Lecture 3
Design Philosophy & Applications

David Andersen
School of Computer Science
Carnegie Mellon University

15-441 Networking, Fall 2006
http://www.cs.cmu.edu/~srini/15-441/F06/

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Lecture Overview

- Last time:
  - Protocol stacks and layering
  - OSI and TCP/IP models
  - Application requirements from transport protocols
- Internet Architecture
- Project information
- Application examples.
  - ftp
  - http
- Application requirements.
  - "ilities"
  - Sharing

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Internet Architecture

- Background
  - "The Design Philosophy of the DARPA Internet Protocols" (David Clark, 1988).
- Fundamental goal: Effective network interconnection
- Goals, *in order of priority:*
  1. Continue despite loss of networks or gateways
  2. Support multiple types of communication service
  3. Accommodate a variety of networks
  4. Permit distributed management of Internet resources
  5. Cost effective
  6. Host attachment should be easy
  7. Resource accountability

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Priorities

- The effects of the order of items in that list are still felt today
  - E.g., resource accounting is a hard, current research topic
- Let's look at them in detail

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Survivability

- If network disrupted and reconfigured
  - Communicating entities should not care!
  - No higher-level state reconfiguration
  - Ergo, transport interface only knows "working" and "not working." Not working == complete partition.
- How to achieve such reliability?
  - Where can communication state be stored?

	Network	Host
Failure handing	Replication	"Fate sharing"
Net Engineering	Tough	Simple
Switches	Maintain state	Stateless
Host trust	Less	More

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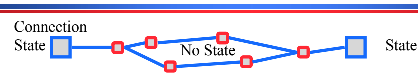
Fate Sharing



- Lose state information for an entity if (and only if?) the entity itself is lost.
- Examples:
  - OK to lose TCP state if one endpoint crashes
    - NOT okay to lose if an intermediate router reboots
  - Is this still true in today's network?
    - NATs and firewalls
- Survivability compromise: Heterogenous network -> less information available to end hosts and Internet level recovery mechanisms

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Types of Service

- Recall from last time TCP vs. UDP
  - Elastic apps that need reliability: remote login or email
  - Inelastic, loss-tolerant apps: real-time voice or video
  - Others in between, or with stronger requirements
  - Biggest cause of delay variation: reliable delivery
    - Today's net: ~100ms RTT
    - Reliable delivery can add *seconds*.
- Original Internet model: "TCP/IP" one layer
  - First app was remote login…
  - But then came debugging, voice, etc.
  - These differences caused the layer split, added UDP
- No QoS support assumed from below
  - In fact, some underlying nets only supported reliable delivery
    - Made Internet datagram service less useful!
  - Hard to implement without network support
  - QoS is an ongoing debate…

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Varieties of Networks

- Discussed a lot of this last time -
  - Interconnect the ARPANET, X.25 networks, LANs, satellite networks, packet networks, serial links…
- Mininum set of assumptions for underlying net
  - Minimum packet size
  - Reasonable delivery odds, but not 100%
  - Some form of addressing unless point to point
- Important non-assumptions:
  - Perfect reliability
  - Broadcast, multicast
  - Priority handling of traffic
  - Internal knowledge of delays, speeds, failures, etc.
- Much engineering then only has to be done once

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The "Other" goals

- Management
  - Today's Internet is decentralized - BGP
  - Very coarse tools. Still in the "assembly language" stage
- Cost effectiveness
  - Economies of scale won out
  - Internet cheaper than most dedicated networks
  - Packet overhead less important by the year
- Attaching a host
  - Not awful; DHCP and related autoconfiguration technologies helping. A ways to go, but the path is there
- But…

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Accountability

- Huge problem.
- Accounting
  - Billing? (mostly flat-rate. But phones are moving that way too - people like it!)
  - Inter-provider payments
    - Hornet's nest. Complicated. Political. Hard.
- Accountability and security
  - Huge problem.
  - Worms, viruses, etc.
    - Partly a host problem. But hosts very trusted.
  - Authentication
    - Purely optional. Many philosophical issues of privacy vs. security.
- … Questions before we move on to the project?

