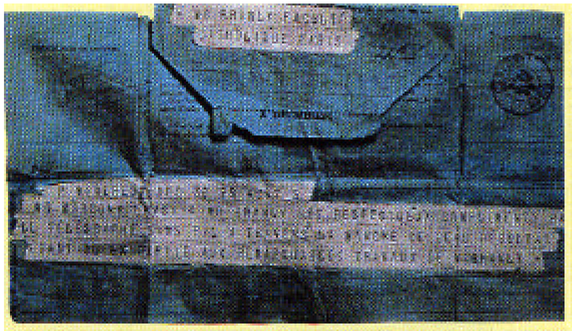
The Telephone Legacy

- Telephones and networks
  - history and how telephones work
  - the telephone network
  - limitations of telephone network for multimedia
  - what to expect from the telephone system in the future (will there ever be a video phone in your home?)

History - Wireless and Telegram



1895 - Guggielmo Marconi made first wireless transmission.

1899 - Marconi set up wireless station to communicate from England to France (50 km over the English Channel). Marconi Wireless Telegraph and Signal Company formed.

1900 - Radiotelephone developed by Reginald A. Fessenden demonstrated in December at Cob Point, Maryland.

1901 - Marconi made successful wireless transmission from Cornwall to St. Johns, Newfoundland, 3,200 km away (compare with mean radius of Earth = 6371 km).

1907 - all large ocean liners used Marconi equipment that allowed them to communicate in Morse code. When the Titanic struck an iceberg it radioed the Carpathia, 933 km away, and 705 people were saved.

1909 - Marconi awarded the Nobel Prize for Physics.

Wireless Today - Network Growth

1979 - Ericsson Co. introduces the cellular telephone in Sweden.

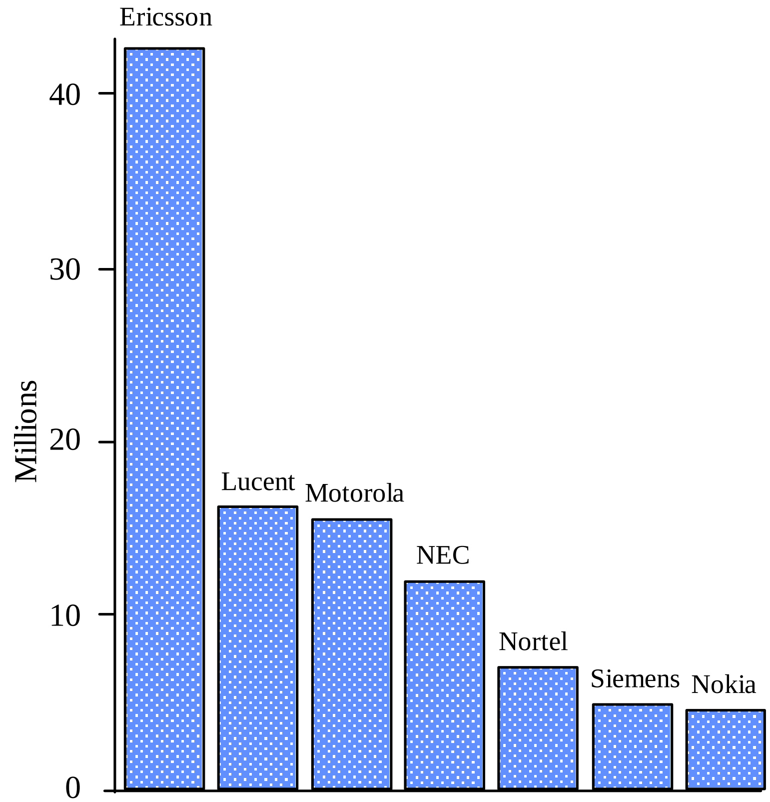
Ericsson projects that world mobile telephone users will increase from 110 million (mid 1996) to 450 million by the year 2000.

This represents a compound growth of greater than 40% per year over a four year period.

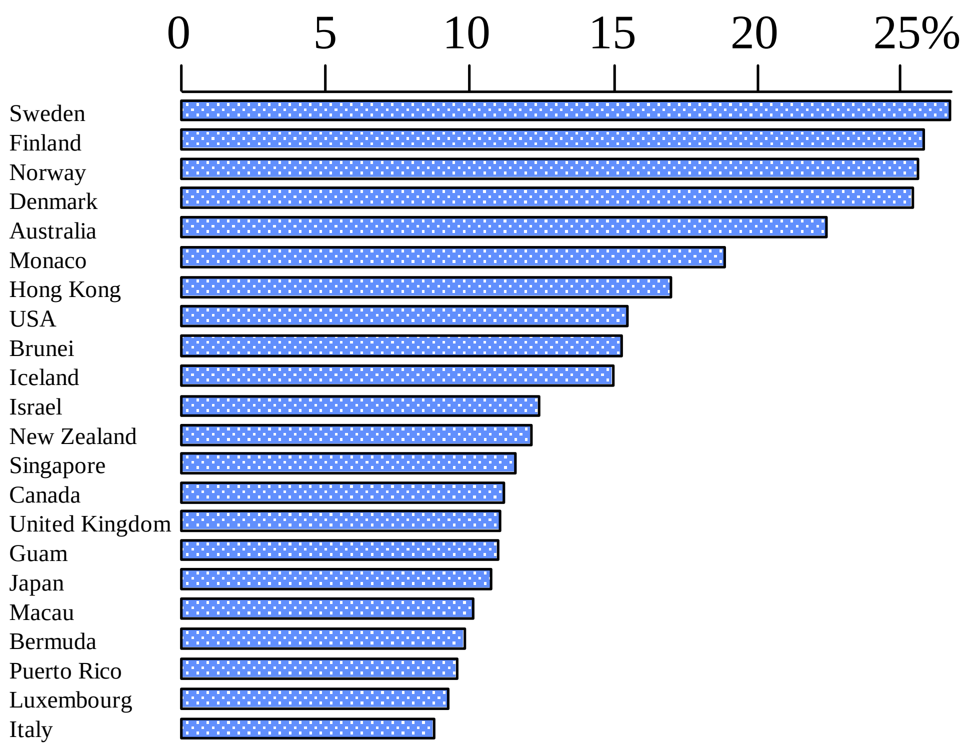
Companies such as Motorola ($28B total revenue in 1996) are expected to capture a significant fraction of this growth.

1997, May 5, Motorola successfully launched first five satellites of Iridium Telecom System designed as a world-wide satellite communication network.

World-wide wireless suppliers and subscribers



Wireless subscribers served by system suppliers
July 1996



Wireless telephone penetration by country
July 1996

The Invention of the Telephone

1876 - Alexander Graham Bell filed patent for telephone at noon, January 14, in NYC (Elisha Gray filed similar patent at 2.00 p.m.).

1878 - First manual telephone exchange New Haven, Connecticut with 21 subscribers (including Mark Twain).

1891 - Almon B. Strowger, a funeral director from Kansas City, filed a patent for the first automatic telephone exchange.

1924 - Research initiated by H. Nyquist results in “telephotography”, AT&T’s experimental fax machine.

1949 - Muirhead Ltd. installed first fax system in Japan for the Asahi Times. Commercially successful in Japan for transmitting ideograms. Worldwide market expanded in the 1970s.

1962 - The AT&T Telstar satellite launched by NASA on July 10.

William Gray and the Pay Telephone

1888 - 1902 Gray filed 23 patents for pay telephones with a slot for coins.

1891 - Gray Telephone Pay Station Company formed. The pay phone drove the telephone industry and helped create demand for household telephones.

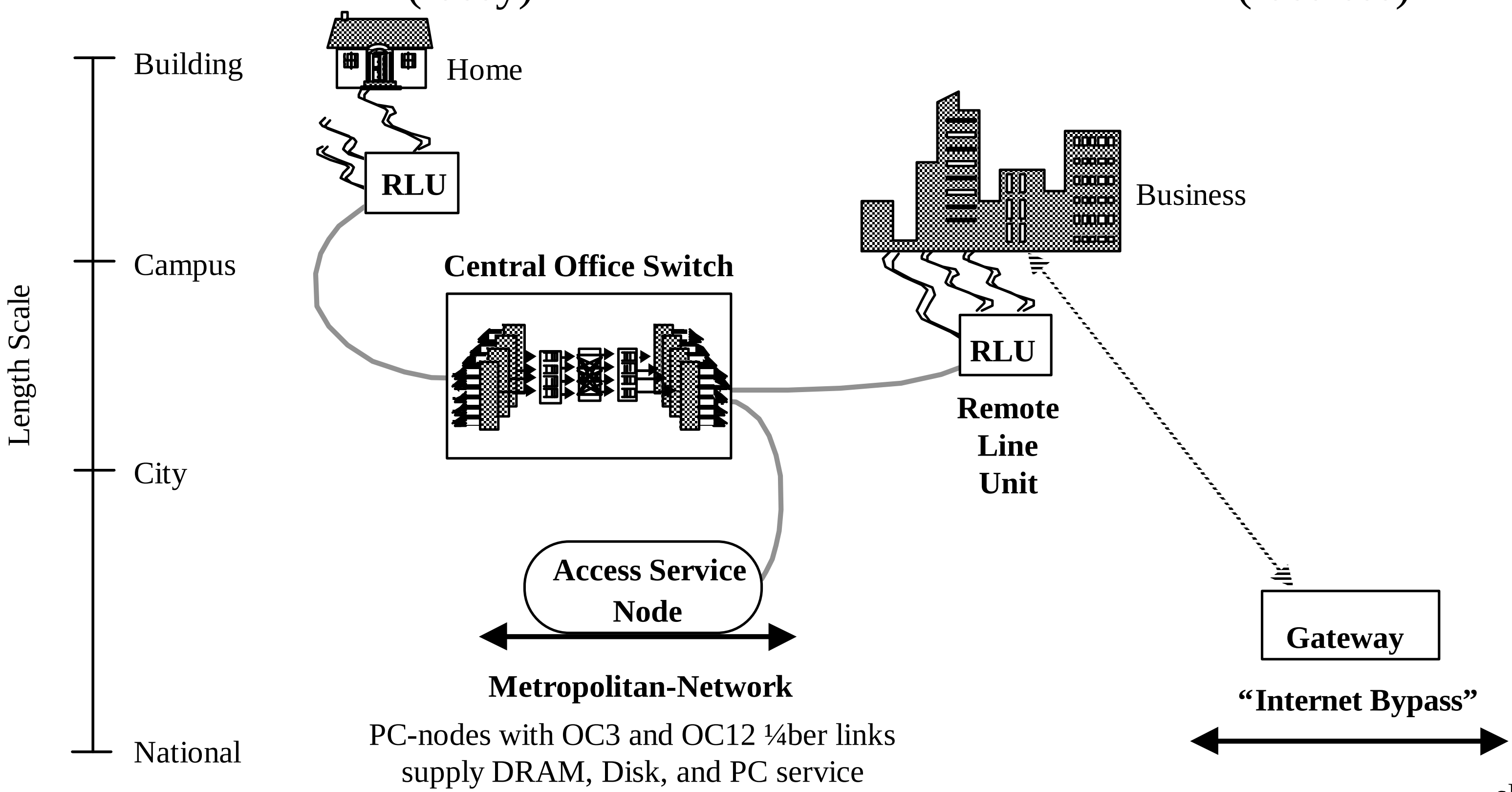
Use of telephones in World War II created consumer expectation and demand for telephones in every home.

