Distance vector protocols

Distance Vector routing principles

Routing loops and countermeasures to loops

Bellman-Ford algorithm

RIP, RIP-2

Distance Vector Routing Principles

Distance Vector Routing

- Distance vector (DV) protocols are based on the Bellman-Ford algorithm
- The routing table contains information about other known nodes
  - link (interface) identifier
  - distance (cost) in hops
- The nodes periodically send distance vectors based on the routing tables on all their links
- The nodes update their routing table with received distance vectors
- Routing Information Protocol (RIP) is a basic distance vector protocol

Routing table:

E to	Link	Distance
E	-	0
B	4	1
A	4	2
D	6	1
C	5	1

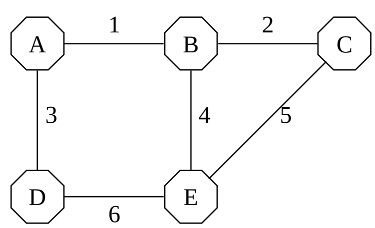
Distance vector:

E=0, B=1, A=2, D=1, C=1

Let us study the principles of DV protocols

Example network with nodes A, B, C, D, E and links 1, 2, 3, 4, 5, 6.

The cost of each link is 1.



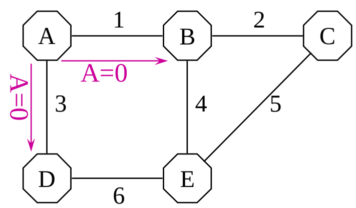
Initial state: Nodes know their own addresses and interfaces, nothing more.

Node A creates its routing table:

From node A to …	Link	Distance
A	- (local)	0

The corresponding distance vector (DV) is: A=0

Generation of routing tables starts when all routers send their DVs on all interfaces



Let's look at reception in Node B. First the table of B is:

From node B to …	Link	Distance
B	-	0

1. B receives the distance vector A=0
2. B ***increments the DV with +1*** ⇒ A=1
3. B looks for the result in its routing table, no match
4. B adds the result to its RT, the result is

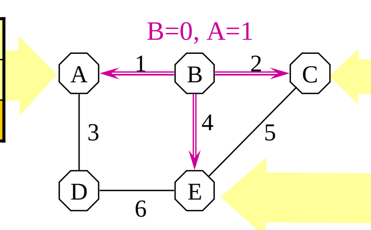
From node B to …	Link	Distance
B	-	0
A	1	1

5. B generates its distance vector B=0, A=1

B creates its own DV and sends it to all neighbors

A to	Link	Distance
A	-	0
B	1	1

A=2 > A=0

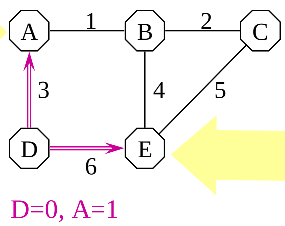


C to	Link	Distance
C	-	0
B	2	1
A	2	2

E to	Link	Distance
E	-	0
B	4	1
A	4	2

D sends its distance vector to all neighbors

A to	Link	Distance
A	-	0
B	1	1
D	3	1



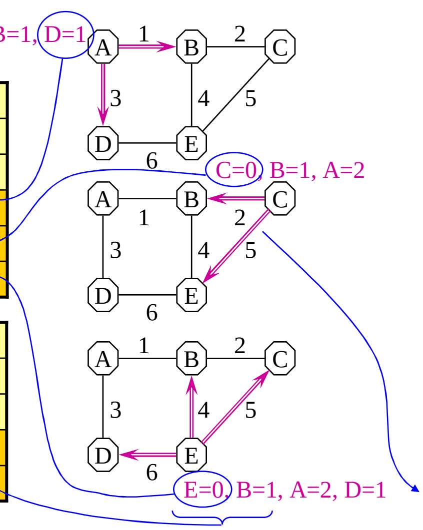
E to	Link	Distance
E	-	0
B	4	1
A	4	2
D	6	1

A=2 == A=2 ⇒ no change

The nodes whose RT changed create DVs and send them to neighbors

B to	Link	Distance
B	-	0
A	1	1
D	1	2
C	2	1
E	4	1

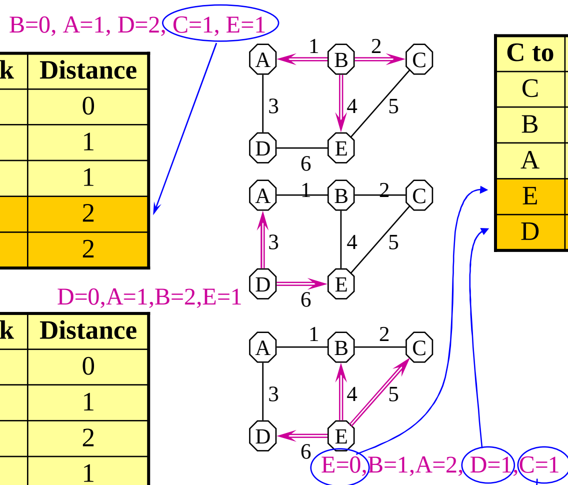
D to	Link	Distance
D	-	0
A	3	1
B	3	2
E	6	1



E to	Link	Distance
E	-	0
B	4	1
A	4	2
D	6	1
C	5	1

Again the changes are sent ...

