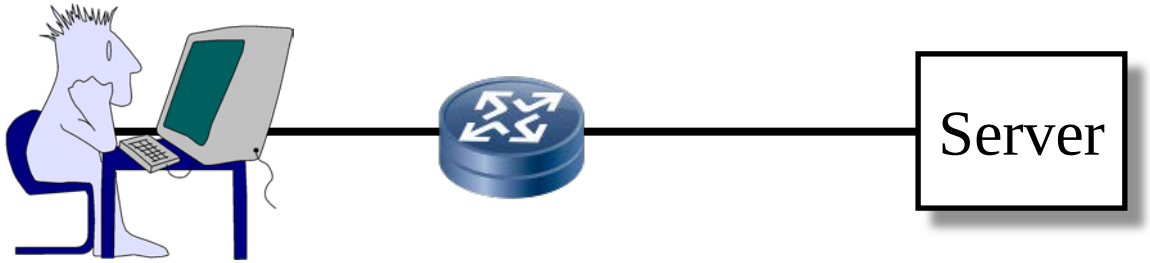
Computer Networks and the Internet



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Audio/Video recordings of this lecture are available on-line at:

http://www.cse.wustl.edu/~jain/cse4703-26/

Student Questions

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Overview

- What is Internet?
- Switching: Circuit vs. Packet
- Edge vs. Core
- Network Performance Measures: Delay, Loss, Throughput
- Protocol Layers
- Network Security
- History

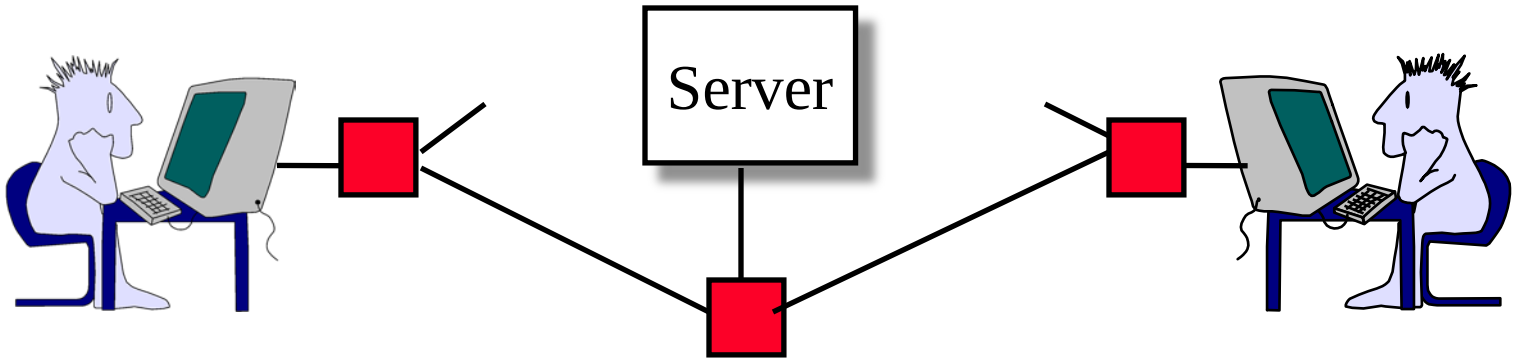
Note: This class lecture is based on Chapter 1 of the textbook (Kurose and Ross) and the slides provided by the authors.

Student Questions

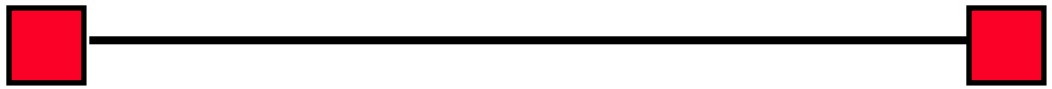
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What is a Network?

- **Network**: Enables data transfer among nodes
  - Generally heterogeneous nodes, e.g., a PC and a Mac
  - More than two nodes
  - E.g., Your home or office network



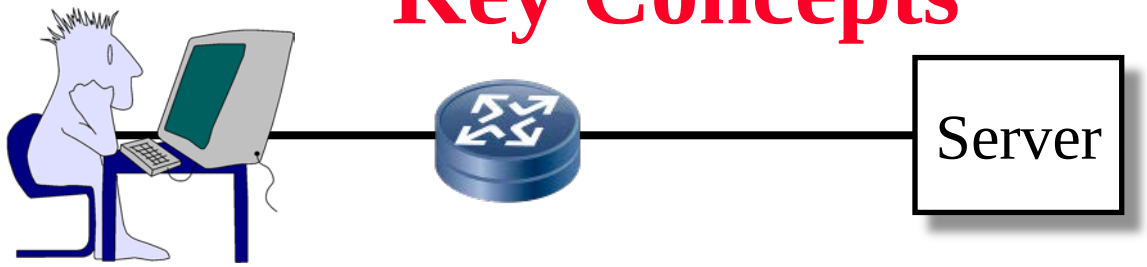
- **Communication**: Two nodes.
  - Link-level electrical issues.



Student Questions

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Key Concepts

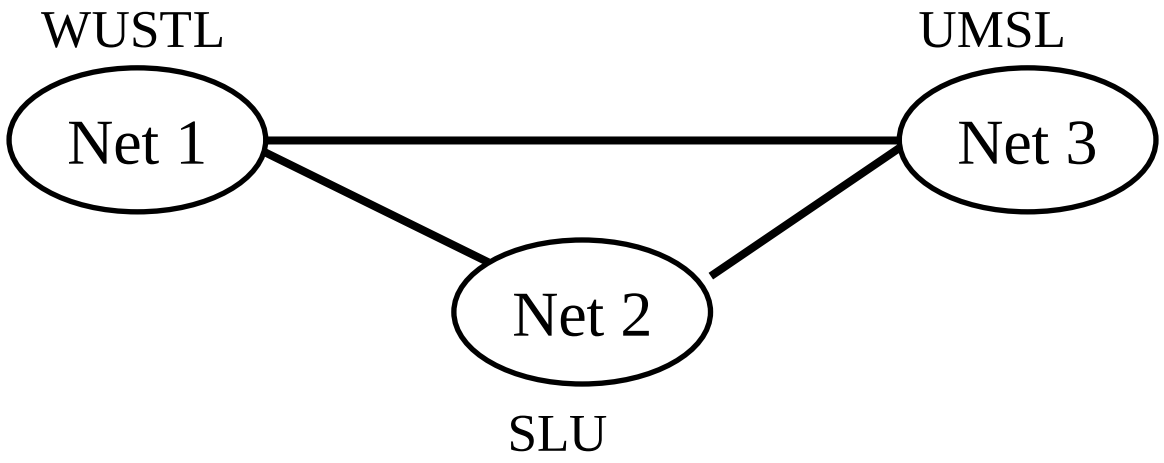


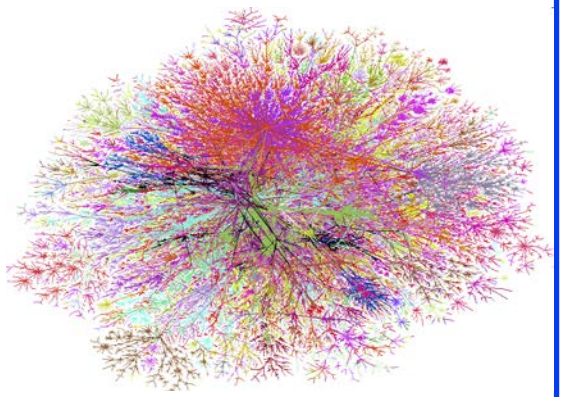
- **End Systems**: Systems that are sinks or sources of data, e.g., Desktops, Laptops, Servers, Printers, Cell Phones, etc.
- **Intermediate Systems**: Systems that forward/switch data from one link to another, e.g., routers, switches
- **Hosts**: End Systems
- **Gateways**: Routers
- **Servers**: End Systems that provide service, e.g., print server, storage server, Mail server, etc.
- **Clients**: End systems that request service
- **Links**: Connect the systems.
  Characterized by transmission rate, propagation delay

Student Questions

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What is Internet?





- Internet = Inter-Network = Network connecting networks
- Approximately 20-30+ B hosts on the Internet in 2026.
- ISP: **Internet Service Provider**.
  - Provide access to the Internet.
  - Telecommunications (Telephone) Companies, AT&T, Verizon, Comcast, ...
  - Coffee Shops (Wi-Fi)

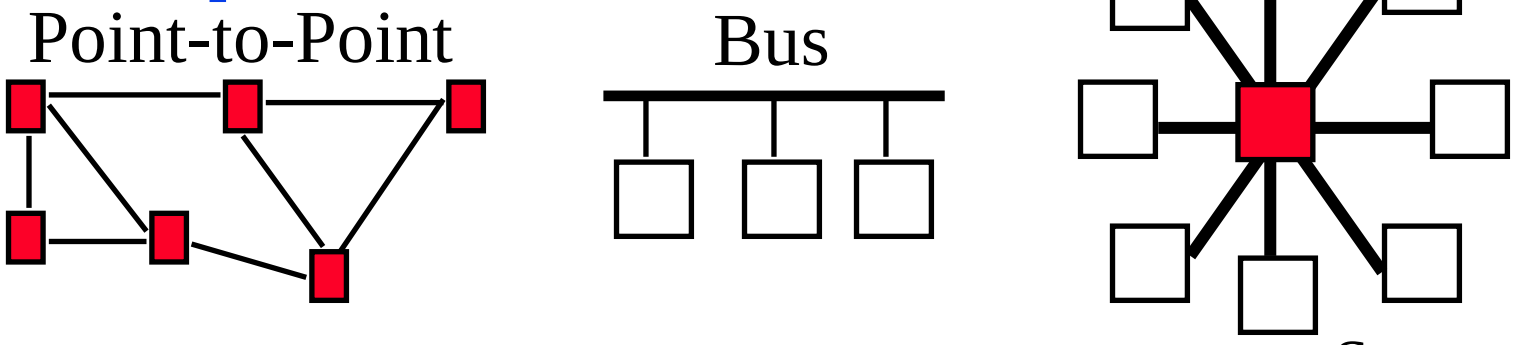
Ref: http://www.statista.com/statistics/264473/number-of-internet-hosts-in-the-domain-name-system/

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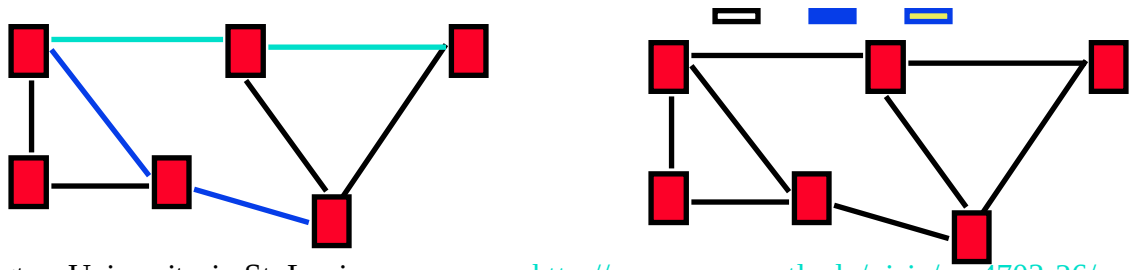
Student Questions

Types of Networks

- **Point to point vs. Broadcast**



- **Circuit-switched vs. packet-switched.**
  - **Circuit:** A path (circuit) is set up before transmission. All bits follow the same path, e.g., the Phone
  - **Packet:** Packets of bits are forwarded individually



