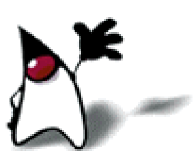
Introduction to Networks & Distributed Computing
CECS 327



Interconnection Devices

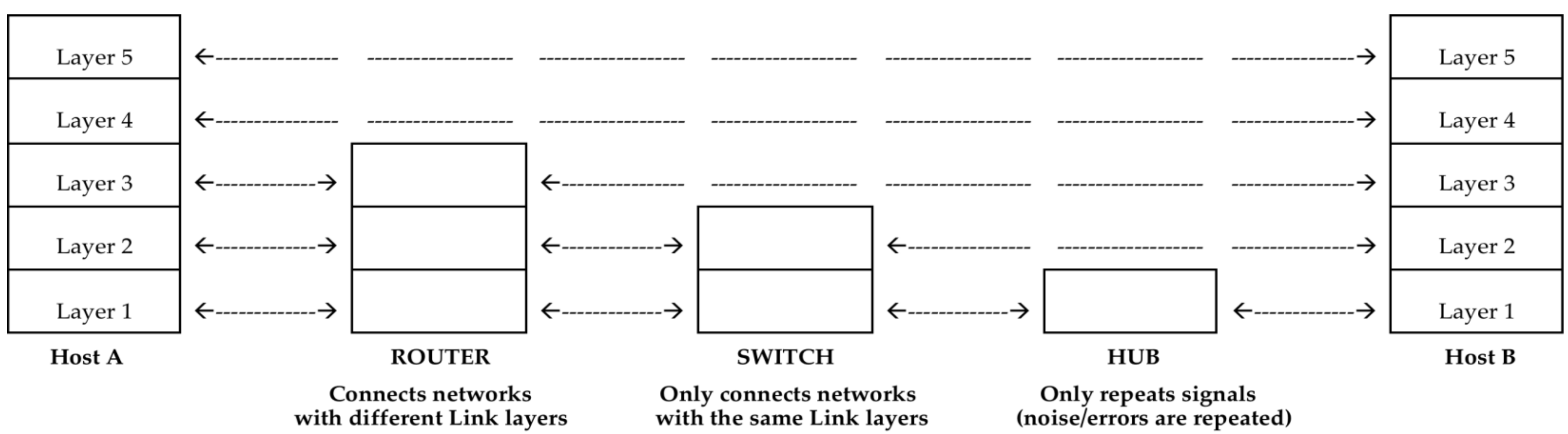
Interconnection Devices

Repeaters, Hubs, Bridges, Switches & Routers

for LANs, MANs & WANs

Interconnection Devices - Router

No.	Layer Name	Name of a "Packet" used at the layer	Address Typed used at layer	Names of Interconnection Device in Each Layer	End-to-end or link-to-link operation
5	Application	Message	IP Addresses	Protocol Translator	End-to-End
4	Transport	Segment	IP Addresses		End-to-End
3	Internet	IP Datagram	IP Addresses	Router	Link-to-Link
2	Network Interface or Link	Frame	MAC Addresses	Switch or Bridge	Link-to-Link
1	Physical	bits	---------	Hub or Repeater	Link-to-Link



Interconnection Devices - Router

A router does two main functions:

- Forwarding: move packets from router's input to appropriate router output.
- Routing: determine route taken by packets from source to destination.
  - routing algorithms

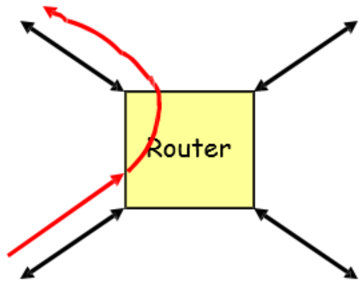
Analogy:

- Routing: process of planning trip from source to destination.
- Forwarding: process of getting through single interchange.

Routing

When packet arrives at router:

- Examine header for intended destination
- Look up next hop in table
- Send packet out appropriate port



(a)	
Prefix/Length	Next Hop
18/8	171.69.245.10

(b)		
Prefix/Length	Interface	MAC Address
18/8	if0	8:0:2b:e4:b:1:2

Example rows from (a) routing and (b) forwarding tables

Routing

Routing protocol:

Goal: determine “good” path (sequence of routers) through network from source to destination.

