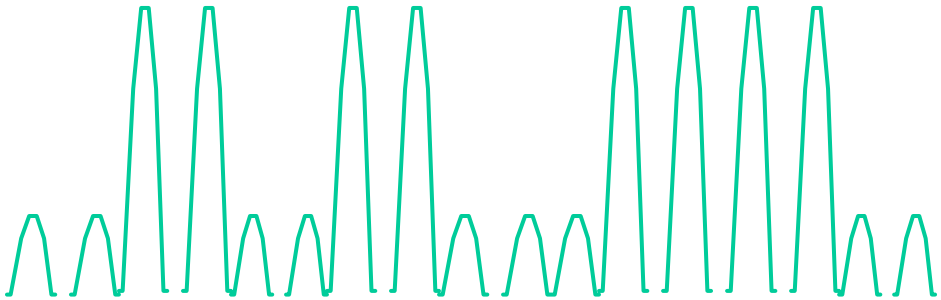
Data over Telephone Network

- **Private line data service**
  - 56kbps, T1, T3
- **How to extend data service to home over analog subscriber loop?**
  - Modem: digital signal over analog transmission channel

Modulation

- **Sender changes the nature of the signal in a way that the receiver can recognize.**
- **Amplitude modulation: change the strength of the signal, typically between on and off.**
  - Sender and receiver agree on a “rate”
  - On means 1, Off means 0
- **Similar: frequency or phase modulation**

Amplitude and Frequency Modulation



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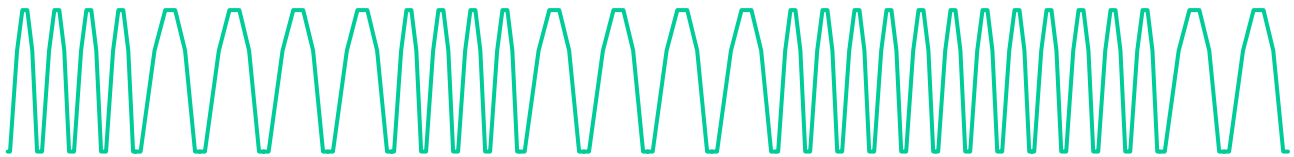


0 1 1 0 1 1 0 0 0 1

Channel Bandwidth and Capacity For Digital Signal

- **Question: given a channel with bandwidth H, what is the capacity of the channel for digital signal?**
- **How to measure channel capacity?**
  - Baud rate: number of symbols per second (HZ)
  - Bit rate: Baud rate x bits/symbol
- **Nyquist Theorm:**
  - a noiseless channel of width H can at most transmit a signal of rate 2H
- **Examples**
  - the twisted pair long loop has channel bandwidth of 3200 HZ
  - Use Phase-Shift Modulation, there are 8 possible configurations per symbol
  - Channel bit rate?

