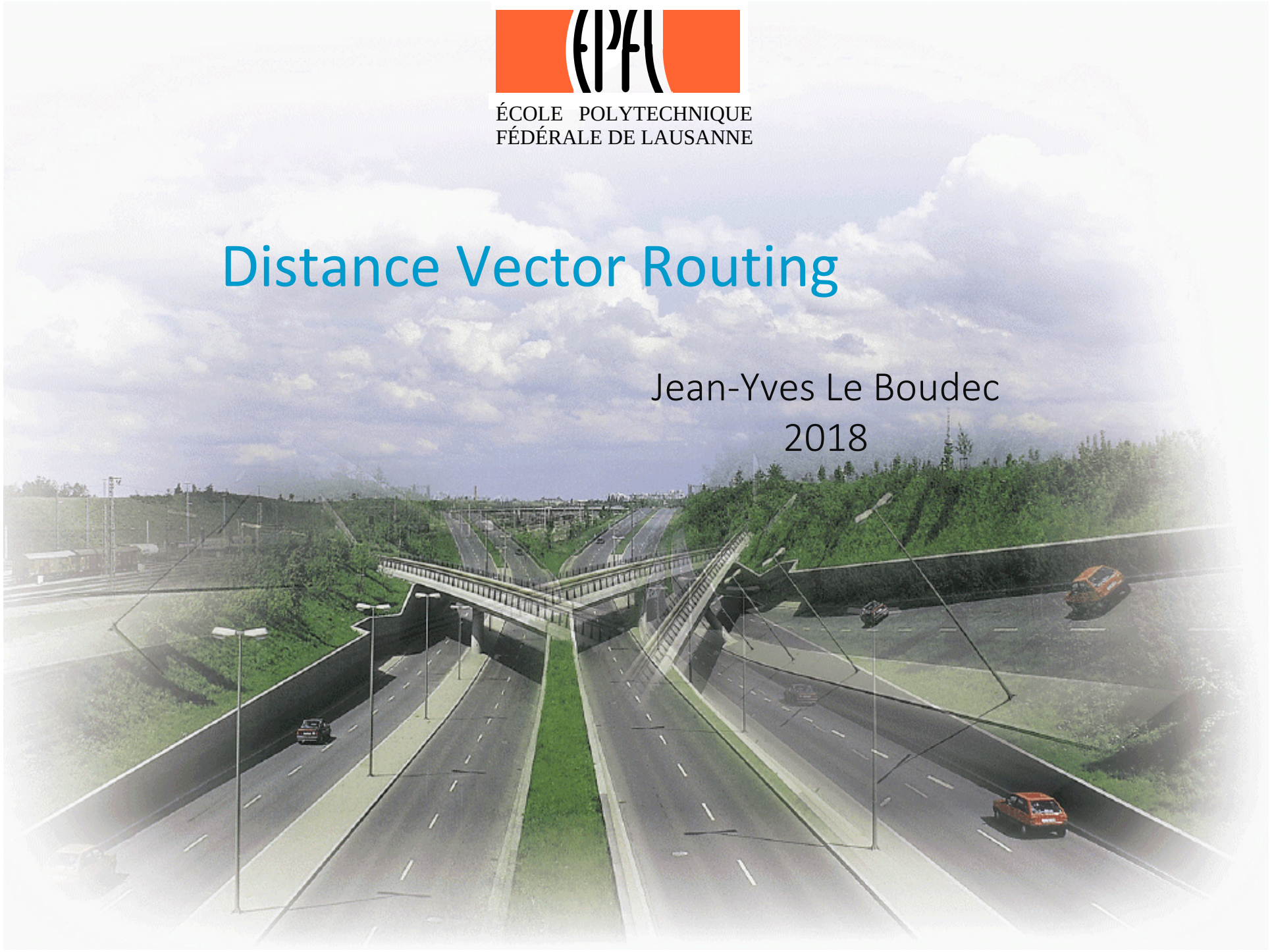


ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Distance Vector Routing

Jean-Yves Le Boudec

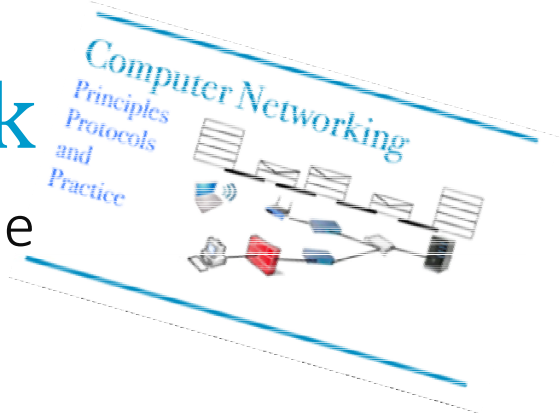
2018

Contents

1. Distance vector: theory
2. Distance vector: practice

Textbook

Section 5.1.1, The control plane



1. Distance Vector: Theory

What it does: it computes shortest paths to all destinations

- Cost of a path = sum of the cost of network links along the path
- Cost of a link is setup by configuration
- Shortest path = path whose cost is minimal
- Distance from node A to node B = cost of a shortest path from A to B

How it works

- uses the “Distributed Bellman-Ford” algorithm
- Fully distributed
- Using as only information the distances from self to all destinations

The *Centralized* Bellman-Ford Algorithm

Algorithm BF-C

input: a directed graph with links costs $A(i,j)$; assume $A(i,j)>0$ and $A(i,j) = \infty$ when nodes i and j are not connected.

output: vector p s.t. $p(i)$= cost of best path from node i to node 1

$p^0(1) = 0, \quad p^0(i) = \infty$ for $i \neq 1$

for $k = 1,2, \ldots$ **do**

$$p^k(i) = \min_{j \neq i}[A(i,j) + p^{k-1}(j)] \text{ for } i \neq 1$$

$$p^k(1) = 0$$

until $p^k = p^{k-1}$

return(p^k)

Example: shortest paths to node 1: run BF-C for $k = 1$

$p^0(1) = 0, \quad p^0(i) = \infty$ for $i \neq 1$

for $k = 1,2, \ldots$ **do**

$p^k(i) = \min_{j \neq i}[A(i,j) + p^{k-1}(j)]$ for $i \neq 1$

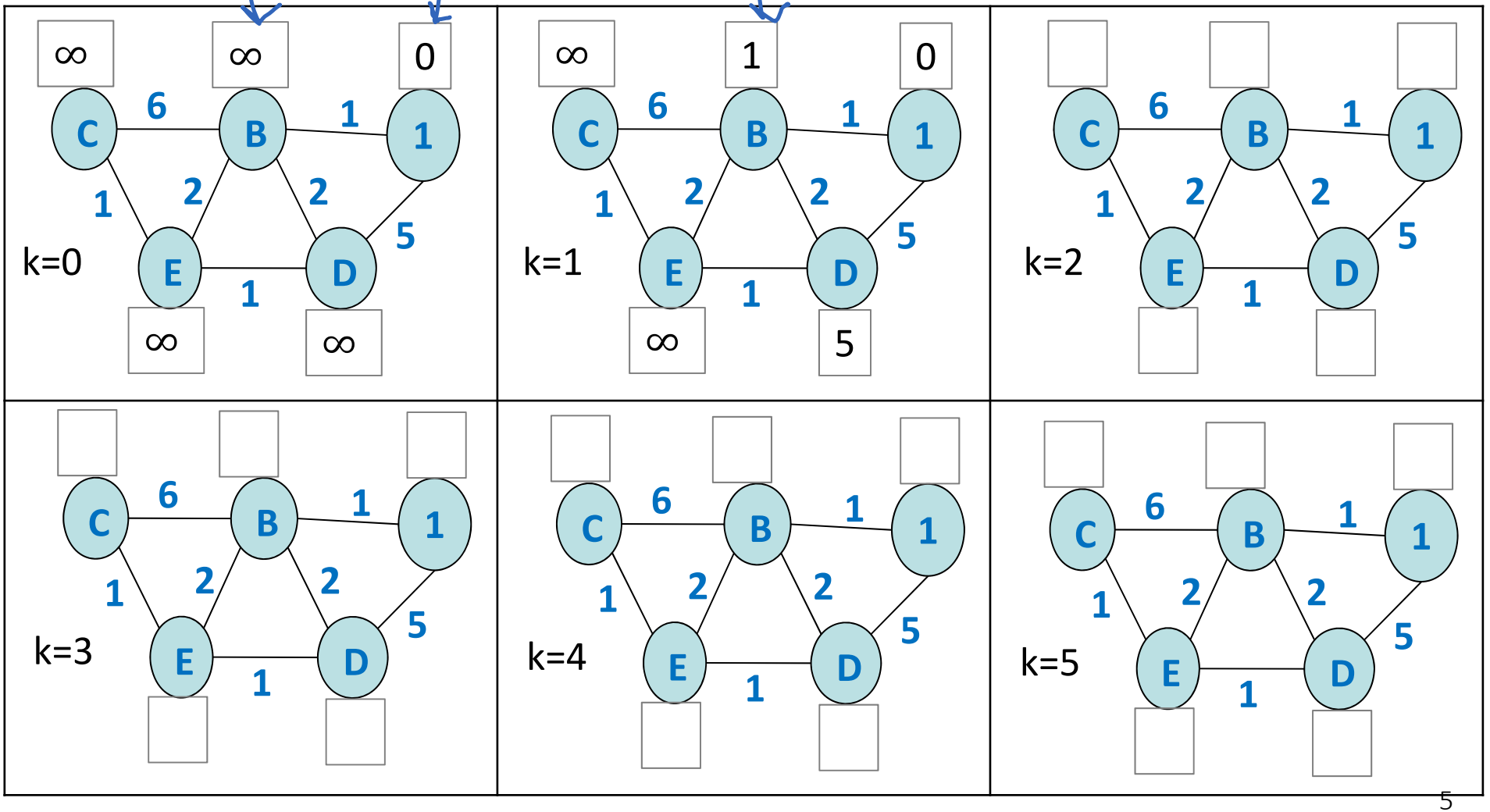
$p^k(1) = 0$

until $p^k = p^{k-1}$

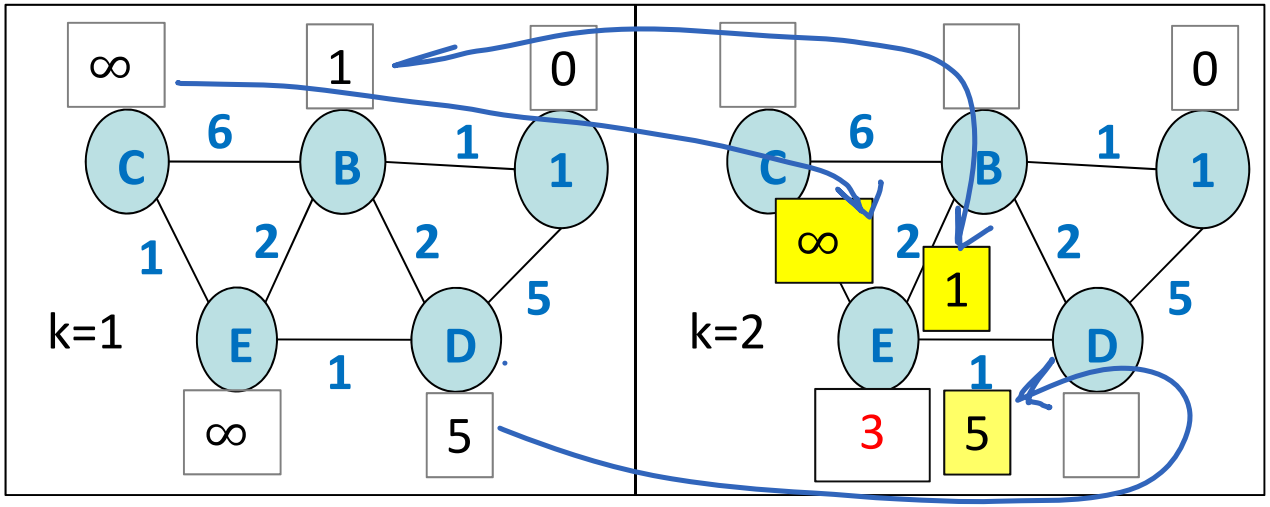
return(p^k)

