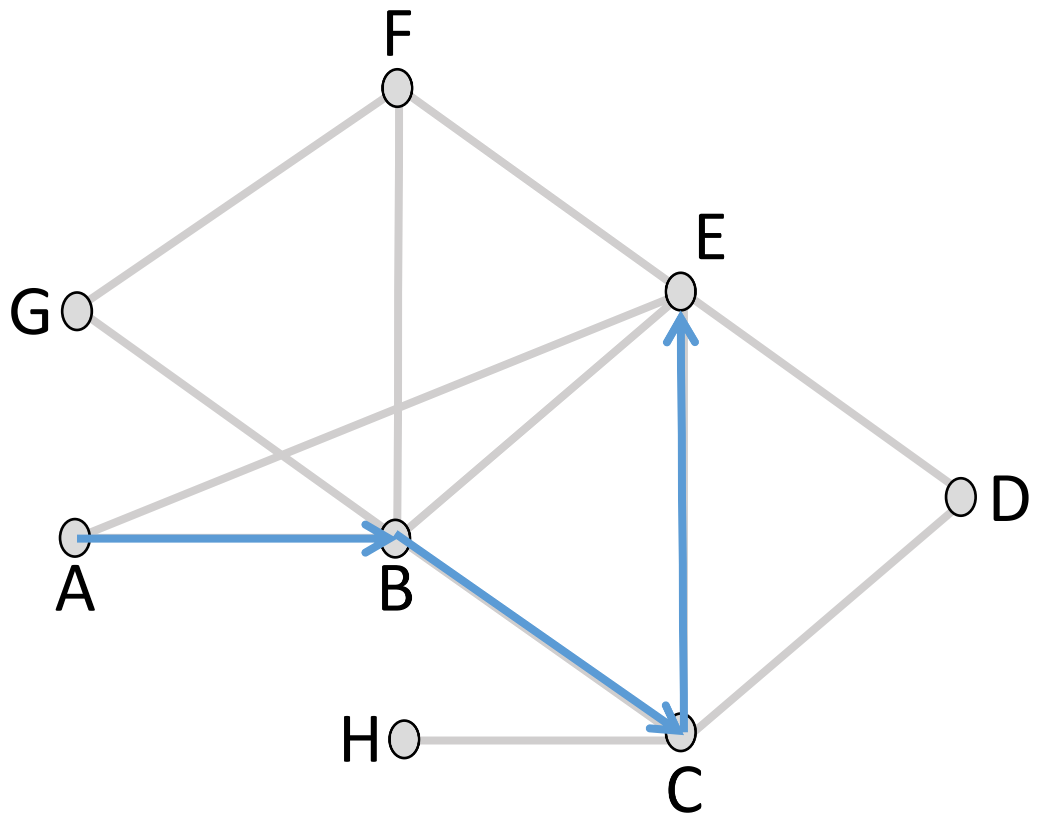
Finding “Best” Paths

What are "Best" paths anyhow?

- Many possibilities:
  - Latency, avoid circuitous paths
  - Bandwidth, avoid slow links
  - Money, avoid expensive links
  - Hops, to reduce switching

- But only consider topology
  - Ignore workload, e.g., hotspots



Shortest Paths

We'll approximate "best" by a cost function that captures the factors

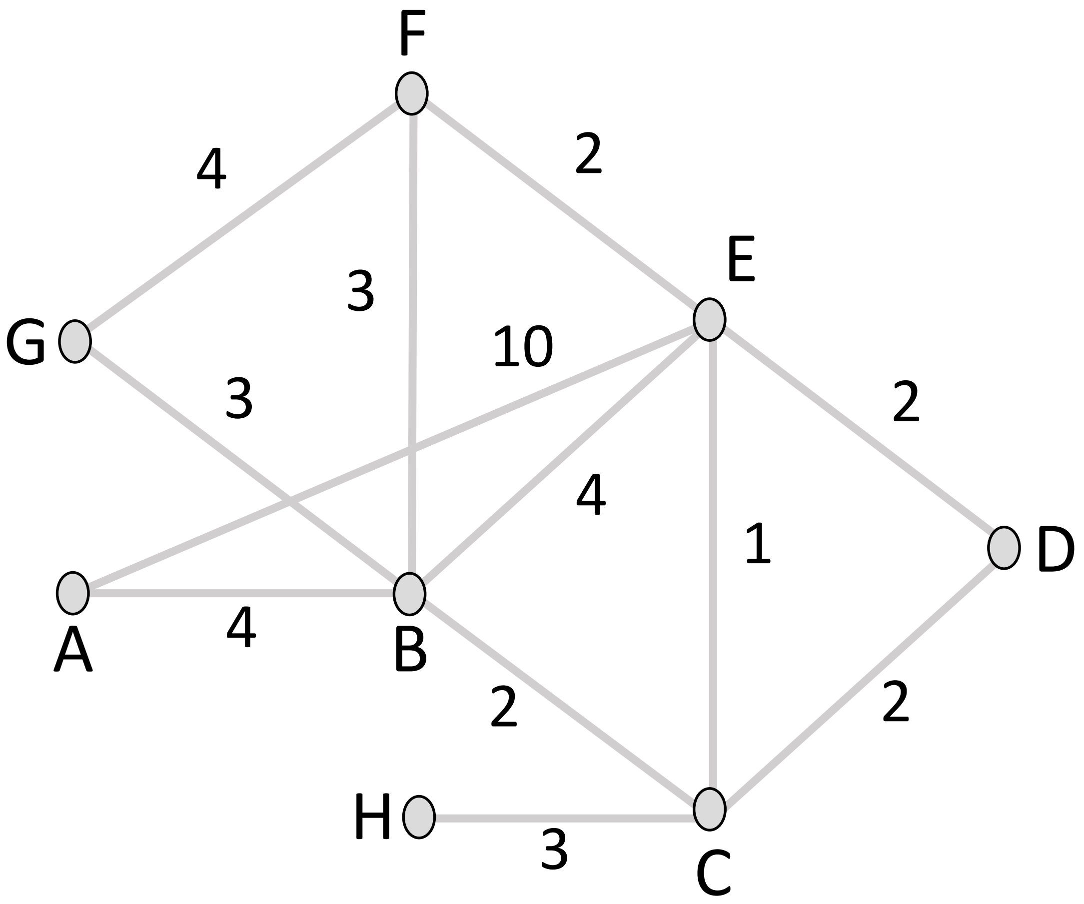
- Often called "least cost" or "shortest"

1. Assign each link a cost (distance)
2. Define best path between each pair of nodes as the path that has the least total cost
3. Pick randomly to any break ties

Shortest Paths (2)