Today 95% of households have telephones (98% have televisions).

The Telephone System

Audio/Video Distribution
(lossy)

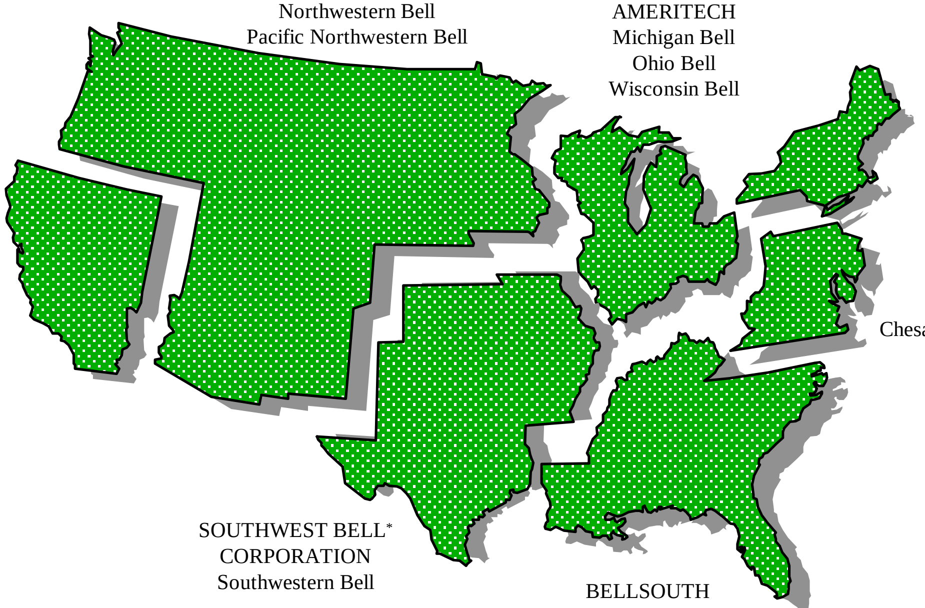
Data Distribution
(lossless)



Public and Private Networks

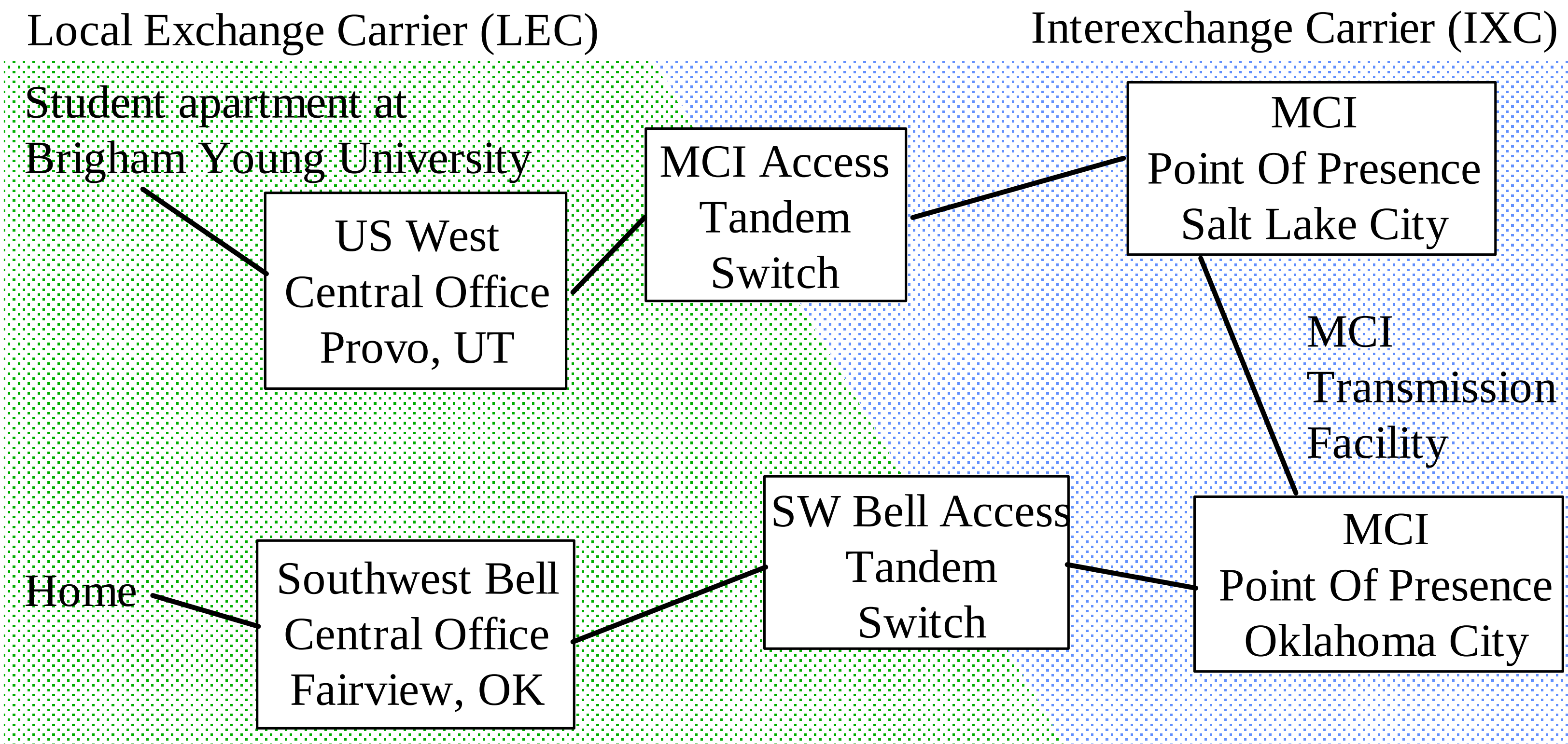
- Public Networks
  - Local Exchange (LECs) such as RBOCs created in 1984.
  - Interexchange Carriers (IXCs) such as AT&T, MCI, and Sprint.
  - Value Added Carriers (VACs) such as America Online and Compuserve. VACs handles management and maintenance of WAN services and does some protocol service.
- Private Networks
  - manages its own switching equipment. Usually large organizations.

The Regional Bell Operating Companies (RBOCs)



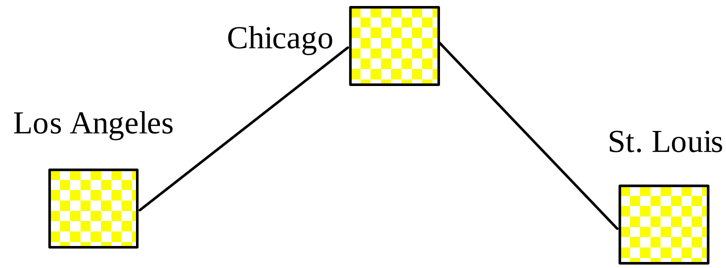
*SBC Communications Inc. of San Antonio, Texas, is the holding company for Southwestern Bell, Pacific Bell, Nevada Bell, and Cellular One. SBC Communications Inc. acquired Pacific Telisis Group April 1, 1997.

Example - Student Calling Home

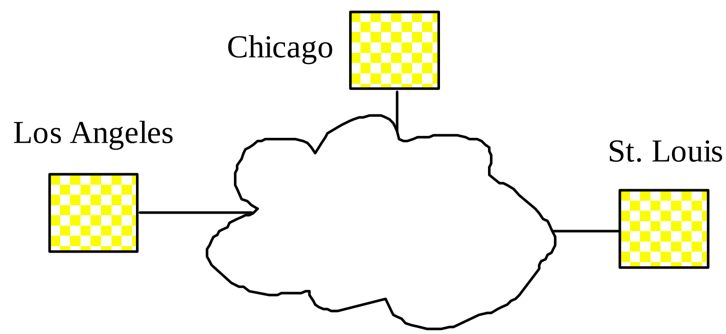


Access Tandem is switch to concentrate trunk calls from CO to IXC POP.
Total local access fees charged by LEC to IXC in the United States was $23B in 1996.

Dedicated and Switched Services



- Dedicated line service
  - permanent connection
    - can be expensive!



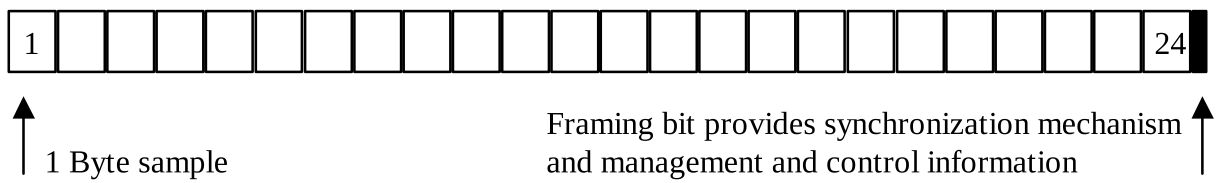
- Switched line service
  - circuit-switching service
    - traffic that requires fixed, guaranteed bandwidth such as delay sensitive video applications.
  - packet-switching service
    - bursty traffic that can withstand variable delays.