BF-C

$p^0(B) = \infty$ $p^0(1) = 0$ $p^1(B) = 1$



Message Passing Interpretation of Bellman-Ford



$p^0(1) = 0, \quad p^0(i) = \infty$ for $i \neq 1$

for $k = 1,2, \ldots$ **do**

$p^k(i) = \min_{j \neq i}[A(i,j) + p^{k-1}(j)]$ f

$p^k(1) = 0$

until $p^k = p^{k-1}$

return(p^k)

With BF-C it is as if :

at iteration k, node i receives from neighbors j their previous costs $p^{k-1}(j)$ and updates own cost by picking the best

BF-C can be interpreted as a *synchronous* message passing algorithm

synchronous = nodes wait until iteration $k-1$ is finished before starting iteration k

Example: shortest paths to node 1: run BF-C, $k = 2, 3$

$p^0(1) = 0, \quad p^0(i) = \infty$ for $i \neq 1$

for $k = 1,2, \ldots$ **do**

$p^k(i) = \min_{j \neq i}[A(i,j) + p^{k-1}(j)]$ for $i \neq 1$

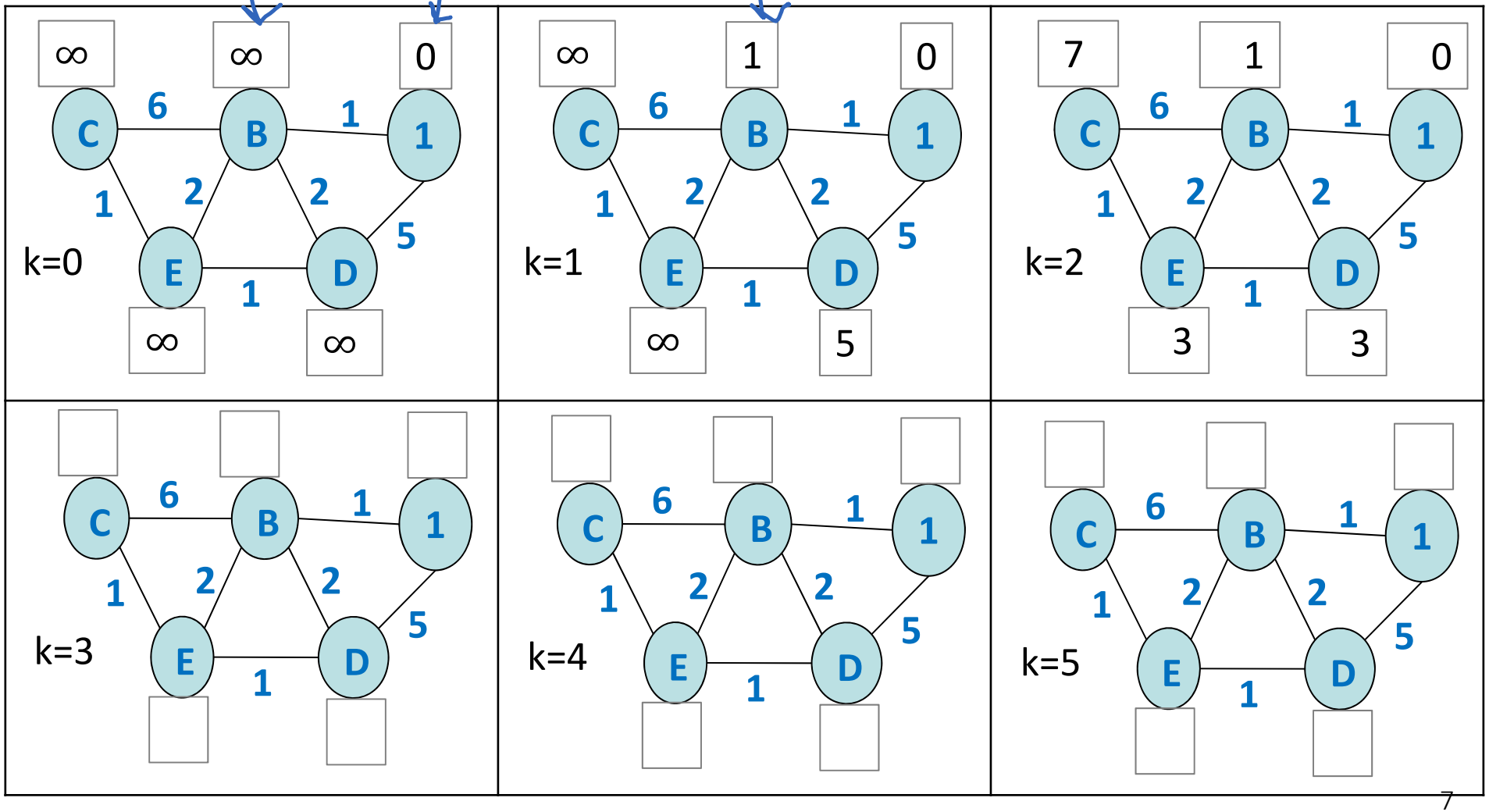
$p^k(1) = 0$

until $p^k = p^{k-1}$

return(p^k)

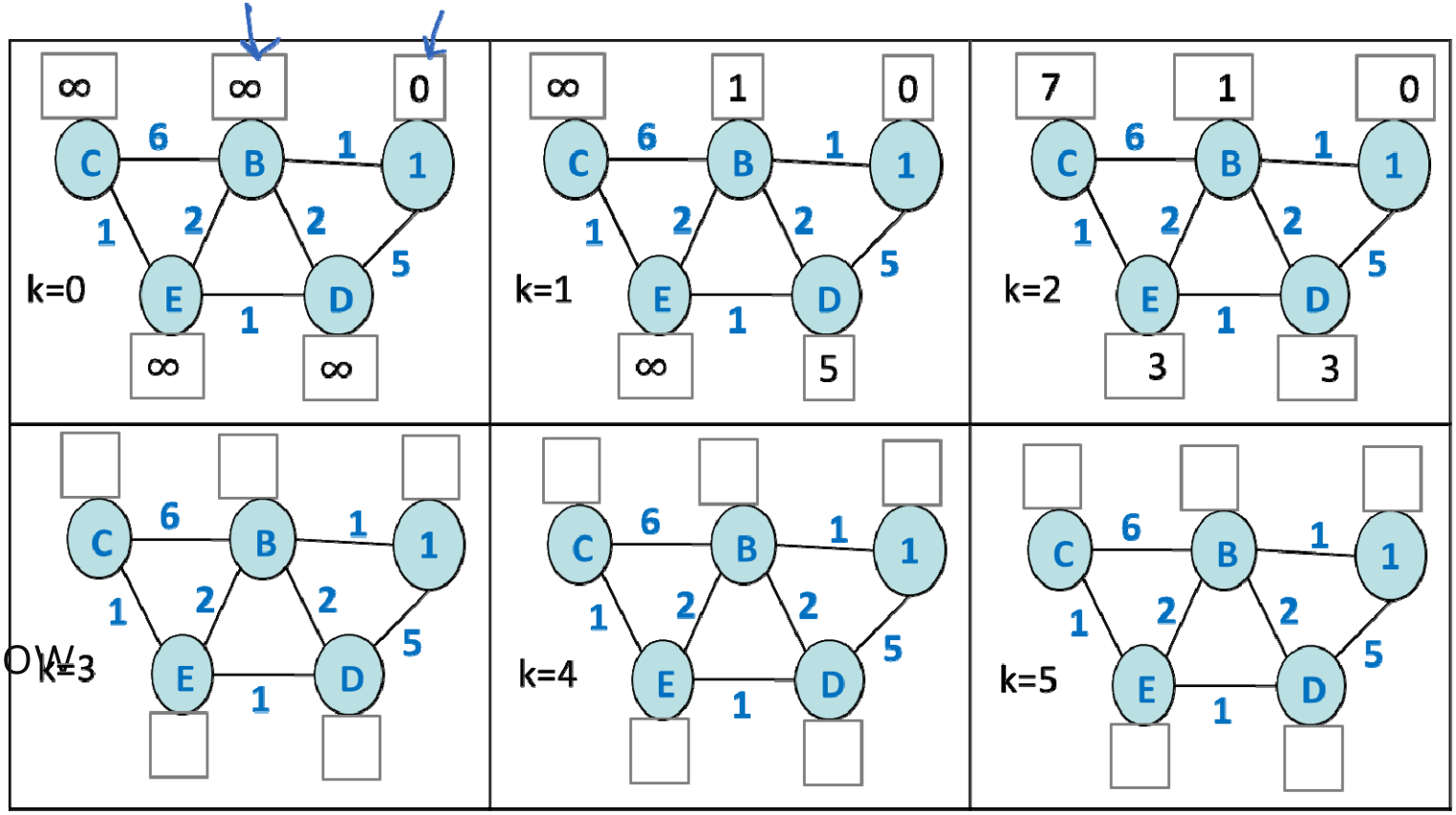
BF-C

$p^0(B) = \infty$ $p^0(1) = 0$ $p^1(B) = 1$



At which k does the algorithm stop ?
(i.e. what is the smallest k such that $p^k = p^{k-1}$?)

A. k = 1
B. k = 2
C. k = 3
D. k = 4
E. k = 5
F. k ≥ 6
G. I don't know



Correctness of BF-C

Algorithm BF-C

input: a directed graph with links costs $A(i,j)$; assume $A(i,j)>0$ and $A(i,j) = \infty$ when nodes i and j are not connected.

output: vector p s.t. $p(i)$= cost of best path from node i to node 1

$p^0(1) = 0, \;\; p^0(i) = \infty$ for $i \neq 1$

for $k = 1,2, \ldots$ **do**

$$p^k(i) = \min_{j \neq i}[A(i,j) + p^{k-1}(j)] \text{ for } i \neq 1$$

$$p^k(1) = 0$$

until $p^k = p^{k-1}$

return(p^k)

Theorem 1

1.If the network is fully connected, BF-C stops at the latest at $k = n$ (where $n =$ number of nodes) and outputs the distance along shortest path from i to 1, for all i

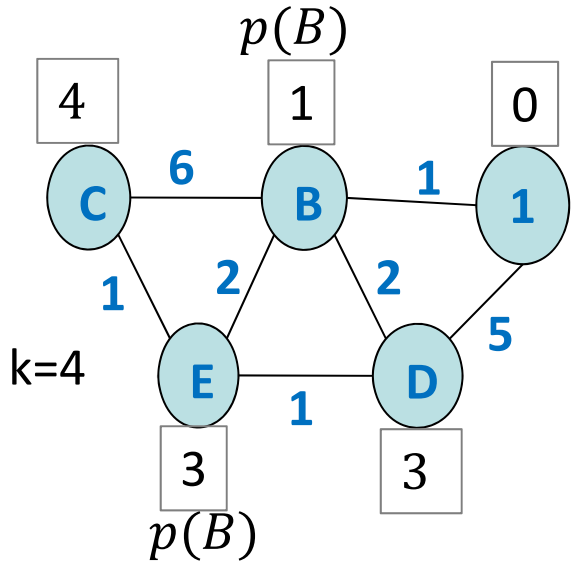
2.$p^k(i)$ is the distance from i to 1 in at most k hops

3.The next hop along a shortest path from $i \neq 1$ to 1 is found by nextHop(i) $\in$ Argmin$_{j \neq i}$ $[A(i,j) + p(j)]$

Computation of shortest path tree

3. The next hop along a shortest path from $i \neq 1$ to 1 is found by $\text{nextHop(i)} \in \text{Argmin}_{j \neq i} \; [A(i,j) \; + \; p(j)]$

When algorithm has converged, the next hop of node C is obtained by looking for j that minimizes $A(C,j) + p(j)$



$j = B$: $6 + 1 = 7$

$j = E$: $1 + 3 = 4$

$other\ j$: ∞

$Argmin\ is\ \{j = E\}$

$nextHop(C) = E$

Assume we start from other initial conditions. What will happen ?