Student Questions

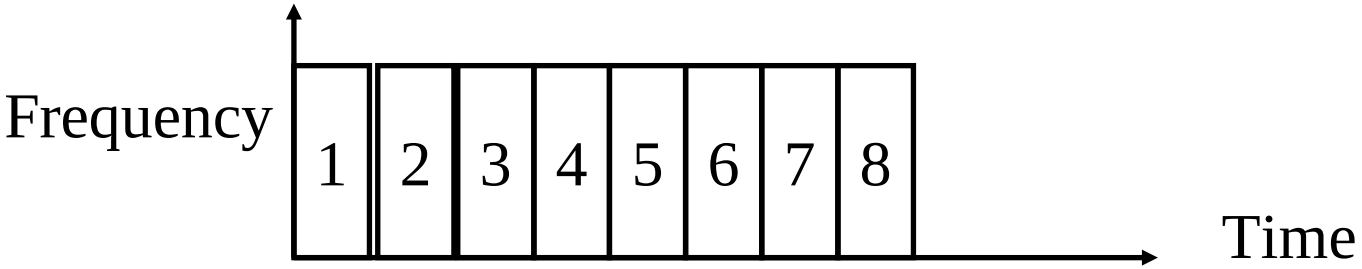
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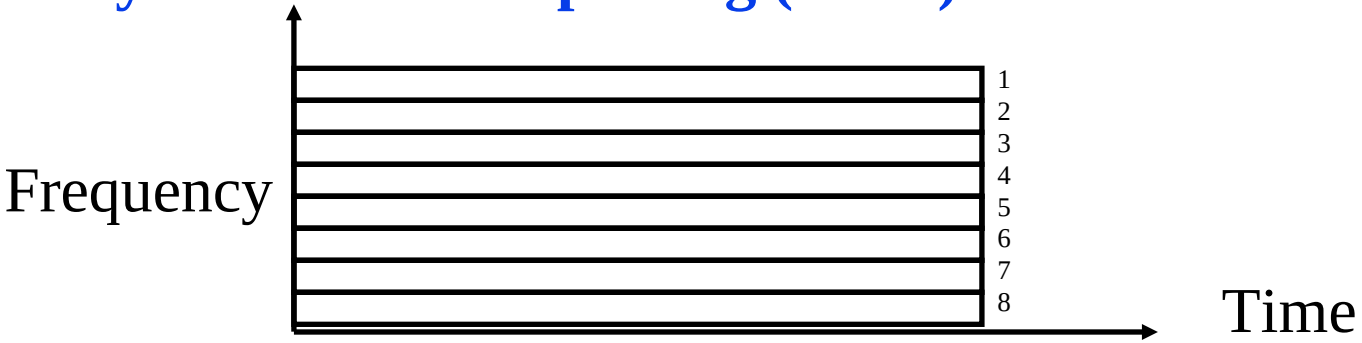
Multiplexing

How can multiple users share a link?

- **Time Division Multiplexing (TDM)**



- **Frequency Division Multiplexing (FDM)**



- Other multiplexing methods will be covered as needed.

Student Questions

- When to use TDM and when to use FDM?

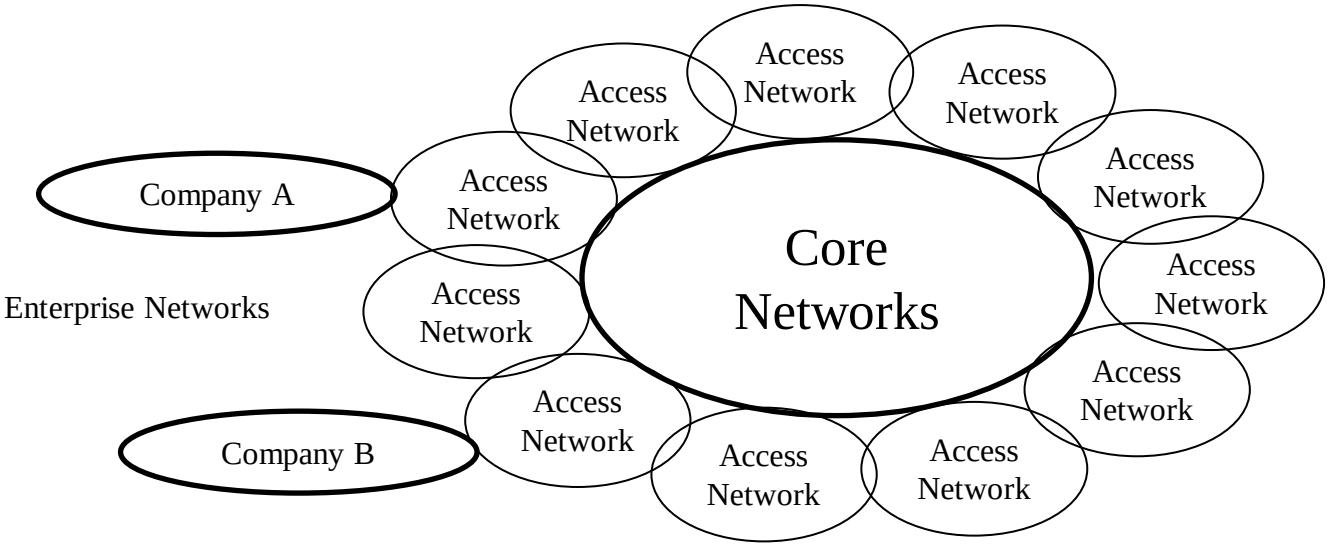
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Types of Networks (Cont)

- **Local Area Networks (LAN)**: 0-2 km, Single Ownership
  Metropolitan Area Networks (MAN) 2-50 km,
  Wide Area Networks (WAN) 50+ km
  - Originally LAN/MAN/WAN technologies were different
  - Now they are all the same
- Telecom Networks:
  - **Access**: Between the subscriber and the service provider
  - **Metro**: Covering a city
  - **Core**: Between cities

Student Questions

Structure of the Internet

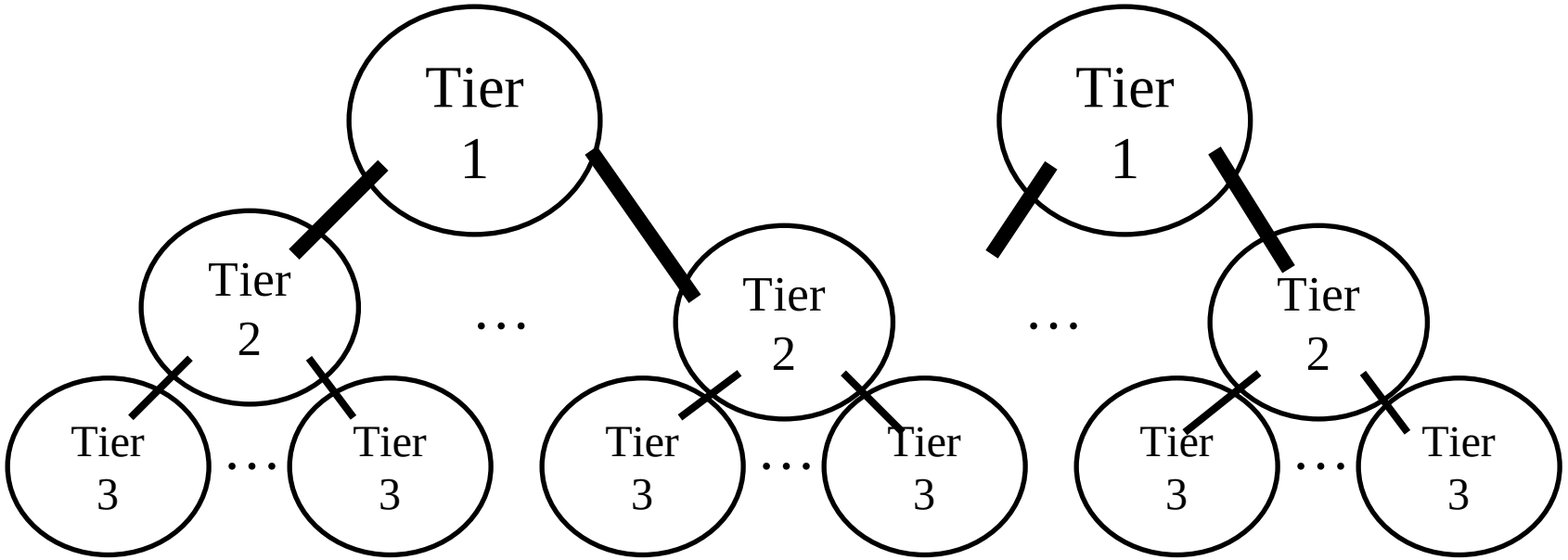


- Enterprise/Home Networks: **Stub** Networks.
  Privately owned ⇒ Not owned by ISP
  e.g., WUSTL network: Ethernet and WiFi
- **Access** Network: Enterprise/Users to ISP (in the city)
  WiFi, 3G/4G, DSL
- **Core** Network: ISP's network (between city): Optical Fiber

Student Questions

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Types of ISPs



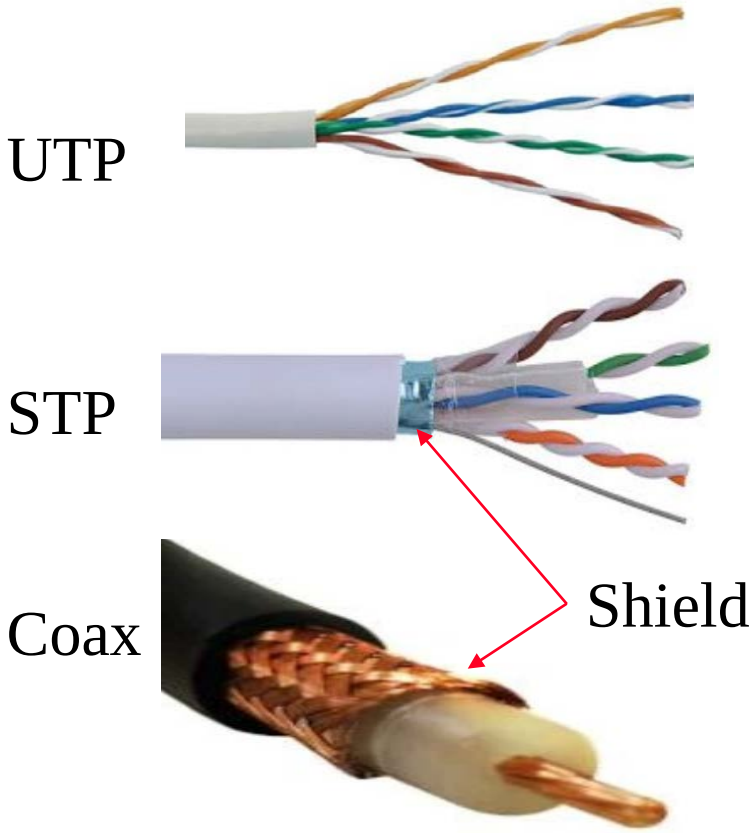
- **Tier** 1: Global or National, e.g., AT&T, Verizon, …
- Tier 2: Regional
- Tier 3: Local

Student Questions

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Transmission Media

- **Guided**:
  - Twisted Pair
  - Coaxial cable
  - Optical fiber
- **Unguided**:
  - Microwave
  - Satellite
  - Wireless



Student Questions

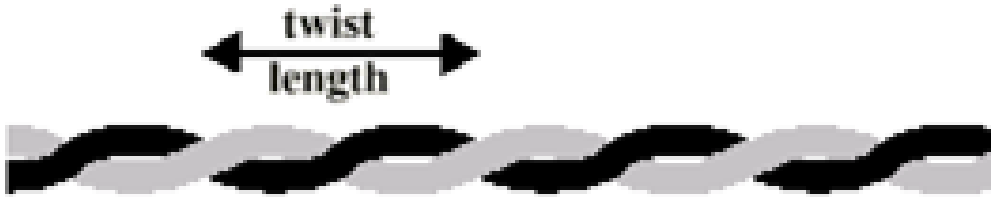
- What are the signal speeds of different transport mediums (i.e., fiber, UTP, coax, etc.)?

Every medium comes in different qualities. CAT-8 is now used for 5 Gbps Ethernet. Single-mode fiber is faster than multimode fiber, etc.