Digital Services

- Circuit switched service
  - Integrated Service Digital Network (ISDN)
  - Frame Relay
- Cell switched services
  - Asynchronous Transfer Mode (ATM)
  - Switched Multimegabit Data Service (SMDS)
- Dedicated digital services
  - T1 signaling at 1.544 Mb/s
  - T3 signaling at 44.736 Mb/s

T1 Digital Service

- 0.3 kHz - 3.4 kHz analog bandwidth sampled at 8 kHz with 8-bit resolution (2^8 = 256 levels) gives 8000 X 8 = 64 kb/s per voice channel (DS0). For voice traffic may only use 7 of the 8 bits and use 1 bit for encoding
- T1 frame is 24 X DS0 time division multiplexed full duplex circuit

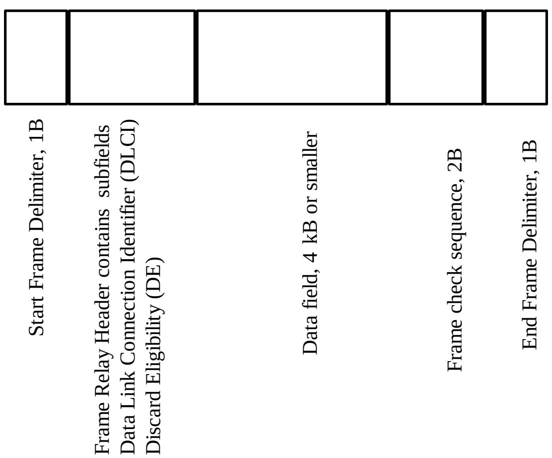


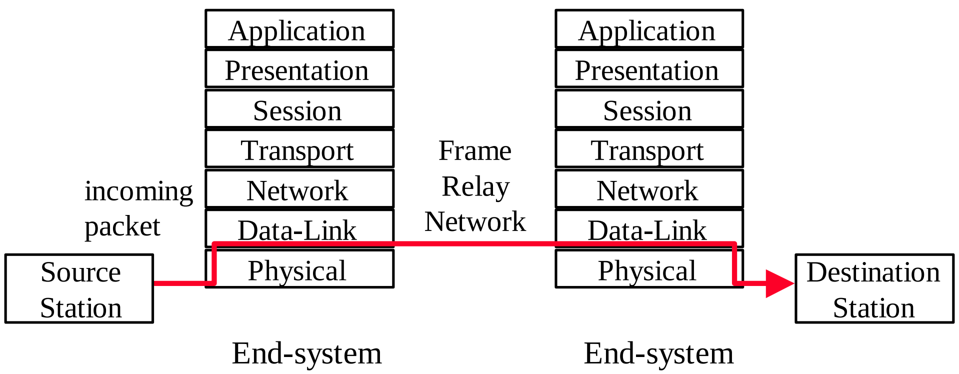
- 24 X DSO + frame = (24 X 8 X 8000) + (1 X 8000) = 1.544 Mb/s
- Digital Cross-connect System allows any DS0 from one T1 line to be connected to any other T1 line without additional multiplexing or switching
- T3 = 672 X DS0 + frame = 44.736 Mb/s (i.e. T3 ~ 28 X T1)

For a tutorial on T1 cabling and signaling see http://www.laruscorp.com/

Frame Relay

1989 - Frame Relay introduced as part of Integrated Services Digital Network (ISDN). Assumes network is quite reliable. Frame relay switch routes incoming frames to correct output port, checks Frame Check sequence field and discards packets with errors, checks if switch buffers are full and if so discards packets. There is no flow control. Multiplexed, connectionless, packet switched Permanent Virtual Circuits (PVCs). PVCs connect two ports which remain active and provide Committed Information Rate (CIR).





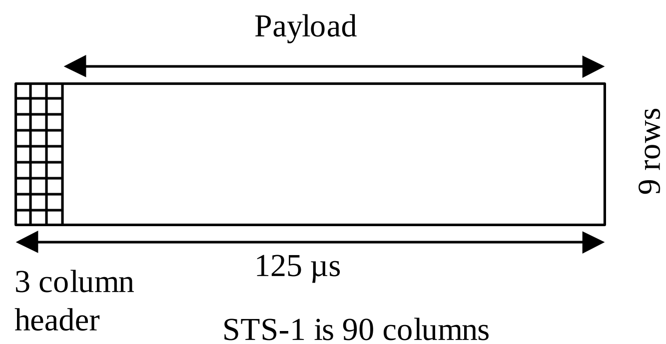
Synchronous Optical Network (SONET)

SONET is a clock-based frame transmission ANSI standard developed by Bellcore for digital transmission over fiber

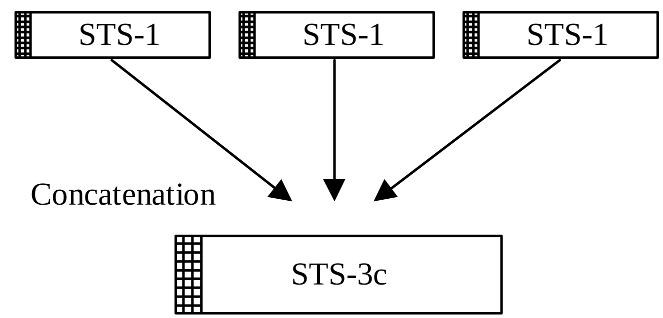
Coding is NRZ data and an XOR with a 127 bit-long scrambling pattern to ensure a large number of transitions which can be used for clock recovery

Fixed frame time of 125 µs defines frame size for different clock rates, e.g. Synchronous Transport Signal STS-1 at 51.84 Mb/s = 810 Bytes long, STS-2 at 155.52 Mb/s = 2430 Bytes long and STS-48 at 2488.32 Mb/s = 38880 Bytes long

Concatenation of three STS-1 frames gives a STS-3c frame



Each column is a Byte wide so that a STS-1 frame is 9 X 90 = 810 Bytes
First two Bytes of each row is frame start delimiter



Growth in SONET Transmission Equipment Market

Telecommunication vendors are committed to SONET for long-distance transmission. The North American Synchronous Optical Network (SONET) transmission equipment market will grow at a compound annual growth of 12% from $5B in 1996 to $11B in 2003.

Year	Total North American Revenue ($ billion)
1996	4.97
1997	5.80
1998	6.79
1999	7.66
2000	8.41
2001	9.20
2002	10.06
2003	10.96

Asynchronous Transfer Mode (ATM)

1988 - initiated as part of ISDN by Consultative Committee for International Telegraph and Telephone (CCITT)

1991 - ATM Forum to reach agreement on interfaces in North America. Participants include vendors, carriers, and users.

ATM is cell switched, connection oriented, full duplex, point-to-point protocol using asynchronous time division multiplexing (TDM) to control flow

The 53 Byte fixed length cells consist of 5 Byte header and 48 Byte payload (5X8 + 48X8 = 424 bit)

5 Byte header	48 Byte data payload

Header contains address information in form of a virtual circuit connection (VC)

PVC - permanent virtual circuit for dedicated bandwidth

SVC - switched virtual circuit sets up circuit as needed by the application

ATM strengths

- **Small fixed-length cells**

  Easier to build hardware for processing fixed cells

  - buffer size, segmentation and reassembly

  Easier to implement hardware that can process in parallel

  - large parallel scaleable systems with identical switch elements
- **Comprehensive framework for traffic management**

  Queue output time per cell small and fixed allowing fine control of queues

  - control of delay and jitter important for multimedia
- **QoS support (definition, enforcement, implementation)**

4	8	16	3	1		384 (48 Bytes)
GFC	VPI	VCI	Type	CLP	HEC (CRC-8)	Payload

User-Network Interface (UNI) cell format:

GFC - Generic Flow Control arbitrates local access to shared medium. Part of VPI in Network-Network Interface (NNI) cell format

VPI - Virtual Path Identifier

VCI - Virtual Circuit Identifier

Type - reserved for management, valid data, switch congestion indication, AAL5 frame deliniation

CLP - Cell Loss Priority indicates which cells can be droped in case of network overload

HEC - Header Error Check to protect integrity of header

Payload - data

Virtual Circuit Switching

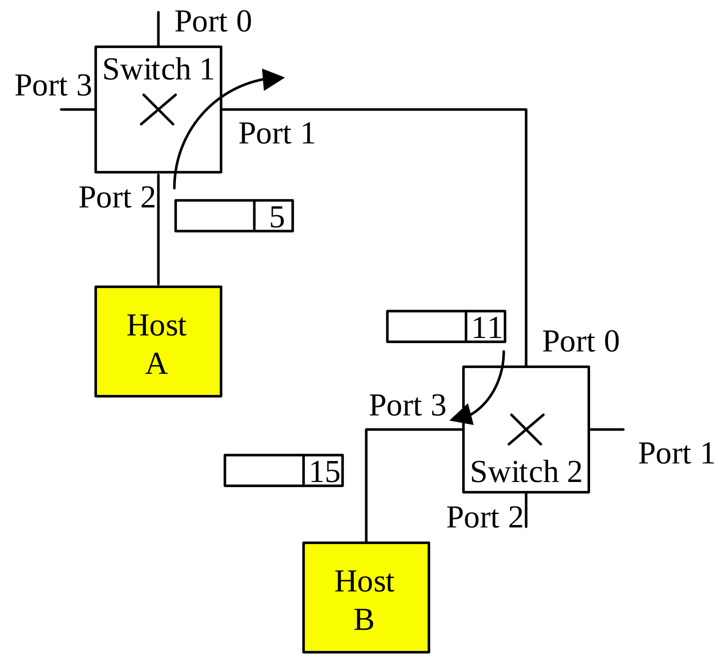
Connection oriented virtual circuit conducive to hop-by-hop flow control protocol in which QoS resources such as switch buffers and bandwidth are allocated at each switch.

Connection request from host A to host B contains address for B and a VCI (in this case 5) which switch 1 uses to identify future packets that A wants to send to B.

Switch 1 assigns new port and VCI for link from switch 1 to switch 2 and creates lookup table for routing future packets from host A.

Connection request makes its way through network to B which accepts (or rejects) the connection and sends notice back to A.

Connection is terminated by sending a teardown message which deletes the lookup tables throughout the network



Switch	input port	incoming VCI	output port	outgoing VCI
1	2	5	1	11
2	0	11	3	15

Quality of Service

During connection setup the end stations can request bandwidth allocation from the switched network. The ATM User to Network Interface (UNI) is used to establish dedicated levels of bandwidth to stations and applications.

CBR - Constant Bit Rate. Useful in multimedia applications for time sensitive traffic such as video, audio or interactive sessions requiring rapid response (virtual reality applications for example). CBR easiest to implement with PVC.

VBR - Variable Bit Rate. Realtime and non-realtime. Useful for LAN Emulation and attaching to best-effort legacy networks such as Ethernet

ABR - Available Bit Rate. Best effort service based on Mimimum Cell Rate (MCR) with low cell loss

UBR - Unspecified Bit Rate. Makes use of excess bandwidth. Subject to increased cell loss and discard of complete packets

ATM Adaptation Layers

ATM Adaptation Layer (AAL) interprets data from higher levels and deals with segmentation and reassembly.

AAL sits between ATM and variable length packet protocols such as IP.

Different AAL are provided for different services. Adaptation layer of interest to computer and multimedia applications is AAL5 which can pass large variable size packets.

AAL5 encapsulates ATM data payload into Protocol Data Units (PDUs) in the convergence sublayer and segments PDUs into cells in the segmentation and reassembly (SAR) sublayer. Dedicated SAR hardware (needed to do this efficiently) increases the cost of network adapters. AAL5 reduces overhead by providing error cheking on complete packet.

