CSE 461
Final Review

Admin

- Assignment 5 - due Dec. 11
- Project 3 - due Dec. 9; can use late days until Dec. 13
- Final - Dec. 17 (Thursday) from 8:30-10:20 a.m.

Before Midterm

Before Midterm

- **RTT (round trip time)**
  - ▶️ Time it takes between sending a request and getting a reply
- **Bandwidth (bps)**
  - ▶️ How much data can be sent during a unit time
- **Bandwidth-Delay Product:**
  - ▶️ Amount of data can be in transit in network

Network Layer

- Network Service Models
- Internet Protocol - IP
- IP Forwarding (DHCP, ARP)
- Error Handling (ICMP)
- IPV6
- NAT
- Routing Algorithms
- Subnetting
- BGP Routing

Motivation

What does the network layer do?

- Connect different networks (routers send packets over multiple networks)

Why do we need the network layer?

- Switches don’t scale to large networks
- Switches don’t work across more than one link layer technology
- Switches don’t give much traffic control

Network Service Models

Datagrams

- Connectionless service
- Packets contain destination address
- Router looks up destination address in its forwarding table to determine the next hop
- IP (32 bit addresses)
- Easier to mask failures, but more difficult to add QOS

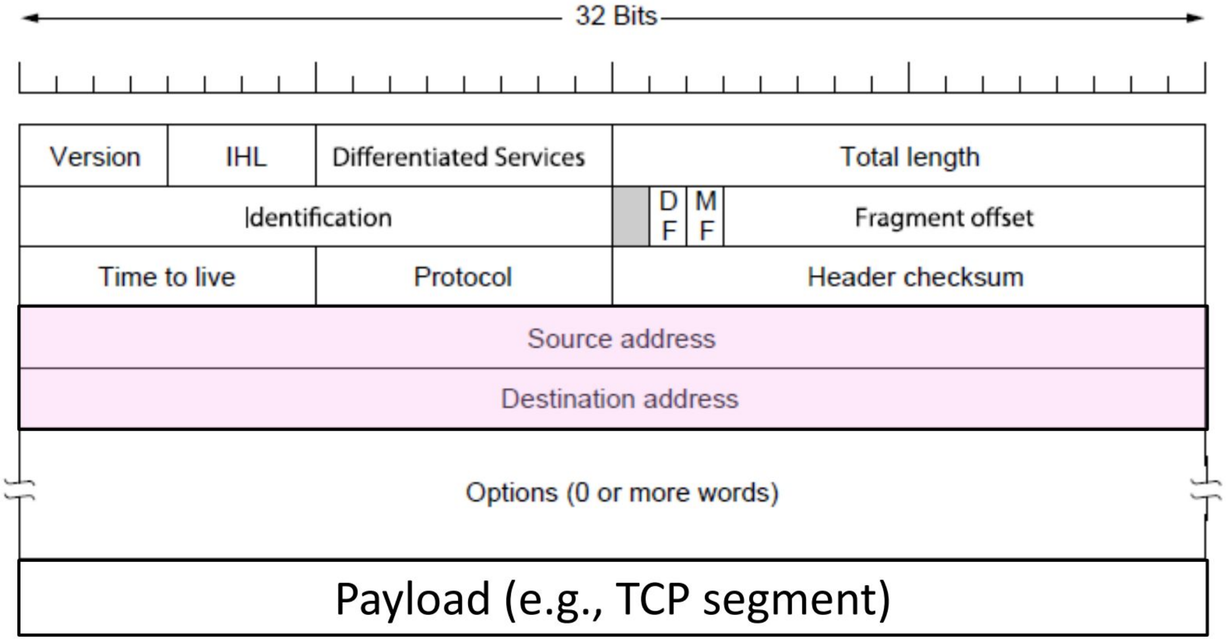
Virtual Circuits

- Connection-oriented service
- Connection establishment → data transfer → connection teardown
- Packets contain label for circuit
- Router looks up circuit in forwarding table
- MPLS