~~$p^0(1) = 0,\ p^0(i) = \infty$ for $i \neq 1$~~

replaced by values on graph →

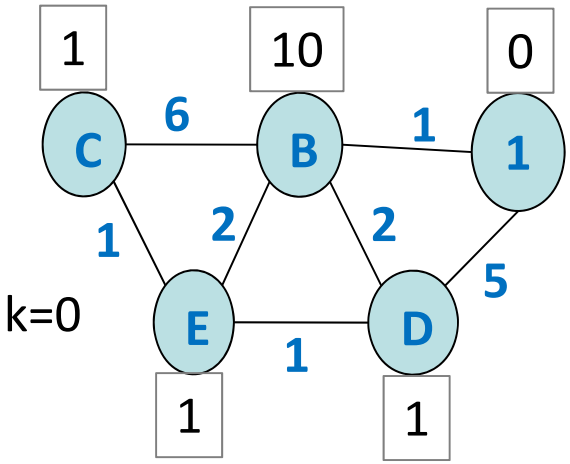
for $k = 1,2, \ldots$ **do**

$$p^k(i) = \min_{j \neq i}[A(i,j) + p^{k-1}(j)] \text{ for } i \neq 1$$

$$p^k(1) = 0$$

until $p^k = p^{k-1}$

return(p^k)



A. The algorithm converges to the correct distances
B. The algorithm does not converge
C. The algorithm converges but not to the correct distances
D. I don't know

Run BF-C with bizarre initial conditions

the value of $p^1(D)$ is…

for $k = 1,2,\ldots$ **do**

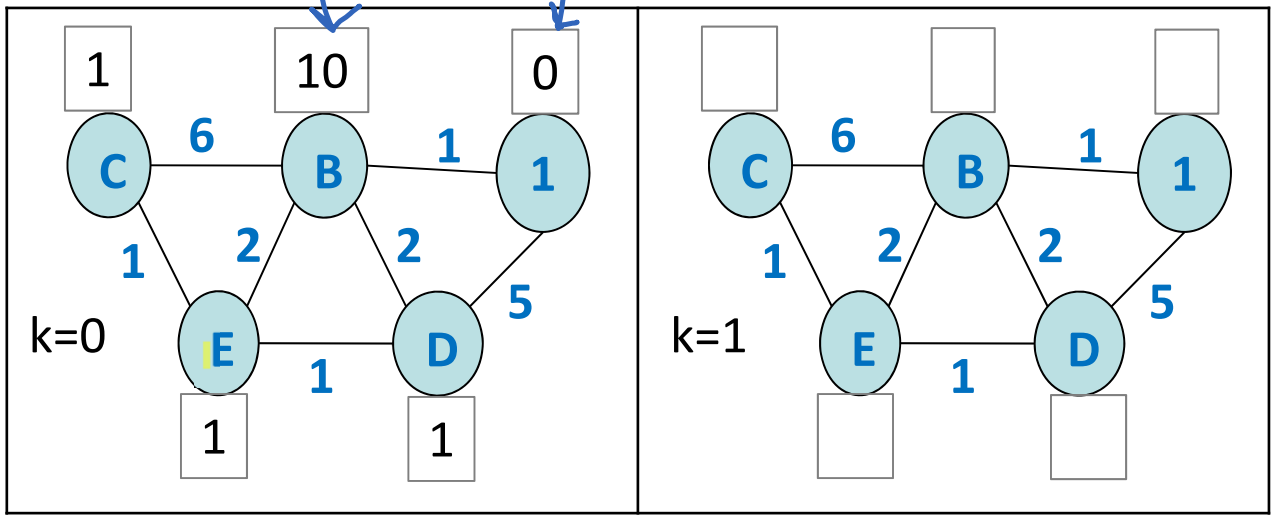
$p^k(i) = \min_{j \neq i}[A(i,j) + p^{k-1}(j)]$ for $i \neq 1$

$p^k(1) = 0$

until $p^k = p^{k-1}$

return(p^k)

$p^0(B) = 10$ $p^0(0) = 0$



$p^1(D) = ?$

A. 1

B. 2

C. 3

D. 4

E. 5

F. ≥ 6

G. I don't know

Assume we break some links and start from these initial conditions. What will happen ?

$p^0(1) = 0, \;\; p^0(i) = \infty$ for $i \neq 1$

replaced by values on graph →

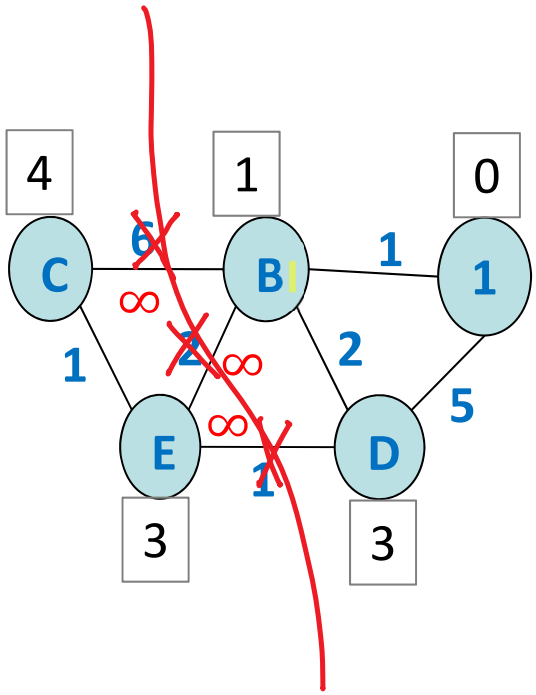
for $k = 1,2, \ldots$ **do**

$p^k(i) = \min_{j \neq i}[A(i,j) + p^{k-1}(j)]$ for $i \neq 1$

$p^k(1) = 0$

until $p^k = p^{k-1}$

return(p^k)



A. The algorithm converges to the correct distances
B. The algorithm does not converge
C. The algorithm converges but not to the correct distances
D. I don't know

Run BF-C with disconnected network the value of $p^1(E)$ is…

$p^0(1) = 0,\ \ p^0(i) = \infty$ for $i \neq 1$

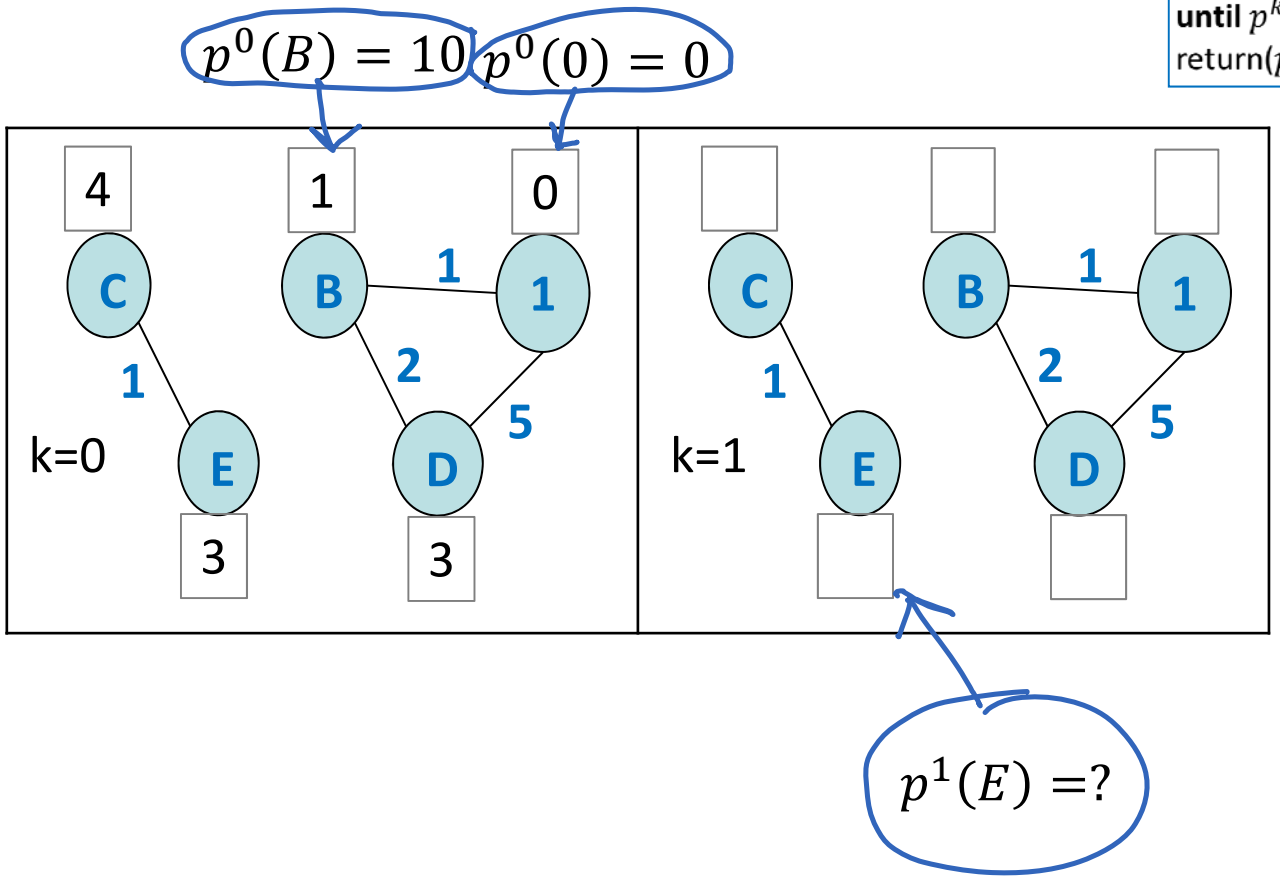
for $k = 1,2, \ldots$ **do**

$p^k(i) = \min_{j \neq i}[A(i,j) + p^{k-1}(j)]$ for $i \neq 1$

$p^k(1) = 0$

until $p^k = p^{k-1}$

return(p^k)



A. 1

B. 2

C. 3

D. 4

E. 5

F. ≥ 6

G. I don't know

Correctness of BF-C with arbitrary initial condition and arbitrary network

Algorithm BF-C

input: a directed graph with links costs $A(i,j)$; assume $A(i,j)>0$ and $A(i,j) = \infty$ when nodes i and j are not connected.

output: vector p s.t. $p(i)$= cost of best path from node i to node 1

~~$p^0(1) = 0,\ p^0(i) = \infty$ for $i \neq 1$~~

$p^0(i) =$ any nonnegative value

for $k = 1,2, \ldots$ **do**

$$p^k(i) = \min_{j \neq i}[A(i,j) + p^{k-1}(j)] \text{ for } i \neq 1$$

$$p^k(1) = 0$$

until $p^k = p^{k-1}$

return(p^k)

Theorem 2

1.If there is a path from i to 1, then for k large enough $p^k(i) = p(i) \forall i$ where $p(i)$ is the distance from i to 1. It follows that if the network is fully connected, BF-C with arbitrary initial conditions terminates and eventually computes the correct distances. However, in general, when k is small $p^k(i)$ is *not* the distance from i to 1 in $\leq k$ hops.

2.If there is no path from i to 1 then $\lim_{k \to \infty} p^k(i) = \infty$. It follows that if the network is not fully connected, BF-C does not terminate ("count to infinity").

Proof

We do the proof assuming all nodes are connected.

1. Let p^k be the vector $p^k[i]$, i=2,…. Let B be the mapping that transforms an array $x[i]_{i=2\ldots}$ into the array Bx defined for $i \neq 1$ by

   $$Bx[i]=\min_{j \neq i,\, j \neq 1}[A(i,j) + x(j)]$$

   Let b be the array defined for $i \neq 1$ by

   $$b[i]= A(i,1)$$

   The algorithm can be rewritten in vector form as

   (1) $p^k = B\, p^{k-1} \wedge b$

   where $\wedge$ is the pointwise minimum

2. Eq (1) is a min-plus linear equation and the operator B satisfies $B(x \wedge y)= Bx \wedge By$. Thus, Eq(1) can be solved using min-plus algebra into

   (2) $p^k = B^k p^0 \wedge B^{k-1} b \wedge \ldots \wedge Bb \wedge b$

3. Define the array e for $i \neq 1$ by $e[i]= \infty$. Let $p^0=e$. Eq (2) becomes

   (3) $p^k = B^{k-1} b \wedge \ldots \wedge Bb \wedge b$. Now we have the Bellman Ford algorithm with classical initial conditions, thus, by Theorem 1:

   (4) for $k \geq n-1$: $B^{k-1} b \wedge \ldots \wedge Bb \wedge b = q$

   where q[i] is the distance from i to 1.