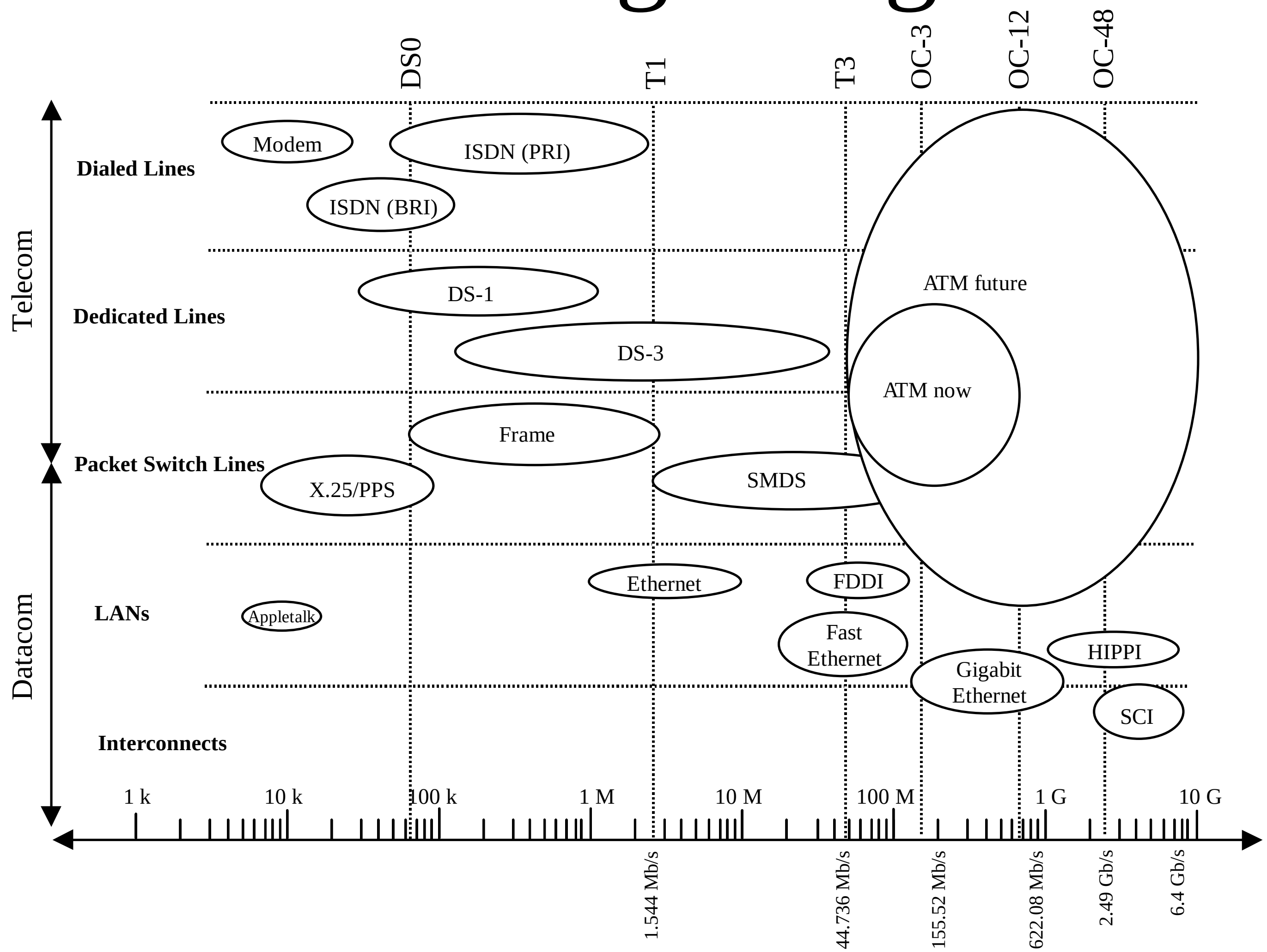
< 64 kB	0 - 47 Byte	16	16	32
Data	Pad	Reserved	Length	CRC-32

ATM and ISO - OSI Reference Model

- Relation among the ISO-OSI and ATM reference models

Application	ATM adaptation layer
Presentation	
Session	ATM adaptation layer (AAL) Consists of: (i) Convergence sublayer (ii) Segmentation And Reassembly (SAR) sublayer
Transport	
Network	ATM layer
Data-Link	
Physical	Physical

Network Signaling Rates



Undersea Telegraphic Cable

1837 - Samuel F. B. Morse applied for electric telegraph patent, September 28.

1847 - Werner von Siemens developed machine to apply gutta-percha onto cables for insulation.

1850 - use of copper wires twisted to form single strand for strength, covered in tar-cloth and reinforced with ten galvanized wires, resulted in reliable undersea telegraphic cable between England and France.

1866 - July 27, first transatlantic cable completed. Cyrus Field (U.S., 1819 - 1892) spent his entire fortune on the project (the first four attempts failed).

Undersea Telephone Cable

1956 - first transatlantic telephone cable link, September 26. It was a joint project of American Telephone and Telegraph, British General Post Office, and Canadian Overseas Telecommunications. The cable had a capacity that could handle 588 simultaneous transatlantic telephone conversations.

1988 - first fiber-optic transatlantic Telephone cable, TAT-8. The cable is 6,600 km long and has a capacity of 37,500 simultaneous telephone conversations. This is a joint project of AT&T, British Telecom International, and DGT of France.

Today Optical Networks Span the Globe

- Intercontinental networks using new fiber-optic technology carry huge amounts of data around the world.
- New intercontinental fiber-optic systems are configured as networks.
- The corporations that own the networks anticipate very large profits.

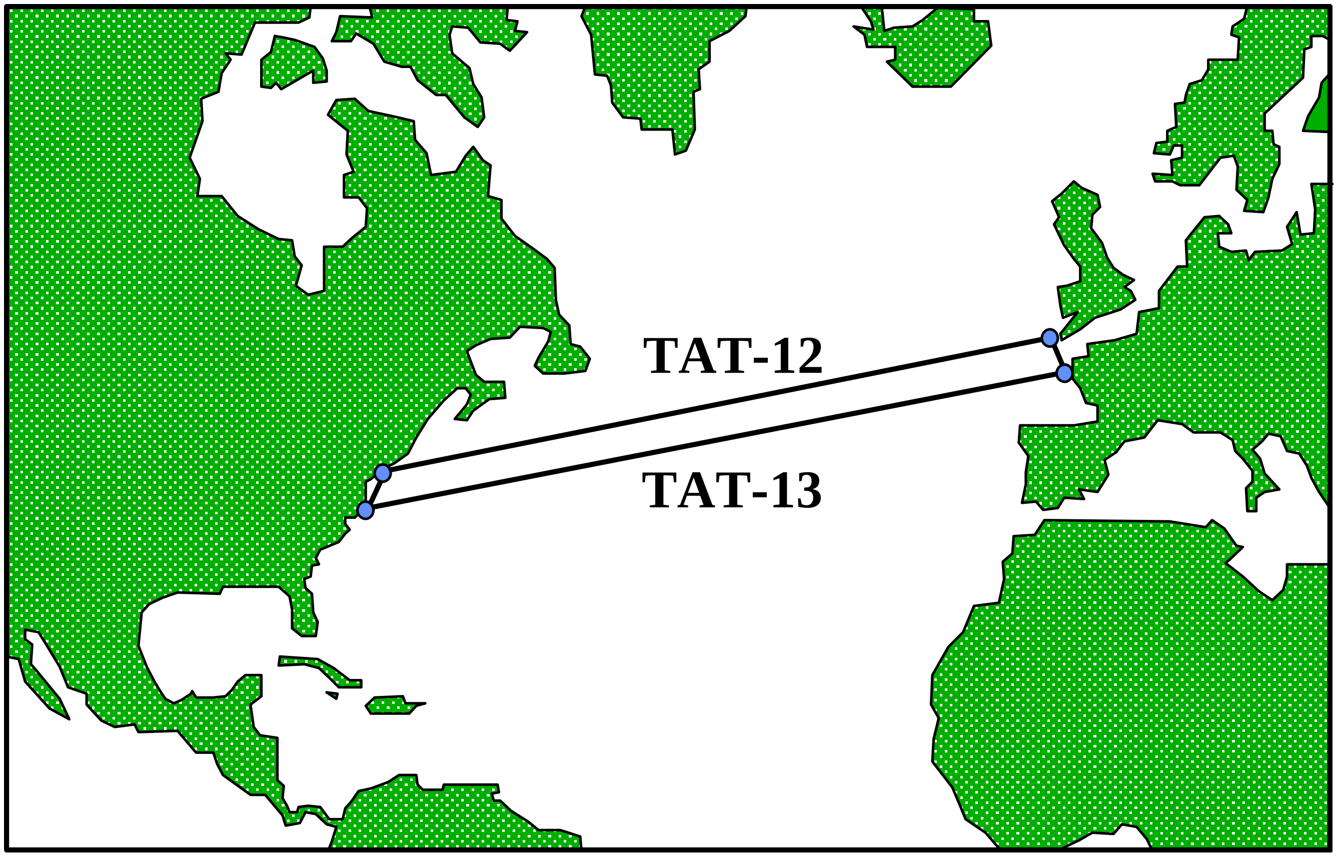
New Fiber-Optic Technologies

- 1987 - Robert Mears and colleagues at Southampton University (UK) invent the Erbium-doped fiber-optic amplifier for use in systems operating with signaling near λ = 1500 nm wavelength
- Wavelength Division Multiplexing (WDM) increases capacity by adding signals at adjacent optical wavelengths and transmitting through the **same** glass fiber

First Intercontinental Network using Fiber-Amplifiers

- Trans-Altlantic Telephone (TAT) 12 and 13 Undersea Cable
- TAT-12/13 is self-healing ring network linking USA, UK, and France
- Began to carry traffic October, 1995
- Two fiber pairs in each cable, each pair transfers data at 5Gb/s
- Total length of ring = 14,000 km
- Fiber-optic amplifiers every 45 km

Submarine Cable: TAT-12/13



TAT-12/13 as a Revenue Source

- Cost $750M to install and 25 year expected lifetime
- Capacity = 300,000 simultaneous voice channels
- Assuming $1 per minute revenue per telephone call TAT-12/13 could generate $18M per hour at peak capacity or revenue equal to total installation cost in less than 2 days of operation!
- Assuming average of 10% of peak capacity, revenues exceed installation cost within 3 weeks of operation

TAT-12/13 with Competitive Pricing

- Assume 15% return on investment so principle and interest = $115M per year
- Cable maintenance and R&D = $85M per year
- Management of accounts = $50M per year
- Average 10% of peak capacity used = 30,000 simultaneous telephone calls 24 hours per day on average
- Cost of transatlantic portion of telephone call is less than $0.016 per minute!

