COMP 3331/9331: Computer Networks and Applications

Week 8

Network Layer: Control Plane (Routing)

Chapter 5: Section 5.1 – 5.2, 5.6

Network layer, control plane: outline

5.1 introduction

5.2 routing protocols

- link state
- distance vector
- hierarchical routing

Self study

5.6 ICMP: The Internet Control Message Protocol

Network-layer functions

Recall: two network-layer functions:

- *forwarding:* move packets from router' s input to appropriate router output
- *routing:* determine route taken by packets from source to destination

data plane

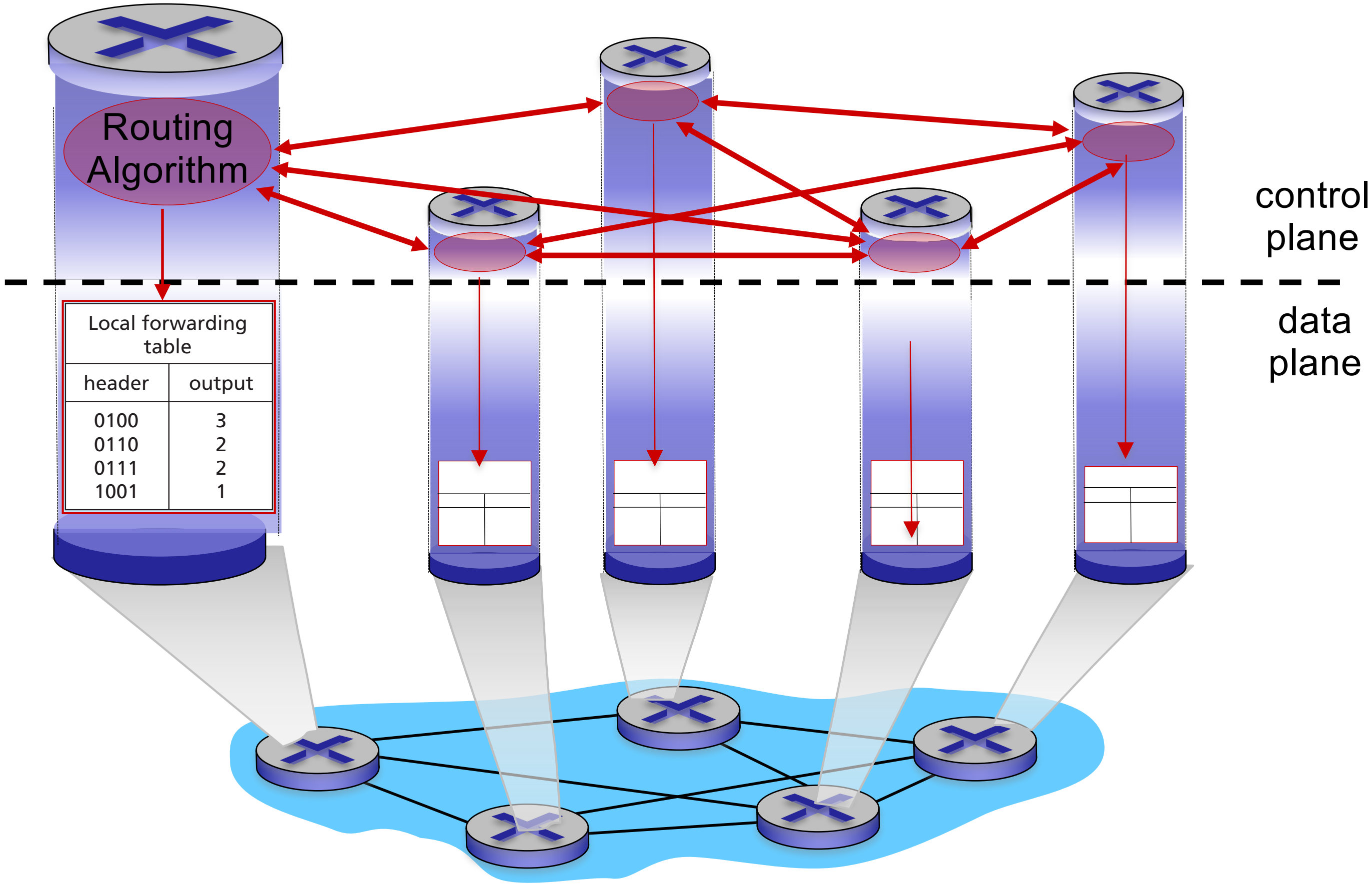
control plane

Two approaches to structuring network control plane:

- per-router control (traditional)
- logically centralized control (software defined networking)

Per-router control plane

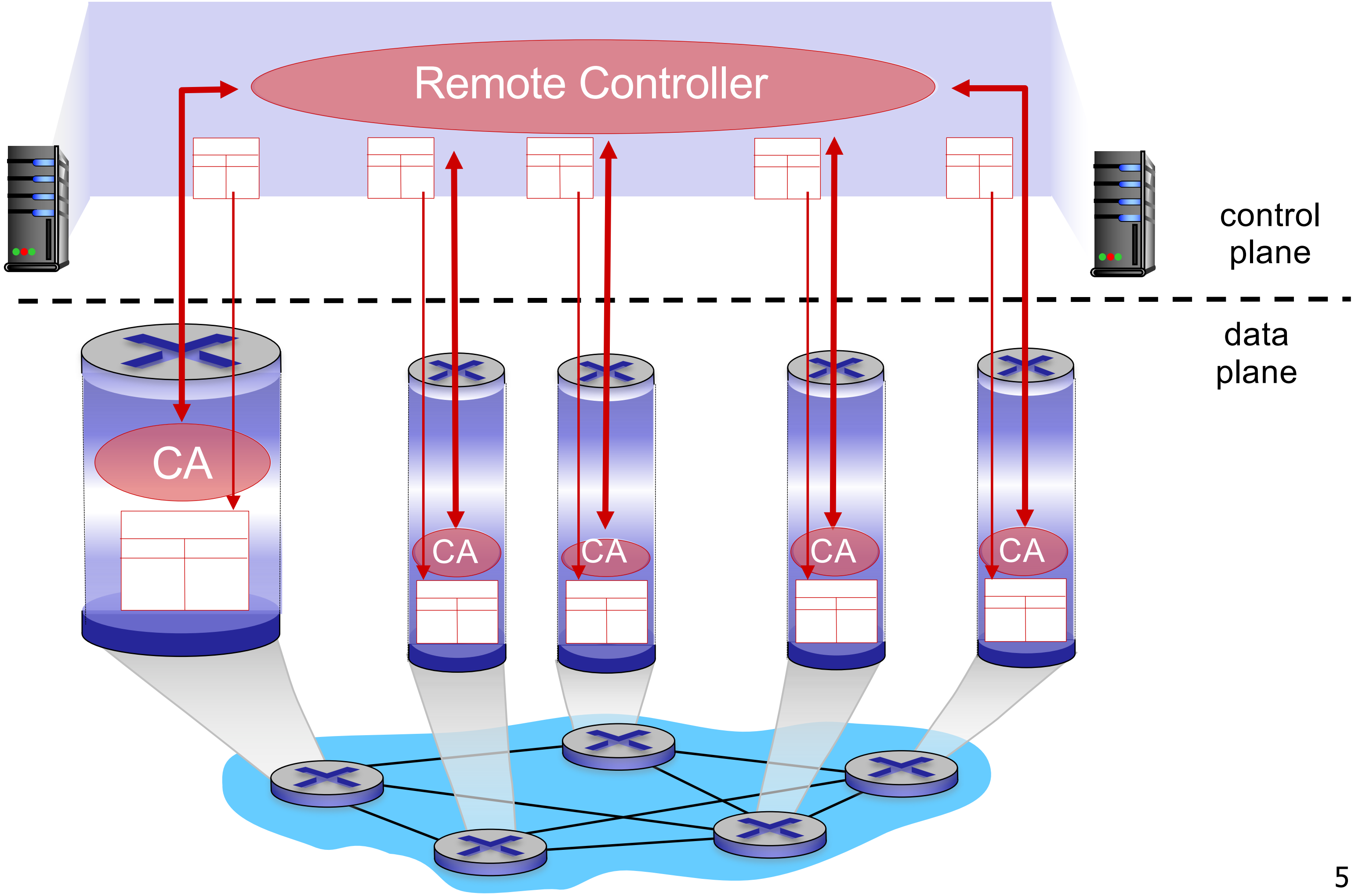
Individual routing algorithm components *in each and every router* interact with each other in control plane to compute forwarding tables



header	output
0100	3
0110	2
0111	2
1001	1

Logically centralized control plane

A distinct (typically remote) controller interacts with local control agents (CAs) in routers to compute forwarding tables



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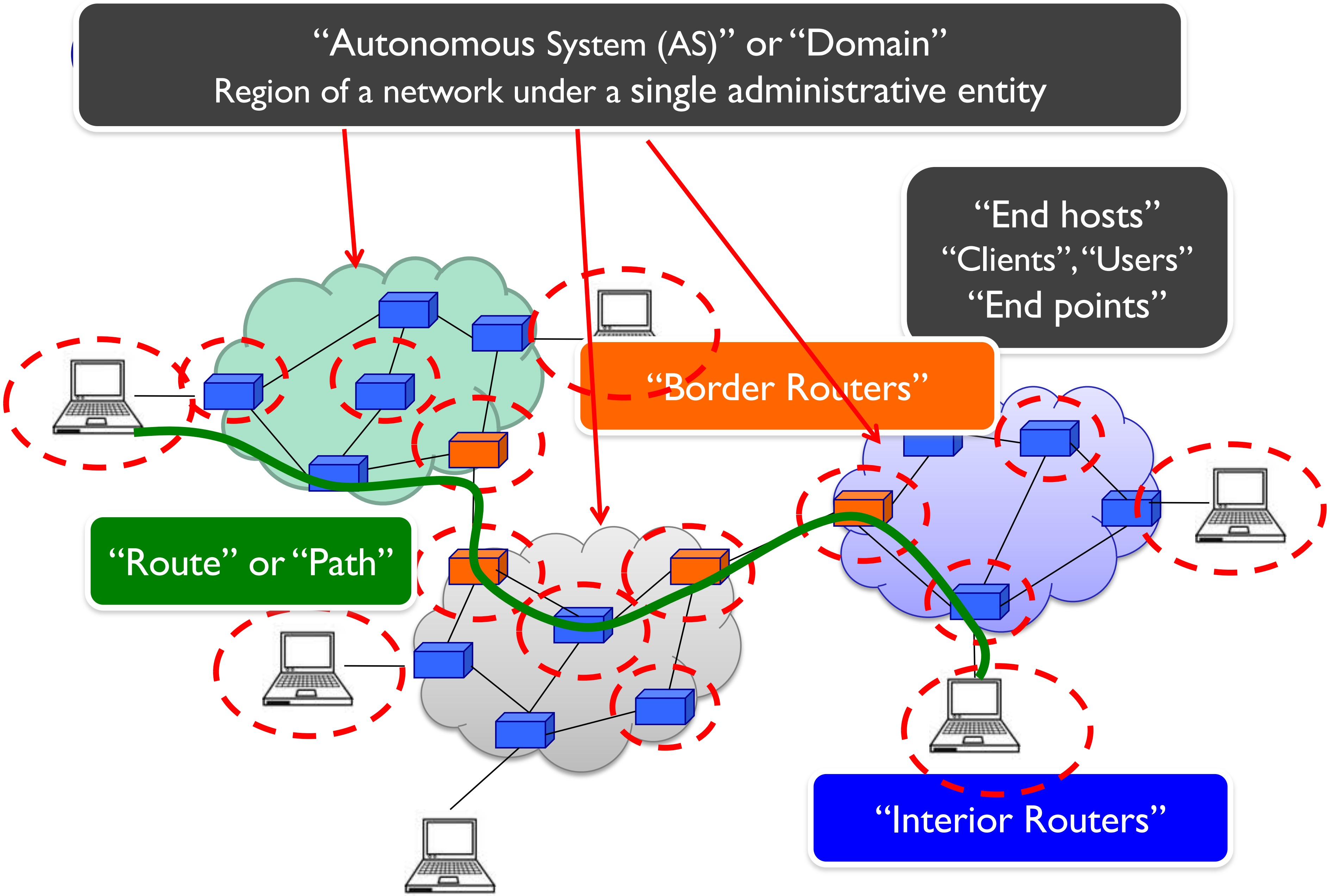
- distance vector
- Hierarchical routing

5.6 ICMP: The Internet
Control Message
Protocol



"Autonomous System (AS)" or "Domain"
Region of a network under a single administrative entity

"End hosts"
"Clients", "Users"
"End points"

"Border Routers"

"Route" or "Path"

"Interior Routers"