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Project 1

- Out today, due 10/12
  - Two checkpoints, one in a week
  - Get started early. Get started early. Get …
- Project partners
  - Choose very soon
  - Mail to George Nychis, gnychis@cs.cmu.edu
- Project is an IRC server (Internet Relay Chat)
  - Text-based chat protocol. Features, in order:
  1. Basic server (connect, channels, talk, etc.)
     - can do now
  2. Link-state routing to send messages to users across servers
     1. OSPF lecture (9/28). Book: Chapter 4 (4.2)
  3. Multicast routing to let channels span servers
     1. MOSPF lecture (10/5). Paper: Deering "Multicast Routing"

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Project 1 goals

- Skill with real network applications
  - Select, dealing with multiple streams of data, remote clients and servers
  - Protocol "grunge" - headers, layers, packets, etc.
  - Be able to implement a [whatever] server.
- Meet a real protocol
  - Create it from the spec
- Familiarity with routing protocols and techniques
- Don't be dismayed by the size of the handout. It breaks down into reasonable chunks.

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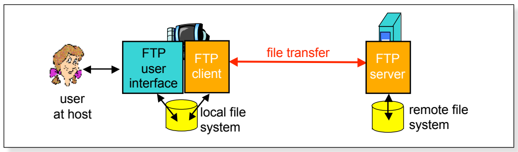
FTP: The File Transfer Protocol



- Transfer file to/from remote host
- Client/server model
  - » *Client:* side that initiates transfer (either to/from remote)
  - » *Server:* remote host
- ftp: RFC 959
- ftp server: port 21

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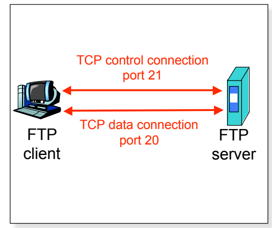
Ftp: Separate Control, Data Connections

- Ftp client contacts ftp server at port 21, specifying TCP as transport protocol
- Two parallel TCP connections opened:
  - » Control: exchange commands, responses between client, server.
    "out of band control"
  - » Data: file data to/from server
- Ftp server maintains "state": current directory, earlier authentication



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Ftp Commands, Responses

Sample Commands:

- sent as ASCII text over control channel
- `USER` *`username`*
- `PASS` *`password`*
- `LIST` return list of files in current directory
- `RETR filename` retrieves (gets) file
- `STOR filename` stores (puts) file onto remote host

Sample Return Codes

- status code and phrase
- `331 Username OK, password required`
- `125 data connection already open; transfer starting`
- `425 Can't open data connection`
- `452 Error writing file`

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HTTP Basics

- HTTP layered over bidirectional byte stream
  - » Almost always TCP
- Interaction
  - » Client sends request to server, followed by response from server to client
  - » Requests/responses are encoded in text
- Stateless
  - » Server maintains no information about past client requests

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How to Mark End of Message?

- Size of message → Content-Length
  - » Must know size of transfer in advance
- Delimiter → MIME style Content-Type
  - » Server must "escape" delimiter in content
- Close connection
  - » Only server can do this

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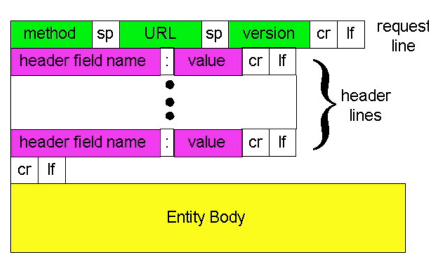
HTTP Request



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HTTP Request

- Request line
  - » Method
    - – GET – return URI
    - – HEAD – return headers only of GET response
    - – POST – send data to the server (forms, etc.)
  - » URI
    - – E.g. http://www.intel-iris.net/index.html with a proxy
    - – E.g. /index.html if no proxy
  - » HTTP version

HTTP Request

- Request headers
  - » Authorization – authentication info
  - » Acceptable document types/encodings
  - » From – user email
  - » If-Modified-Since
  - » Referrer – what caused this page to be requested
  - » User-Agent – client software
- Blank-line
- Body

HTTP Request Example

GET / HTTP/1.1
Accept: */*
Accept-Language: en-us
Accept-Encoding: gzip, deflate
User-Agent: Mozilla/4.0 (compatible; MSIE 5.5; Windows NT 5.0)
Host: www.intel-iris.net
Connection: Keep-Alive