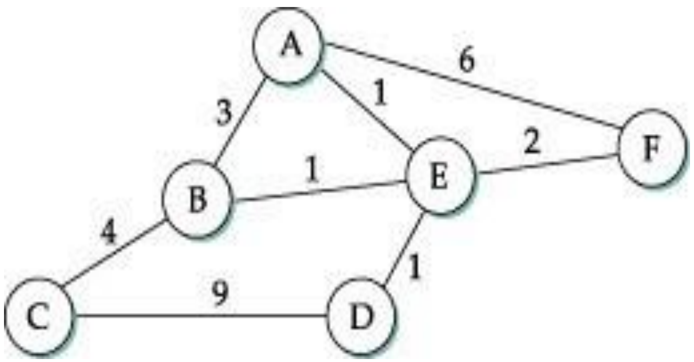
“good” path: typically means minimum link cost path

- Link cost: delay, $ cost, or congestion level

Routing

- Network as a Graph:
  - Represent each router as node
  - Direct link between routers represented by edge

- Link cost C(x,y)
  - C(x,y) = sum of link costs



Question: What's the least-cost path between B and F ?

Routing

Routing Classification:

Static:

- Network administrator configures the routes
- Router installs the routes in the routing table
- Packets are routed using the static routes

Dynamic: (Routing Protocols)

- Discover remote networks
- Maintaining up-to-date routing information
- Choosing the best path to destination networks
- Ability to find a new best path if the current path is no longer available

Routing

Dynamic Intradomain Routing Protocols (RIP/OSPF):

- Distance vector
  - Routes are advertised as vectors of distance & direction
  - Incomplete view of network topology
  - Generally, periodic updates
- Link state
  - Complete view of network topology is created
  - Updates are not periodic

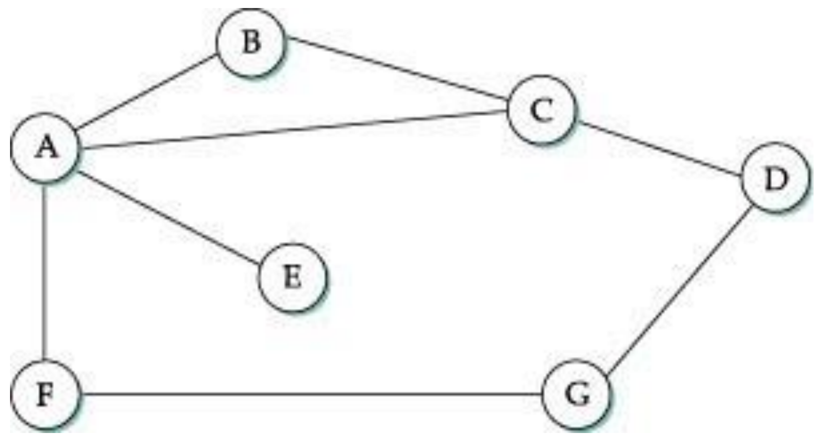
Exterior Routing Protocols:

- Border Gateway Protocol (BGP):

Routing

Distance vector

Initial Table for A		
Destination (Dest)	Cost	Next Hop
B	1	B
C	1	C
D	∞	-
E	1	E
F	1	F
G	∞	-



Note: the process of getting consistent routing information to all the nodes is called ***convergence.***

Idea:
Each node has the information (i.e., cost) to all other node and distributes the 'cost' information to its immediate neighbors

Initially:

- Only have 'cost' information for directly connected nodes
- Use cost ∞ when no path known