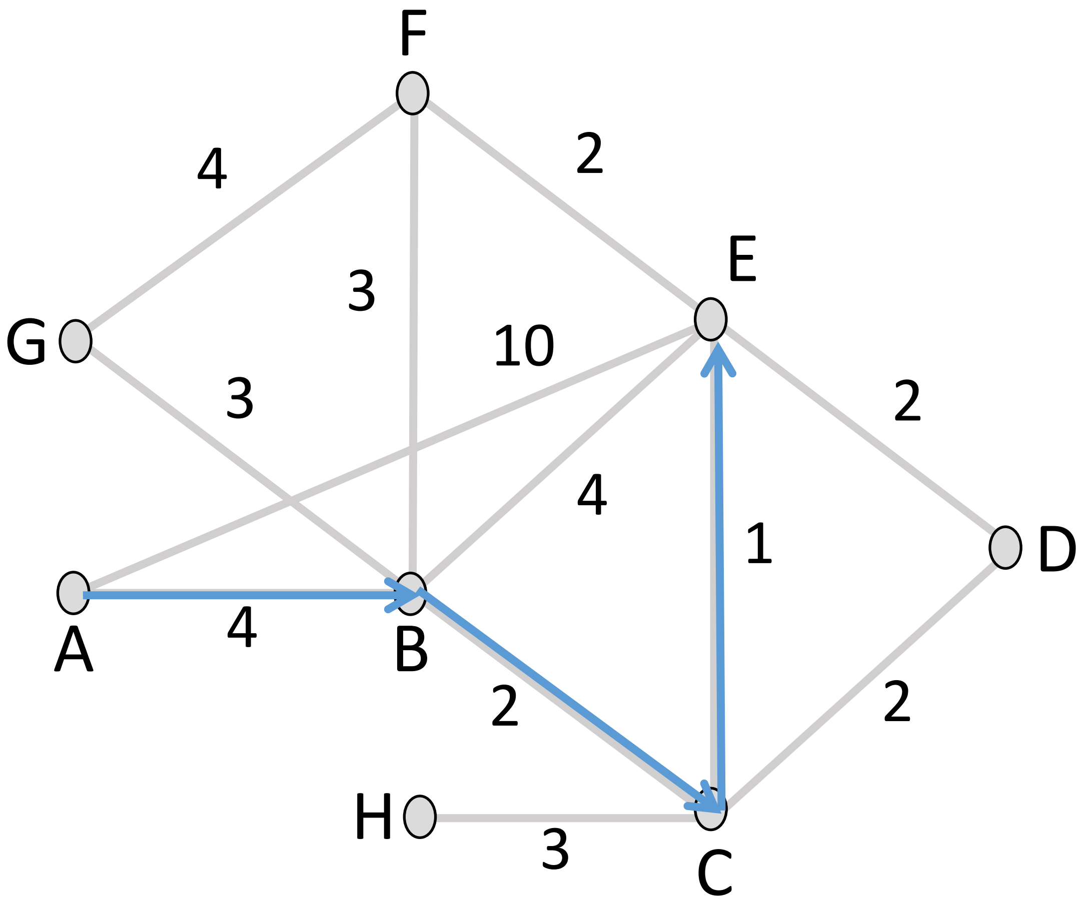
- Find the shortest path A → E

- All links are bidirectional, with equal costs in each direction
  - Can extend model to unequal costs if needed



Shortest Paths (3)

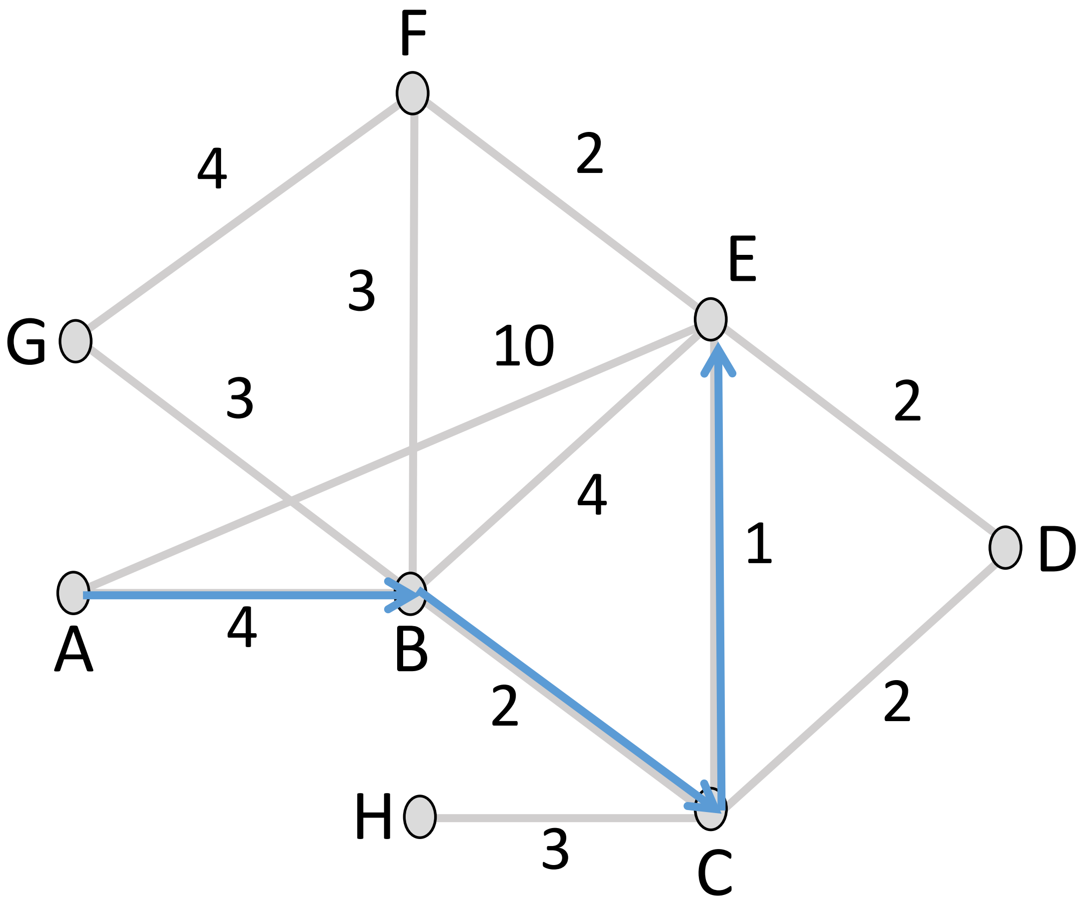
- ABCE is a shortest path
  - cost(ABCE) = 4 + 2 + 1 = 7
- It is shorter than:
  - cost(ABE) = 8
  - cost(ABFE) = 9
  - cost(AE) = 10
  - cost(ABCDE) = 10



Shortest Paths (4)

