Routing

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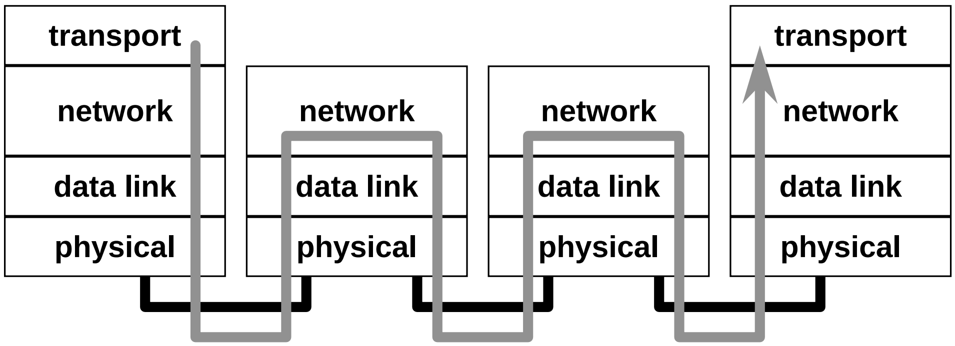
(modified by Marc Abrams for Spring 1998)

Routing Topics

- Basics
- Two standard approaches
  - Distance vector
  - Link state
- Routing in the Internet
  - Autonomous Systems
  - Border Gateway Protocol
  - Open Shortest Path First (OSPF) Protocol

Review: Routing done at Network Layer

- Data Link layer handles point-to-point or multiaccess communication
- Transport layer handles source-to-destination transactions
- Network entities must cooperate for routing



Routing (1)

- Routing is the protocol used to guide packets through a communication network from source to destination
  - Typically a network layer function
  - Routing decision made at connection set-up for a virtual circuit (e.g. ATM)
  - Routing made on a per packet basis for datagrams (e.g. IP)

Routing (2)

- Routing is accomplished by distributed processing of shared information
  - Requires coordination between all nodes in a subnet rather than just a pair of nodes
  - Link and node failures require table updates and redirection of traffic
  - Congestion requires the algorithm to modify routes

Routing Functions

- Routing may be performed by
  - Dedicated routers
  - Hosts with multiple network connections
- Routing algorithms must
  - Select routes for various source-destination pairs ("routing")
    - Potentially complex
    - Distributed
  - Deliver packets to correct destination using selected routes ("switching")
    - Relatively easy
    - Confined to a single router

Review: Interconnected Network Routing

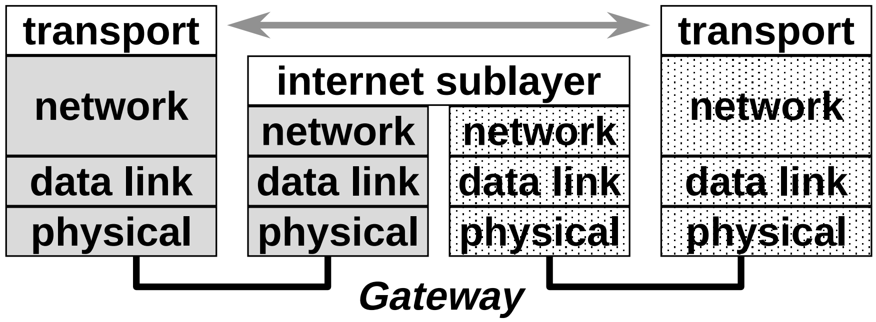
- Networks often consists of interconnected local area and wide area networks

- Interface devices
  - Gateways (above layer 3)
  - Routers (layer 3)
  - Bridges (layer 2)
  - Repeaters (layer 1)