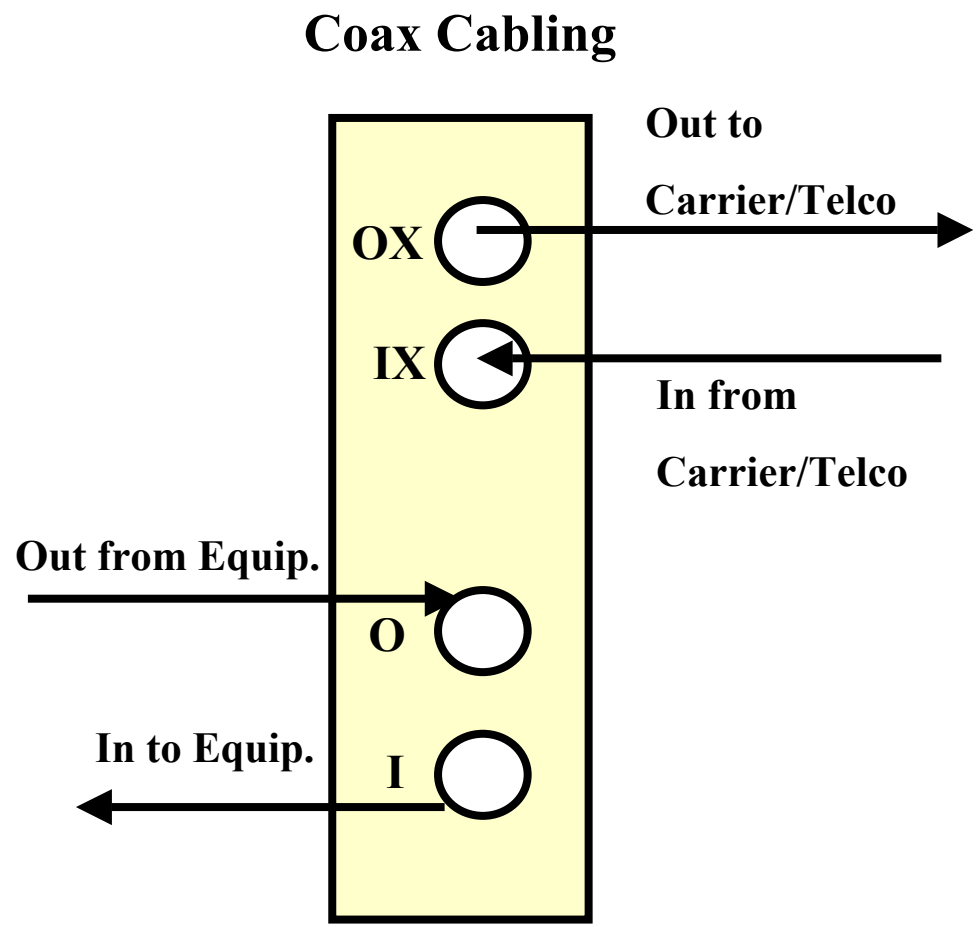
Capacity of Noisy Channel

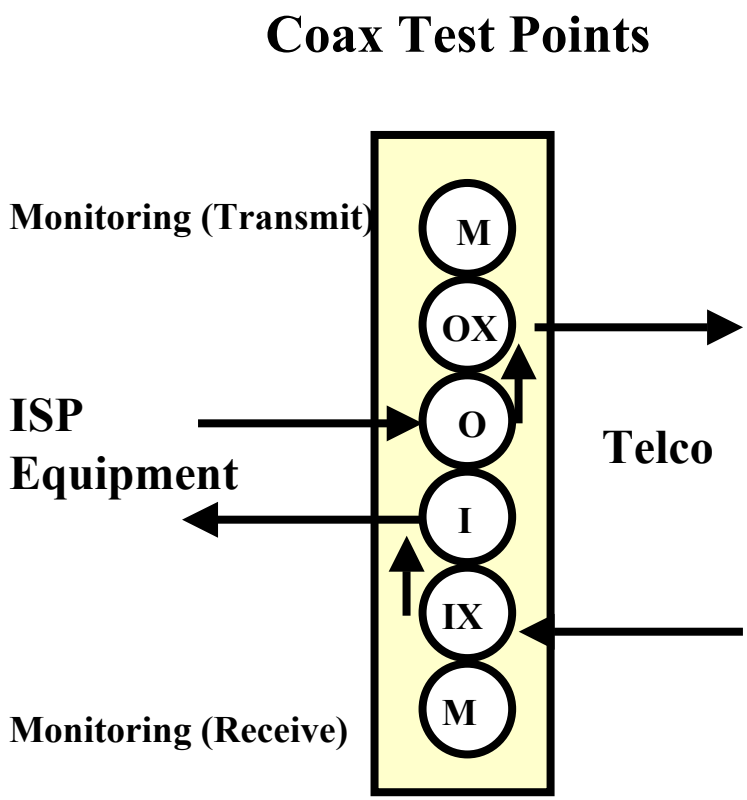
- **Nyquist establishes the channel capacity of an ideal channel, what about noisy channels?**
- **Shannon's theorem:**
  - C = B x log (1 + S/N)
  - C: maximum capacity (bps)
  - B: channel bandwidth (Hz)
  - S/N: signal to noise ratio of the channel
- **Example:**
  - Local loop bandwidth: 3200 HZ
  - Typical S/N: 1000
  - What is the upper limit?

Copper Wire

- **Unshielded twisted pair**
  - Two copper wires twisted - avoid antenna effect
  - Grouped into cables: multiple pairs with common sheath
  - Category 3 (voice grade) versus category 5
  - 100 Mbps up to 100 m, 1 Mbps up to a few km (assuming digital transmission)
- **Coax cables.**
  - One connector is placed inside the other connector
  - Holds the signal in place and keeps out noise
  - Gigabit up to a km
- **Signaling processing research pushes the capabilities of a specific technology.**
  - E.g. modems, use of cat 5