A to	Link	Distance
A	-	0
B	1	1
D	3	1
C	1	2
E	1	2

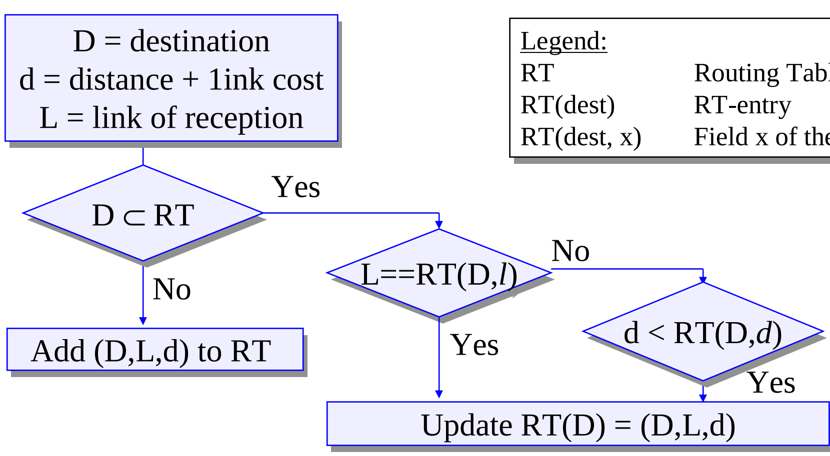


D to	Link	Distance
D	-	0
A	3	1
B	3	2
E	6	1
C	6	2

C to	Link	Distance
C	-	0
B	2	1
A	2	2
E	5	1
D	5	2

A, D, and C create new DVs, send them, but they have no impact.

Processing of received distance vectors



Legend:

RT	Routing Table
RT(dest)	RT-entry
RT(dest, x)	Field x of the entry

Note: this is simplified, shows only the principle!

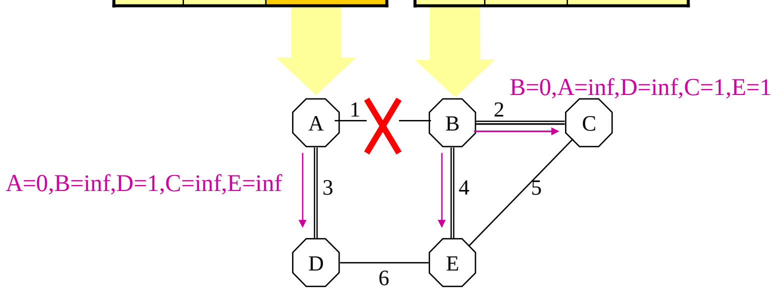
A link breaks...

A round of updates starts on link failure

A gives an infinite distance to the nodes reached through link 1

A to	Link	Distance
A	-	0
B	1	Inf.
D	3	1
C	1	Inf.
E	1	Inf.

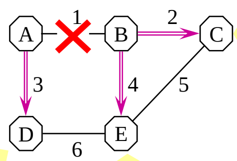
B to	Link	Distance
B	-	0
A	1	Inf.
D	1	Inf.
C	2	1
E	4	1



D, E and C update their routing tables

B=0,A=inf,D=inf,C=1,E=1

A=0,B=inf,D=1,C=inf,E=inf
+1 =
A=1,B=inf,D=2,C=inf,E=inf



C to	Link	Distance
C	-	0
B	2	1
A	2	Inf.
E	5	1
D	5	2

D to	Link	Distance
D	-	0
A	3	1
B	3	Inf.
E	6	1
C	6	2

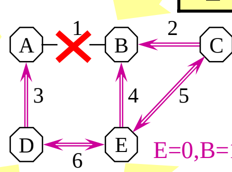
E to	Link	Distance
E	-	0
B	4	1
A	4	Inf.
D	6	1
C	5	1

if L==RT(D, l) the routing table is updated even if the new distance is longer! (see ”processing of received distance vectors”)

D, C, E generate their distance vectors...