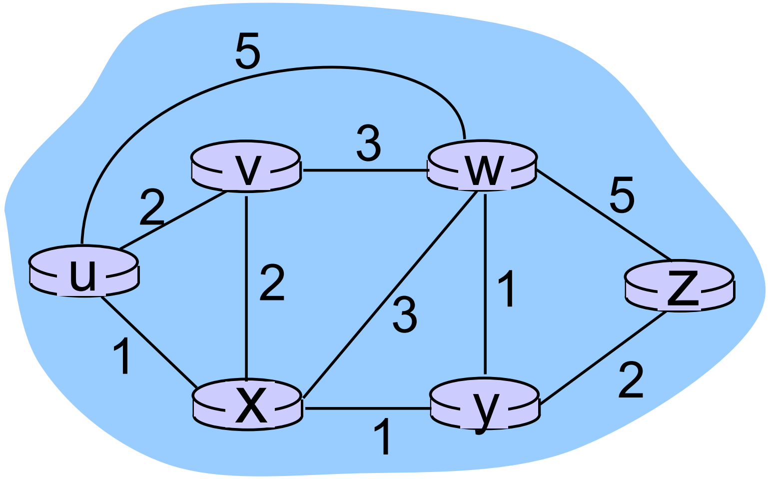
Internet Routing

- Internet Routing works at two levels

- Each AS runs an intra-domain routing protocol that establishes routes within its domain
  - AS -- region of network under a single administrative entity
  - Link State, e.g., Open Shortest Path First (OSPF)
  - Distance Vector, e.g., Routing Information Protocol (RIP)

- ASes participate in an inter-domain routing protocol that establishes routes between domains
  - Path Vector, e.g., Border Gateway Protocol (BGP)

Graph abstraction

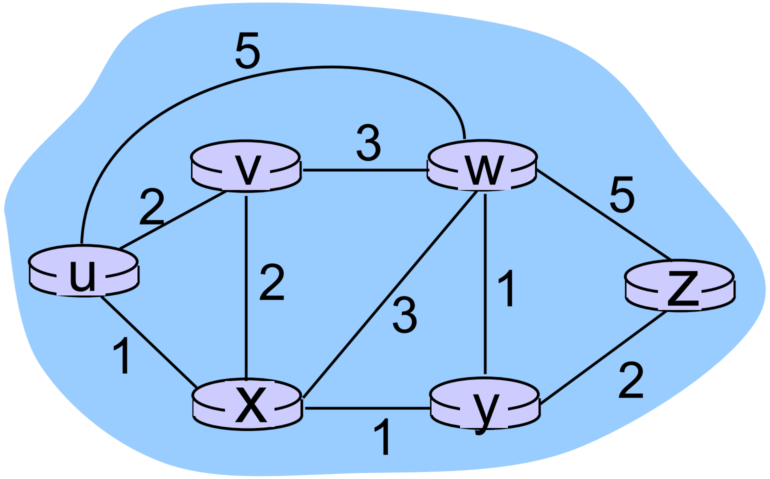


graph: G = (N,E)

N = set of routers = { u, v, w, x, y, z }

E = set of links ={ (u,v), (u,x), (u,w), (v,x), (v,w), (x,w), (x,y), (w,y), (w,z), (y,z) }

Graph abstraction: costs



c(x,x’) = cost of link (x,x’)
e.g., c(w,z) = 5

cost of path $(x_1, x_2, x_3,\ldots, x_p) = c(x_1,x_2) + c(x_2,x_3) + \ldots + c(x_{p-1},x_p)$

key question: what is the least-cost path between u and z ?
routing algorithm: algorithm that finds that least cost path

Link Cost

- Typically simple: all links are equal

- Least-cost paths => shortest paths (hop count)

- Network operators add policy exceptions
  - Lower operational costs
  - Peering agreements
  - Security concerns

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Routing algorithm classes

Link State (Global)

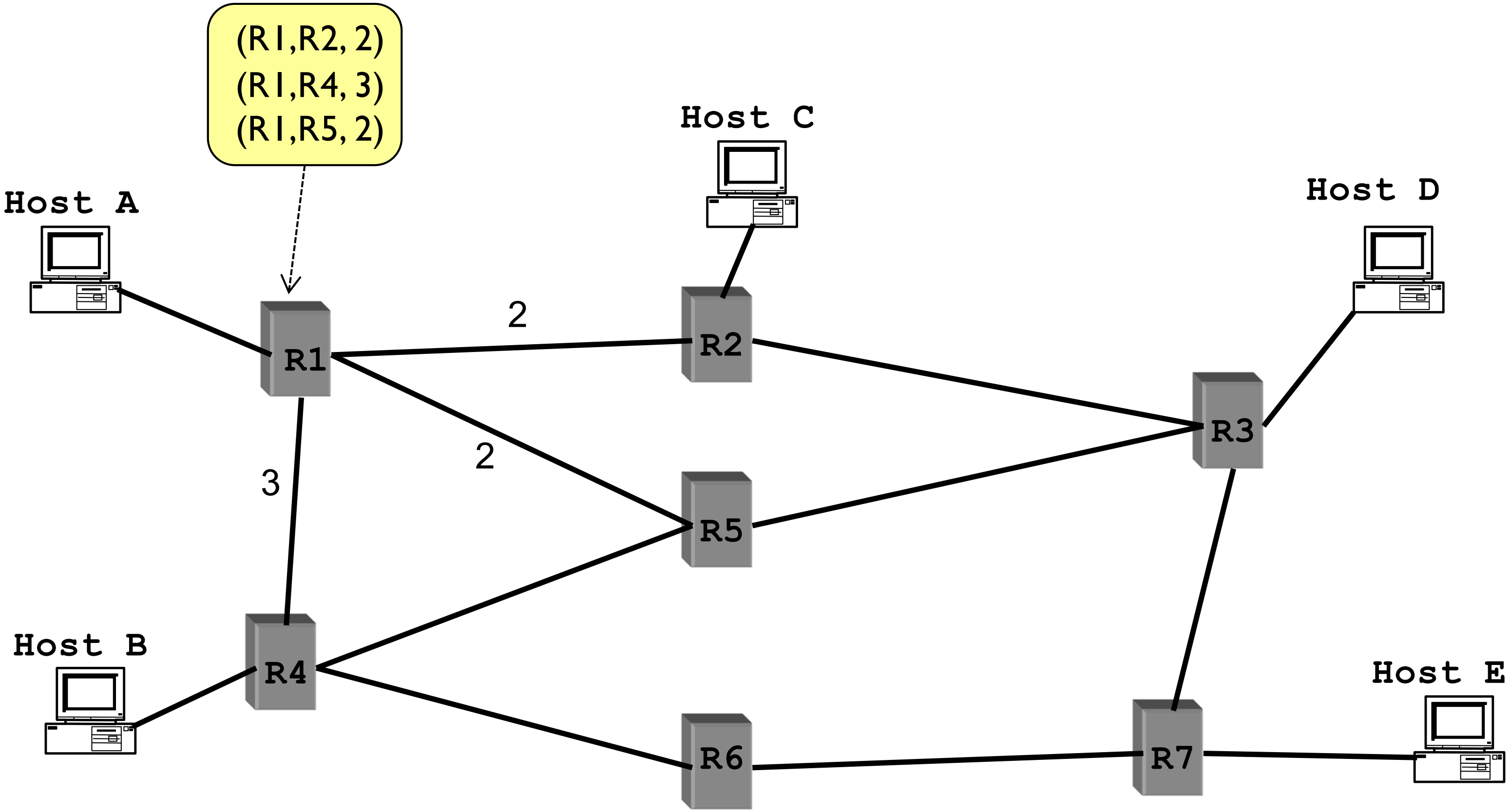
- Routers maintain cost of each link in the network
- Connectivity/cost changes flooded to all routers
- Converges quickly (less inconsistency, looping, etc.)
- Limited network sizes

Distance Vector (Decentralised)

- Routers maintain next hop & cost of each destination.
- Connectivity/cost changes iteratively 传播 propagate from neighbour to neighbour
- Requires multiple rounds to converge
- Scales to large networks

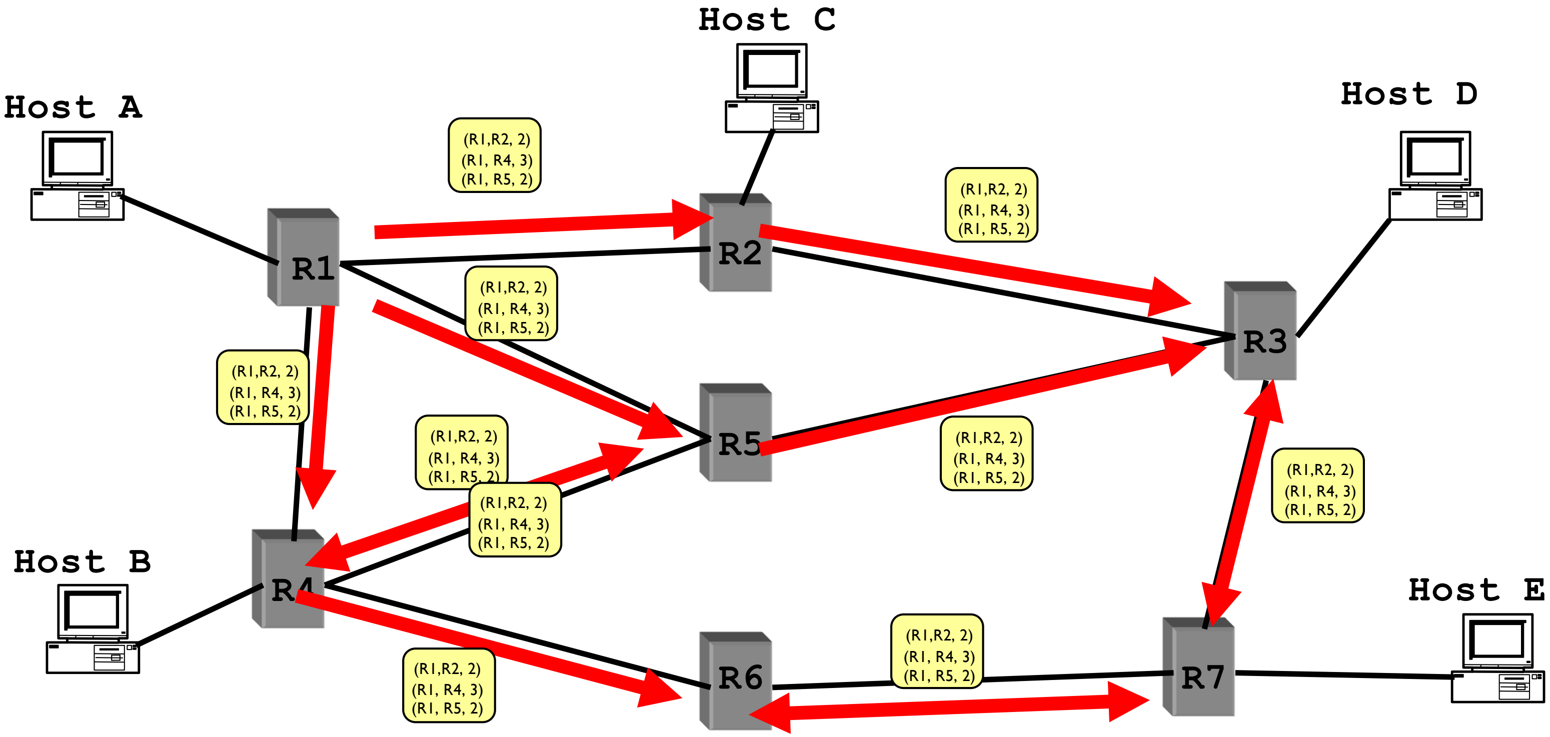
Link State Routing

- Each node maintains its local "link state" (LS)
  - i.e., a list of its directly attached links and their costs



Link State Routing

- Each node maintains its local "link state" (LS)
- Each node floods its local link state
  - on receiving a new LS message, a router forwards the message to all its neighbors other than the one it received the message from

