Advanced Computer Networks

Internal routing - distance vector protocols

Prof. Andrzej Duda
duda@imag.fr

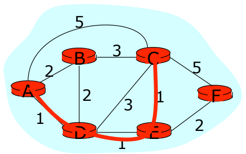
`http://duda.imag.fr`

Contents

Routing

Routing protocol
Goal: determine "good" path (sequence of routers) thru network from source to dest.

Graph abstraction for routing algorithms:
- graph nodes are routers
- graph edges are physical links
  - link cost: delay, $ cost, or congestion level



- "good" path:
  - typically means minimum cost path
  - other def's possible

Routing algorithms

- Problem
  - find the **best** route to a destination
- What does it mean the best?
  - metric to measure how a route is good
  - hops
  - link capacity
  - performance measures: link load, delay
  - cost
- Graph optimization - Shortest Path
  - find the shortest path in a graph
  - shortest in the sense of a metric

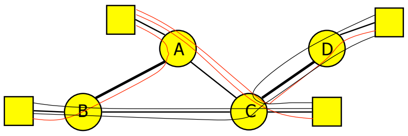
Main algorithms

- Distance vector (Bellman-Ford)
  - routers only know their local state
    - link metric and neighbor estimates
  - internal routing protocols (RIP, IGRP)
- Link state
  - knowledge of the global state
    - metrics of all links
    - global optimization (Shortest Path First - Dijkstra)
  - internal routing protocols (OSPF, PNNI (ATM))
- Path vector
  - knowledge of the global state
    - path: sequence of AS with attributes
    - global optimization and policy routing
  - external routing protocols (BGP)

Metrics

- Static - do not depend on the network state
  - number of hops
  - link capacity and static delay
  - cost
- Dynamic - depend on the network state
  - link load
  - current delay

Traffic matrix

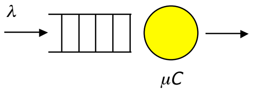


	A	B	C	D
A	0	8	2	3
B		0	6	4
C			0	1
D				0

	A	B	C	D
A		AB	AC	ACD
B			BC	BCD
C				CD
D				

Traffic

- Link model
  - queueing system M/M/1
    - exponentially distributed service and interarrival times



$$T = \frac{1}{\mu C - \lambda}$$

Delay

- Parameters
  - 1 Mb/s and 0.5 Mb/s links
  - mean packet length $1/\mu$ - 5 Kbytes (40 000) bits
  - transmission time on 1 Mb/s link: 40 ms
  - transmission time on 0.5 Mb/s link: 80 ms

	λ pq/s	C Mb/s	μC pq/s	T
AB	8	1	25	58 ms
AC	5	0.5	12.5	133 ms
BC	10	0.5	12.5	400 ms
CD	8	1	25	58 ms

Flooding

- Simple and robust routing
  - no need for routing tables
  - each packet duplicated on each outgoing link
  - packet duplication
  - duplicated packets destroyed at destination
  - robust - tolerates link or router failures
  - optimal in some sense
    - the first packet has found the shortest path to the destination
    - cannot be compared to the shortest path calculated by Link State - no packet duplication
- Problem
  - increased load due to packet duplication
- Used in OSPF to distribute link state information and in ad hoc routing protocols (AODV, OLSR)

Distance vector

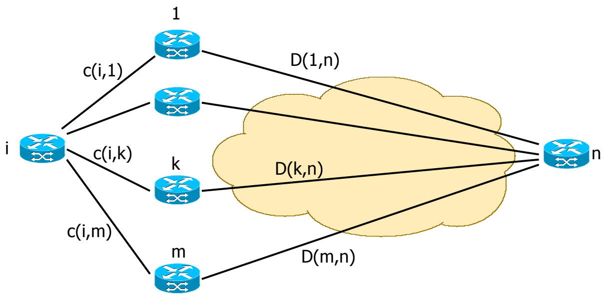
- Dynamic routing based on distributed estimation of the distance to the destination
  - uses the distributed algorithm by Bellman-Ford (dynamic programming)
  - each router receives aggregated information from its neighbors
  - estimates the local cost to its neighbors
  - computes the best routes
  - no global network states
- Distance
  - number of hops
  - delay