B to	Link	Distance
B	-	0
A	1	Inf.
D	4	2
C	2	1
E	4	1

A to	Link	Distance
A	-	0
B	1	Inf.
D	3	1
C	3	3
E	3	2



C=0,B=1,A=inf,E=1,D=2

D=0,A=1,B=inf,E=1,C=2

E=0,B=1,A=inf,D=1,C=1

D to	Link	Distance
D	-	0
A	3	1
B	6	2
E	6	1
C	6	2

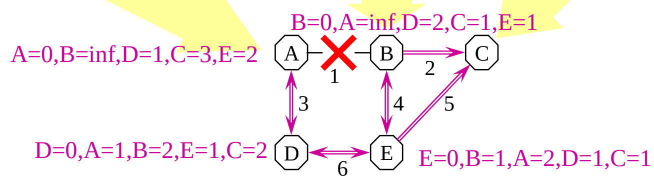
E to	Link	Distance
E	-	0
B	4	1
A	6	2
D	6	1
C	5	1

A, B, D, E generate their distance vectors

A to	Link	Distance
A	-	0
B	3	3
D	3	1
C	3	3
E	3	2

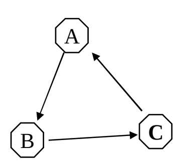
B to	Link	Distance
B	-	0
A	4	3
D	4	2
C	2	1
E	4	1

C to	Link	Distance
C	-	0
B	2	1
A	5	3
E	5	1
D	5	2

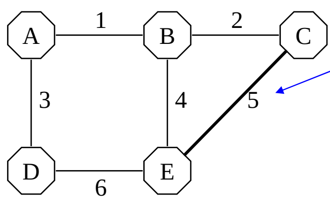


The result is that all nodes are able to communicate with all other nodes again.

Routing loops



The DV-protocol may create a transient routing loop



Let's assume that cost of link 5 is 8.

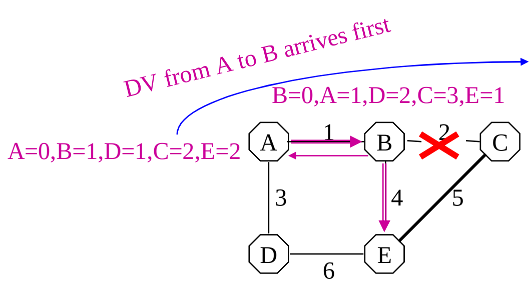
A stable initial state for routes to C would be:

x to C	Link from x	Distance
A→C	1	2
B→C	2	1
C→C	-	0
D→C	3	3
E→C	4	2

Let's just look at the first link of each route.

transient = hetkellinen, ohimenevä, väliaikainen

Link 2 fails



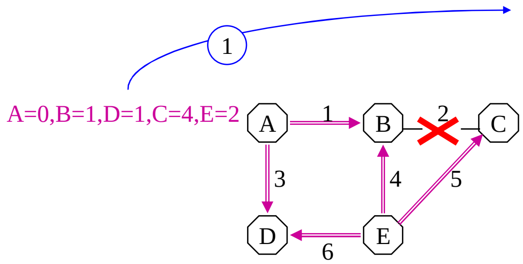
x to C	Link from x	Distance
A→C	1	2
B→C	2	Inf.
C→C	-	0
D→C	3	3
E→C	4	2

Intermediate state

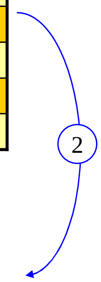
x to C	Link from x	Distance
A→C	1	4
B→C	1	3
C→C	-	0
D→C	3	3
E→C	4	4

All packets to C are sent to B. B sends them to A. A sends them back to B… until TTL=0. (Bouncing effect)

A and E send their distance vectors



x to C	Link from x	Distance
A→C	1	4
B→C	1	5
C→C	-	0
D→C	3	5
E→C	4	4

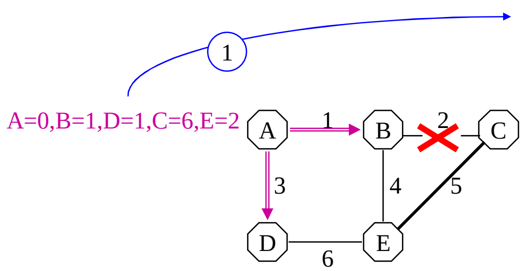


B generates a new DV:
B=0,A=1,D=2,C=5,E=1

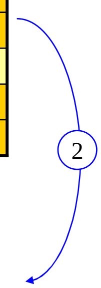
⇒ Distance seen by A to C grows to 6

Distance vectors sent by C do not change anything because of high link cost

A sends a new distance vector



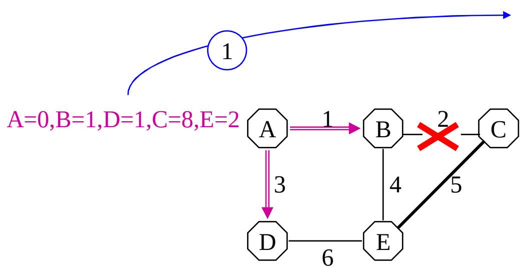
x to C	Link from x	Distance
A→C	1	6
B→C	1	7
C→C	-	0
D→C	3	7
E→C	4	6