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Twisted Pair (TP)

—Separately insulated
—Twisted together
—Often "bundled" into cables
—Usually installed in building during construction



(a) Twisted pair

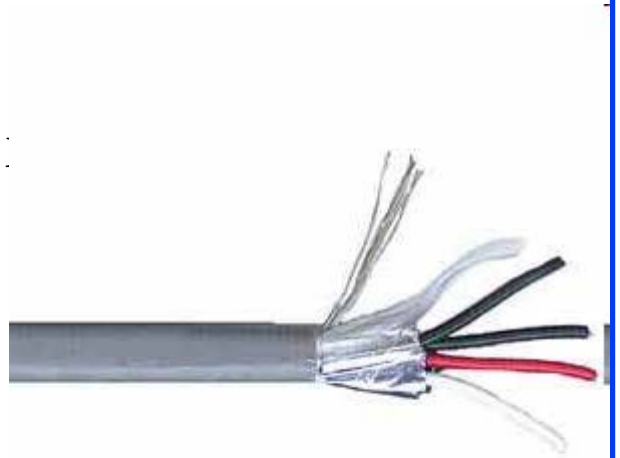
- Twists decrease the cross-talk
- Neighboring pairs have different twist length
- Most of telephone and network wiring in homes and offices is TP.

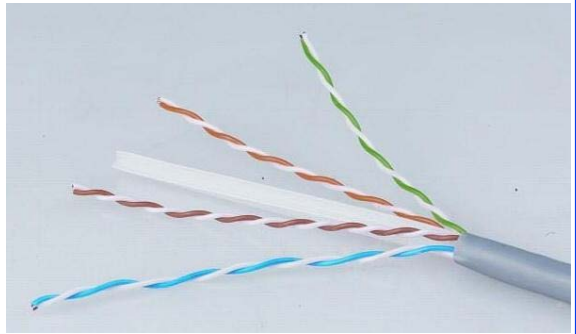
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Shielded and Unshielded TP

- **Shielded Twisted Pair (STP)**
  - Metal braid or sheathing that reduces
  - More expensive
  - Harder to handle (thick, heavy)
  - Used in token rings
- **Unshielded Twisted Pair (UTP)**
  - Ordinary telephone wire
  - Cheap, Flexible
    ⇒ Easiest to install
  - No shielding
    ⇒ Suffers from external interference
  - Used in Telephone and Ethernet





Student Questions

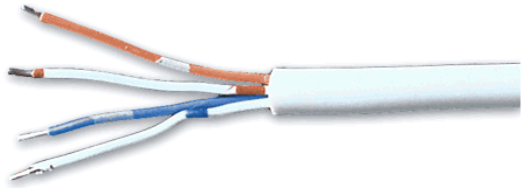
- When is Shielded Twisted Pair Used? Is it common today? Can it be used for Ethernet?

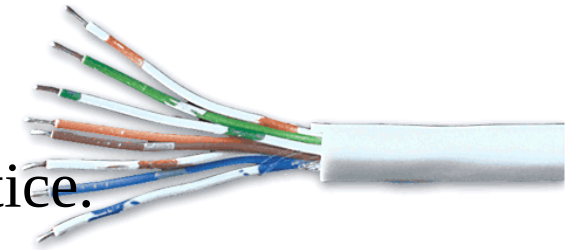
Yes, it is still produced and used. Mostly in high-noise environments, such as industrial settings.

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UTP Categories

- **Cat 3**
  - Up to 16MHz
  - Voice grade found in most offices
  - Twist length of 7.5 cm to 10 cm
- **Cat 4**
  - Up to 20 MHz. Not used much in practice.
- **Cat 5**
  - Up to 100MHz
  - Used in 10 Mbps and 100 Mbps Ethernet
  - Twist length 0.6 cm to 0.85 cm
- Cat 5E (Enhanced to 100 MHz)
- Cat 6 (250 MHz), Cat 6A (500 MHz)
- Cat 7 (700 MHz), CAT 7A (1000 MHz)
- Cat 8 (2000 MHz), …



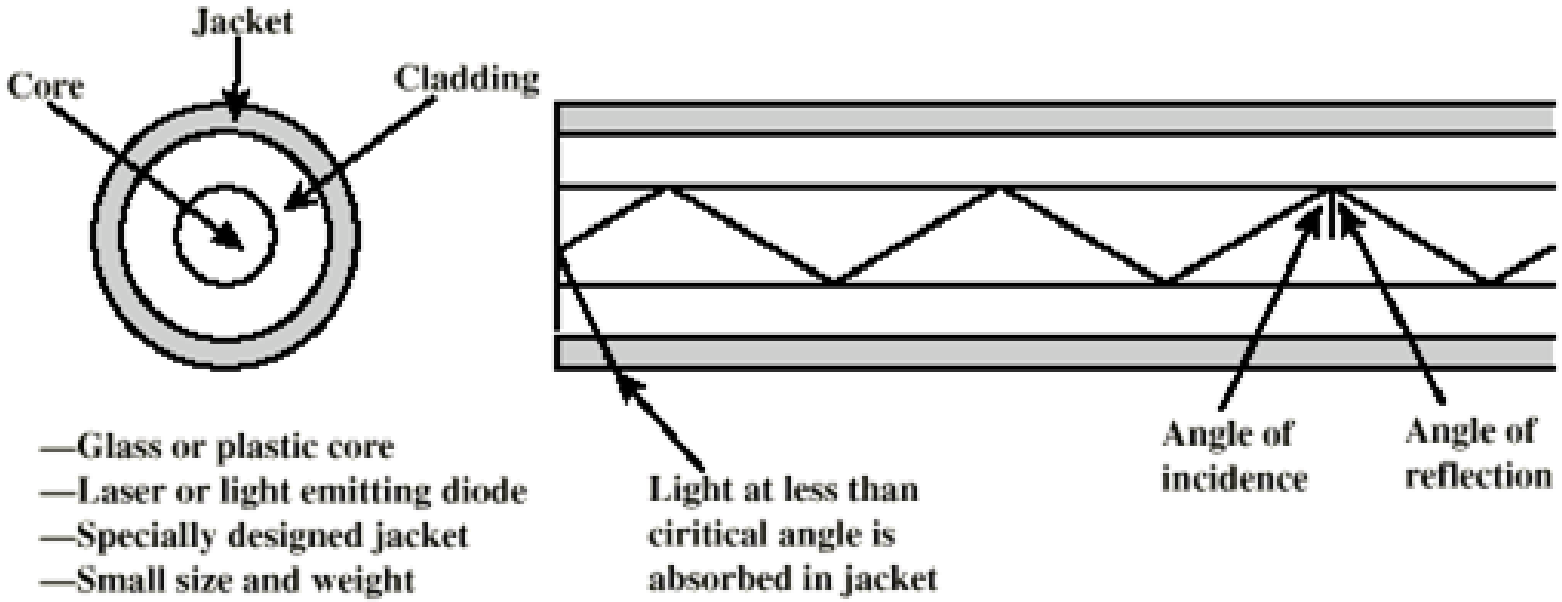




Ref: https://en.wikipedia.org/wiki/ISO/IEC_11801

Student Questions

Optical Fiber

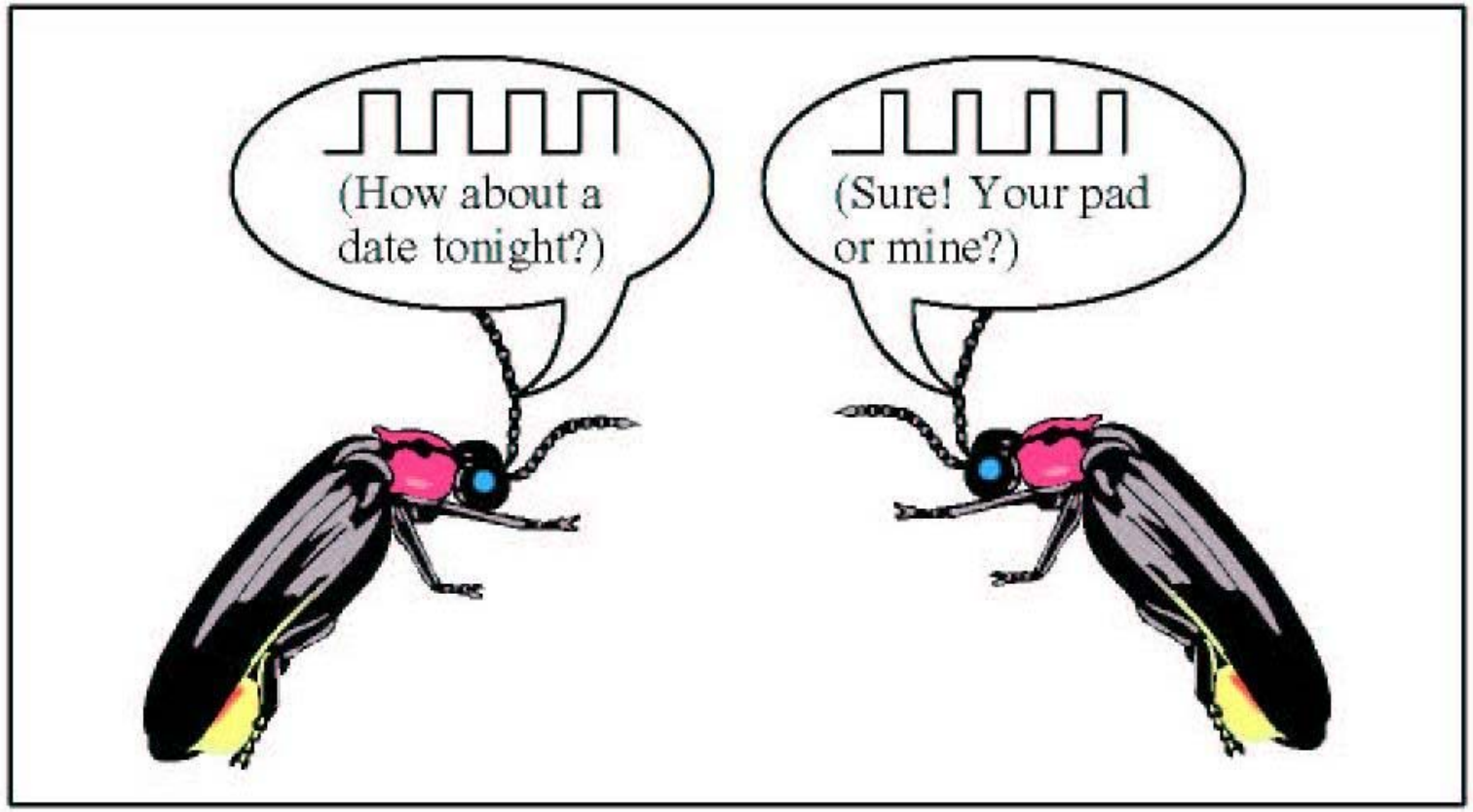


- A cylindrical mirror is formed by the cladding.
- The light wave propagates by continuous reflection in the fiber
- Not affected by external interference ⇒ low bit error rate
- Fiber is used in all long-haul or high-speed communication
- Infrared light is used in communication

Student Questions

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Optical Communication…History