Bellman-Ford algorithm

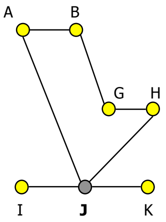
- Bellman-Ford algorithm
  - node *i* knows cost *c(i,k)* to its immediate neighbours (+∞ for most values of *k*)
  - distance *D(i,n)* is given by: $D(i,n) = \min_k (c(i,k) + D(k,n))$
  - in the worst case, convergence after *N*-1 iterations
- Distributed Bellman-Ford algorithm
  - initially: *D(i,n)* = 0 if *i* directly connected to *n* and *D(i,n)* = +∞ otherwise
  - node *i* receives from neighbour *k* latest values of *D(k,n)* for all *n* (distance vector)
  - node *i* computes the best estimates

$$D(i,n) = \min_k (c(i,k) + D(k,n))$$

Bellman-Ford algorithm



Example of Bellman-Ford



	A	I	H	K	Table of J	
A	0	24	20	21	8	A
B	12	36	31	28	20	A
G	18	31	6	31	18	H
H	17	20	0	19	12	H
I	21	0	14	22	10	I
J	9	11	7	10	0	-
K	24	22	22	0	6	K
J:	8	10	12	6		

computation of G : 18+8=26, 31+10=41, 6+12=18, 6+31=37
→ choice of 18, H

Distance vector example

- Simple network
  - routers connected by links
  - destinations = subnetworks connected to routers
  - symmetric links
  - cost = number of hops