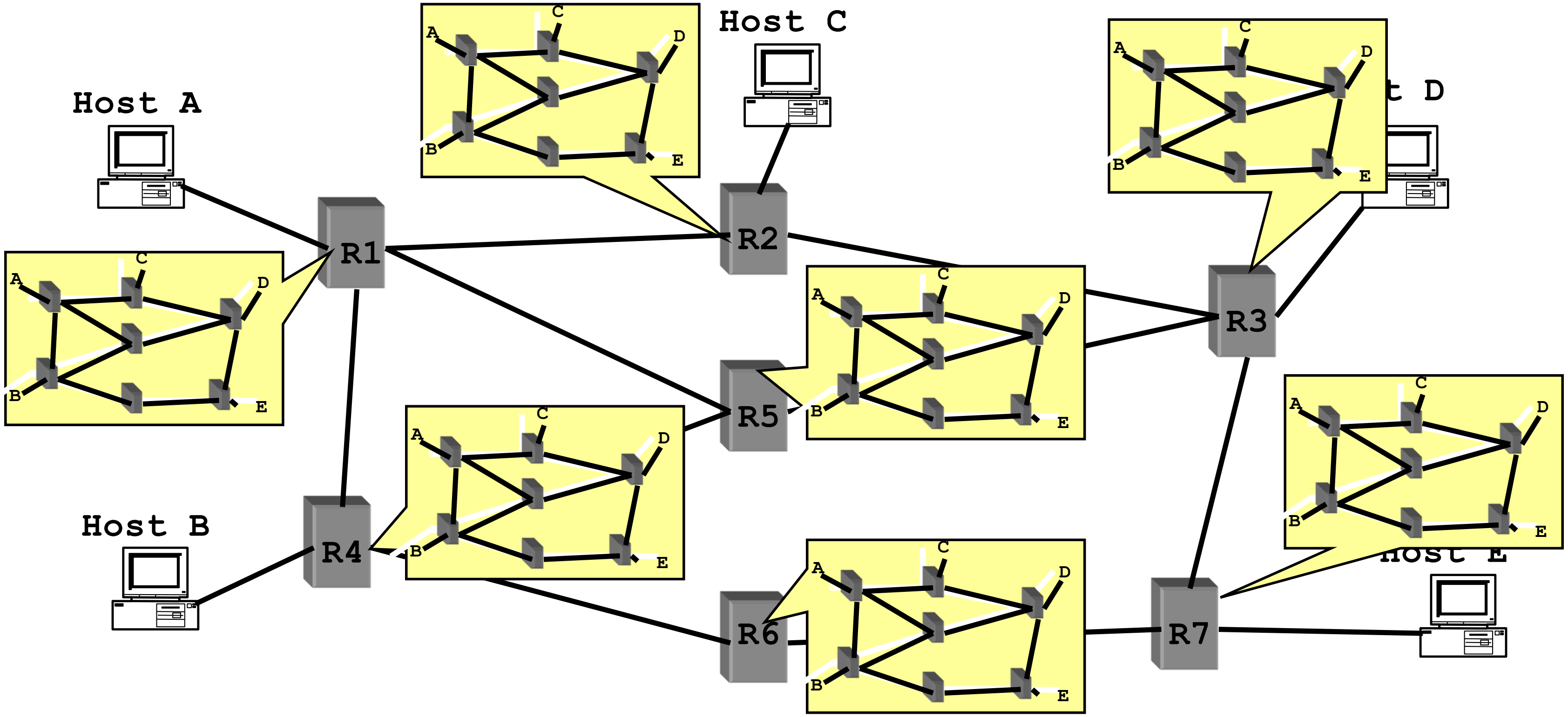


Flooding LSAs

- Routers transmit Link State Advertisement (LSA) on links
    - A neighbouring router forwards out on all links except incoming
    - Keep a copy locally; don’t forward previously-seen LSAs
- Challenges
    - Packet loss
    - Out of order arrival
- Solutions
    - Acknowledgements and retransmissions
    - Sequence numbers
    - Time-to-live for each packet

Link State Routing

- Each node maintains its local "link state" (LS)
- Each node floods its local link state
- Eventually, each node learns the entire network topology
  - Can use Dijkstra's to compute the shortest paths between nodes



A Link-State Routing Algorithm

Dijkstra's algorithm

- net topology, link costs known to all nodes
  - accomplished via "link state broadcast"
  - all nodes have same info
- computes least cost paths from one node ('source") to all other nodes
  - gives *forwarding table* for that node
- iterative: after k iterations, know least cost path to k dest.'s

notation:

- c(x,y): link cost from node x to y; = ∞ if not direct neighbors
- D(v): current value of cost of path from source to dest. v
- p(v): predecessor node along path from source to v
- N': set of nodes whose least cost path definitively known

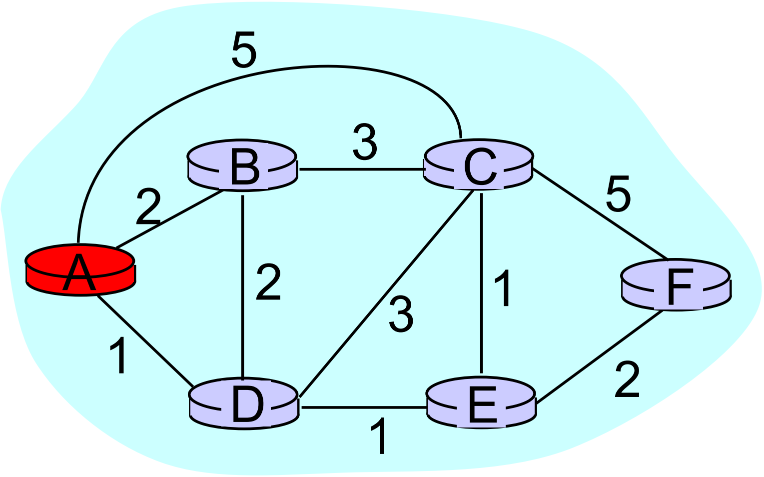
Dijsktra’ s Algorithm

```
Initialization:
  N' = {u}
  for all nodes v
    if v adjacent to u
        then D(v) = c(u,v)
    else D(v) = ∞

Loop
  find w not in N' such that D(w) is a minimum
  add w to N'
  update D(v) for all v adjacent to w and not in N' :
     D(v) = min( D(v), D(w) + c(w,v) )
  /* new cost to v is either old cost to v or known
   shortest path cost to w plus cost from w to v */
until all nodes in N'
```

Example: Dijkstra’s Algorithm

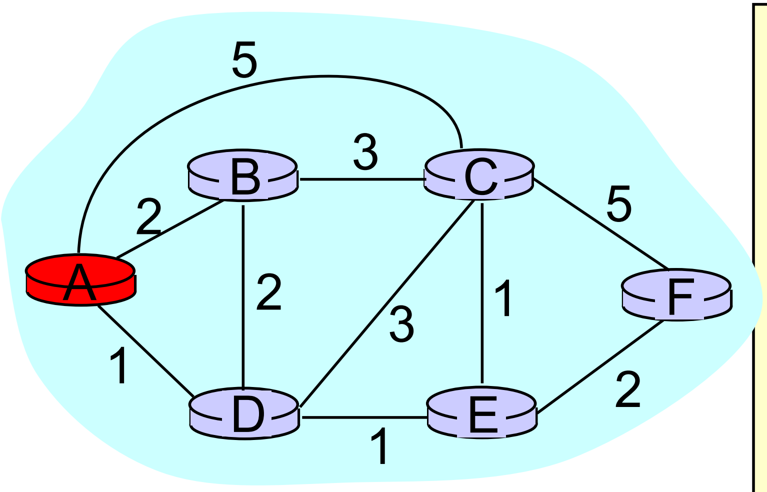
Step	Set N’	D(B),p(B)	D(C),p(C)	D(D),p(D)	D(E),p(E)	D(F),p(F)
0	A	2,A	5,A	1,A	∞	∞
1						
2						
3						
4						
5						



```
Initialization:
  N’ = {A};
  for all nodes v
    if v adjacent to A
      then D(v) = c(A,v);
      else D(v) = ∞;
…
```

Example: Dijkstra’s Algorithm

Step	Set N’	D(B),p(B)	D(C),p(C)	D(D),p(D)	D(E),p(E)	D(F),p(F)
0	A	2,A	5,A	1,A	∞	∞
1						
2						
3						
4						
5						



```
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Loop
    find w not in N’ s.t. D(w) is a minimum;
    add w to N’;
    update D(v) for all v adjacent
        to w and not in N’:
    If D(w) + c(w,v) < D(v) then
        D(v) = D(w) + c(w,v); p(v) = w;
until all nodes in N’;
```

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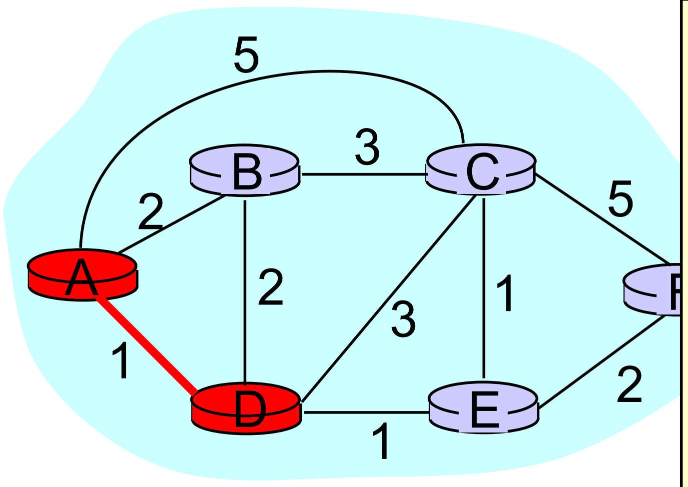
0	A	2,A	5,A	1,A	∞	∞
1	AD					
2						
3						
4						
5						



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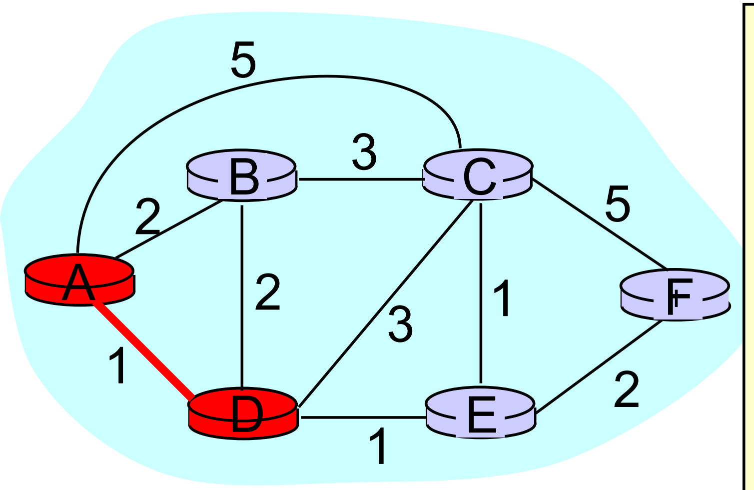
0	A	2,A	5,A	1,A	∞	∞
1	AD	2, A	4,D		2,D	
2						
3						
4						
5						



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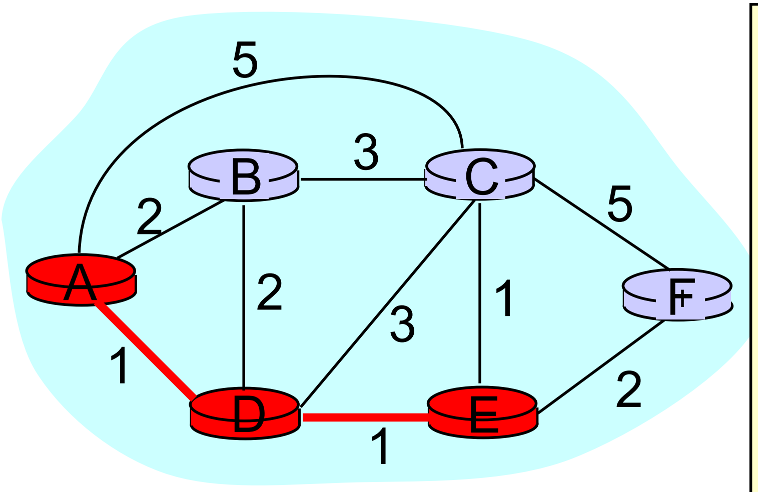
0	A	2,A	5,A	1,A	∞	∞
1	AD	2, A	4,D		2,D	
2	ADE	2, A	3,E			4,E
3						
4						
5						



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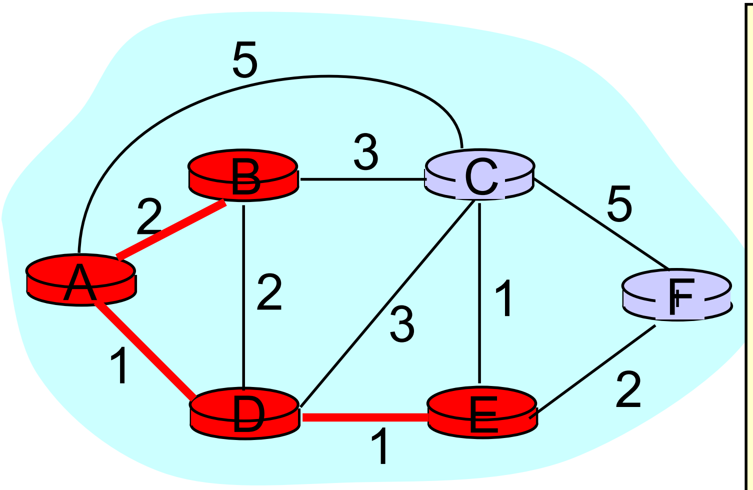
1	AD	2,A	4,D		2,D	
2	ADE	2,A	3,E			4,E
3	ADEB		3,E			4,E
4						
5						



