

The Network Layer: Routing in the Internet

Dr. Michele Weigle

Department of Computer Science

Old Dominion University

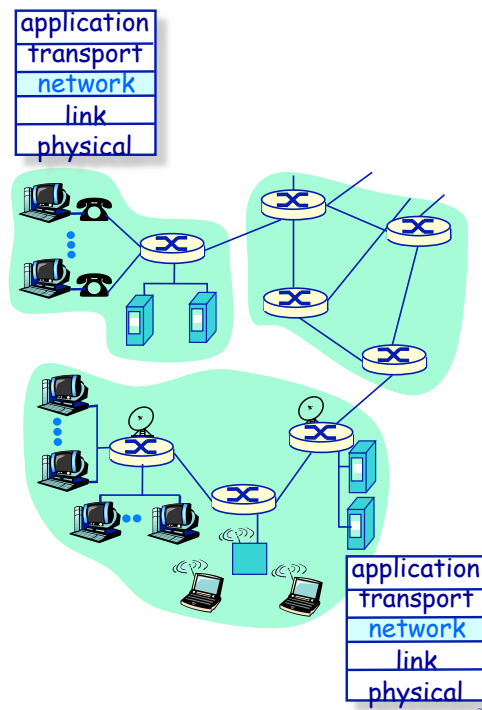
mweigle@cs.odu.edu

<http://www.cs.odu.edu/~mweigle/CS455-S13>

1

The Network Layer: Routing & Addressing Outline

- ◆ Network layer functions
- ◆ Virtual circuits and datagram networks
- ◆ Router architecture
- ◆ IP Internet Protocol
 - » Addressing
- ◆ Routing algorithms
 - » Least cost path computation algorithms
- ◆ Hierarchical routing
 - » Connecting networks of networks
- ◆ Routing on the Internet
 - » Intra-domain routing
 - » Inter-domain routing



2

The Network Layer: Routing & Addressing

Hierarchical routing

- ◆ The theory of routing: relatively simple algorithms with manageable shortcomings
- ◆ Critical assumptions:
 - » All routers are identical
 - » The network is "flat"
- ◆ The reality: Routing is dominated by issues of scale
 - » The Internet has 100 million hosts!
 - ❖ Can't store all host destinations in routing tables!
 - ❖ Routing table exchange would swamp links!
 - » We must route to *networks*, not hosts
- ◆ Routing also dominated by issues of administrative autonomy
 - » The Internet is a network of networks — each network owner may want to control routing in its own network

3

Hierarchical Routing

Gateway routers

- ◆ Aggregate routers into regions, "autonomous systems" (AS)
- ◆ All routers inside same AS run same routing protocol among themselves
 - » "*Intra-AS*" routing protocol
 - » Routers in different AS can run different *intra-AS* routing protocol