The Trans-Pacific Cable TPC-5

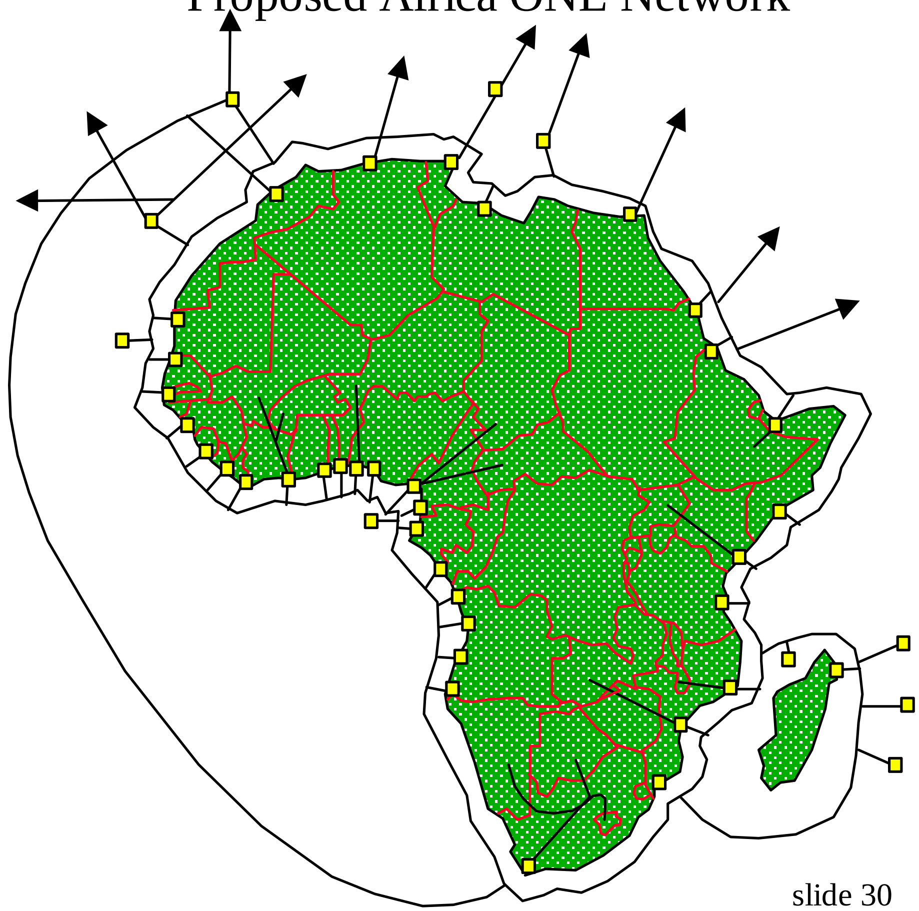
- TPC-5 links the USA and Japan
- Began to carry traffic in early 1996
- TPC-5 is 20,000 km long
- Used in July of 1996 to transmit video of the Olympic games held in Atlanta to Japan and the rest of Asia

Future Fiber-Optic Networks

- Fiber Link Around the Globe (FLAG) is a privately owned consortium lead by NYNEX to link 12 sites along a 29,000 km undersea cable route connecting Europe, North Africa, India, Asia and Japan.
- Africa ONE is a ring around Africa proposed by AT&T and Alcatel. The 39,000 km long undersea cable has an estimated cost $2.65B. Awaiting financial backing from World Bank.

For more information http://www.att.com/africaone/

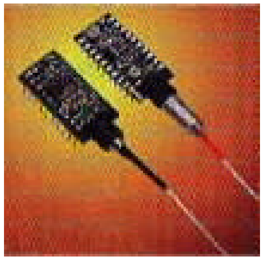
Proposed Africa ONE Network



Recent Telecommunication Corporation News

- 4.12.97 - Tyco International Ltd. said it agreed to buy AT&T Corp.'s underwater telecommunications cable business for about $850M
- 5.27.97 - Wall Street Journal reports AT&T and SBC in $50B merger talks (talks break down after a few weeks)
- 6.18.97 - Philips Electronics and Lucent Technologies merge consumer telecommunication equipment operations to create worlds largest supplier of telephones with $2.5B in sales
- 7.7.97 - US Justice Department clears $24B purchase of MCI Communications by British Telecommunications. New company called Concert would have annual revenue of $43B from operations in 72 countries.
- 8.22.97 - British Telecommunications lowers MCI purchase price to $17B after MCI reveals greater than expected cost of entering local US market.

Laser Diodes

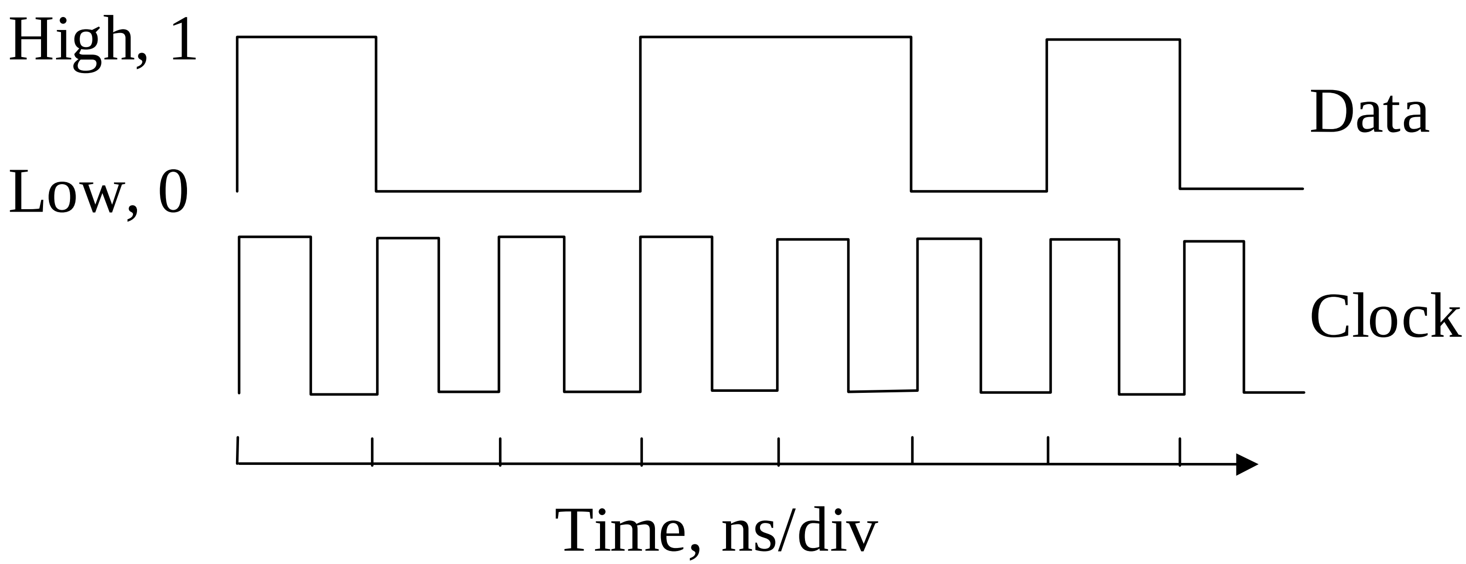


- 1958 - Basic principles of Light Amplification through Stimulated Emission of Radiation (LASER) described by A. Shawlow and C. H. Townes
- 1962 - Semiconductor laser diode demonstrated. Made possible use of a small electrically driven device with intense optical emission at one wavelength to transmit information
- 1970 - CW laser diode operation at λ = 850 nm wavelength
- 1979 - CW laser diode operation at λ = 1550 nm wavelength

- Telephone companies typically use laser diodes operating at λ = 1550 nm wavelength (low transmission loss in standard glass fiber) or λ = 1310 nm wavelength (zero chromatic dispersion in standard glass fiber)
- Local Area Networks will increasingly use inexpensive Vertical Cavity Surface Emitting Laser (VCSEL) diodes with λ = 850 nm (ATM Forum standard)

Optical Signaling

Gb/s Non-Return to Zero (NRZ)

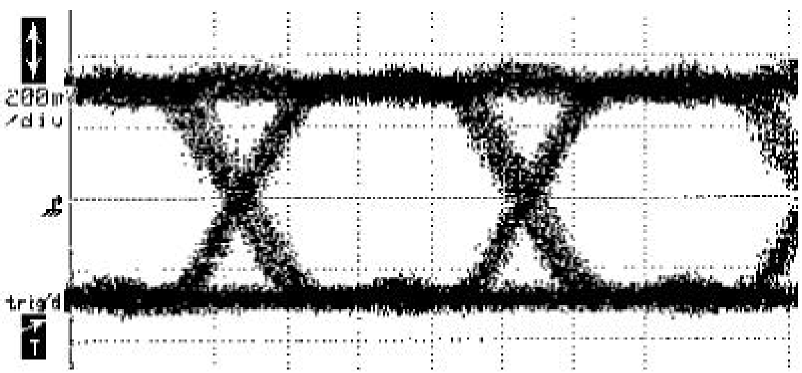


"Eye Diagram" generated on oscilloscope triggered by data clock.
Effectively, all transitions are folded into one time slot.

Gb/s Eye Diagram of VCSEL

- New technology has sub-mA drive current
- VCSELs used in LAN applications:
  - ATM/SONET
  - Gigabit Ethernet/Fiber Channel

History of the Vertical Cavity Surface Emitting Laser
1979 - Invented in Japan
1980s - Improved at AT&T Bell Laboratories and Bellcore
1990 - 1999 - Developed by US Government / Industry partnership
1997 - Commercial product in US



200 ps/div

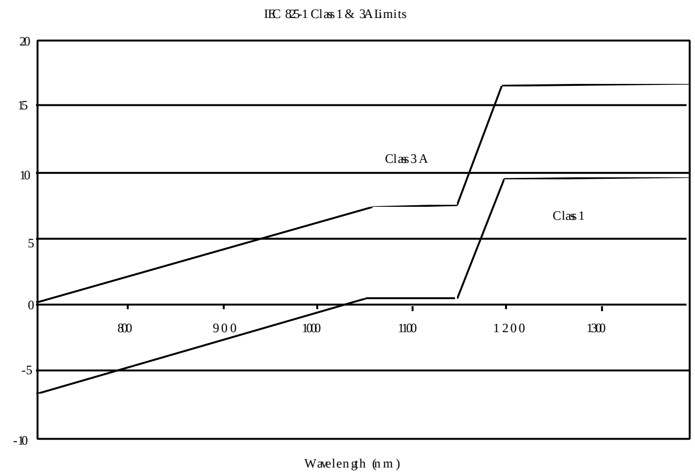
1.25 Gb/s (800 ps/bit)
2^{31}-1 NRZ PRBS
No errors