HTTP Response

- Status-line
  - » HTTP version
  - » 3 digit response code
    - – 1XX – informational
    - – 2XX – success
      - 200 OK
    - – 3XX – redirection
      - 301 Moved Permanently
      - 303 Moved Temporarily
      - 304 Not Modified
    - – 4XX – client error
      - 404 Not Found
    - – 5XX – server error
      - 505 HTTP Version Not Supported
  - » Reason phrase

HTTP Response

- Headers
  - » Location – for redirection
  - » Server – server software
  - » WWW-Authenticate – request for authentication
  - » Allow – list of methods supported (get, head, etc)
  - » Content-Encoding – E.g x-gzip
  - » Content-Length
  - » Content-Type
  - » Expires
  - » Last-Modified
- Blank-line
- Body

HTTP Response Example

HTTP/1.1 200 OK
Date: Tue, 27 Mar 2001 03:49:38 GMT
Server: Apache/1.3.14 (Unix) (Red-Hat/Linux) mod_ssl/2.7.1 OpenSSL/0.9.5a DAV/1.0.2 PHP/4.0.1pl2 mod_perl/1.24
Last-Modified: Mon, 29 Jan 2001 17:54:18 GMT
ETag: "7a11f-10ed-3a75ae4a"
Accept-Ranges: bytes
Content-Length: 4333
Keep-Alive: timeout=15, max=100
Connection: Keep-Alive
Content-Type: text/html
.....

Cookies: Keeping "state"

Many major Web sites use cookies

Four components:

1) Cookie header line in the HTTP response message
2) Cookie header line in HTTP request message
3) Cookie file kept on user's host and managed by user's browser
4) Back-end database at Web site

Example:

- Susan accesses Internet always from same PC
- She visits a specific e-commerce site for the first time
- When initial HTTP requests arrives at site, site creates a unique ID and creates an entry in backend database for ID

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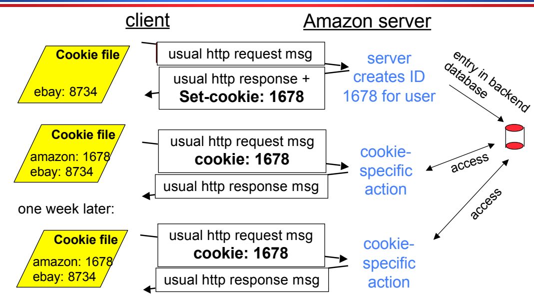
Cookies: Keeping "State" (Cont.)



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Typical Workload (Web Pages)

- Multiple (typically small) objects per page
- File sizes
  - Why different than request sizes?
  - Also heavy-tailed
    - Pareto distribution for tail
    - Lognormal for body of distribution
- Embedded references
  - Number of embedded objects = pareto – $p(x) = ak^a x^{-(a+1)}$

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HTTP 1.1 - new features

- Newer versions of HTTP add several new features (persistent connections, pipelined transfers) to speed things up.
- Let's detour into some performance evaluation and then look at those features

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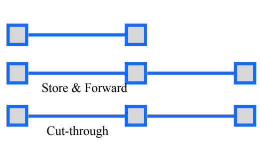
Packet Delay



Prop + xmit

2*(Prop + xmit)

2*prop + xmit

When does cut-through matter?

Next: Routers have finite speed (processing delay)

Routers may buffer packets (queueing delay)

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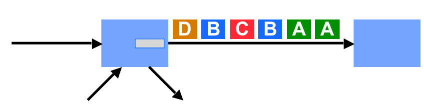
Packet Delay

- Sum of a number of different delay components.
- Propagation delay on each link.
  - Proportional to the length of the link
- Transmission delay on each link.
  - Proportional to the packet size and 1/link speed
- Processing delay on each router.
  - Depends on the speed of the router
- Queuing delay on each router.
  - Depends on the traffic load and queue size



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A Word about Units

- What do “Kilo” and “Mega” mean?
  - » Depends on context
- Storage works in powers of two.
  - » 1 Byte = 8 bits
  - » 1 KByte = 1024 Bytes
  - » 1 MByte = 1024 Kbytes
- Networks work in decimal units.
  - » Network hardware sends bits, not Bytes
  - » 1 Kbps = 1000 bits per second
  - » To avoid confusion, use 1 Kbit/second
- Why? Historical: CS versus ECE.

