Computer Networks: Network Layer

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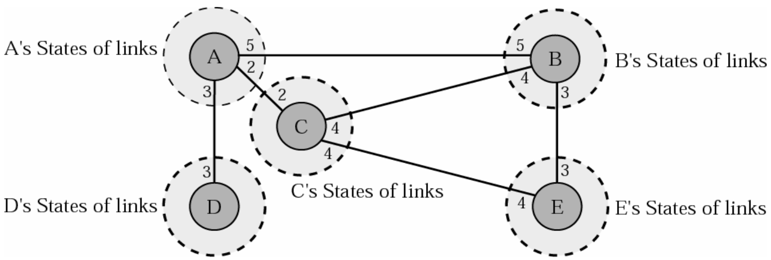
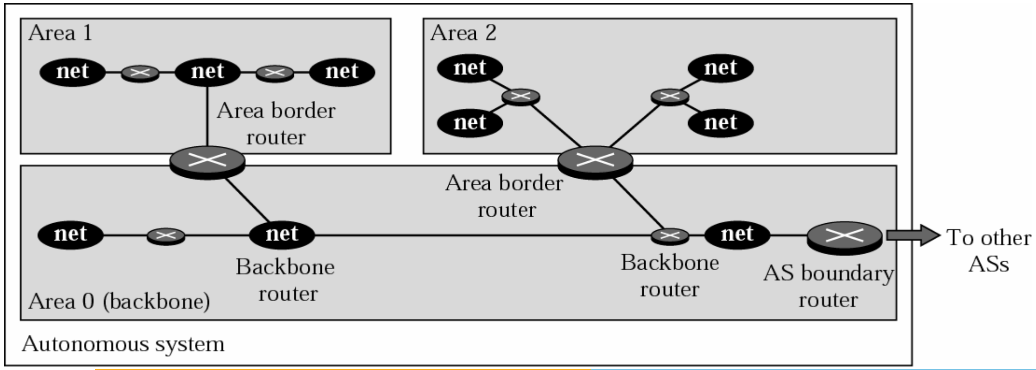
Acknowledgement: Slides and Images adapted from Kurose, and Forouzan (TMH)

Open Shortest Path First (OSPF)

- “open”: publicly available
- uses Link State algorithm
  - LS packet dissemination
  - topology map at each node
  - route computation using Dijkstra’s algorithm



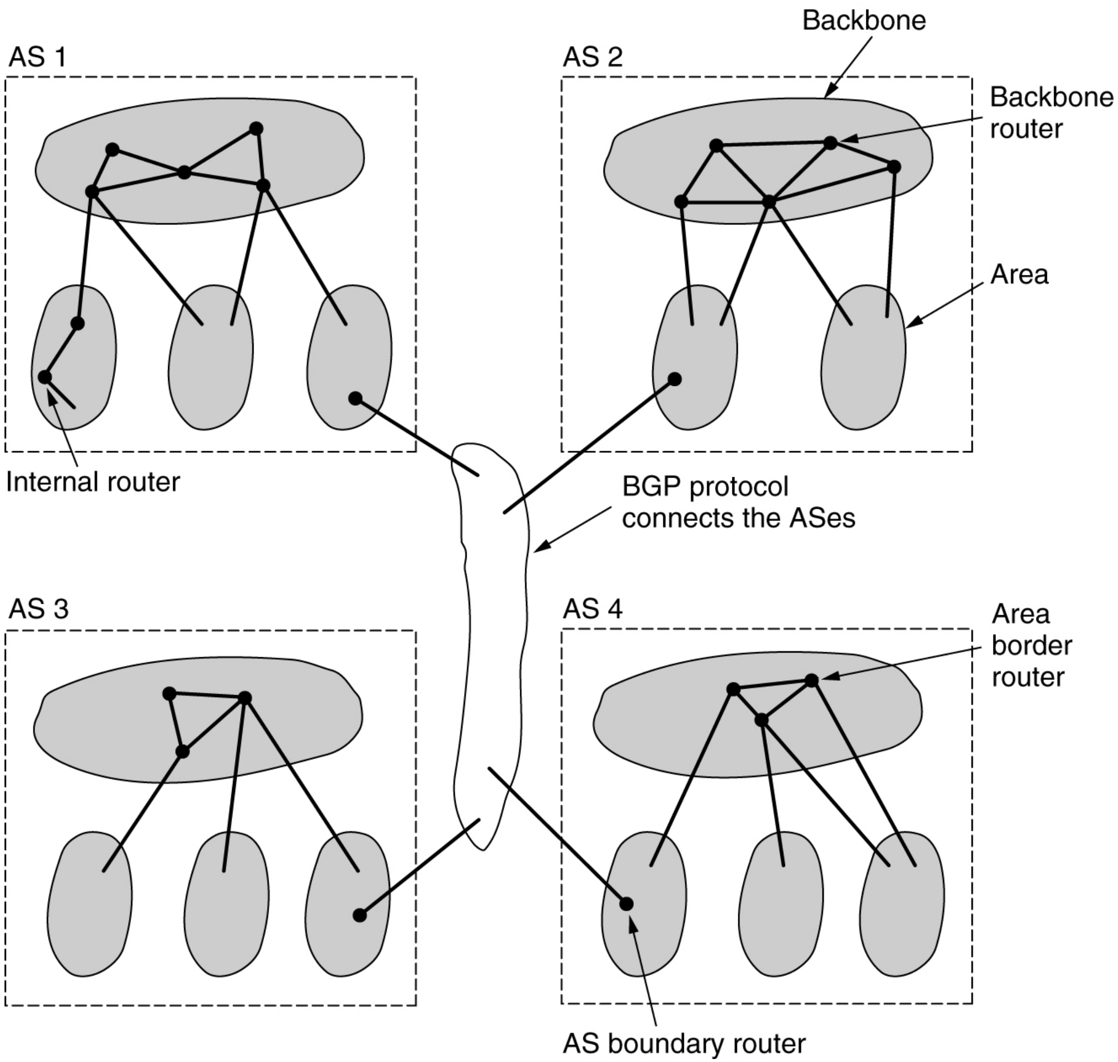
- OSPF advertisement carries one entry per neighbor router
- advertisements disseminated to entire AS (via flooding)
  - carried in OSPF messages directly over IP (rather than TCP or UDP)



OSPF “advanced” features (not in RIP)

- security: all OSPF messages authenticated (to prevent malicious intrusion)
- multiple same-cost paths allowed (only one path in RIP)
- For each link, multiple cost metrics for different TOS (e.g., satellite link cost set “low” for best effort; high for real time)
- integrated uni- and multicast support:
  - Multicast OSPF (MOSPF) uses same topology data base as OSPF
- hierarchical OSPF in large domains.