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Loop
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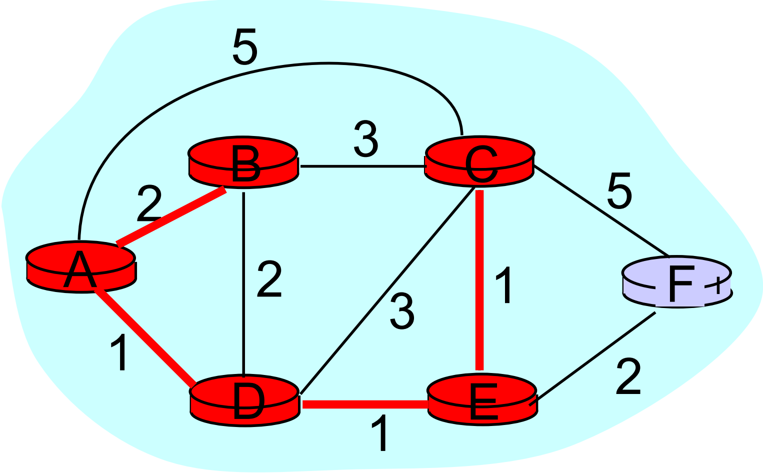
0	A	2,A	5,A	1,A	∞	∞
1	AD	2,A	4,D		2,D	
2	ADE	2,A	3,E			4,E
3	ADEB		3,E			4,E
4	ADEBC					4,E
5						



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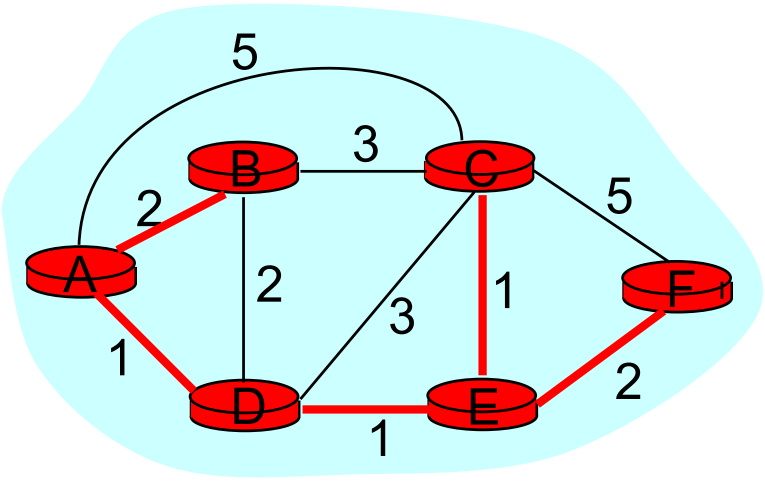
1	AD	2,A	4,D		2,D	
2	ADE	2,A	3,E			4,E
3	ADEB		3,E			4,E
4	ADEBC					4,E
5	ADEBCF					



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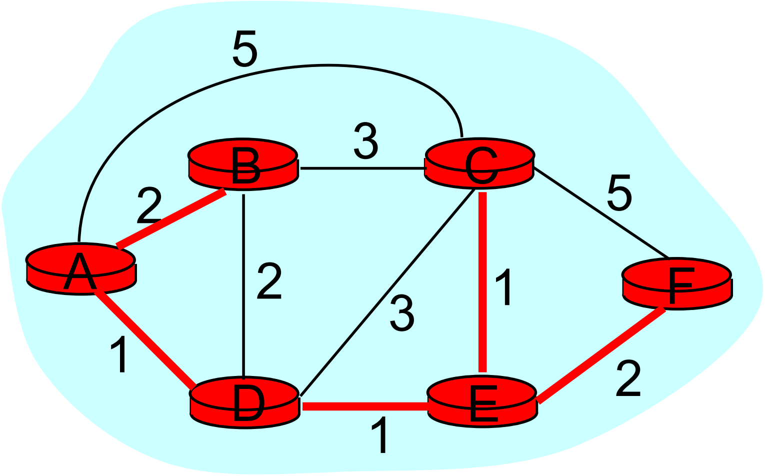
1	AD		4,D		2,D	
2	ADE		3,E			4,E
3	ADEB					
4	ADEBC					
5	ADEBCF					

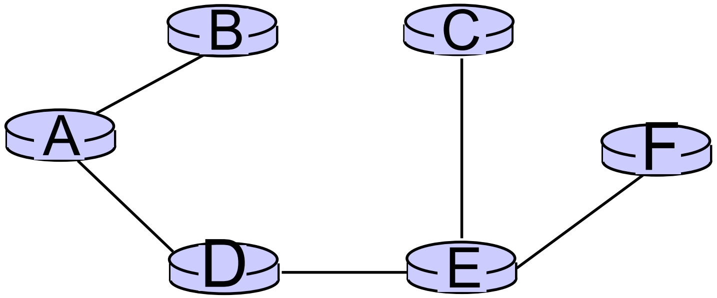


To determine path A → C (say), work backward from C via p(v)

The Forwarding Table

- Running Dijkstra at node A gives the shortest path from A to all destinations
- We then construct the *forwarding table*

resulting shortest-path tree from A:



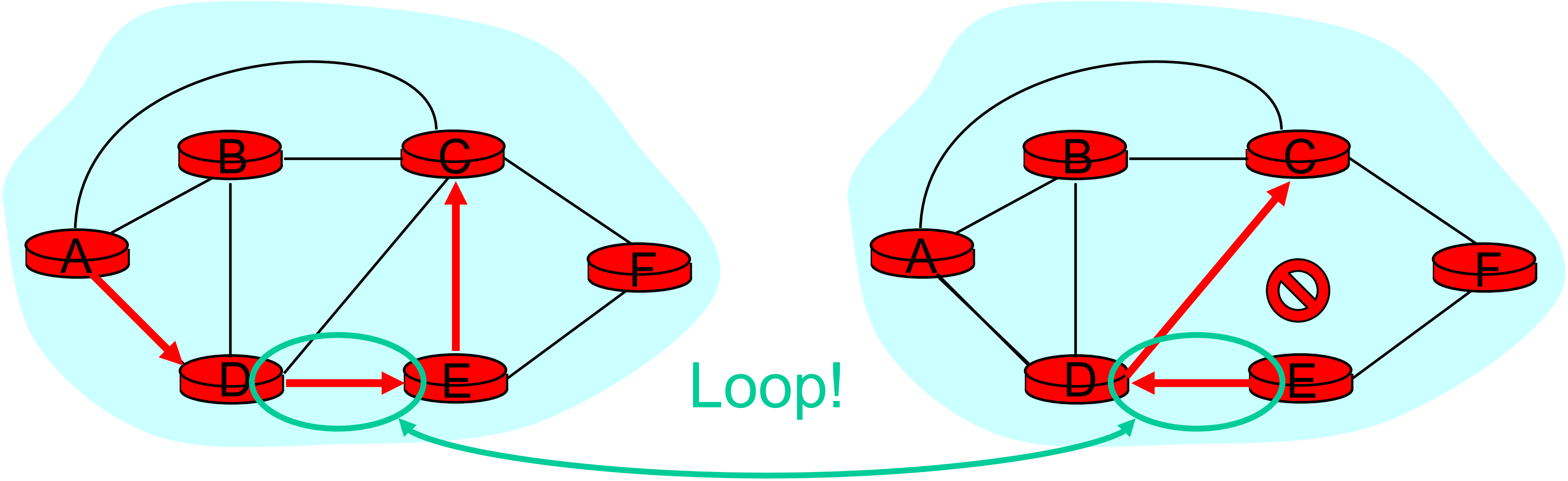
Destination	Link
B	(A,B)
C	(A,D)
D	(A,D)
E	(A,D)
F	(A,D)

Issue #1: Scalability

- How many messages needed to flood link state messages?
  - O(N x E), where N is #nodes; E is #edges in graph
- Processing complexity for Dijkstra's algorithm?
  - O(N^2), because we check all nodes w not in N' at each iteration and we have O(N) iterations
- How many entries in the LS topology database? O(E)
- How many entries in the forwarding table? O(N)

Issue#2: Transient Disruptions

- Inconsistent link-state database
  - Some routers know about failure before others
  - The shortest paths are no longer consistent
  - Can cause **transient** forwarding loops



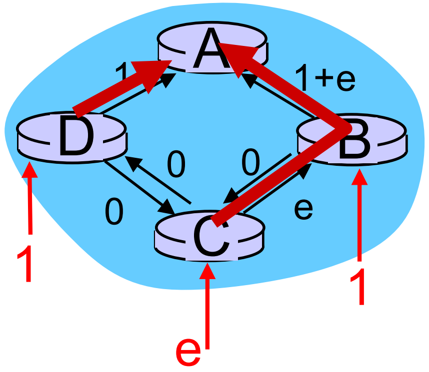
A and D think that this is the path to C

E thinks that this is the path to C

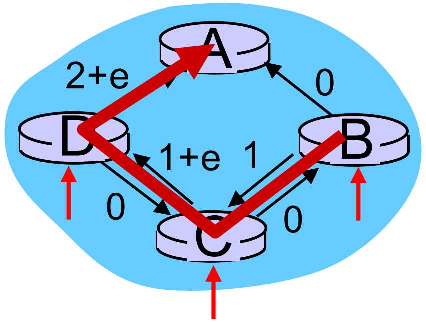
Oscillations

oscillations possible:

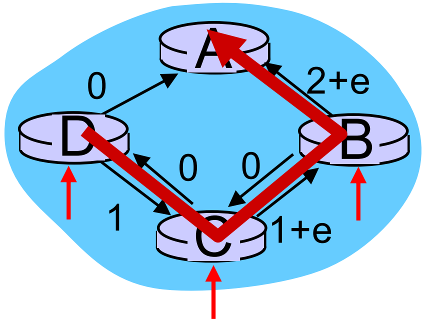
- e.g., suppose link cost equals amount of carried traffic:



initially



given these costs,
find new routing….
resulting in new costs



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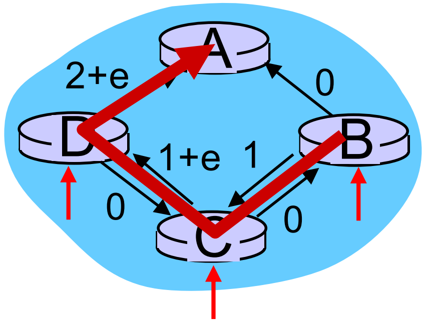