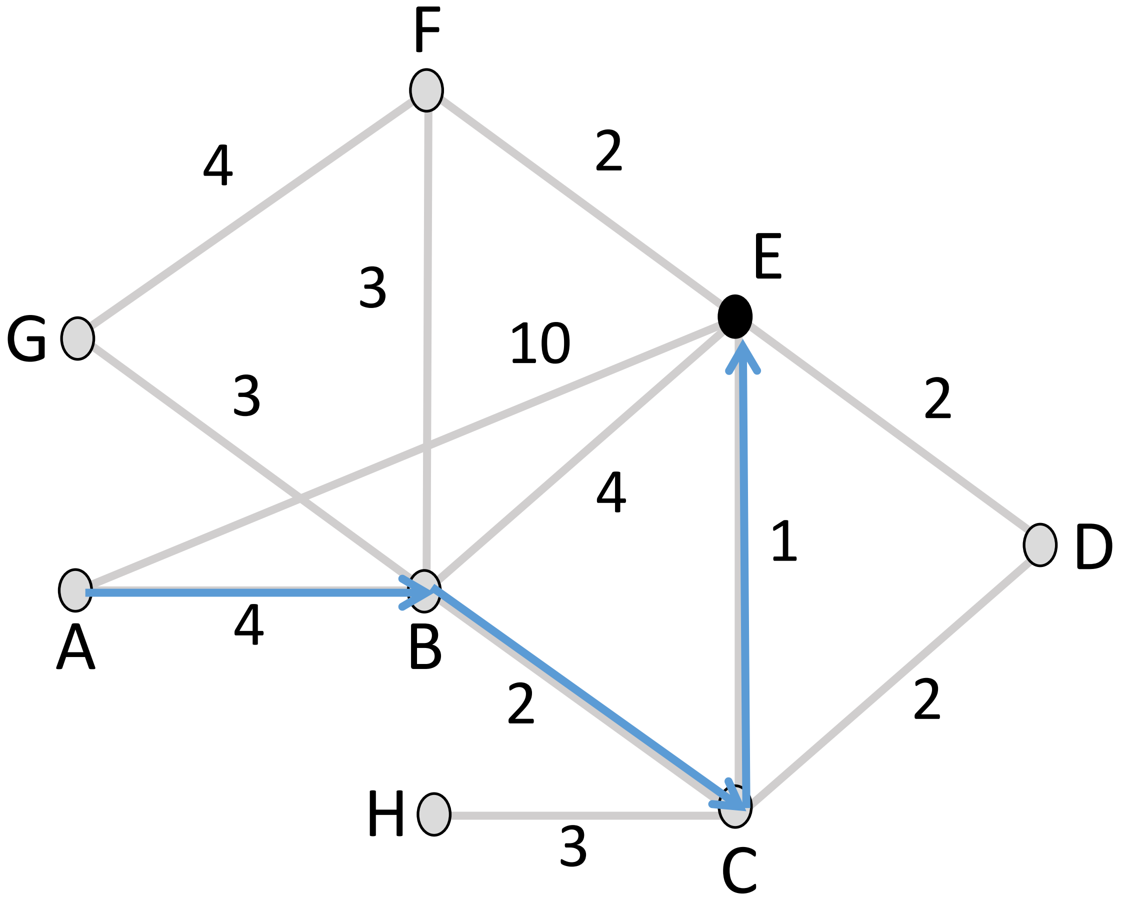
- Optimality property:
  - Subpaths of shortest paths are also shortest paths
- ABCE is a shortest path

  →So are ABC, AB, BCE, BC, CE



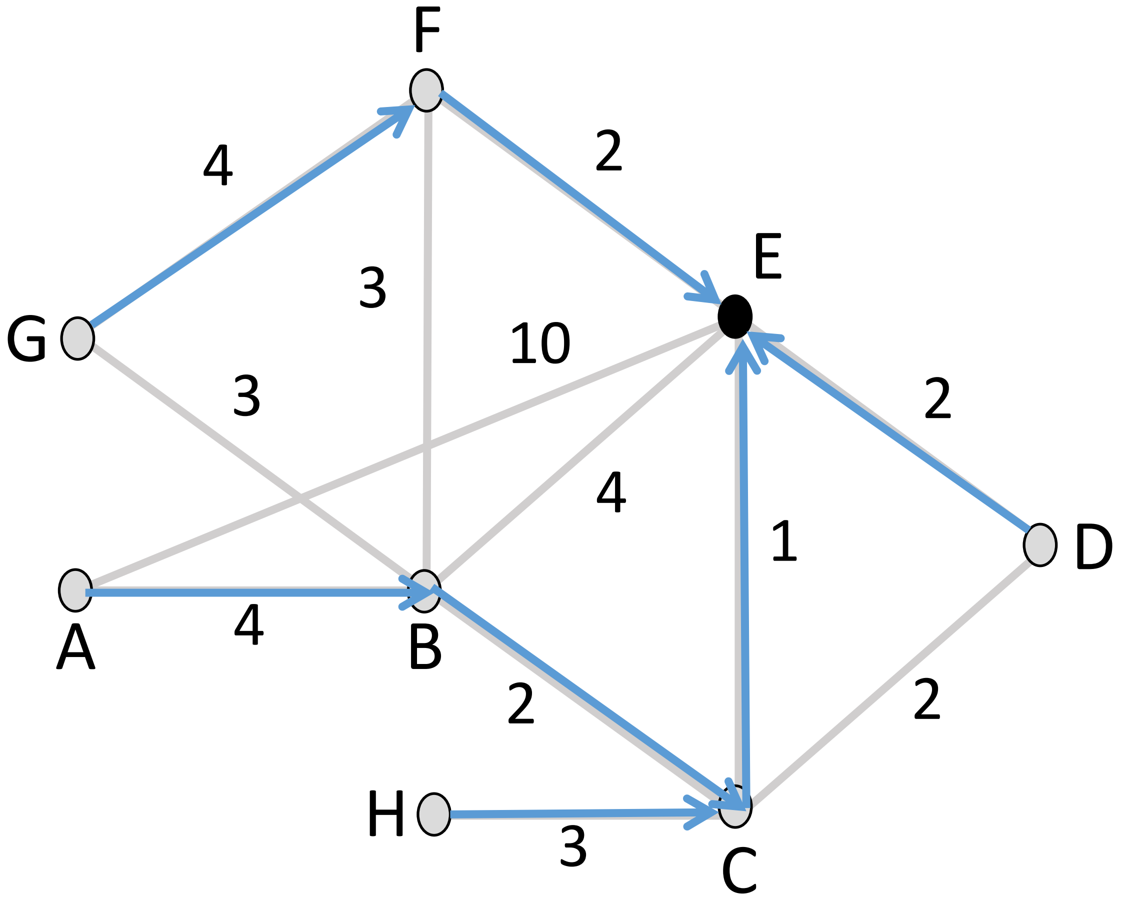
Sink Trees

- Sink tree for a destination is the union of all shortest paths towards the destination
  - Similarly source tree
- Find the sink tree for E



Sink Trees (2)

- Implications:
  - Only need to use destination to follow shortest paths
  - Each node only need to send to the next hop
- Forwarding table at a node
  - Lists next hop for each destination
  - Routing table may know more



Routing recap

Routing goal: Find shortest or least cost paths

Shortest paths have the subset optimality property

Today: Computing shortest paths in a fully distributed manner

Distance Vector Routing

Distance Vector Routing

- Simple, early routing approach
  - Used in ARPANET, and RIP
- One of two main approaches to routing
  - Distributed version of Bellman-Ford
  - Works, but very slow convergence after some failures
- Link-state algorithms are now typically used in practice
  - More involved, better behavior

Distance Vector Setting

Each node computes its forwarding table in a distributed setting:

1. Nodes know only the cost to their neighbors; not topology
2. Nodes can talk only to their neighbors using messages
3. All nodes run the same algorithm concurrently
4. Nodes and links may fail, messages may be lost