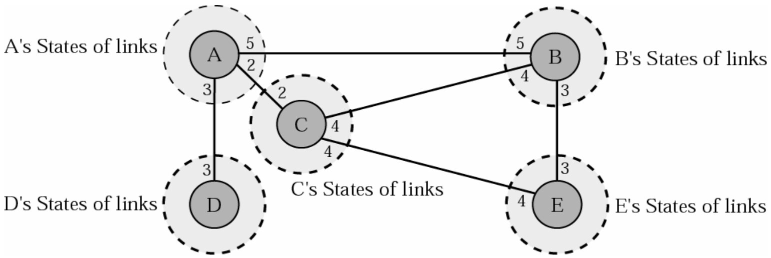
Hierarchical OSPF



Challenges for Interdomain Routing

- Scale
  - Prefixes: 150,000-200,000, and growing
  - ASes: 20,000 visible ones, and growing
  - AS paths and routers: at least in the millions…
- Privacy
  - ASes don’t want to divulge internal topologies
  - … or their business relationships with neighbors
- Policy
  - No Internet-wide notion of a link cost metric
  - Need control over where you send traffic
  - … and who can send traffic through you

Open Shortest Path First (OSPF)



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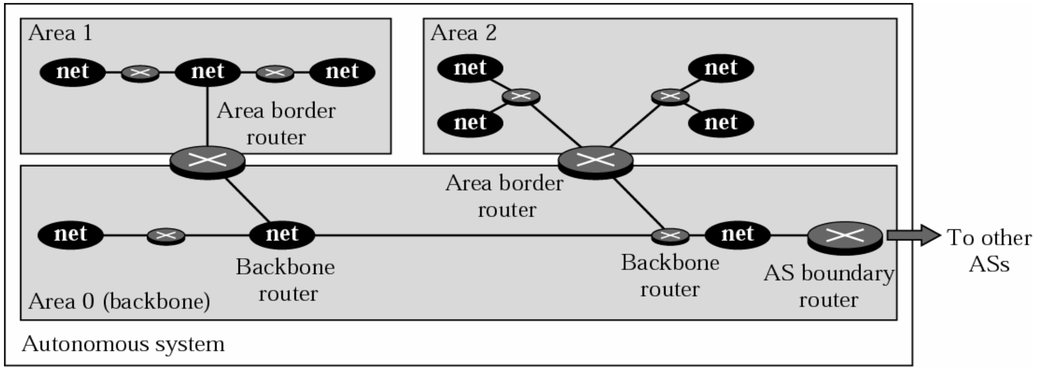

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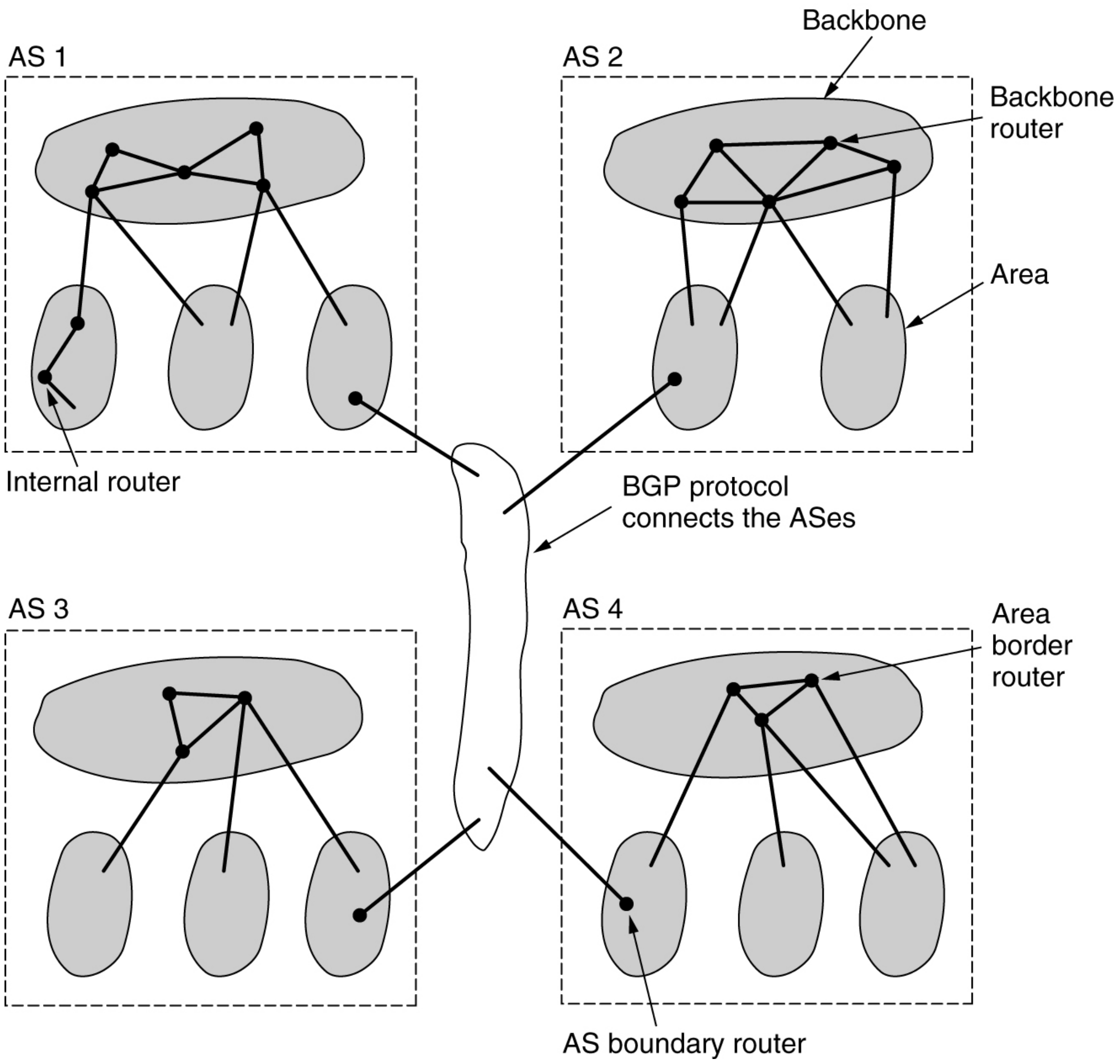