- There are not always clear distinctions between the type of devices

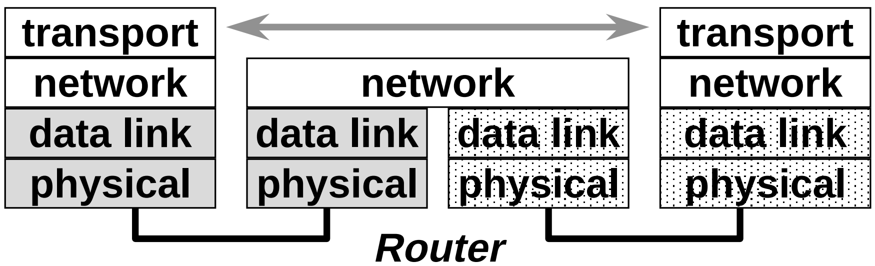
Gateways

- Gateways provide interfaces between different networks
  - Allow packets to traverse networks with ***<u>different network layers</u>***
  - May perform routing



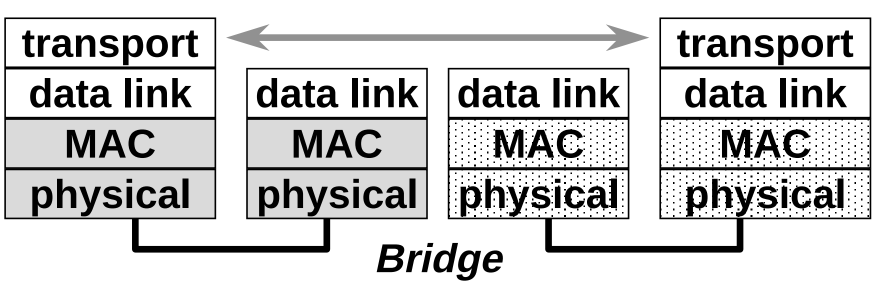
Routers

- Routers route ***between different sub-networks,*** often different LANs
  - Operate at the network layer
  - Provide routing, e.g. adaptive (dynamic) routing or multiple-path routing



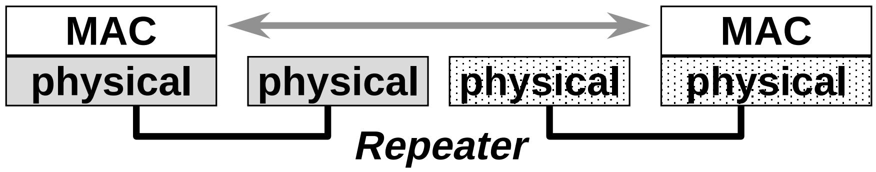
Bridges

- Bridges interconnect LAN segments
  - At the MAC sublayer; form *extended LANs*
  - Perform primitive routing in that they selectively copy packets across segments



Repeaters

- Repeaters provide only physical connectivity between LAN segments
  - Operate at the physical layer
  - Signal regeneration and synchronization
  - Translation between different signaling

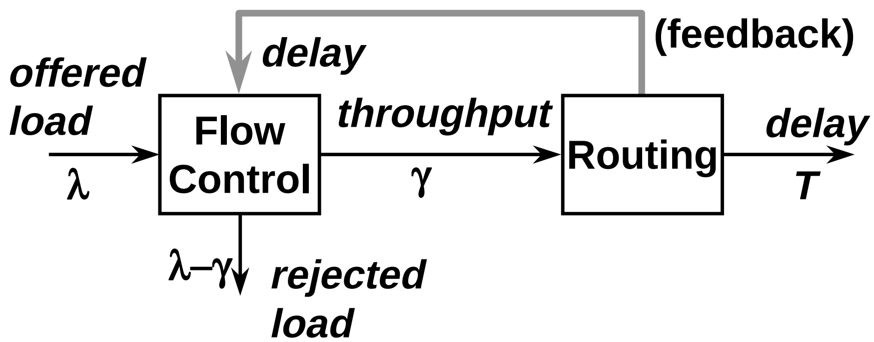


Effects of Routing on Network Performance

- Routing directly affects link utilization, and therefore significantly affects …
  - Throughput (quantity of service)
  - Average packet delay (quality of service)
- Routing algorithms attempt to minimize latency and maximize throughput
  - *Link metrics* specify a “goodness” of using a particular link
  - Routing algorithm must determine paths that optimize “goodness”
- Routing and flow control interact

