Lecture 2
Protocol Stacks and Layering

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15-441, Computer Networks

Last Time

- The Big Picture
  - » Goals:
    - – Efficiency
    - – "ilities" (scalability, manageability, availability),
    - – Ease of creating applications
  - » Challenges:
    - – Scale
    - – Geography
    - – Heterogeneity (** today's focus!)
- A few specific details:
  - » Circuits vs. packets
  - » Little bit about routing
  - » Service model and how to construct services (** today!)

Today's Lecture

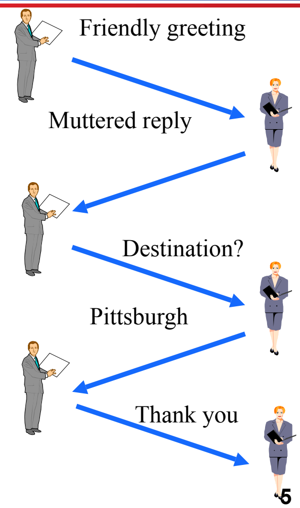
- Last time: "Big picture"
- Today:
  - » General architectural principles for networks
  - » Introduces a few concrete models & examples
- Where we are going:
  - » Tuesday: Socket programming review++ (for project)
  - » Thursday: Application examples (still high level)
  - » After that: Burrowing into the details, ground up
- Today's specifics:
  - » What is a protocol.
  - » Protocol stacks.
  - » Some history.
  - » Standards organizations.
  - » Application layer.

Why protocols and layering?

- Interoperability
- Reuse
- Hiding underlying details

What is a Protocol

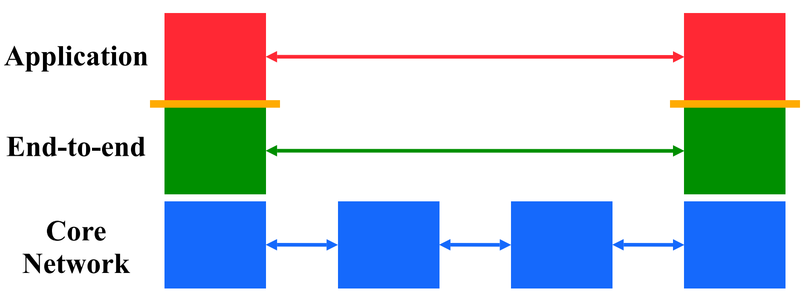
- An agreement between parties on how communication should take place.
- Protocols may have to define many aspects of the communication.
- Syntax:
  - » Data encoding, language, etc.
- Semantics:
  - » Error handling, termination, ordering of requests, etc.
- Protocols at hardware, software, *all* levels!
- Example: Buying airline ticket by typing.
- Syntax: English, ascii, lines delimited by "\n"



Interfaces

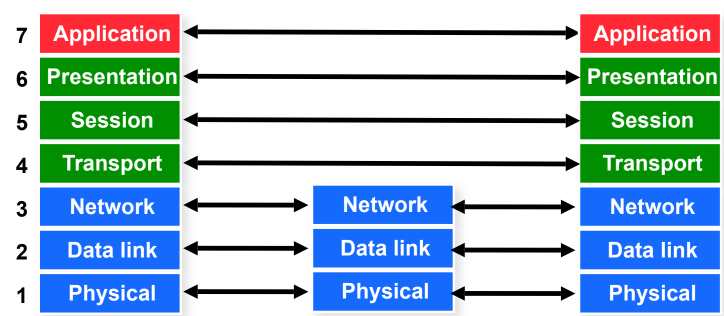
- Each protocol offers an interface to its users, and expects one from the layers on which it builds
  - » Syntax and semantics strike again
    - – Data formats
    - – Interface characteristics, e.g. IP service model
- Protocols build upon each other
  - » Add value
    - – E.g., a reliable protocol running on top of IP
  - » Reuse
    - – E.g., OS provides TCP, so apps don't have to rewrite

Protocol and Service Levels



A Layered Network Model

The Open Systems Interconnection (OSI) Model.



OSI Motivation

- Standard way of breaking up a system in a set of components, but the components are organized as a set of layers.
  - Only horizontal and vertical communication
  - Components/layers can be implemented and modified in isolation
- Each layer offers a service to the higher layer, using the services of the lower layer.
- “Peer” layers on different systems communicate via a protocol.
  - higher level protocols (e.g. TCP/IP, Appletalk) can run on multiple lower layers
  - multiple higher level protocols can share a single physical network
- “It’s only a model!” - TCP/IP has been crazy successful, and it’s not based on a rigid OSI model. But the OSI model has been very successful at shaping thought.