INTERNETWORKING ~ to connect different networks

IPV4

- Network layer, uses datagrams



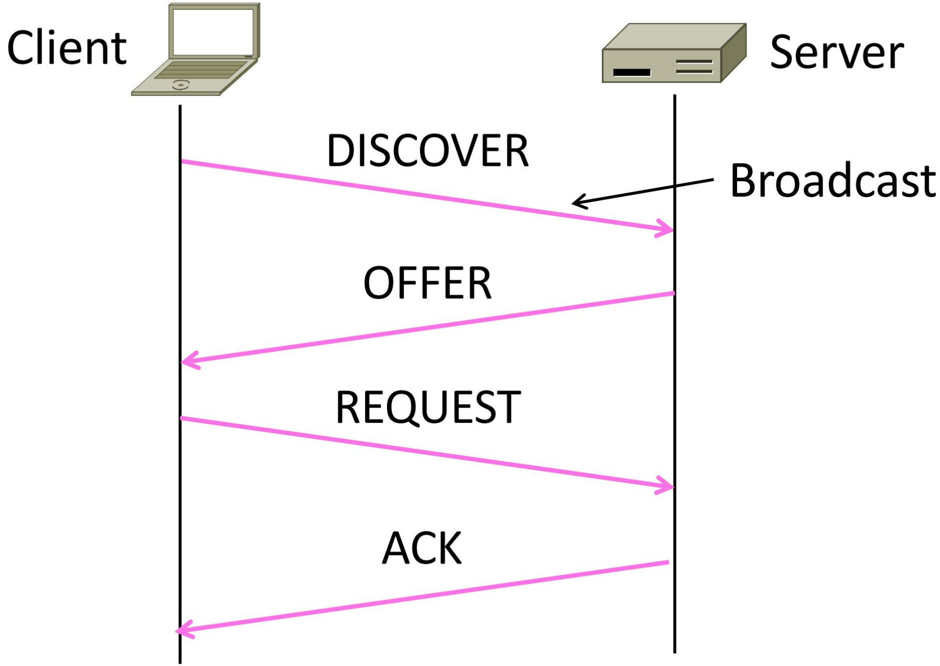
IP Addresses and Forwarding

- IPv4 addresses ~ 32 bits represented by 4 8 bit numbers
  - L bit prefix -- network
  - (32-L) bit -- host
- All addresses on one network belong to the same prefix (2^{32-L} addresses)

- How do nodes determine the next hop given IP address? → longest matching prefix
- How does a node know its IP addresses? → DHCP
- How to map destination IP address to link address → ARP