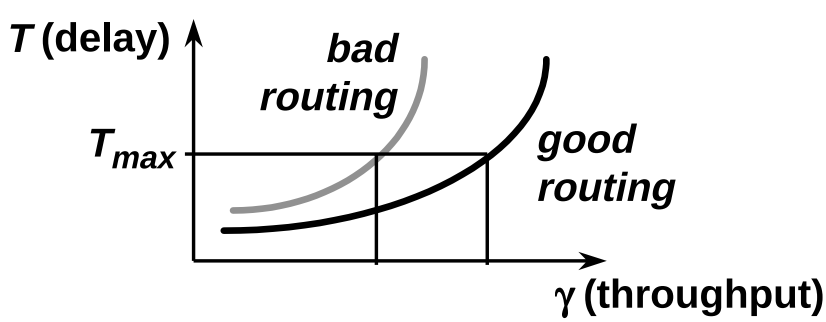
Routing and Flow Control Interaction (1)

- *Flow control* must determine accepted traffic $\gamma(\lambda)$ to input to the network to ensure that delay objectives are met
- The accepted traffic depends on offered load λ and delay T



Routing and Flow Control Interaction (2)

- Delay per packet is affected by the network paths chosen by the routing algorithm
- As the routing algorithm does a better job of keeping delay low, the flow control algorithm allows more traffic into the network



Routing Tables (1)

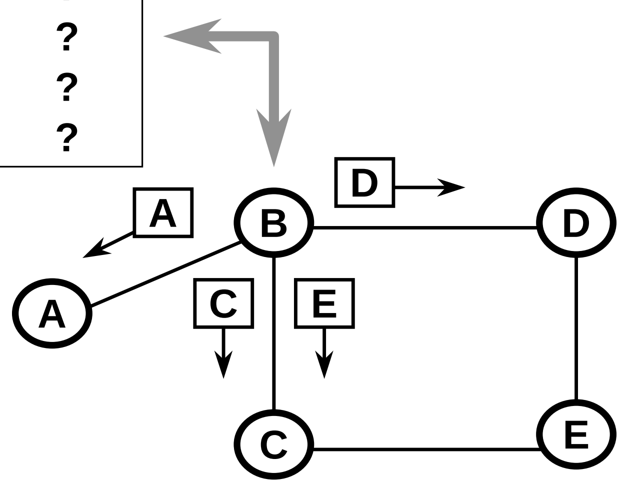
- **Routing accomplished using *routing tables* at each router**
  - **Route selection determines table entries**
  - **Table is used to forward packets**

- **Each table entry contains**
  - **Destination node**
  - **Next node or link**
  - **Metric indicating “goodness” of the path**

Routing Tables (2)

Dest	Next	Metric
A	A	?
C	C	?
D	D	?
E	C	?

Node B’s routing table

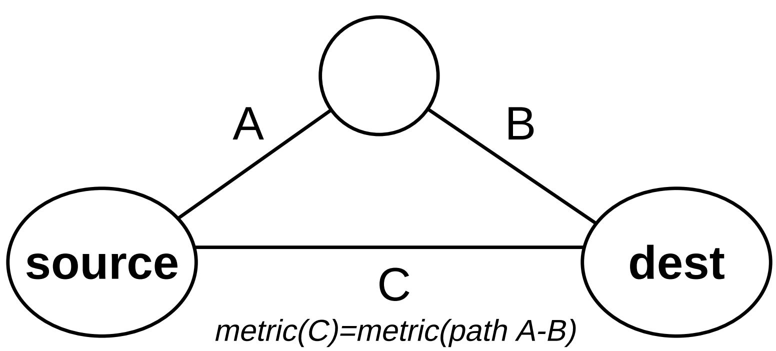


Example Routing Metrics

Metric	Values
Hop count	1 - 255
Unitless number	1 - 64K
Bandwidth	9.6K - 1G
Delay	10 msec - 1 sec
Monetary cost	0 - ?
Reliability	0 - 1
Utilization	0 - 1

Metric Concatenation

- **Suppose path C has the same physical properties as A-B:**



Example:

Metric	Function
Hop count	x + y
Bandwidth	min(x,y)

