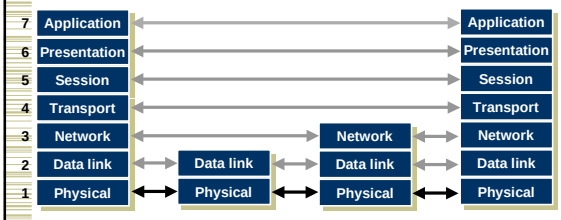
Course Review

Outline

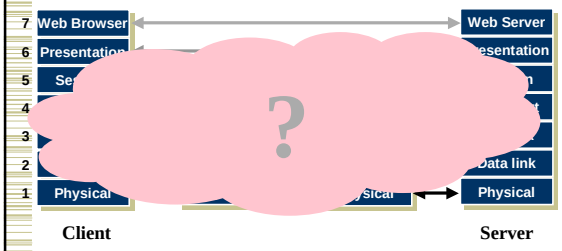
- Networks: A top down view (for a change).
- Other topics.
  - Security
  - QoS
  - Multicast
- Questions?

Protocol Stacks

The Open Systems Interconnection (OSI) Model.



Browsing the Web



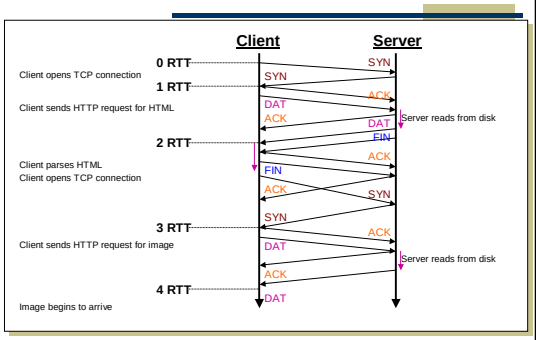
HTTP Request Example

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.seshan.org
Connection: Keep-Alive

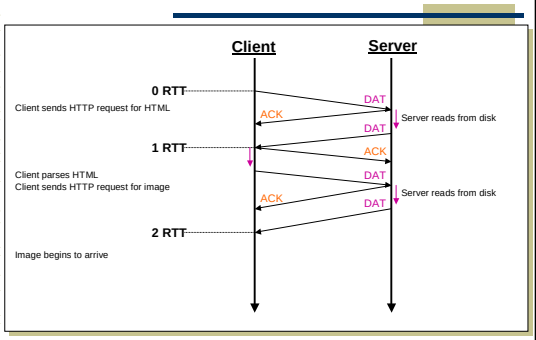
HTTP Response Example

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
…..

Single Transfer Example

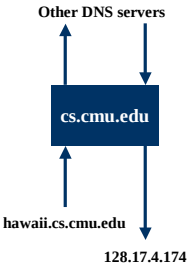


Persistent Connection Example



DNS Server

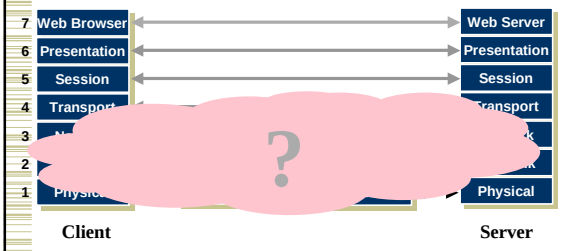
- A DNS server is responsible for maintaining the name-address mapping in a specific domain.
  - E.g. cs.cmu.edu
- The network manager can add, remove, or change mappings.
- Computers can send requests to the server to translate a name into an address.
  - But how do you find the server?
  - Recursively contact the parent in the hierarchical name space
- Caching is used to speed up the lookup of frequently used names.



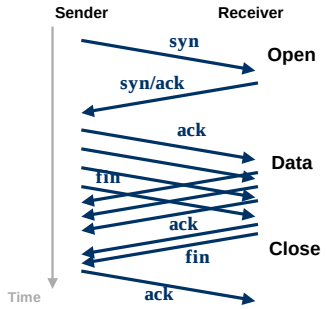
Typical Exchange

- Sender creates and initializes a socket.
- Sender issues an open connection command.
  - Specifies destination IP and application port addresses
  - Sender blocks while connection is established
- If the connection succeeds, data exchange can start.
  - Lots of things can go wrong: wrong addresses, receiver or network down.
- Receiver creates and initializes a socket.
- Receiver listens on the socket for a connection request.
  - Can sometimes restrict the type of connection
- If receiver accepts the connection and the connection succeeds, data exchange can start.
  - Communication typically uses a different socket