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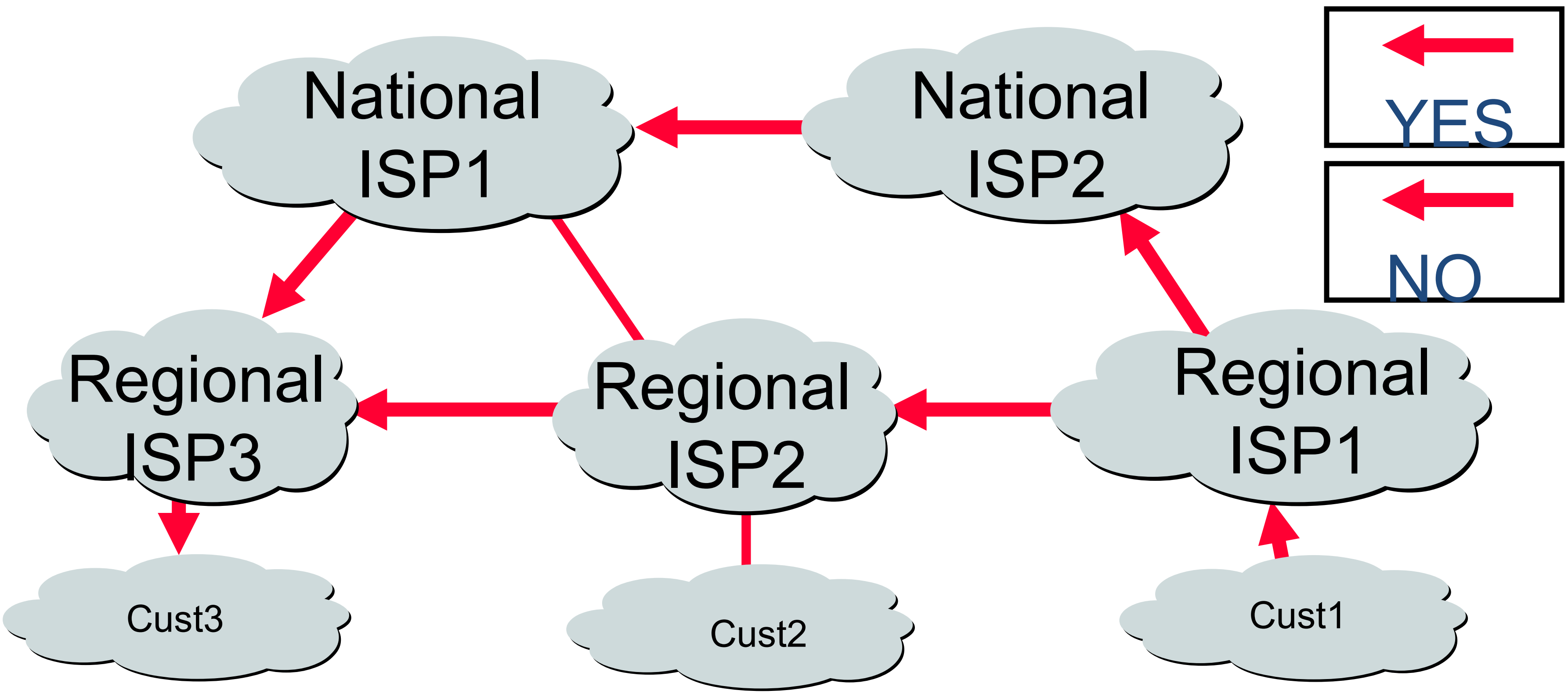
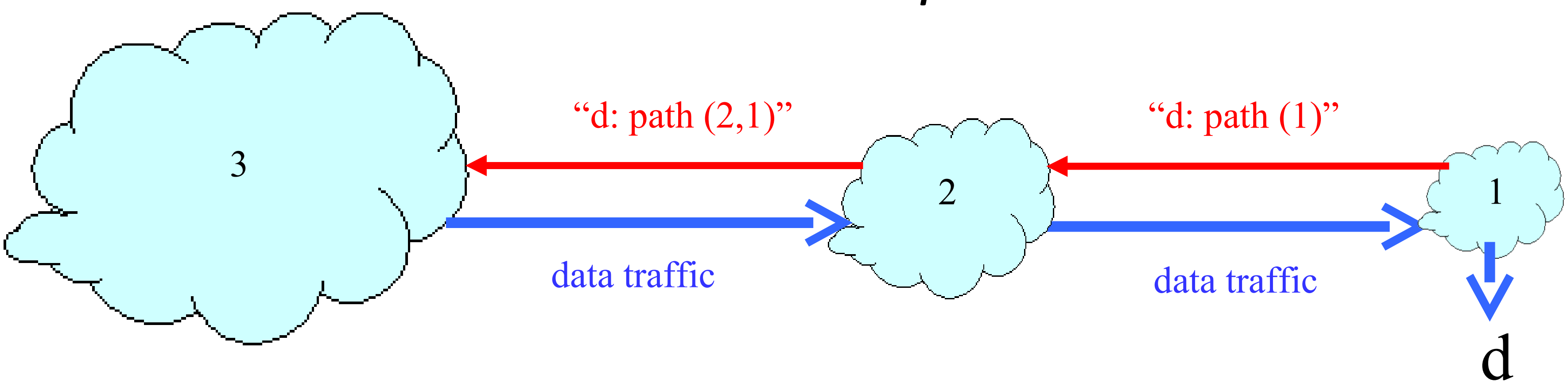
Shortest-Path Routing is Restrictive

- All traffic must travel on shortest paths
- All nodes need common notion of link costs
- Incompatible with commercial relationships



