Introduction to Computer Networks

COSC 4377

Lecture 14

Spring 2012

March 7, 2012

Announcements

- HW6 due this week
- HW7 due 3/21

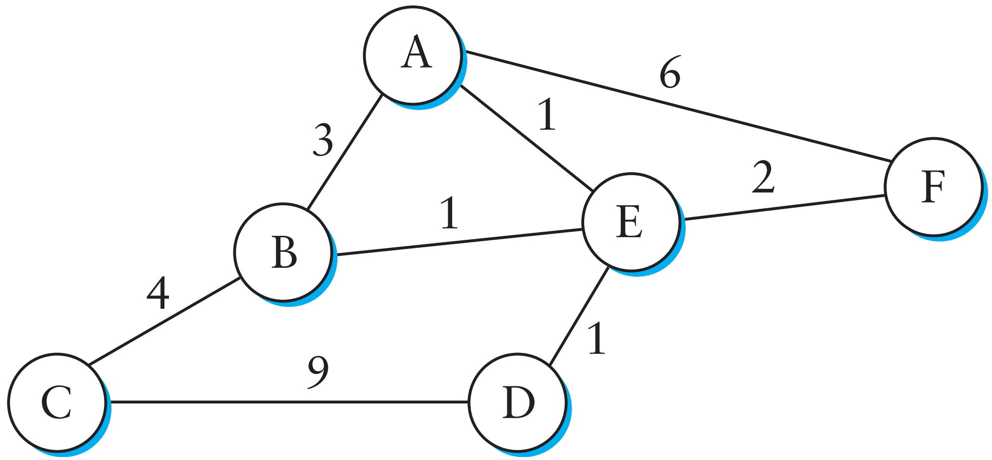
HW7 Preview

- RIP (Routing Information Protocol)
- Components
  - Forwarding
  - Routing
- Driver, libraries, etc. provided so the focus is on networking code
- Port assignments

Today's Topics

- Distance Vector Routing
- Link State Routing
- Inter-AS Routing

Network as a graph



- Nodes are routers
- Assign *cost* to each edge
  - Can be based on latency, b/w, queue length, …
- Problem: find lowest-cost path between nodes
  - Each node individually computes routes

Basic Algorithms

- Two classes of intra-domain routing algorithms
- Distance Vector
  - Requires only local state
  - Harder to debug
  - Can suffer from loops
- Link State
  - Each node has global view of the network
  - Simpler to debug
  - Requires global state