DS-3 Coax Connectors and Usage

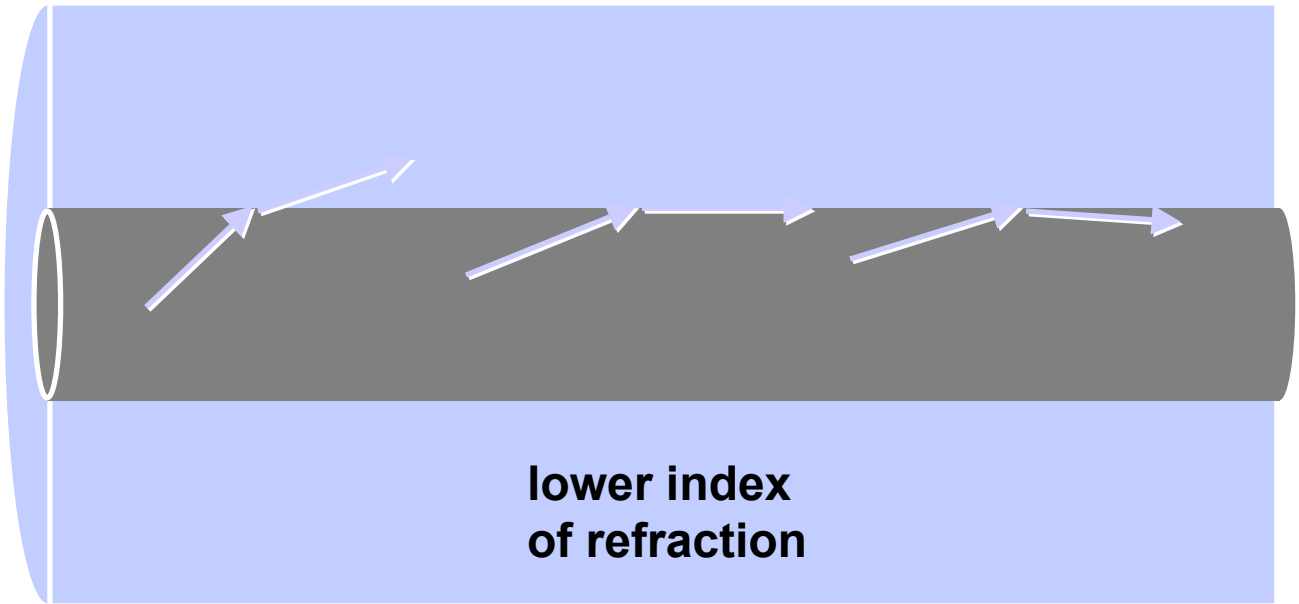




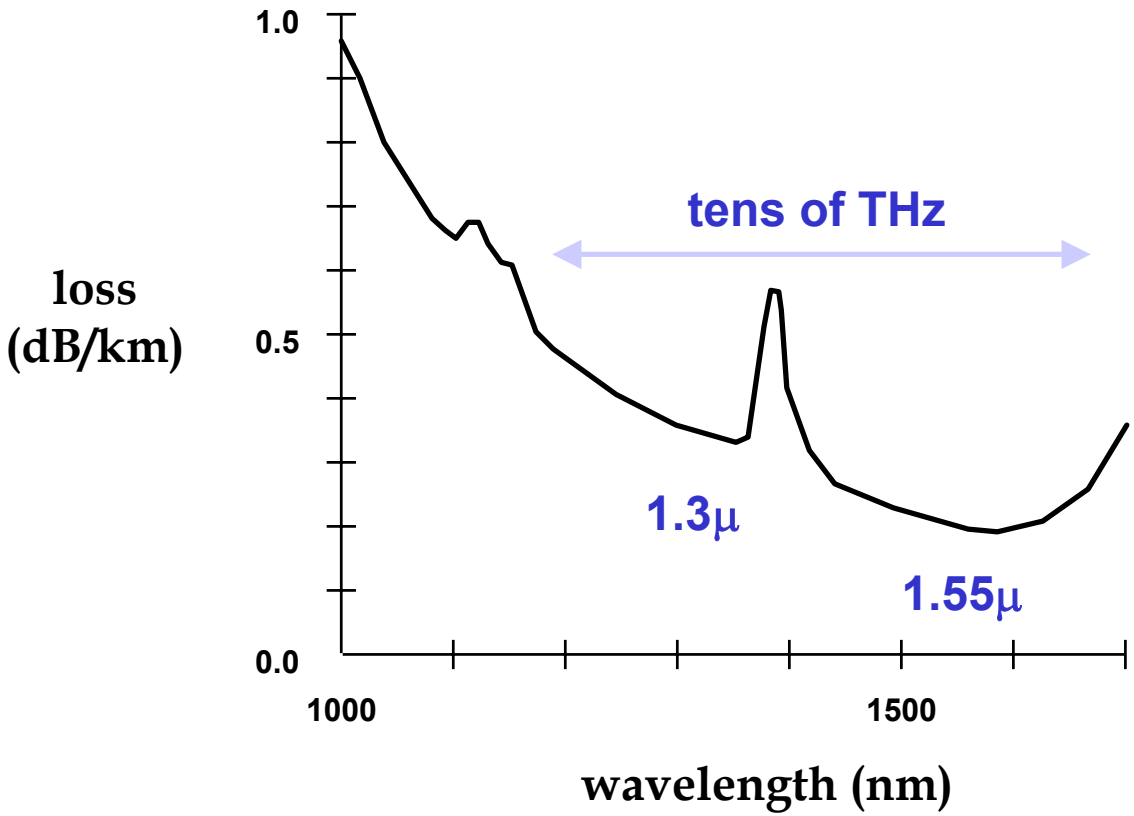
Age of Fiber and Optics

- **Enabling technology: optical transmission over fiber**
- **Advantages of fiber**
  - Huge bandwidth (TeraHz): huge capacity
  - Low attentuation: long distance

Ray Propagation



Light Transmission in Fiber

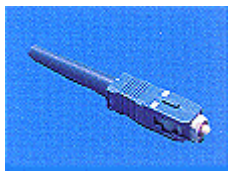


Fiber and Optical Source Types

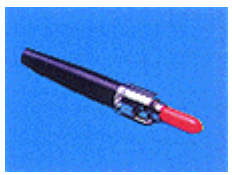
- **Multimode fiber.**
  - 62.5 or 50 micron core carries multiple “modes”
  - used at 850 nm or 1310 nm, usually LED source
  - subject to mode dispersion: different propagation modes travel at different speeds
  - typical limit: 1 Gbps at 100m
- **Single mode**
  - 8 micron core carries a single mode
  - used at 1.3 or 1.55 microns, usually laser diode source
  - typical limit: 10 Gbps at 40 km or more, rapidly improved by technology advances
  - still subject to chromatic dispersion

Fiber Connectors

- SC - “Stick and Click”, most common type in our network



- ST - “Stick and Twist”



- FC -

Gigabit Ethernet: Physical Layer Comparison

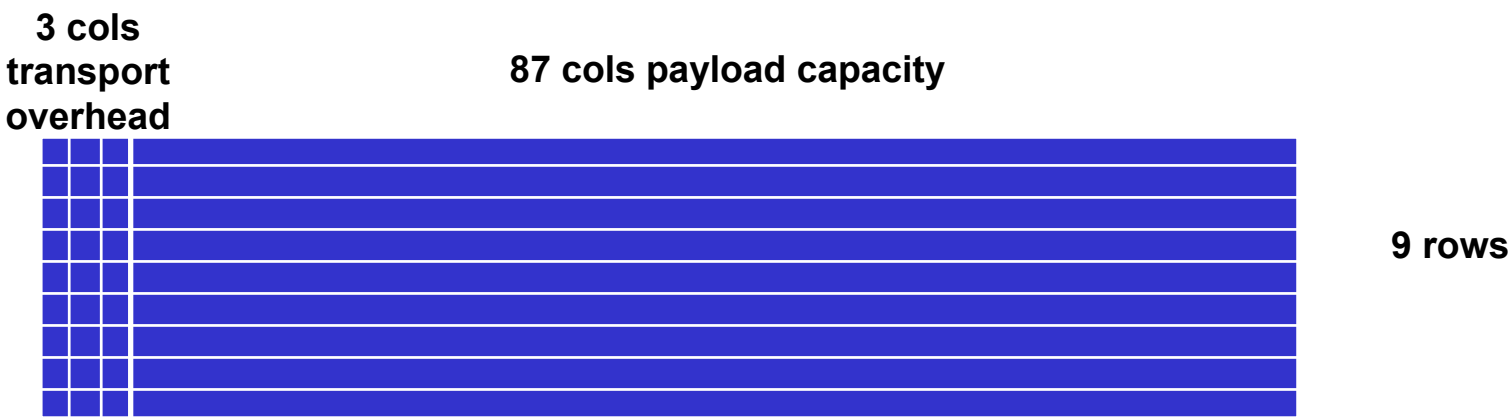
Medium	Transmit/receive	Distance	Comment
Copper	1000BASE-CX	25 m	machine room use
MM fiber 62 μm	1000BASE-SX	260 m	
	1000BASE-LX	500 m	
MM fiber 50 μm	1000BASE-SX	525 m	
	1000BASE-LX	550 m	
SM fiber	1000BASE-LX	5000 m	
Twisted pair	100BASE-T	100 m	2p of UTP5/2-4p of UTP3
MM fiber	100BASE-SX	2000m	

SONET

- **Synchronous Optical Network**
- **Optical network standard for telecommunication networks**
- **Functions:**
  - Multiplexing/demultiplexing
  - Add/drop traffic
  - Performance monitoring
  - Resiliency under failures
- **SDH is the standard used in Europe and Asia**