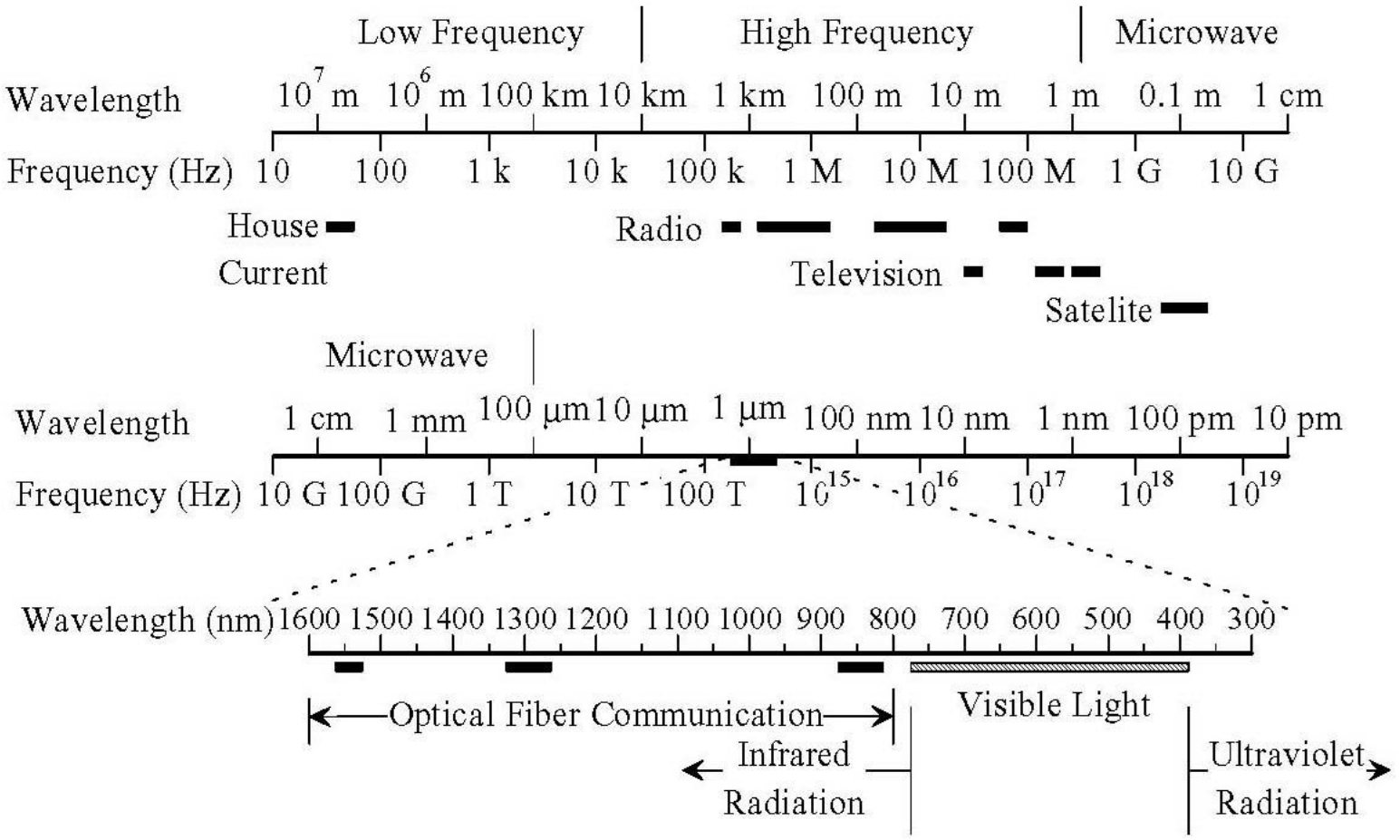


Fireflies use pulse-width modulation.

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Electromagnetic Spectrum



- Infrared light is used for optical communication.

Student Questions

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Homework 1A: Networking Media

- [6 points] Which networking media will you use for the following applications and why?
  - Very large file transfer at home
  - High-speed multiple-channel video transmission at an office
  - News reading while traveling in a car

Student Questions

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Network Edge: Enterprise Networks

- Ethernet
- Wi-Fi

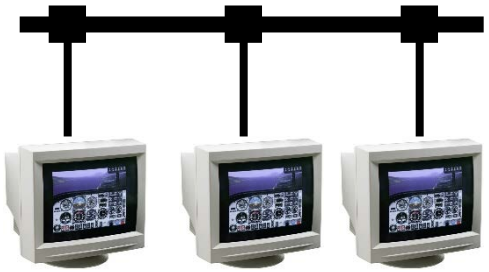
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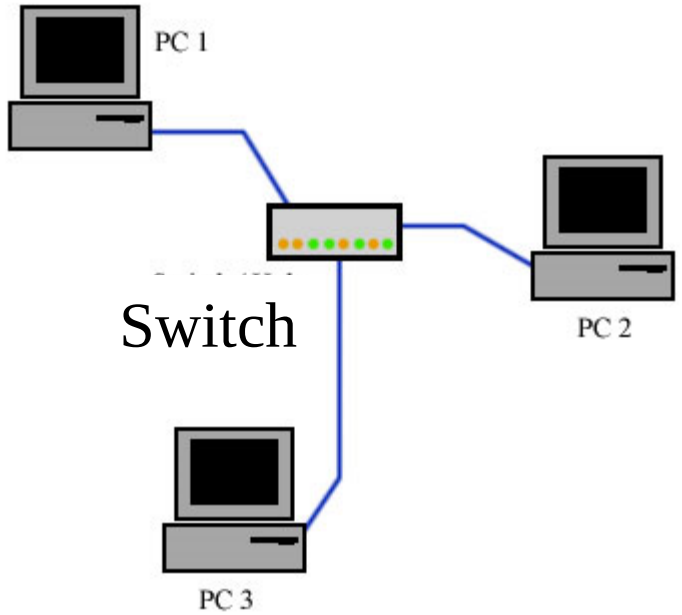
End of Part 1

Ethernet



- Uses UTP (Unshielded Twisted Pair)
- 10 Mbps, 100 Mbps, 1 Gbps, 10 Gbps
- Originally bus, now point-to-point (Star) topology





Student Questions

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Wi-Fi

- IEEE 802.11
  (Institution of Electrical and Electronic Engineers)
- Uses 2.4 GHz and 5.8 GHz

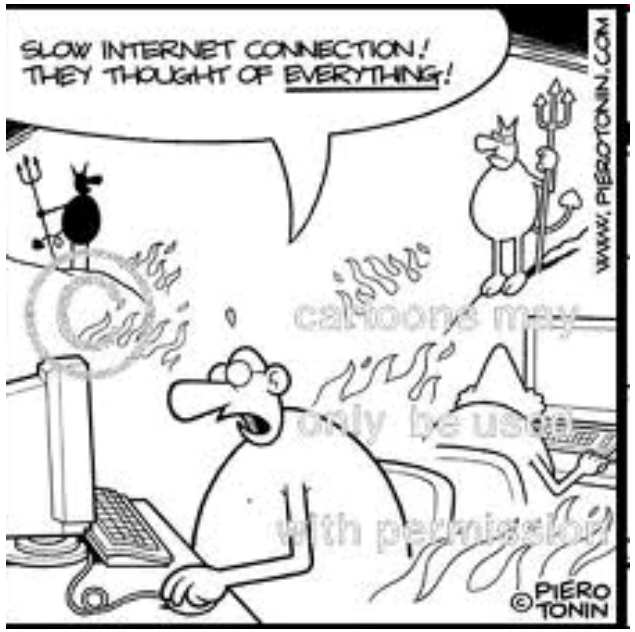


Student Questions

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Access Networks

- DSL (Digital Subscriber Line)
- Cable
- Fiber-To-The-Home
- Wi-Fi
- 5G



Student Questions

Digital Subscriber Line (DSL)

- Can transmit very high data rates on phone wire using special equipment at the phone company, allowing higher frequency signal



- DSL Access Multiplexer (**DSLAM**)
- 100 kbps - 100 Mbps

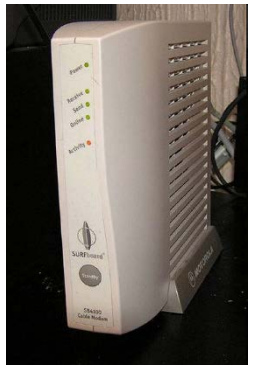
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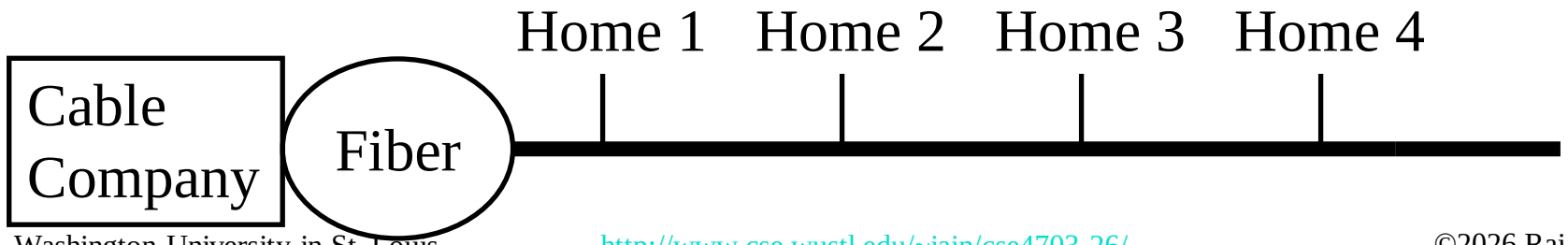


Cable

- Cable companies have a very-high-speed medium (for video transmission)
- Phone wire = 4kHz for voice
  Video Cable = 500 MHz for video
  One TV Channel = 6 MHz
- 100 Mbps down/10 Mbps up
- Fiber in the main line + Coax in tributaries
  ⇒ Hybrid Fiber Coax (HFC)



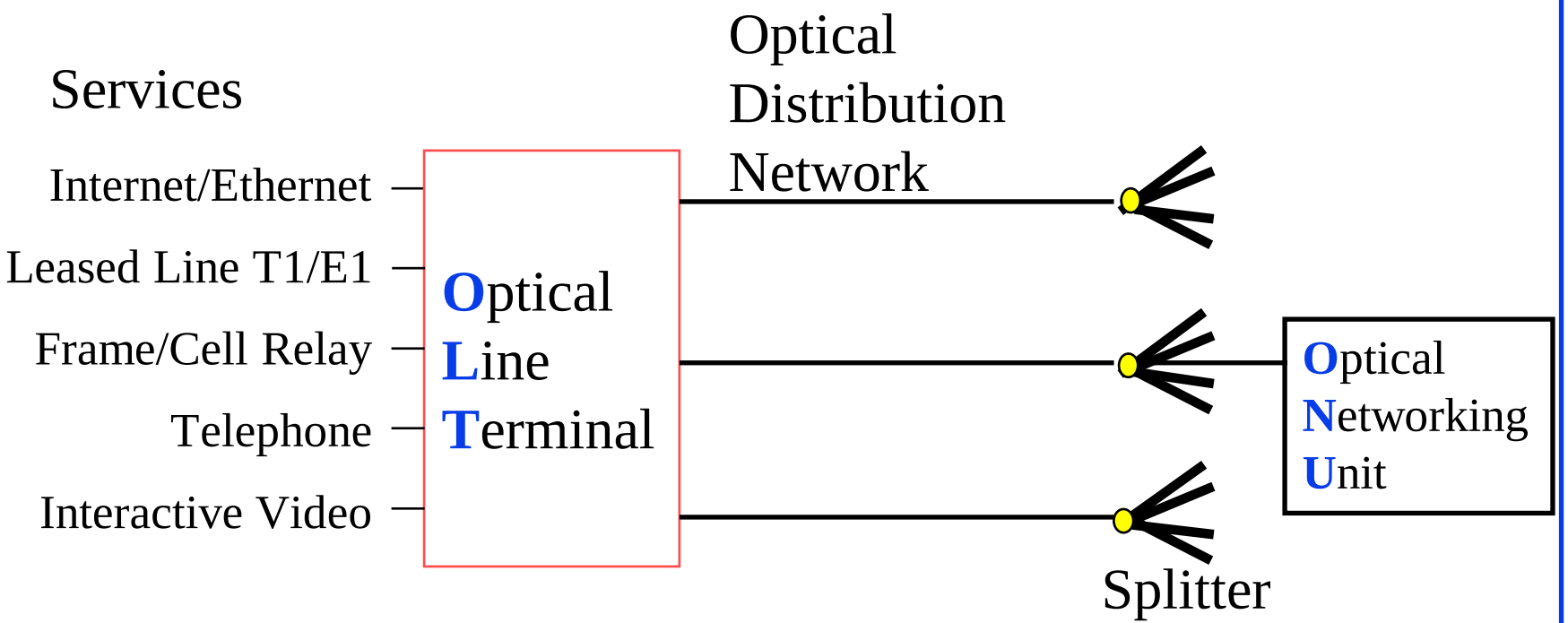
Cable Modem



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Fiber-To-The-Home (FTTH)