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Distance vector algorithm

Bellman-Ford equation

let

$d_x(y)$:= cost of least-cost path from x to y

then

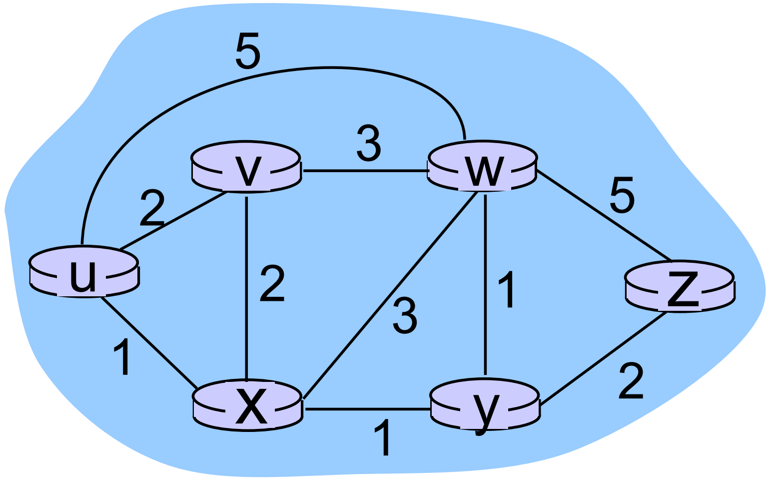
$$d_x(y) = \min_v \{c(x,v) + d_v(y)\}$$

cost from neighbor v to destination y

cost to neighbor v

min taken over all neighbors v of x

Bellman-Ford example



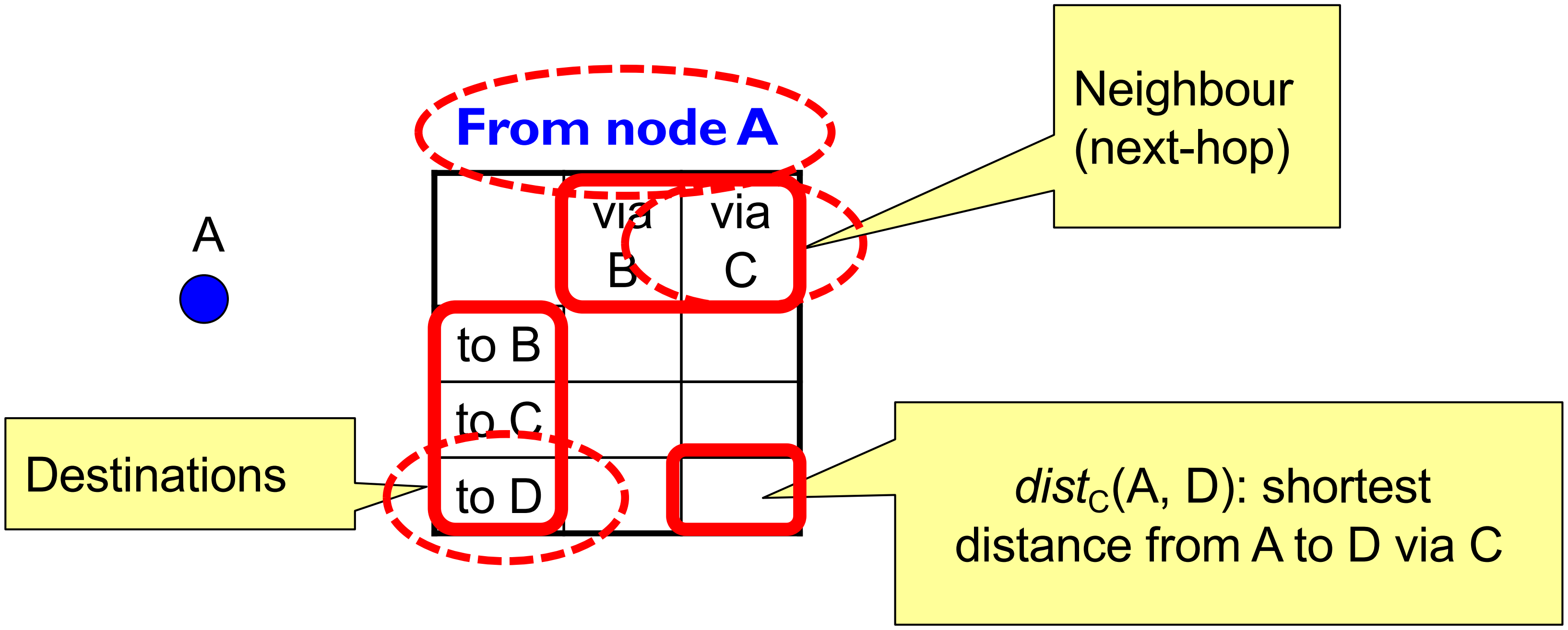
clearly, $d_v(z) = 5$, $d_x(z) = 3$, $d_w(z) = 3$

B-F equation says:

$$
\begin{aligned}
d_u(z) &= \min \{ c(u,v) + d_v(z), \\
&\qquad c(u,x) + d_x(z), \\
&\qquad c(u,w) + d_w(z) \} \\
&= \min \{2 + 5, \\
&\qquad 1 + 3, \\
&\qquad 5 + 3\} = 4
\end{aligned}
$$

node achieving minimum is next
hop in shortest path, used in forwarding table

How Distance-Vector (DV) works



From node A

	via B	via C
to B		
to C		
to D		

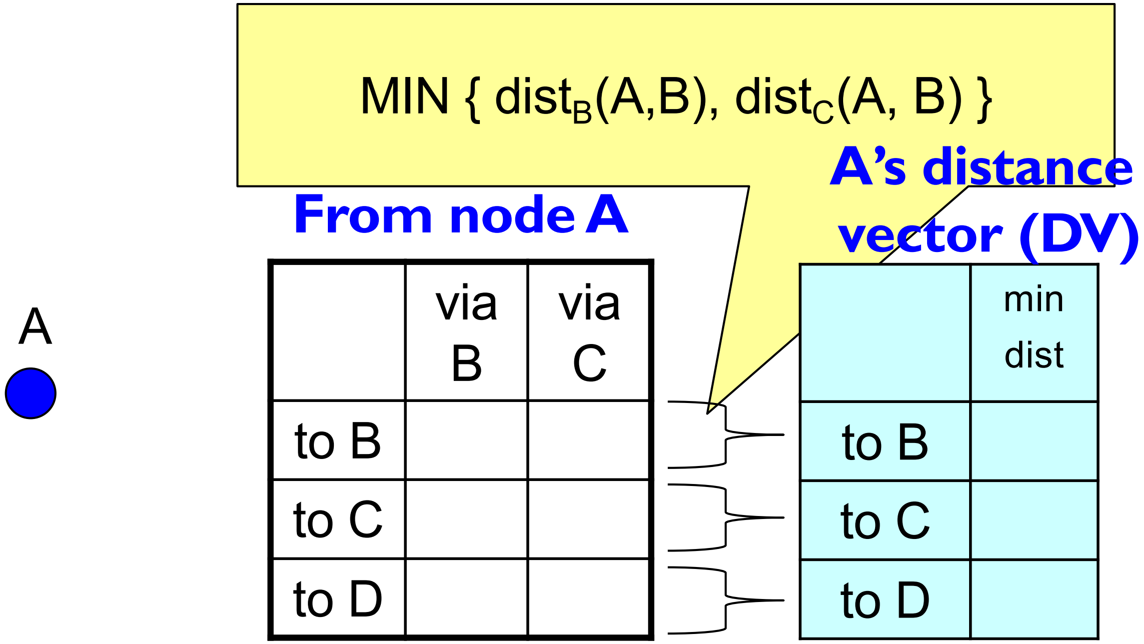
Neighbour (next-hop)

Destinations

dist$_C$(A, D): shortest distance from A to D via C

Each router maintains its shortest distance to every destination via each of its neighbours

How Distance-Vector (DV) works



$\text{MIN}\ \{\ \text{dist}_B(A,B),\ \text{dist}_C(A,\ B)\ \}$

From node A

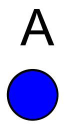
	via B	via C
to B		
to C		
to D		

A's distance vector (DV)

	min dist
to B	
to C	
to D	

Each router computes its shortest distance to every destination via any of its neighbors

How Distance-Vector (DV) works



From node A

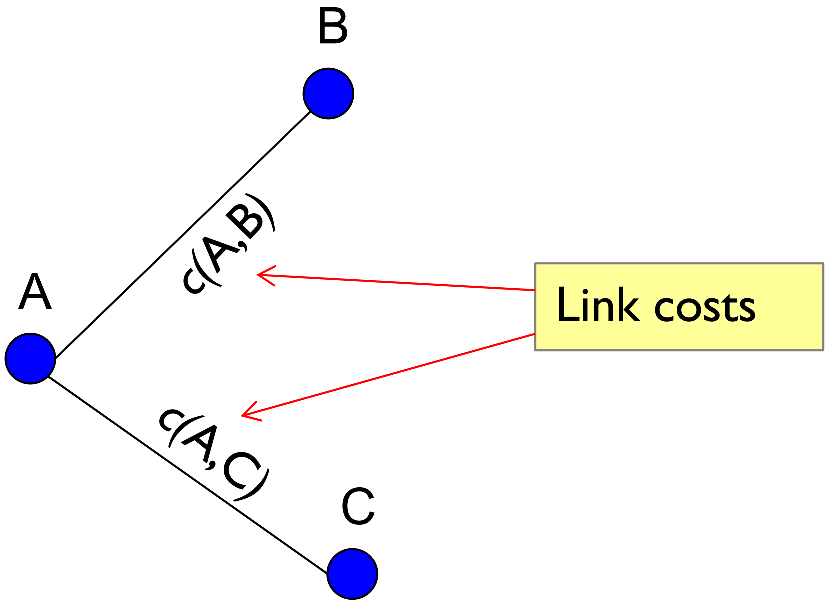
	via B	via C
to B	?	?
to C	?	?
to D	?	?

A's DV

	min dist
to B	?
to C	?
to D	?

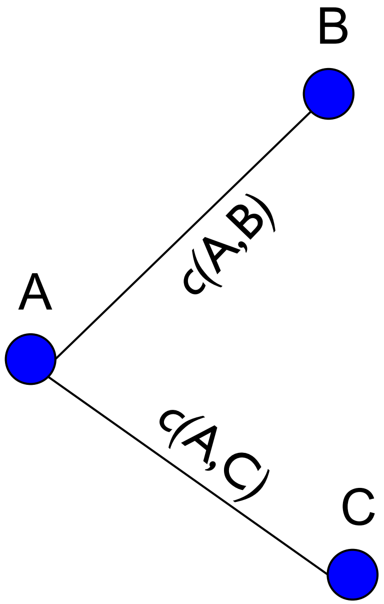
How does A initialize its dist() table and DV?

How Distance-Vector (DV) works



How does A initialize its dist() table and DV?

How Distance-Vector (DV) works



From node A

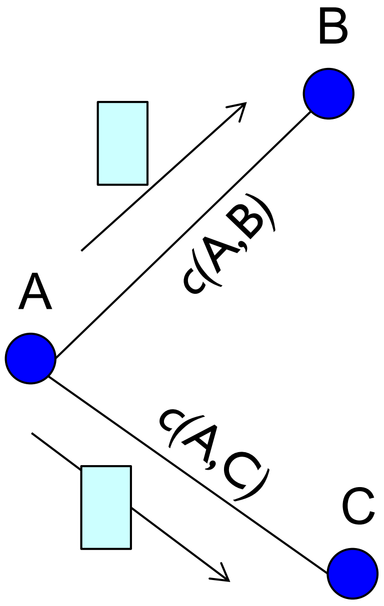
	via B	via C
to B	*c*(A,B)	∞
to C	∞	*c*(A,C)
to D	∞	∞

A's DV

	mindist
to B	c(A,B)
to C	c(A,C)
to D	∞

Each router initializes its *dist*() table based on its immediate neighbors and link costs

How Distance-Vector (DV) works



Assume that A's DV is as follows at some later time

From node A

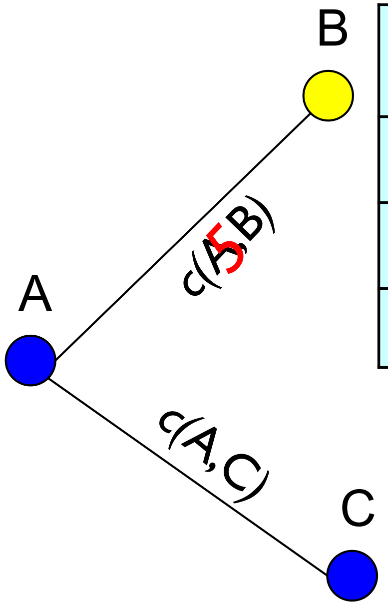
	via B	via C
to B	*c*(A,B)	∞
to C	∞	*c*(A,C)
to D	∞	∞

A's DV

	mindist
to B	5
to C	6
to D	2

Each router sends its DV to its immediate neighbors

How Distance-Vector (DV) works



A's DV

	min
to B	5
to C	6
to D	2

From node B

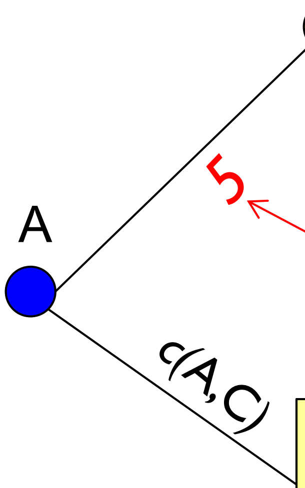
	via A	via C
to A	5	∞
to C	15	1
to D	∞	∞

B's DV

	mindist
to A	5
to C	1
to D	∞

Routers process received DVs

How Distance-Vector (DV) works



A's DV

	min
to B	5
to C	6
to D	2

From node B

	via A	via C
to A	5	∞
to C	11	1
to D	7	∞

B's DV

	mindist
to A	5
to C	1
to D	7

new = c(B,A) + *mindist*(A, D)

Routers process received DVs

And repeat…

Distance Vector Routing

- Each router knows the links to its neighbors
- Each router has provisional “shortest path” to every other router -- its distance vector (DV)
- Routers exchange this DV with their neighbors
- Routers look over the set of options offered by their neighbors and select the best one
- Iterative process converges to set of shortest paths