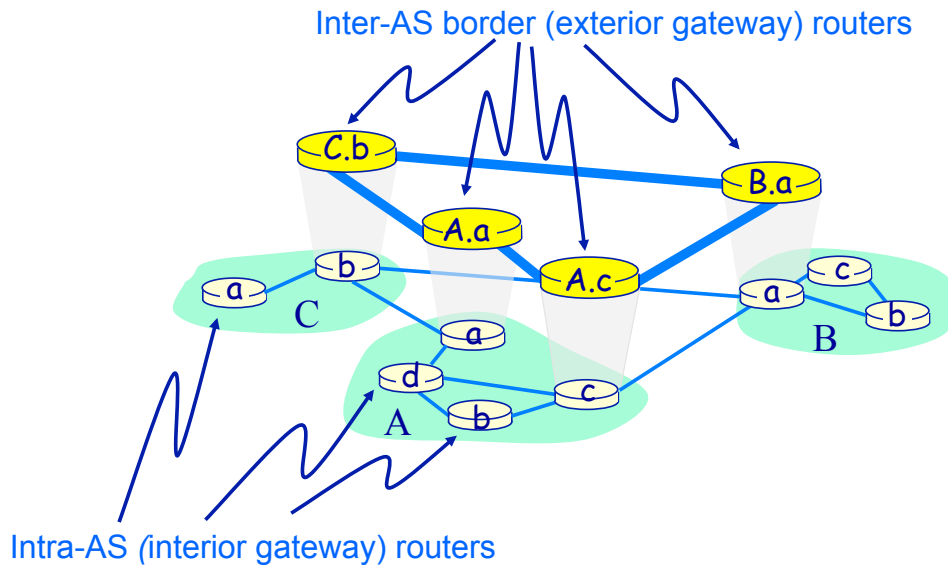
Gateway routers

- ◆ Special routers in AS
- ◆ Run *intra-AS* routing protocol with all other routers inside AS
- ◆ Responsible for routing to destinations outside AS
 - » Also run *inter-AS* routing protocol with gateway routers in adjacent AS