- 1+ Gbps per home. Multiple services.
- No electronic components in the distribution system
  ⇒ Passive ⇒ Reliable
- Passive Optical Network (PON)

Student Questions

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Wireless Access Networks

- Wi-Fi hot spots
- Cellular access: 2G/3G/4G/5G

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Network Performance Measures

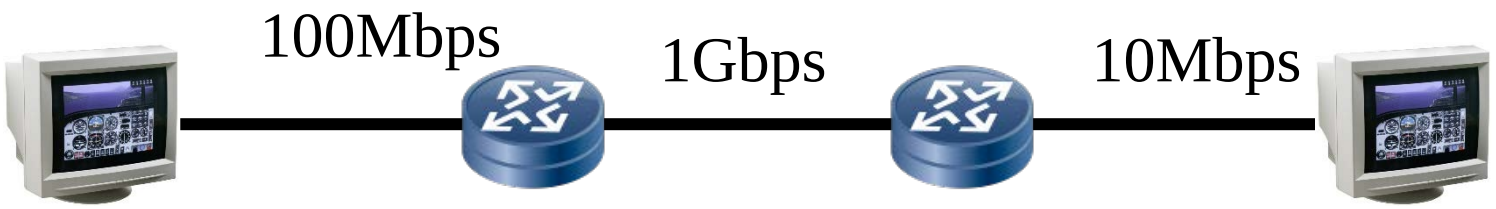
- Delay
- Throughput
- Loss Rate

Student Questions

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Throughput

- Measured in Bits/Sec
- Capacity: Nominal Throughput
- Throughput: Realistic
- Bottleneck determines the end-to-end throughput



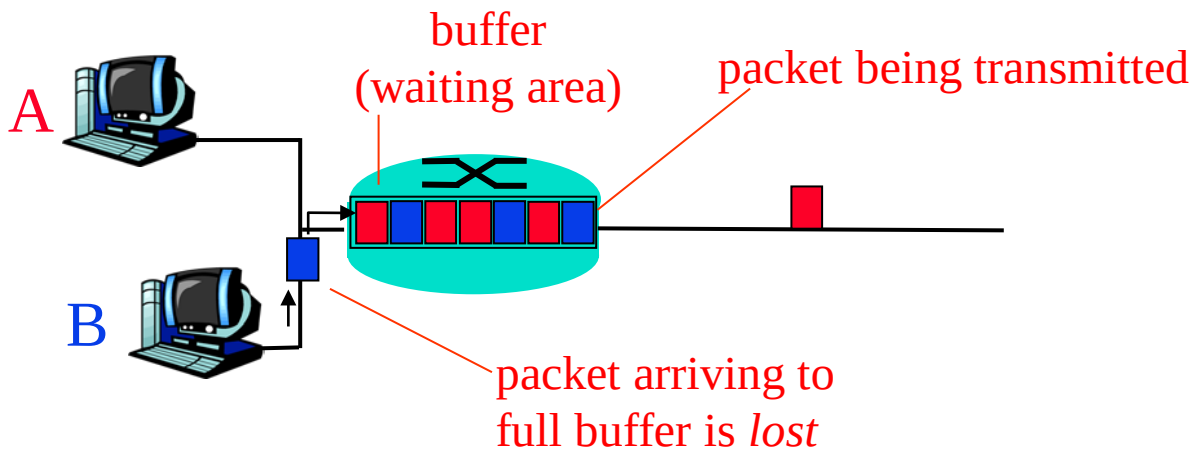
- Net end-to-end capacity = 10 Mbps
- Actual throughput will be less due to sharing and overhead.

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Loss Rate

- Queuing ⇒ Buffer overflow
- Bit Error Rate on the link
- Lost packets are retransmitted by the previous node or the source.

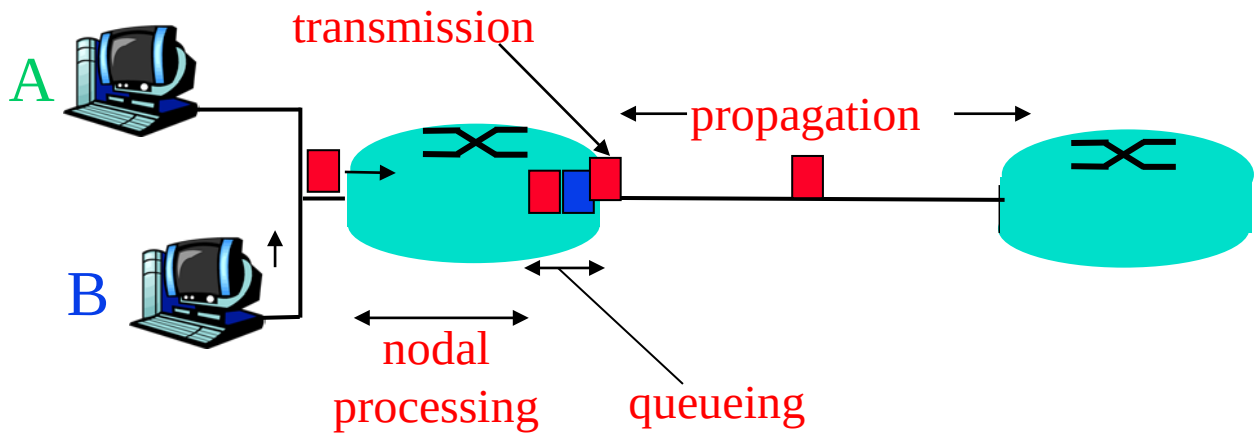


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Packet Switching Delay

- **Processing Delay**: Check packets, decide where to send, etc.
- **Queuing Delay**: Wait behind other packets
- **Transmission Delay**: First-bit out to last-bit out on the wire = **Packet Length/bit rate**
- **Propagation Delay**: Time for a bit to travel from in to out = Distance/speed of signal
- **Speed of Signal**: **300 m/µs** light in vacuum, **200 m/µs** light in fiber, **250 m/µs** electricity in copper cables



Student Questions

- Do we get provided with speed of signal in the exam?

No.

- Can you clarify the difference between transmission delay and propagation delay again?

Transmission=Exiting from the source
Propagation=travelling on the path
Transmission delay depends on the bps. Propagation delay depends on the distance and the media.

- Do routers communicate with other routers that they are congested to minimize delay?

Backpressure was tried but discouraged.

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Packet Switching Delay: Example

- 1500 **B**yte packets on 10 M**b**ps Ethernet, 1km segment
- Transmission Delay = $1500\times8/10\times10^6$ = 1200 μs = 1.2ms
- Propagation delay = 1000 m/2.5×10^8 =4 μs

Student Questions

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Delay Example (CBR Circuits)

- How long would it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link is shared by 24 users
  - 500 ms to establish an end-to-end circuit

Per User Rate = 1536/24 = 64 kbps

Time to transfer = 640kb/64kb = 10 s

Total time = .5 s + 10 s = 10.5 s

Student Questions

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Homework 1B: Network Performance

P5 [14 points]: Consider two hosts, A and B, connected by a single link of rate R bps. Suppose that the two hosts are separated by *m* meters, and suppose the propagation speed along the link is *s* meters/sec. Host A is to send a packet of size *L* bits to Host B.

A. What is the propagation delay, d_{prop} =m*s or m/s or s/m

B. What is the transmission time of the packet, d_{trans} =*L*R*, *L/R*, *m/R*, *L/s*

C. Ignoring processing queuing delays, What is the end-to-end delay:

End-to-End delay = $d_{trans}+d_{prop}$, $2d_{trans}+d_{prop}$, $d_{trans}+2d_{prop}$

D. Suppose Host A begins to transmit the packet at time *t=0*. At time $t=d_{trans}$, where is the last bit of the packet? At the source, on the wire, at the destination

E. Suppose d_{prop} is greater than d_{trans}. At time $t=d_{trans}$, where is the first bit of the packet? At the source, on the wire, at the destination

F. Suppose d_{prop} is less than d_{trans}, at time $t=d_{trans}$, where is the first bit of the packet? At the source, on the wire, at the destination

G. Suppose $s=3\times10^8$ m/s, L=**290** bits, and R=60 kbps,. Find the distance *m* so that d_{prop} equals d_{trans}.

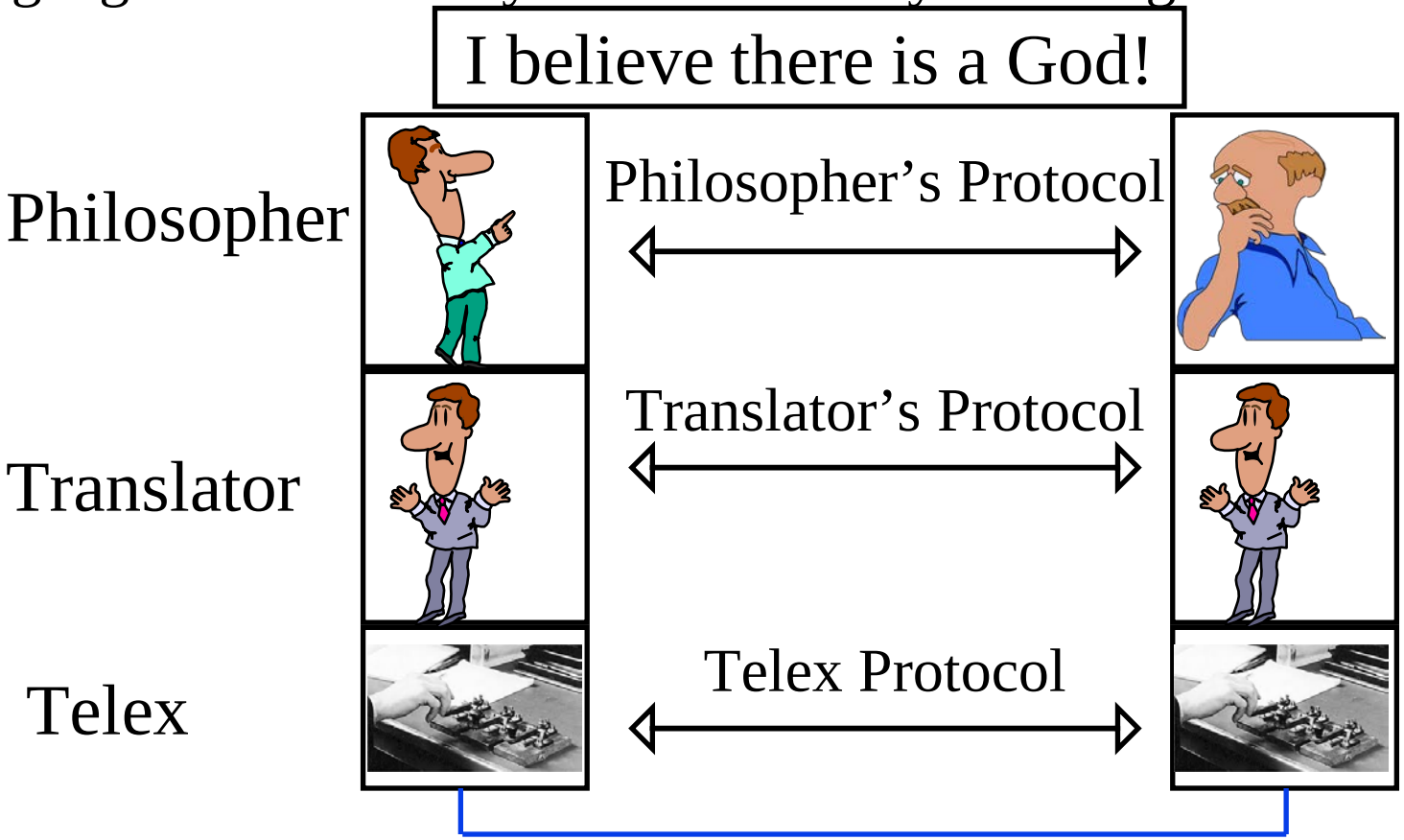
Student Questions

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End of Part 1

Protocol Layers

- Problem: Philosophers in different countries speak different languages. The Telex system works only with English.