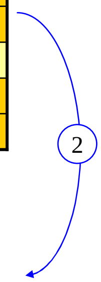
B generates a new DV
B=0,A=1,D=2,C=7,E=1

⇒ Distance seen by A to C grows to 8

A sends a new distance vector



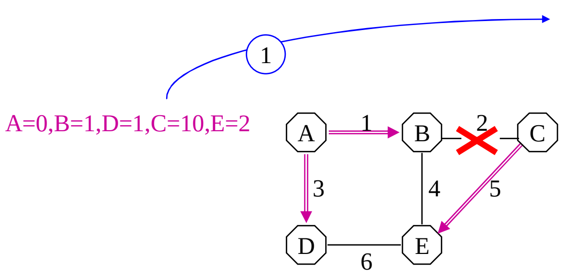
x to C	Link from x	Distance
A→C	1	8
B→C	1	9
C→C	-	0
D→C	3	9
E→C	4	8



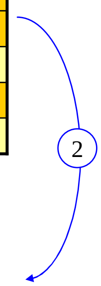
B generates a new DV
B=0,A=1,D=2,C=9,E=1

⇒ Distance seen by A to C grows to 10

A sends a new distance vector



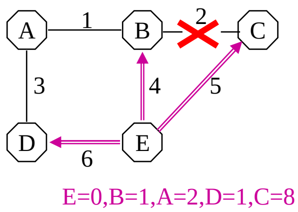
x to C	Link from x	Distance
A→C	1	10
B→C	1	11
C→C	-	0
D→C	3	11
E→C	5	8



B generates a new DV
B=0,A=1,D=2,C=11,E=1

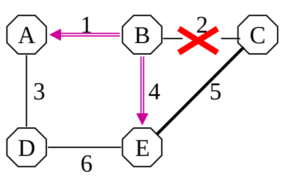
E generates a new DV
E=0,B=1,A=2,D=1,C=8

E sends a new distance vector



x to C	Link from x	Distance
A→C	1	10
B→C	4	9
C→C	-	0
D→C	6	9
E→C	5	8

B send its DV but the tables are already OK



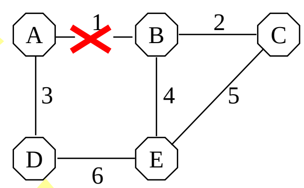
x to C	Link from x	Distance
A→C	1	10
B→C	4	9
C→C	-	0
D→C	6	9
E→C	5	8

- Each update round increased the costs by 2
- The process progresses in a random order, because it is genuinely parallel in nature.
- During the process, the state of the network is bad. DV-packets may be lost due to the overload created by bouncing user messages

Counting to infinity occurs when failures break the network into isolated islands (1)

- Link 1 is broken, and the network has recovered.
- All link costs = 1

A to	Link	Distance
D	3	1
A	-	0
B	3	3
E	3	2
C	3	3

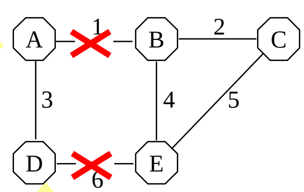


D to	Link	Distance
D	-	0
A	3	1
B	6	2
E	6	1
C	6	2

Counting to infinity occurs when failures break the network into isolated islands (2)

- Also link 6 breaks.
- D updates its routing table but has not yet sent its distance vector.

A to	Link	Distance
D	3	1
A	-	0
B	3	3
E	3	2
C	3	3



D to	Link	Distance
D	-	0
A	3	1
B	6	Inf.
E	6	Inf.
C	6	Inf.

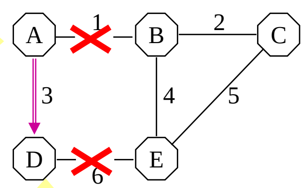
Counting to infinity occurs when failures break the network into isolated islands (3)

- A sends its distance vector first:

A=0,B=3,D=1,C=3,E=2

- D adds the information sent by A into its routing table.

A to	Link	Distance
D	3	1
A	-	0
B	3	3
E	3	2
C	3	3

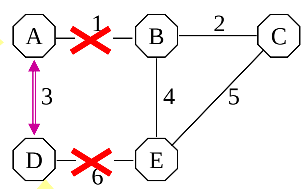


D to	Link	Distance
D	-	0
A	3	1
B	3	4
E	3	3
C	3	4

Counting to infinity occurs when failures break the network into isolated islands (4)

- The result is a loop. Costs are incremented by 2 on each round.
- We need to define infinity as a cost greater than any normal route cost.