Distance Vector Algorithm

Each node maintains a vector of (distance, next hop) to all destinations

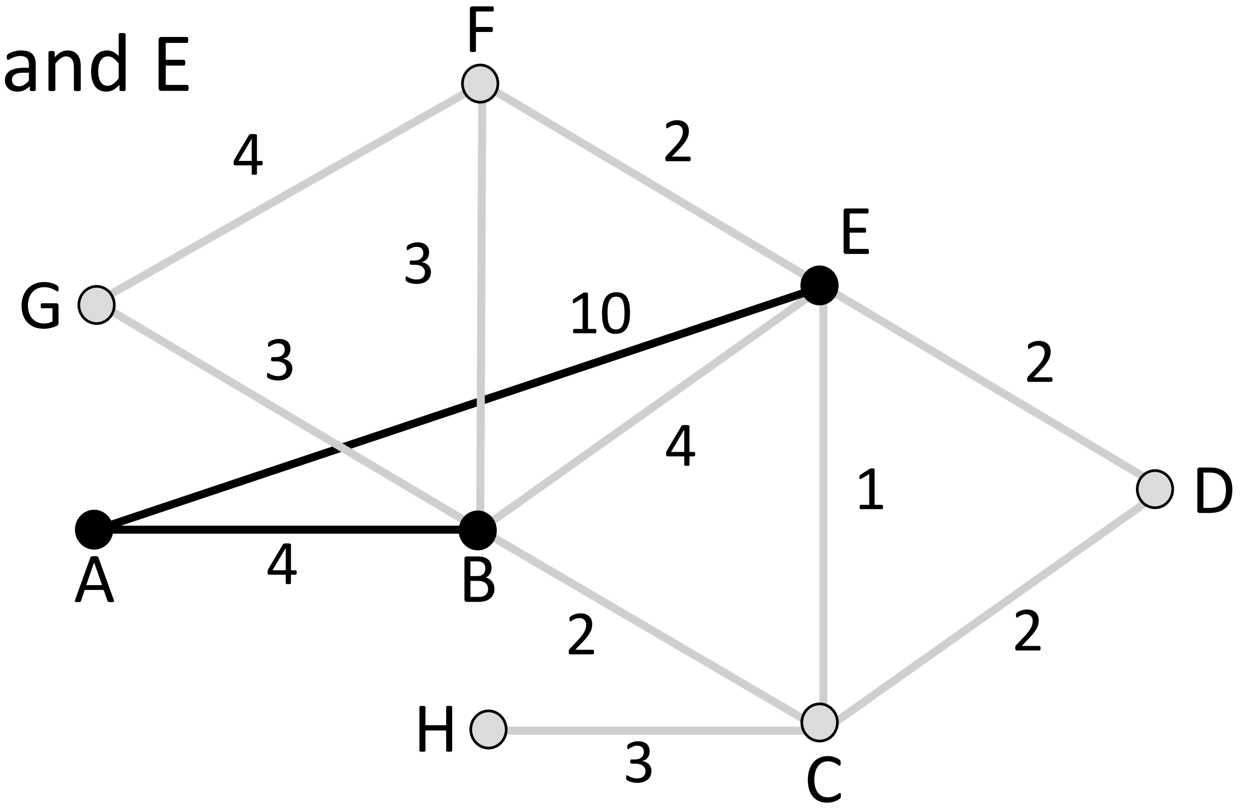
1. Initialize vector with 0 (zero) cost to self, ∞ (infinity) to other destinations
2. Periodically send vector to neighbors
3. Update vector for each destination by selecting the shortest distance heard, after adding cost of neighbor link
4. Use the best neighbor for forwarding

Distance Vector (2)

- Consider from the point of view of node A
  - Can only talk to nodes B and E

Initial vector

To	Cost
A	0
B	∞
C	∞
D	∞
E	∞
F	∞
G	∞
H	∞



Distance Vector (3)

- First exchange with B, E; learn best 1-hop routes

To	B says	E says
A	∞	∞
B	0	∞
C	∞	∞
D	∞	∞
E	∞	0
F	∞	∞
G	∞	∞
H	∞	∞

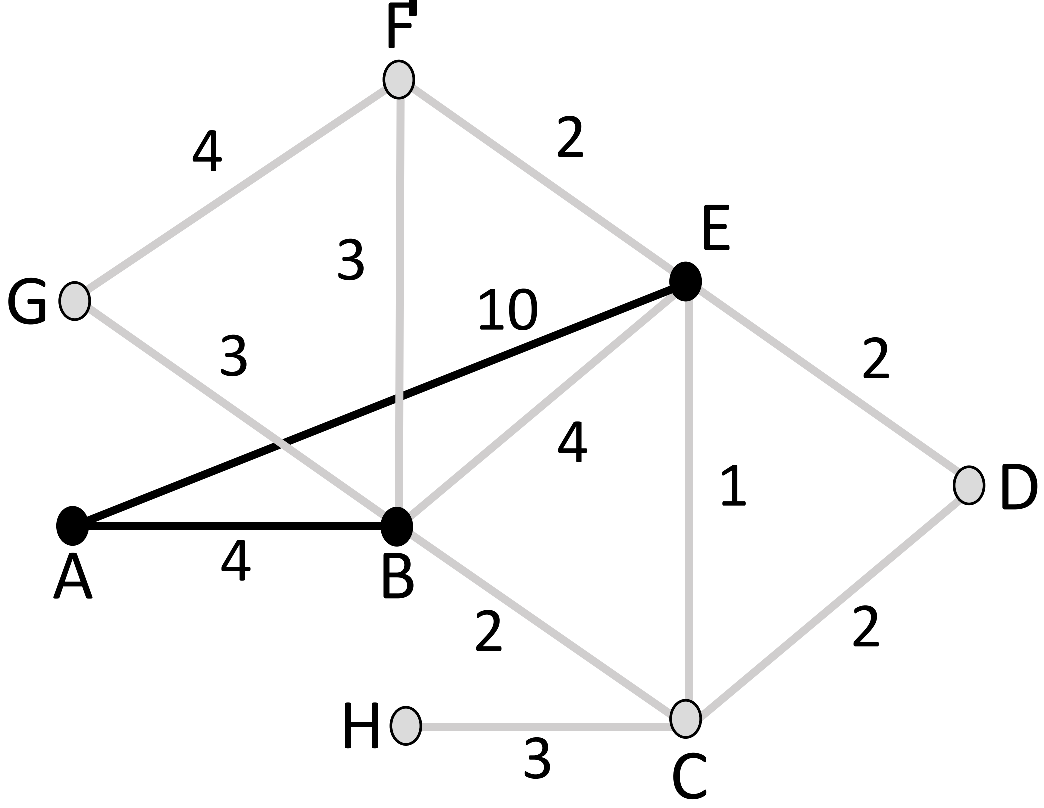
→

B +4	E +10
∞	∞
4	∞
∞	∞
∞	∞
∞	10
∞	∞
∞	∞
∞	∞

→

A's Cost	A's Next
0	--
4	B
∞	--
∞	--
10	E
∞	--
∞	--
∞	--

Learned better route



Distance Vector (4)