4

Hierarchical Routing

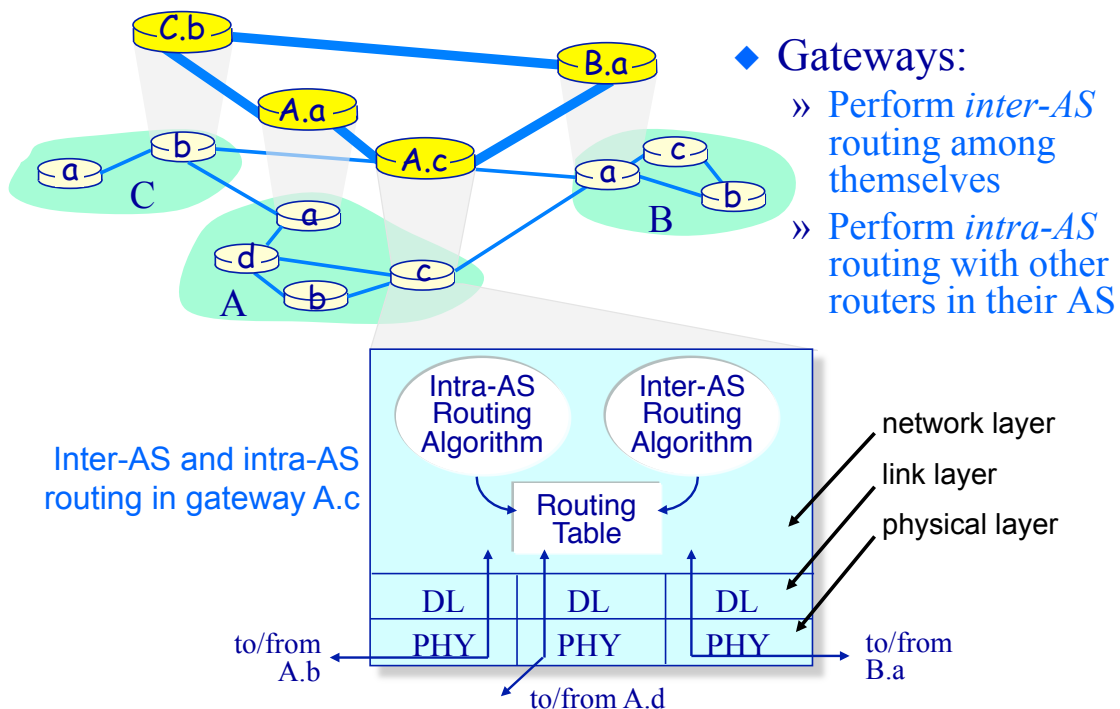
The Internet AS hierarchy



5

Hierarchical Routing

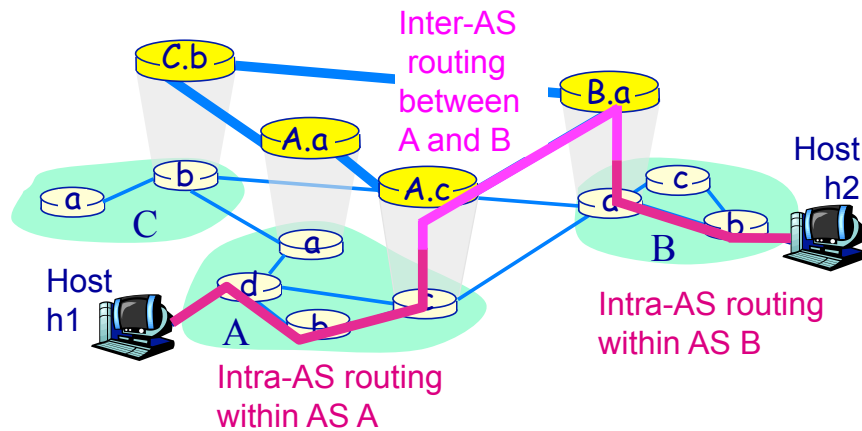
Intra-AS & Inter-AS Routing



6

Hierarchical Routing

Intra-AS & Inter-AS Routing



7

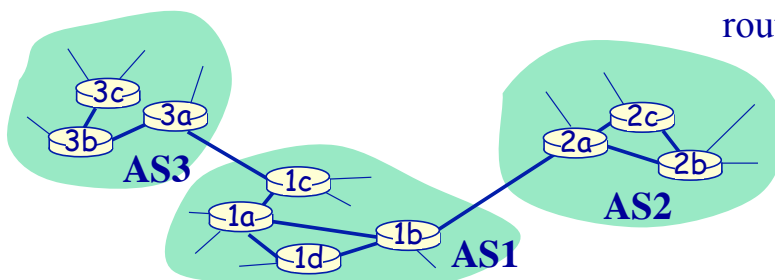
Hierarchical Routing

Inter-AS Tasks

- ◆ Suppose router in AS1 receives datagram destined outside of AS1:
 - » router should forward packet to gateway router, but which one?

AS1 must:

1. learn which destinations are reachable through AS2, which through AS3
2. propagate this reachability info to all routers in AS1



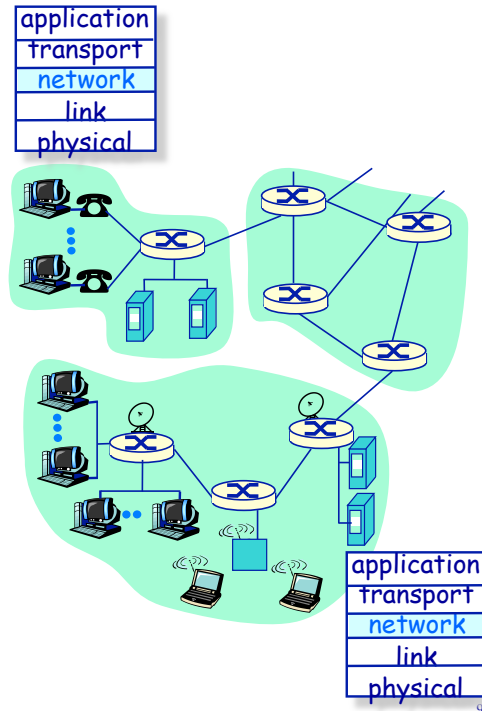
This is the job of inter-AS routing!

8

The Network Layer: Routing & Addressing

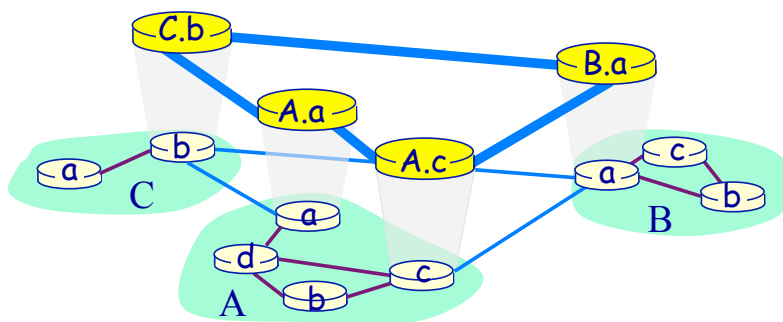
Outline

- ◆ Network layer functions
- ◆ Virtual circuits and datagram networks
- ◆ Router architecture
- ◆ IP Internet Protocol
 - » Addressing
- ◆ Routing algorithms
 - » Least cost path computation algorithms
- ◆ Hierarchical routing
 - » Connecting networks of networks
- ◆ Routing on the Internet
 - » Intra-domain routing
 - » Inter-domain routing