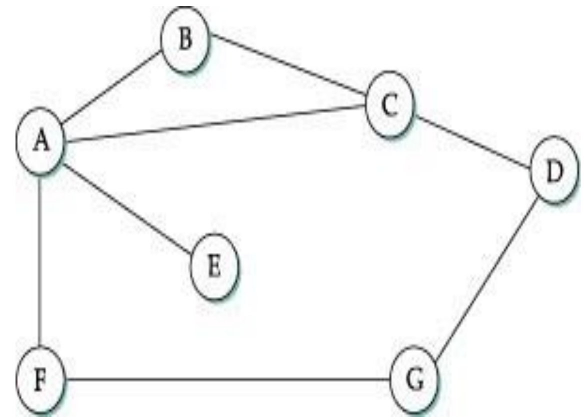
Routing

- **Distance vector**

Initial Table for A		
Dest	Cost	Hop
B	1	B
C	1	C
D	∞	-
E	1	E
F	1	F
G	∞	-

Table for A		
Dest	Cost	Hop
B	1	B
C	1	C
D	∞	-
E	1	E
F	1	F
G	2	F

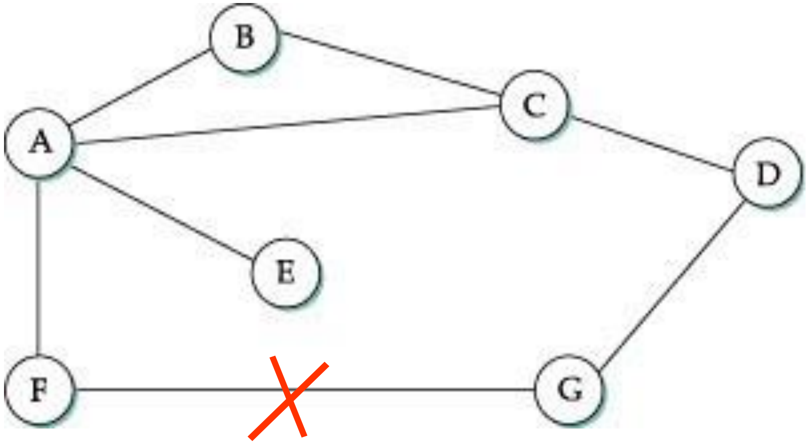
Table for A		
Dest	Cost	Hop
B	1	B
C	1	C
D	2	C
E	1	E
F	1	F
G	2	F



Initial Table for F		
Dest Cost Hop		A 1
A		
B.	∞	-
X.	∞	-
Δ.	∞	-
E.	∞	-
G	1	G

Routing

- **Distance vector**



Link failure:

F➔G: ∞

Table for A		
Dest	Cost	Hop
B	1	B
C	1	C
D	2	C
E	1	E
F	1	F
G	2	F

Table for A		
Dest	Cost	Hop
B	1	B
C	1	C
D	2	C
E	1	E
F	1	F
G	∞	F

Table for A		
Dest	Cost	Hop
B	1	B
C	1	C
D	2	C
E	1	E
F	1	F
G	3	C

Table for F

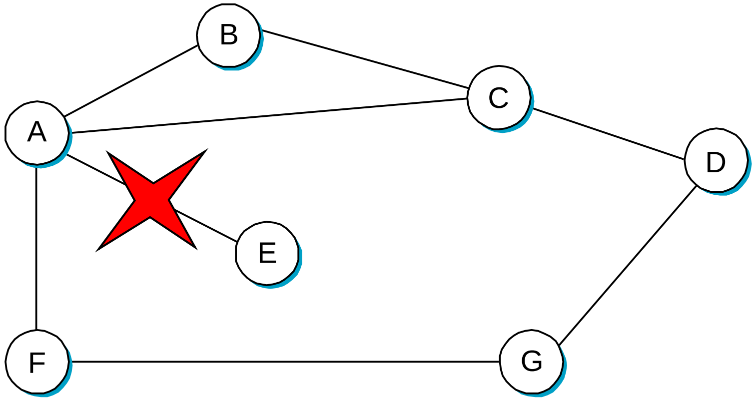
F➔G: 4

Routing

Count to Infinity

- A discovers that link to E is lost.
- If before A's message (saying that link cost to E is ∞) is received, if B or C advertise that they can reach E in two hops, then A can be confused.
- Another possibility, B gets A's update followed by C's update which says that E is reachable in 2 hops.
- So B tells A this, and A thinks it can now reach E via B in 3 hops.
- This information reaches C who now thinks that it can reach E in 4 hops via A.
- This will keep ongoing until it reach the ∞

- The process continues and thus, the system does not stabilize.
- This is the count to infinity problem.