Browsing the Web



Connection management



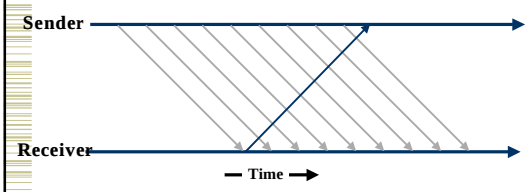
Reliability

- Checksum guarantees end-end data integrity.
- Sequence numbers detect packet sequencing problems:
  - duplicate: ignore
  - reordered: reorder or drop
  - lost: retransmit
- Lost packets detected by sender.
  - uses time out to detect lack of acknowledgment
  - requires reliable roundtrip time estimate
- Retransmission requires that sender keeps copy of the data until ACK is received.
  - performance issue

When to Send a Packet?

- End-to-end flow control.
  - avoid buffer overflow on receiver
  - receiver advertizes a window size
- Congestion control.
  - estimates amount of data that can be in network
  - implemented using the congestion window, slow start, and fast retransmit/recovery mechanisms
- Efficiency considerations.
  - try to send large packets (if possible)
    - more efficient in the network and on end points
  - piggybacking of acks

Window Size versus Throughput

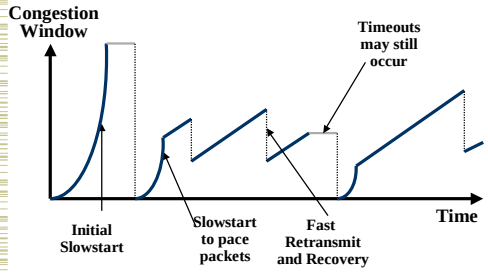


$$\text{Throughput} = \frac{\text{Window Size}}{\text{Roundtrip Time}}$$

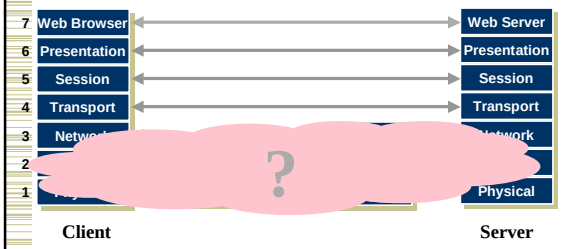
TCP Congestion Avoidance

- Congestion avoidance limits how fast TCP can send data.
  - Implemented using a congestion window that limits how much data can be in the network
    - independent from flow control window
  - transmission is limited by minimum of the two windows
  - window grows in response to acknowledgement
- Packet loss is seen as sign of congestion.
  - multiplicative decrease of the congestion window
  - have to cut back fast since cost of congestion is high
- How do you detect when more bandwidth becomes available?
  - gradually increment congestion window (probing)
  - results in oscillation around congestion window size!

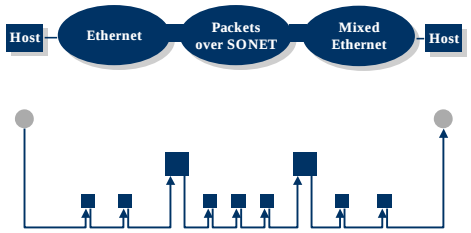
TCP Saw Tooth Behavior



Browsing the Web



Hop-by-Hop Packet Forwarding in the Internet



Addressing in IP v4 (Basic)

- Each host has an Internet address.
- Addresses are hierarchical.
  - address contains hint about location
- Address space is divided in three classes of point-to-point addresses, multicast addresses, and some special addresses.

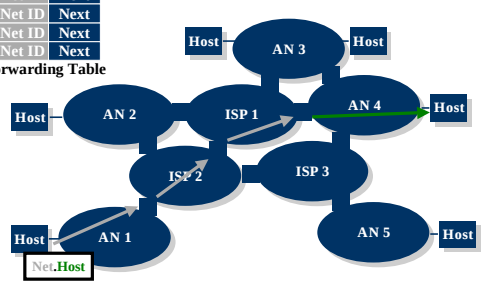
	type	network	host
A	1	7	24
B	2	14	16
C	3	21	8
D	4	(multicast)	28