The Internet AS Hierarchy

Intra-AS routing



- ◆ Also known as "Interior Gateway Protocols" (IGPs)
- ◆ Most common IGPs:
 - » RIP: Routing Information Protocol
 - » OSPF: Open Shortest Path First

Intra-AS Routing

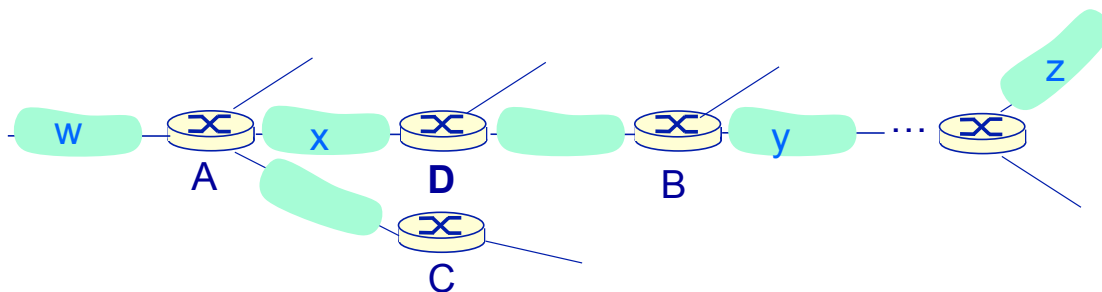
Routing Information Protocol (RIP)

- ◆ Distance vector-*like* algorithm
 - » Commonly used in the early Internet
- ◆ Distance metric: Number of hops
 - » Maximum value = 15 hops ($\infty = 16$)
- ◆ Routing tables (including costs) are exchanged with adjacent nodes every 30 seconds via a Response Message (also called a "route advertisement")
 - » *Receiver* determines if adjacent node has found a new minimum cost to a destination
- ◆ Each advertisement consists of the minimum cost route for up to 25 destination networks

11

RIP

Example



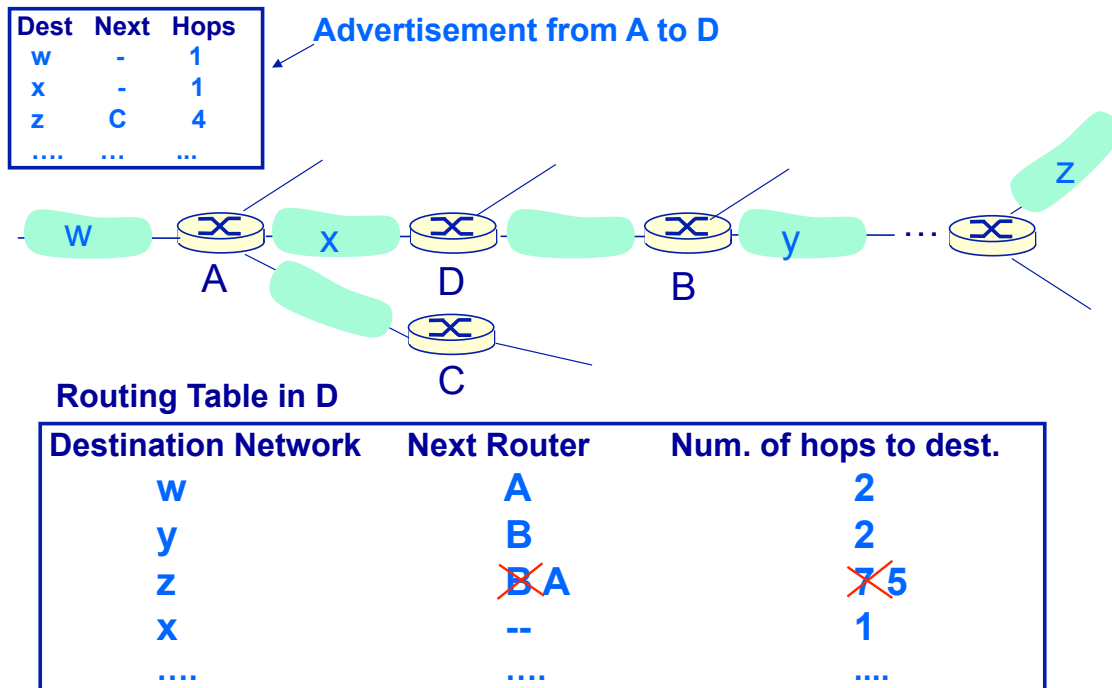
Routing Table in D

Destination Network	Next Router	Num. of hops to dest.
w	A	2
y	B	2
z	B	7
x	--	1
....

