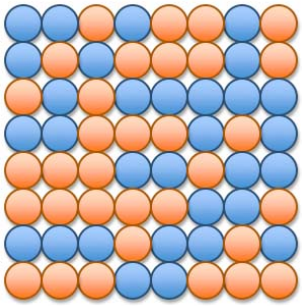

UNIT 11B

The Internet: Protocol Layers

1

Last Lecture

- Networking basics
  - Communication links
  - LANs, WANs
  - Internetworking
- The Internet
  - Packet-switching
- Protocol adoption and standardization

2

Protocols

- Agreement between communicating parties
  - Syntax: how are the messages' contents organized?
  - Semantics: what do the messages mean?
  - Synchronization: when are messages sent?
- How are protocols that govern the operation of the Internet organized?

3

Layering Abstractions

- It is often useful to divide large systems into layers
  - Higher layer uses a lower layer as a service
  - Lower layers are implemented independently from higher layers
  - Interface between two layers needs to be specified
- Example: Dice game uses `roll`
  `roll` uses `rand`
  `rand` uses some LCRG method

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Internet Protocol Hierarchy

- Each layer addresses one aspect of the overall communications task
  - Layers: Link, Internet, Transport, Application
  - A change in one layer will not cause a change to other layers, leading to easier maintenance
- This hierarchy is referred to as TCP/IP, named after two of its protocols.

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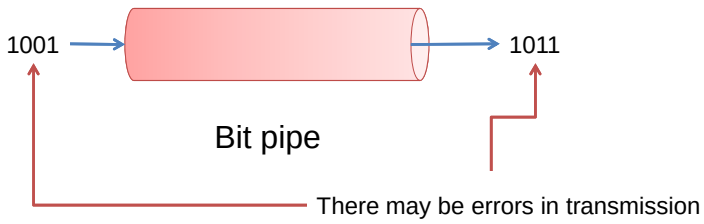
Physical Links



- How do we know if a bit is present on the line?
- How much time will a bit remain on the line?
- If the bit is in the form of analog signal or a digital signal
- What voltage levels are used to represent 0 and 1?

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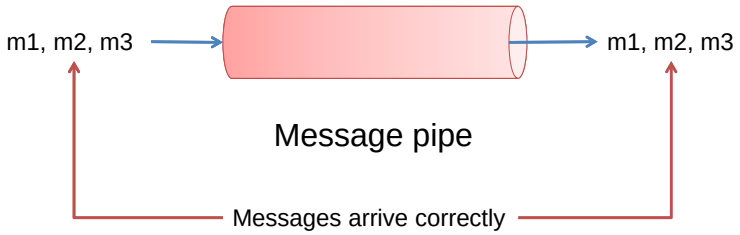
Data Links



- Error detection and correction
- Framing: Which bits in the incoming stream identify the start and end of a bit string?

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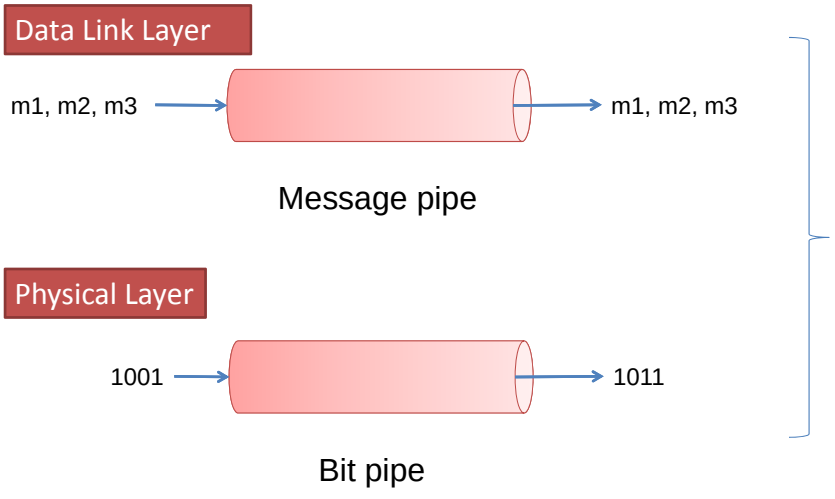
Link Layer



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Network Layer

- The link layer enables us to transmit messages from node A to node B, only if these two are connected by a physical link.
- In networks other than LANs, majority of nodes are not directly connected.
- Network layer is responsible for delivering messages from their source to destination.