A to	Link	Distance
D	3	1
A	-	0
B	3	5
E	3	4
C	3	5

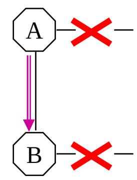


D to	Link	Distance
D	-	0
A	3	1
B	3	4
E	3	3
C	3	4

The first method to avoid loops is to send less information

<u>The split horizon rule:</u>
If node A sends to node X through node B, it does not make sense for B to try to reach X through A

⇒ A should not advertise to B its short distance to X



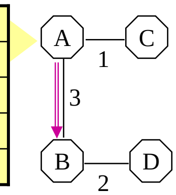
<u>Implementation choices:</u>

1. Split horizon
   - A does not advertise its distance to X towards B at all
   - ⇒ the loop of previous example can not occur

2. Split horizon with poisonous reverse
   - A advertises to B: X=inf.
   - ⇒ two node loops are killed immediately

Split horizon example

A to	Link	Distance
B	3	1
A	-	0
D	3	2
C	1	1



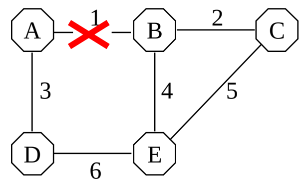
- Normally:
  - A sends: A=0,B=1,C=1,D=2
- Split horizon:
  - A sends: A=0,C=1
- Split horizon with poisonous reverse:
  - A sends: A=0,B=inf,C=1,D=inf,

Note that A sends different DVs on link 1

→ *2-node loops are impossible!*

Three-node loops are still possible (1)

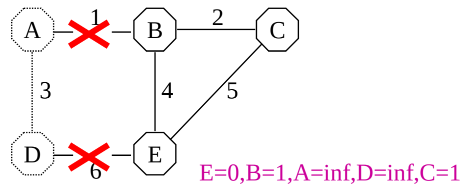
- Link 1 is broken, and the network has recovered.
- All link costs = 1



x to D	Link from x	Distance
B→D	4	2
C→D	5	2
E→D	6	1

Three-node loops are still possible (2)

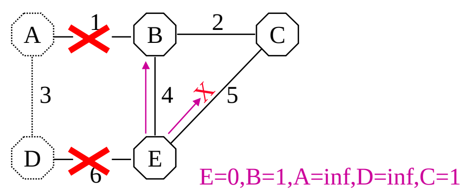
- Also link 6 fails.
- E sends its distance vector to B and C
  E=0,B=1,A=inf,D=inf,C=1



x to D	Link from x	Distance
B→D	4	2
C→D	5	2
E→D	6	Inf.

Three-node loops are still possible (3)

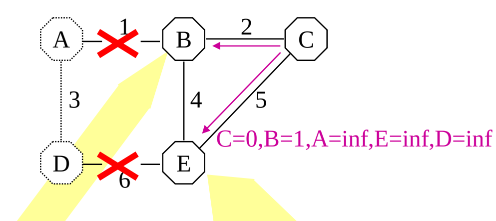
- Also link 6 fails.
- E sends its distance vector to B and C
  E=0,B=1,A=inf,D=inf,C=1
- ... But the DV sent to C is lost



x to D	Link from x	Distance
B→D	4	Inf.
C→D	5	2
E→D	6	Inf.

Three-node loops are still possible (4)

- Now C sends its poisoned DV

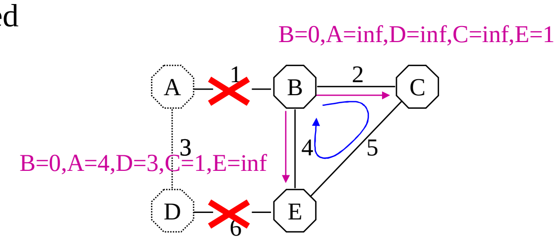


B to	Link	Distance
B	-	0
A	2	4
D	2	3
C	2	1
E	4	1

E to	Link	Distance
B	4	1
A	6	Inf.
D	6	Inf.
C	5	1
E	-	0

Three-node loops are still possible (5)

- B generates its poisoned distance vectors
- The three node loop is ready
- On link 5 cost=4 is advertised. C's knowledge about the distance to D grows ...
- Routes to D do not change except that the costs keep growing, nodes count to infinity.This finally breaks the loop.



x to D	Link from x	Distance
B→D	2	3
C→D	5	2
E→D	4	4

How often should a DV-protocol advertise?