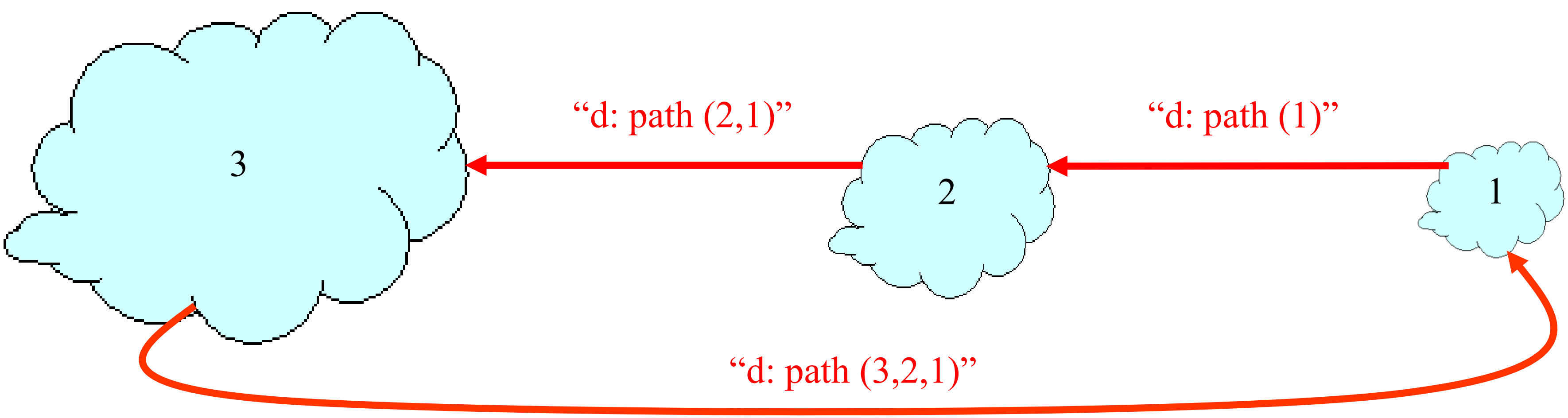
Path-Vector Routing

- Extension of distance-vector routing
  - Support flexible routing policies
  - Avoid count-to-infinity problem
- Key idea: advertise the entire path
  - Distance vector: send *distance metric* per dest d
  - Path vector: send the *entire path* for each dest d



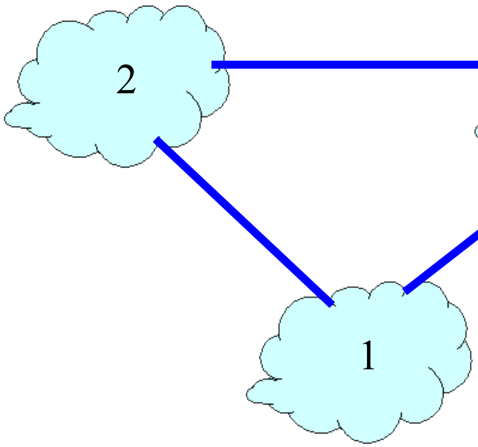
Faster Loop Detection

- Node can easily detect a loop
  - Look for its own node identifier in the path
  - E.g., node 1 sees itself in the path “3, 2, 1”
- Node can simply discard paths with loops
  - E.g., node 1 simply discards the advertisement

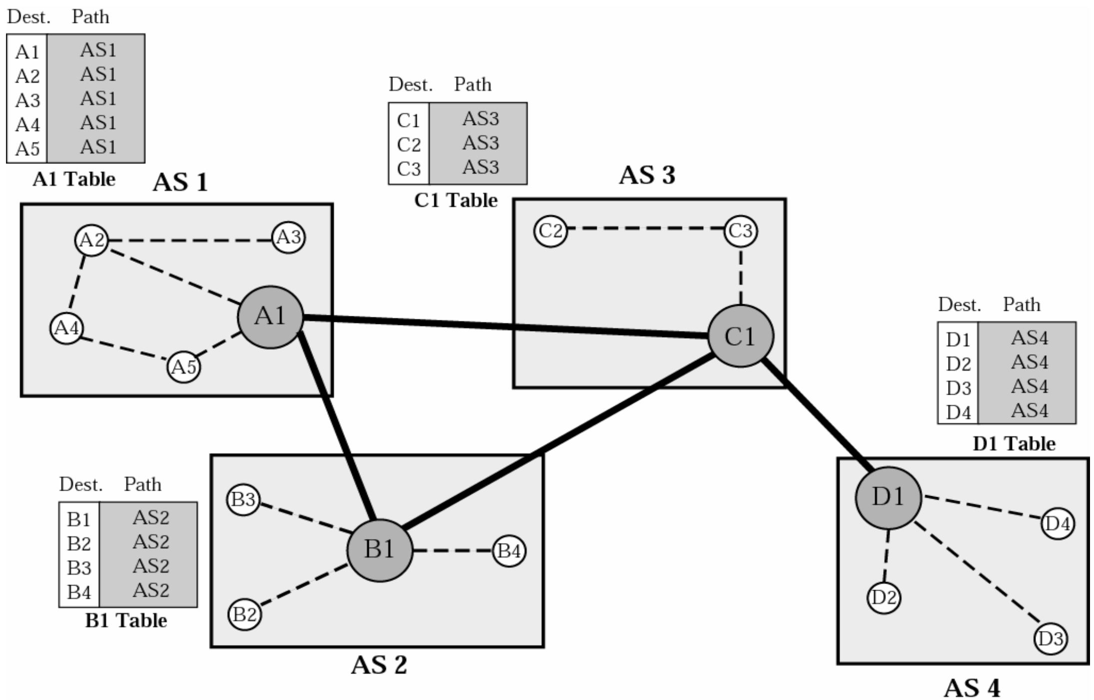


Flexible Policies

- Each node can apply local policies
  - Path selection: Which path to use?
  - Path export: Which paths to advertise?
- Examples
  - Node 2 may prefer the path “2, 3, 1” over “2, 1”
  - Node 1 may not let node 3 hear the path “1, 2”



Path Vector Routing: An example



Dest.	Path
A1	AS1
...	
A5	AS1
B1	AS1-AS2
...	...
B4	AS1-AS2
C1	AS1-AS3
...	...
C3	AS1-AS3
D1	AS1-AS2-AS4
...	...
D4	AS1-AS2-AS4

A1 Table

Dest.	Path
A1	AS2-AS1
...	
A5	AS2-AS1
B1	AS2
...	...
B4	AS2
C1	AS2-AS3
...	...
C3	AS2-AS3
D1	AS2-AS3-AS4
...	...
D4	AS2-AS3-AS4