Routing

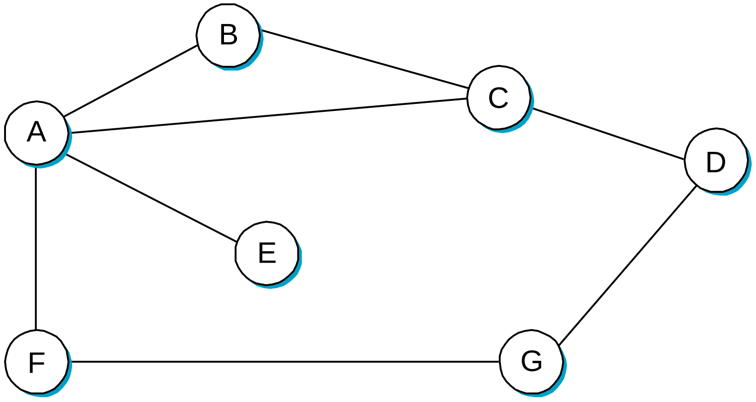
Hope Count:

- One solution would be to approximate ∞ to say 16 hops.

Split Horizon:

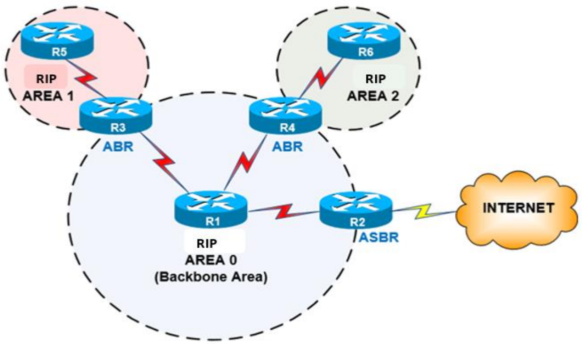
- With **Split Horizon**, when a node sends a routing table update to its neighbors, it "does not" send those routes it learned from "a particular" neighbor, back to that neighbor.
  - For example, B had E, 2, A. When it sends a route update to A, it does not include this.

- With split horizon with poison reverse, this update is reported but the link weight is set to ∞.
  - For example B sends (E, ∞) to A.



Routing

Routing Information Protocol (RIP)