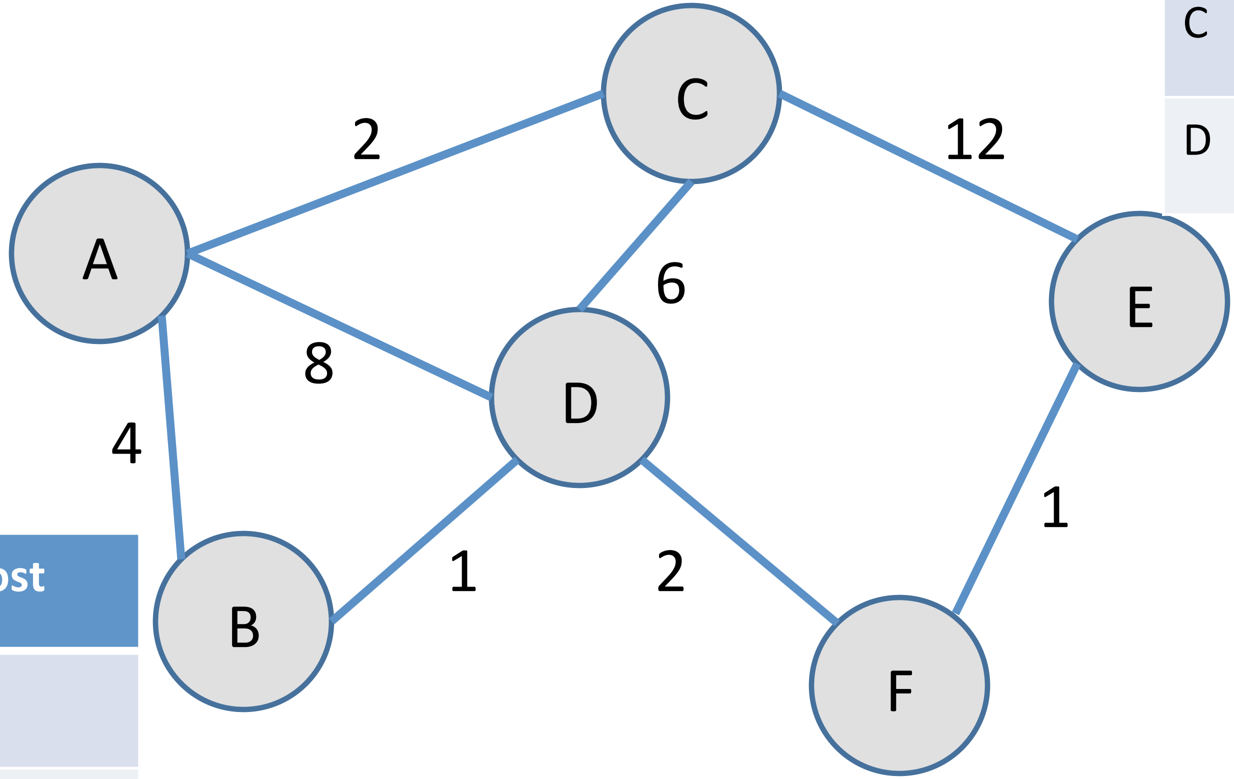
Distance Vector

- Local routing algorithm
- Each node maintains a set of triples
  - <*Destination, Cost, NextHop*>
- Exchange updates with neighbors
  - Periodically (seconds to minutes)
  - Whenever table changes (*triggered* update)
- Each update is a list of pairs
  - <*Destination, Cost*>
- Update local table if receive a "better" route
  - Smaller cost
- Refresh existing routes, delete if time out