12

RIP

Example



13

RIP

Link failure and recovery

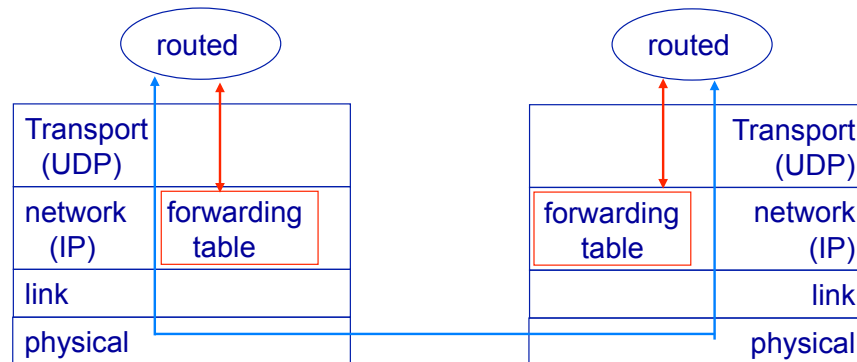
- ◆ If no advertisement heard after 180 seconds, adjacent node/link declared "failed"
 - » Routes via that adjacent node invalidated
 - » New advertisements sent to other adjacent nodes
 - » Advertisement receivers in turn send out new advertisements (if their tables changed)
 - » Link failure information quickly propagates to entire net
 - » Poisoned reverse used to prevent ping-pong loops
 - ❖ "infinity" = 16

14

RIP

Table processing

- ◆ RIP routing tables managed by application-level process called route-d (daemon)
- ◆ Advertisements sent in UDP packets (port 520), periodically repeated



15

Intra-AS routing

Open Shortest Path First (OSPF)

- ◆ "Open": publicly available
- ◆ Uses the Link State minimum cost path computation algorithm
 - » LS update flooding
 - » Topology map at each node
 - » Route computation using Dijkstra's algorithm
- ◆ OSPF advertisement carries one entry per adjacent node
- ◆ Advertisements disseminated to an entire AS (via flooding)

16

OSPF

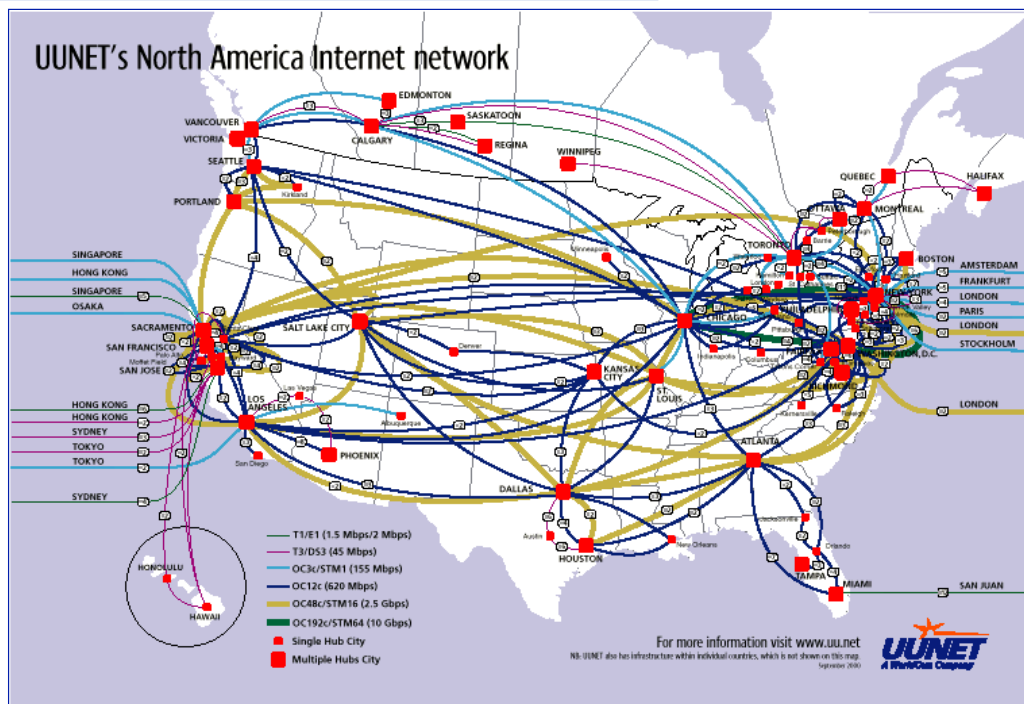
"Advanced" features (not in RIP)