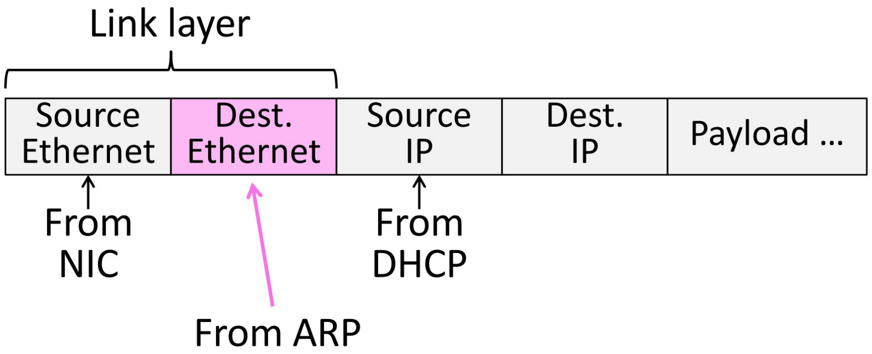
DHCP

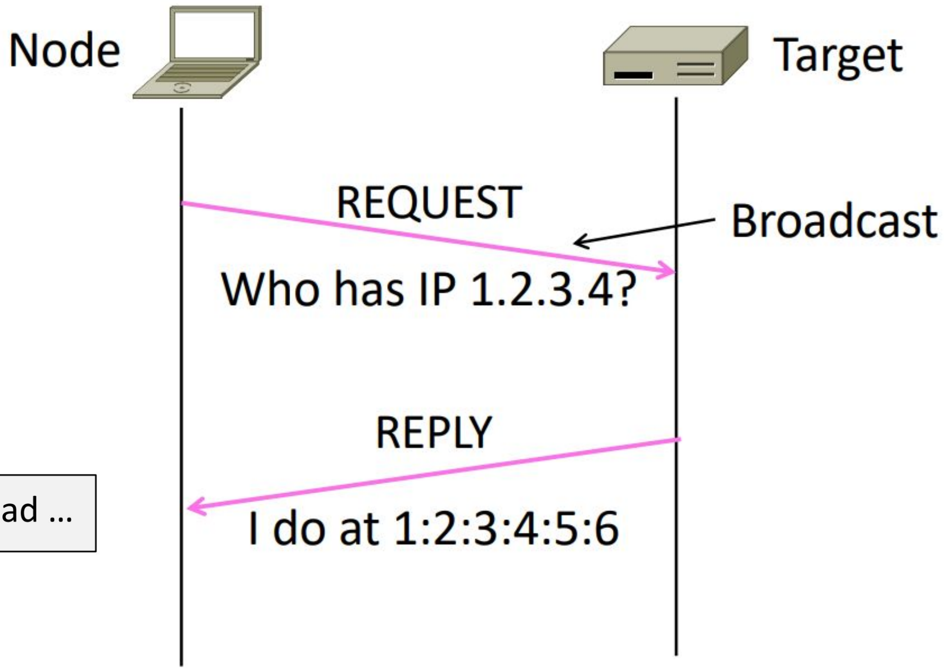
- Dynamic Host Configuration Protocol
- Leases IP address to computer
- Can renew leases
- Based on UDP
- Bootstrapping
- Also setup other parameters:
  - DNS server
  - Gateway IP address
  - Subnet mask



ARP

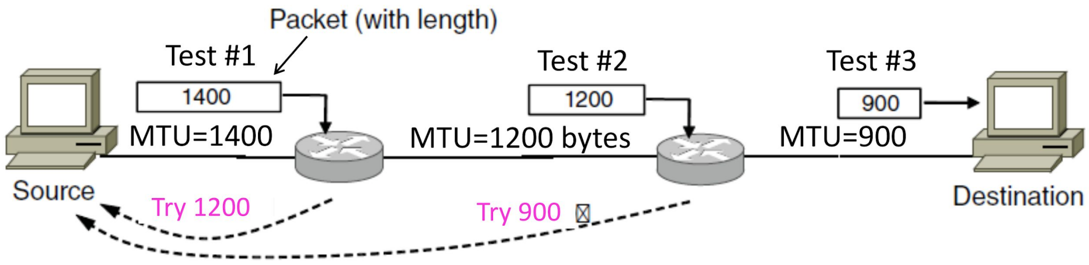
- Address Resolution Protocol
- Sits on top of link layer
- MAC is needed to send a frame over the local link
- ARP to map the MAC to IP