Time of advertisement is a compromise:

- \+ immediate delivery of changed info
- \+ recovery from packet loss
- \+ need to monitor the neighbors
- \- sending all changes at the same time
- \- traffic load created by the protocol

\+ = Faster
\- = Slower

- Entries in the routing tables have refresh and obsolescence timeouts
- In RIP, the refresh timeout is 30 seconds and the obsolescence timeout is 180 seconds

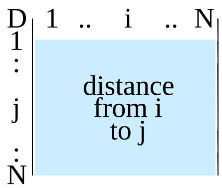
The second method to avoid loops is to use triggered updates

- A triggered update happens when an entry in the routing table is modified (e.g. when a link breaks)
- Triggered updates reduce the probability of loops
- Triggered updates also speed up counting to infinity
- RIP advertises
  - when the refresh timer expires, and
  - when a change occurs in an entry
- Loops are still possible, e.g. because of packet loss

The Bellman-Ford algorithm

Distance vector protocols are based on the Bellman-Ford algorithm

- Definitions:
  - Let N be the number of nodes and M the number of links.
  - L is the link table with M rows, $L[l].m$ - link cost
    $L[l].s$ - link source
    $L[l].d$ - link destination
  - D is an $N \times N$ matrix, such that $D[i,j]$ is the distance from i to j
  - H is an $N \times N$ matrix, such that $H[i,j]$ is the link that i uses to send to j



Both directions are presented separately in the link table and distance table!

A column ≡ DV of the corresponding node

The Bellman-Ford algorithm: Initialized distance and link matrices

	1	..	i	..	N
1	**0**	∞	∞	∞	∞
:	∞	**0**	∞	∞	∞
j	∞	∞	**0**	∞	∞
:	∞	∞	∞	**0**	∞
N	∞	∞	∞	∞	**0**

Distance matrix D

	1	..	i	..	N
1	-1	-1	-1	-1	-1
:	-1	-1	-1	-1	-1
j	-1	-1	-1	-1	-1
:	-1	-1	-1	-1	-1
N	-1	-1	-1	-1	-1

Link matrix H

From i to j

The Bellman-Ford algorithm (centralized version)

1. Initialization: *(previous slide)*

   If i=j, then D[i,j] = 0, else D[i,j] = inf.

   Initialize $\forall$ H[i,j] = -1.

2. $\forall$ links l and $\forall$ destinations k:

   i. set i = L[l].s, j = L[l].d

   ii. calculate d = L[l].m + D[j,k]

   iii. if d < D[i,k], set D[i,k] = d; H[i,k] = l.

3. If at least one D[i,k] changed, go to step 2, else stop.

Properties of the Bellman-Ford algorithm

- First in D-matrix appear one hop link distances, then two hop link distances, etc.
- Number of steps ≤ N

  (because there cannot be a path longer than N)
- Complexity: O(M·N^2)
- Complexity of the distributed version: O(M·N)

The RIP protocol

RIP-protocol properties (1)

- Simple protocol. Used before standardization.
- RIP version 1
  - RFC 1058 in 1988
- RIP is used inside an autonomous system
  - Interior routing protocol
- RIP works both on shared media (Ethernet) and in point-to-point networks.
- RIP runs on top of UDP (port 520) and IP.

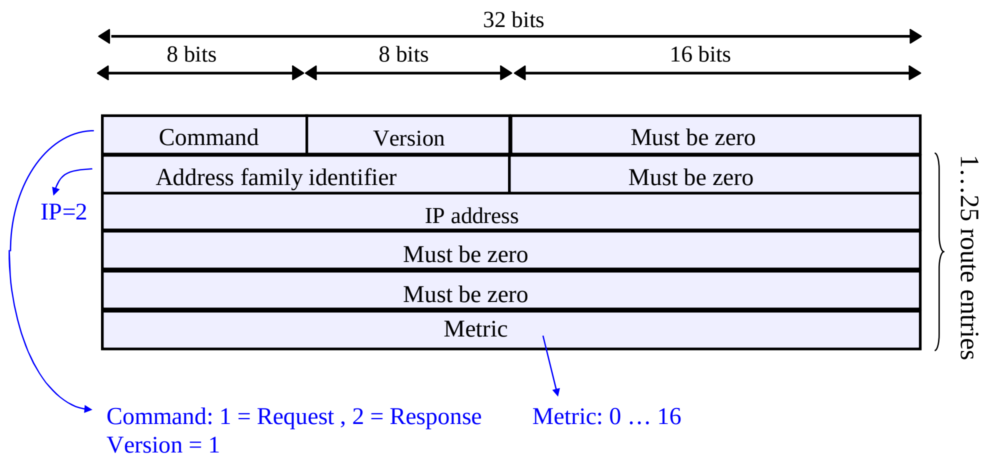
RIP-protocol properties (2)

- An entry in the routing table represents a network, a sub-network or a host:
  - <netid,0,0> represents a network
  - <netid,subnetid,0> represents a sub-network
  - <netid,subnetid,host> represents a host (used only in exceptional cases)
  - <0.0.0.0> represents a route out from the autonomous system
- The mask must be manually configured.
- Sub-network entries are aggregated to a network entry on interfaces belonging to another network.