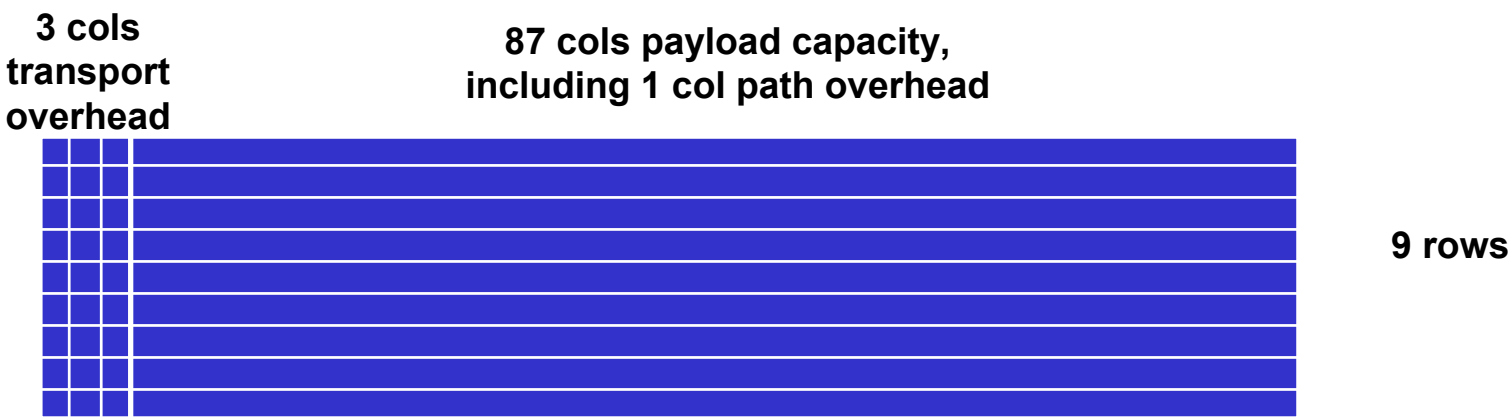
Synchronous Data Transfer

- **Sender and receiver are always synchronized.**
  - Frame boundaries are recognized based on the clock
  - No need to continuously look for special bit sequences
- **SONET frames contain room for control and data.**
  - Data frame multiplexes bytes from many users
  - Control provides information on data, management, …



SONET Framing

- **Base channel is STS-1 (Synchronous Transport System).**
  - Takes 125 μsec and corresponds to 51.84 Mbps
  - 1 byte corresponds to a 64 Kbs channel (PCM voice)
  - Also called OC-1 = optical carrier
- **Standard ways of supporting slower and faster channels.**
  - Slower: select a set of bytes in each frame
  - Faster: interleave multiple frames at higher rate

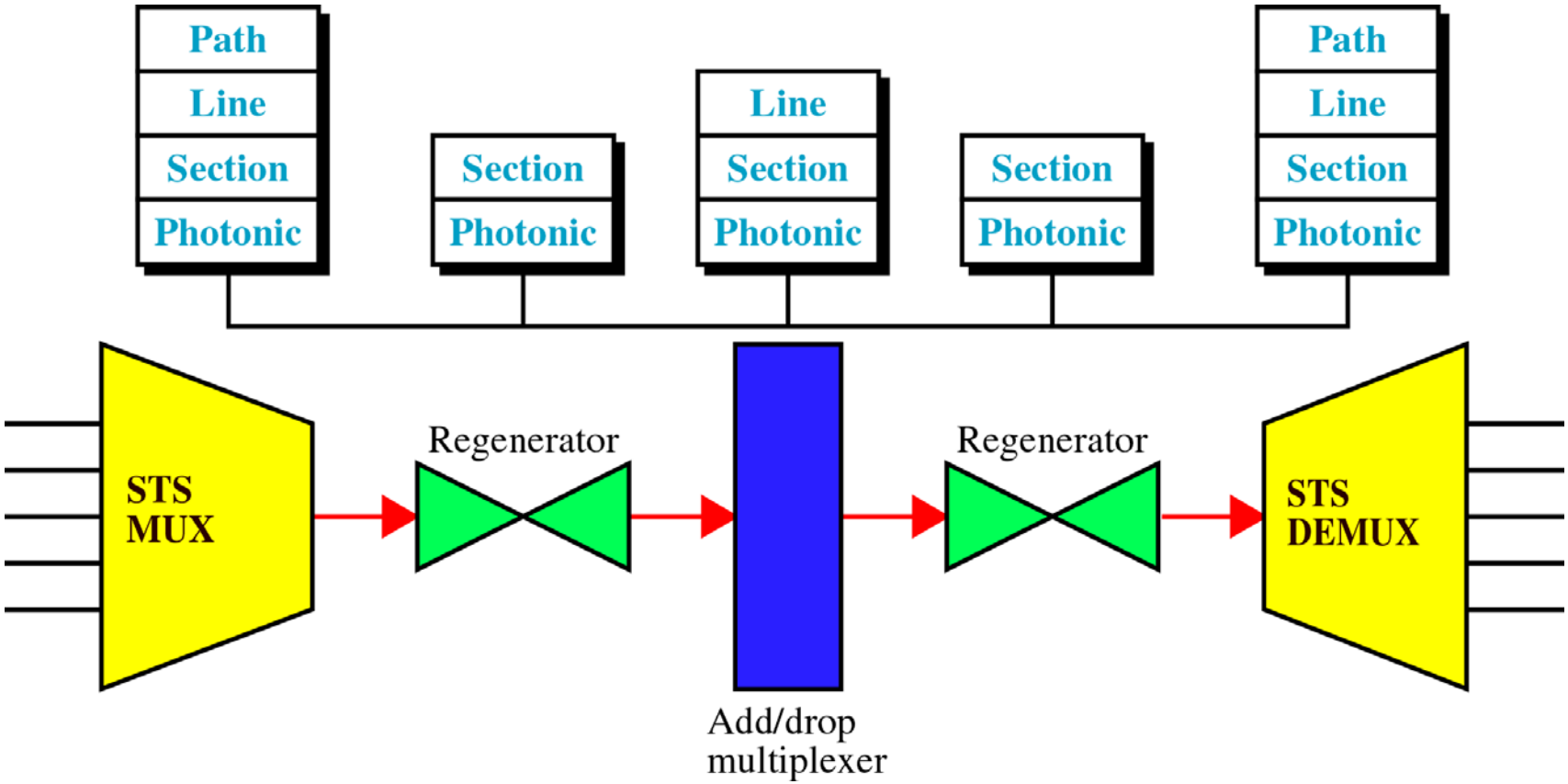


Know Your Signal Line Rates

Signal Type	Line Rate	Asynchronous Payload Carrying Capacity		
		# of DS0	# of DS1	# of DS3
DS0 (POTS eq.)	64,000 bps	-	-	-
DS1	1.544 Mbps	24	-	-
DS3	44.736 Mbps	672	28	-
EC-1 (STS-1E)	51.84 Mbps	672	28	-
OC-3	155 Mbps	2,016	84	3
OC-12	622 Mbps	8,064	336	12
OC-48	2.49 Gbps	32,256	1,344	48
OC-192	9.95 Gbps	129,024	5,376	192
OC-768	39.8 Gbps	516,096	21,504	768