4. We can rewrite Eq(2) for $k \geq n-1$ as

   (5) $p^k = B^k p^0 \wedge q$

5. $B^k p^0[i]$ can be written as $A[i,i_1]+ A[i_1,i_2]+ \ldots + A[i_{k-1},i_k]+ p[i_k]$ thus

   (6) $B^k p^0[i] \geq k\, a$, where a is the minimum of all A[i,j]. Thus $B^k p^0[i]$ tends to ∞ when k grows. Thus for k large enough, $B^k p^0$ is larger than q and can be ignored in Eq(5). In other words, for k large enough :

   (6) $p^k = q$

Distributed Bellman Ford

BF-C can be used to compute p(i) i.e. find the shortest path. However, this is not its main interest, because there is a better algorithm (Dijkstra) that can be used in a centralized way.

But: it can be distributed as follows.

Distributed Bellman-Ford Algorithm , BF-prelim

node i maintains an estimate $q(i)$ of the true distance $p(i)$ to node 1;
node i also keeps a record of latest values $q(j)$ for all neighbors j
initial conditions are arbitrary but $q(1) = 0$ at all steps;

from time to time, i sends its value $q(i)$ to all neighbours

when i receives an updated value $q(j)$ from neighbor j, node i recomputes $q(i)$:

eq (1) $\quad q(i) \leftarrow \min_{j \text{ neighbor}} \left(\mathrm{A(i,j)} + \mathrm{q(j)}\right)$

nextHop(i) is set to a value of j that achieves the min in eq(1)

This is *asynchronous* message passing, i.e. nodes do not wait for complete rounds of iteration to be performed.

Correctness of BF-prelim

Theorem: Assume at least one message is reliably sent to all neighbors by every node every T time units and the network is fully connected. BF-prelim converges to the same result as the centralized version BF-C (i.e. to the correct distances) in $\leq mT$ time units, where m is the number of steps performed by BF-C with same initial conditions.

Distributed Bellman-Ford Algorithm , BF-prelim

node i maintains an estimate $q(i)$ of the true distance $p(i)$ to node 1;
node i also keeps a record of latest values $q(j)$ for all neighbors j
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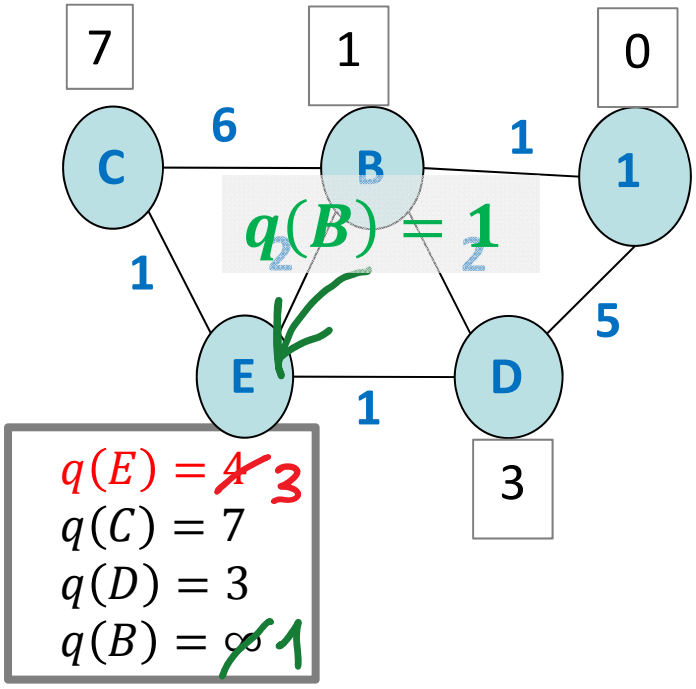
nextHop(i) is set to a value of j that achieves the min in eq(1)

Distributed Bellman-Ford BF-prelim



A possible run of algorithm BF-prelim. The table shows the successive values of $q(i)$

q(i)	1	B	C	D	E
	0	∝	∝	∝	∝
1 -> B	0	1	∝	∝	∝
B -> D	0	1	∝	3	∝
B -> C	0	1	7	3	∝
C -> E	0	1	7	3	8
D -> E	0	1	7	3	4
1 -> D	0	1	7	3	4
B -> E	0	1	7	3	3
E -> B	0	1	7	3	3
E -> C	0	1	4	3	3

$$q(E) \leftarrow \min(1 + 2, 7 + 1, 3 + 1) = 3$$

Converged !

Super-Duper Bellman-Ford

BF-prelim requires a node to remember all estimates *q(j)* received from all neighbors j, even for j not on the shortest path to destination; can we do better ?

A possible modification would be to replace eq(1) by

Super-Duper Bellman-Ford:

when i receives an updated value $q(j)$ from neighbor j, node i recomputes $q(i)$:

eq (1s) $\quad q(i) \leftarrow \min_{j \text{ neighbor}} (A(i,j) + q(j),\ q(i))$

Node *i* now needs to store only its own estimate $q(i)$

Q. does this work ?

Is Super-Duper Bellman-Ford correct ?

when i receives an updated value $q(j)$ from neighbor j, node i recomputes $q(i)$:

eq (1s) $\quad q(i) \leftarrow \min_{j \text{ neighbor}} (A(i,j) + q(j),\ q(i))$

A. Yes, regardless of initial condition
B. Only if initial conditions are $q(i) = \infty, i \neq 0$ and $q(1) = 0$ at time 0
C. It may fail, even with initial conditions as in 2.
D. I don't know

Distributed Bellman-Ford

Requires only to remember distance from self to destination + the best neighbor (nextHop(i))

and works for all initial conditions

Distributed Bellman-Ford Algorithm, BF-D

node i maintains an estimate $q(i)$ of the distance $p(i)$ to node 1;
node i remembers the best neighbor nextHop(i)

initial conditions are arbitrary but $q(1) = 0$ at all steps;

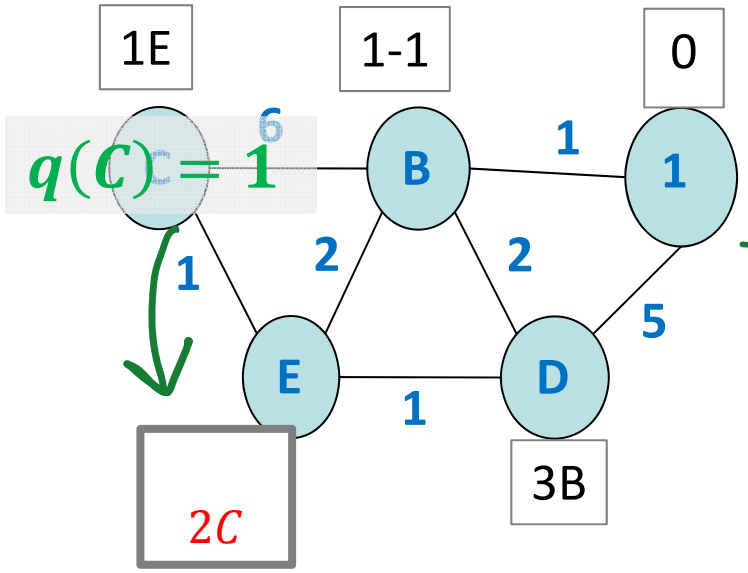
from time to time, i sends its value $q(i)$ to all neighbors

when i receives an updated value $q(j)$ from j, node i recomputes $q(i)$:

eq (2) if $j ==$ nextHop(i)
then $q(i) \leftarrow A(i,j) + q(j)$
else $q(i) \leftarrow \min\big(A(i,j) + q(j),\ q(i)\big)$

if eq(2) causes $q(i)$ to be modified, nextHop$(i) \leftarrow j$

Distributed Bellman-Ford BF-D

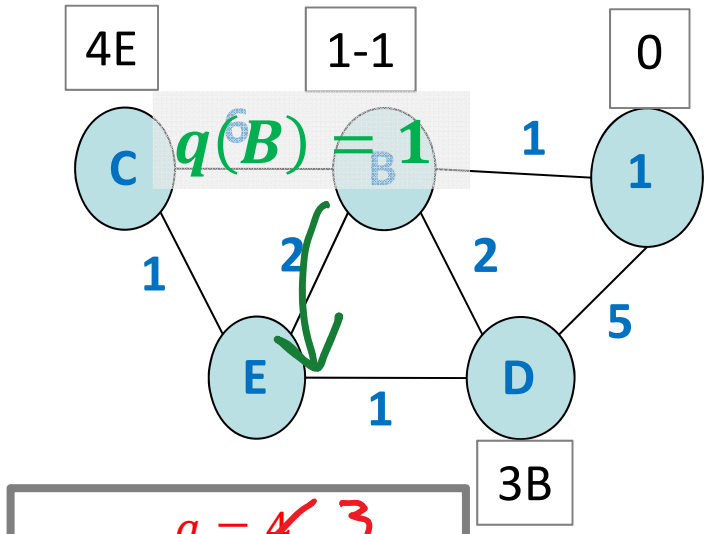


A possible run of algorithm BF-D. The table shows the successive values of $q(i)$ and nextHop

i	1	B	C	D	E
	0	10C	1E	6E	1C
1 -> B	0	1-1	1E	6E	1C
B -> D	0	1-1	1E	3B	1C
B -> C	0	1-1	1E	3B	1C
B -> E	0	1-1	1E	3B	1C
D -> E	0	1-1	1E	3B	1C
C -> E	0	1-1	1E	3B	2C

$$q(E) \leftarrow 1 + 1 = 2$$

Distributed Bellman-Ford BF-D, cont'd



$$q(E) \leftarrow \min(1 + 2, 4) = 3$$
$$\text{nextHop}(E) \leftarrow B$$

A possible run of algorithm BF-D. The table shows the successive values of $q(i)$

i	1	B	C	D	E
	0	10C	1E	6E	1C
1 -> B	0	1-1	1E	6E	1C
B -> D	0	1-1	1E	3B	1C
B -> C	0	1-1	1E	3B	1C
B -> E	0	1-1	1E	3B	1C
D -> E	0	1-1	1E	3B	1C
C -> E	0	1-1	1E	3B	2C
E -> C	0	1-1	2E	3B	2C
C -> E	0	1-1	2E	3B	3C
E -> C	0	1-1	3E	3B	3C
C -> E	0	1-1	3E	3B	4C
E -> C	0	1-1	4E	3B	4C
B -> E	0	1-1	4E	3B	3B

Correctness of BF-D

Theorem: Assume at least one message is reliably sent to all neighbors by every node every T time units and the network is fully connected. BF-D converges to the same result as the centralized version BF-C (i.e. to the correct distances) in $\leq mT$ time units, where m is the number of steps performed by BF-C with same initial conditions.

Comment: The main difference with BF-prelim is that eq(2) replaces eq(1). Assume we use BF-D, and we start from a condition such that q(i) is indeed equal to the minimum given by eq (1) (which is what, intuitively, is true most of the time).

When j is not equal to nextHop(i), both eq(1) and eq(2) have the same effect: the new value of q(i) is the same in both cases. In contrast, if j == nextHop(i), then eq (2) sets q(i) to the new value A(i,j)+q(j), whereas eq(1) sets it to $\min_{j \text{ neighbor}}$ (A(i,j)+q(j)). Eq(2) provides an upper bound on eq(1), in this case. It turns out that the algorithm still works, by the same mechanism that makes the algorithm work even when the initial conditions are arbitrary. Indeed, node i will send its new value to all remaining neighbors, who will in turn do an update and eventually, node i will receive values of q(j) that will correct the problem. In other words, if the new value of q(i) is too high (compared to what would be obtained with eq (1)), this is repaired in one round of exchanges with the neighbors.