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Network Layer

- Key functions:
  - Create a universal addressing scheme for all network nodes
  - Deliver messages between any two nodes in the network
- The network layer in the Internet is called IP (Internet Protocol).

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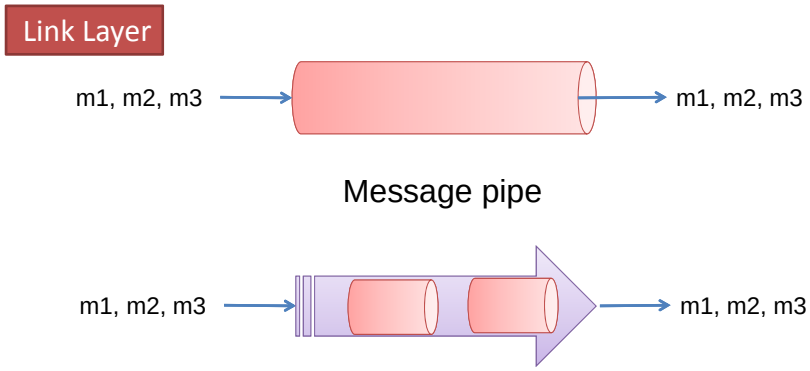
Link vs. Network Layers



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IP Addresses (IPv4)

- Computers on the Internet are assigned an IP Address consisting of four numbers between 0 and 255 inclusive

  ____ . ____ . ____ . ____

  Example: 128.2.13.163

- This means that each part of the address is an 8-bit value, and an IP address is 32 bits. Hence, it supports up to 2^{32} computers on the network at the same time.

- ISPs can reassign IP addresses dynamically.

IPv4 Address Assignment

- The original IPv4 had several classes of addresses that could be decomposed into a network and host part
  - Class A **0** + 7-bit network + 24-bit address
    Accommodates up to 2^{24} unique IP addresses in a company or location.
  - Class B **10** + 14 bit network + 16-bit address
    Accommodates up to 2^{16} unique IP addresses in a company or location.
  - Class C **110** + 21-bit network + 8-bit address
    Accommodates up to 2^{8} unique IP addresses in a company or location.

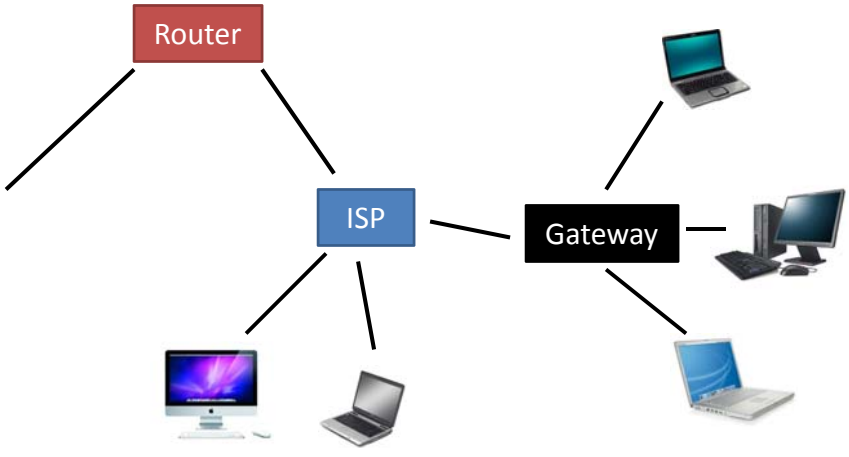
IPv4 Address Assignment

- In 1993, the Internet switched to classless internet-domain routing.
- In this scheme, the network part is an arbitrary length prefix of the address, such as 10.10.1.32/27, which has a 27-bit network part and a 5-bit host part (so there can only be 32 machines on that network).

New IP (IPv6)

- IPv6 uses 128-bit addresses, which implies 2^{128} (3.4×10^{38}) unique computer addresses ,($4.8 * 10^{28}$ addresses per person)
- Allows for many more devices (cell phones, video game machines, appliances, automobiles, etc.)
- Designed to deal with the approaching use of all available addresses in IPv4.
- IPv6 also follows classless routing, but the standard subnetwork size is 64-bits.