- Second exchange; learn best 2-hop routes

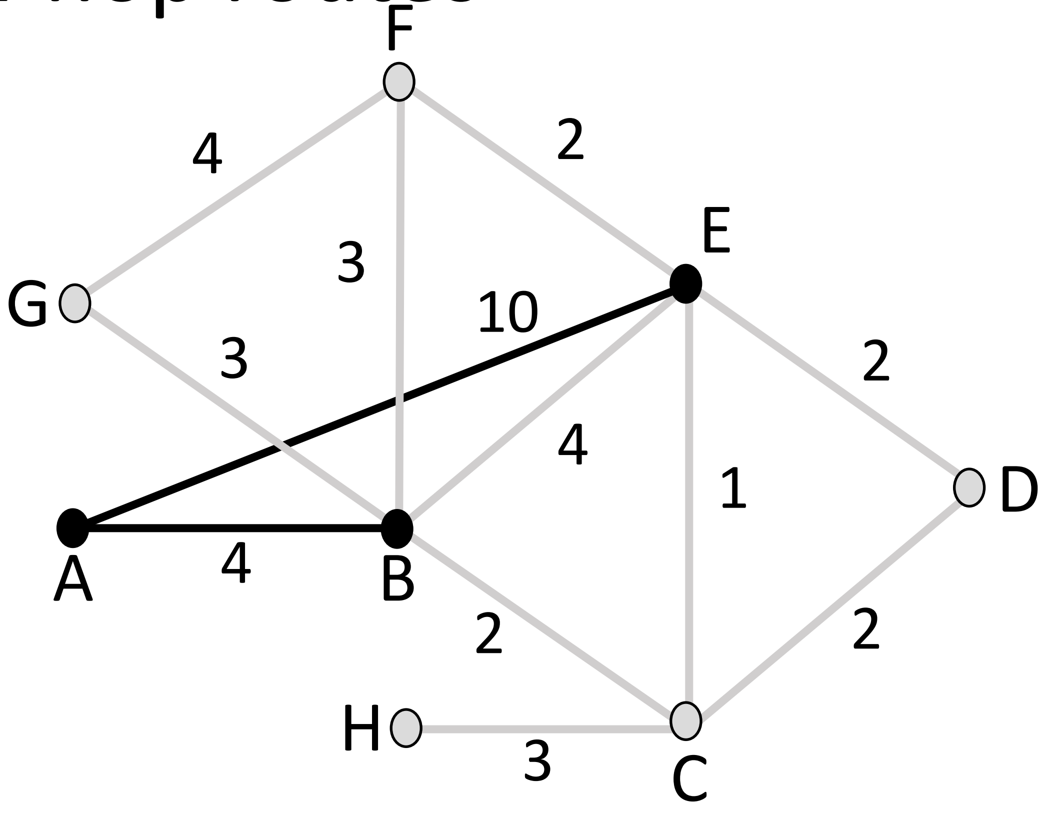
To	B says	E says
A	4	10
B	0	4
C	2	1
D	∞	2
E	4	0
F	3	2
G	3	∞
H	∞	∞

→

B +4	E +10
8	20
4	14
6	11
∞	12
8	10
7	12
7	∞
∞	∞

→

A's Cost	A's Next
0	--
4	B
6	B
12	E
8	B
7	B
7	B
∞	--



Distance Vector (4)

- Third exchange; learn best 3-hop routes

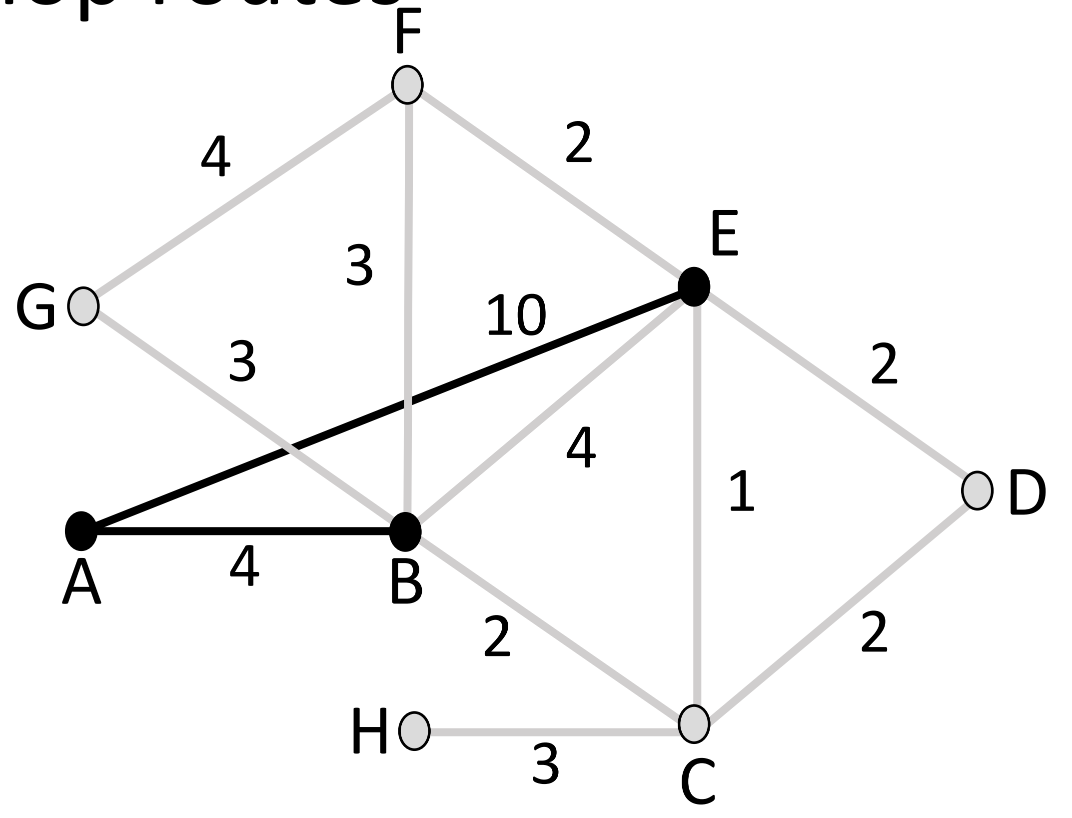
To	B says	E says
A	4	8
B	0	3
C	2	1
D	4	2
E	3	0
F	3	2
G	3	6
H	5	4

→

B +4	E +10
8	18
4	13
6	11
8	12
7	10
7	12
7	16
9	14

→

A's Cost	A's Next
0	--
4	B
6	B
8	B
7	B
7	B
7	B
9	B



Distance Vector (5)