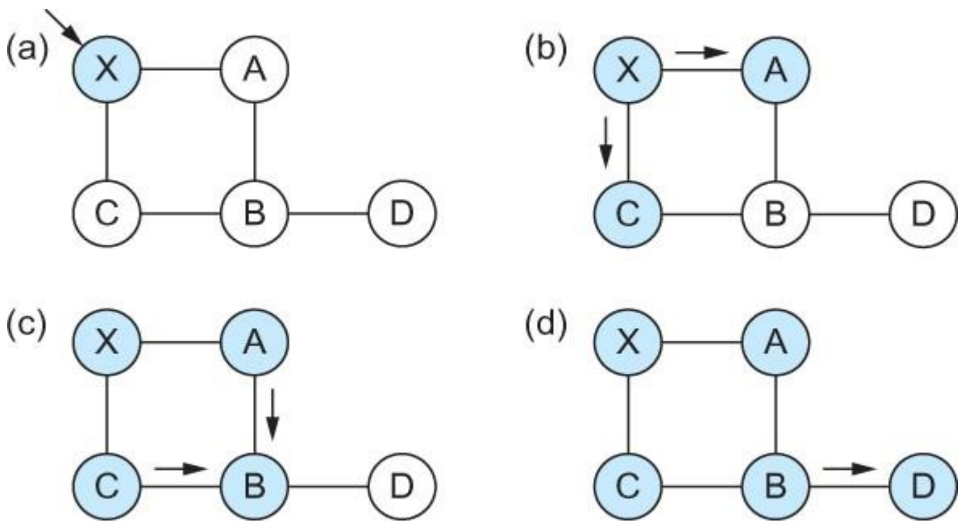


- Earliest IP routing protocol (1982 BSD)
  - Current standard is version 2 (RFC 1723)
- Features
  - Every link has cost of 1 → Hop count
  - “Infinity” = 16
    - Limits to networks where everything reachable within 15 hops
  - Uses Distance Vector (DV) algorithm
- Sending Updates
  - Every router listens for updates on UDP port 520
  - Triggered
    - When every entry changes, send copy of entry to neighbors
  - Periodic
    - Every 30 seconds, router sends copy of its table to each neighbor

Routing

Link State Method

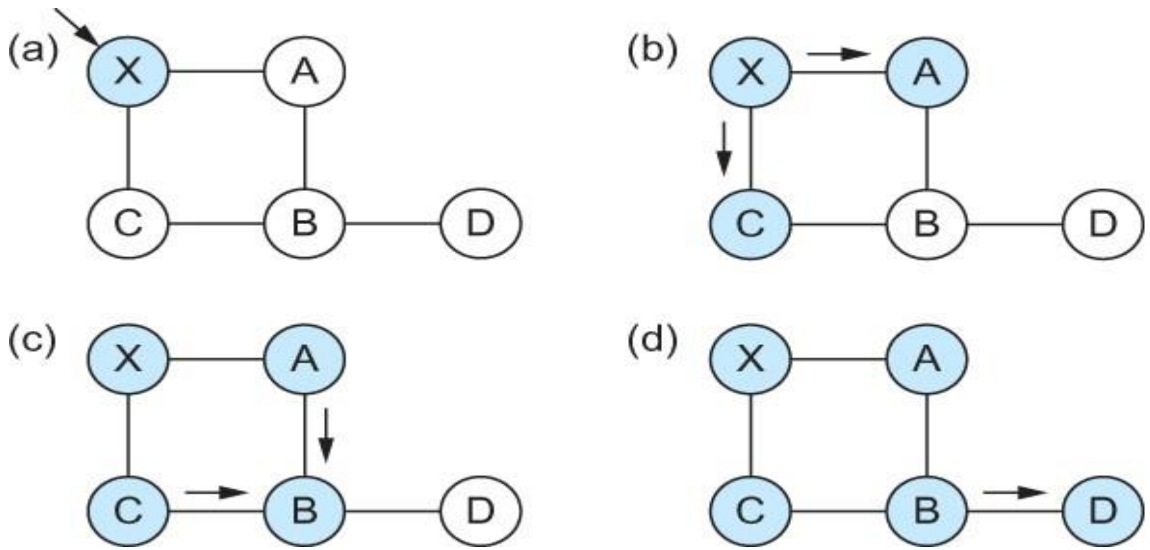
Strategy: Send to all nodes (not just neighbors) information about directly connected links (not entire routing table). This strategy is also called "**Flooding**"



Routing

Link State Packets Contains:

- The ID of the node that created the LSP.
- A list of directly connected neighbors of that node.
- A sequence number.
- A TTL for this packet.



Flooding of link-state packets (LSP). (a) LSP arrives at node X; (b) X floods LSP to A and C; (c) A and C flood LSP to B (but not X); (d) flooding is complete.

Routing

A Link-State Routing Algorithm (Dijkstra's algorithm):

- Network topology, link costs known to all nodes
  - accomplished via "link state broadcast"
  - all nodes have same information