RIP-protocol properties (3)

- Distance = hop count = number of links on a path (route).
  - No other metrics
- Distance 16 = infinite.
- RIP advertises once in 30s.
  - If an entry is 180s old $\Rightarrow$ distance is set to infinite
  - Advertisements must be randomized to avoid bursts of RIP updates.
- RIP also sends 1-5 s after an update (triggered updates).
- RIP uses poisoned vectors.

RIP message format



RIP routing table

A routing table entry contains

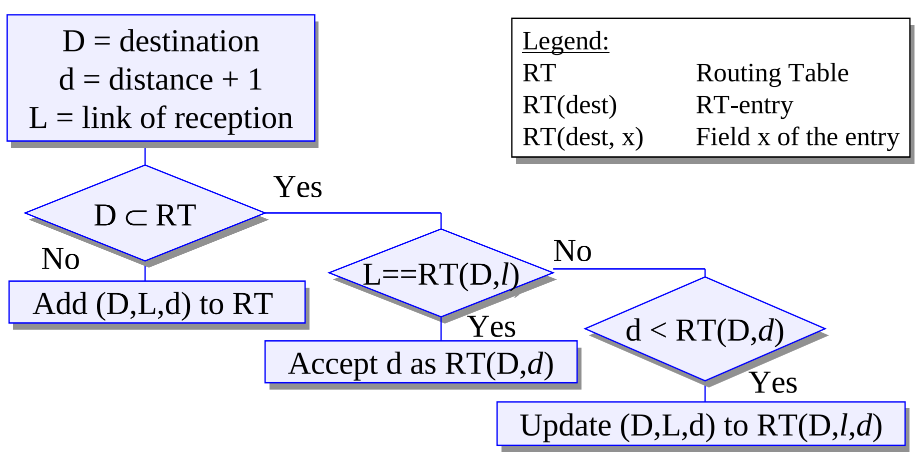
- Destination IP address (network)
- Distance to destination
- Next hop IP address
- "Recently updated" flag
- Several timers (refresh, obsolescence...)

Routing table example

- Example Kernel routing table

```
# netstat -nr
Kernel routing table
Destination     Gateway         Genmask         Flags Metric Ref Use   Iface
127.0.0.1       *               255.255.255.255 UH    1      0   2130  lo0
191.72.1.0      *               255.255.255.0   U     1      0   3070  eth0
191.72.2.0      191.72.1.1      255.255.255.0   UG    2      0   1236  eth0
191.72.3.0      191.72.1.2      255.255.255.0   UG    2      0   3212  eth0
```


Processing of Received Distance Vectors



Note: this is simplified, shows only the principle!

RIP response messages

- Distance vectors are sent in response messages
- Periodic updates (30 seconds period)
  - All routing table entries
  - Different DV on different links because of poisoned vectors
  - More than 25 entries $\Rightarrow$ several messages
- Triggered updates after changes
  - Contains changed entries
  - 1-5 seconds delay, so that the message contains all updates that are related to the same change
- Destinations with infinite distance can be omitted if the next hop is same as before.

RIP request messages

- The router can request routing tables from its neighbors at startup
  - Complete list
  - Response similar to normal update (+ poisoned vectors)
- Partial routing table
  - For debugging
  - No poisoned vectors

Silent nodes

- When only RIP was used, hosts could listen to routing traffic and maintain their own routing tables
  - Which router is closest to the destination?
  - Which link, if several available?
- These where ”silent nodes”, that only listened to routing traffic without sending
- Nowadays there are too many routing protocols
  - RIP-2, OSPF, IGRP, ...

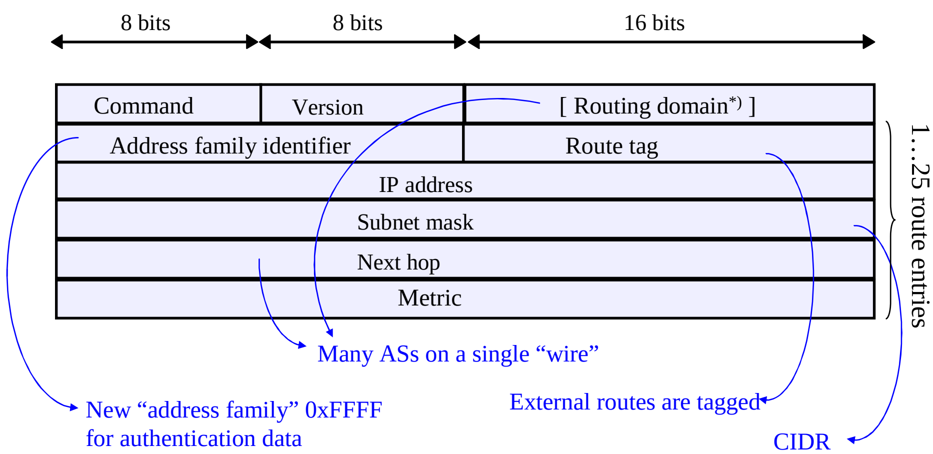
Historical

RIP version 2

RIP version 2

- RFC-1388 (1387,1389)
- Why?
  - Simple and lightweight alternative to OSPF and IS-IS
- RIP-2 is an update that is partially interoperable with RIP-1
  - A RIP-1 router understands some of what a RIP-2 router is saying.
- Improvements
  - Authentication
  - Support for CIDR
  - Next hop –field
  - Subnet mask
  - Support for external routes
  - Updates with multicast