- Subsequent exchanges; converged

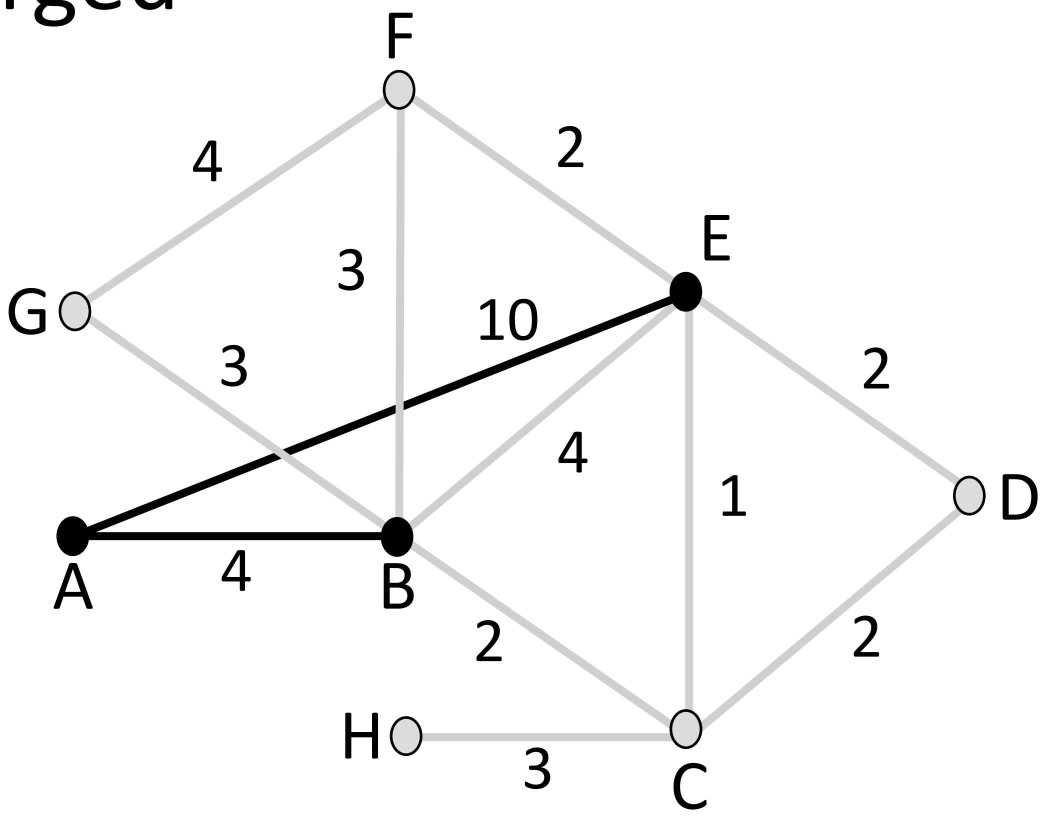
To	B says	E says
A	4	7
B	0	3
C	2	1
D	4	2
E	3	0
F	3	2
G	3	6
H	5	4

→

B +4	E +10
8	17
4	13
6	11
8	12
7	10
7	12
7	16
9	14

→

A's Cost	A's Next
0	--
4	B
6	B
8	B
8	B
7	B
7	B
9	B



Distance Vector Dynamics

- Adding routes:
  - News travels one hop per exchange
- Removing routes:
  - When a node fails, no more exchanges, other nodes forget

Problem?

Count to Infinity: Problem

- Good news travels quickly, bad news slowly

A	B	C	D	E	
	•	•	•	•	Initially
	1	•	•	•	After 1 exchange
	1	2	•	•	After 2 exchanges
	1	2	3	•	After 3 exchanges
	1	2	3	4	After 4 exchanges

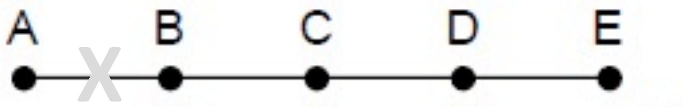
Desired convergence

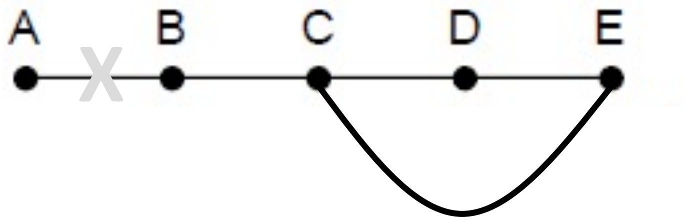
A	X	B	C	D	E	
		1	2	3	4	Initially
		3	2	3	4	After 1 exchange
		3	4	3	4	After 2 exchanges
		5	4	5	4	After 3 exchanges
		5	6	5	6	After 4 exchanges
		7	6	7	6	After 5 exchanges
		7	8	7	8	After 6 exchanges
			⋮			

"Count to infinity" scenario

Count to Infinity: Heuristics

- “Split horizon”
  - Don’t send route back to where you learned it from.
- Poison reverse
  - Send “infinity” when you notice a disconnect





Count to Infinity: Heuristics (2)

- Neither split horizon and poison reverse are very effective in practice
  - Link state is now favored except when resource-limited

RIP (Routing Information Protocol)

- DV protocol with hop count as metric
  - Infinity is 16 hops; limits network size
  - Includes split horizon, poison reverse
- Routers send vectors every 30 seconds
  - Runs on top of UDP
  - Time-out in 180 secs to detect failures
- RIPv1 specified in RFC1058 (1988)

Link-State Routing

Link-State Routing

- Second broad class of routing algorithms
  - More computation than DV but better dynamics
- Widely used in practice
  - Used in Internet/ARPANET from 1979
  - Modern networks use OSPF (L3) and IS-IS (L2)

Link-State Setting

Same distributed setting as for distance vector:

1. Nodes know only the cost to their neighbors; not topology
2. Nodes can talk only to their neighbors using messages
3. All nodes run the same algorithm concurrently
4. Nodes/links may fail, messages may be lost

Link-State Algorithm

Proceeds in two phases:

1. Nodes <u>flood</u> topology with link state packets
    - Each node learns full topology
2. Each node computes its own forwarding table
    - By running Dijkstra (or equivalent)