Eye-opening:
560 ps (70%) / 385 mV at 10^{-7} BER

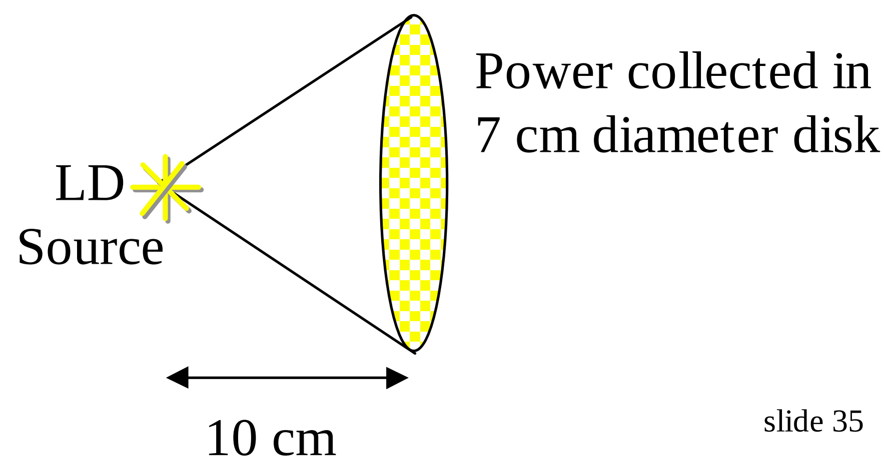
Maximum bit rate:
1.7 Gb/s at 10^{-9} BER

Laser Diode Eye Safety

International Electrotechnical Commission (IEC) Radiation Safety of Laser Products:



- Class 1
  - considered inherently safe
- Class 3a
  - not safe viewed with optical instruments
- Class 3b
  - dangerous radiation

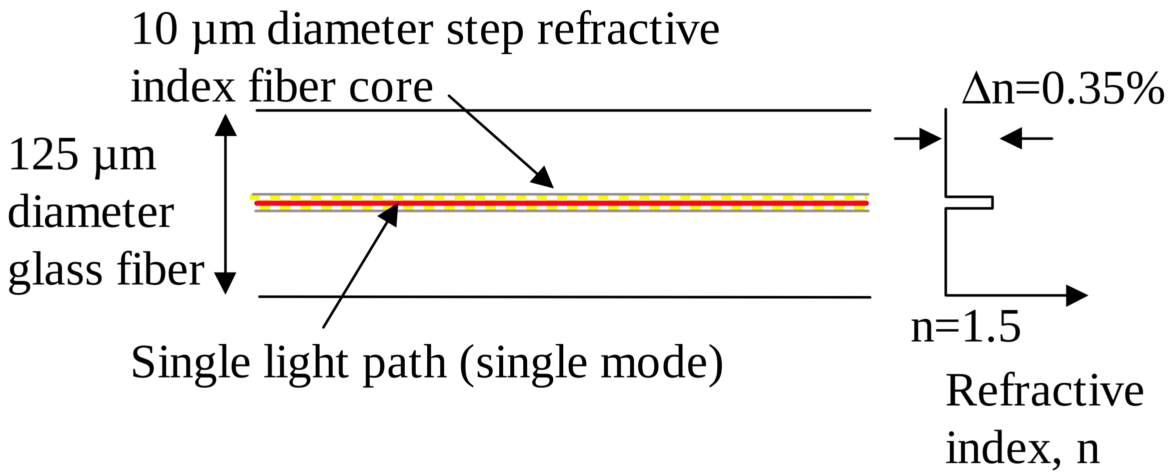


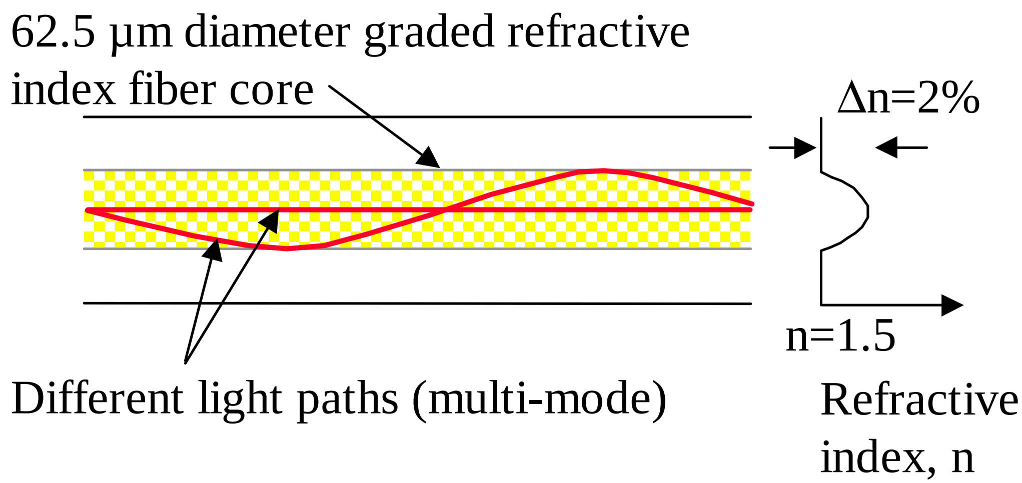
Silica Glass Fiber

- 1977 - Installation of first fiber-optic telephone link 2.4 km long under downtown Chicago

- SiO_2 125 µm diameter glass fiber with Ge-doped core used to guide laser light
- 250 µm diameter acrylate coating to protect glass
- Single Mode (SM) for very high performance
- Multi-Mode (MM) for low-cost short links
- Bare glass fiber is priced at $0.10 - $0.25 / m
- Connectorization price is $10 - $25 each end (FC, SC, ST)

SM and MM Glass Fiber



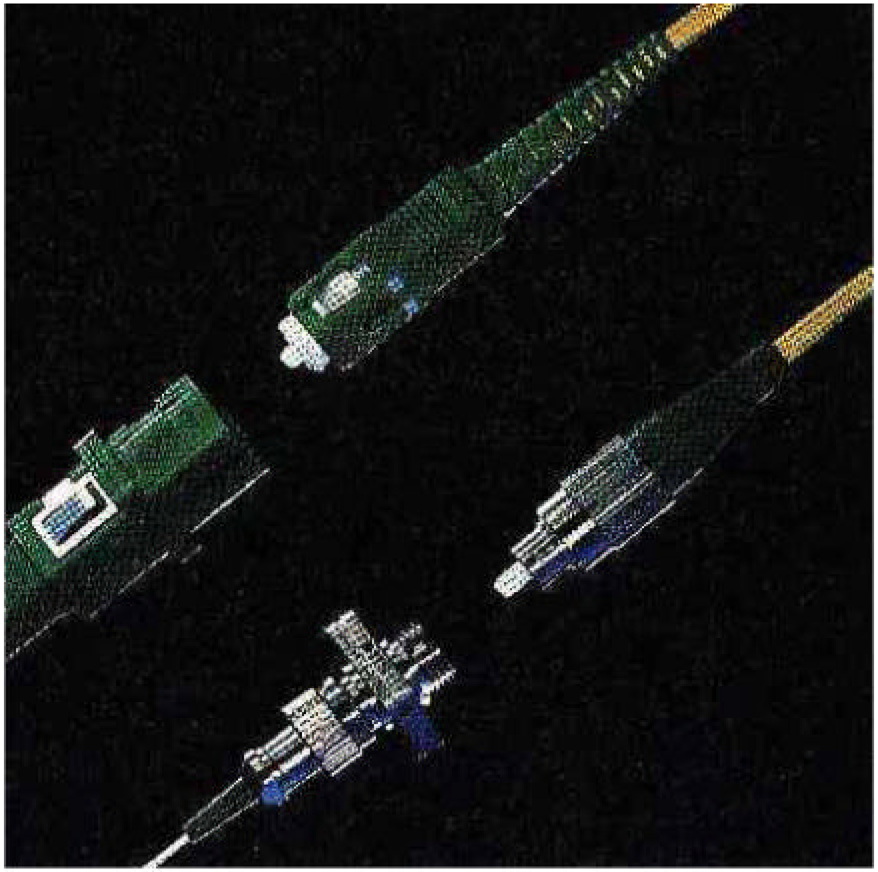


Light travels faster at edge of core to minimize modal dispersion resulting from different light paths (modes)

Fiber Connectors

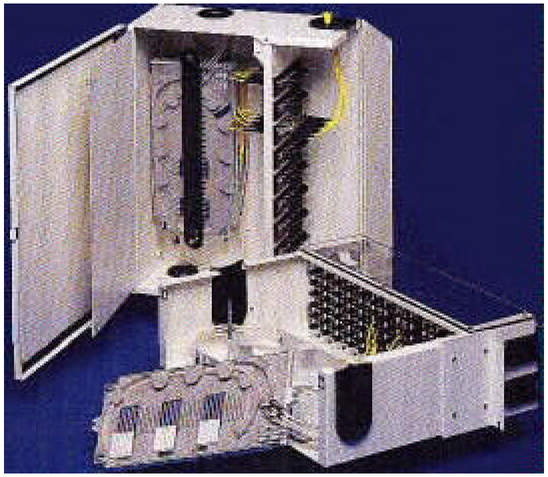
SC - MM simplex and duplex fiber cable

FC - SM simplex fiber cable



Building Wiring and Fiber Distribution Box

- Transition building wiring to user wiring using distribution box



Fiber Technology

Examples:

