Network Layer Overview

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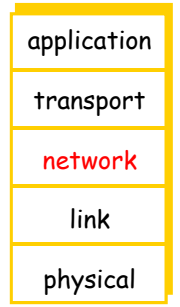
Internet Architecture

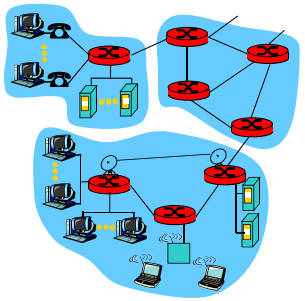
Bottom-up:

- physical: electromagnetic signals "on the wire"
- link: data transfer between neighboring network elements
  - encoding, framing, error correction, access control for shared links
- network: host-to-host connectivity
  - routing, addressing
- transport: host-host data transport
  - reliable data transport, congestion control, flow control
- application: anything you want to do on computer networks

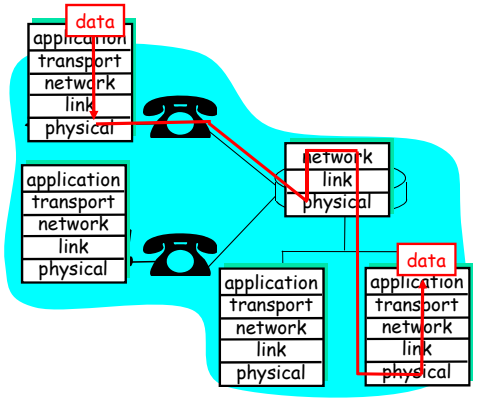


Network Layer Function

- transport packet from sending to receiving hosts
  - routing: determine a path from source to dest and route packets along the path
  - addressing: uniquely identify each node in the network
- network connecting devices
  - called "routers"
  - participate in network protocols
- links
  - connect adjacent hosts, routers

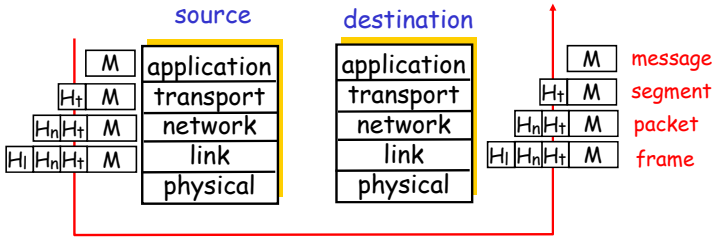


Protocol Layers and Data Flows



Data Formation Across Layers

Each layer takes data from above
- adds header information to create new data unit
- passes new data unit to layer below



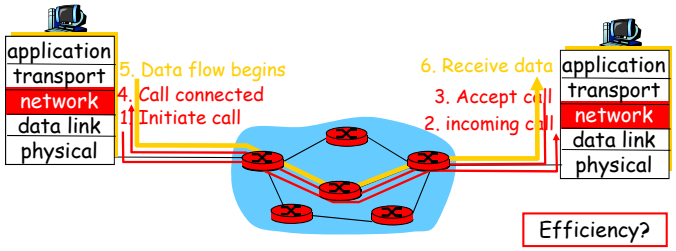
Network Service Model

- loss-free delivery?
- in-order delivery?
- preservation of inter-packet delay (no jitter)?
- guaranteed bandwidth?
- congestion feedback to sender?

connection-based or packet switching?

Connection-based Networks

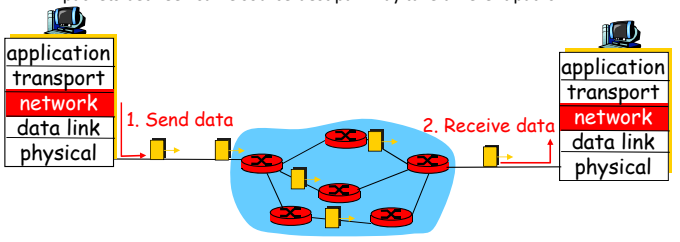
- guaranteed bandwidth, jitter-free, in-order delivery build on the concept of connections, or virtual circuits
- require signaling protocols to setup, maintain, and teardown virtual circuit
- router maintains state about ongoing connections



Efficiency?