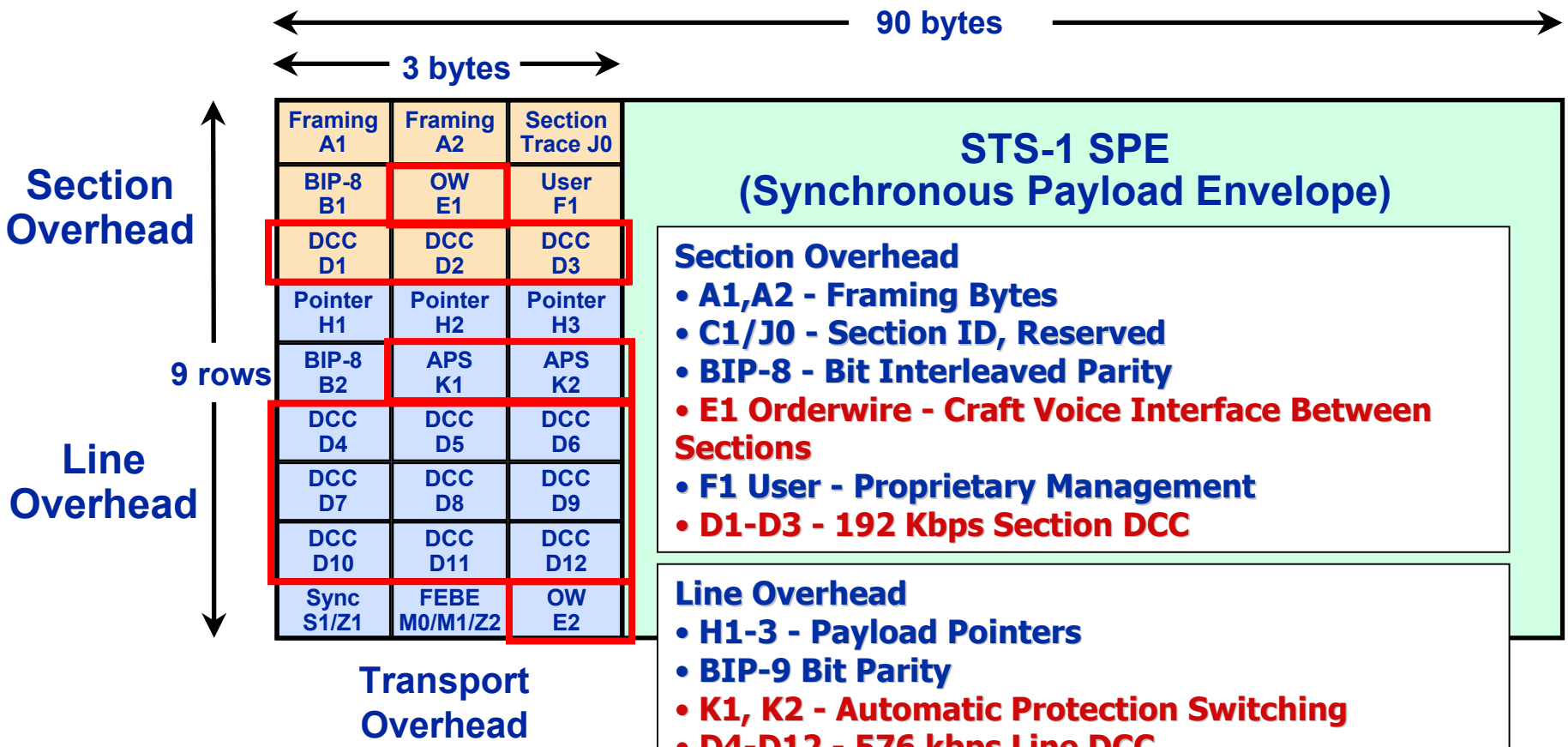
Figure 20-4

SONET Device Layers



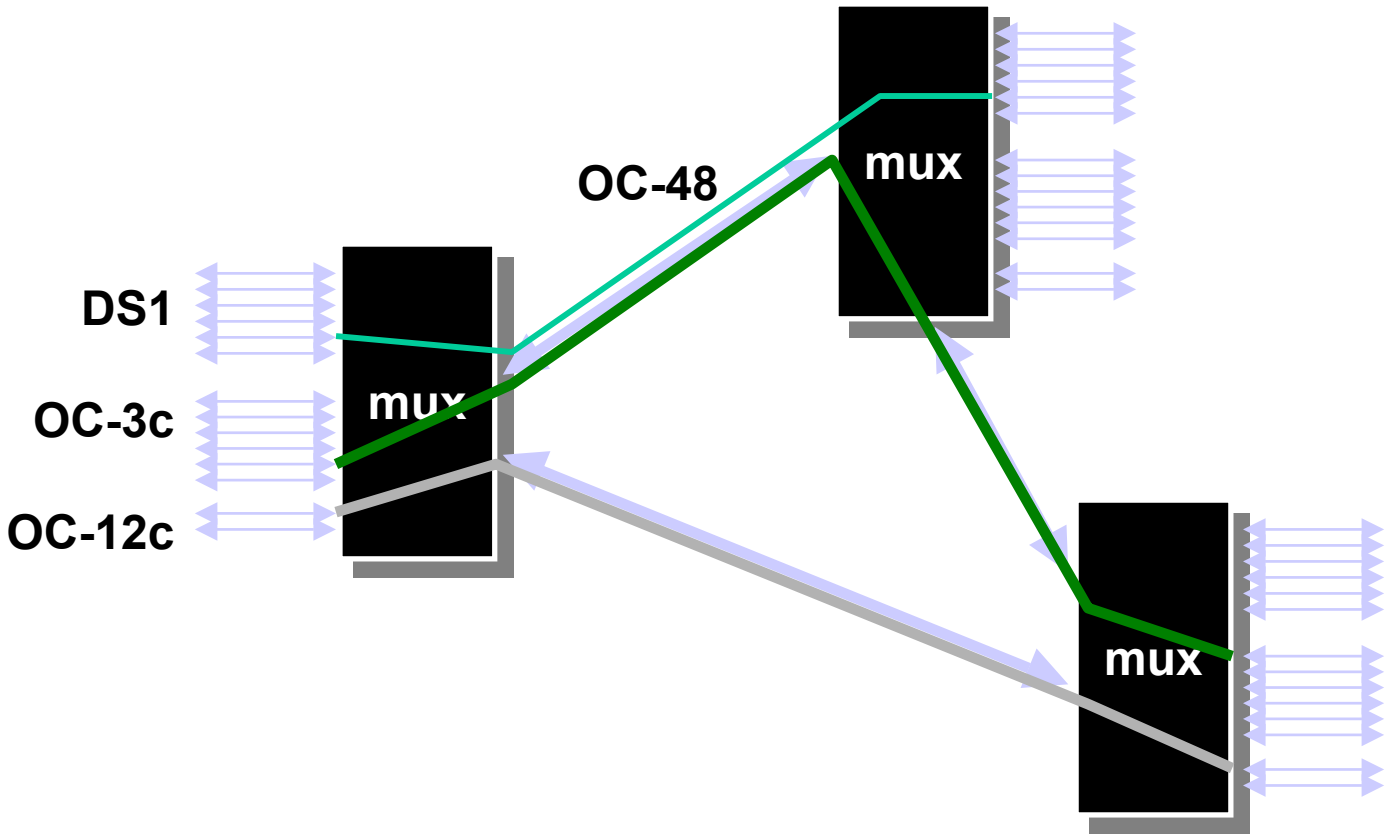
- Section Termination (STE) - Span between regens
- Line Termination (LTE) - Span(s) between muxes
- Path Termination (PTE) - SONET path ends