Example: 128.2.209.19

Routing based on Network Identifier

Net ID	Next
Net ID	Next
Net ID	Next
Net ID	Next

Forwarding Table



Problems with Simple Address Structure

- Running out of addresses.
  - Especially true for mid-sized networks
- Routing tables are becoming too big.
  - 100 of thousands of entries
- Temporary solution: classless inter-domain routing.
  - Use address space more efficiently by relaxing the strict address structure,
    - length of network address is variable
    - generalization of subnetting idea
  - have internet service providers hand out blocks of addresses to their customers

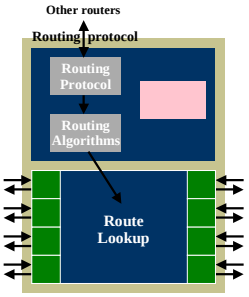
Route Lookup with CIDR

- Problem: with CIDR there can be multiple matches when looking up an address.
  - Can for example happen when a customer switches ISPs but keeps addresses
- Solution: lookup is based on longest prefix match.
  - If there are multiple matches in the lookup, the longest match (longest netmask) wins

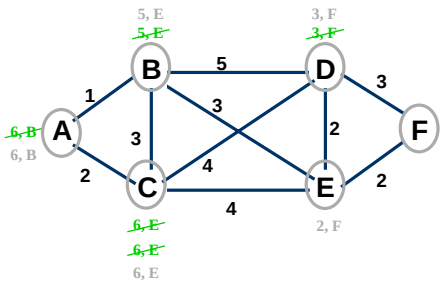
10110110	hosts
10110110 010	hosts
10110110 010 0100011	

What Does Routing Do?

- Routing protocol specifies how routers jointly collect information about the network.
  - Routing protocols must be standardized
- Routing algorithm uses network information to select appropriate routes and to set up the routing table.
- The data forwarding engine performs route lookup in the routing table.
  - through which interface should a packet be forwarded?



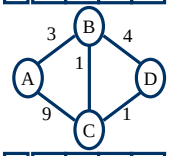
Dijkstra's Algorithm (Link State)



Distance Vector Routing Example

A	-	A/3	A/3	A/3
C	-	C/1	C/1	C/1
D	-	D/4	C/2	C/2

B	-	B/3	B/3	B/3
C	-	C/9	B/4	B/4
D	-	-	B/7	B/5

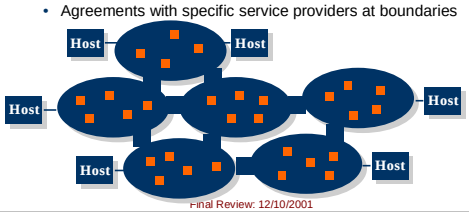


A	-	-	B/7	C/5
B	-	B/4	C/2	C/2
C	-	C/1	C/1	C/1

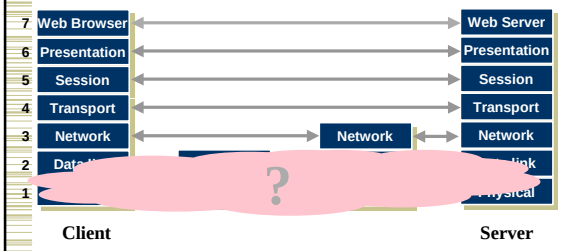
A	-	A/9	B/4	B/4
B	-	B/1	B/1	B/1
D	-	D/1	D/1	D/1

Hierarchical Routing

- Two level routing based on intra-domain and inter-domain routing to improve scalability.
- Matches the structure of the address space.
- Driven in part by business/management concerns.
  - Local network information is kept internal
  - Agreements with specific service providers at boundaries

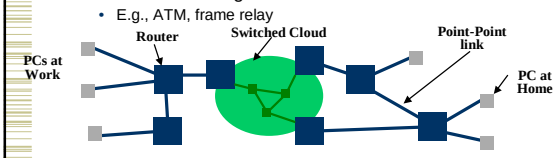


Browsing the Web



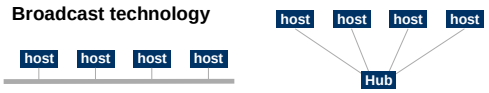
Datalink in the Backbone

- Routers are connected by point-point links or by (datalink layer) switched clouds.
- Point-point links typically based on SONET.
  - E.g. Packets over SONET
- Switched clouds often uses virtual connection datalink technologies.
  - E.g., ATM, frame relay



802.3 Ethernet

Broadcast technology



- Carrier-sense multiple access with collision detection (CSMA/CD).
- 10Mbps cable rate.
- Maximum diameter 2.5km.
- Minimum frame = 64 bytes.
- Thick or thin coax; 10Base-T unshielded twisted pair in star configuration using hub.