- ◆ Security: all OSPF messages can be authenticated to prevent malicious intrusion
 - » TCP connections used in flooding
- ◆ Multiple same-cost paths can be used (only one path in RIP)
 - » packets in a connection may travel different paths even if routing tables don't change
- ◆ For each link, multiple cost metrics for different network-layer "services"
 - » (e.g., satellite link cost set "low" for best effort; high for real time)
- ◆ Hierarchical OSPF used in large networks

17

OSPF

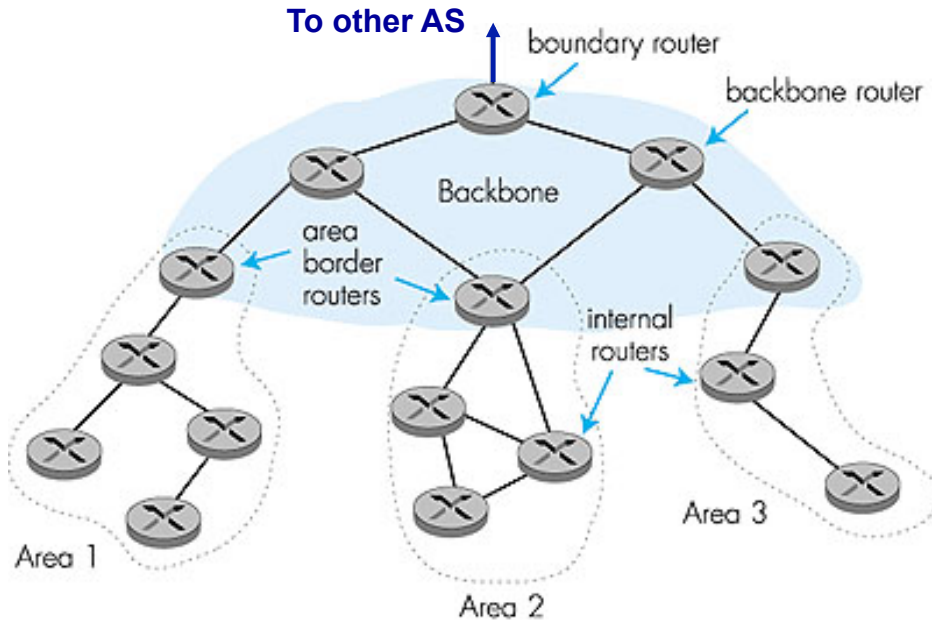
Why hierarchical OSPF?