B1 Table

Dest.	Path
A1	AS3-AS1
...	
A5	AS3-AS1
B1	AS3-AS2
...	...
B4	AS3-AS2
C1	AS3
...	...
C3	AS3
D1	AS3-AS4
...	...
D4	AS3-AS4

C1 Table

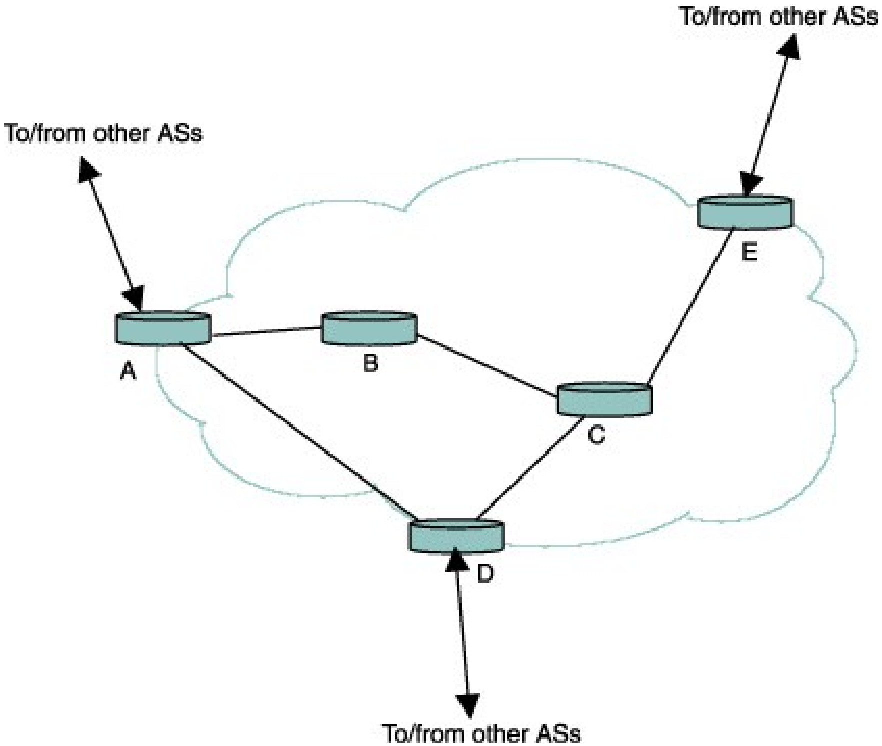
Dest.	Path
A1	AS4-AS3-AS1
...	
A5	AS4-AS3-AS1
B1	AS4-AS3-AS2
...	...
B4	AS4-AS3-AS2
C1	AS4-AS3
...	...
C3	AS4-AS3
D1	AS4
...	...
D4	AS4

D1 Table

BGP: Border Gateway Routing Protocol

- 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.

Joining BGP and IGP



Prefix	BGP Next Hop
18.0/16	E
12.5.5/24	A
128.34/16	D
128.69./16	A

BGP Table for the AS

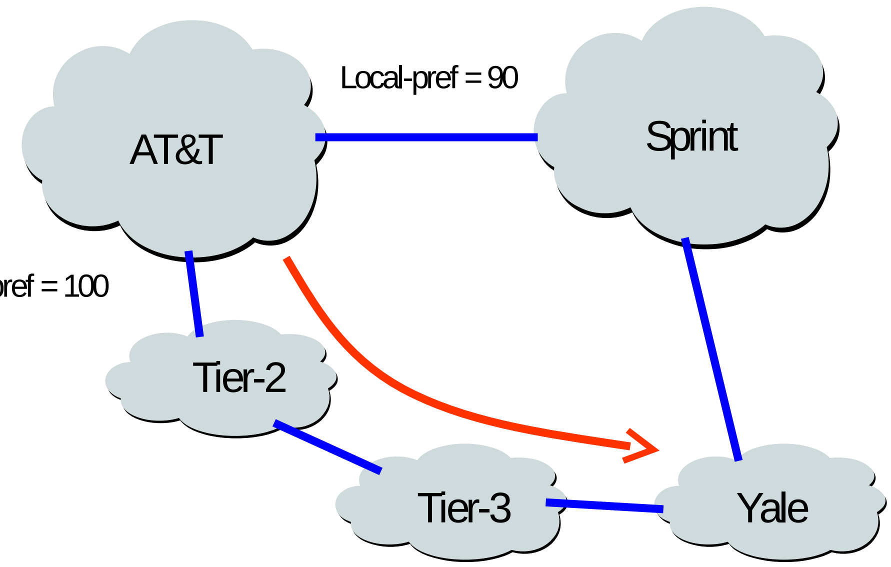
Router	IGP Path
A	A
C	C
D	C
E	C

IGP Table for Router B

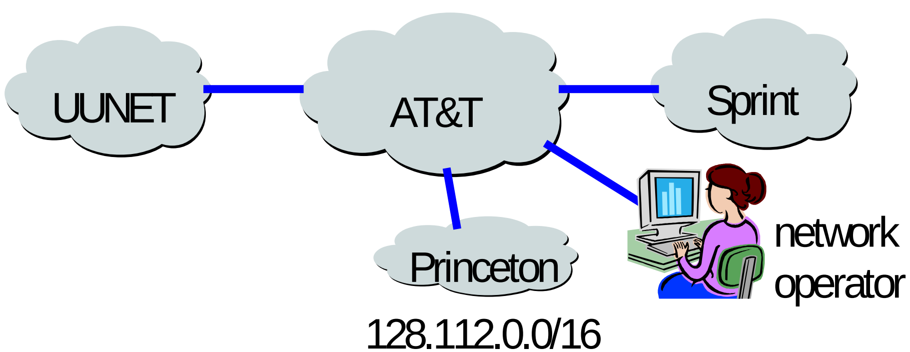
Prefix	IGP Path
18.0/16	C
12.5.5/24	A
128.34/16	C
128.69./16	A

Combined Table for Router B

BGP Policy: Influencing decisions

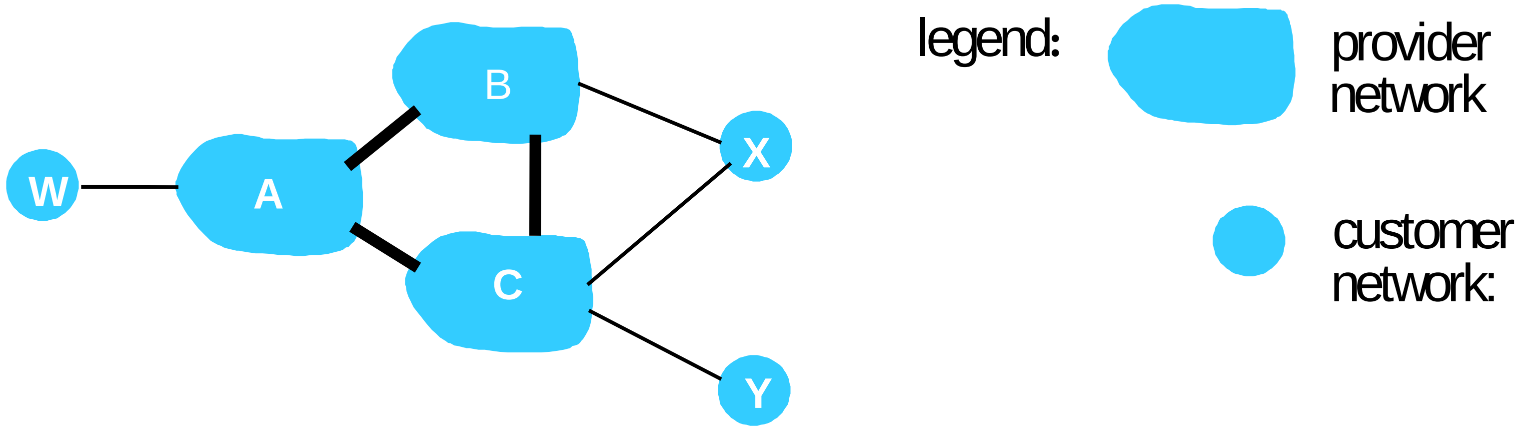


Import Policy: Local preference (Example: prefer customer over peer)