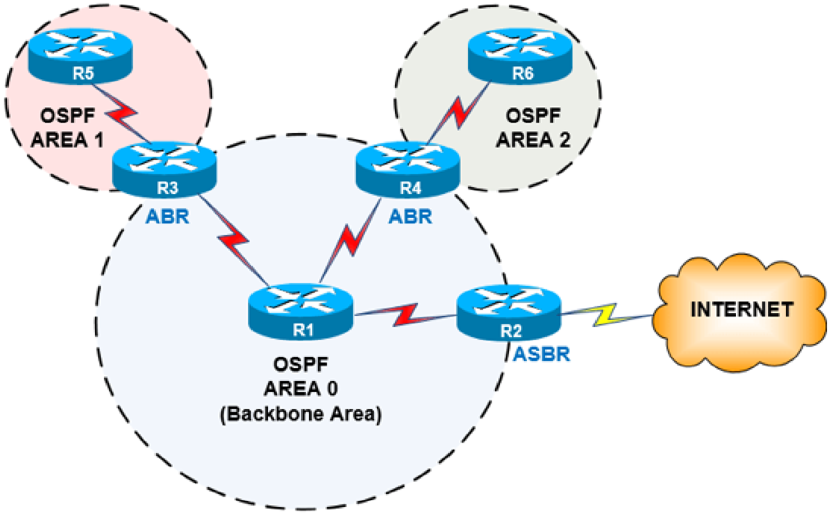
- Computes least cost paths from one node ('source") to all other nodes
  - gives routing table for that node

- Iterative: after k iterations, know least cost path to k destinations

Routing

Open Shortest Path First Routing Protocol (OSPF):

- Uses Link State (LS) algorithm
  - Route computation using Dijkstra's algorithm
- More prevalent than RIP
  - Hierarchical OSPF in large domains
  - Load balancing



Routing

Comparison of RIP and OSPF:

RIP

- Exchange between neighbors only
- Good when networks small and routers had limited memory & computational power

OSPF

- With n nodes, v neighbors, $O(nv)$ messages per node
- Fast convergence when configuration changes
- Full topology map helps

Routing

Interadomain Routing Hierarchy

<u>Issues:</u>

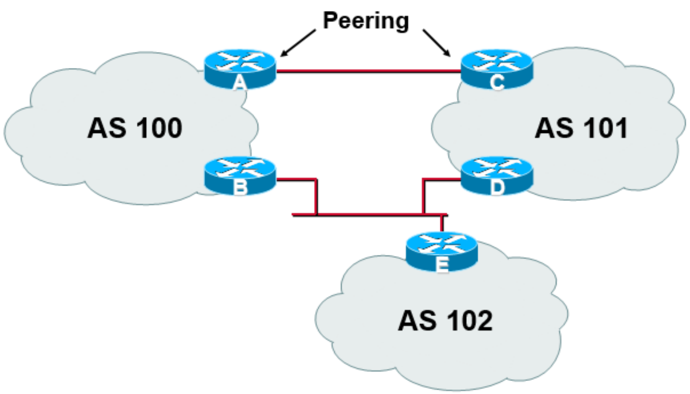
- Doesn't scale with network size
  - Storage → Each node cannot be expected to store routes to every destination (or destination network)
  - Convergence times increase
  - Communication → Total message count increases
- Administrative autonomy
  - Each internetwork may want to run its network independently
    - e.g hide topology information from competitors

<u>Solution</u>: Hierarchy via autonomous systems

Routing - Internet's Hierarchy

What is an Autonomous System (AS)?

- A set of routers under a single technical administration
  - Use an *interior gateway protocol (IGP)* and common metrics to route packets within the AS
  - Connect to other ASes using *gateway routers*
  - Use an *exterior gateway protocol (EGP)* to route packets to other AS's
- IGP: OSPF, RIP
- Today's EGP: BGP version 4
- Similar to an "inter-network"
  - AS could also be a group of internetworks owned by a single commercial entity