OSI Functions

- (1) Physical: transmission of a bit stream.
- (2) Data link: flow control, framing, error detection.
- (3) Network: switching and routing.
- (4) Transport: reliable end to end delivery.
- (5) Session: managing logical connections.
- (6) Presentation: data transformations.
- (7) Application: specific uses, e.g. mail, file transfer, telnet, network management.

Multiplexing takes place in multiple layers

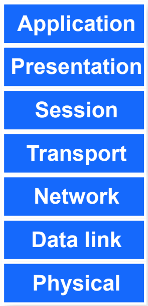
Looking at protocols

- Hop by hop / link protocols
  - Ethernet
- End-to-end protocols
  - TCP, apps, etc.
- Management / “control plane” protocols
  - Routing, etc.
    - Can be either link or e2e themselves
    - Definition somewhat vague.
- Standards
  - File formats, etc.
    - E.g., JPEG, MPEG, MP3, …

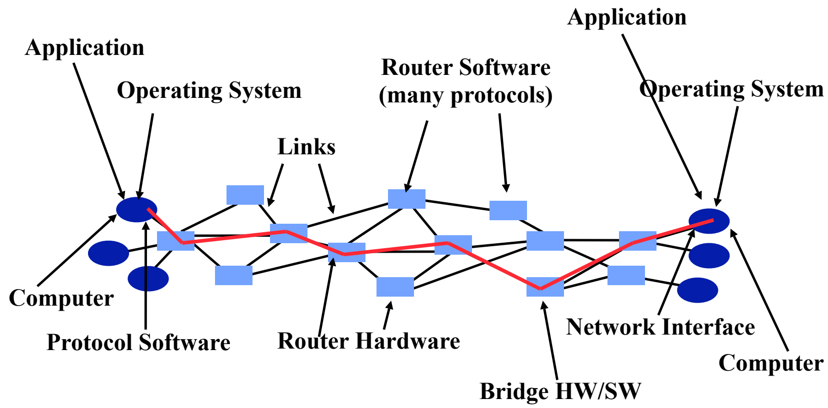
Categories not solid / religious, just a way to view things.

Heterogenous Sources of Components

- Application: web server/browser, mail, distributed game,..
- Presentation/session.
  - Often part of application
  - Sometimes a library
- Transport/network.
  - Typically part of the operating system
- Datalink.
  - Often written by vendor of the network interface hardware
- Physical.
  - Hardware: card and link



Motivation: Many many Network Components



Protocols for Interoperability

- Many implementations of many technologies:
- Hosts running FreeBSD, Linux, Windows, MacOS, …
- People using Mozilla, Explorer, Opera, …
- Routers made by cisco, juniper, …
- Hardware made by IBM, Dell, Apple, …
- And it changes all the time.
- Phew!

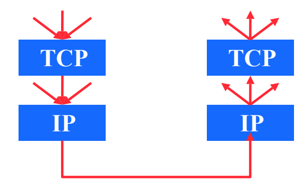
- But they can all talk together because they use the same protocol(s)
  - » Application level protocols: HTTP, SMTP, POP, IMAP, etc.
  - » Hardware protocols (ethernet, etc)

Protocols for Abstraction & Reuse

- Multiple choices of protocol at many layers
  - » Physical: copper, fiber, air, carrier pigeon
  - » Link: ethernet, token ring, SONET, FDDI
  - » Transport: TCP, UDP, SCTP
- But we don't want to have to write "a web (HTTP) browser for TCP networks running IP over Ethernet on Copper" and another for the fiber version…
  - » Reuse! Abstraction!
  - » Protocols provide a standard interface to write to
  - » Layers hide the details of the protocols below

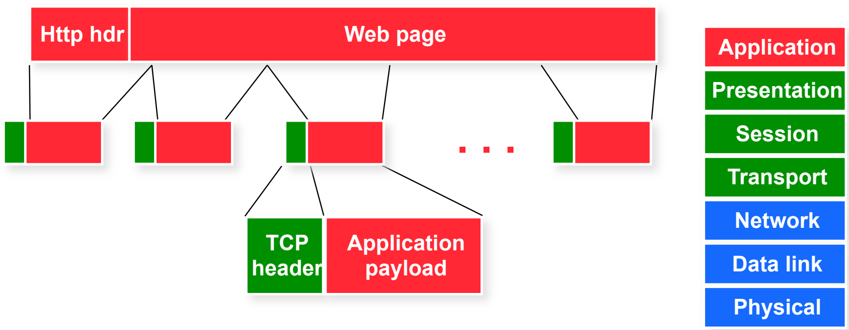
Multiplexing and Demultiplexing

- There may be multiple implementations of each layer.
  - » How does the receiver know what version of a layer to use?
- Each header includes a demultiplexing field that is used to identify the next layer.
  - » Filled in by the sender
  - » Used by the receiver
- Multiplexing ooccurs at multiple layers. E.g., IP, TCP, …



V/HL	TOS	Length
ID		Flags/Offset
TTL	Prot.	H. Checksum
Source IP address		
Destination IP address		
Options..		