Network Address Translation (NAT)



Network Address Translation (NAT)

- Used to accommodate more users on the Internet, security, and administration.
- The gateway assigns an additional code called a port for each user. Packets are tagged with the port.
- The gateway knows where to route the messages on the private network, but all messages from that private network share the same single IP address.

Host Names

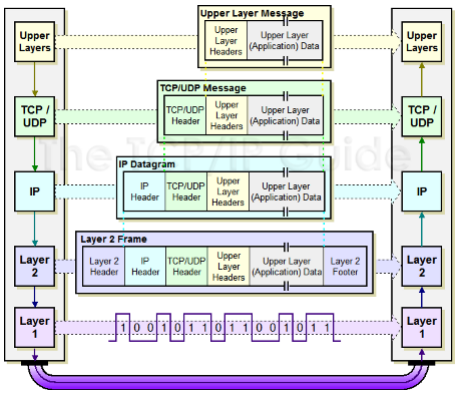
Domain Name Service (DNS)

- Phone book for the Internet: translates human-friendly computer hostname into IP addresses.
- hierarchical
  - root name servers knows how to find DNS servers for each top-level domain (e.g., "edu")
  - top-level domain servers know how to find DNS servers for each second-level domain (e.g., "cmu.edu")
  - second-level domain servers know how to find each host in directly in the second-level domain (e.g., "www.cmu.edu") and how to find DNS servers for each third-level domain (e.g., "andrew.cmu.edu")

Layers of the TCP/IP Reference Model

- Application Layer
  - Handles requests from the user for data on the Internet.
- Transport Layer
  - Handles splitting messages into packets for delivery.
- Internet Layer
  - Handles the task of sending packets across one or more networks.
- Link Layer
  - Handles the physical transfer and reception of bits.

Layers of the TCP/IP Reference Model



Application Layer

Transport Layer

Network Layer

Link Layer

Transport Layer

- Internet Protocol (IP)
  - Delivers packets to IP address
  - Best effort delivery
- Transport Control Protocol
  - Creates a reliable bi-directional stream (source address/port and destination address/port)
    - acknowledgements, resend, reassembly in correct order,
    - error detection
    - connection must be opened and closed
    - flow/congestion control

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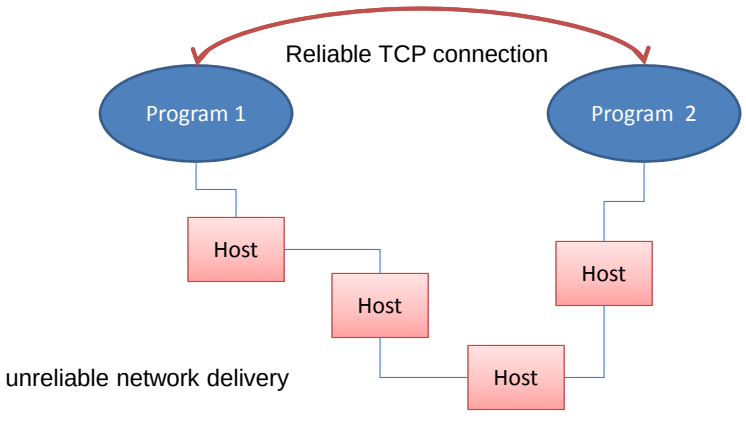
Transport Layer