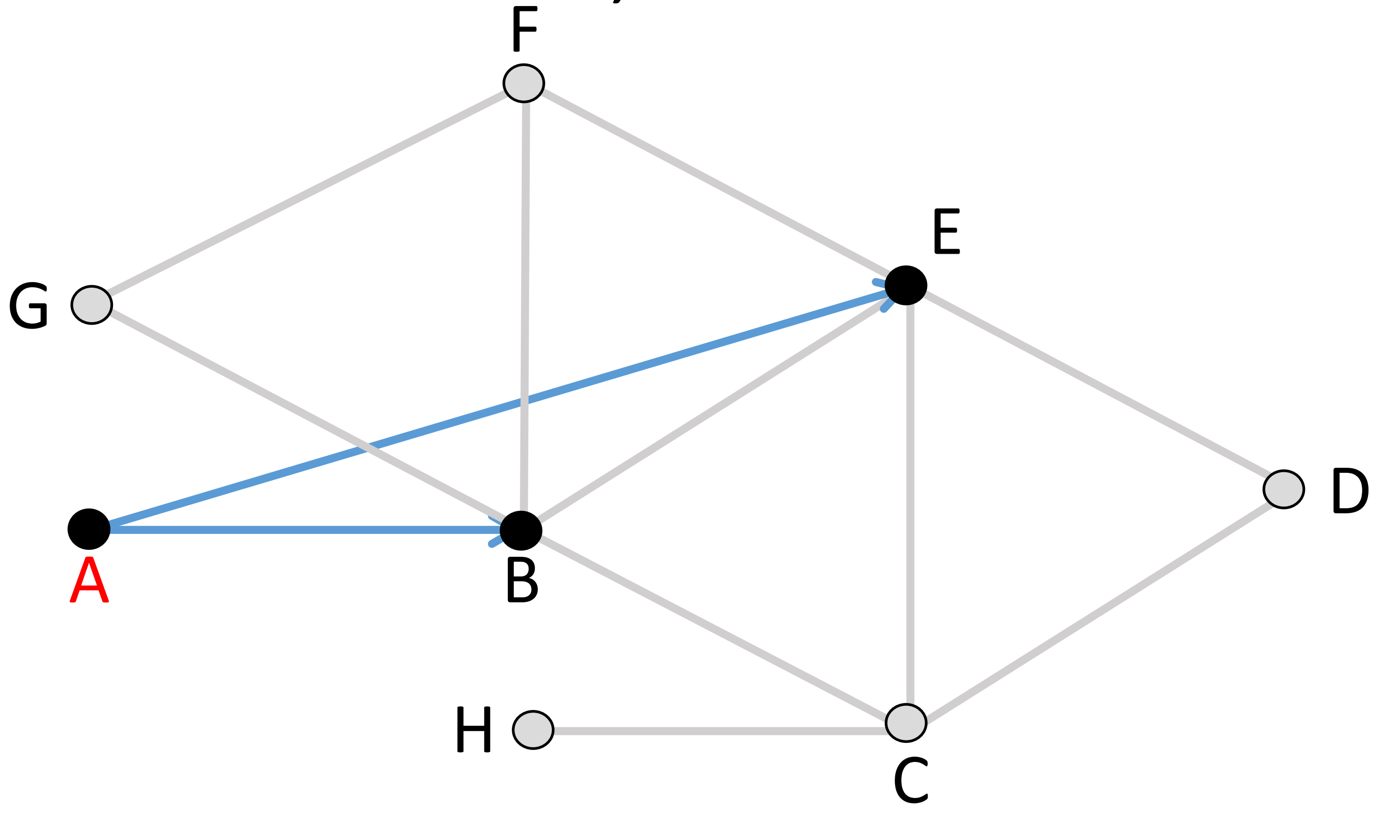
Part 1: Flooding

Flooding

- Rule used at each node:
  - Sends an incoming message on to all other neighbors
  - Remember the message so that it is only flood once

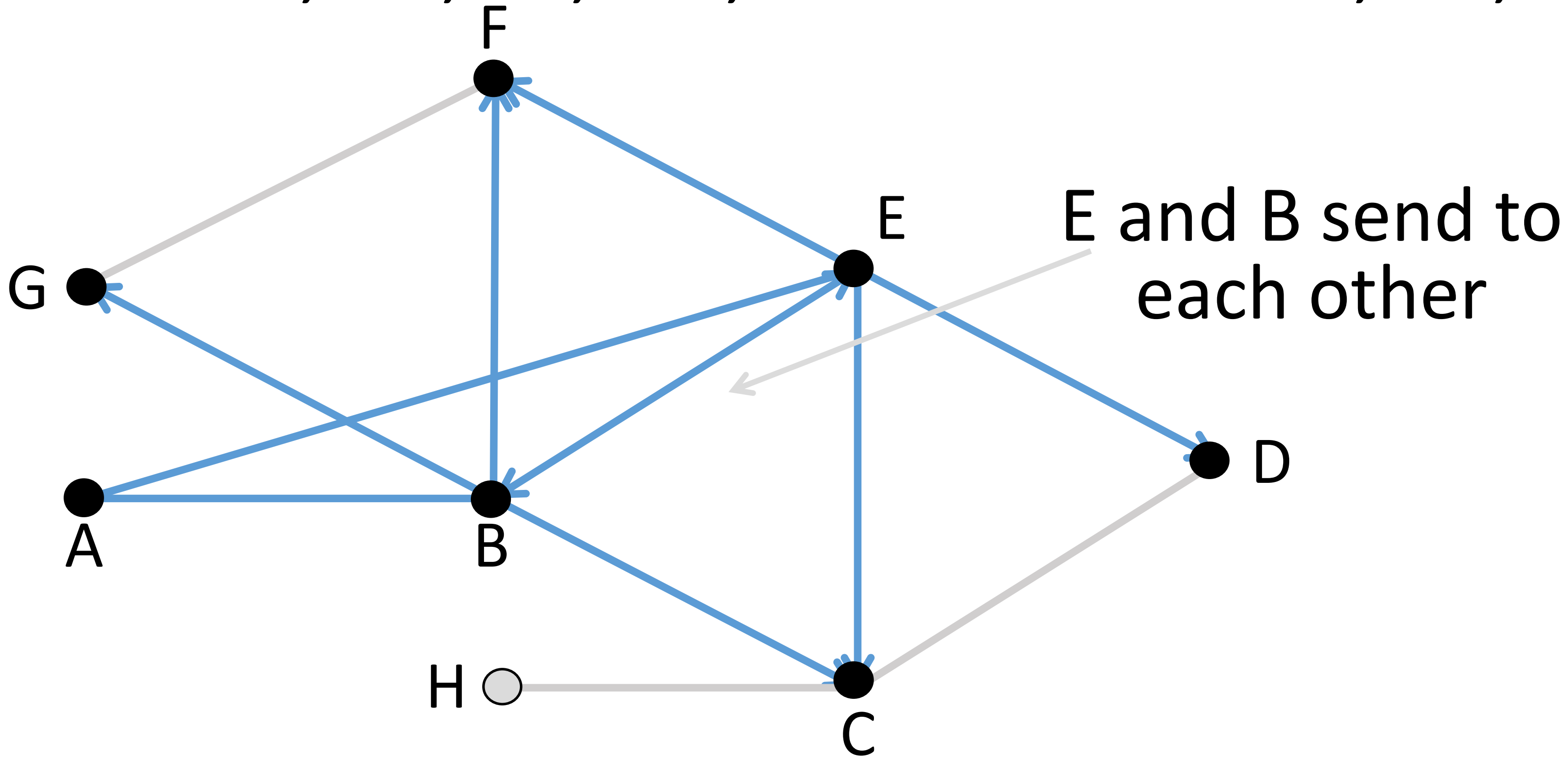
Flooding (2)

- Consider a flood from A; first reaches B via AB, E via AE



Flooding (3)