Distance vector routing

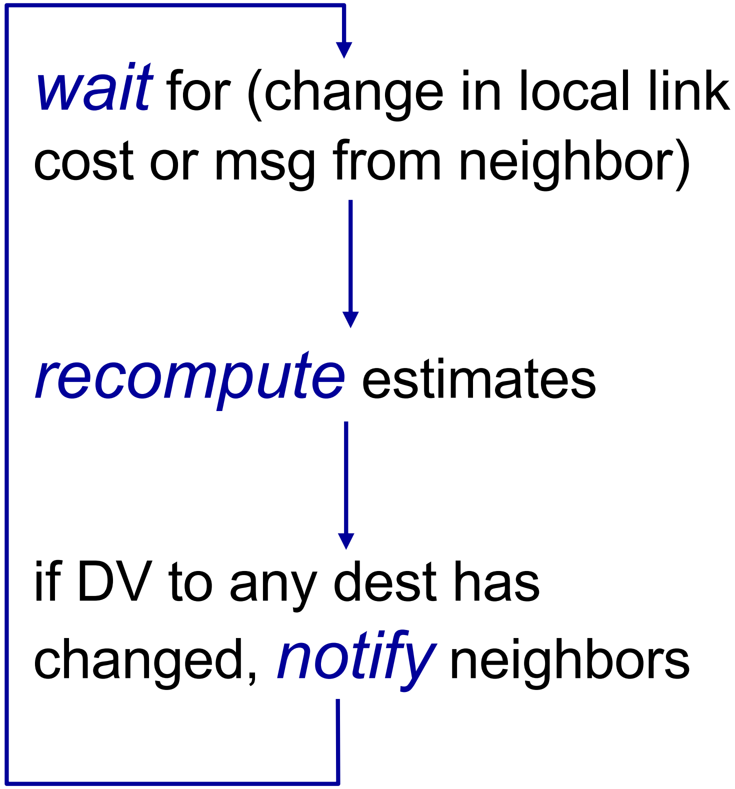
iterative, asynchronous: each local iteration caused by:

- local link cost change
- DV update message from neighbor

distributed:

- each node notifies neighbors *only* when its DV changes
  - neighbors then notify their neighbors if necessary

each node:



wait for (change in local link cost or msg from neighbor)

recompute estimates

if DV to any dest has changed, *notify* neighbors

Distance Vector

- c(i,j): link cost from node *i* to *j*
- $dist_Z(A,V)$: shortest dist. from A to V via Z
- mindist(A,V): shortest dist. from A to V

```
At node A
Initialization:
    for all destinations V do
        if V is neighbor of A
            $dist_V(A, V) = mindist(A,V) = c(A,V)$;
        else
            $dist_V(A, V) = mindist(A,V) = \infty$;
    send mindist(A, *) to all neighbors
loop:
    wait (until A sees a link cost change to neighbor V  /* case 1 */
          or until A receives mindist(V,*) from neighbor V)    /* case 2 */
    if (c(A,V) changes by $\pm d$)  /* $\Leftarrow$ case 1 */
        for all destinations Y do
            $dist_V(A,Y) = dist_V(A,Y) \pm d$
    else /* $\Leftarrow$ case 2: */
        for all destinations Y do
            $dist_V(A,Y) = c(A,V) + mindist(V, Y)$;
    update mindist(A,*)
    if (there is a change in mindist(A, *))
        send mindist(A, *) to all neighbors
forever
```

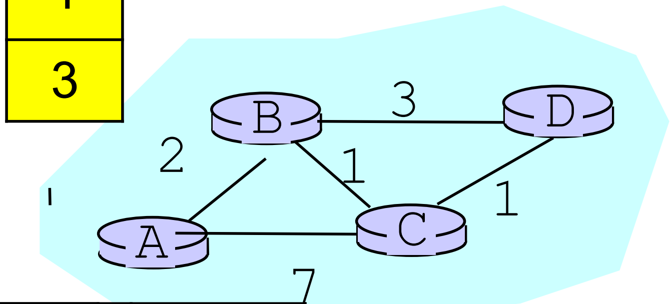
Example: Initialization

from Node B

	via A	via C	via D	min dist
to A	2	∞	∞	2
to B	-	-	-	0
to C	∞	1	∞	1
to D	∞	∞	3	3

from Node D

	via B	via C	min dist
to A	∞	∞	∞
to B	3	∞	3
to C	∞	1	1
to D	-	-	0



from Node A

	via B	via C	min dist	min dist
to A	-	-	0	0
to B	2	∞	2	2
to C	∞	7	7	7
to D	∞	∞	∞	∞

from Node C

	via A	via B	via D	min dist
to A	7	∞	∞	7
to B	∞	1	∞	1
to C	-	-	-	0
to D	∞	∞	1	1

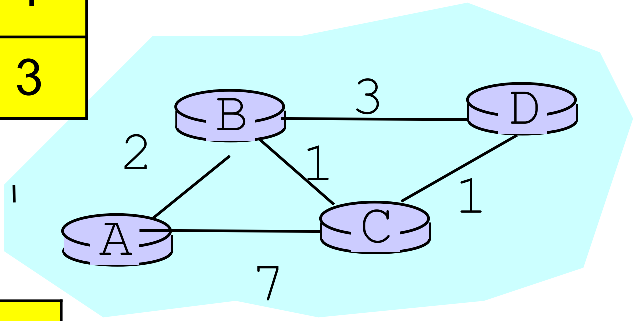
Example: C sends update to A

from Node B

	via A	via C	via D	min dist
to A	2	∞	∞	2
to B	-	-	-	0
to C	∞	1	∞	1
to D	∞	∞	3	3

from Node D

	via B	via C	min dist
to A	∞	∞	∞
to B	3	∞	3
to C	∞	1	1
to D	-	-	0



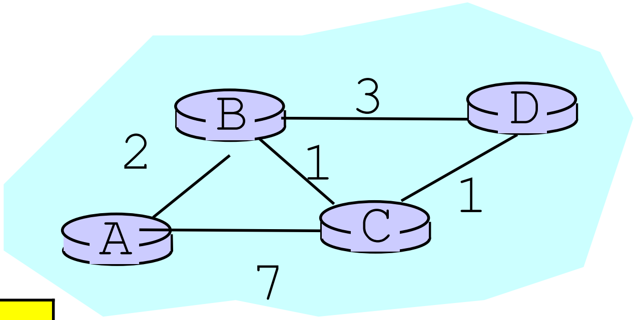
from Node A

	via B	via C	min dist
to A	-	-	0
to B	2	∞	2
to C	∞	7	7
to D	∞	∞	∞

from Node C

	via A	via B	via D	min dist
to A	7	∞	∞	7
to B	∞	1	∞	1
to C	-	-	-	0
to D	∞	∞	1	1

Example: C sends update to A



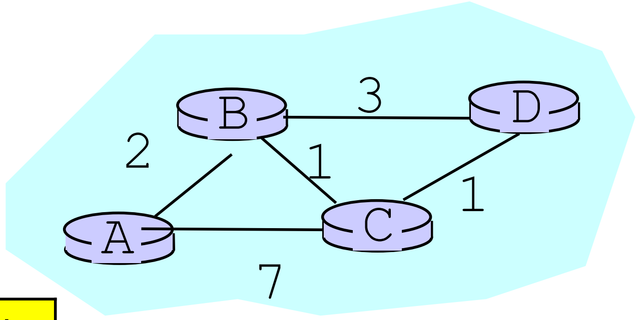
from Node A

	via B	via C
to A	-	-
to B	2	∞
to C	∞	7
to D	∞	∞

min dist
0
2
7
∞

min dist
7
1
0
1

Example: C sends update to A



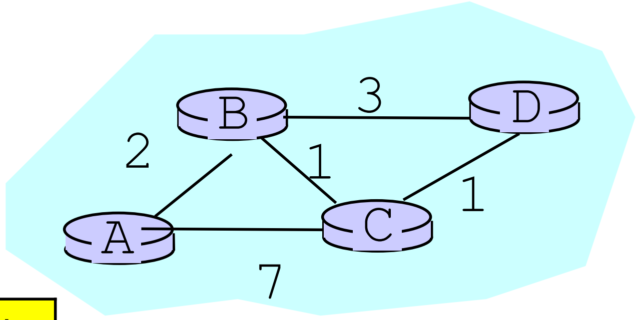
from Node A

	via B	via C
to A	-	-
to B	2	**8**
to C	∞	7
to D	∞	**8**

min dist
0
2
7
∞

min dist
7
1
0
1

Example: C sends update to A



from Node A

	via B	via C
to A	-	-
to B	2	**8**
to C	∞	7
to D	∞	**8**

min dist
0
2
7
8

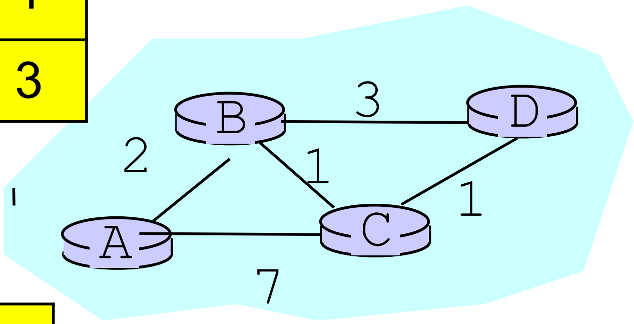
Example: now B sends update to A

from Node B

	via A	via C	via D	min dist
to A	2	∞	∞	2
to B	-	-	-	0
to C	∞	1	∞	1
to D	∞	∞	3	3

from Node D

	via B	via C	min dist
to A	∞	∞	∞
to B	3	∞	3
to C	∞	1	1
to D	-	-	0



from Node A

	via B	via C	min dist
to A	-	-	0
to B	2	8	2
to C	∞	7	7
to D	∞	8	8

from Node C

	via A	via B	via D	min dist
to A	7	∞	∞	7
to B	∞	1	∞	1
to C	-	-	-	0
to D	∞	∞	1	1

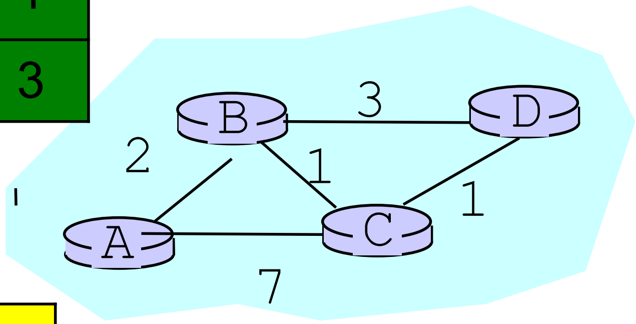
Example: now B sends update to A

from Node B

	via A	via C	via D	min dist
to A	2	∞	∞	2
to B	-	-	-	0
to C	∞	1	∞	1
to D	∞	∞	3	3

from Node D

	via B	via C	min dist
to A	∞	∞	∞
to B	3	∞	3
to C	∞	1	1
to D	-	-	0



from Node A

	via B	via C	min dist
to A	-	-	0
to B	2	8	2
to C	∞	7	7
to D	∞	8	8

from Node C

	via A	via B	via D	min dist
to A	7	∞	∞	7
to B	∞	1	∞	1
to C	-	-	-	0
to D	∞	∞	1	1

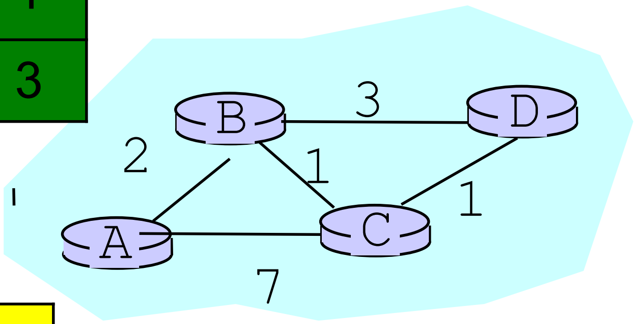
Example: now B sends update to A

from Node B

	via A	via C	via D	min dist
to A	2	∞	∞	2
to B	-	-	-	0
to C	∞	1	∞	1
to D	∞	∞	3	3

from Node D

	via B	via C	min dist
to A	∞	∞	∞
to B	3	∞	3
to C	∞	1	1
to D	-	-	0



from Node A

	via B	via C	min dist
to A	-	-	0
to B	2	8	2
to C	3	7	7
to D	5	8	8

from Node C

	via	via	via
to C	-	-	-
to D	∞	∞	1

min dist
7
1
0
1

Make sure you know why this is 5, not 4!

Example: now B sends update to A

from Node B

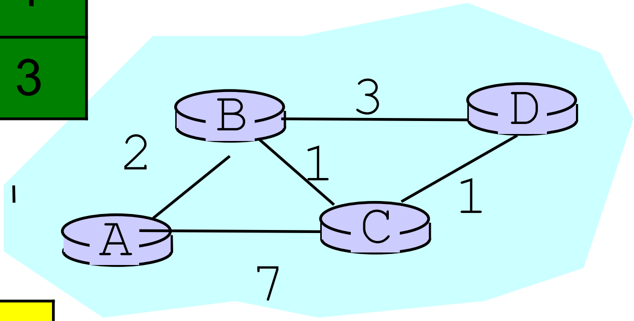
	via A	via C	via D
to A	2	∞	∞
to B	-	-	-
to C	∞	1	∞
to D	∞	∞	3

min dist
2
0
1
3

from Node D

	via B	via C
to A	∞	∞
to B	3	∞
to C	∞	1
to D	-	-

min dist
∞
3
1
0



from Node A

	via B	via C
to A	-	-
to B	2	8
to C	3	7
to D	5	8

min dist
0
2
3
5

from Node C

	via A	via B	via D
to A	7	∞	∞
to B	∞	1	∞
to C	-	-	-
to D	∞	∞	1

min dist
7
1
0
1

All nodes know the best two-hop paths.