Student Questions

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What is a Networking Protocol?

- Network protocols define the format of messages, their meanings, sequence, and actions

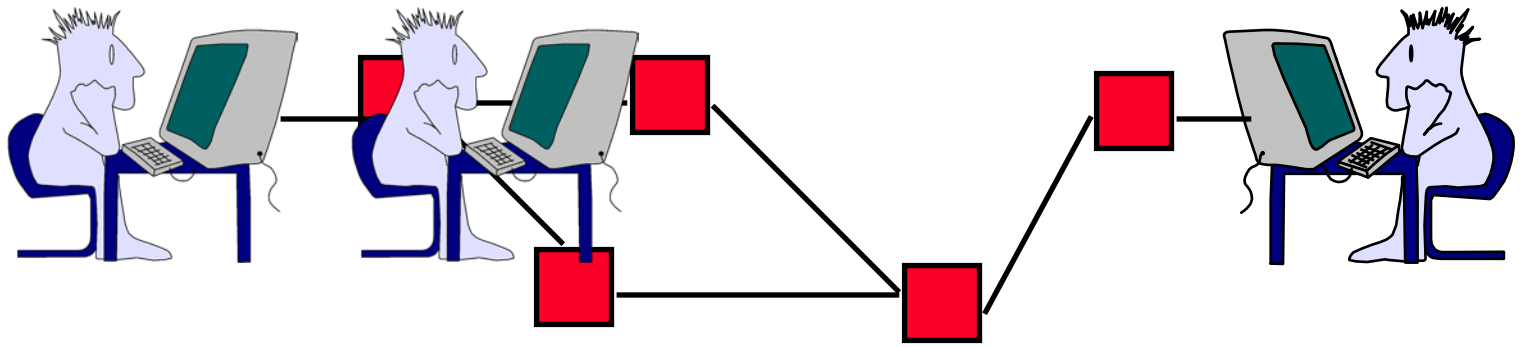


Student Questions

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ISO/OSI Reference Model

5	Application	File transfer, Email, Remote Login
	Presentation	ASCII Text, Sound
	Session	Establish/manage connection
4	Transport	End-to-end communication: TCP
3	Network	Routing, Addressing: IP
2	Datalink	Two party communication: Ethernet
1	Physical	How to transmit signal: Coding



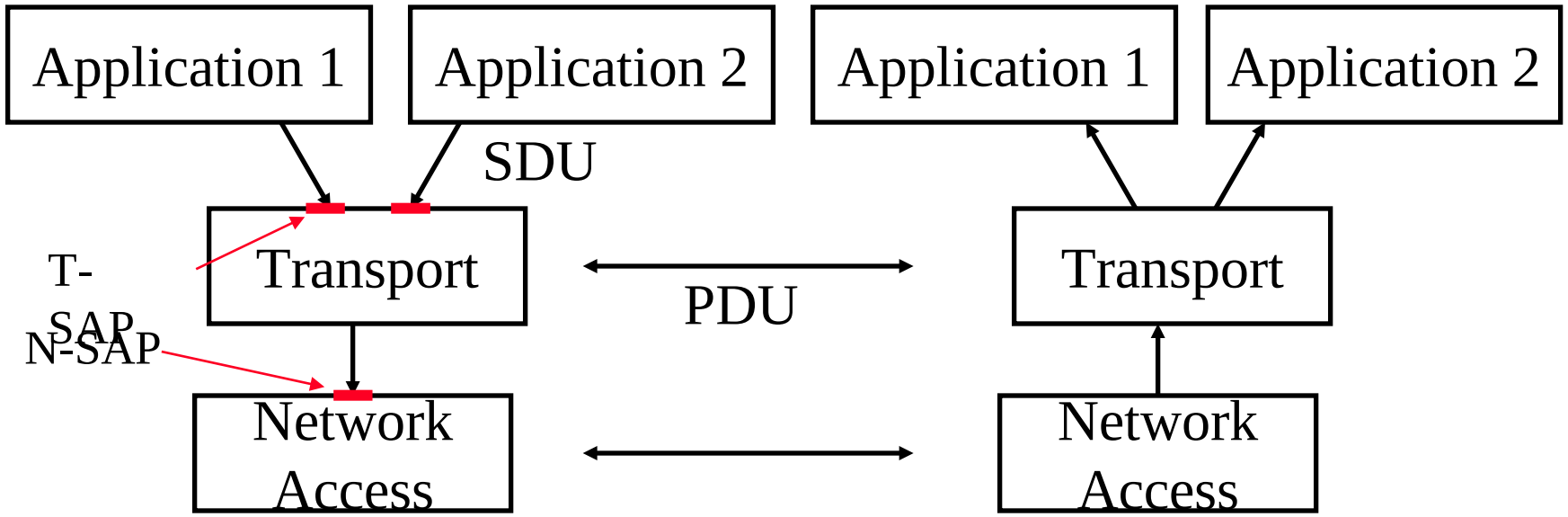
Student Questions

- Can you clarify the difference between the Application, Session, and Presentation layers?

Session: movie, phone call
Presentation: Projector, speaker
Application: file transfer, video, audio

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Service and Protocol Data Units

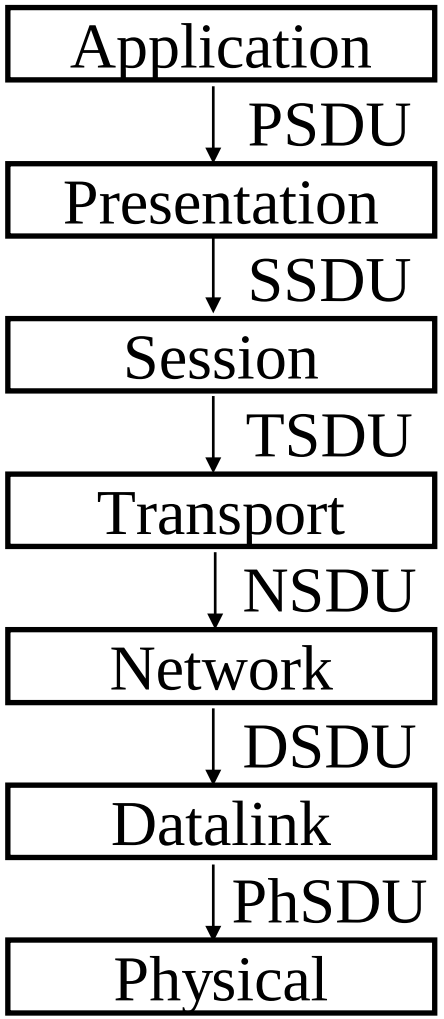


- Service Access Points (SAPs)
- Service Data Units (SDUs)
- Protocol Data Units (PDUs)

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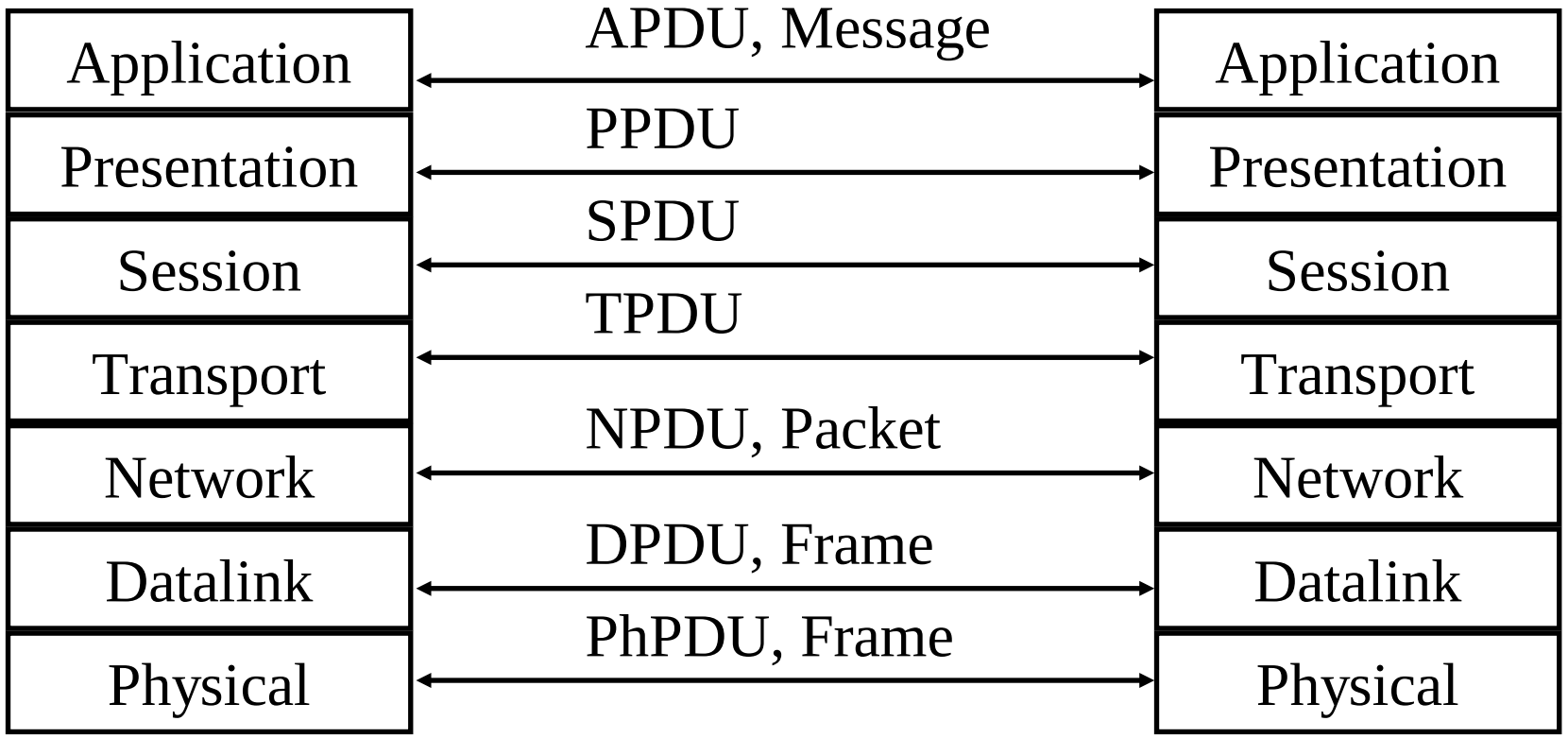
Service Data Unit (SDU)



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Protocol Data Unit (PDU)