Recap

Bellman-Ford, Distributed (BF-D), allows a node to compute distances to one destination

Stored information is:

- Next hop to destination
- Distance to destination

BF-D works by message passing: every node informs its neighbors of its current distance

BF-D works even when initial conditions are not as expected (which occurs due to topology changes)

If destination is unreachable (distance $= \infty$) then the algorithm counts to infinity.

2. Distance Vector routing in practice: RIP

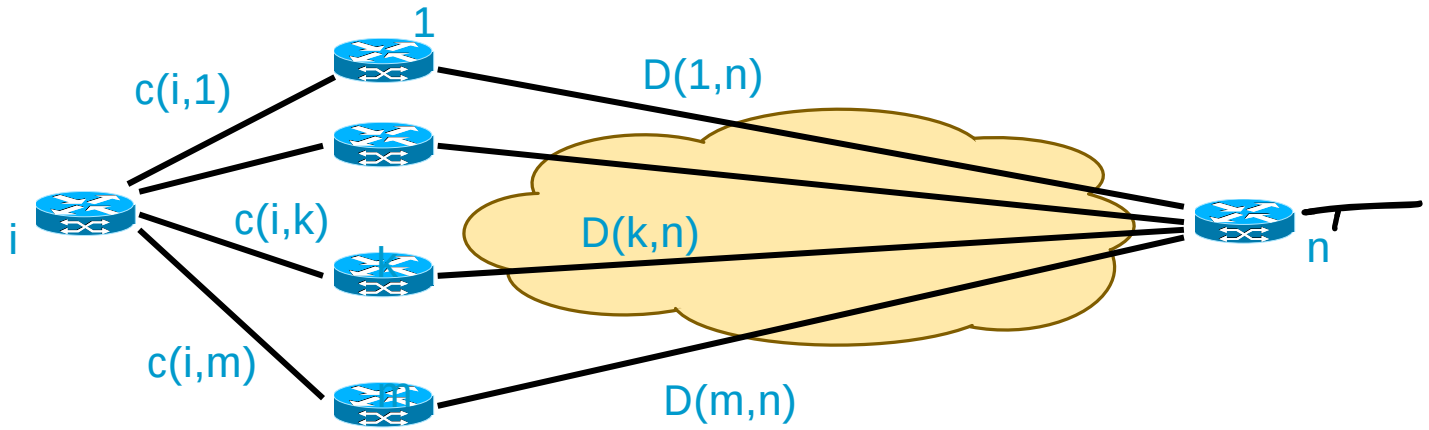
Distance vector routing in RIP = based on BF-D

BF-D is run in all routers *for all possible destination prefixes*

Router *i* computes shortest path and next hop for all network prefixes *n* that it heard of.

Initially: *D(i,n)* = 1 if *i* directly connected to *n* and implicitly *D(i,n)* = +∞ for any *n* that was never heard of.

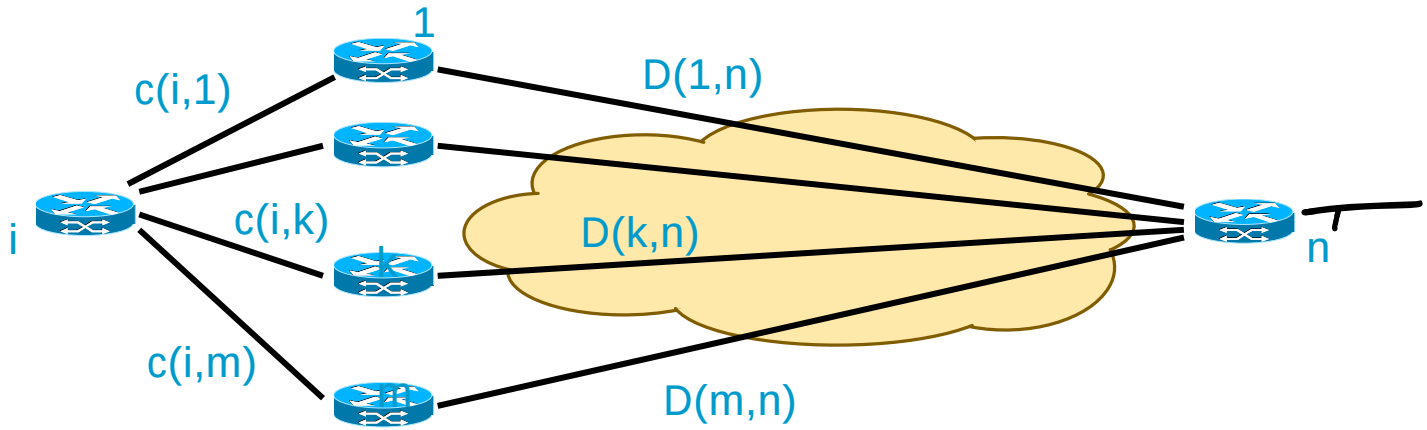
Node *i* receives from neighbour *k* latest values of *D(k,n)* for all *n* (this is the distance vector). Node *i* computes the best estimates according to algorithm BF-D



Periodic Updates

Updates are sent periodically (e.g. every 30 sec)

If neighbour *k* is no longer present, node *i* will no longer receive hello messages, and after a timeout, this has the same effect as if node *i* would receive the message from *k*: $D(k,n) = \infty$ for all n.
Then algorithm BF-D is run:
It follows that if k was the next hop to n, then i declares n unreachable.



Example 1

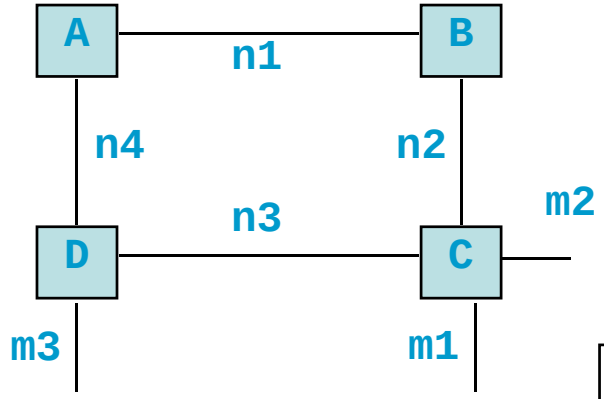
All link costs = 1

A

net	dist	nxt
n1	1	n1,A
n4	1	n4,A

B

net	dist	nxt
n1	1	n1,B
n2	1	n2,B



D

net	dist	nxt
n3	1	n3,D
n4	1	n4,D
m3	1	m3,D

C

net	dist	nxt
n2	1	n2,C
n3	1	n3,C
m1	1	m1,C
m2	1	m2,C

Example 1

All link costs = 1

A

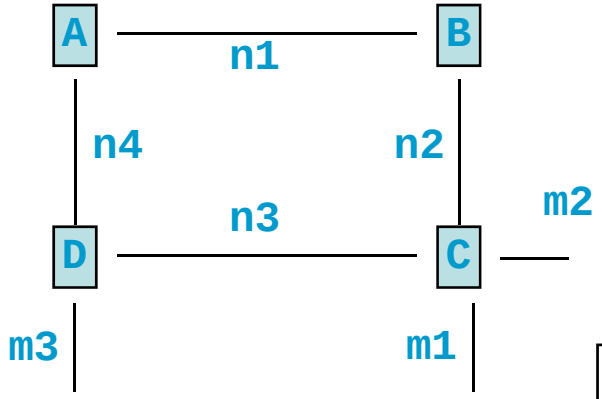
net	dist	nxt
n1	1	n1,A
n4	1	n4,A

from A

n1	1
n4	1

B

net	dist	nxt
n1	1	n1,B
n2	1	n2,B
n4	2	n1,A



D

net	dist	nxt
n3	1	n3,D
n4	1	n4,D
m3	1	m3,D

from D

n3	0
n4	0
m3	0

C

net	dist	nxt
n2	1	n2,C
n3	1	n3,C
m1	1	m1,C
m2	1	m2,C
n4	2	n3,D
m3	2	n3,D

Example 1

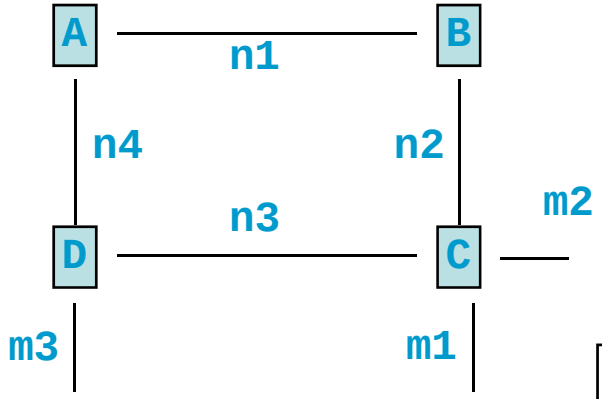
All link costs = 1

A

net	dist	nxt
n1	1	n1,A
n4	1	n4,A

B

net	dist	nxt
n1	1	n1,B
n2	1	n2,B
n3	2	n2,C
n4	2	n1,A
m1	2	n2,C
m2	2	n2,C
m3	3	n2,C



from C

n2	1
n3	1
m1	1
m2	1
n4	2
m3	2

D

net	dist	nxt
n3	1	n3,D
n4	1	n4,D
m3	1	m3,D

C

net	dist	nxt
n2	1	n2,C
n3	1	n3,C
m1	1	m1,C
m2	1	m2,C
n4	2	n3,D
m3	2	n3,D

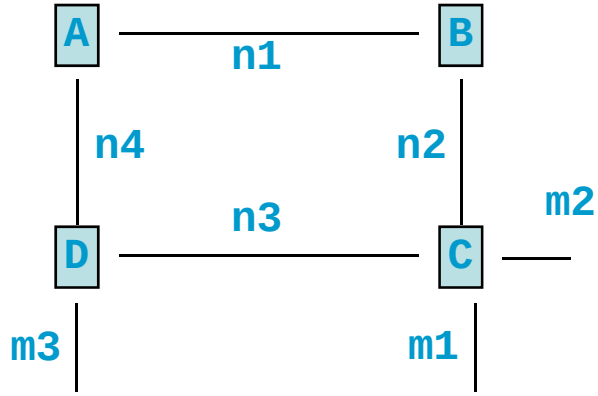
Example 1 - Final

A

net	dist	nxt
n1	1	n1,A
n2	2	n1,B
n3	2	n4,D
n4	1	n4,A
m1	3	n4,D
m2	3	n4,D
m3	2	n4,D

B

net	dist	nxt
n1	1	n1,B
n2	1	n2,B
n3	2	n2,C
n4	2	n1,A
m1	2	n2,C
m2	2	n2,C
m3	3	n2,C



D

net	dist	nxt
n1	2	n4,A
n2	2	n3,C
n3	1	n3,D
n4	2	n4,D
m1	2	n3,C
m2	2	n3,C
m3	1	m3,D

C

net	dist	nxt
n1	2	n2,B
n2	1	n2,C
n3	1	n3,C
m1	1	m1,C
m2	1	m2,C
n4	2	n3,D
m3	2	n3,D