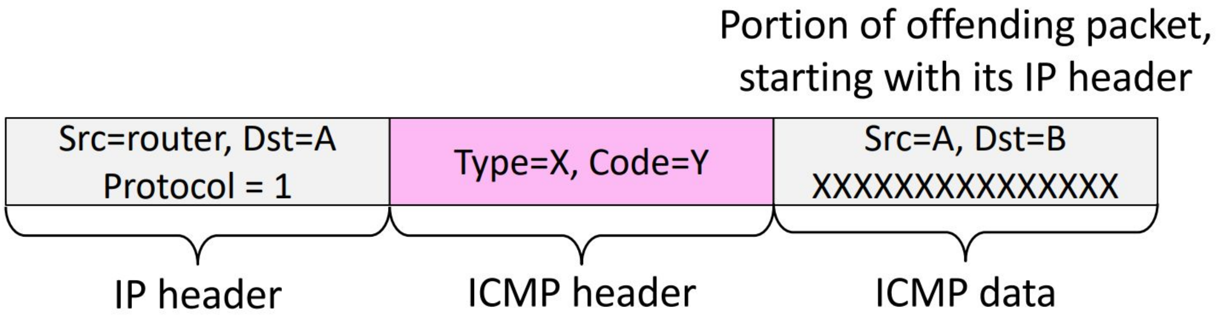
Packet Fragmentation

- Different networks have different Maximum Transmission Units (MTU)
- Fragmentation
  - Routers fragment packets that are too large, and receiving host reassembles packets
  - Header fields
  - Magnifies loss rate; security concerns
- Discovery
  - Path MTU discovery to avoid fragmentation
  - Implemented with ICMP; used today in IP



ICMP - Error Handling

- Companion protocol to IP (sits on top of IP)
- Provides error reporting and testing
- TTL (time to live) field in IP header



IPV6

- 128 bits
- Other smaller changes
- But IPV6 is incompatible with IPV4 !?!
  - Tunnel that acts as a single link
  - Network Address Translation (NAT)

NAT

- Network Address Translation
- Connect internal network to external network
- Many private IP -> One public IP, different port (IPv4 address pool exhausted)
- Break layering: IP, Transport Layer

What host thinks	What ISP thinks
Internal IP:port	**External IP : port**
192.168.1.12 : 5523	44.25.80.3 : 1500
192.168.1.13 : 1234	44.25.80.3 : 1501
192.168.2.20 : 1234	44.25.80.3 : 1502

Routing

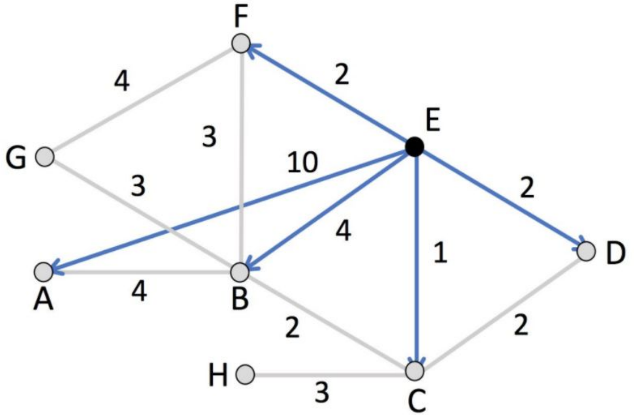
- Shortest path routing
- Distance vector routing
- Flooding
- Link-state routing
- Equal-cost multi-path
- Inter-domain routing (BGP)

Link State Routing

Two Phases:

- Nodes flood topology (neighbors) with LSP (link state packets)
  - Each node learns full topology by combining LSPs
- Each node computes its own forwarding table
  - By running Dijkstra (or equivalent)