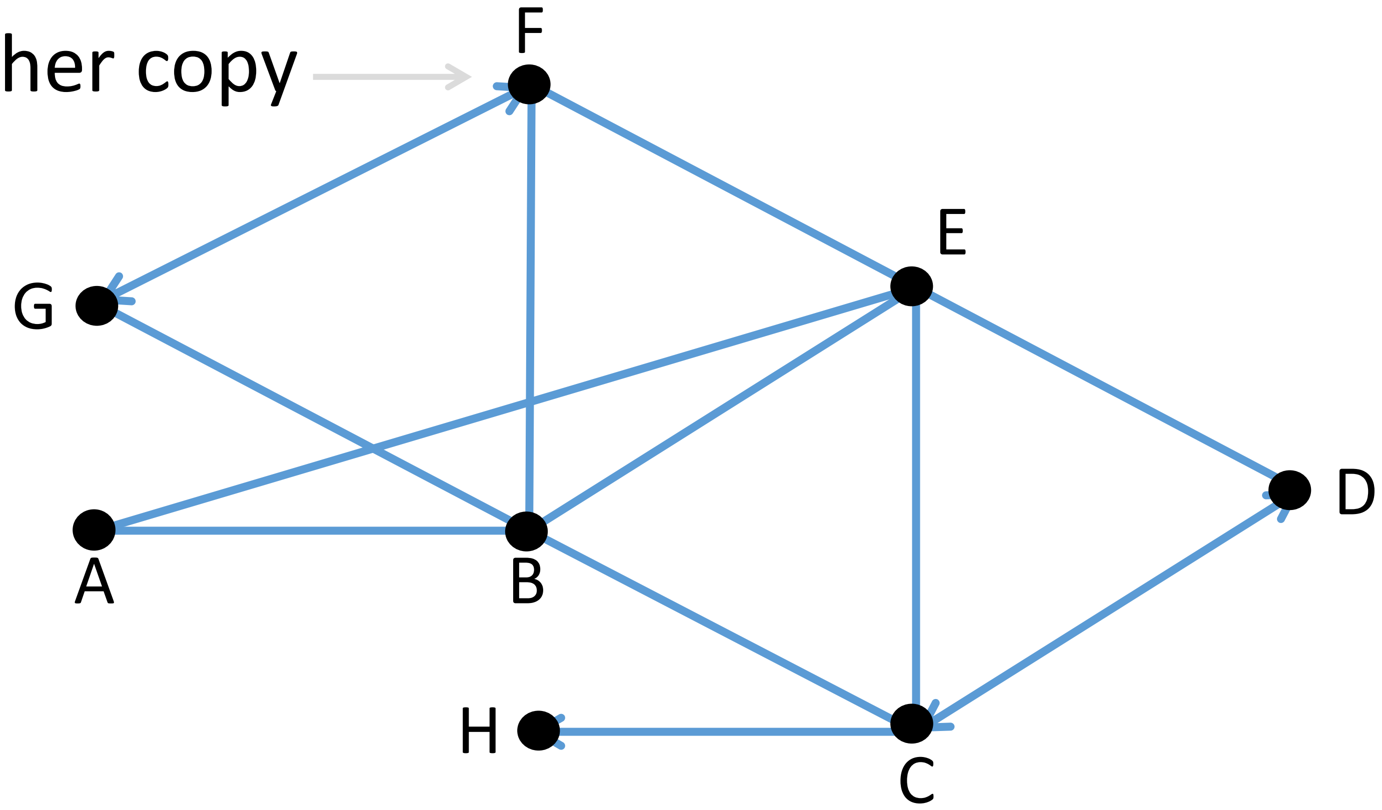
- Next B floods BC, BE, BF, BG, and E floods EB, EC, ED, EF



Flooding (4)

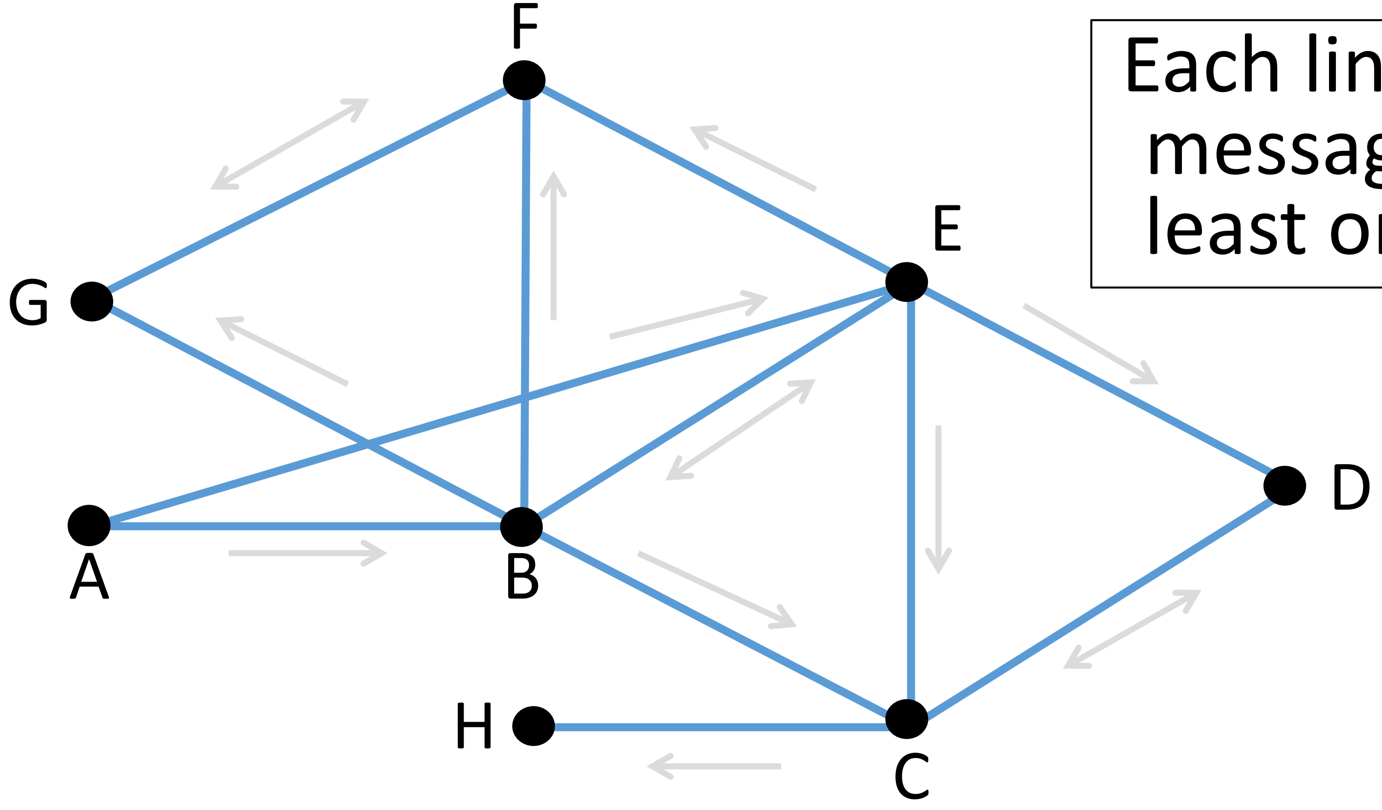
- C floods CD, CH; D floods DC; F floods FG; G floods GF

F gets another copy



Flooding (5)

- H has no-one to flood … and we're done



Each link carries the message, and in at least one direction

Flooding Details

- Remember message (to stop flood) using source and sequence number
  - So next message (with higher sequence) will go through
- To make flooding reliable, use ARQ
  - So receiver acknowledges, and sender resends if needed

Problem?

Flooding Problem

- F receives the same message multiple times