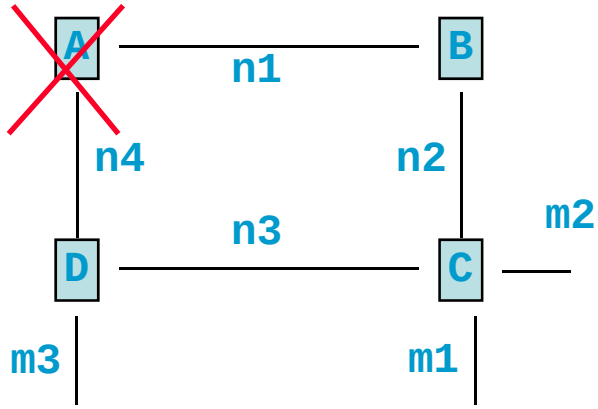
Example 1 – Router Failure

All link costs = 1

We show only the router in the next hop field

B

net	dist	nxt
n1	1	B
n2	1	B
n3	2	C
n4	2	A
m1	2	C
m2	2	C
m3	3	C



D

net	dist	nxt
n1	2	A
n2	2	C
n3	1	D
n4	1	D
m1	2	C
m2	2	C
m3	1	D

C

net	dist	nxt
n1	2	B
n2	1	C
n3	1	C
m1	1	C
m2	1	C
n4	2	D
m3	2	D

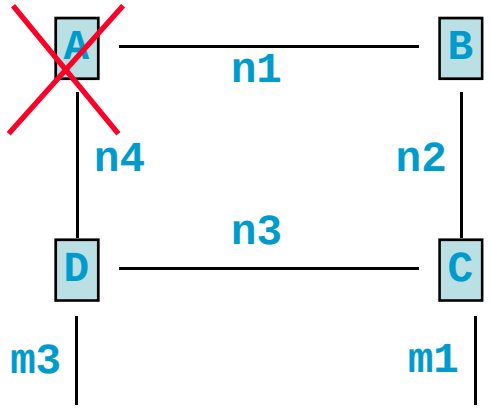
Example 1 - Failure

All link costs = 1

B

net	dist	nxt
n1	1	B
n2	1	B
n3	2	C
~~n4~~	~~2~~	~~A~~
m1	2	C
m2	2	C
m3	3	C

timeout



D

timeout

net	dist	nxt
~~n1~~	~~2~~	~~A~~
n2	2	C
n3	1	D
n4	1	D
m1	2	C
m2	2	C
m3	1	D

C

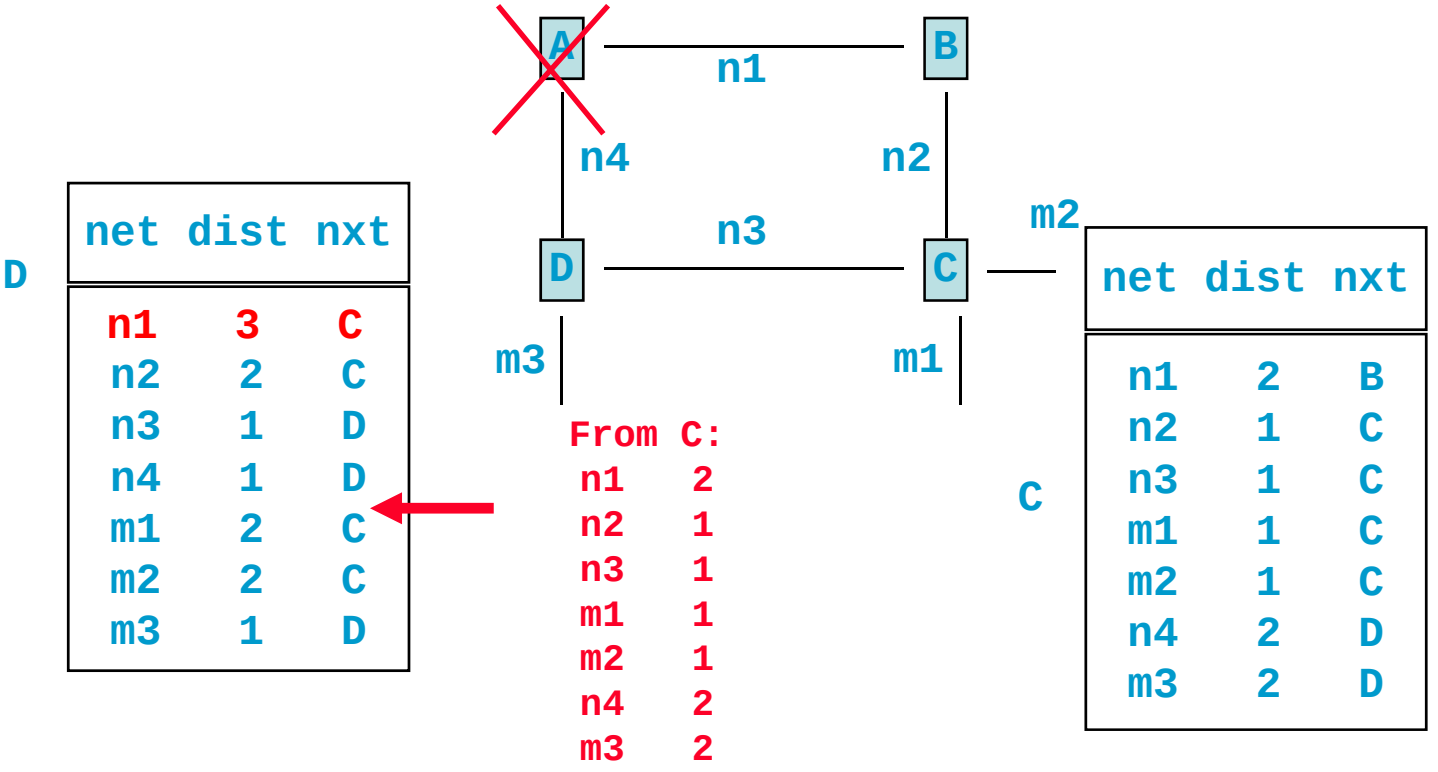
net	dist	nxt
n1	2	B
n2	1	C
n3	1	C
m1	1	C
m2	1	C
n4	2	D
m3	2	D

Example 1 - Failure

All link costs = 1

B

net	dist	nxt
n1	1	B
n2	1	B
n3	2	C
m1	2	C
m2	2	C
m3	3	C



D

net	dist	nxt
n1	3	C
n2	2	C
n3	1	D
n4	1	D
m1	2	C
m2	2	C
m3	1	D

C

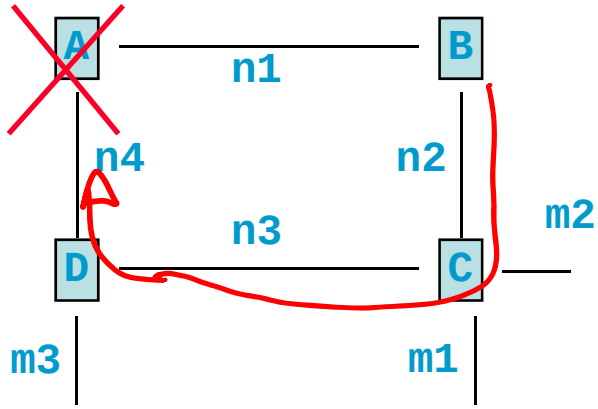
net	dist	nxt
n1	2	B
n2	1	C
n3	1	C
m1	1	C
m2	1	C
n4	2	D
m3	2	D