Transport Overhead
Section and Line

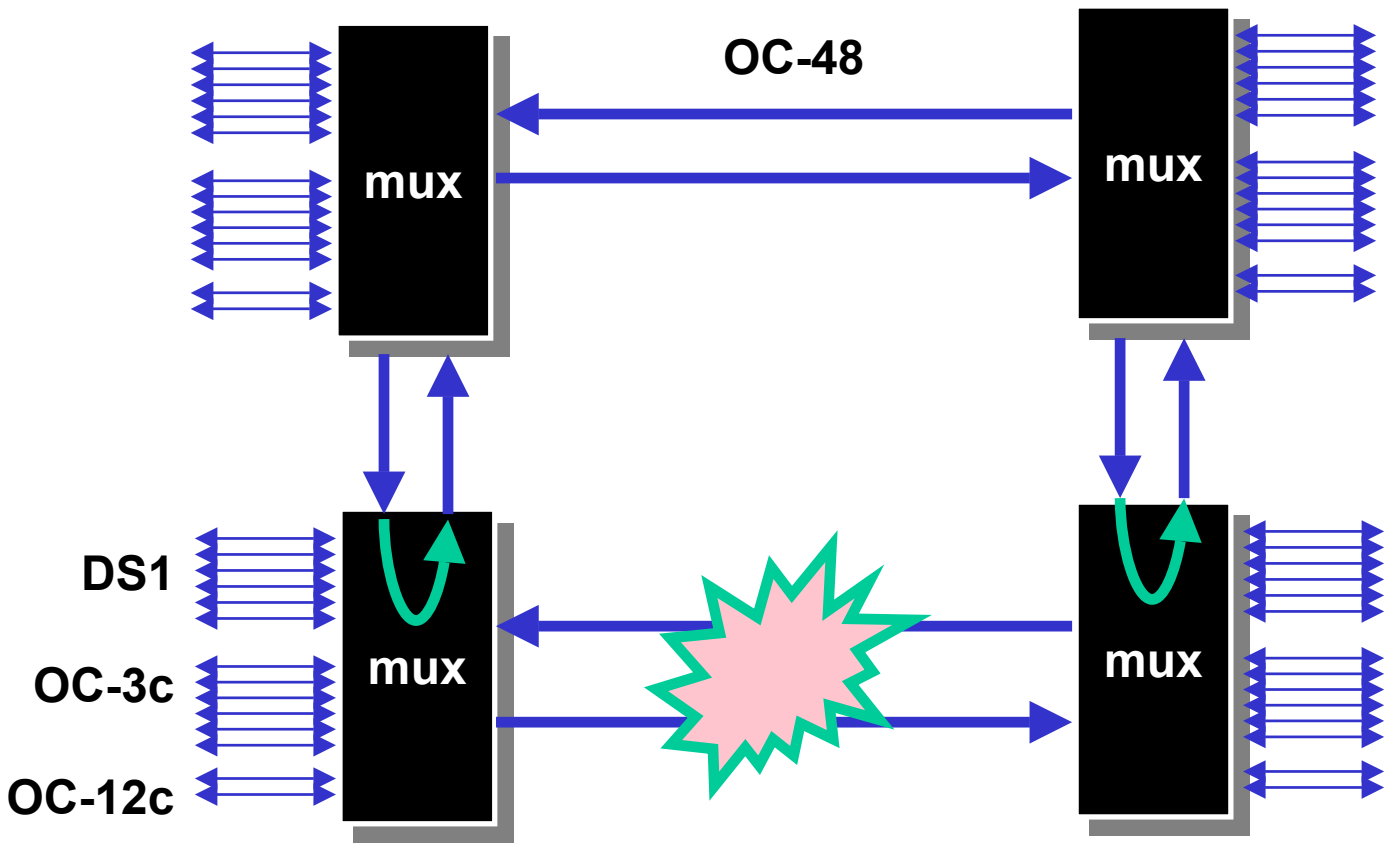


Using SONET in Networks

Add-drop capability allows soft configuration of networks, usually managed manually.



Self-Healing SONET Rings

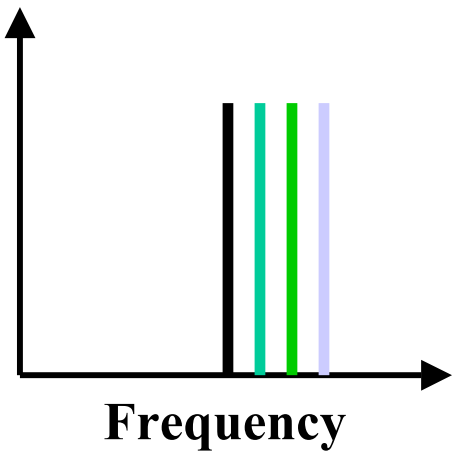


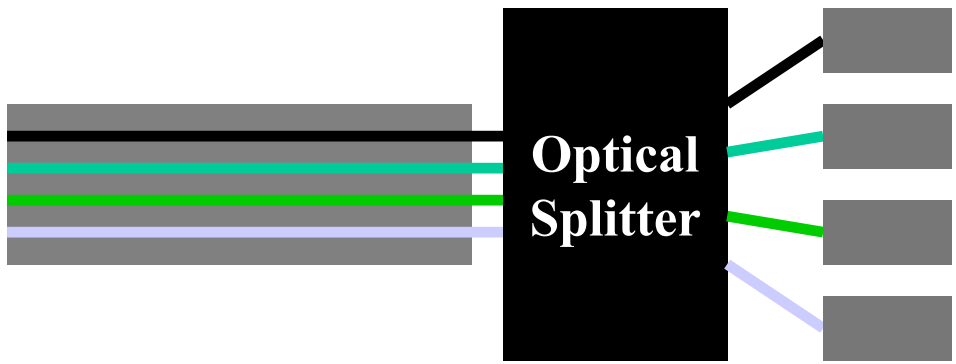
Optical Amplication

- At end of span, either regenerate electronically or amplify.
- Electronic repeaters are potentially slow, but can eliminate noise.
- Amplification over long distances made practical by erbium doped fiber amplifiers offering up to 40 dB gain, linear response over a broad spectrum. Ex: 10 Gbps at 500 km.