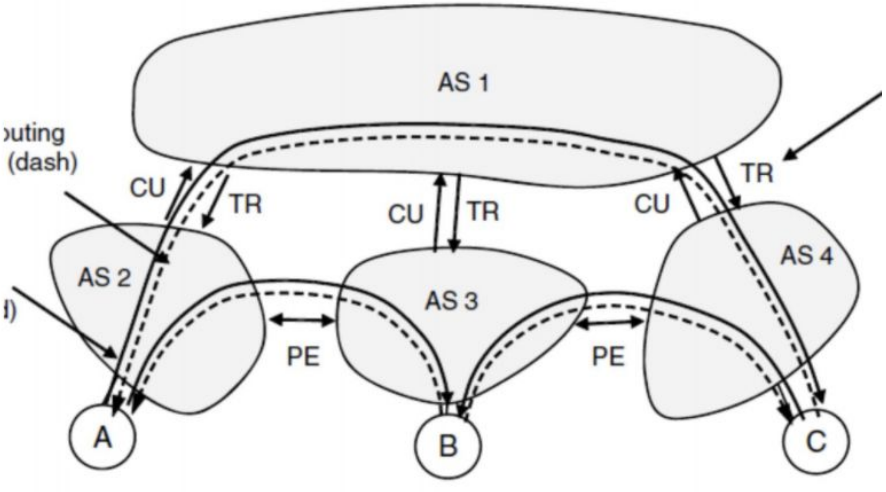
Seq. #	
A	10
B	4
C	1
D	2
F	2



BGP Routing

- ISPs are called AS (Autonomous Systems)
- ASes can be in relationships: Peer and Transit (Customer)
- Border routers of ASes announce BGP routes
  - Announce paths only to other parties who may use those paths

- Transit (ISP & Customer)
  - ISP announce everything it can reach to its customer
  - Customer ISP only announce its customers to ISP
- Peer (ISP 1 & ISP 2)
  - ISP 1 only announces its customer to ISP 2