Shortest Path Example

E’s table

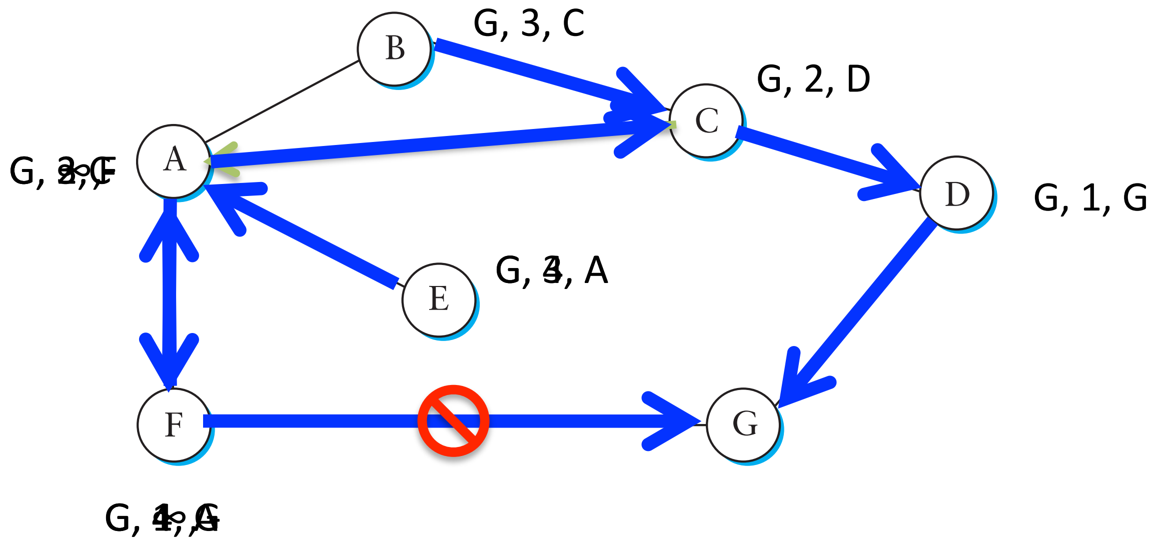
ID	Nextho p
C	F
D	F



B’s table

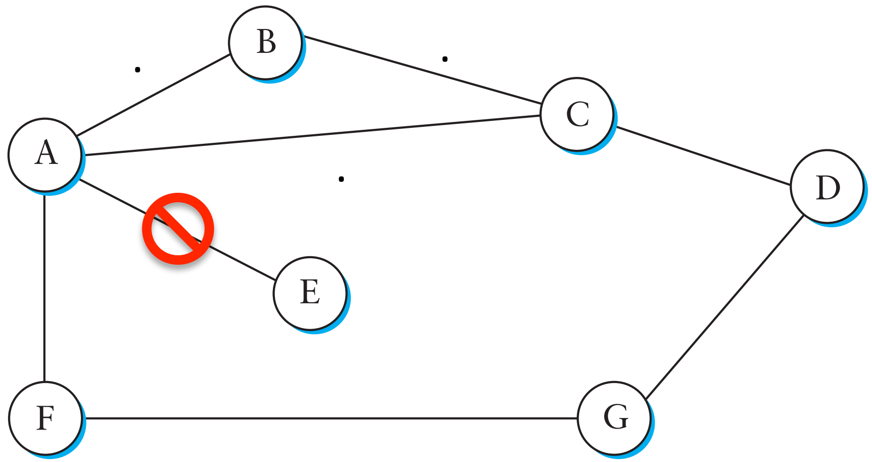
ID	Cost
A	4
D	1

Adapting to Failures



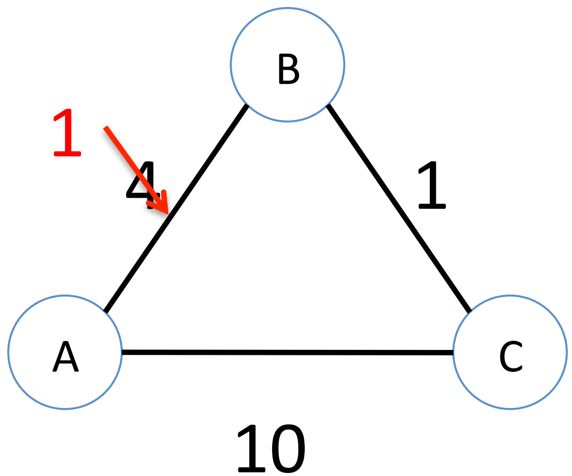
- F-G fails
- F sets distance to G to infinity, propagates
- A sets distance to G to infinity
- A receives periodic update from C with 2-hop path to G
- A sets distance to G to 3 and propagates
- F sets distance to G to 4, through A

Count-to-Infinity



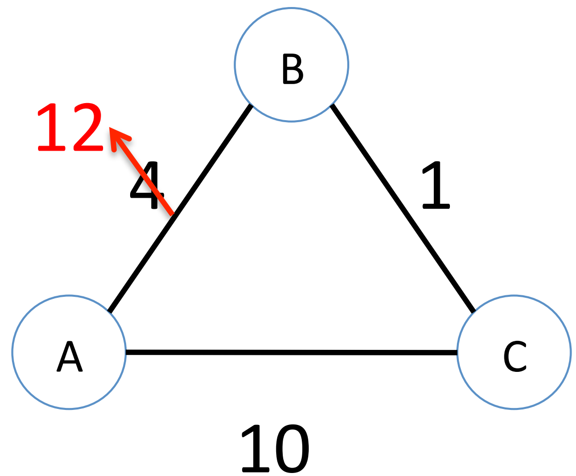
- Link from A to E fails
- A advertises distance of infinity to E
- B and C advertise a distance of 2 to E
- B decides it can reach E in 3 hops through C
- A decides it can reach E in 4 hops through B
- C decides it can reach E in 5 hops through A, …
- When does this stop?

Good news travels fast



- A decrease in link cost has to be fresh information
- Network converges at most in O(diameter) steps

Bad news travels slowly



- An increase in cost may cause confusion with old information
- May form loops

How to avoid loops

- IP TTL field prevents a packet from living forever
  - Does not *repair* a loop
- Simple approach: consider a small cost *n* (e.g., 16) to be infinity
  - After *n* rounds decide node is unavailable
  - But rounds can be long, this takes time

Better loop avoidance

- Split Horizon
  - When sending updates to node A, don't include routes you learned from A
  - Prevents B and C from sending cost 2 to A
- Split Horizon with Poison Reverse
  - Rather than not advertising routes learned from A, explicitly include cost of ∞.
  - Faster to break out of loops, but increases advertisement sizes

Warning

- Split horizon/split horizon with poison reverse only help between two nodes
  - Can still get loop with three nodes involved
  - Might need to delay advertising routes after changes, but affects convergence time

Link State Routing

- Strategy
  - send to all nodes information about directly connected neighbors
- Link State Packet (LSP)
  - ID of the node that created the LSP
  - Cost of link to each directly connected neighbor
  - Sequence number (SEQNO)
  - TTL

