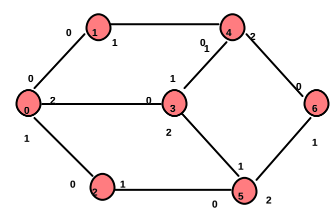
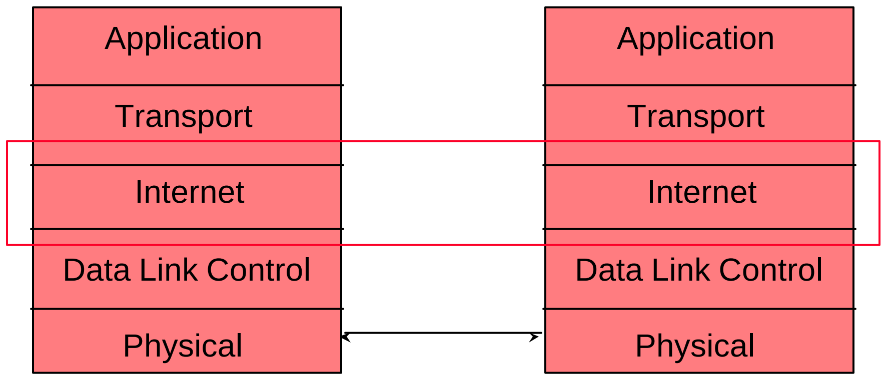
Network Layer



Lecture Overview

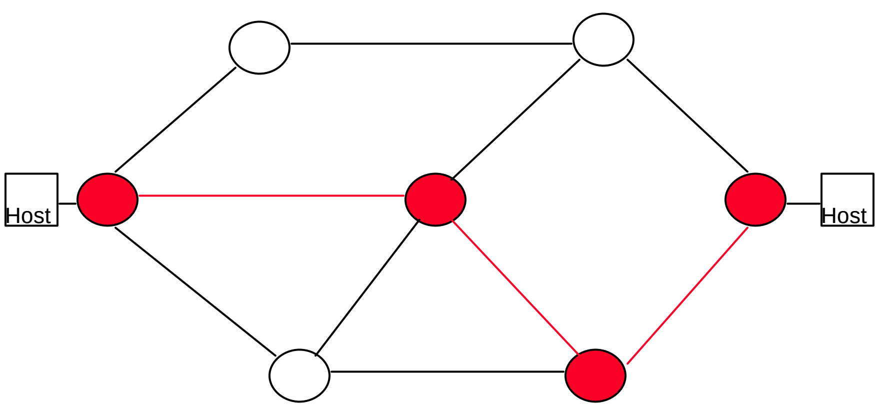
- packet switching concepts
- network layer functions
- routing models
- the routing process

Internet Protocol Suite Reference Model

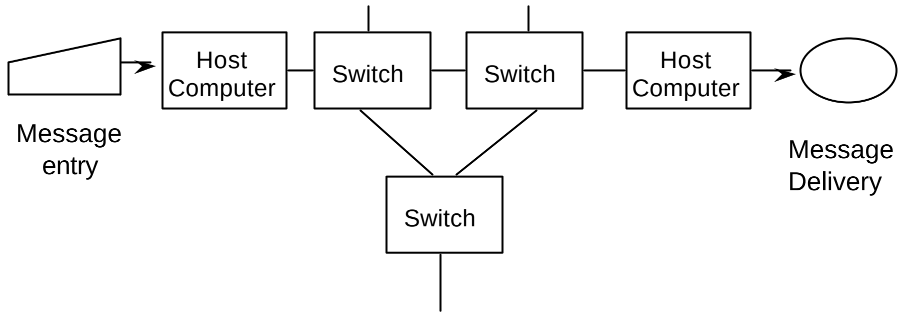


The DLC and Physical layers sometimes are referred to collectively as the “host to network” layer

Network Layer Switching



Roots of Packet Switching
Message Switching



Message Switching

- No direct connection
  - uses address in message to deliver
- Not real-time
- Evens out communications load
- Interoperation possible among different protocols
- Tune line speed to average traffic
- Broadcast capability
- Prioritization possible