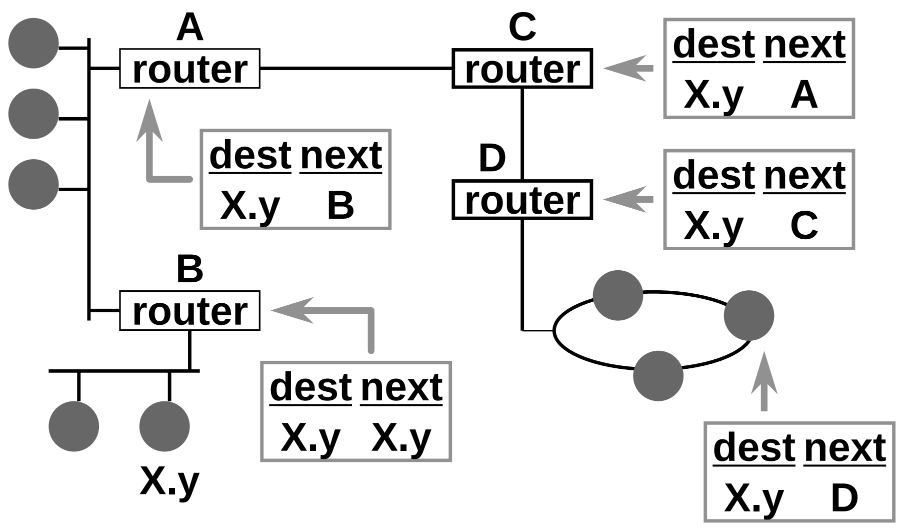
Hierarchical versus Nonhierarchical Routing (1)

- Consider a large network consisting of interconnected subnetworks
- Nonhierarchical routing
  - Network viewed as a single large network
  - All routing considers all nodes
  - Routing tables have an entry for every node, so they are large
  - Updating tables is slow
    - Computationally because of table size
    - Time to propagate information through the network

Hierarchical versus Nonhierarchical Routing (2)

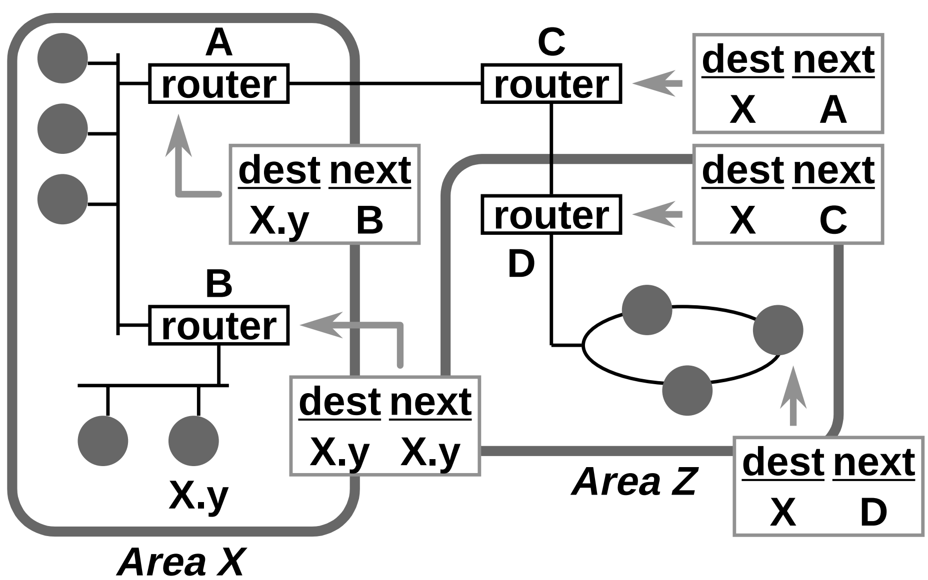
- Hierarchical routing
  - Networks decomposed into subnets (areas, levels, domains)
  - There may be two or more levels of hierarchy
  - At the top level, routing treats each subnet like a node for routing purposes
  - One or more routers for a subnet route to individual nodes
  - May not yield the best path since information is limited

Nonhierarchical Routing



Notice that *all* routers have entry for X.y

Hierarchical Routing



Routers outside Area X only have entry for X, not X.y

Routing Taxonomy (1)