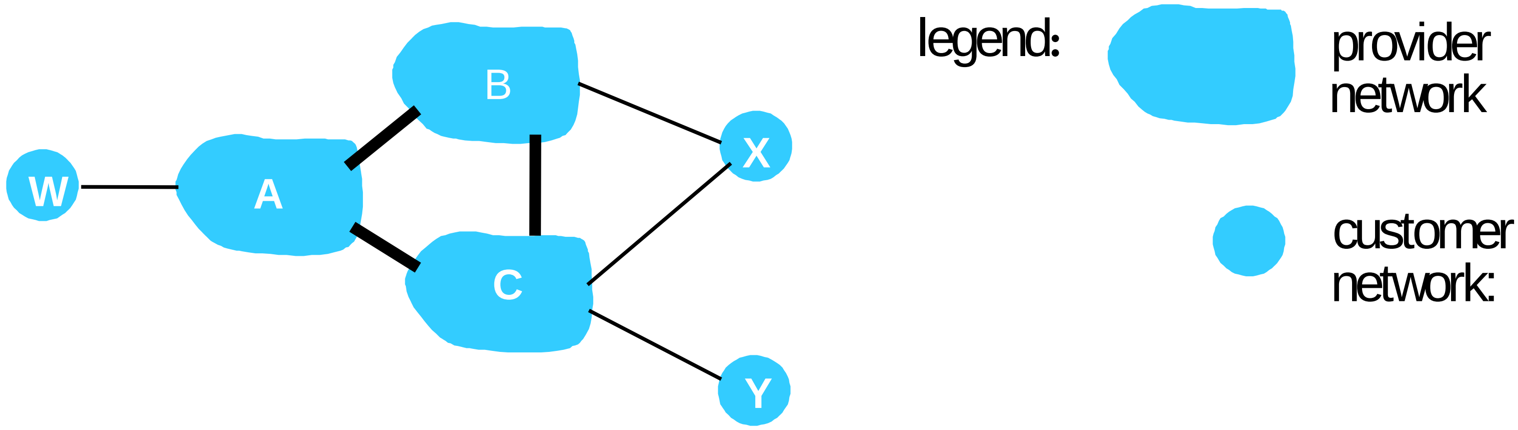
Export Policy: Filtering

BGP routing policy Example



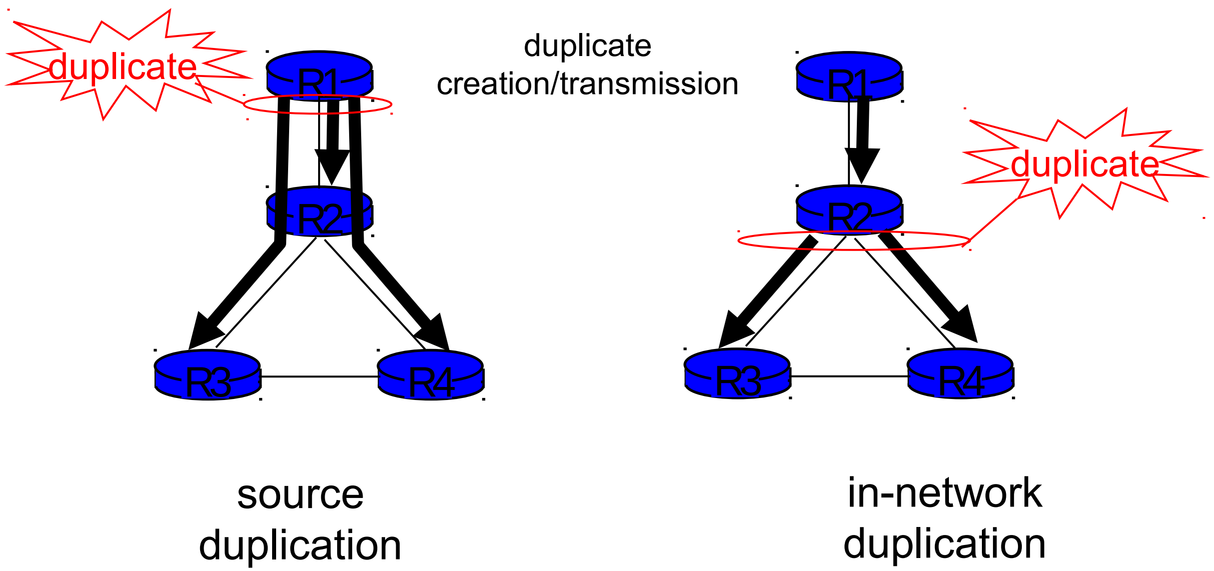
- A,B,C are provider networks
- X,W,Y are customer (of provider networks)
- X is dual-homed: attached to two networks
  - X does not want to route from B via X to C
  - .. so X will not advertise to B a route to C

Continued...



- A advertises path AW to B
- B advertises path BAW to X
- Should B advertise path BAW to C?
  - No way! B gets no “revenue” for routing CBAW since neither W nor C are B’s customers
  - B wants to force C to route to w via A
  - B wants to route *only* to/from its customers

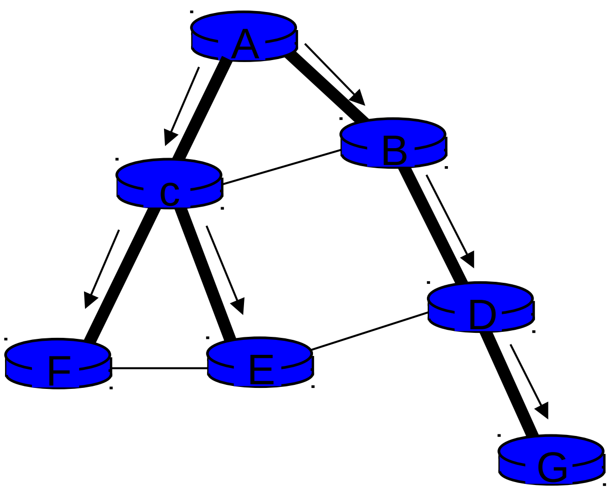
Broadcast Routing



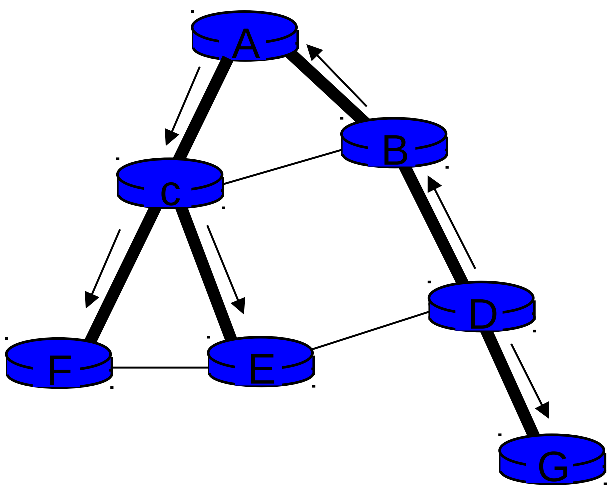
- source duplication: how does source determine recipient addresses?