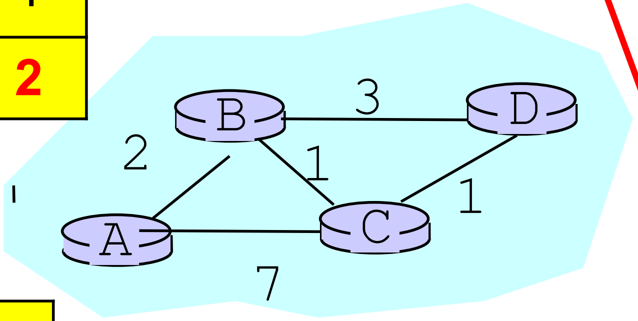
Make sure you believe this

from Node B

	via A	via C	via D	min dist
to A	2	8	∞	2
to B	-	-	-	0
to C	9	1	4	1
to D	∞	2	3	**2**

from Node D

	via B	via C	min dist
to A	5	8	**5**
to B	3	2	**2**
to C	4	1	1
to D	-	-	0



from Node A

	via B	via C	min dist
to A	-	-	0
to B	2	8	2
to C	3	7	**3**
to D	5	8	**5**

from Node C

	via A	via B	via D	min dist
to A	7	3	∞	**3**
to B	9	1	4	1
to C	-	-	-	0
to D	∞	4	1	1

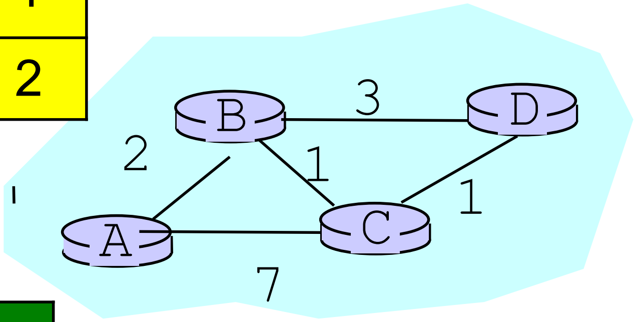
Example: Now A sends update to B

from Node B

	via A	via C	via D	min dist
to A	2	8	∞	2
to B	-	-	-	0
to C	9	1	4	1
to D	∞	2	3	2

from Node D

	via B	via C	min dist
to A	5	8	5
to B	3	2	2
to C	4	1	1
to D	-	-	0



from Node A

	via B	via C	min dist
to A	-	-	0
to B	2	8	2
to C	3	7	3
to D	5	8	5

from Node C

	via A	via B	via D	min dist
to A	7	3	∞	3
to B	9	1	4	1
to C	-	-	-	0
to D	∞	4	1	1

Example: Now

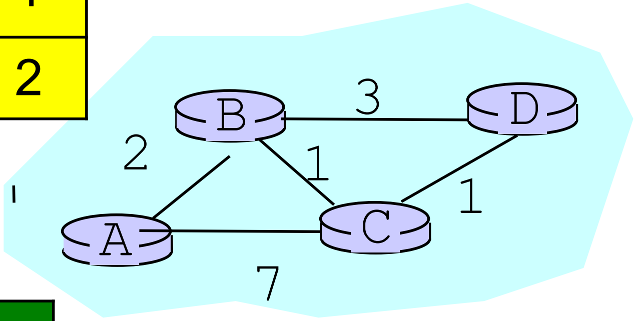
Updated

from Node B

	via A	via C	via D	min
to A	2	8	∞	
to B	-	-		0
to C	5	1	4	1
to D	7	2	3	2

from Node D

	via B	via C	min dist
to A	5	8	5
to B	3	2	2
to C	4	1	1
to D	-	-	0



from Node A

	via B	via C	min dist
to A	-	-	0
to B	2	8	2
to C	3	7	3
to D	5	8	5

from Node C

	via A	via B	via D	min dist
to A	7	3	∞	3
to B	9	1	4	1
to C	-	-	-	0
to D	∞	4	1	1

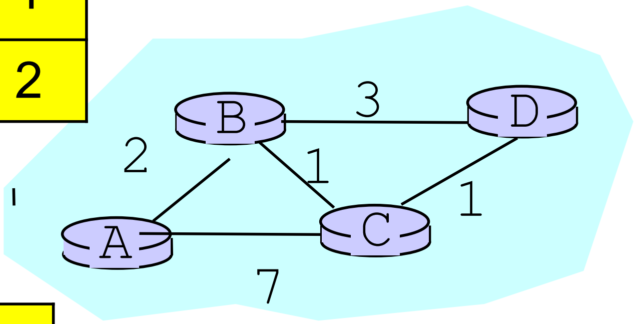
Check: *All nodes know the best three-hop paths.*

from Node B

	via A	via C	via D	min dist
to A	2	4	8	2
to B	-	-	-	0
to C	5	1	4	1
to D	7	2	3	2

from Node D

	via B	via C	min dist
to A	5	4	4
to B	3	2	2
to C	4	1	1
to D	-	-	0



from Node A

	via B	via C	min dist
to A	-	-	0
to B	2	8	2
to C	3	7	3
to D	4	8	4

Check

from Node C

	via A	via B	via D	min dist
to A	7	3	6	3
to B	9	1	3	1
to C	-	-	-	0
to D	12	3	1	1

Example: End of 3rd Full Exchange

No further change in DVs → Convergence!

from Node B

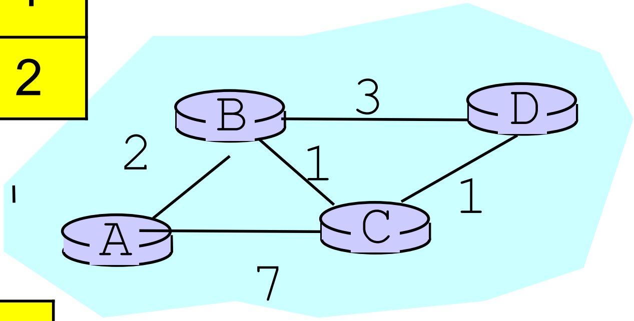
	via A	via C	via D
to A	2	4	7
to B	-	-	-
to C	5	1	4
to D	6	2	3

min dist
2
0
1
2

from Node D

	via B	via C
to A	5	4
to B	3	2
to C	4	1
to D	-	-

min dist
4
2
1
0



from Node A

	via B	via C
to A	-	-
to B	2	8
to C	3	7
to D	4	8

min dist
0
2
3
4

from Node C

	via A	via B	via D
to A	7	3	5
to B	9	1	3
to C	-	-	-
to D	11	3	1

min dist
3
1
0
1

Intuition

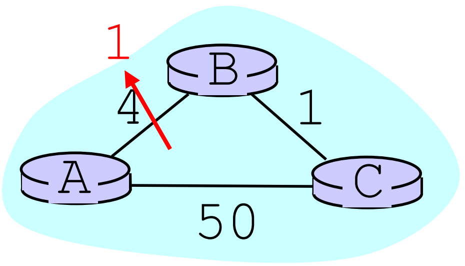
- Initial state: best one-hop paths
- One simultaneous round: best two-hop paths
- Two simultaneous rounds: best three-hop paths
- …
- Kth simultaneous round: best (k+1) hop paths

- Must eventually converge
  - as soon as it reaches longest best path
- …..but how does it respond to changes in cost?

Problems with Distance Vector

- A number of problems can occur in a network using distance vector algorithm
- Most of these problems are caused by slow convergence or routers converging on incorrect information
- *Convergence* is the time during which all routers come to an agreement about the best paths through the internetwork
  - whenever topology changes there is a period of instability in the network as the routers converge
- Reacts rapidly to good news, but leisurely to bad news

DV: Link Cost Changes



via

to

Stable state

Node A

	B	C
B	4	51
C	5	50

Node B

	A	C
A	4	6
C	6	1

Node C

	A	B
A	50	5
B	54	1

A-B changed

Node A

	B	C
B	1	51
C	2	5[illegible]

Node B

	A	C
A	1	6
C	6	1

Node C

	A	B
A	50	5
B	54	1

A sends its DV to B, C

Node A

	B	C
B	1	51
C	[illegible]	[illegible]

Node B

	[illegible]	[illegible]
A	[illegible]	[illegible]
C	3	1

Node C

	A	B
A	50	5
B	51	1

B sends its DV to A, C

Node A

	B	C
B	1	51
C	[illegible]	[illegible]

Node B

	[illegible]	[illegible]
A	[illegible]	[illegible]
C	3	1

Node C

	A	B
A	50	2
B	51	1

C sends its DV to A, B

Node A

	B	C
B	1	51
C	[illegible]	50

Node B

	[illegible]	C
A	[illegible]	3
C	3	1

Node C

	A	B
A	50	2
B	51	1

N

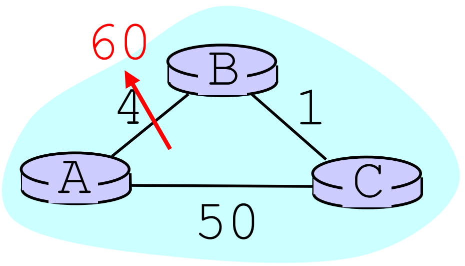
p

deduct 3 from distances $\text{dist}_B(A,*)$ and $\text{dist}_A(B,*)$

Link cost changes here

"good news travels fast"

DV: Link Cost Changes



Stable state

A-B changed

via

to

Node A

Stable state:

	B	C
B	4	51
C	5	50

A-B changed:

	B	C
B	60	51
C	61	50

Node B

Stable state:

	A	C
A	4	6
C	6	1

A-B changed:

	A	C
A	60	6
C	65	1

Node C

Stable state:

	A	B
A	50	5
B	54	1

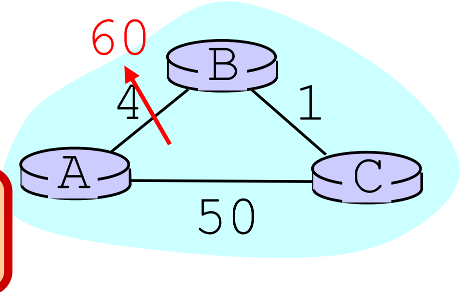
A-B changed:

	A	B
A	50	5
B	54	1

add 56 to distances
$\text{dist}_B(A,*)$ and $\text{dist}_A(B,*)$

Link cost changes here

DV: Link Cost Changes



This is the "Counting to Infinity" Problem

Stable state

via

Node A

to

	B	C
B	4	51
C	5	50

Node B

	A	C
A	4	6
C	9	1

Node C

	A	B
A	50	5
B	54	1

A-B changed

Node A

	B	C
B	60	51
C	61	50

Node B

	A	C
A	60	6
C	65	1

Node C

	A	B
A	50	5
B	54	1

A sends its DV to B, C

Node A

	B	C
B	60	51
C	61	50

Node B

	A	C
A	60	6
C	110	1

Node C

	A	B
A	50	5
B	101	1

B sends its DV to A, C

Node A

	B	C
B	60	51
C	61	50

Node B

	A	C
A	60	6
C	110	1

Node C

	A	B
A	50	7
B	101	1

C sends its DV to A, B

Node A

	B	C
B	60	51
C	61	50

Node B

	A	C
A	60	8
C	110	1

Node C

	A	B
A	50	7
B	101	1

Link cost changes here

"bad news travels slowly"
(not yet converged)