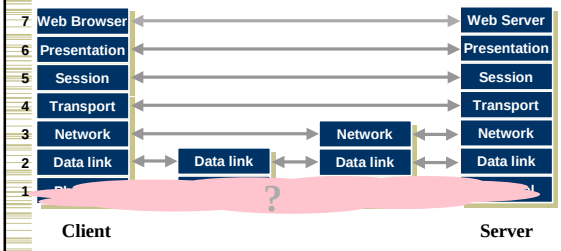
Ethernet Switches

- Bridges make it possible to increase LAN capacity.
  - Packets are no longer broadcasted - they are only forwarded on selected links
  - Adds a switching flavor to the broadcast LAN
- Ethernet switch is a special case of a bridge: each bridge port is connected to a single host.
  - Simplifies the protocol and hardware used (only two stations on the link)
  - Can make the link full duplex (really simple protocol!)
  - Can have different port speeds

Framing

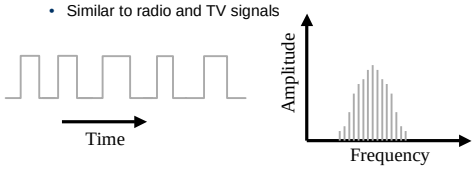
- A link layer function, defining which bits have which function.
- Minimal functionality: mark off units of transmission.
- Some techniques:
  - frame delimiter characters with character stuffing
  - frame delimiter codes with bit stuffing
  - out of band delimiters (e.g. FDDI control symbols)
  - synchronous transmission (e.g. SONET)

Browsing the Web



The Frequency Domain

- A (periodic) signal can be viewed as a sum of sine waves of different strengths.
- Every signal has an equivalent representation in the frequency domain.
  - What frequencies are present and what is their strength
  - Similar to radio and TV signals



Wireless: Good News Bad News

- Great technology: no wires to install, convenient mobility, ..
- High attenuation limits distances.
  - Wave propagates out as a sphere
  - Signal strength reduces quickly $(1/\text{distance})^2$
- High noise due to interference from other transmitters.
  - Use MAC and other rules to limit interference
  - Aggressive encoding techniques to make signal less sensitive to noise
- Other effects: multipath fading, security, ..
- Ether has limited bandwidth.
  - Try to maximize its use

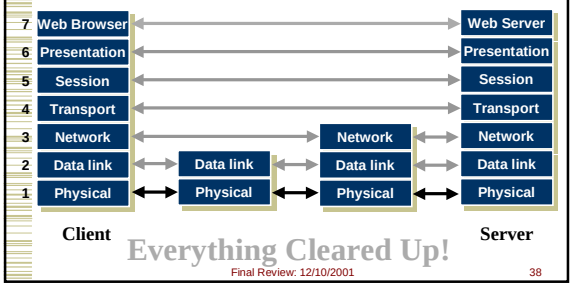
TCP Problems Over Noisy Links

- Wireless links are inherently error-prone
  - Fades, interference, attenuation
  - Errors often happen in bursts
- TCP cannot distinguish between corruption and congestion
  - TCP unnecessarily reduces window, resulting in low throughput and high latency
- Burst losses often result in timeouts
- Sender retransmission is the only option
  - Inefficient use of bandwidth

Proposed Solutions

- End-to-end protocols
  - Selective ACKs, Explicit loss notification
- Split-connection protocols
  - Separate connections for wired path and wireless hop
- Reliable link-layer protocols
  - Error-correcting codes
  - Local retransmission

Browsing the Web



Everything Cleared Up!

Security Threats

- Impersonation.
  - Pretend to be another user with the intent of getting access to information or services
- Secrecy.
  - Get access to the contents of packets
- Message integrity.
  - Change a message unbeknownst to the sender or receiver
- Repudiation
  - Denying to have sent a message
- Denial of service.
  - Flooding the system so users with legitimate needs cannot get service
- Range of other threats: password guessing, exploiting programming bugs, …

Encryption

ciphertext = E(plaintext, k)

plaintext = D(ciphertext, k')

- Private key (symmetric, e.g. DES)
  - the two parties share a common private key k
- Public key (asymmetric, e.g. RSA)
  - derive two keys, $k_{private}$ and k_{public}
  - $k_{private}$ is kept private by its owner
  - k_{public} is published
- Tradeoffs between private and public key cryptography.
  - Key management, speed
- Challenge: key management.