18

OSPF

Hierarchical OSPF



19

OSPF

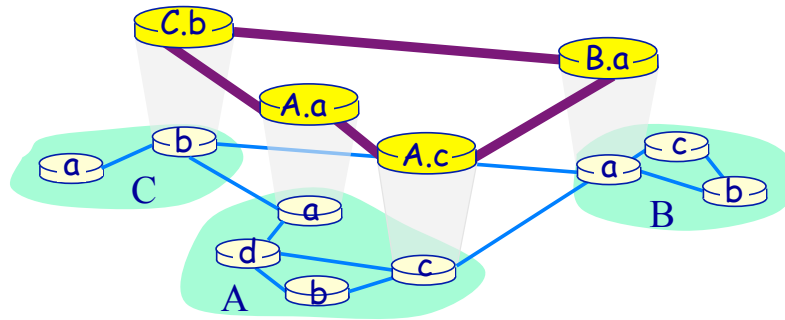
Hierarchical OSPF

- ◆ Two-level hierarchy: local area, backbone
 - » Link-state advertisements only in area
 - » Each area node has detailed area topology; only knows shortest path to networks in other areas
- ◆ Area Border Routers: "summarize" distances to networks in own area and advertise to other Area Border routers
- ◆ Backbone Routers: run OSPF routing limited to backbone
- ◆ Boundary Routers: connect to other AS

20

The Internet AS Hierarchy

Inter-AS Routing

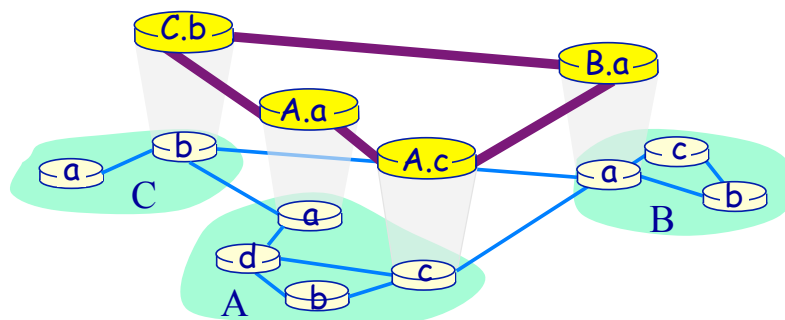


- ◆ Border Gateway Protocol (BGP) is the *de facto* standard
- ◆ BGP allows each subnet to advertise its existence to the rest of the Internet ("I'm here!")

21

Inter-AS Routing

BGP



- ◆ BGP provides each AS a means to:
 1. Obtain subnet reachability information from neighboring ASs.
 2. Propagate reachability information to all AS-internal routers.
 3. Determine "good" routes to subnets based on reachability information and policy.

22

The Internet AS Hierarchy

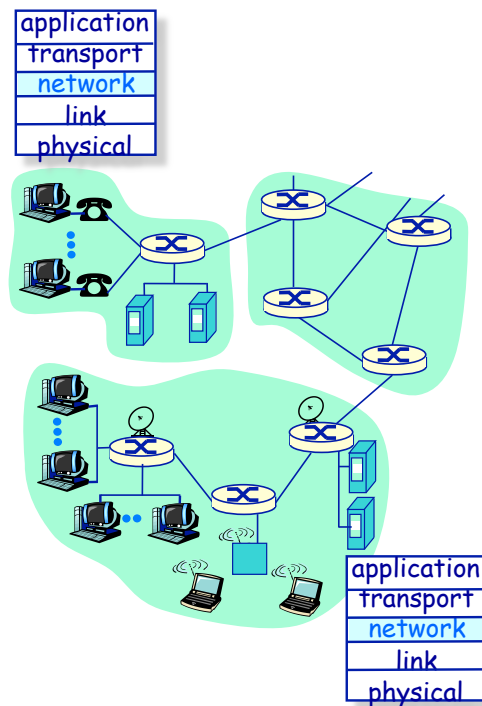
Why different intra- and inter-AS routing?

- ◆ Policy:
 - » Inter-AS: administration wants control over how its traffic routed and who routes through its network
 - » Intra-AS: single administration, so no "policy" decisions needed
- ◆ Scale:
 - » Hierarchical routing saves table size, reduced update traffic
- ◆ Performance:
 - » Intra-AS: can focus on performance
 - » Inter-AS: policy may dominate over performance

23

The Network Layer: Routing & Addressing Outline

- ◆ Network layer functions
- ◆ Virtual circuits and datagram networks
- ◆ Router architecture
- ◆ IP Internet Protocol
 - » Addressing
- ◆ Routing algorithms
 - » Least cost path computation algorithms
- ◆ Hierarchical routing
 - » Connecting networks of networks
- ◆ Routing on the Internet
 - » Intra-domain routing
 - » Inter-domain routing



24