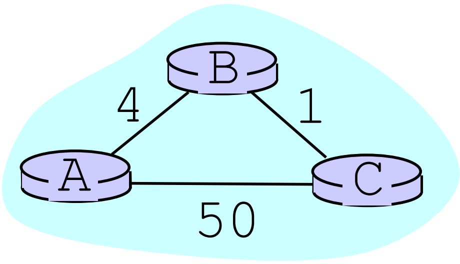
The “Poisoned Reverse” Rule

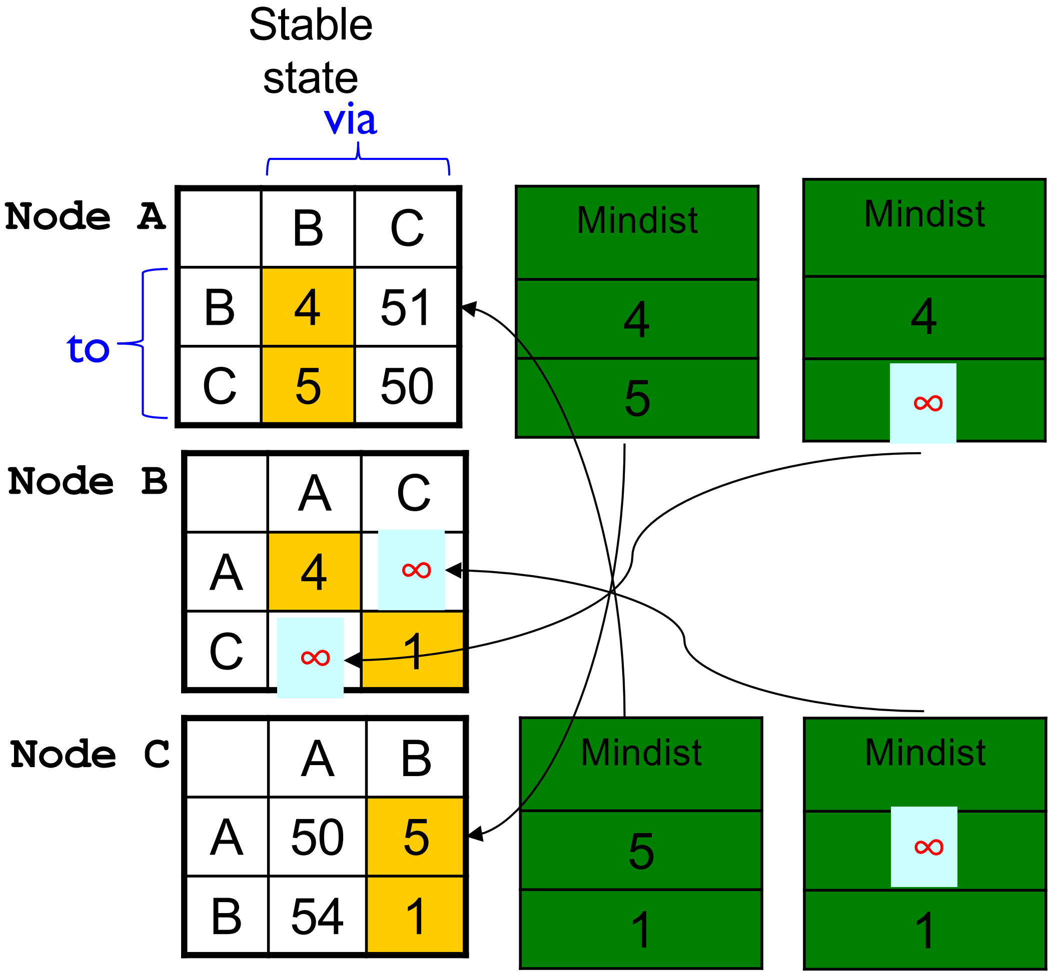
- Heuristic to avoid count-to-infinity

- If B routes via C to get to A:
  - B tells C its (B’s) distance to A is infinite (so C won’t route to A via B)

DV: Poisoned Reverse

If B routes through C to get to A:
B tells C its (B's) distance to A is infinite





Stable state

via

to

Node A

	B	C
B	4	51
C	5	50

Node B

	A	C
A	4	∞
C	∞	1

Node C

	A	B
A	50	5
B	54	1

Mindist
4
5

Mindist
4
∞

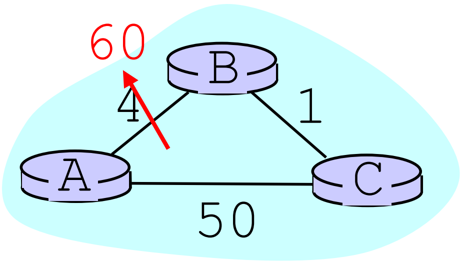
Mindist
5
1

Mindist
∞
1

DV: Poisoned Reverse

If B routes through C to get to A:

B tells C its (B's) distance to A is infinite



Stable state

A-B changed

via

to

Node A

Stable state:

	B	C
B	4	51
C	5	50

A-B changed:

	B	C
B	60	51
C	61	50

Node B

Stable state:

	A	C
A	4	∞
C	∞	1

A-B changed:

	A	C
A	60	6
C	65	1

Node C

Stable state:

	A	B
A	50	5
B	54	1

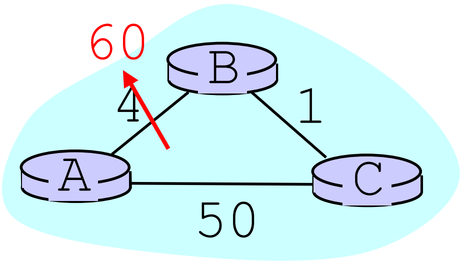
A-B changed:

	A	B
A	50	5
B	54	1

Link cost changes here

DV: Poisoned Reverse

If B routes through C to get to A:
B tells C its (B's) distance to A is infinite



Stable state | A-B changed | A sends its DV to B, C | B sends its DV to A, C

via

to

Node A

Stable state

	B	C
B	4	51
C	5	50

A-B changed

	B	C
B	60	51
C	61	50

A sends its DV to B, C

	B	C
B	60	51
C	61	50

B sends its DV to A, C

	B	C
B	60	51
C	61	50

Node B

Stable state

	A	C
A	4	∞
C	∞	1

A-B changed

	A	C
A	60	∞
C	∞	1

A sends its DV to B, C

	A	C
A	60	∞
C	110	1

B sends its DV to A, C

	A	C
A	60	∞
C	110	1

Node C

Stable state

	A	B
A	50	5
B	54	1

A-B changed

	A	B
A	50	5
B	54	1

A sends its DV to B, C

	A	B
A	50	5
B	∞	1

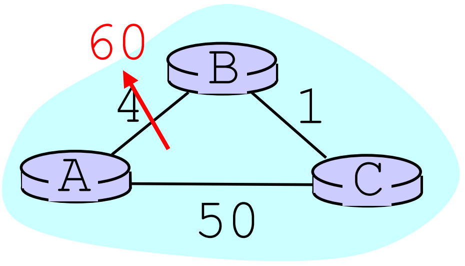
B sends its DV to A, C

	A	B
A	50	7
B	∞	1

Link cost changes here

DV: Poisoned Reverse

If B routes through C to get to A:
B tells C its (B’s) distance to A is infinite



Stable state — A-B changed — A sends its DV to B, C — B sends its DV to A, C

via

Node A

to

	B	C
B	4	51
C	5	50

	B	C
B	60	51
C	61	50

	B	C
B	60	51
C	61	50

	B	C
B	60	51
C	61	50

Node B

	A	C
A	4	∞
C	∞	1

	A	C
A	60	∞
C	∞	1

	A	C
A	60	∞
C	110	1

	A	C
A	60	∞
C	110	1

Node C

	A	B
A	50	5
B	54	1

	A	B
A	50	5
B	54	1

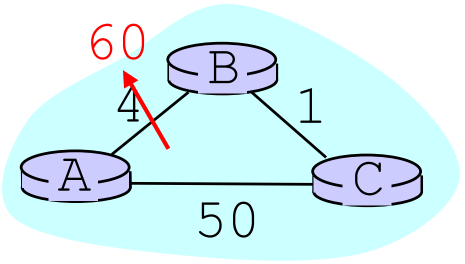
	A	B
A	50	5
B	∞	1

	A	B
A	50	61
B	∞	1

Link cost changes here

DV: Poisoned Reverse

If B routes through C to get to A:
B tells C its (B's) distance to A is infinite



Stable state

via

to

Node A

	B	C
B	4	51
C	5	50

Node B

	A	C
A	4	∞
C	∞	1

Node C

	A	B
A	50	5
B	54	1

A-B changed

Node A

	B	C
B	60	51
C	61	50

Node B

	A	C
A	60	∞
C	∞	1

Node C

	A	B
A	50	5
B	54	1

A sends its DV to B, C

Node A

	B	C
B	60	51
C	61	50

Node B

	A	C
A	60	∞
C	110	1

Node C

	A	B
A	50	5
B	∞	1

B sends its DV to A, C

Node A

	B	C
B	60	51
C	61	50

Node B

	A	C
A	60	∞
C	110	1

Node C

	A	B
A	50	61
B	∞	1

C sends its DV to A, B

Node A

	B	C
B	60	51
C	61	50

Node B

	A	C
A	60	51
C	110	1

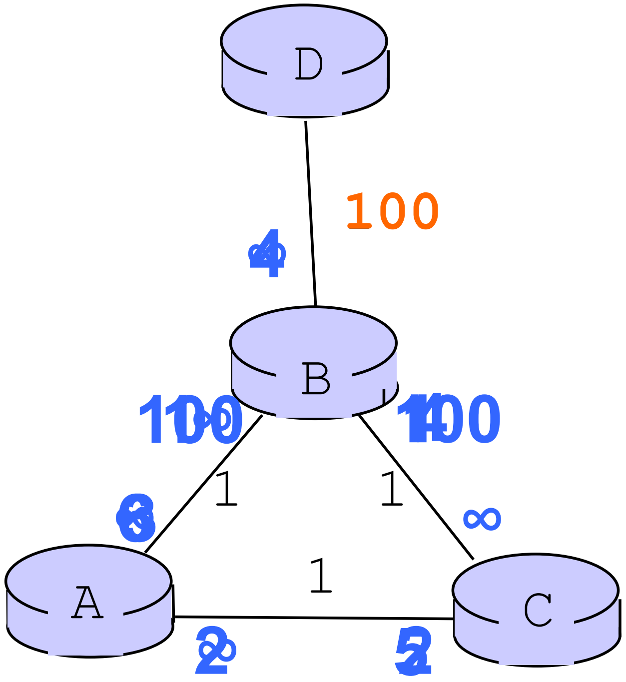
Node C

	A	B
A	50	∞
B	∞	1

Link cost changes here

Converges after C receives another update from B

Will Poison-Reverse Completely Solve the Count-to-Infinity Problem?



Numbers in blue denote the best cost
to destination D advertised along the link

Comparison of LS and DV algorithms

message complexity

- ***LS:*** with n nodes, E links, O(nE) msgs sent
- ***DV:*** exchange between neighbors only
  - convergence time varies

speed of convergence

- ***LS:*** O(n^2) algorithm requires O(nE) msgs
  - may have oscillations
- ***DV:*** convergence time varies
  - may be routing loops
  - count-to-infinity problem

robustness: what happens if router malfunctions?

LS:

- node can advertise incorrect *link* cost
- each node computes only its *own* table

DV:

- DV node can advertise incorrect *path* cost
- each node' s table used by others
  - error propagate thru network

Real Protocols

Link State

Open Shortest Path First (OSPF)

Intermediate system to intermediate system (IS-IS)

Distance Vector

Routing Information Protocol (RIP)

Interior Gateway Routing Protocol (IGRP-Cisco)

Border Gateway Protocol (BGP)

Network layer, control plane: outline

5.1 introduction

5.2 routing protocols

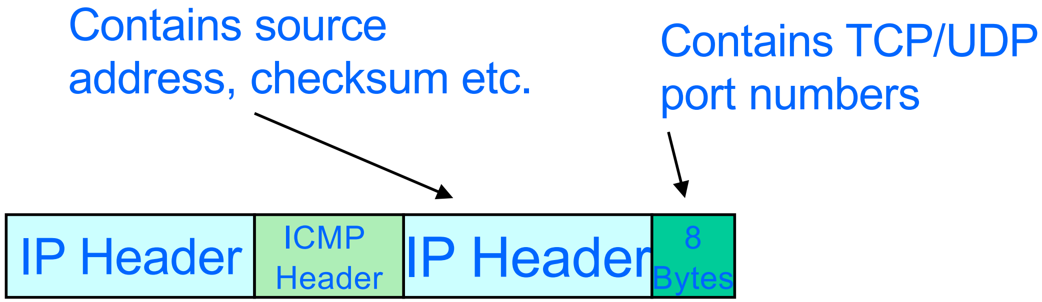
- link state
- distance vector
- hierarchical routing

Self study

5.6 ICMP: The Internet Control Message Protocol

ICMP: Internet Control Message Protocol

- Used by hosts & routers to communicate network level infromation
  - Error reporting: unreachable host, network, port
  - Echo request/reply (used by ping)
- Works above IP layer
  - ICMP messages carried in IP datagrams
- ICMP message: type, code plus IP header and first 8 bytes of IP datagram payload causing error



Contains source address, checksum etc.

Contains TCP/UDP port numbers

ICMP: Internet Control Message Protocol

Type	Code	Description
0	0	echo reply(ping)
3	0	dest. network unreachable
3	1	dest host unreachable
3	3	dest port unreachable
3	4	frag needed; DF set
8	0	echo request(ping)
11	0	TTL expired
11	1	frag reassembly time exceeded
12	0	bad IP header

Traceroute and ICMP

- Source sends series of UDP segments to dest
  - first set has TTL =1
  - second set has TTL=2, etc.
  - unlikely port number
- When *n*th set of datagrams arrives to nth router:
  - router discards datagrams
  - and sends source ICMP messages (type 11, code 0)
  - ICMP messages includes IP address of router

- when ICMP messages arrives, source records RTTs

stopping criteria:

- UDP segment eventually arrives at destination host
- destination returns ICMP "port unreachable" message (type 3, code 3)
- source stops