Corning 62.5/125µm CPC3 Multi-Mode Local Network Fiber

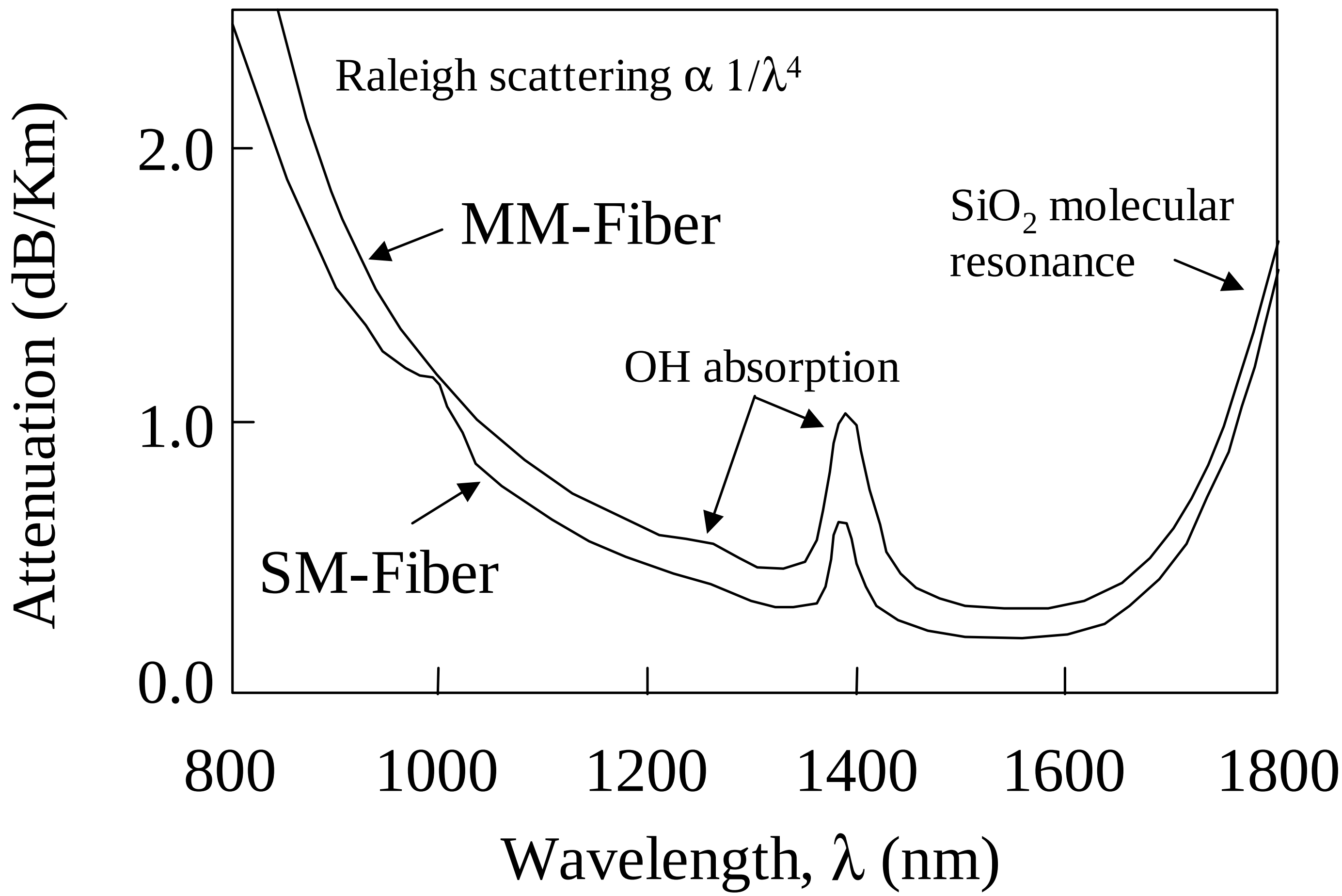
Corning SMF-28 CPC3 Single-Mode Fiber

Optical Specifications:

- Standard Attenuation Cells
- Chromatic Dispersion
- Modal Dispersion
- Standard Bandwidth Cells

Mechanical and Environmental Specifications:

Wavelength Dependence of Attenuation

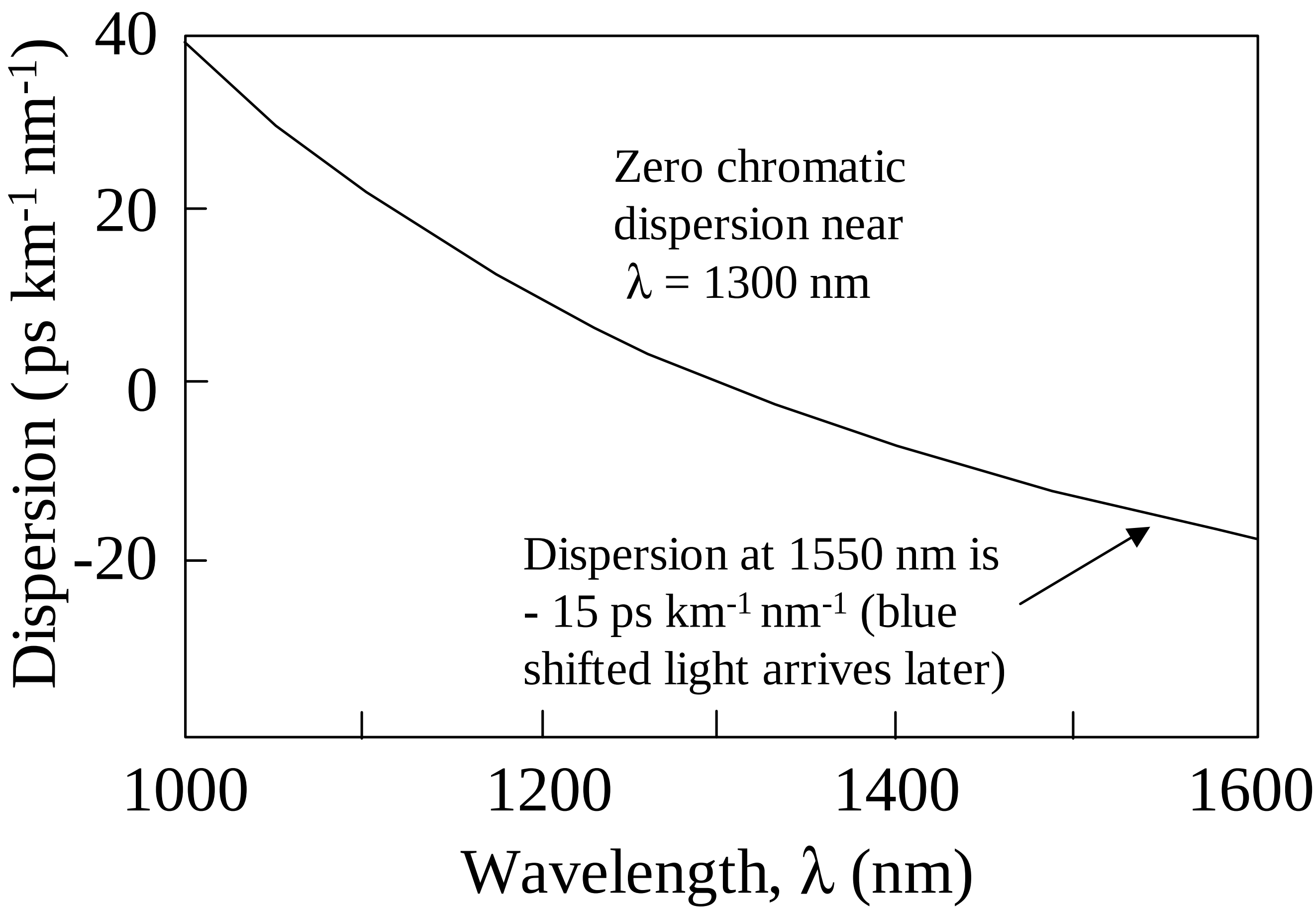


Standard Attenuation Cells

Example: Corning 62.5/125 CPC3 Multi-Mode Fiber

Attenuation Cells [dB/km]					
850 nm		1300 nm		850/1300 nm	
<2.5	<3.0	<0.6	<0.7	<2.8/0.6	<3.0/0.7

Chromatic Dispersion

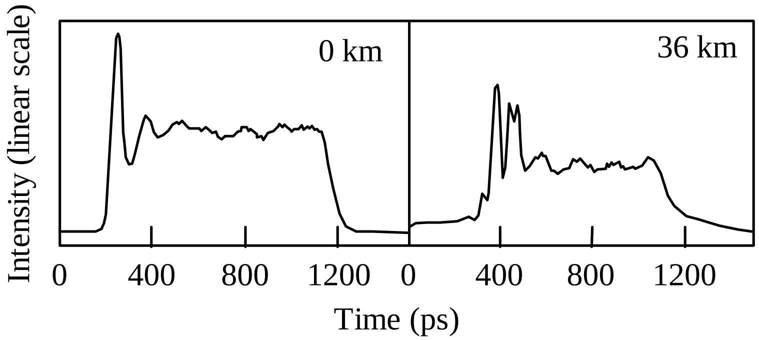


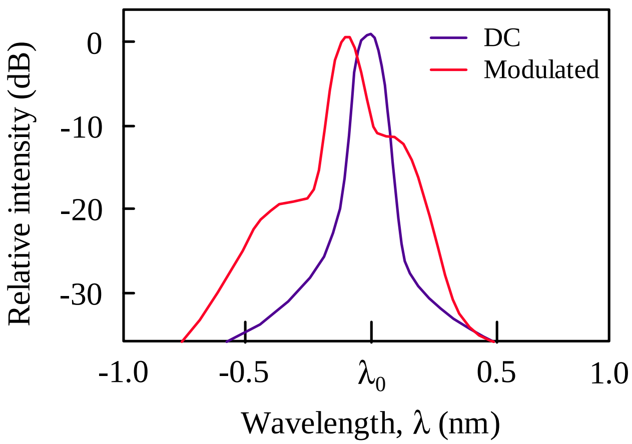
Limitations of NRZ transmission using SM Fiber

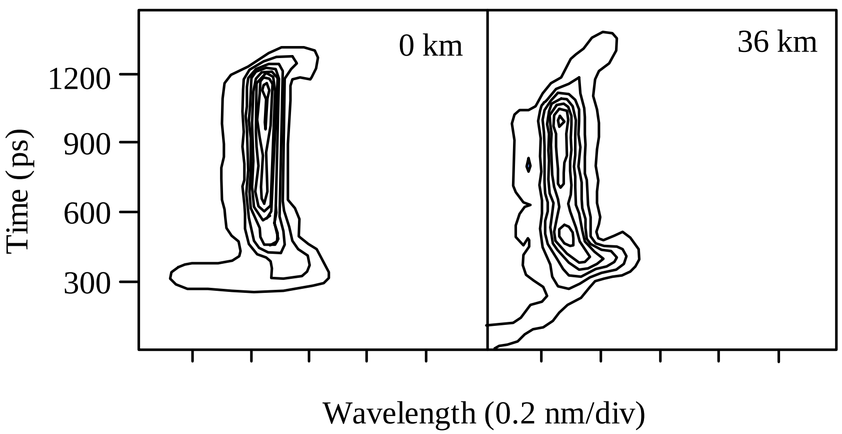
- Attenuation lowest near λ=1550 nm wavelength. (0.2 dB/km means the signal has 50% of the initial power after traveling 15 km)
- Chromatic dispersion near λ=1550 nm wavelength limits 2.5 Gb/s spans to around 45 km
- Regenerator spacing can be increased by using dispersion shifted fiber or by dispersion management

Example of Signal Degradation

Transmission experiment over
36 km of standard SM fiber
DFB $\lambda_0 = 1560$ nm
1.7 Gb/s, 2^{15}-1 50% mark ratio PRBS
IEEE Trans. Phot. Tech. Lett. **3**, 1150 (1991)







Modal Dispersion

- Only applies in MM fibers
- Broadening of optical pulse due to fact that different fiber modes travel at different effective speeds
- Dominates bandwidth of typical MM fiber