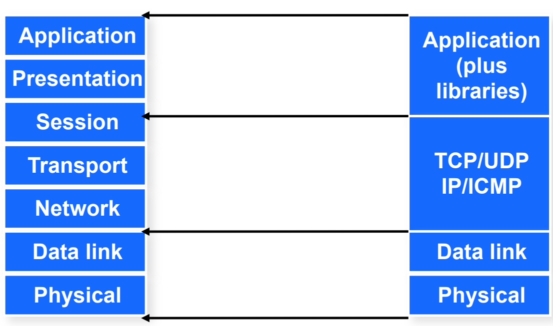
Example: Sending a Web Page



Limitations of the Layered Model

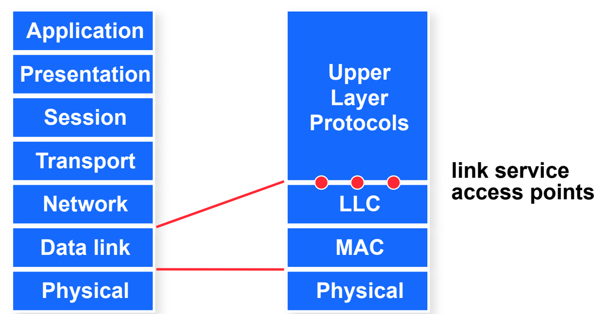
- Some layers are not always cleanly separated.
  - » Inter-layer dependencies in implementations for performance reasons
  - » Some dependencies in the standards (header checksums)
- Higher layers not always well defined.
  - » Session, presentation, application layers
- Lower layers have “sublayers”.
  - » Usually very well defined (e.g., SONET protocol)
- Interfaces are not always well standardized.
  - » It would be hard to mix and match layers from independent implementations, e.g., windows network apps on unix (w/out compatability library)
  - » Many cross-layer assumptions, e.g. buffer management

The TCP/IP Model

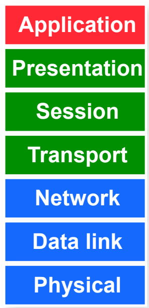


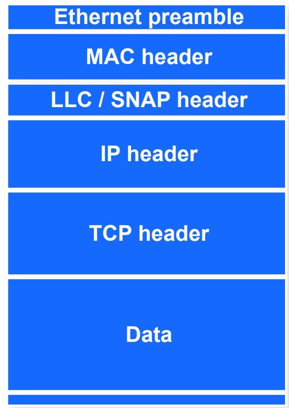
Local Area Network Protocols

IEEE 802 standards “refine” the OSI data link layer.



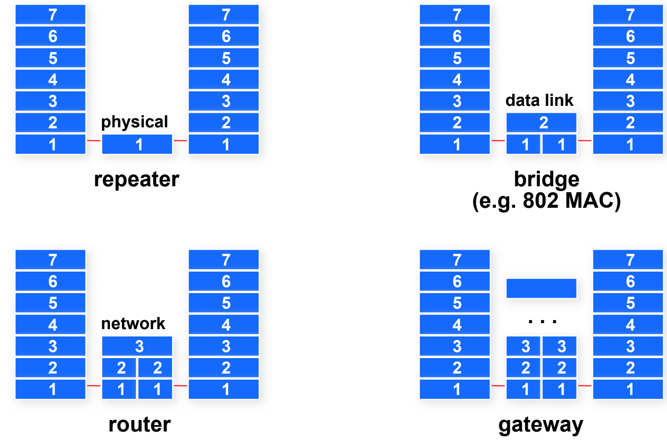
A TCP / IP / 802.3 Packet



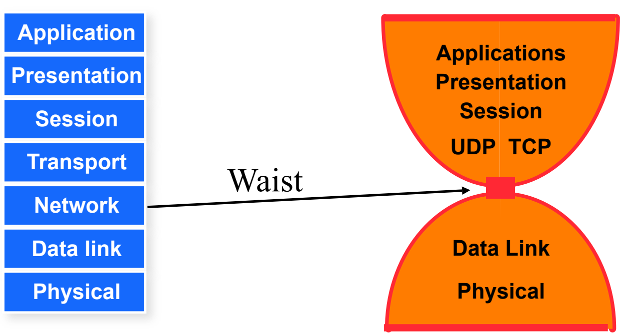


Homework explores tradeoffs in header sizes, etc., with different applications

Internetworking Options



The Internet Protocol Suite



The Hourglass Model

The waist facilitates

Interoperability.