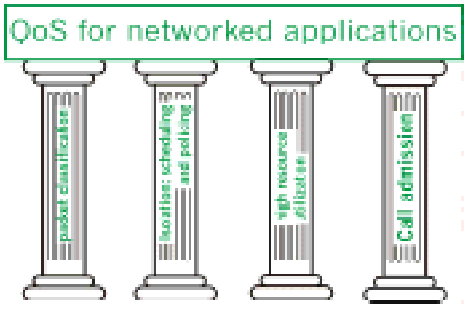
Example Applications

- Kerberos.
  - Support security in corporate environment
  - Based on key distribution center that knows all the entities
    - Know = share secret
- Secure socket layer (SSH).
  - Support secure channels in open internet environment
  - Based on certificates and certification authorities
  - Provides privacy, but trust is limited
- Pretty good privacy (PGP).
  - Provides privacy, authentication, repudiation in internet environment
  - Key management based on a "web of trust"

How to Provide QoS?

- Admission control limits number of users.
  - You cannot provide guarantees if there are too many users sharing the same set of resources (bandwidth)
  - For example, telephone networks - busy tone
  - This implies that your request for service can be rejected
- Traffic enforcement limits how much traffic users can inject based on predefined limits.
  - Make sure user respects the traffic contract
  - Data outside of contract can be dropped (before entering the network!) or can be sent at a lower priority
- Scheduling support in the routers guarantee that users get their share of the bandwidth.
  - Again based on pre-negotiated bounds
- Signaling protocol gives routers the information they need to provide QoS.
  - E.g. RSVP

Qos Summary



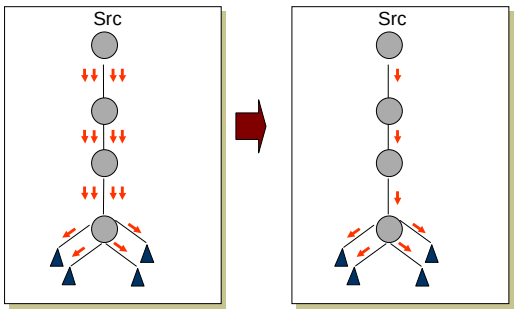
IETF QoS Models

- Integrated services: diverse QoS at the micro-flow level.
  - Range of QoS: best effort, controlled load, guaranteed
  - Specific end-to-end service defined for each class
  - Requires end-to-end support, e.g. edge and core routers
  - Concern about complexity, cost, marketing/charging
- Differentiated services: QoS at the aggregate flow level.
  - Defines range of "forwarding behaviors", but services are defined by the providers
  - Pushes most complexity to the edge of the network – fast core routers work only with small number of traffic classes
- Based on the same building blocks.

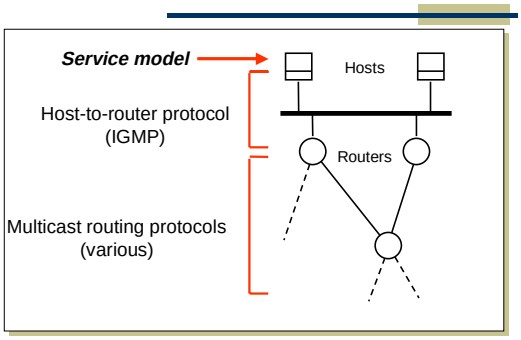
Multimedia Challenges

- TCP/UDP/IP suite provides best-effort, no guarantees on expectation or variance of packet delay
- Streaming applications delay of 5 to 10 seconds is typical and has been acceptable, but performance deteriorate if links are congested (transoceanic)
- Real-Time Interactive requirements on delay and its jitter have been satisfied by over-provisioning (providing plenty of bandwidth), what will happen when the load increases?...

Multicast – Efficient Data Distribution



IP Multicast Architecture



Multicast Routing

- Basic objective – build distribution tree for multicast packets
- Core based protocols
  - Examples: CBT, PIM-SM
- Flood and prune
  - Examples: DVMRP, PIM-DM
- Link-state multicast protocols
  - Example: MOSPF

Shared vs. Source-based Trees

- Source-based trees
  - Separate shortest path tree for each sender
  - DVMRP, MOSPF, PIM-DM, PIM-SM
- Shared trees
  - Single tree shared by all members
  - Data flows on same tree regardless of sender
  - CBT, PIM-SM

Questions?