Standard MM Bandwidth Cells

Example: Corning 62.5/125 CPC3 Multi-Mode Fiber

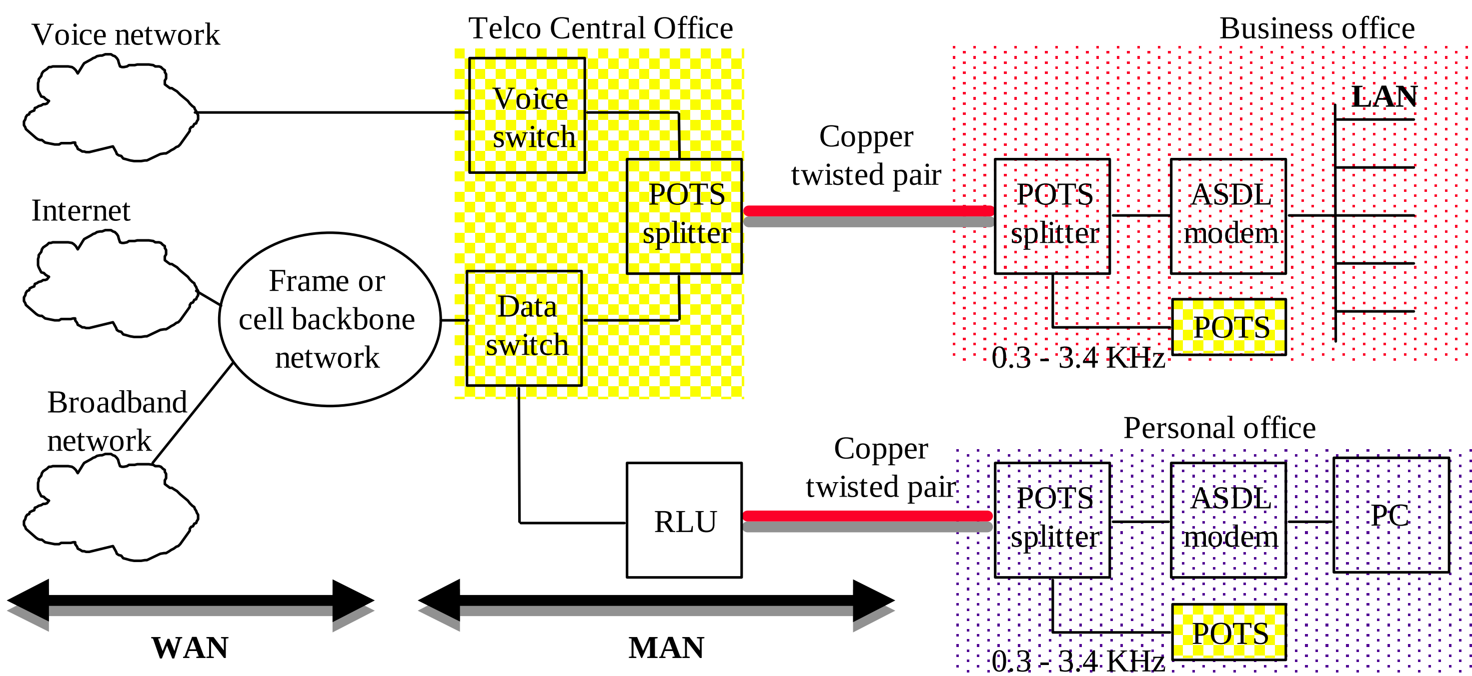
Bandwidth Cells [MHz•km]					
850 nm		1300 nm		850/1300 nm	
>160	>200	>200	>600	>160/200	>200/600

Broadband over Copper Wires

Digital Subscriber Line (xDSL) technologies provide point-to-point public network access over twisted-pair copper wire on the loop between a network service provider central office and the customer site.

Supports internet access, online services, TV, and POTS.

Example: Asymmetric Digital Subscriber Line (ADSL) 7 Mb/s down stream 1 Mb/s upstream for distances up to 3.6 km (12,000 ft) 24-gauge copper twisted wire



ADSL Modulation

Today there are two competing Asymmetric Digital Subscriber Line (ADSL) modulation schemes which are variants on Quadrature Amplitude-phase Modulation (QAM). Conventional QAM on a carrier uses changes in amplitude and phase to create symbols which can be transmitted at a lower baud rate than the actual data rate. This is an efficient use of available bandwidth and an excellent way to transmit high-speed data over copper wires. ADSL is leveraging the QAM signaling techniques that have been used for many years in wireless communication.

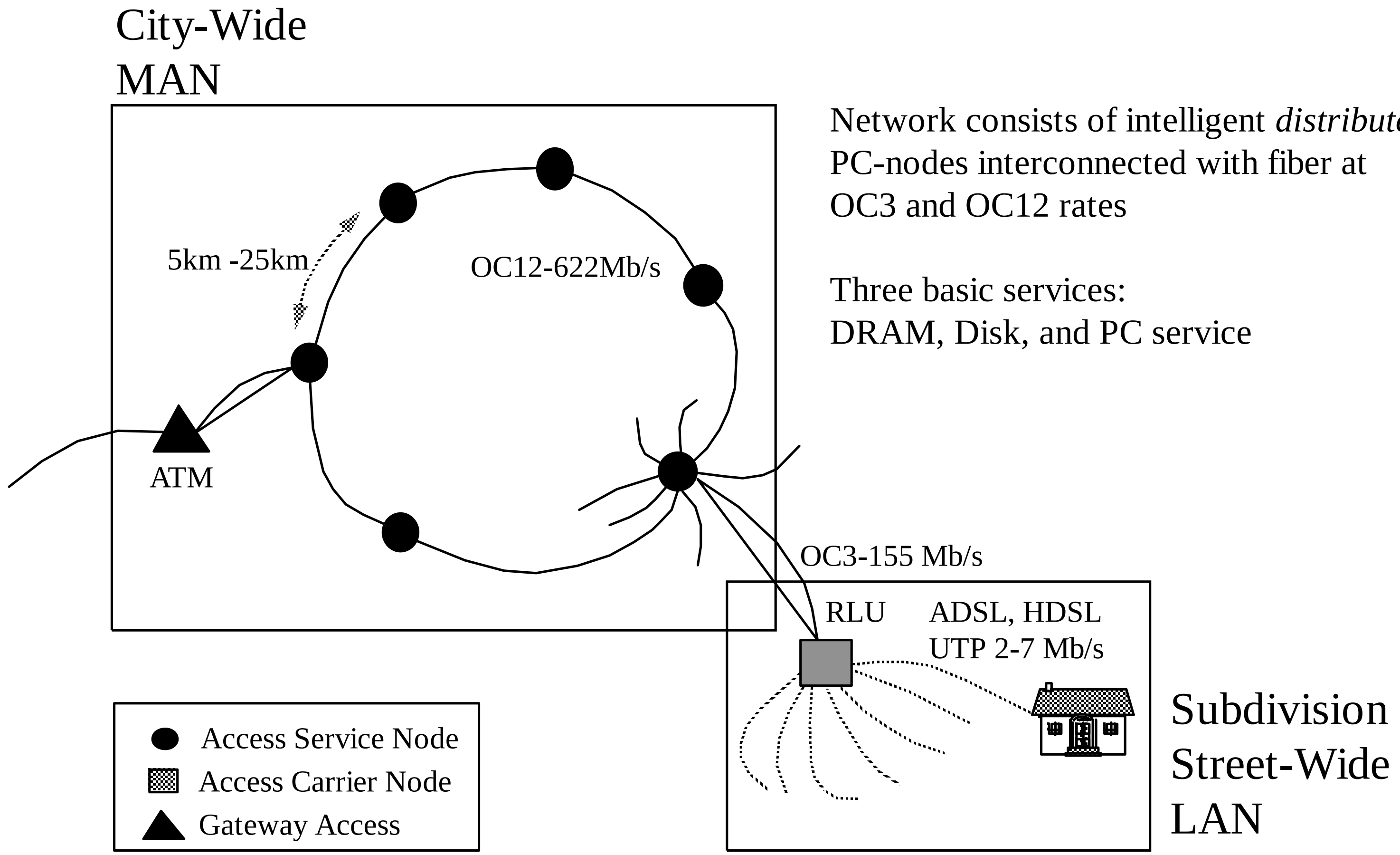
(i) Carrierless Amplitude Pase (CAP) modulation

At start-up, CAP tests the quality of the the line and implements the most efficient QAM. CAP is low-cost due to its simplicity. It is not a standard.

(ii) Discrete Multi-Tone (DMT) Modulation

DMT divides the available frequency bandwidth into 256 subchannels or tones. At start-up the line is tested to determine the best distribution of subchannels to carry data. Typically, to rise above noise, more data resides in the lower frequencies and less in the upper ones. DMT is much more complex and hence initially more expensive than CAP. DMT is faster (x4 downstream, x10 upstream) than CAP at all distances. DMT is an ANSI and ETSI standard.

Future Metropolitan Networks



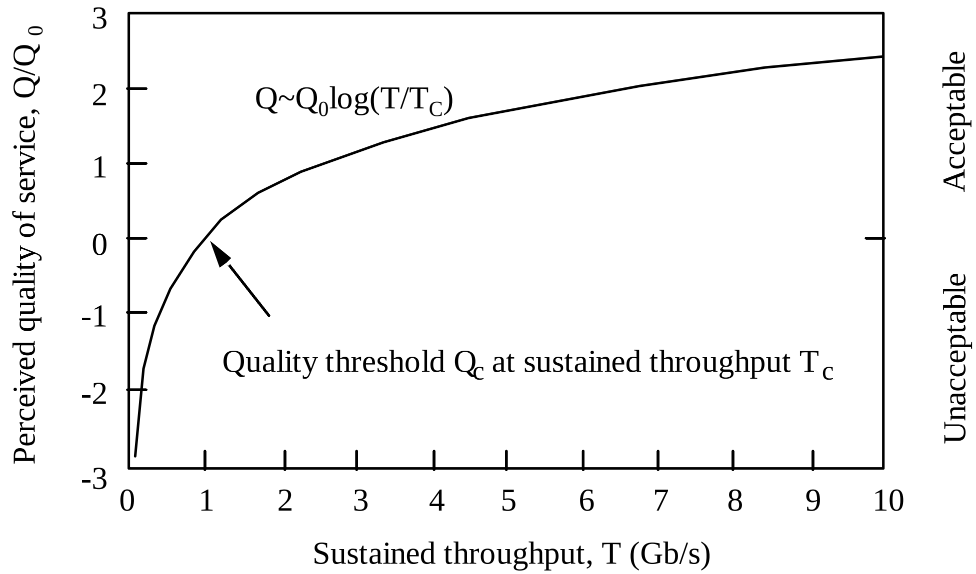
Network consists of intelligent *distributed* PC-nodes interconnected with fiber at OC3 and OC12 rates

Three basic services:
DRAM, Disk, and PC service

Multimedia needs

- Multimedia contains two distinct types of information:
    - Voice, audio and video which can tolerate lossy compression (telecom)
    - Data, audio and video which can not tolerate lossy compression (datacom)
- Datacom applications will require higher bandwidth compared to telecom

Quality of Service



Assume perceived quality Q, scales with throughput T, as $Q \sim Q_0 \log(T/T_C)$

Critical sustained throughput T_C, for acceptable quality of service

Perceived visual quality saturates for T above $T_C \sim 1$Gb/s=24x1280x1029x30 b/s

Acceptable service only when $T > T_C$

Perceived audio quality also saturates but at lower sustained throughput