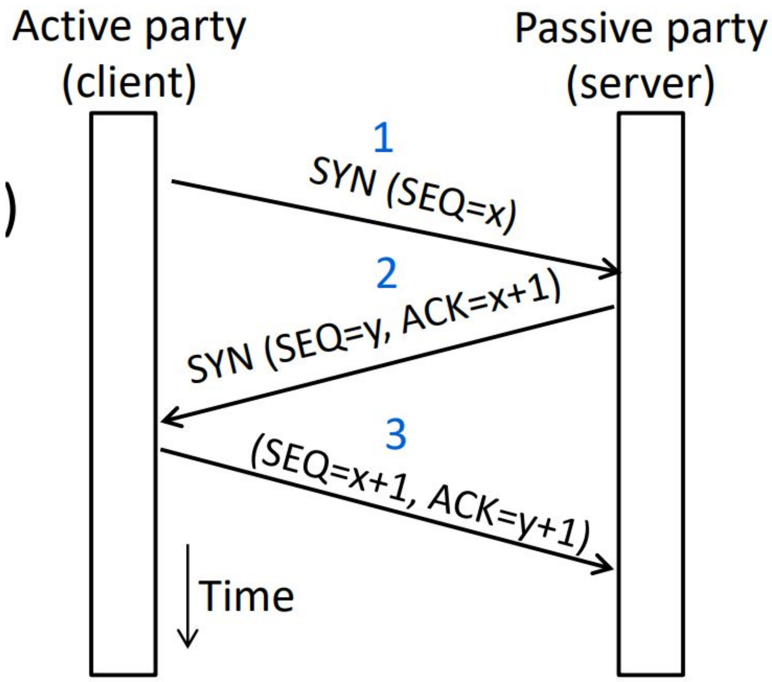
Transport Layer

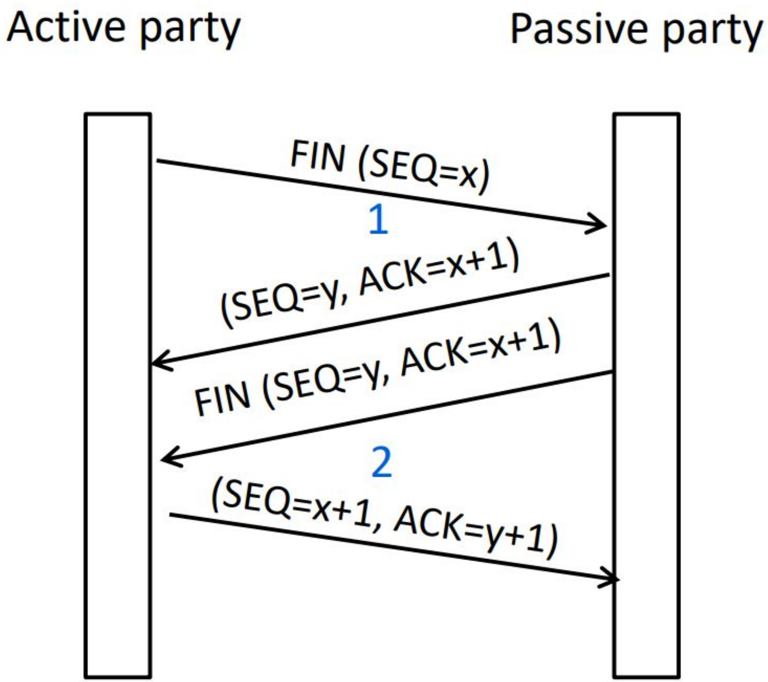
- TCP vs UDP
- Connection Establishment
- Retransmissions and Timeouts
- Flow Control
- TCP Congestion Control
- Bandwidth Allocation

TCP vs UDP

TCP (Streams)	UDP (Datagrams)
Connections	Datagrams
Bytes are delivered once, reliably, and in order	Messages may be lost, reordered, duplicated
Arbitrary length content	Limited message size
Flow control matches sender to receiver	Can send regardless of receiver state
Congestion control matches sender to network	Can send regardless of network state

TCP Connection Establishment and Release





Sliding Window Protocol

- Limitation of stop-and-wait: allows for only 1 outstanding packet
- Sliding Window: can send W packets per 1 RTT; to fill network path, W=2B

- Go-Back-N Protocol
  - Receiver buffers 1 segment; keeps track of LAS and checks that sequence number is LAS+1
  - Sender uses a single timer to detect losses and resends buffered packets
- Selective Repeat Protocol
  - Receiver buffers out-of order segments ([LAS+1 : LAS+W]); keeps track of LAS
  - Sender uses a timer for each unacked segment to detect losses and resends unacked segment

Flow Control

How to ensure that sender doesn’t send faster than the rate at which the receiver can receive?

- Avoid loss at receiver by telling sender the available buffer space (WIN)
- Sender uses minimum of WIN and W as the effective window size

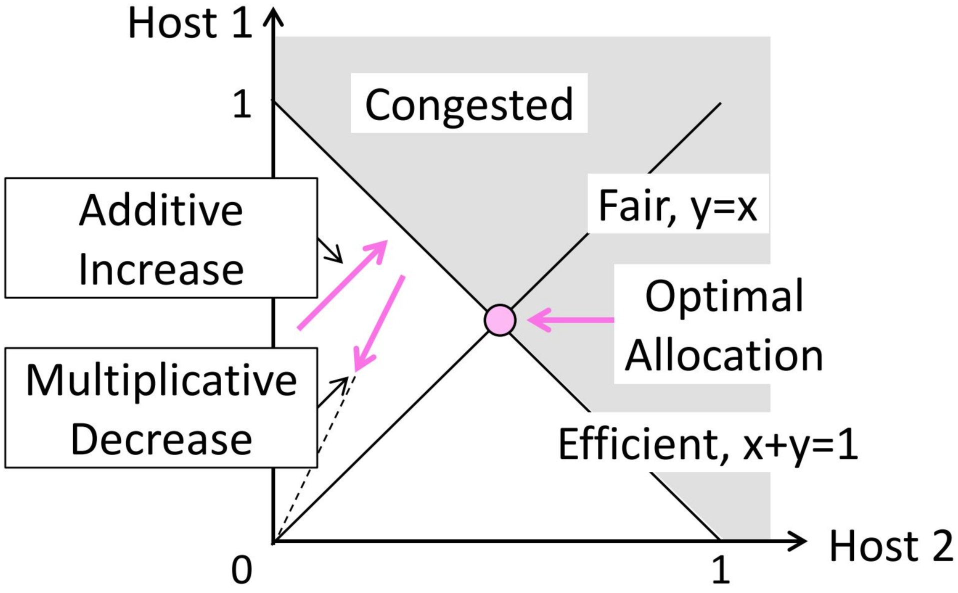
How to set timeout for retransmission?