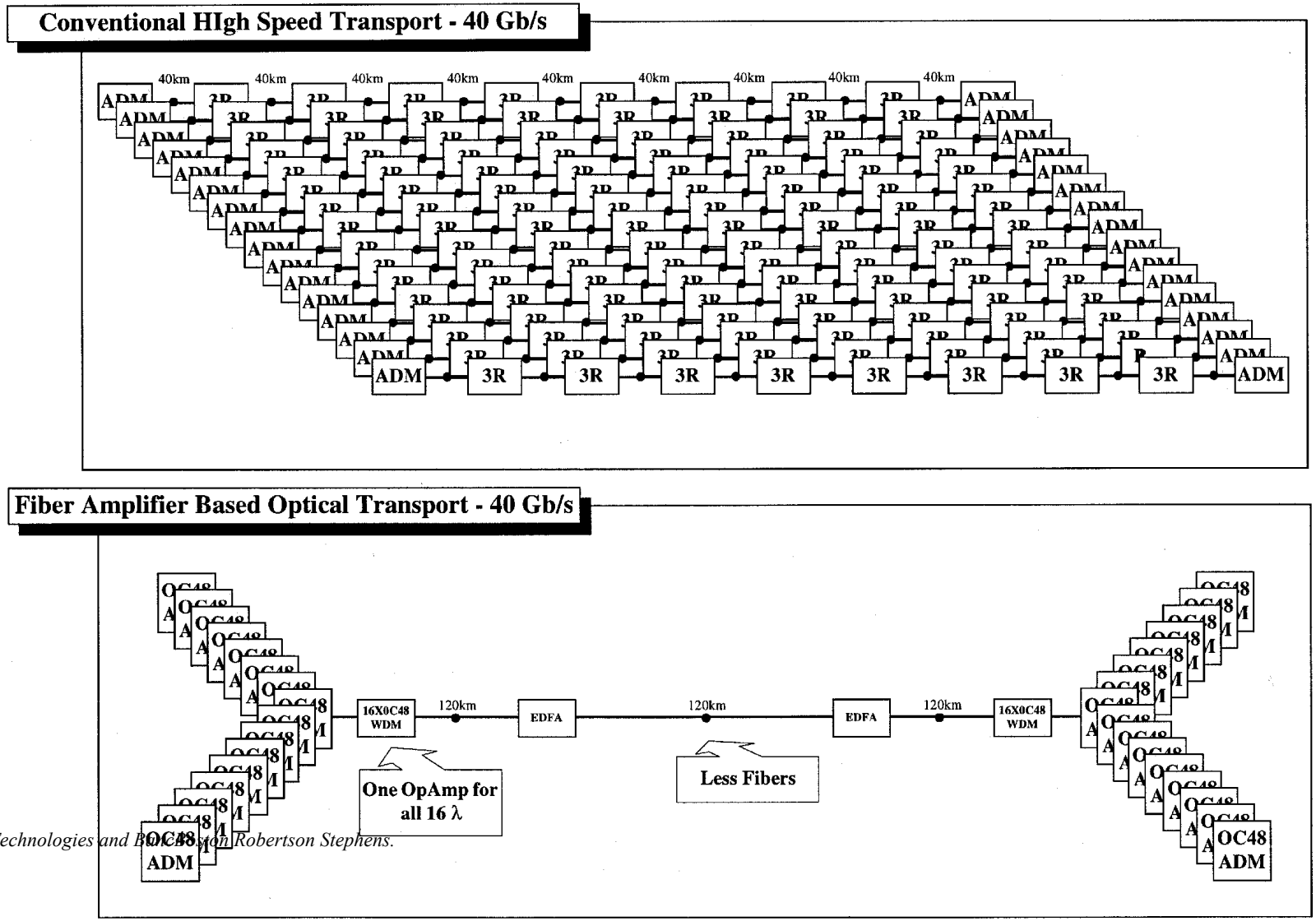
Wavelength Division Multiplexing

- **Send multiple wavelengths through the same fiber.**
  - Multiplex and demultiplex the optical signal on the fiber
- **Each wavelength represents an optical carrier that can carry a separate signal.**
  - ITU grid: 40 wavelengths around 1510 nm