Reliable Flooding

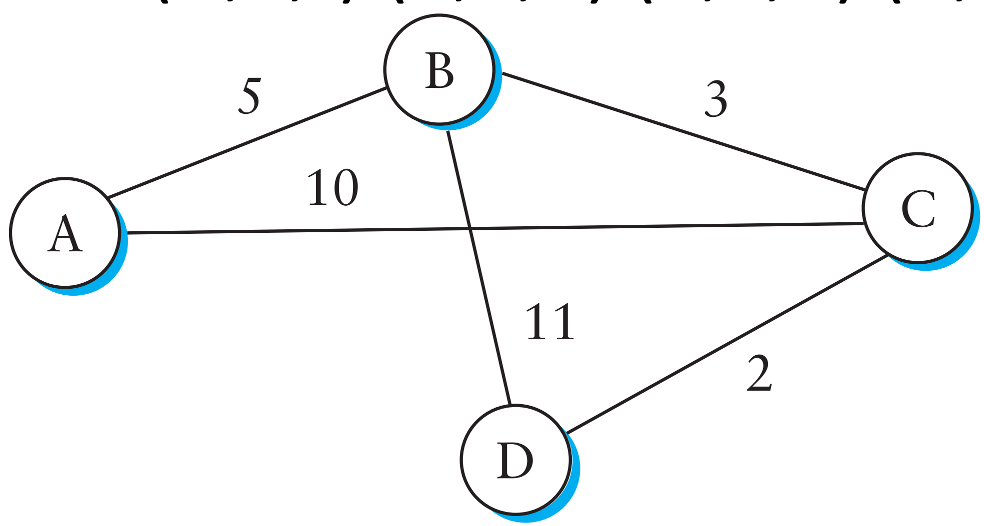
- Store most recent LSP from each node
  - Ignore earlier versions of the same LSP
- Forward LSP to all nodes but the one that sent it
- Generate new LSP periodically
  - Increment SEQNO
- Start at SEQNO=0 when reboot
  - If you hear your own packet with SEQNO=n, set your next SEQNO to n+1
- Decrement TTL of each stored LSP
  - Discard when TTL=0

Calculating best path

- Djikstra's single-source shortest path algorithm
  - Each node computes shortest paths from itself
- Let:
  - N denote set of nodes in the graph
  - l(i,j) denote the non-negative link between i,j
    - ∞ if there is no direct link between i and j
  - C(n) denote the cost of path from s to n
  - s denotes yourself (node computing paths)
- Initialize variables
  - M = {s} (set of nodes incorporated thus far)
  - For each n in N-{s}, C(n) = l(s,n)
  - R(n) = n if l(s,n) < ∞, – otherwise

Djikstra’s Algorithm

- While N≠M
  - Let w ∈(N-M) be the node with lowest C(w)
  - M = M ∪ {w}
  - Foreach n ∈ (N-M), if C(w) + l(w,n) < C(n)
  - then C(n) = C(w) + l(w,n), R(n) = R(w)
- Example: D: (D,0,-) (C,2,C) (B,5,C) (A,10,C)



Distance Vector vs. Link State

- # of messages (per node)
  - DV: O(d), where d is degree of node
  - LS: O(nd) for n nodes in system
- Computation
  - DV: convergence time varies (e.g., count-to-infinity)
  - LS: $O(n^2)$ with O(nd) messages
- Robustness: what happens with malfunctioning router?
  - DV: Nodes can advertise incorrect *path* cost
  - DV: Others can use the cost, propagates through network
  - LS: Nodes can advertise incorrect *link* cost

Examples

- RIPv2
  - Fairly simple implementation of DV
  - RFC 2453 (38 pages)
- OSPF (Open Shortest Path First)
  - More complex link-state protocol
  - Adds notion of *areas* for scalability
  - RFC 2328 (244 pages)

RIPv2

- Runs on UDP port 520
- Link cost = 1
- Periodic updates every 30s, plus triggered updates
- Relies on count-to-infinity to resolve loops
  - Maximum diameter 15 (∞ = 16)
  - Supports split horizon, poison reverse

Packet format

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  command (1)  |  version (1)  |       must be zero (2)        |
+---------------+---------------+-------------------------------+
|                                                               |
~                         RIP Entry (20)                        ~
|                                                               |
+---------------+---------------+---------------+---------------+
```

RIPv2 Entry

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| address family identifier (2) |       Route Tag (2)           |
+-------------------------------+-------------------------------+
|                        IP address (4)                         |
+---------------------------------------------------------------+
|                        Subnet Mask (4)                        |
+---------------------------------------------------------------+
|                        Next Hop (4)                           |
+---------------------------------------------------------------+
|                        Metric (4)                             |
+---------------------------------------------------------------+
```