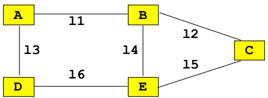
Initialization

A

dest	link	cost
A	local	0

B

dest	link	cost
B	local	0



C

dest	link	cost
C	local	0

D

dest	link	cost
D	local	0

E

dest	link	cost
E	local	0

Distance vector announcement

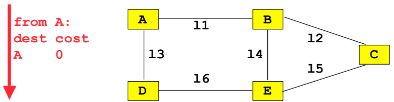
A

dest	link	cost
A	local	0

from A:
dest cost
A 0

B

dest	link	cost
B	local	0
A	11	1



from A:
dest cost
A 0

C

dest	link	cost
C	local	0

D

dest	link	cost
D	local	0
A	13	1

E

dest	link	cost
E	local	0

Distance vector announcement

A

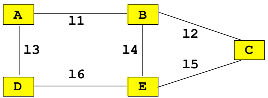
dest	link	cost
A	local	0
B	11	1

from B:
dest cost
A 1
B 0

B

dest	link	cost
B	local	0
A	11	1

from B:
dest cost
A 1
B 0



C

dest	link	cost
C	local	0
A	12	2
B	12	1

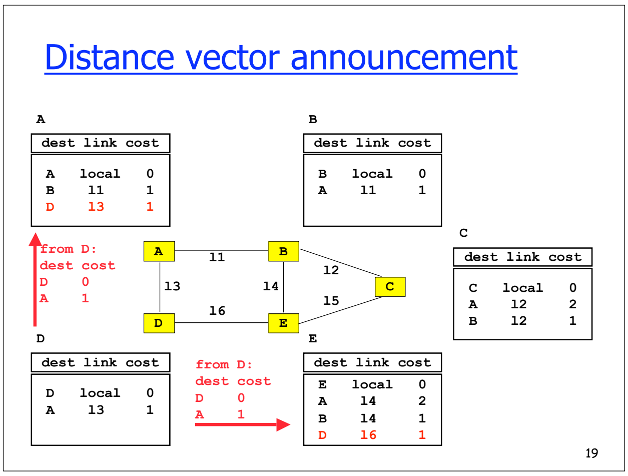
D

dest	link	cost
D	local	0
A	13	1

from B:
dest cost
B 0
A 1

E

dest	link	cost
E	local	0
A	14	2
B	14	1



Distance vector announcement

A

dest	link	cost
A	local	0
B	11	1
D	13	1

B

dest	link	cost
B	local	0
A	11	1

C

dest	link	cost
C	local	0
A	12	2
B	12	1

from D:
dest cost
D 0
A 1

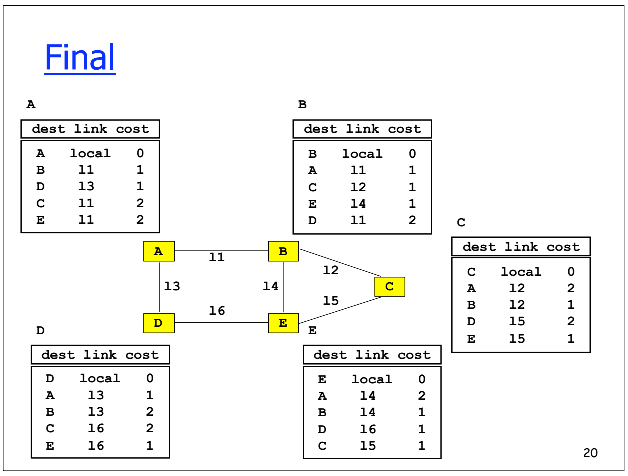
D

dest	link	cost
D	local	0
A	13	1

from D:
dest cost
D 0
A 1

E

dest	link	cost
E	local	0
A	14	2
B	14	1
D	16	1



Final

A

dest	link	cost
A	local	0
B	11	1
D	13	1
C	11	2
E	11	2

B

dest	link	cost
B	local	0
A	11	1
C	12	1
E	14	1
D	11	2

C

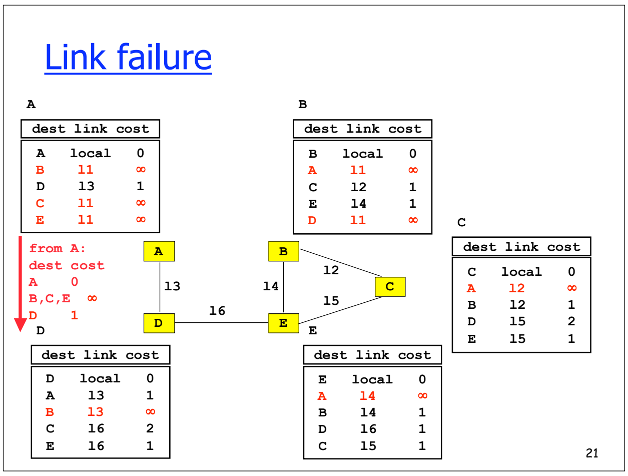
dest	link	cost
C	local	0
A	12	2
B	12	1
D	15	2
E	15	1