- Location of routing decisions
  - Centralized
  - Distributed
    - Distance vector (a.k.a. Bellman-Ford)
    - Link-state (a.k.a. shortest path first or reliable broadcast)
  - Originating node
    - Source routing
- Routing decision time
  - Per packet (datagram)
  - Per connection (virtual circuit)

Routing Taxonomy (2)

- Routing strategy
  - Static
    - Fixed
      - Simple
      - Inefficient unless traffic is fixed
      - Limited use (e.g. routing from end node with one route)
    - Flooding
      - Send to all neighbors
      - Robust, always uses the shortest path
      - Heavy load on the network
      - Must discard duplicates
      - Applications for high priority message

Routing Taxonomy (3)

- Routing strategy (continued)
  - Dynamic
    - Random
      - Simple
      - Very inefficient
      - Not used
    - Adaptive
      - Adapts to changing traffic conditions
      - Computationally complex (processing overhead)
      - Requires that status be shared (network load)
      - Potential stability and oscillation problems
      - Widely used

Standard Approaches to Routing

- There are two standard approaches to routing
  - Distance vector (a.k.a. Bellman-Ford)
    - Slow to converge after link or router failure, but fast to compute
  - Link-state (usually based on Dijkstra's shortest path first algorithm)
    - Fast to converge (a few seconds), but complex to compute
- Both are distributed, dynamic, and adaptive
- Form the basis for most standard routing protocols

Routing in the Internet

- **The Internet is composed of many *autonomous systems* (AS)**
  - **Each AS is operated largely independently**
  - **Policies and even protocols within an AS may vary**
  - **Some standardization is needed, of course**
- **Types of routing protocols**
  - **Interior Gateway Protocol (IGP): a routing protocol operating *within* an AS**
  - **Exterior Gateway Protocol (EGP) or Interdomain Routing Protocols: a protocol to route *between* ASes**

See Stallings 5th ed., section 16.4 for more info.

Routing Protocols

- **Interior Gateway Protocols**
  - **HELLO: older, not presently used**
  - **Routing Information Protocol (RIP): widely used, but growing out of favor**
  - **Open Shortest Path First (OSPF) protocol: emerging as the new “standard” protocol**
- **Exterior Gateway Protocols**
  - **Border Gateway Protocol (BGP)**

Example of Autonomous Systems

Insert Stallings Fig. 16.10

Border Gateway Protocol (BGP)

- **Allows routers in different ASes to exchange routing info**
- **Four message types:** ***<u>Open, Notify, Keepalive, Update</u>***
- **Three functions:**
  - ***Neighbor acquisition***
    - **"Neighbor" = two routers sharing same subnet (e.g., R1, R5)**
    - **R5 sends *<u>Open</u>* request to acquire R1**
    - **R1 responds with *<u>Notification</u>* to accept or reject request**
  - ***Neighbor reachability***
    - **Send *<u>Keepalive</u>* messages after each *<u>Holdtime</u>***
  - ***Network reachability***
    - **Border routers maintain database of subnets it can reach and preferred route**
    - **Upon change to database, broadcast *<u>Update</u>* to BGP routers**

More on BGP

- Update messages send *paths*
- Path contains sequence of ASes to traverse to reach each subnets in a given AS
- Thus router can avoid AS that is untrustworthy, expensive, congested, …
- Example:
  - Using IGP, R1 exchanges routing info w/ other routers in AS1
  - R1 issues update to R5; tells R5 how to reach subnets in R1
  - Suppose R5 is connected to R9 in As3.
    - R5 forwardes R1's update to R9.
    - R9 gets AS sequence AS2->AS1 to reach subnets in R1.

IGP: Open Shortest Path First (OSPF)

- Allows routers ***within*** AS to exchange route info
- First map an autonomous system to a graph

  See Stallings Figures 16.12, 16.13
- Using Dijkstra's algorithm, each router compute least-cost path to each destination subnet within AS. Results in ***spanning tree.***

  See Stallings Figure 16.14
- But table at each router only gives ***next hop.***

  See Stallings Table 16.5.