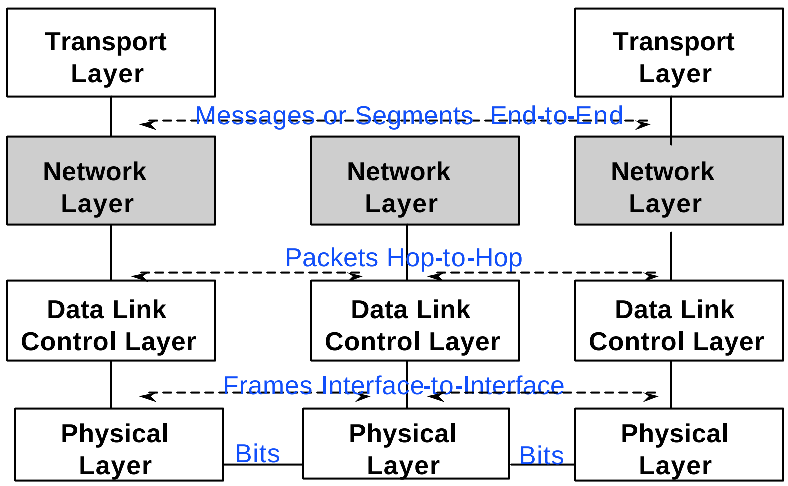
Packet Switching

- Message switching with small messages
- Can be real-time
- Makes best average use of links if data is bursty
- Prioritization possible
  - may be essential when some traffic is real-time
- Can route around failures and congestion
- Shares resources across community of users

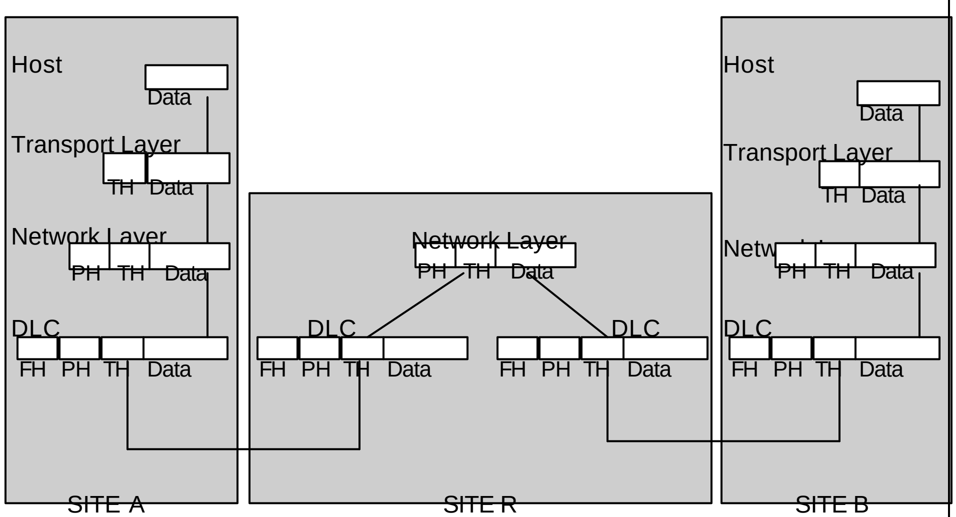
Which Form of Switching is Best?

- Dialup (circuit switching) is good for small / infrequent connections
- Message switching is good for non-real-time traffic
  - and it can ride on a packet-switched system
- Packet switching is good for frequent bursty applications, higher reliability
- Public packet switching (e.g. Internet) provides quick access to many other organizations / locations
- No switching (leased line) is good for heavy, constant point-to-point traffic
  - yet still may cost more than Internet because it does not have economy of scale

Layers and Protocol Data Units



Nested Headers



Network Layer Functions

- Addressing
  - Nodes have unique addresses and names
  - Network Layer works with addresses
  - Directory Services are used by the Network Layer to map names to addresses - while not a Network Layer function this is important to usability of the network
- Routing
  - Selecting a path for each packet to take through the network
  - Connectionless (like mail) or Connection-oriented (like telephone call)
- In connection-oriented networks, Congestion Control
  - Networks have limited and varying link capacities and finite packet buffers in network switching nodes