Spanning Tree

- First construct a spanning tree
- Nodes forward copies only along spanning tree



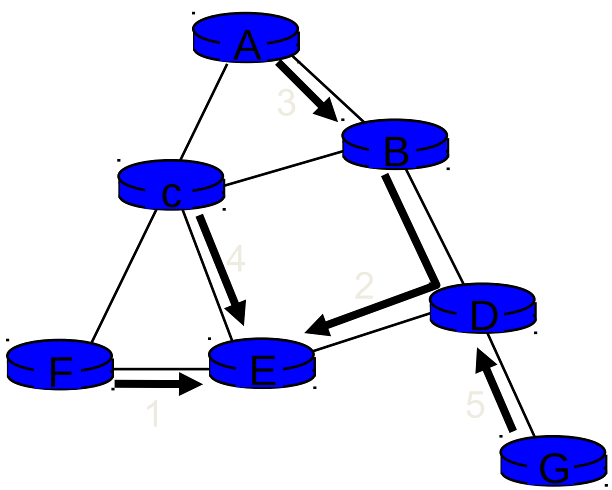
(a) Broadcast initiated at A



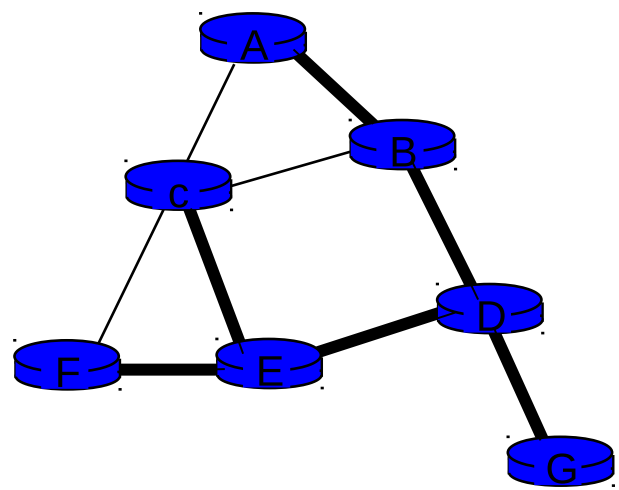
(b) Broadcast initiated at D

Spanning Tree: Creation

- Center node
- Each node sends unicast join message to center node
  - Message forwarded until it arrives at a node already belonging to spanning tree

