

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

application

transport

network

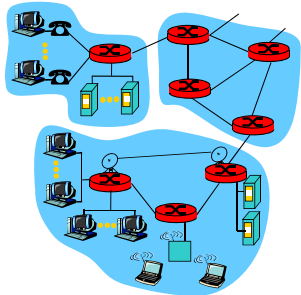
link

physical

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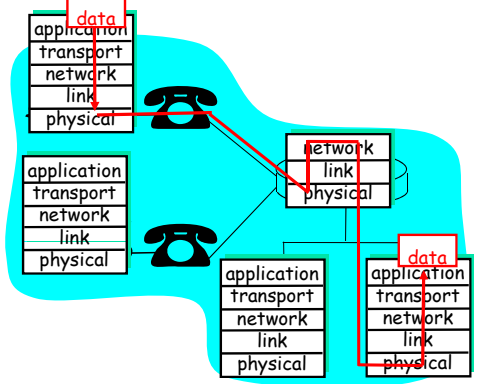
Network Layer Function

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



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Protocol Layers and Data Flows



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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

source destination

M message
H_t M segment
H_n H_t M packet
H_l H_n H_t M frame

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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?

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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

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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

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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.

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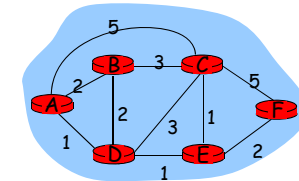
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Routing Principles

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

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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

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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

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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 *How to find them?*
 - 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*.

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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					

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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(n²)
- Update 1-more-hop paths: O(e)
- Total: O(n²+e), or O(n²)
- Using Fibonacci heap to find minimum distance node
 ⇒ O(nlogn + e)

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Dijkstra's Algorithm: Stability

Oscillations possible:

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

... recompute routing ... recompute ... recompute

Solutions:

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

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