Some History: The Early Days

- **Early packet switching networks (61-72).**
  - » Definition of packet switching
  - » Early DARPA net: up to tens of nodes
    - – single network
    - – discovery of "interesting" applications
- **Internetworking (72-80).**
  - » Multiple networks with inter-networking: networks are independent, but need some rules for interoperability
  - » Key concepts: best effort service, "stateless" routers, decentralized control (very different from telephones!)
  - » Basis for Internet: TCP, IP, congestion control, DNS, …
  - » Rapid growth: 10 to 100000 hosts in 10 years
    - – Driven by NSF net, research communigy

Recent History: Commercialization

- Industry interest in networking encourages first commercial network deployment.
  - » In part also encouraged by NSFNET policies
- Introduction of the Web makes networks more accessible.
  - » Killer application
  - » Good user interface that is accessible to anybody
  - » Network access on every desktop and in every home
  - » Shockingly recent - 1989, caught on in ‘92 or so

Standardization

- Key to network interoperability.
- A priori standards.
  - » Standards are defined first by a standards committee
  - » Risk of defining standards that are untested or unnecessary
  - » Standard may be available before there is serious use of the technology
- De facto standards.
  - » Standards is based on an existing systems
  - » Gives the company that developed the base system a big advantage
  - » Often results in competing “standards” before the official standard is established

Relevant Standardization Bodies

- ITU-TS - Telecommunications Sector of the International Telecommunications Union.
  - » government representatives (PTTs/State Department)
  - » responsible for international “recommendations”
- T1 - telecom committee reporting to American National Standards Institute.
  - » T1/ANSI formulate US positions
  - » interpret/adapt ITU standards for US use, represents US in ISO
- IEEE - Institute of Electrical and Electronics Engineers.
  - » responsible for many physical layer and datalink layer standards
- ISO - International Standards Organization.
  - » covers a broad area

The Internet Engineering Task Force

- The Internet society.
  - » Oversees the operations of the Internet
- Internet Engineering Task Force.
  - » decides what technology will be used in the Internet
  - » based on working groups that focus on specific issues
  - » encourages wide participation
- Request for Comments.
  - » document that provides information or defines standard
  - » requests feedback from the community
  - » can be “promoted” to standard under certain conditions
    - – consensus in the committee
    - – interoperating implementations
  - » Project 1 will look at the Internet Relay Chat (IRC) RFC

Higher Level Standards

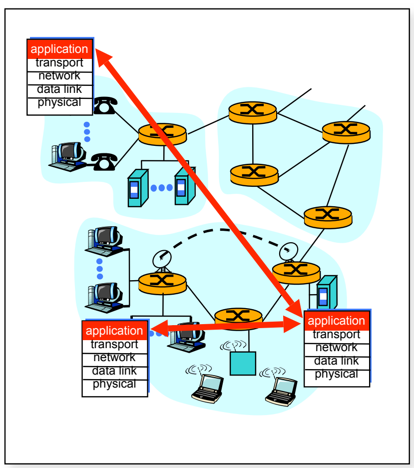
- Many session/application level operations are relevant to networks.
  - » encoding: MPEG, encryption, ...
  - » services: electronic mail, newsgroups, HTTP, ...
  - » electronic commerce, ...
- Standards are as important as for "lower-level" networks: interoperability.
  - » defined by some of the same bodies as the low-level standards, e.g. IETF

Designing applications

- Application architecture
  - » Client-server? (vs p2p vs all in one)
  - » Application requirements
- Application level communication
  - » TCP vs. UDP
  - » Addressing
- Application examples (Lecture 4).
  - » ftp, http
  - » End-to-end argument discussion

Applications and Application-Layer Protocols

- Application: communicating, distributed processes
  - » Running in network hosts in "user space"
  - » Exchange messages to implement app
  - » e.g., email, file transfer, the Web
- Application-layer protocols
  - » One "piece" of an app
  - » Define messages exchanged by apps and actions taken
  - » Use services provided by lower layer protocols
- Sockets API refresher next week (remember from 213)