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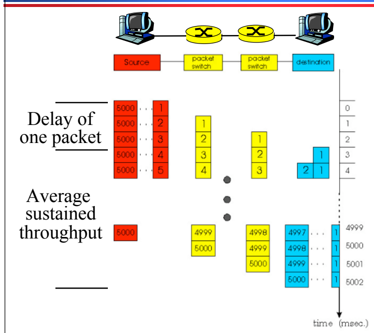
Application-level Delay



$$\text{Delay}^* + \frac{\text{Size}}{\text{Throughput}}$$

Units: seconds + bits/(bits/seconds)

* For minimum sized packet

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Some Examples

- How long does it take to send a 100 Kbit file?
  - » Assume a perfect world
  - » And a 10 Kbit file

Throughput / Latency	100 Kbit/s	1 Mbit/s	100 Mbit/s
500 µsec			
10 msec			
100 msec			

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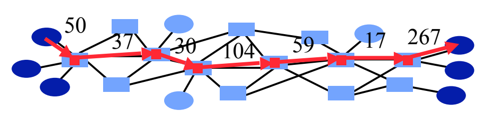
Sustained Throughput

- When streaming packets, the network works like a pipeline.
  - » All links forward different packets in parallel
- Throughput is determined by the slowest stage.
  - » Called the bottleneck link
- Does not really matter why the link is slow.
  - » Low link bandwidth
  - » Many users sharing the link bandwidth



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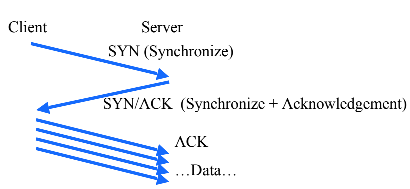
One more detail: TCP

- TCP connections need to be set up
  - » “Three Way Handshake”:



2: TCP transfers start slowly and then ramp up the bandwidth used (so they don’t use too much)

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HTTP 0.9/1.0

- One request/response per TCP connection
  - » Simple to implement
- Disadvantages
  - » Multiple connection setups → three-way handshake each time
    - – Several extra round trips added to transfer
  - » Multiple slow starts

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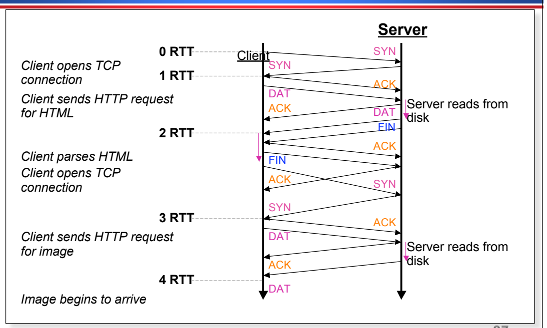
Single Transfer Example



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Performance Issues

- Short transfers are hard on TCP
  - » Stuck in slow start
  - » Loss recovery is poor when windows are small
- Lots of extra connections
  - » Increases server state/processing
- Servers also hang on to connection state after the connection is closed
  - » Why must server keep these?
  - » Tends to be an order of magnitude greater than # of active connections, why?

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Netscape Solution

- Mosaic (original popular Web browser) fetched one object at a time!
- Netscape uses multiple concurrent connections to improve response time
  - » Different parts of Web page arrive independently
  - » Can grab more of the network bandwidth than other users
- Doesn't necessarily improve response time
  - » TCP loss recovery ends up being timeout dominated because windows are small

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Persistent Connection Solution

- Multiplex multiple transfers onto one TCP connection
- How to identify requests/responses
  - » Delimiter → Server must examine response for delimiter string
  - » Content-length and delimiter → Must know size of transfer in advance
  - » Block-based transmission → send in multiple length delimited blocks
  - » Store-and-forward → wait for entire response and then use content-length
  - » Solution → use existing methods and close connection otherwise