- Adaptive Timeout
    - Adaptively determine timeout value based on smoothed estimate of RTT

TCP Congestion Control

Bandwidth allocation model - Additive Increase Multiplicative Decrease (AIMD)

- Slow-start
  - Double cwnd until packet timeout
  - Restart and double until cwnd/2, then AI
- Fast-retransmit
  - Three duplicate ACKs = packet loss
- Fast-recovery (MD)
  - Half cwnd and start AI



TCP Congestion Control

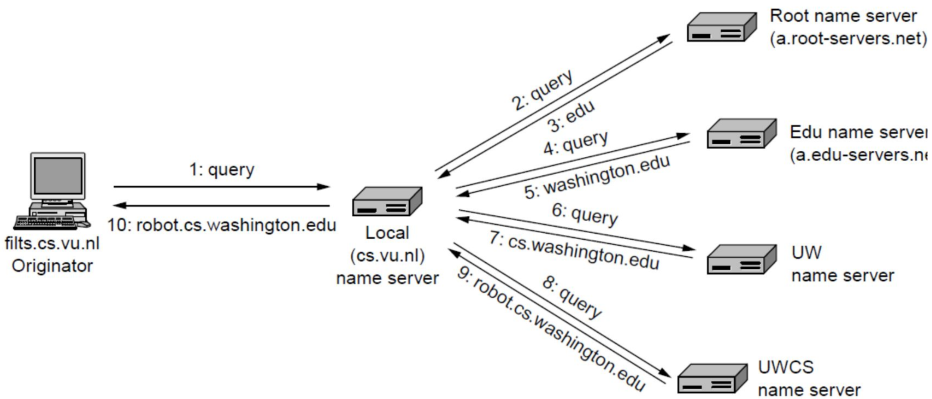
- ACK Clocking
  - Each in-order ACK advances the sliding window and lets a new segment enter the network
  - Smooths out bursts of data segments
- Adaptive Timeout

Application Layer

- DNS
- HTTP

DNS

- Terminology
  - Names - higher-level identifiers for resources
  - Addresses - lower-level locators for resources
  - Resolution - mapping a name to an address
  - Zones - contiguous portions of the namespace
  - Nameserver - server to contact for information about a particular zone
- Maps between host names and address
- Recursive vs iterative query
- Caching
- Built on top of UDP
- Security is an issue



HTTP

Steps to fetch a web HTTP:

- Resolve the server IP
- Setup TCP connection (port 80)
- Send/Receive HTTP request over TCP
- Teardown TCP connection

Steps to fetch a web HTTPS:

- Resolve the server IP
- Setup TCP connection (port 443)
- SSL/TLS negotiation and key exchange
- Send Encrypted messages
- Teardown connection

How to decrease Page Load Time (PLT)?

- Parallel connections and persistent connections
- HTTP caching and proxies
- Move content closer to client (CDNs)

CDNs

- Content Delivery Networks
- Place popular content near clients
- Use DNS to place replicas across the Internet for use by all nearby clients

Security

- Types of encryption
  - Symmetric encryption
    - Key distribution is hard but runtime is fast
  - Public key encryption
    - Key distribution is easy but runtime is slow

Questions

There are many variants of TCP. What are the differences between TCP Tahoe, Reno, New Reno, and SACK?

TCP Tahoe - immediate slow start upon packet loss (both 3 duplicate acks and timeout)

TCP Reno - “fast recovery” back to AI with half cwnd upon packet loss

TCP New Reno - improved “fast recovery” with window-refilling by sending a single new packet upon duplicate ack, “hole”-filling upon partial-progress ack that indicates another single packet loss within the sent window

TCP SACK - “selective ack” used to specify blocks of packets that were received correctly in addition to normal sequence number

What is ECN?