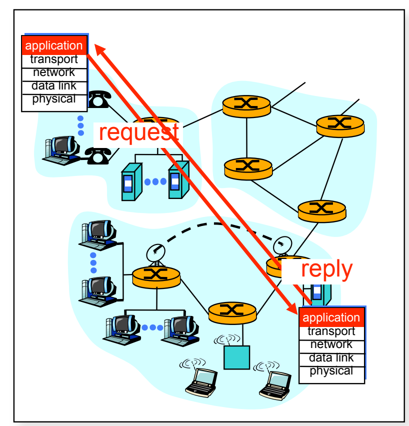
Client-Server Paradigm

Typical network app has two pieces: *client* and *server*

Client:
- Initiates contact with server ("speaks first")
- Typically requests service from server,
- For Web, client is implemented in browser; for e-mail, in mail reader

Server:
- Provides requested service to client
- e.g., Web server sends requested Web page, mail server delivers e-mail

- (We'll cover p2p at semester end)



What Transport Service Does an Application Need?

Data loss
- Some applications (e.g., audio) can tolerate some loss
- Other applications (e.g., file transfer, telnet) require 100% reliable data transfer

Timing
- Some applications (e.g., Internet telephony, interactive games) require low delay to be "effective"

Bandwidth
- Some applications (e.g., multimedia) require a minimum amount of bandwidth to be "effective"
- Other applications ("elastic apps") will make use of whatever bandwidth they get

User Datagram Protocol(UDP): An Analogy

UDP
- Single socket to receive messages
- No guarantee of delivery
- Not necessarily in-order delivery
- Datagram – independent packets
- Must address each packet

Postal Mail
- Single mailbox to receive letters
- Unreliable ☺
- Not necessarily in-order delivery
- Letters sent independently
- Must address each reply

Example UDP applications
Multimedia, voice over IP

Transmission Control Protocol (TCP): An Analogy

TCP
- Reliable – guarantee delivery
- Byte stream – in-order delivery
- Connection-oriented – single socket per connection
- Setup connection followed by data transfer

Telephone Call
- Guaranteed delivery
- In-order delivery
- Connection-oriented
- Setup connection followed by conversation

Example TCP applications
Web, Email, Telnet

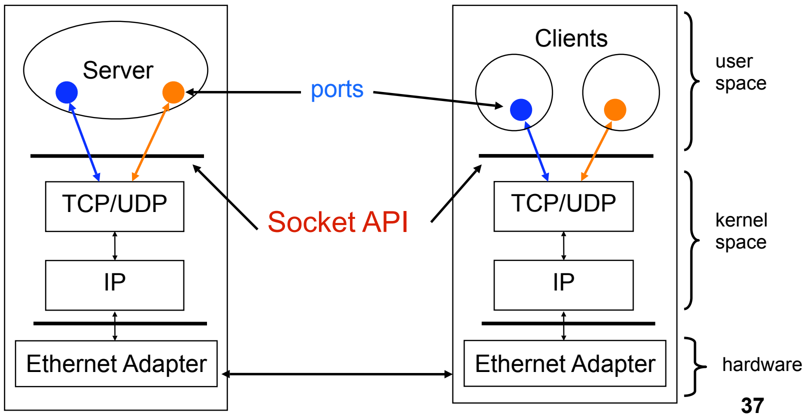
Transport Service Requirements of Common Applications

Application	Data loss	Bandwidth	Time Sensitive
file transfer	no loss	elastic	no
e-mail	no loss	elastic	no
web documents	no loss	elastic	no
real-time audio/ video	loss-tolerant	audio: 5Kb-1Mb video:10Kb-5Mb	yes, 100's msec
stored audio/video	loss-tolerant	same as above	yes, few secs
interactive games	loss-tolerant	few Kbps	yes, 100's msec
financial apps	no loss	elastic	yes and no

- **Interactions between layers are important.**
  - »persistent HTTP
  - »encryption and compression
  - »MPEG frame types. Loss & real-time video.

Server and Client

Server and Client exchange messages over the network through a common Socket API



Readings

- Read two papers on the motivations for the Internet architecture:
  - » "End-to-end arguments in system design", Saltzer, Reed, and Clark, ACM Transactions on Computer Systems, November 1984.
  - » "The design philosophy of the DARPA Internet Protocols", Dave Clark, SIGCOMM 88.
- In-class discussion:
  - » Briefly next Thursday
  - » Revisit the topic in the second half of the semester