Example 1 - After Failure

All link costs = 1

B

net	dist	nxt
n1	1	B
n2	1	B
n3	2	C
n4	3	C
m1	2	C
m2	2	C
m3	3	C



D

net	dist	nxt
n1	3	C
n2	2	C
n3	1	D
n4	1	D
m1	2	C
m2	2	C
m3	1	D

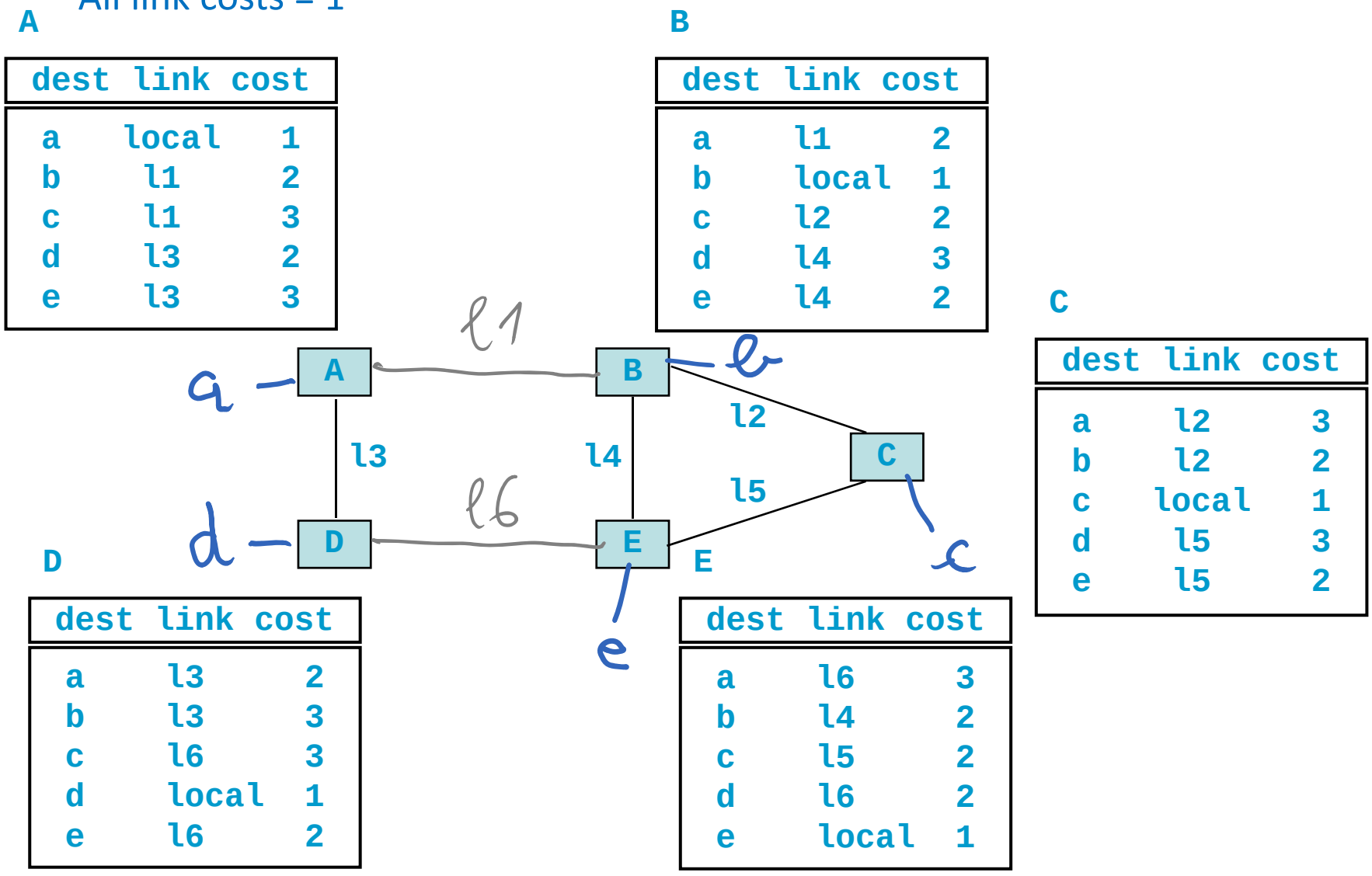
C

net	dist	nxt
n1	2	B
n2	1	C
n3	1	C
m1	1	C
m2	1	C
n4	2	D
m3	2	D

Example 2

Assume RIP has converged

All link costs = 1

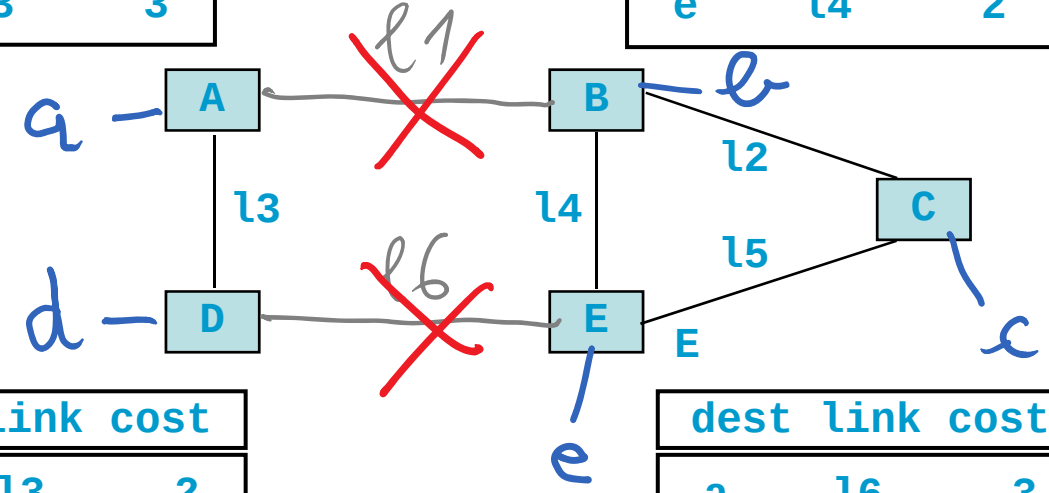


Example 2

Links l1 and l6 fail simultaneously,

D detects failure

All link costs = 1



A

dest	link	cost
a	local	1
b	l1	2
c	l1	3
d	l3	2
e	l3	3

B

dest	link	cost
a	l1	2
b	local	1
c	l2	2
d	l4	3
e	l4	2

C

dest	link	cost
a	l2	3
b	l2	2
c	local	1
d	l5	3
e	l5	2

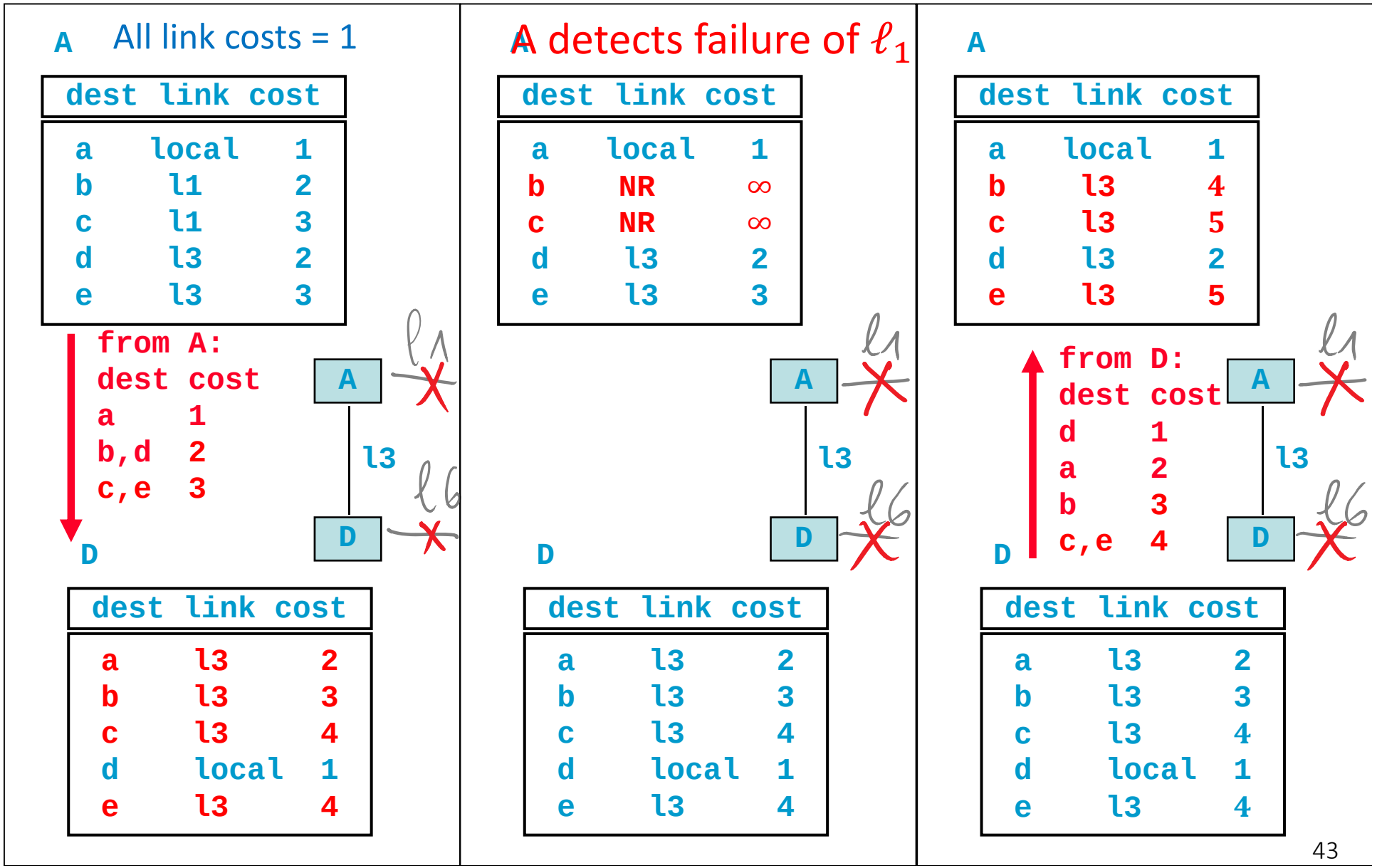
D

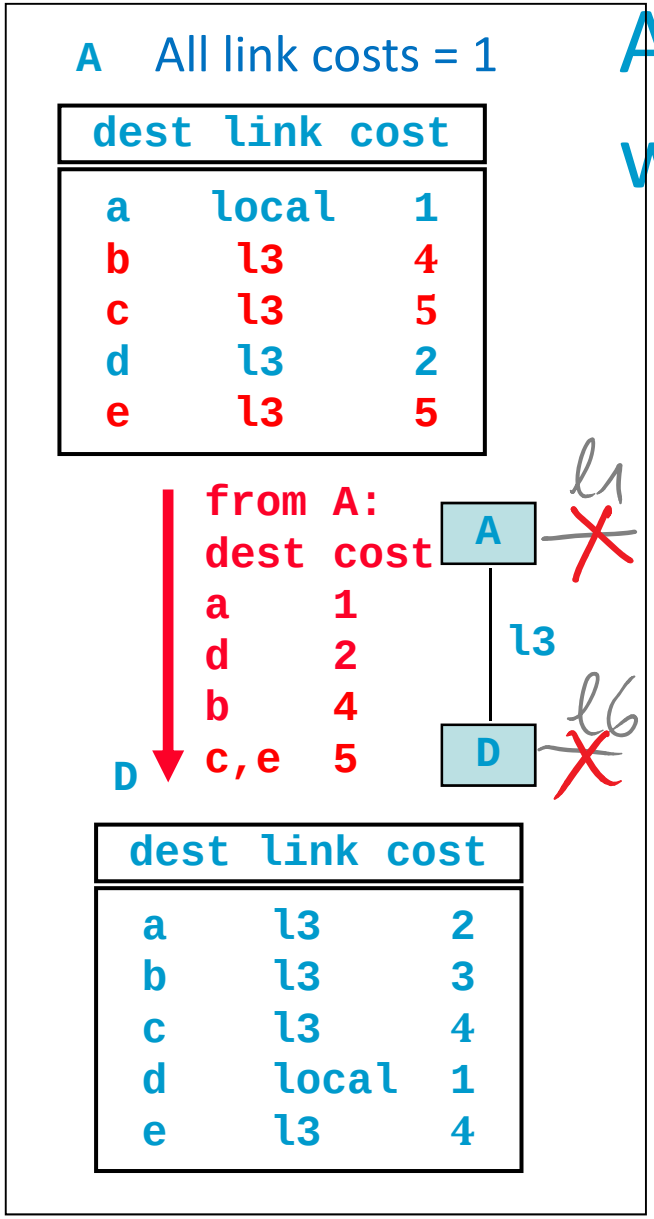
dest	link	cost
a	l3	2
b	l3	3
c	NR	∞
d	local	1
e	NR	∞

E

dest	link	cost
a	l6	3
b	l4	2
c	l5	2
d	l6	2
e	local	1

Example 2 : Zoom on A and B





After processing this update, what is the distance at D to e ?

A. 1

B. 2

C. 3

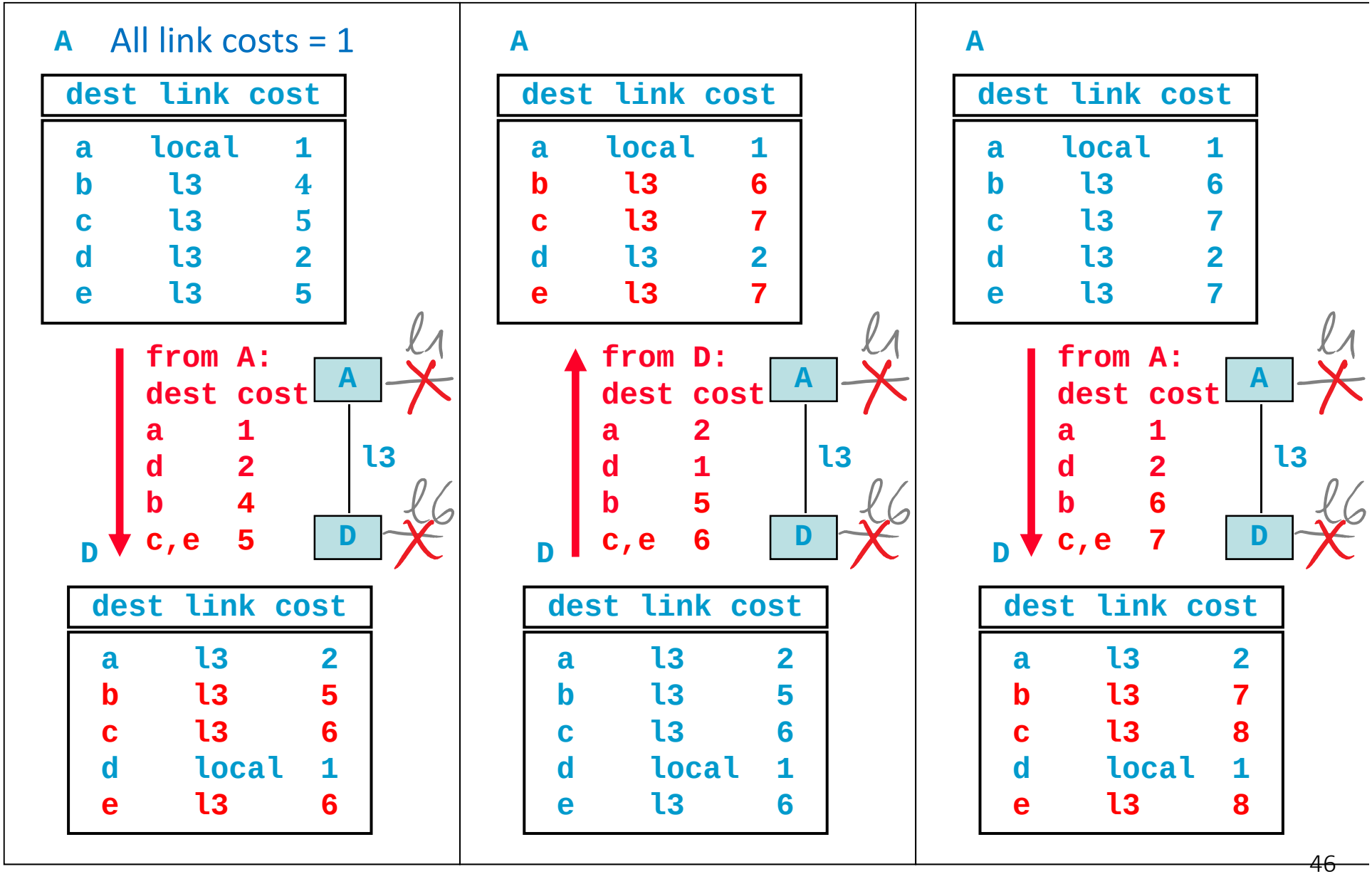
D. 4

E. 5

F. 6

G. I don't know

Count to Infinity



Conclusion from Example 2

The costs to b,c,e grow unbounded “Count to Infinity”

- the true costs are infinite
- this is the expected behaviour of Bellman-Ford

RIP enforces convergence by setting $\infty =$ large number = 16

Several optimizations (route poisoning, split horizon) exist to accelerate convergence:

RIP optimizations: Route poisoning and Split Horizon

Two practical heuristics in order to

- Avoid count to infinity
- Reduce occurrence of ping-pong loops

Route poisoning : if A detects that route to x is not reachable, A immediately sends «distance to x = ∞» to neighbours

Further, when a distance = ∞ is received for x, any further update about x is ignored for some time (holddown timer)

Split Horizon : if A routes packets to x via B, A does not announce this route to B

Example 2
with Route Poisoning and Split Horizon

All link costs = 1

A

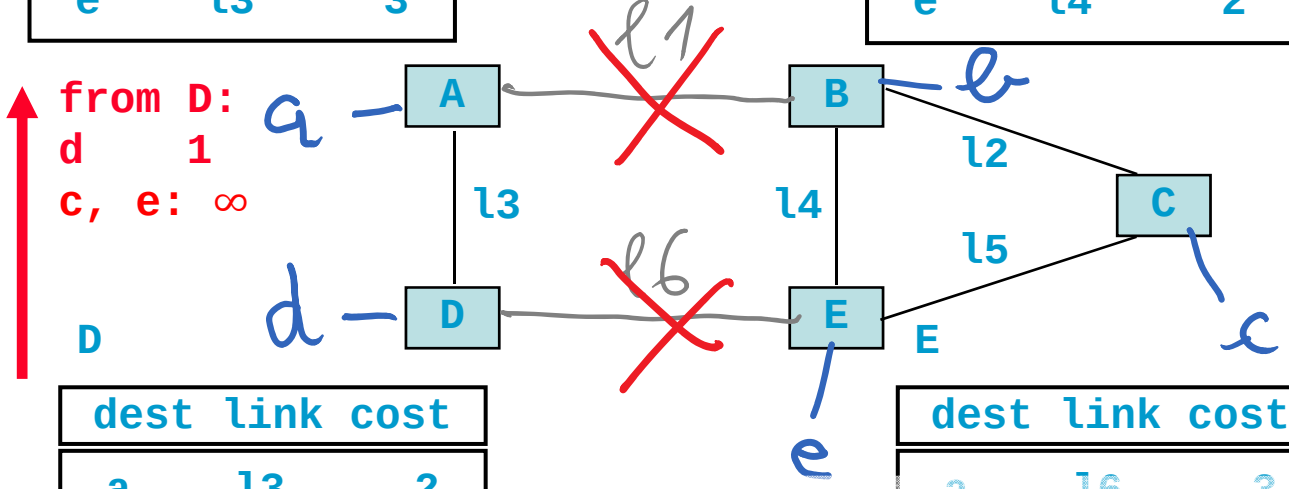
dest	link	cost
a	local	1
b	l1	2
c	l1	3
d	l3	2
e	l3	3

B

dest	link	cost
a	l1	2
b	local	1
c	l2	2
d	l4	3
e	l4	2

C

dest	link	cost
a	l2	3
b	l2	2
c	local	1
d	l5	3
e	l5	2



D

dest	link	cost
a	l3	2
b	l3	3
c	NR	∞
d	local	1
e	NR	∞

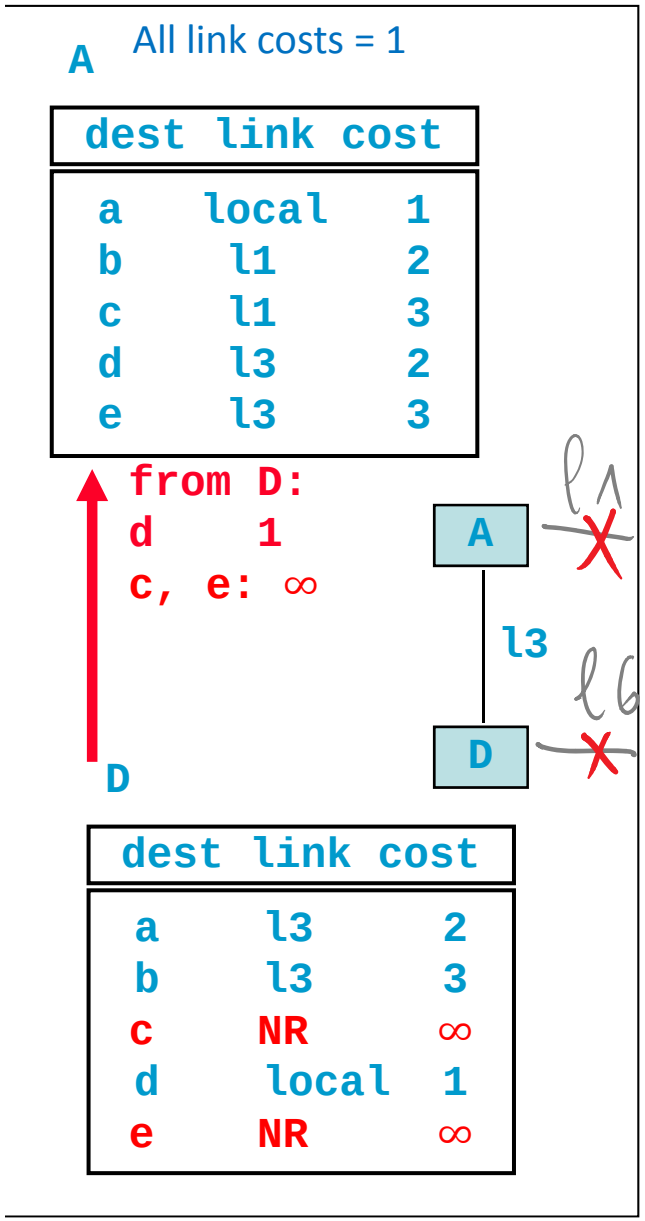
E

dest	link	cost
a	l6	3
b	l4	2
c	l6	2
d	l6	2
e	local	1

D detects failure

D immediately sends update to A with poisoned routes (∞ distances)

Routes to a and b are not advertized (split horizon)



After processing this update, what are the distances at A to c and e ?

A. $d(c) = 3, d(e) = 3$

B. $d(c) = \infty, d(e) = 3$

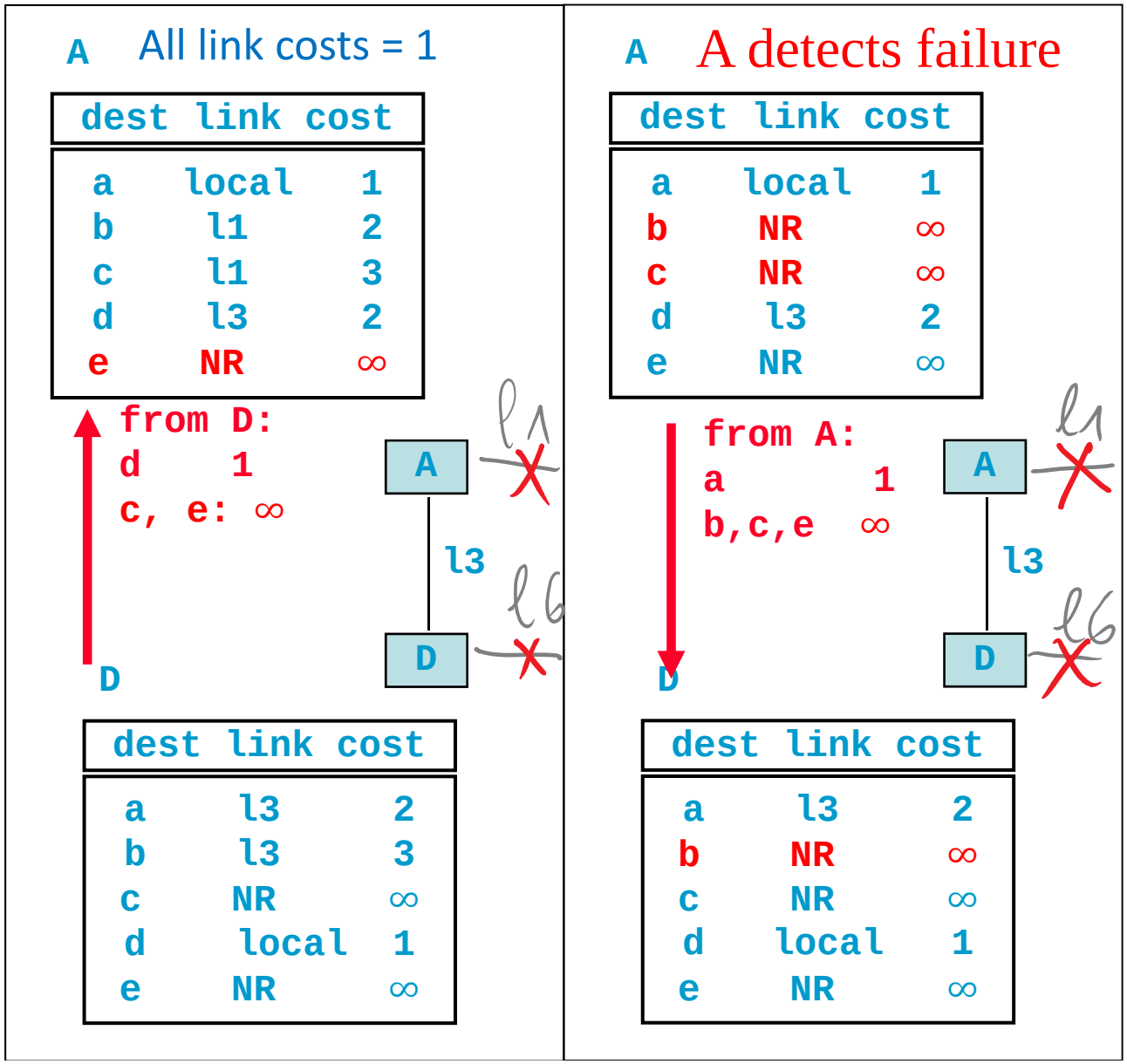
C. $d(c) = 3, d(e) = \infty$

D. $d(c) = \infty, d(e) = \infty$

E. None of the above

F. I don't know

Example 2 with Route poisoning and Split Horizon



No count to infinity

After some time, the ∞ distances are removed by timeout

RIP (Routing Information Protocol)

Implements BF-D

Makes a difference between

- cost from self to directly attached network $A(i, n)$ (default = 1)
- cost from router i to j $A(i, j)$ (default =1)

Allows to control

- Which link participates in RIP
- Which directly attached prefix is *originated* (redistributed into RIP)

$\infty = 16$; therefore network span limited to 15

Split horizon and route poisoning

UDP port 520 and multicast address 224.0.0.9 / ff02::9

RIP (continued)

Sends distance vector update every 30 seconds (by default) or when change is detected (“triggered update”)

- Route not announced during 3 minutes becomes invalid

Authentication in RIPv2 by shared secret

RIP for IPv4, RIPng for IPv6

Other Distance Vector Protocols

EIGRP (Cisco):

- uses Bellman-Ford prelim + additional heuristics that guarantee to avoid loops (therefore no limit of 15 as in RIP)
- keeps a Routing Information Base (RIB) which is much more than with RIP but less than with OSPF
- also uses dynamic metrics

Babel, AODV add a sequence number put by destination to avoid routing loops and count to infinity (Destination Sequenced Distance Vector).

Dynamic Metric example

Metric

- Trans = 10000000/Bandwidth (time to send 10 Kb)
- delay = (sum of Delay)/10
- m = [K_1*Trans + (K_2*Trans)/(256-load) + K_3*delay]
- default: K1=1, K2=0, K3=1, K4=0, K5=0
- if K5 ≠ 0, m = m * [K_5/(Reliability + K_4)]

Bandwidth in Kb/s, Delay in μs

- At Venus: Route for 172.17/16: Metric = 10000000/784 + (20000+1000)/10 = 14855
- At Saturn: Route for 12./8: Metric = 10000000/224 + (20000 + 1000)/10 = 46742

Conclusion

Distance vector is simple and smart: Fully distributed, little information stored.

But: relatively slow

- Not suited for large and complex networks
- Link State protocols can be used instead

LS versus DV

- LS avoids convergence problems of DV
- supports flexible cost definitions; can be used for routing specific flows