RIP version 2 – messages

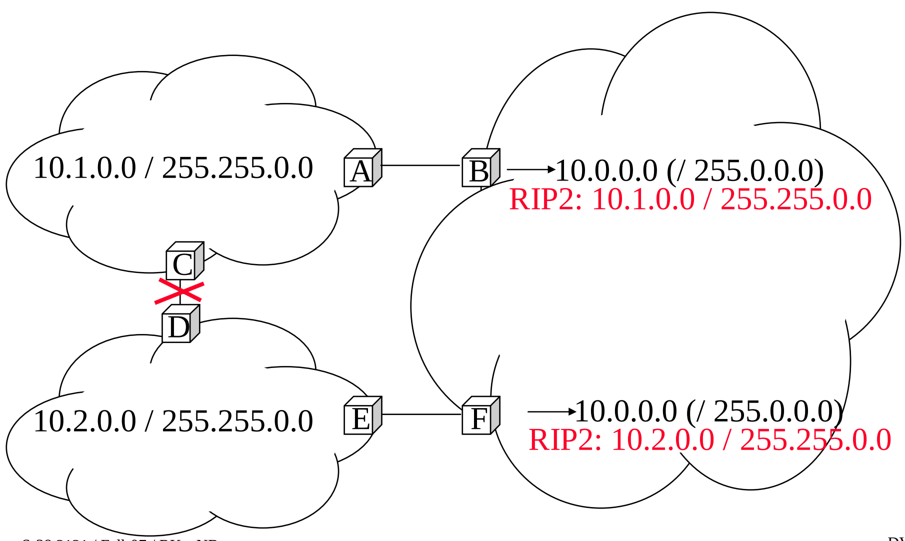


*) Not in standard

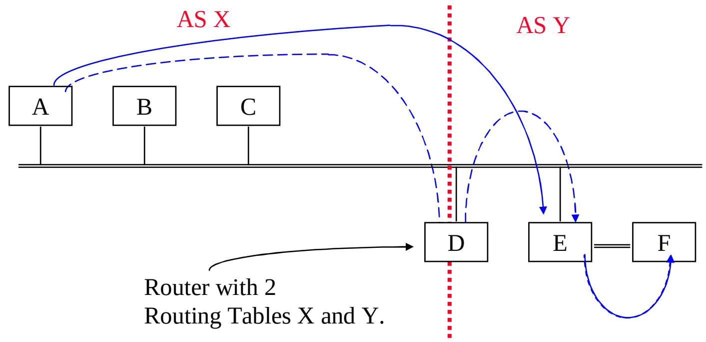
Routing from one sub-net to another (1)

- In RIP-1 the subnet mask is not known outside the subnet, only network-id is sent in an advertisement out from a subnet
  - ⇒ A host and a subnet can not be distinguished
  - ⇒ All subnets must be interconnected with all other subnets and exterior traffic is received in the nearest router independent of the final destination inside our network
- RIP-2 corrects the situation by advertising both the subnet and the subnet mask
  - Masks of different length within a network
  - CIDR
  - RIP-1 does not understand

Routing from one sub-net to another (2)



Routing domain and next hop



Next hop ⇒ D advertises in X: the distance to F is f and the next hop is E!

Support for local multicast

- RIP-1 broadcasts advertisements to all addresses on the wire
  - Hosts must examine all broadcast packets
- RIP-2 uses a multicast address for advertisements
  - 224.0.0.9 (all RIP-2 routers)
  - No real multicast support needed, since packets are only sent on the local network
- Compatibility problems between RIP-1 and RIP-2

Acknowledged updates (extension)

- When RIP is used on ISDN links a new call is established per 30s
  $\Rightarrow$ Expensive.
- Slow network $\Rightarrow$ queue length are restricted.
  - RIP sends its DVs 25 entries/message in a row $\Rightarrow$ RIP messages may be lost.
- A correction proposal: ack all DVs: no periodic updates
  $\Rightarrow$ If there are no RIP message: assume that neighbor is alive and reachable
  $\Rightarrow$ Info on all alternative routes is stored.

Not part of RIP-2

The synchronization problem

- Routers have a spontaneous tendency to synchronize their send times. This increases the probability of losses in the net.
- Reason: send interval = constant + time of message packing + processing time of messages that are in the queue.
- Therefore, send instants are randomized between 15s ... 45s.