1 Peer-to-Peer connectivity

- Line Discipline: Coordinates link systems
- Flow Control: Coordinates amount of data that can be sent or recieved
- Error Control: Receiver must inform sender of lost and/or damaged packets
- Stop and wait
  - Source transmit frame
  - Dest. receives frame and sends ACK
  - Source waits for ACK
  - Only one frame in transit at a time
- Sliding window
  - uses timeouts to detect loss/reordering of messages then retransmits
  - Sender sends transmission and if no ACK, resends it
  - Receiver anticipates sequence number and sends ACK if the anticipated message is recieved

2 Multiaccess Communications

- Mac Protocols
  - **Centralized**: Distinguished node (master) makes access decisions for remaining nodes (slaves)
  - **Distributed**: All nodes are equivalent and access decision is derived together
- Static Partitioning Schemes: Partition transmission medium into seperate dedicated channels
- MAC Schemes: Dynamic/on-demand
- Measuring propagation time
  - t_{prop} is bit propagation time, d is distance between 2 stations, v = speed of medium
  - $t_{prop} = d/v$
- If user A detects a collision, it must occupy the channel for a period of $2t_{prop}$ time units
- $a = dR/vL$, where d is distance, v is medium speed, L is packet length length, R is bit transmission rate

- Large distances result in low efficiency
- In ethernet w/ broadcasting message passing, every node is listening to the network and may only transmit when the network is silent

3 LANs: Ethernet

- Uncoordinated Contention
  - Probability of a successful transmission is equal to the probability that exactly one node transmits - maximizes when $p = \frac{1}{n}$
  - $Pr(Success) = np(1-p)^{n-1}$
- Only way to improve performance of contention is to limit number of users
- Limit contention algorithms resolve collisions after they occur
- Backoff Protocols
  - Based on poisson distribution
  - Queue of stations/nodes, each tracking number of transmit attempts
- **CSMA**: Station wishing to transmit must first listen for an idle line
- Collision Detection: If collision is detected, station waits for line to clear before retransmitting
- successful transmission only occurs when stations select different values $a_t \neq b_t$
- **CSMA 1 Persistance**: Listens and sends if channel is idle, if collision, waits before retransmitting
- **CSMA non-Persistance**: If channel is busy, waits before listening and retransmits
- **Tree Splitting**: We know this already

4 Localization & GPS

- Triangulation: Using known points to determine the location of another point
- Network Techniques use service providers network to locate device
- Handset Techniques require client software n the device to locate item
- Hybrid Techniques use a combination to determine location
- **Lateration**

  - Fixed number of anchor nodes at known positions
  - Anchors are synchronized to emit a signal at the same time
- **TOA**
  - A computes distance from B_1, B_2, B_3. A lies on circles centered at B_1, B_2, B_3.
- **AOA**
  - A determines directions from which signals arrive from nodes B_1, B_2 with respect to a reference axis using array antennas
  - Only needs 2 measuring units for 2D and 3 for 3D w/no synchronization
  - Not good when there are signal reflections or movement

5 Location Awareness

- When a sensor transmit to another sensor located d distance away, the signal power being recieved is $\frac{P}{d^2}$
- **Rayleigh's Principle**: when k sensors are sensors are transmitting at a time, only the most powerful can be recieved
- Random geometric graphs, formed as as unit disk graphs w/ randomly generate disk centers have also been used as a model of percolation and various other phenomena
- 2 mobile hosts, A, B are adjacent if they are within reach of each other
- **Gabriel Test**
  - Assume 2 points A, B are within range, draw a circle w/ diameter AB
  - If 3^{rd} point C, remove remove link between AB
  - AB is a Gabriel edge if circle with diameter AB has no other points
- **Compass Routing**
  - Start at Source (S) node
  - Choose edge with smallest slop and traverse to new point
  - Draw line to destination (t) and repeat
- **Face routing**
  - Start at Source (S) node
  - Choose face that ST intersects
  - Apply left or right hand rule (direction)
  - Repeat with faces intersected by ST Until it reaches destination
  - **CANNOT cross line ST while traversing**

6 WANS

- LANs (local access network): extend less than 1km
- MANs (metropolitan access network): confined to a city
- WANs (wide access network): Can be world wide
- WAN is a computer network covering a broad area; largest and most well-known is the internet
- Used to connect LANs and other types of networks together
- Many are built for one organization and are private
- Others from ISPs provide connections from an organizations LANs to the internet
- Network contains numerous transmission lines, each connecting to a pair of routers
- Nearly all WANs have **Store-and-forward Subnets**
  - Recieving router stores packet until output line is free, then forwards it
- Interconnecting methods:
  - Leased line: point-to-point connection between 2 computers
  - Circuit Switching: Dedicated circuit path created between 2 end points
  - Packet Switching: Devices transport via shared link across carrier internetwork
  - Cell Relay: uses fixed length cells (data) transported
- Devices
  - Repeaters: Used at physcal layer
  - Bridges: Used at MAC or Data link layer (Nodes are unaware of them)
  - Routers: Used at the network layer
  - Gateways: Used at higher layer for protocol conversion or security
- WANs do not relay on their own hardware, rather they can use public/leased/private Communication equipment or combinations
- Switches allow for interconnecting nodes (Star topology)
  - Networks built by interconnecting switches