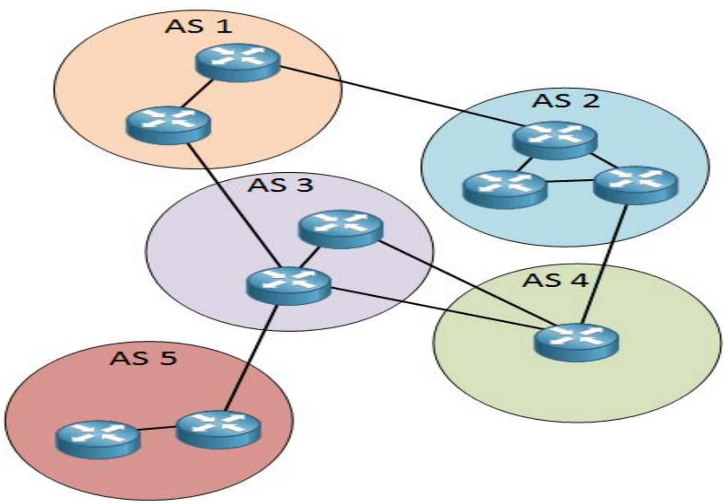


Routing - Internet’s Hierarchy

More about AS

- Stub AS: an AS that has only a single connection to one other AS; such AS will only carry local traffic
- Multihomed AS: maintains connections to more than one other AS, but does not allow traffic from one AS to pass through on its way to another AS. (no transit traffic)
- Transit AS: an AS that has connections to more than one other AS and that is designed to carry both transit and local traffic.
  - Example:

ISPs are always transit ASs, because they provide connections from one network to another. The ISP is considered to be 'selling transit service' to the customer network, thus the term transit AS.



Routing - Internet’s Hierarchy

Autonomous System Numbers (ASN)

- Typically, a unique ASN is allocated to each AS for use in BGP routing. Why?
- ASN is used for exchanging exterior routing information between neighboring AS, and as an identifier of the AS itself.
- ASNs are 16/32 bit values
- An organization is eligible for an ASN assignment if it:
  - is multihomed and has a single, clearly defined routing policy that is different from its providers' routing policies.

Example:

- MIT: 3
- Comcast: 7015, 7757…
- How about CSULB?

Check http://bgp.potaroo.net/cidr/autnums.html for more information.

Routing - Internet's Hierarchy

BGP Preliminaries

- Pairs of routers exchange routing info over TCP connections (port 179)
  - One TCP connection for every pair of neighboring gateway routers
  - Routers called “BGP peers”
  - BGP peers exchange routing info as messages
  - TCP connection + messages → BGP session

- Neighbor ASes exchange info on which CIDR prefixes are reachable via them

- Primary objective: reachability not performance

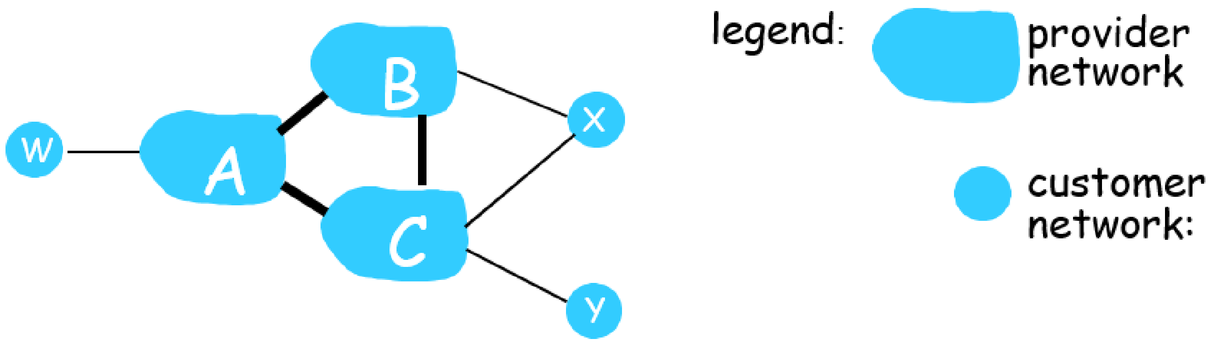
Routing - Internet’s Hierarchy

Policy with BGP

- BGP provides capability for enforcing various policies
- Policies are **<u>not</u>** part of BGP: they are provided to BGP as configuration information
- **<u>Enforces</u>** policies by
  - *Choosing appropriate paths* from multiple alternatives
  - *Controlling advertisement* to other AS’s

Routing - Internet’s Hierarchy

Policy with BGP - Example



- A,B,C are provider networks
- X,W,Y are customer (of provider networks)
- X is dual-homed: attached to two networks
  - X does not want to route from B via X to C
  - .. so X will not advertise to B a route to C

References

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