Network Layer Routing

- Routing means selecting a path for packets to follow through the network from source to destination
- For each arriving packet, the switch must be able to select the departing interface very rapidly
- Major models of routing:
  - connection-oriented
  - connectionless
  - source routing

Source Routing

- Source node inserts the sequence of routers to be visited in the packet header
  - implies that the source node knows complete current network topology and loading
  - this is impractical in a large network
    - source routing is not scalable
  - therefore it is not applied to user traffic in large wide-area networks
  - used in LAN bridging

Connection-oriented Routing

- Connection-oriented networks establish a virtual circuit among network hops between a given source-destination
  - before packets are sent, a virtual circuit must be established between a source-destination pair, like setting up a telephone circuit
  - all packets flowing over a virtual circuit (VC) use the same route
  - consequently they always arrive in the order sent
  - any node or link along the path is a single point of failure
  - allows quality of service to be established per VC
  - major examples: X.25 and ATM
  - neither of these has the scalability of IP

Connectionless Routing

- Connectionless networks route packets hop-to-hop as datagrams
  - •each datagram is routed individually like pieces of mail
  - •successive datagrams between a given source-destination pair can take different routes
  - •this means packets can arrive in an order other than the sending order
  - •very flexible and robust
  - •quality of service can be problematic
  - •major example: Internet Protocol (IP)
  - •IP switches are called routers

Network Layer Congestion Control

- An overloaded network can result in large packet queues leading to buffer overflows, compounded by retransmissions from source hosts
- What can the network layer do to control congestion?
  - Inform hosts (e.g., source quench messages)
  - Allocate dedicated buffers (e.g., a virtual circuit)
  - Discard packets to reduce queues and delays (connectionless networks only)
  - Require sending hosts to use sliding window or rate-based flow control (connection-oriented only)
  - Route packets around congestion (connectionless networks only)

Routing

A route is a closed path through the network from source node to destination node that does not visit any node more than once. It is expressed as a sequence of nodes: 1 - 5 - 7 - 9 that starts with the source and ends with the destination.

Routing: determining the route

Forwarding: implementing the route

Ideally, routing is correct, simple, robust, stable, and optimal

The Routing Problem

Given: The network topology, with each link weighted with a cost metric (e.g. delay, price, quality) that changes over time.

Optimally: Solve for the collection of routes among the nodes that globally optimizes the cost metric over time for all sessions. The routes will change over time if the offered load changes.

Practically: Provide routes between all pairs of nodes that are "good enough" in terms of cost.

Routers use this information to determine the proper outgoing interface for each packet.

If each router makes the right choice, and the network contains a path, the packet will get to its destination

Flooding

- Every node sends a copy of each received packet on each other link to which it connects
- Care must be taken to avoid overwhelming the network with excessive retransmission of packets
- Provides a simple, yet expensive, mechanism to broadcast messages to all nodes
- Sometimes used to send control or management frames when the network topology is uncertain.

Methods for Routing

Shortest - path**:** find the shortest path in number of links (or "hops") from source to destination.

Optimal**:** collect data globally to optimize overall network usage, based on "link state" (some cost metric associated with each link)

NOTE: routing can never be completely optimal because in a network, no node knows exact current state of other nodes, only what the states were when last sent out

Routing Algorithms

- A routing algorithm computes the path packets follow to their destination.
- Static Routing Algorithms
  - Routes determined in advance, off-line
  - Routes distributed to switching nodes at network startup
- Adaptive Routing Algorithms
  - Routes chosen in real-time based on measurements or estimates of current traffic and topology
  - Routes updated dynamically to adapt to changes in demand and topology
  - Adaptive algorithms can be centralized or distributed

Spanning Tree Routing

- Packets routed to a destination along the branches of a tree routed at the destination
- This approach limits the number of packet transmissions
- Algorithms exist to compute “optimal” trees; thus, packets are routed along the shortest path