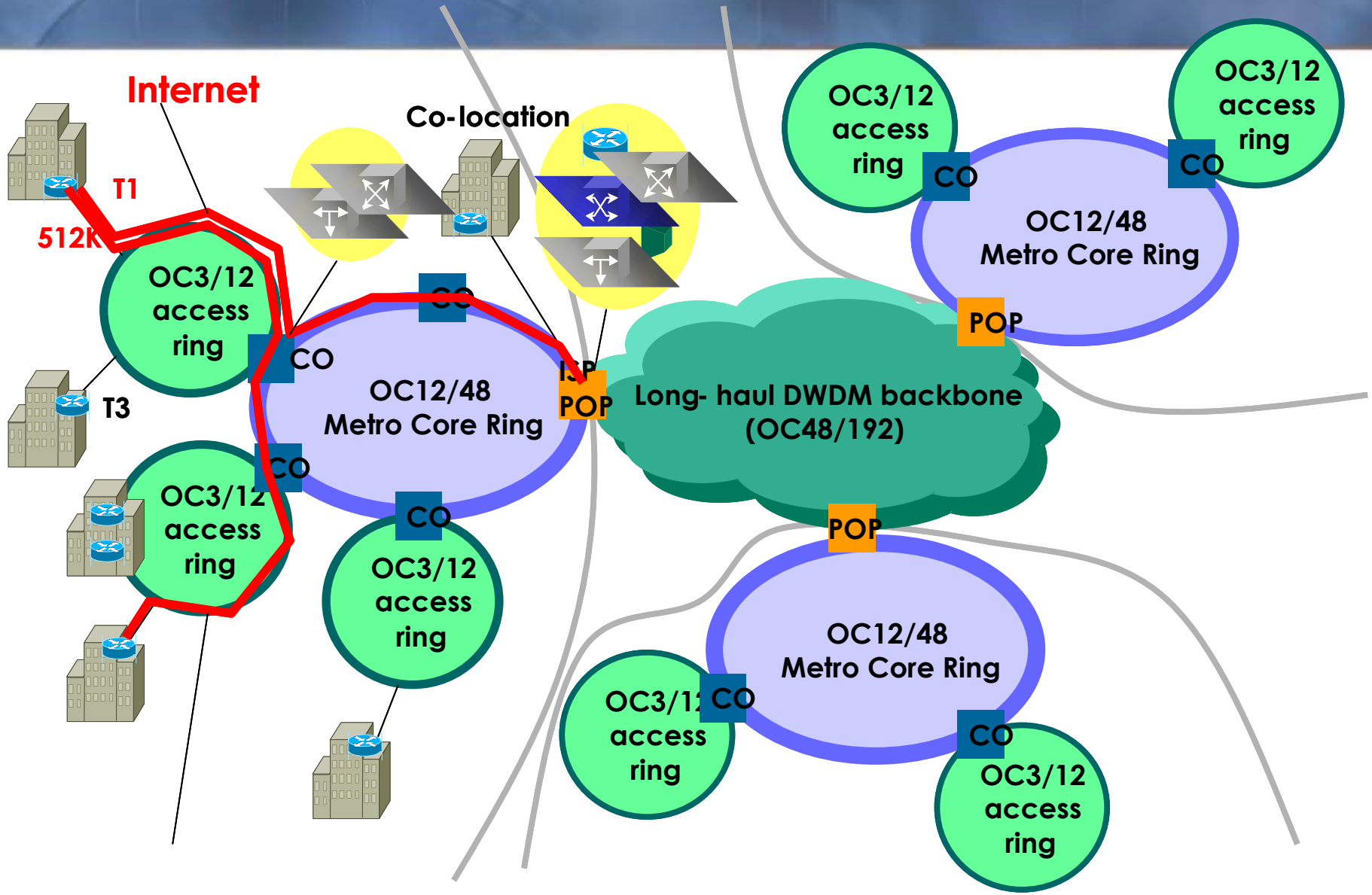


WDM: A Winner in Long Haul

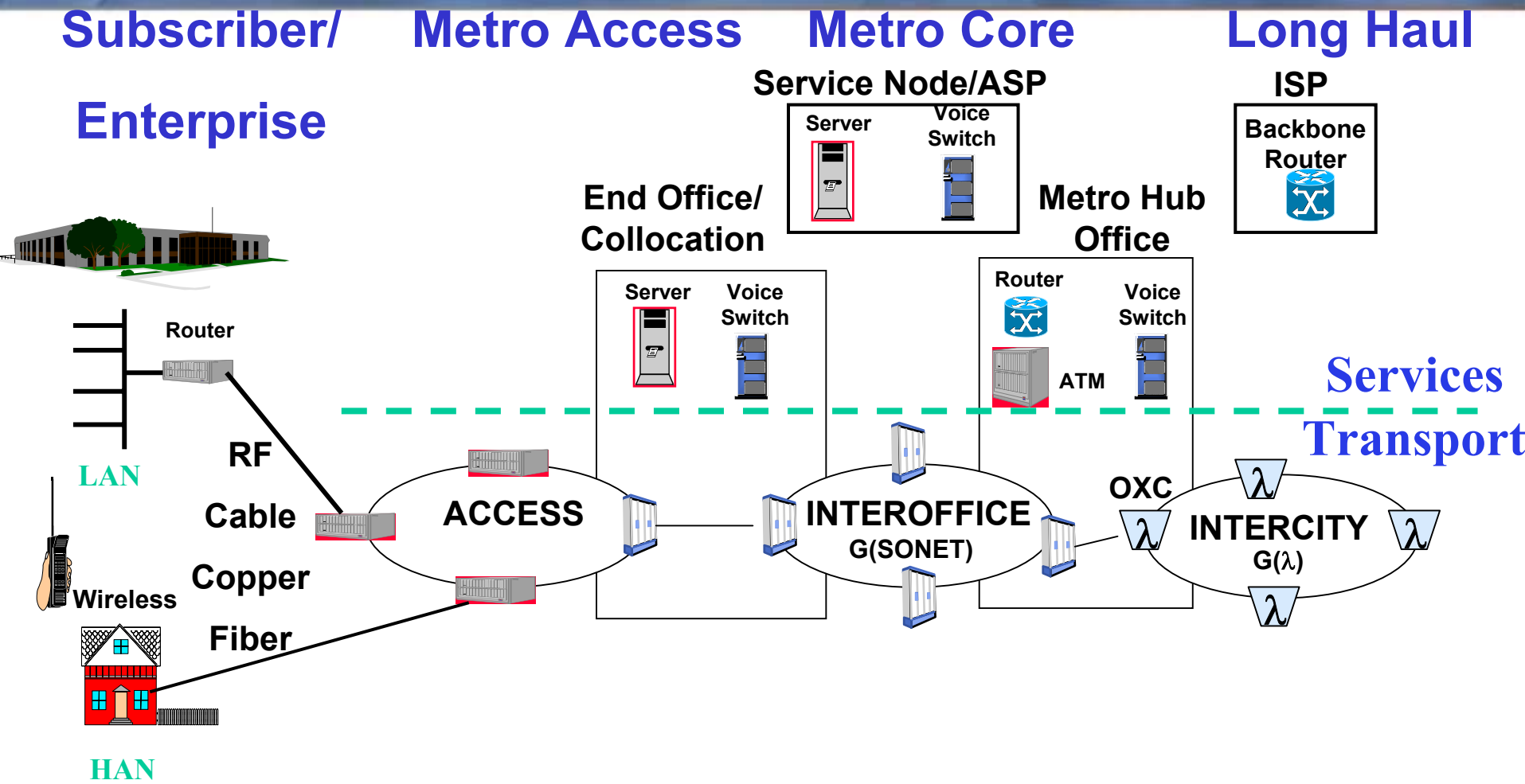


Source: Lucent Technologies and Bunch from Robertson Stephens.

Putting It All Together



2x4 Network Architecture



Some Observations

- **2x4 Network architecture**
  - Premise, access, metro, core
  - Transport and service layers
- **Optical vs. Copper**
  - Premise and access dominated by copper loops
  - DWDM very effective solution for long-haul
  - Metro is dominated by SONET