  - Primary role is forwarding
- How does a switch decide which input goes to which output
  - Connectionless (datagram)
  - Virtual Circuit (Connections oriented)
  - Source Routing
- Virtual Circuit
  - Connection setup from host to destination
  - long lived (PVC) or dynamically set up by host (SVC)
  - If a link or node fails, whole VC fails
- Crossbar Switch
  - Every input had a packet to send to a given output at the same time
- Knockout Switch
  - For some $L < n$, L inputs have a packet to send to a given output at the same time
  - Play packets against each other in a knockout tounament, selecting L winners

7 Routing

- Routing: Used to deliver packets between nonadjacent nodes in a network
- Route Discovery: Used to discover a route, precedes routing
- Routing table: Contains an entry for each possible destination with its out-going link
- Source Routing: Table entries contain a complete path from source to destination
- Virtual circuit routing: Table used to maintain virtual circuits between nodes
- LANs with some MAC sublayer can be interconnected by a bridge
- Autonomous systems
  - Consists of a number of subnets exchanging packets via routes
  - Interior routing protocol
- Routers used to connect different AS are gateways

- Protocols used by gateways are external routing protocols
- Distance vector routing
  - Idea of shortest path routing handling topology changes
  - Routing table with (dest, nexthop, and distance) tuples
  - Each node periodically broadcasts its distance vector to neighbors
  - If a node or link crashes, a neighbor sets its distance to ∞
  - If a node is repaired or entered, a neighbor serts its distance to 1
  - Nodes locally maintain their own info
  - convergence: Getting consistent routing info
  - Routing cost tables: each node
    - Transmit its vector to all neighbors
    - receives vectors from all neighbors
    - Updates its vector on the basis of what it receives
- Linkk State protocols
  - Each node maintains state info of all links in the network
  - When a state changes, node broadcasts info to all nodes in network (flooding)
  - Node maintains 2 data structures
    - Tree containing nodes which are "are"
    - List of candidates
  - Each router constructs a link state packet containing
    - ID of node that created the packet
    - List of all neighbors together with cost
    - sequence number
    - A time to live (TTL) for this packet
- Flooding: sends a packet to all edges but the one you recieved a packet from
- Breadth-First-Search-Tree
  - Spanning tree of a graph where for every node, the tree path is the min-hop path to root
  - Uses FIFO queue
  - Finding all nodes within one connected component
  - Finding Shortest path between a node
  - **Dijkstra's Algorithm**: Computes weights of path

- Spanning Trees
  - Subnetwork containing no cycles & includes all nodes of network
  - Min weight spanning tree is a ST of min weight
  - Prim's Algorithm: $O(|E| + |V| \log |V|)$
  - Kruskal's Algorithm: sort edges in increasing order, add edges to tree if not cycle. $O(|E| \log |E|)$
- Link-state: Foster convergence, multiple paths for routing
- Distance-vector: Simple structure, less required storage space
- Delay Metric: (Depart Time - Arrival Time) + transmission Time + Latency
- Internet is heterogeneous
- CIDR aggregates routes, addresses assigned as a block

8 Internetworking

- IPV4: Connectionless protocol for use on packet switched link layer networks
- Internetwork
  - Arbitrary collection of networks interconnected to provide h-h packet delivery
  - Interconnected with routers or gateways
- IPV4 datagrams consist of a header plus a number of data bytes
- IP based internets designed to support delay insensitive applications
- IP with no options is 20 bytes
- IHL is header length in 32-bit words
- TOS provides guidance on selecting next hop. Subfield provides route selection
- Procedence subfield indicates degree of urgency
- Addressing
  - Nodes have both a net ID and a host Id
  - All hosts connected to the same network have some net ID
  - Total length is 32 bits: class, IVet-ID, Host-ID
  - 5 classes: A-E

class	Net ID	Host ID
A	7 bits	24 bits
B	14 bits	16 bits
C	21 bits	8 bits

  - D is for multicasting
  - E is for experiments
  - ID's with all 1s or 0s are for broadcasting
- IP address defines a hosts connection to its network
- class A,B,C only 2 levels
- Subnetting
  - Rest of internet doesn't need to know of the subnet
  - 3 levels: net ID, Subnet ID, Host ID
  - Subnet is a logical subdivision of an IP network
  - provides routing boundaries
- IP Masking
  - 32-bit num masking an IP address
  - More supported networks, flexibility allocates address space
  - Extracts address of physical network from an IP address
- Subnetting takesa a single IP address and allocates it to several physcal networks
- Subnet masking
  - Network number shared among multiple networks
  - all hosts on the same network have the same subnet number
  - Bitwise and address and subnet mask gives subnet number
- IPV6 uses 128 bit addresses, can address upto $2^{128} = (2^{32})^4$ hosts
- IPV6 nodes automatically identity routes on the subnet

9 TCP

- UDP
  - Establishing low latency, loss-tolerating connections between applications
  - Extends host-to-host into process to process

- Ports
  - number mapping published periodically in an RFC, available in /etc/services/
  - Implement by message queue
- UDP suitable for purposes where error checking/correction is not necessary or performed in the application. Used by time-sensitive applications
- TCP is a byte oriented protocol, decides to send when it collected enough bytes
- Timer implemented to retransmit if taking too long
- All connections start in closed state
- Each byte/segment transmitted has a sequence number
- TCP has no ACK, contains a timer (slightly above round trip delay)
  - $ARRt(k) = \frac{1}{k}$
- No distributed control binding TCP entities, use sliding window for control
- Measure RTT to learn traffic behaviour, use RTO (timeout to improve performance)
- If link is overloaded, packet are lost and source slows down
  - Increases speed again until congestion occurs again
- Flow doesn't know how many flows share a link
- Conjestion window directs size of sliding window
- $E[change] = I(w)(I - P) + (-D(w))P = 0$