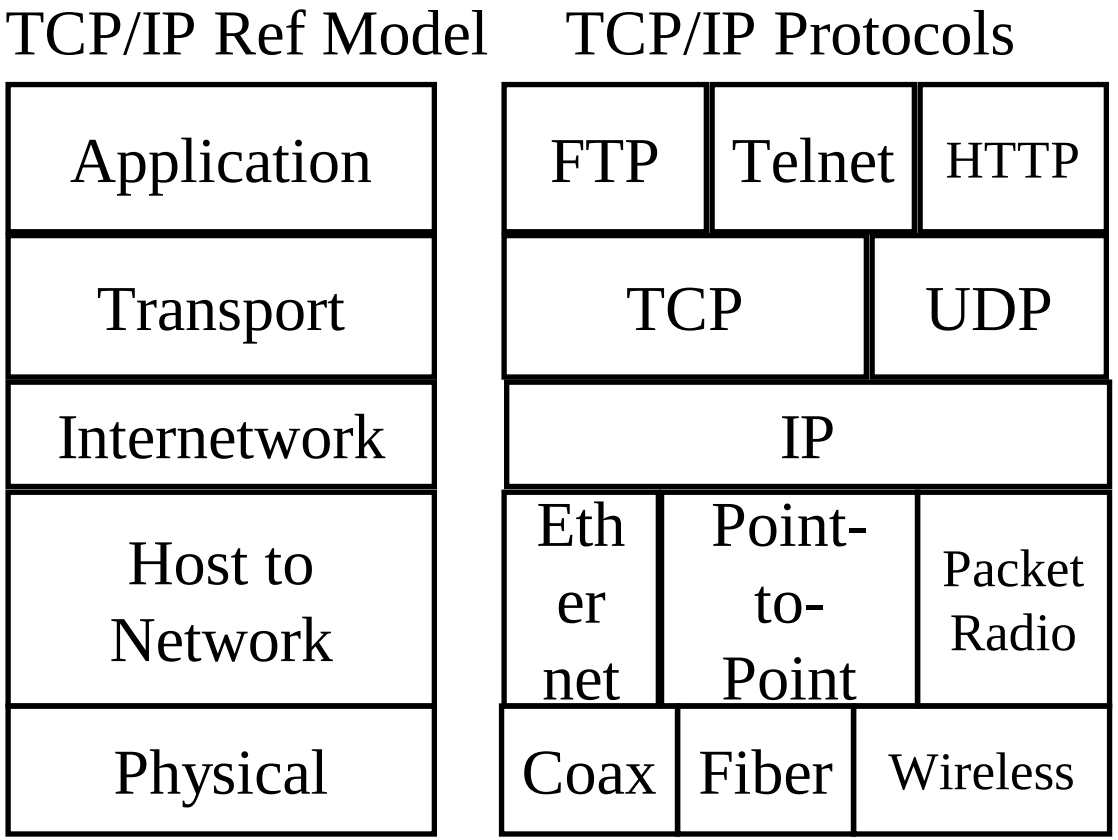
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TCP/IP Reference Model

TCP = Transmission Control Protocol

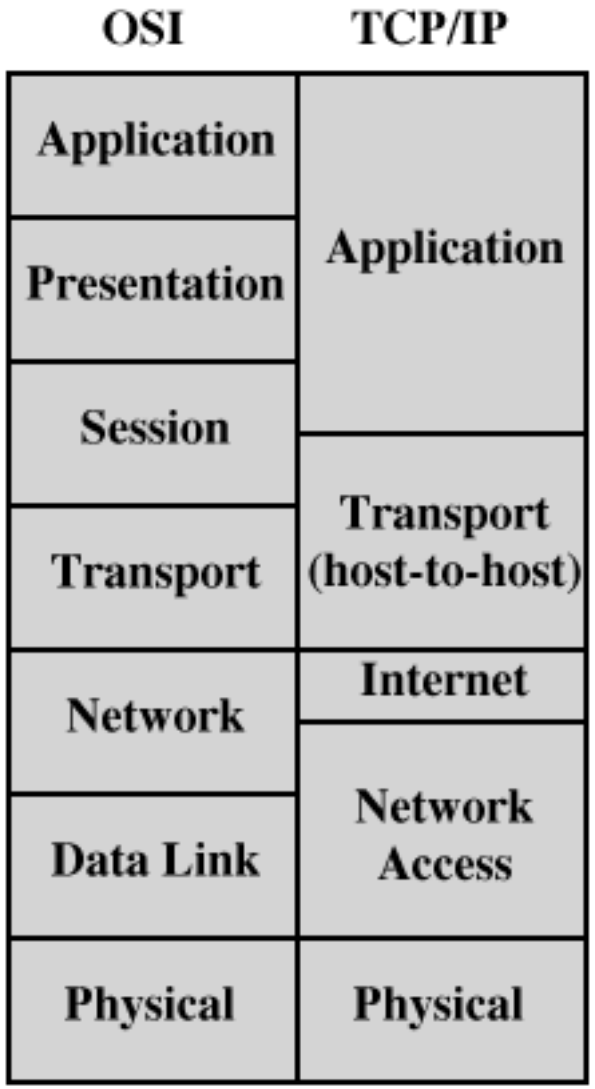
IP = Internet Protocol (Routing)



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OSI vs TCP/IP



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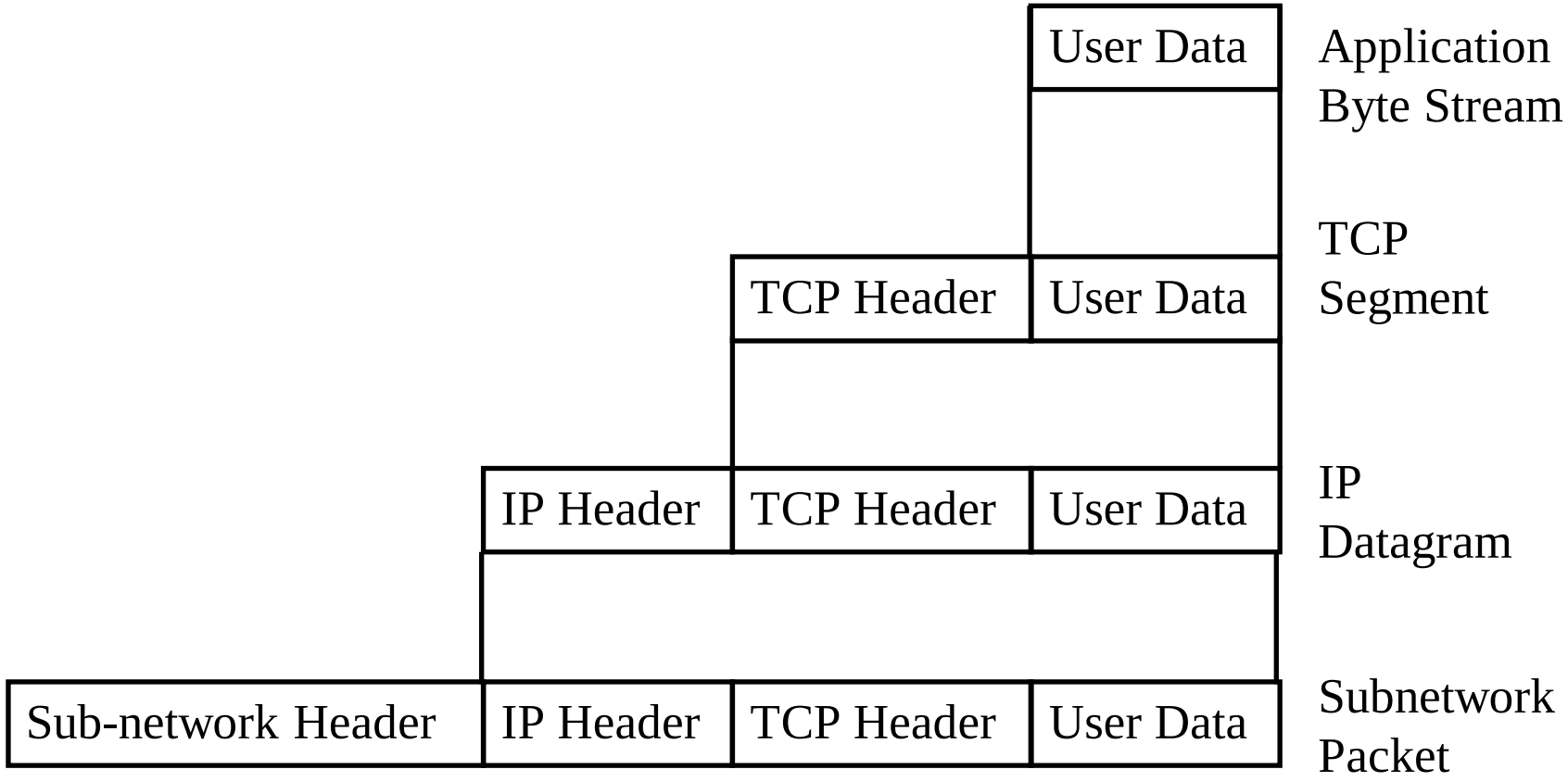
OSI vs TCP Reference Models

- OSI introduced concept of services, interface, protocols. These were force-fitted to TCP later
  ⇒ It is not easy to replace protocols in TCP.
- In OSI, reference model was done before protocols.
  In TCP, protocols were done before the model
- OSI: Standardize first, build later
  TCP: Build first, standardize later
- OSI took too long to standardize.
  TCP/IP was already in wide use by the time.
- OSI became too complex.
- TCP/IP is not general. Ad hoc.

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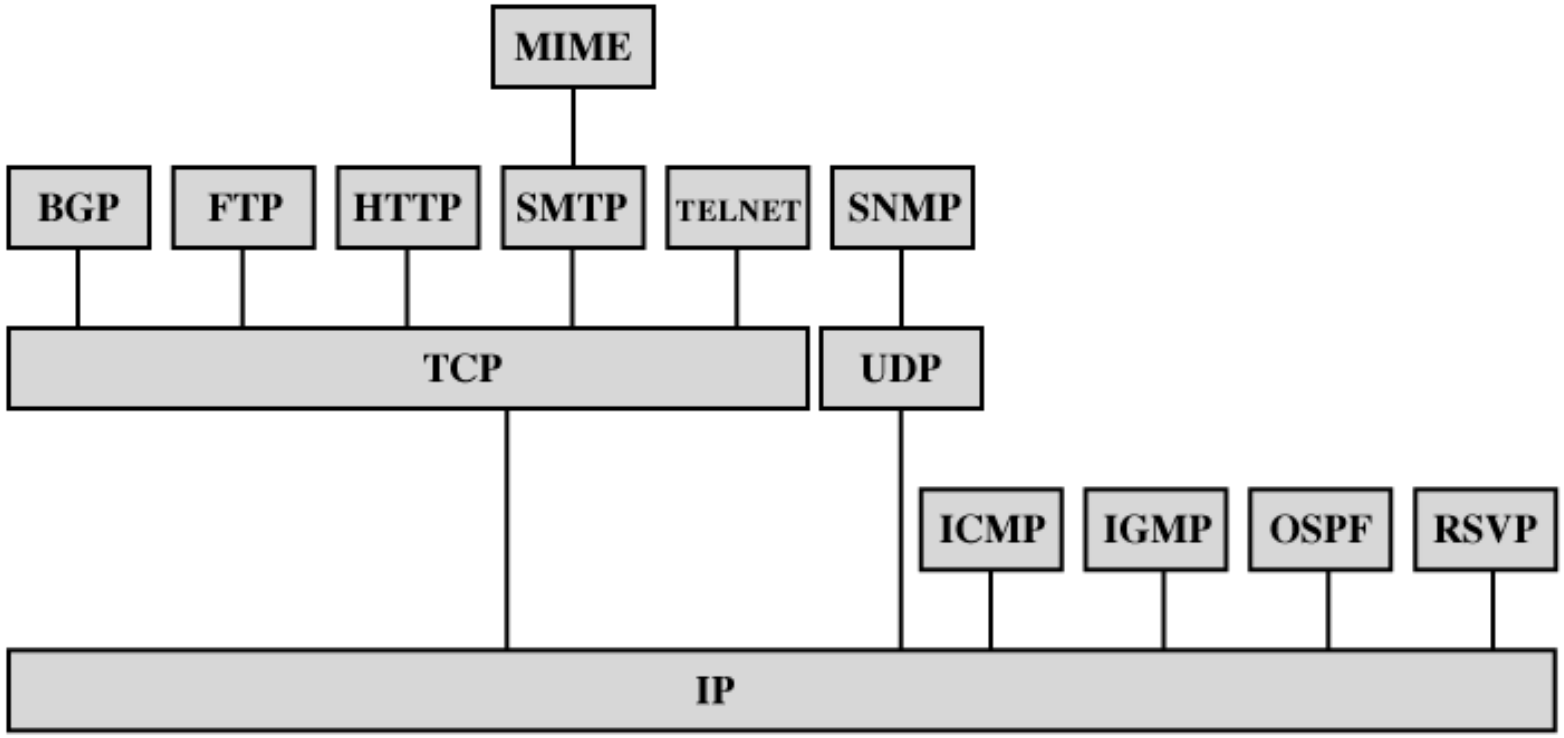
PDUs in TCP/IP Architecture



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TCP/IP Applications



BGP = Border Gateway Protocol
FTP = File Transfer Protocol
HTTP = Hypertext Transfer Protocol
ICMP = Internet Control Message Protocol
IGMP = Internet Group Management Protocol
IP = Internet Protocol
MIME = Multi-Purpose Internet Mail Extension
OSPF = Open Shortest Path First
RSVP = Resource ReSerVation Protocol
SMTP = Simple Mail Transfer Protocol
SNMP = Simple Network Management Protocol
TCP = Transmission Control Protocol
UDP = User Datagram Protocol

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Network Security

- Security Components
- Types of Malware
- Types of Attacks
- Buffer Overflows
- Distributed DoS Attacks

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Security Components

- **Confidentiality**: Need access control, Cryptography, Existence of data
- **Integrity**: No change, content, source, prevention mechanisms, detection mechanisms
- **Availability**: Denial of service attacks,
- Confidentiality, Integrity and Availability (**CIA**)



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Types of Malware

- **Viruses**: Code that *attaches* itself to programs, disks, or memory to propagate itself.
- **Worms**: Installs copies of itself on other machines on a network, e.g., by finding user names and passwords
- **Trojan horses**: Pretend to be a utility. Convince users to install it on their PC.
- **Spyware**: Collect personal information
- This is not a complete list.