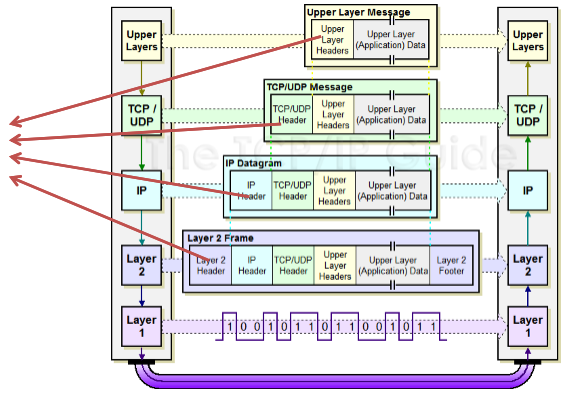


Reliable Communication with TCP

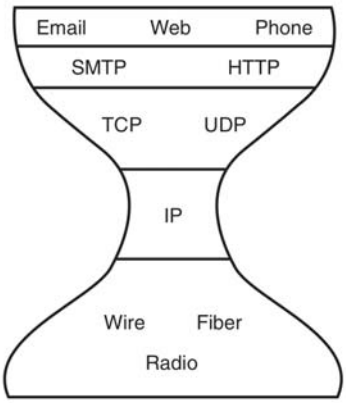
- Suppose Alice and Bob are the TCP implementations of two computers.
  - Alice is asked to send a message to Bob.
  - Alice breaks the message into several packets.
    - Each packet includes parity information, so Bob can check it for accuracy.
    - Packets are sent via IP.
  - Bob receives the packets.
    - If Bob is missing a packet or receives a corrupt packet, he can request retransmission.
    - If the packet is OK, Bob sends an acknowledgement.
  - If Alice doesn't get an acknowledgement, she will retransmit.
  - Bob assembles the incoming packets in order and provides the message to the appropriate application.

Layers of the TCP/IP Reference Model

Headers

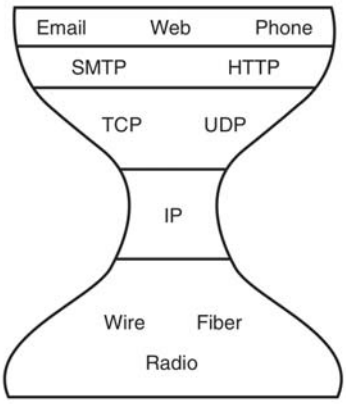


Examples of Protocols



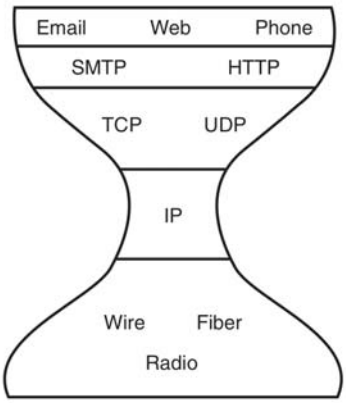
- Application
  - Hypertext Transfer Protocol (HTTP)
  - Simple Mail Transfer Protocol (SMTP)
  - Domain Name System (DNS)
    - XYZ.com **! w.x.y.z**
  - Secure Shell (SSH) Protocol
    - ssh unix.andrew.cmu.edu
  - Voice Over IP (Phone calls)
    - Session Initiation Protocol (SIP)
    - Real-time Transport Protocol (RTP)

Examples of Protocols



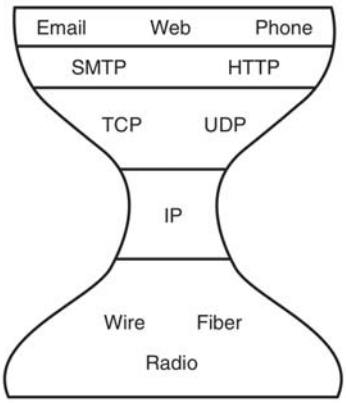
- Transport
  - Transmission Control Protocol (TCP)
    - Connection-oriented
  - User Datagram Protocol (UDP)
    - Connectionless

Examples of Protocols



- Internet
  - IPv4
  - IPv6

Examples of Protocols



- Link
  - 1000BaseT
    — Gigabit Ethernet
  - Data Over Cable Service Interface Specification
    — Cable Modems
  - Long Term Evolution (LTE)
    – 4G cell phone
  - 802.11N (Wi-Fi) — Wireless Ethernet

Web

Hypertext Transfer Protocol (HTTP)

- Retrieves documents (in HTML and other formats) over TCP using port 80
- Can also send form data to the server
- Support multiple requests per connection

Example: Web page Delivery

- A Web page is identified by a Uniform Resource Locator (URL)

  protocol://host address/page

- An HTTP Request

http://www.cs.cmu.edu/~15110/index.html

Program to use

Example: Web page Delivery

1. Web browser extracts the name of the machine and gets it translated to an IP address (e.g. 128.2.217.13)
2. Establishes a TCP connection to port 80 at 128.2.217.13
3. Constructs a message

   GET /~15110/index.html HTTP/1.1
4. Sends the message using services of TCP/IP
5. Web server locates the file and send a response back using services of TCP/IP
6. The connection is terminated.

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