Next Hop field

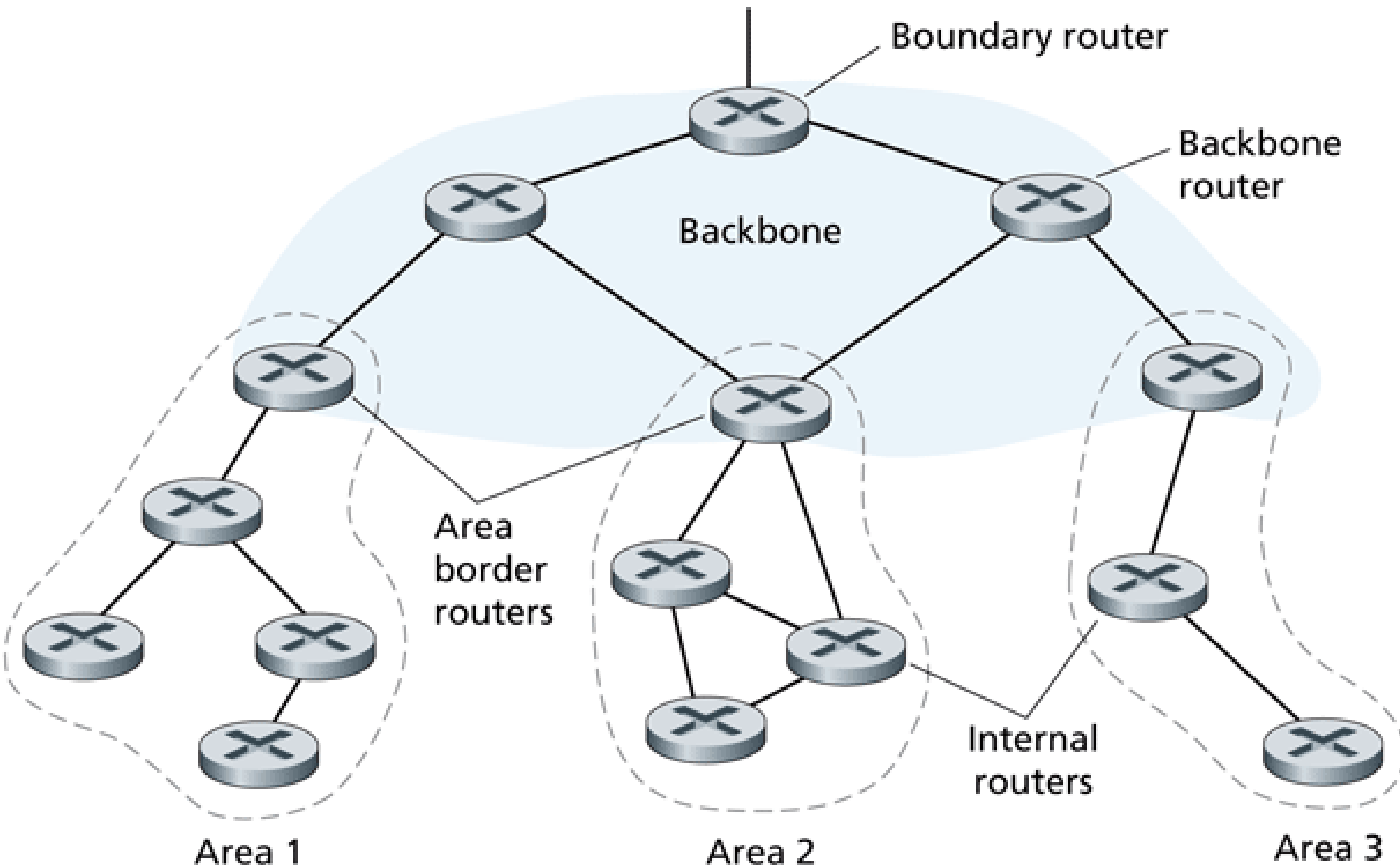
- Allows one router to advertise routes for multiple routers on the same subnet
- Suppose only XR1 talks RIPv2:

```
-----   -----   -----           -----   -----   -----
|IR1|   |IR2|   |IR3|           |XR1|   |XR2|   |XR3|
--+--   --+--   --+--           --+--   --+--   --+--
  |       |       |               |       |       |
--+-------+-------+---------------+-------+-------+--
  <-------------RIP-2------------->
```

OSPFv2

- Link state protocol
- Runs directly over IP (protocol 89)
  - Has to provide its own reliability
- All exchanges are authenticated
- Adds notion of *areas* for scalability

OSPF Areas


Boundary router
Backbone
router
Backbone
Area
border
routers
Internal
routers
Area 1
Area 2
Area 3

Inter-domain Routing

Why Inter vs. Intra

- Why not just use OSPF everywhere?
  - E.g., hierarchies of OSPF areas?
  - Hint: scaling is not the only limitation
- BGP is a policy control and information hiding protocol
  - intra == trusted, inter == untrusted
  - Different policies by different ASs
  - Different costs by different ASs