Explicit congestion notification. In TCP, ECN is implemented through 3 header flags (plus some negotiation during connection setup). Not all TCP implementations support ECN but most do now.

Outline a potential sequence of steps that might happen when a host wants to resolve www.cs.washington.edu. Assume complete lack of caching

After querying your local name server, it will begin resolving the IP by starting from the outermost layers. It will do so until we have resolved the entire URL for an IP.

1. Query the root name server and get back an answer for *edu* server
2. Query the *edu* server and get back an answer for *washington* server
3. Query the *washington* server and get back and answer for the *cs* server
4. Query the *cs* server

What is the difference between Message Authentication Code (MAC) and a signature?

Both are used to validate the integrity/authenticity of a message.

MACs use symmetric keys (technically, even if one is stuck on a hardware key) and signatures use public (asymmetric) keys.

Who advertises what to whom in BGP routing?

ISP will announce everything it can reach to its customers.

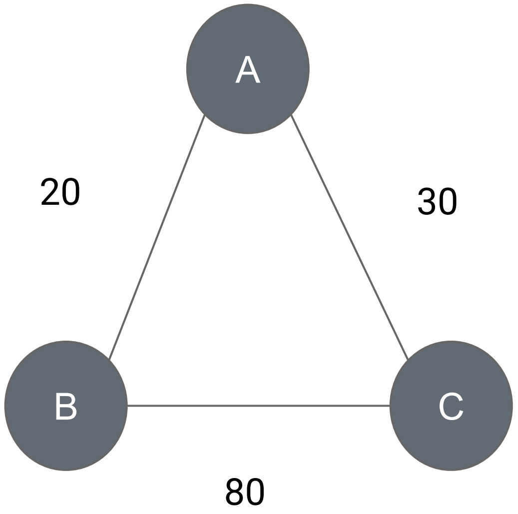
A Customer will announce its customers to the provider.

ISP will announce its customers to its peers.

Will an ISP announce its peers to other peers?

No, routing is not free. If ISP announce peer A to peer B, when peer B wants to send traffic to peer A, the traffic goes through the ISP, even though the ISP has nothing to do with the traffic!

How do nodes A, B, C establish their routing table using the Distance Vector Routing algorithm?

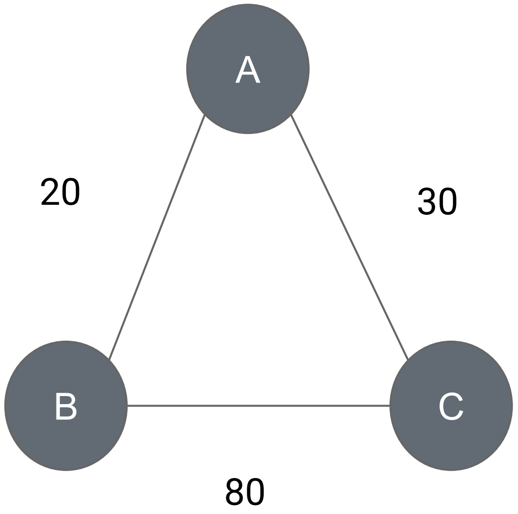


A: (B,20), (C,30)
B: (A,20), (C,80)
C: (A,30), (B,80)

Each node sends it distances to other nodes to each of its neighbors. Each node updates their distance table.

A: (B,20), (C,30)
B: (A,20), (C,50)
C: (A,30), (B,50)

How do nodes A, B, C use Link State Routing to find the shortest paths?



Each node send the link to all other nodes. For example: node A sends to B and C: (AB,20), (AC,30)

Each node use the packets and Dijkstra’s algorithm to create the full topology of the network.

Now each node has the shortest path to each other node.