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Types of Attacks

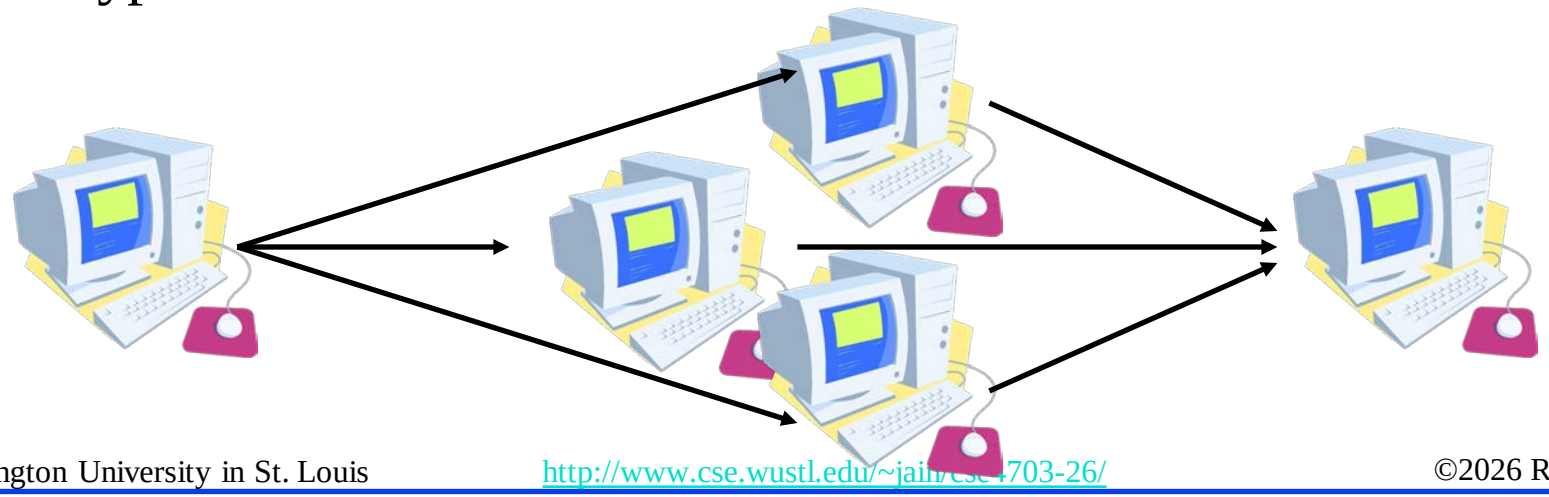
- **Denial of Service (DoS):** Flooding with traffic/requests
- **Buffer Overflows**: Error in system programs. Allows hackers to insert their code into a program.
- **Malware**
- **Brute Force**: Try all passwords.
- **Port Scanning**:
  ⇒ Disable unnecessary services and close ports
- **Network Mapping**

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Distributed DoS Attacks

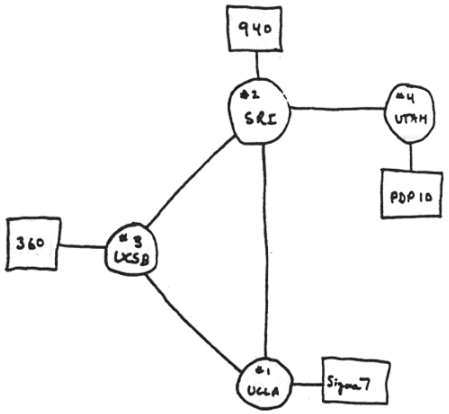
- **Tribe Flood Network** (TFN) clients are installed on compromised hosts.
- All clients start a simultaneous DoS attack on a victim on a trigger from the attacker.
- **Trinoo** attack works similarly. Use UDP packets. Trinoo client report to Trinoo master when the system comes up.
- **Stacheldraht** uses handlers on compromised hosts to receive encrypted commands from the attacker.



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History of Internet

- 1961: Kleinrock developed queueing theory. Showed effectiveness of packet-switching
- 1964: Baran's report on packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: First ARPAnet node operational
  First Request for Comment (RFC)
  www.ietf.org



THE ARPA NETWORK

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- Will there be questions about the history of the Internet?

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History of Internet (Cont)

- Early 1990s: HTML, HTTP: Berners-Lee
- 1994: Mosaic, later Netscape
- 2007:
  - ~500 million hosts
  - Voice, Video over IP
  - P2P applications: BitTorrent (file sharing), Skype (VoIP), PPLive (video)
  - Video applications: YouTube, gaming
  - Wireless, Mobility

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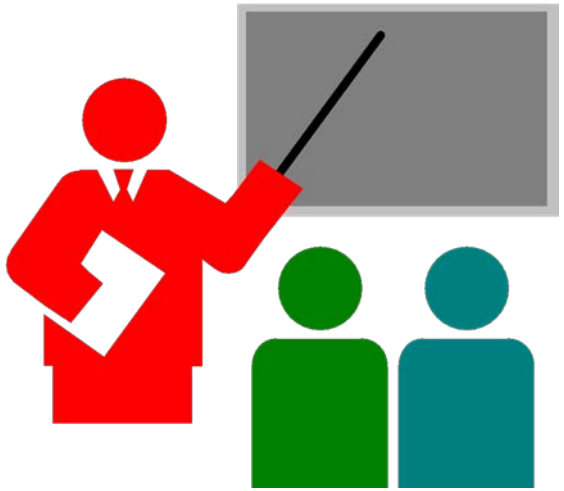
Key Concepts

- **Internet Protocol (IP)**: Protocol
- **Address**: All systems have an IP address, for example, 125.36.47.23
- **Name**: All systems have a human-readable name, e.g., scorpio.cec.wustl.edu, ibm.com.
- Technically called **DNS (domain name systems)** name. Details will be introduced later.
- **IETF**: Internet Engineering Task Force. Make standards for the Internet. IETF.org
- **RFC**: Request for comments. Documents that describe Internet protocols.

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Summary



- The most common medium is **UTP**, wireless, fiber
- **The Internet** is a network of networks
- Enterprise, **access**, and **core** networks
- Performance Measures: **Delay**, **Throughput**, **Loss** Rate
- Protocol Layers: **ISO** and **TCP/IP** reference models

Ref: Read entire Chapter 1 and try R1-R28 8th Edition.

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Lab 1: Internet and Wireshark

[6 points]

1. Find the IP address of your computer (ipconfig, ifconfig)
2. Find the IP address of www.wustl.edu (ping)
3. Measure the delay from your computer to www.wustl.edu (ping or tracert)

For all cases, submit the screen snapshot showing the command used and the output. (Use Alt-Print-screen to capture a window to the clipboard and then paste it to word)

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Lab 1 (Cont)

4. Download Wireshark,
   https://www.wireshark.org/download.html
   - Install it on your laptop.
   - If you are using a windows computer, you will also need npcap (Packet Capture Tool) from nmap.org.
   - Start Wireshark and start logging.
   - **Tracert** to www.google.com
   - Stop logging. Capture the current screen and submit. Do not worry about the part of the trace that is no longer on the screen.
   - Q1: List 3 protocols that you see in the packet trace.
   - Q2: What is the internet address of www.google.com from the trace?

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Lab 1: Hints

The HTTP traffic may not show in Wireshark if:

You may not have installed npcap

You may not be using Tracert. Do not use HTTP for this lab.

2. The websites you are doing your test on use HTTPS (TLS). In this case, Wireshark will identify the protocol as a TLS packet, not an HTTP packet.

3. If you are using Chrome, Edge, or any browser based on Chromium engine, the traffic when accessing google.com will show as QUIC because Google uses QUIC for their websites. Also, this is valid for other websites that use QUIC.

If you want to see the content of A TLS packet, follow this guide: https://wiki.wireshark.org/TLS#:~:text=Step-by-step%20instructions%20to%20decrypt%20TLS%20traffic%20from%20Chrome,from%20step%202%20is%20created.%20More%20items...%20

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Acronyms

APDU	Application Packet Data Unit
ARPAnet	Advanced Research Project Agency Network
ASCII	American Standard Code for Information Interchange
AT&T	American Telephone and Telegraph
CBR	Constant Bit Rate
CIA	Confidentiality, Integrity, Access
DNS	Domain Name Service
DoS	Denial of Service
DPDU	Datalink Packet Data Unit
DSDU	Datalink Service Data Unit
DSL	Digital Subscriber Line
FDM	Frequency Division Multiplexing
FTP	File Transfer Protocol
FTTH	Fiber to the host
GHz	Giga Hertz
HFC	Hybrid Fiber Coax

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Acronyms (Cont)

HTML	Hyper-Text Markup Language
HTTP	Hyper-Text Transfer Protocol
IEEE	Institution of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
ISO	International Standards Organization
ISP	Internet Service Provider
kHz	Kilo Hertz
LAN	Local Area Network
LTE	Long Term Evolution
MAN	Metropolitan Area Network
MHz	Mega Hertz
NPDU	Network Protocol Data Unit
NSDU	Network Service Data Unit
OSI	Open System Interconnect
PC	Personal Computer

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Acronyms (Cont)

PDU	Protocol Data Unit
PhSDU	Physical Service Data Unit
PON	Passive Optical Network
PPDU	PHY protocol data unit
PSDU	PHY Service data unit
RFC	Request for Comments
SAPs	Service Access Points
SDU	Service Data Units
SPDU	Session Protocol Data Unit
SSDU	Session Service Data Unit
STP	Shielded Twisted Pair
TCP	Transmission Control Protocol
TDM	Time Division Multiplexing
TFN	Tribe Flood Network
TP	Twisted Pair
TSDU	Transport Service Data Unit

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Acronyms (Cont)

TV	Television
UDP	Universal Data Protocol
UTP	Unshielded Twisted Pair
VoIP	Voice over IP
WAN	Wide Area Network
WiFi	Wireles Fidelity

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http://rajjain.com

http://www.cse.wustl.edu/~jain/cse4703-26/i_1cni.htm

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Related Modules



CSE 567: The Art of Computer Systems Performance Analysis
https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e_10TiDw





CSE 570: Recent Advances in Networking (Spring 2013)
https://www.youtube.com/playlist?list=PLjGG94etKypLHyBN8mOgwJLHD2FFIMGq5

CSE571S: Network Security (Spring 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u





Video Podcasts of Prof. Raj Jain's Lectures,
https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw

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