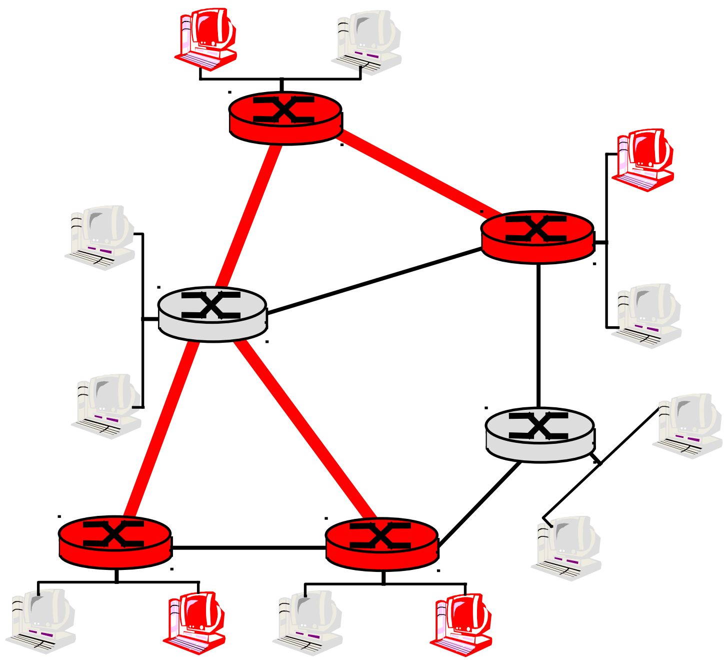


(a) Stepwise construction of spanning tree

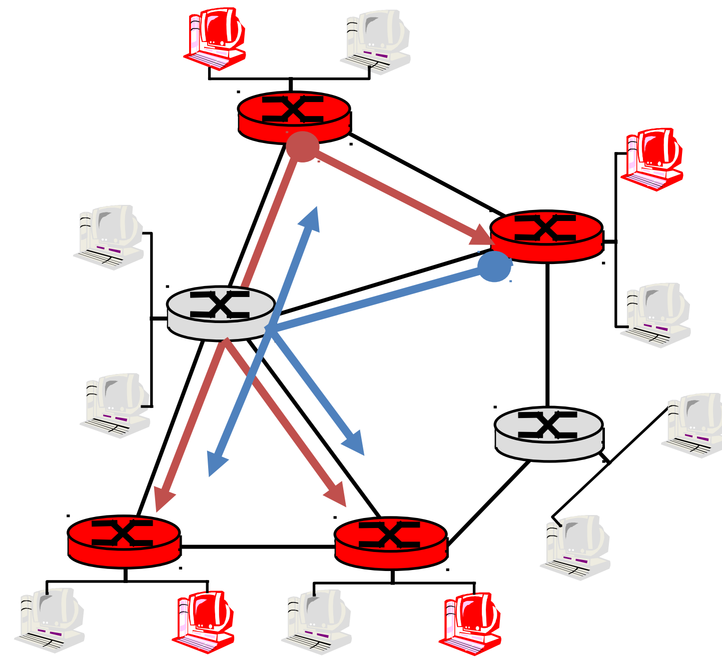


(b) Constructed spanning tree

Multicast Routing: Problem Statement



Shared tree



Source-based trees

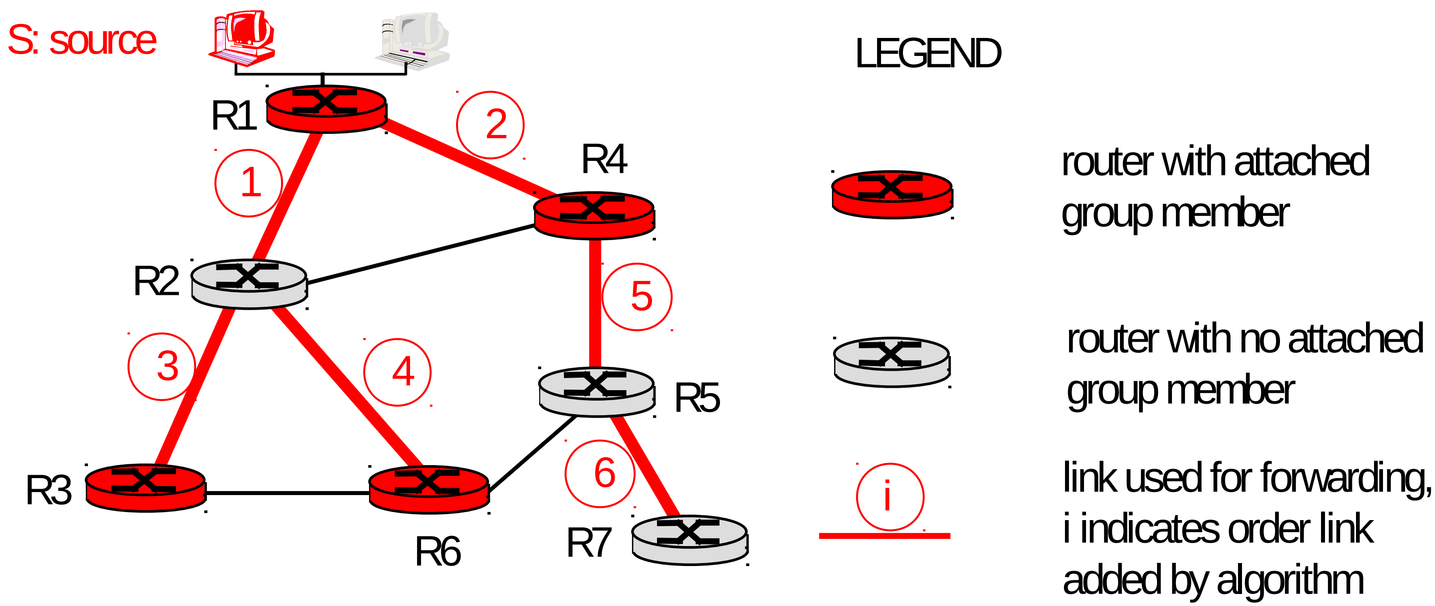
Approaches for building mcast trees

Approaches:

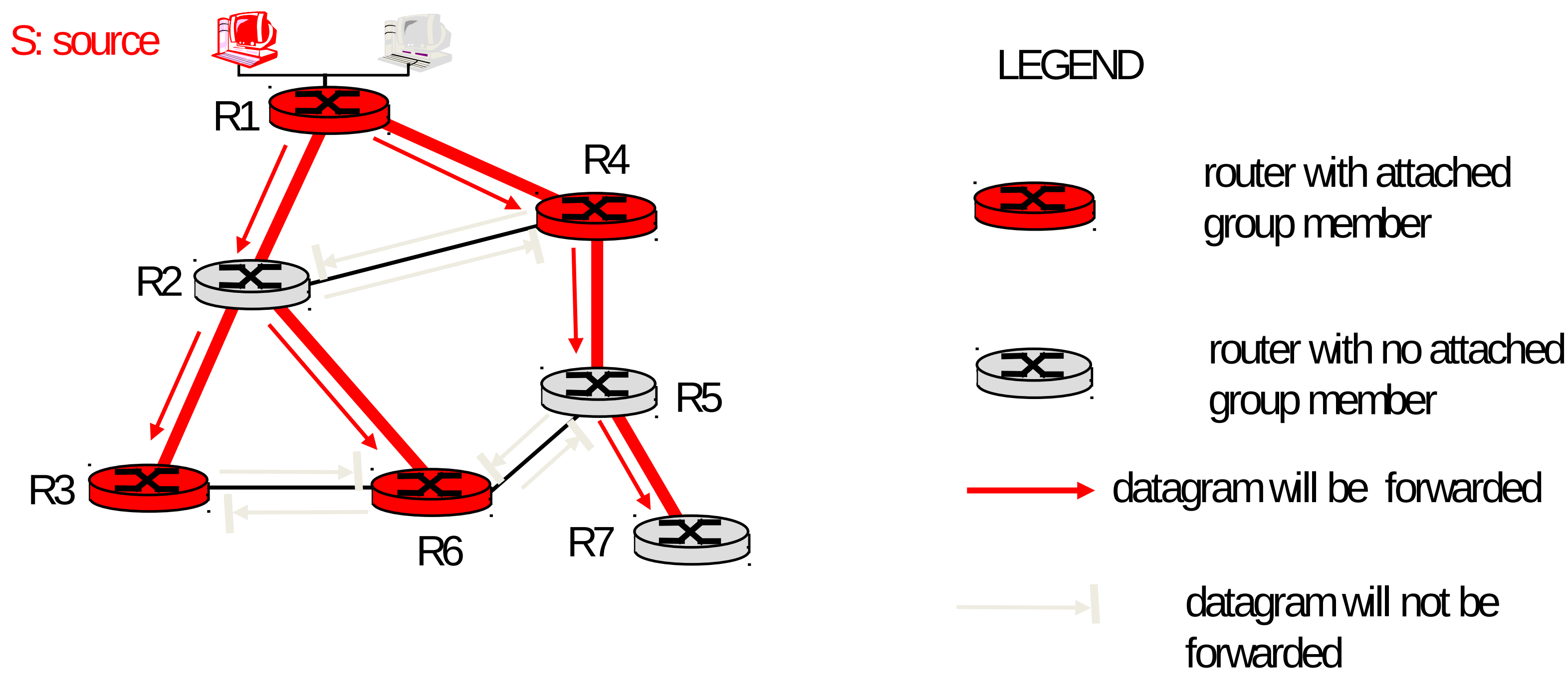
- source-based tree: one tree per source
  - shortest path trees
  - reverse path forwarding
- group-shared tree: group uses one tree
  - minimal spanning (Steiner)
  - center-based trees

Shortest Path Tree

- mcast forwarding tree: tree of shortest path routes from source to all receivers
  - Dijkstra's algorithm



Reverse Path Forwarding: example



- result is a source-specific *reverse* SPT
  - may be a bad choice with asymmetric links

Reverse Path Forwarding: pruning