Packet Switching

- no connection ⇨ every packet is on its own
- stateless routers ⇨ no need to remember anything about packets
- packets forwarded independently from each other
  - packets between same source-dest pair may take different paths



Packet Switching vs. Connection-based Networks

Packet switching
- poor service guarantee
  - "elastic" service
- efficiency
- scalability
- robustness
- flexibility/customization
  - simple network core, complexity at "edge"

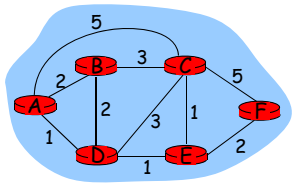
⇒ manage, control, adapt at "smart" end systems (computers)

Connection-based
- evolved from telephony
- guaranteed service
  - e.g., human conversation:
  - strict timing, reliability requirements
- hard to evolve
  - complex network core

Internet employs packet switching; connection-based are more suitable for networks with "dumb" end terminals – telephones.

Routing Principles

Routing protocol
Goal: determine "good" path (sequence of routers) thru network from source to dest.



Graph abstraction for routing algorithms:
- graph nodes are hosts or routers
- graph edges are links
  - link cost: delay, $ cost, or congestion level

- "good" path:
  - typically means minimum cost path

Routing Algorithm Classification

Global information:
- all routers have complete topology, link cost info
- "link state" algorithm

Decentralized:
- router knows connected neighbors, link costs to neighbors
- exchange of info with neighbors to learn remote parts of the network, may take many learning rounds
- "distance vector" algorithm

A Link-State Routing Algorithm

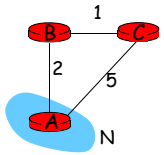
Dijkstra's algorithm
- Network topology, link costs/distances known to all nodes
  - accomplished via "link state broadcast"
  - all nodes have same info
- The algorithm calculates the shortest paths from one specific node ("source") to all other nodes
- Basic approach: gradually expands a set "N", containing nodes whose shortest paths from the source are known
  - initially "N" contains only the source itself
  - at every step one more node's shortest path from the source is learned, this node is then added to "N"
  - eventually "N" includes every node and the algorithm terminates

Dijkstra's Algorithm (cont.)

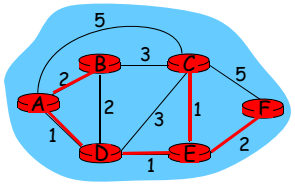
"N", containing nodes with known shortest paths from source

Key step: How to expand "N" to include one more node?

- "1-more-hop paths":
  - paths from source to dest. v (not in N) whose last hop before v is in N
  - D(v) as the distance of the shortest 1-more-hop path to v
- For arbitrary v, is D(v) shortest path distance to v?
- For v* with shortest D(v) among all v's not in N, D(v*) is the shortest path distance to v*.



Dijkstra's Algorithm: An Example



- N: set of nodes whose shortest paths are currently known
- D(v): distance for shortest 1-more-hop path from source to dest. v
- p(v): predecessor node along path from source to dest. v

Step	N	D(B),p(B)	D(C),p(C)	D(D),p(D)	D(E),p(E)	D(F),p(F)
0	A	2,A	5,A	1,A	infinity	infinity
1	AD	2,A	4,D		2,D	infinity
2	ADE	2,A	3,E			4,E
3	ADEB		3,E			4,E
4	ADEBC					4,E
5	ADEBCF					

Dijkstra's Algorithm: Complexity

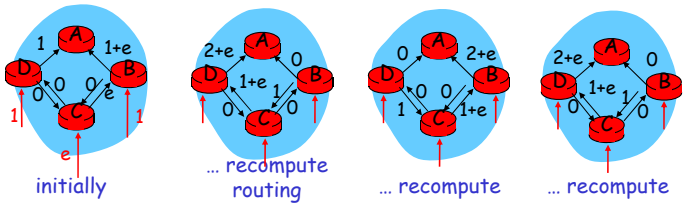
Algorithm complexity: n nodes, e links

- Each iteration: need to check all nodes, v, not in N
  ⇨ $n*(n-1)/2$ checks: $O(n^2)$
- Update 1-more-hop paths: O(e)
- Total: $O(n^2+e)$, or $O(n^2)$
- Using Fibonacci heap to find minimum distance node
  ⇨ O(nlogn + e)

Dijkstra's Algorithm: Stability

Oscillations possible:

- e.g., link cost = amount of carried traffic



Solutions:

- asynchronous (at different time) adjustments across routers
- stable cost metric (independent of routing policy)

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