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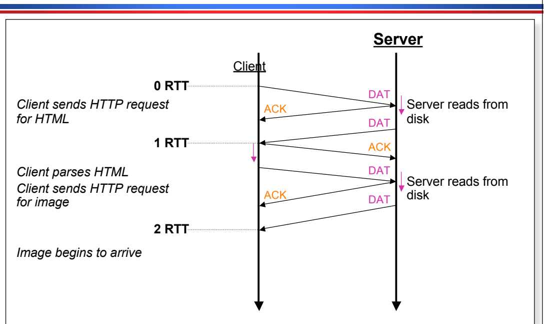
Persistent Connection Solution



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Persistent HTTP

Nonpersistent HTTP issues:

- Requires 2 RTTs per object
- OS must work and allocate host resources for each TCP connection
- But browsers often open parallel TCP connections to fetch referenced objects

Persistent HTTP

- Server leaves connection open after sending response
- Subsequent HTTP messages between same client/server are sent over connection

Persistent without pipelining:

- Client issues new request only when previous response has been received
- One RTT for each referenced object

Persistent with pipelining:

- Default in HTTP/1.1
- Client sends requests as soon as it encounters a referenced object
- As little as one RTT for all the referenced objects

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Persistent Connection Performance

- Benefits greatest for small objects
  - Up to 2x improvement in response time
- Server resource utilization reduced due to fewer connection establishments and fewer active connections
- TCP behavior improved
  - Longer connections help adaptation to available bandwidth
  - Larger congestion window improves loss recovery

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Remaining Problems

- Serialized transmission
  - Much of the useful information in first few bytes
    - May be better to get the 1st 1/4 of all images than one complete image (e.g., progressive JPEG)
  - Can "packetize" transfer over TCP
    - Could use range requests
- Application specific solution to transport protocol problems. :(
  - Solve the problem at the transport layer
  - Could fix TCP so it works well with multiple simultaneous connections
    - More difficult to deploy

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Back to performance

- We examined delay,
- But what about throughput?
- Important factors:
  - Link capacity
  - *Other traffic*

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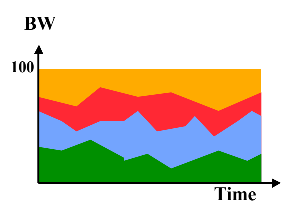
Bandwidth Sharing

- Bandwidth received on the bottleneck link determines end-to-end throughput.
- Router before the bottleneck link decides how much bandwidth each user gets.
  - Users that try to send at a higher rate will see packet loss
- User bandwidth can fluctuate quickly as flows are added or end, or as flows change their transmit rate.



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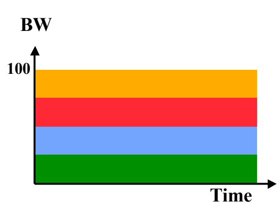
Fair Sharing of Bandwidth

- All else being equal, fair means that users get equal treatment.
  - Sounds fair
- When things are not equal, we need a policy that determines who gets how much bandwidth.
  - Users who pay more get more bandwidth
  - Users with a higher "rank" get more bandwidth
  - Certain classes of applications get priority



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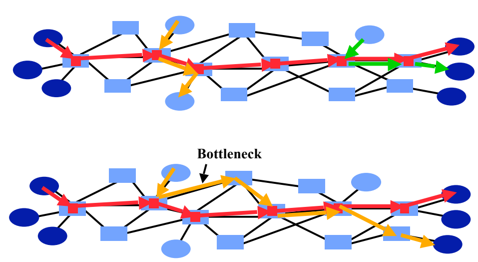
But It is Not that Simple



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Network Service Models

- Set of services that the network provides.
- Best effort service: network will do an honest effort to deliver the packets to the destination.
  - » Usually works
- "Guaranteed" services.
  - » Network offers (mathematical) performance guarantees
  - » Can apply to bandwidth, latency, packet loss, ..
- "Preferential" services.
  - » Network gives preferential treatment to some packets
  - » E.g. lower queuing delay
- Quality of Service is closely related to the question of fairness.

Other Requirements

- Network reliability.
  - » Network service must always be available
- Security: privacy, DOS, ..
- Scalability.
  - » Scale to large numbers of users, traffic flows, ...
- Manageability: monitoring, control, ..
- Requirement often applies not only to the core network but also to the servers.
- Requirements imposed by users and network managers.

Readings

- "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.