D

dest	link	cost
D	local	0
A	13	1
B	13	2
C	16	2
E	16	1

E

dest	link	cost
E	local	0
A	14	2
B	14	1
D	16	1
C	15	1



Link failure

A

dest	link	cost
A	local	0
B	11	∞
D	13	1
C	11	∞
E	11	∞

B

dest	link	cost
B	local	0
A	11	∞
C	12	1
E	14	1
D	11	∞

C

dest	link	cost
C	local	0
A	12	∞
B	12	1
D	15	2
E	15	1

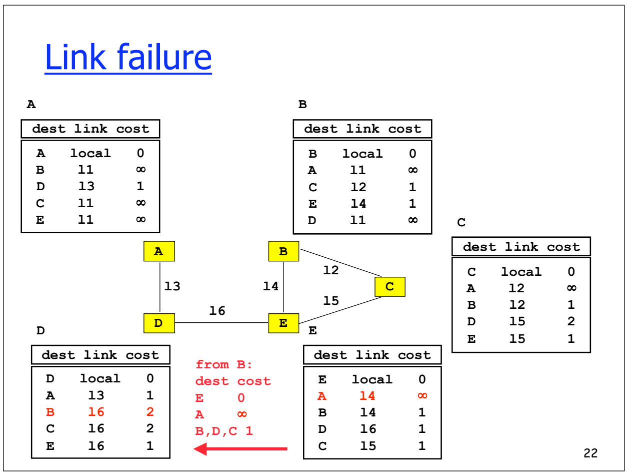
from A:
dest cost
A 0
B,C,E ∞
D 1

D

dest	link	cost
D	local	0
A	13	1
B	13	∞
C	16	2
E	16	1

E

dest	link	cost
E	local	0
A	14	∞
B	14	1
D	16	1
C	15	1



Link failure

A

dest	link	cost
A	local	0
B	11	∞
D	13	1
C	11	∞
E	11	∞

B

dest	link	cost
B	local	0
A	11	∞
C	12	1
E	14	1
D	11	∞

C

dest	link	cost
C	local	0
A	12	∞
B	12	1
D	15	2
E	15	1

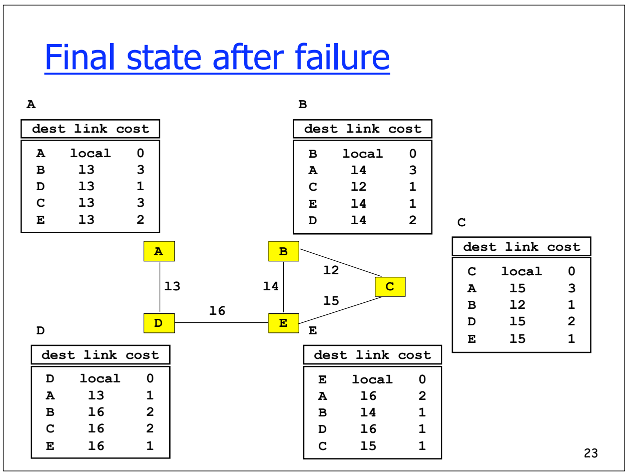
D

dest	link	cost
D	local	0
A	13	1
B	16	2
C	16	2
E	16	1

from B:
dest cost
E 0
A ∞
B,D,C 1

E

dest	link	cost
E	local	0
A	14	∞
B	14	1
D	16	1
C	15	1



Final state after failure

A

dest	link	cost
A	local	0
B	13	3
D	13	1
C	13	3
E	13	2

B

dest	link	cost
B	local	0
A	14	3
C	12	1
E	14	1
D	14	2

C

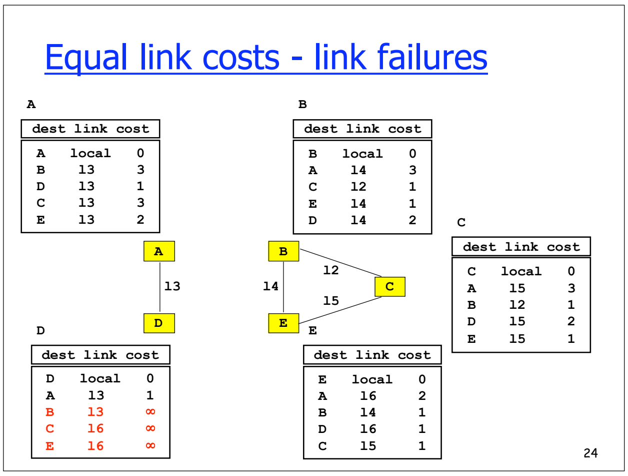
dest	link	cost
C	local	0
A	15	3
B	12	1
D	15	2
E	15	1

D

dest	link	cost
D	local	0
A	13	1
B	16	2
C	16	2
E	16	1

E

dest	link	cost
E	local	0
A	16	2
B	14	1
D	16	1
C	15	1



Equal link costs - link failures

A

dest	link	cost
A	local	0
B	13	3
D	13	1
C	13	3
E	13	2

B

dest	link	cost
B	local	0
A	14	3
C	12	1
E	14	1
D	14	2

C

dest	link	cost
C	local	0
A	15	3
B	12	1
D	15	2
E	15	1

D

dest	link	cost
D	local	0
A	13	1
B	13	∞
C	16	∞
E	16	∞

E

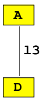
dest	link	cost
E	local	0
A	16	2
B	14	1
D	16	1
C	15	1

Counting to infinity

A

dest	link	cost
A	local	0
B	13	3
D	13	1
C	13	3
E	13	2

from A:
dest cost
A 0
B,C 3
D 1
E 2



D

dest	link	cost
D	local	0
A	13	1
B	13	4
C	13	4
E	13	3

- Loop between A and D
- Exchange of routes, costs increase by 2 each cycle
- Convergence to a stable state
  - ∞ = large number
  - e.g. RIP: ∞ = 16

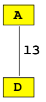
Split horizon

- Minimize the effects of bouncing and counting to infinity
- Rule
  - if A routes packets to X via B, it does not announce this route to B

Example of split horizon

A

dest	link	cost
A	local	0
B	13	3
D	13	1
C	13	3
E	13	2

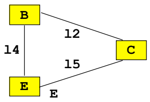


D

dest	link	cost
D	local	0
A	13	1
B	13	∞
C	16	∞
E	16	∞

B

dest	link	cost
B	local	0
A	14	3
C	12	1
E	14	1
D	14	2



E

dest	link	cost
E	local	0
A	16	2
B	14	1
D	16	1
C	15	1

C

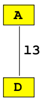
dest	link	cost
C	local	0
A	15	3
B	12	1
D	15	2
E	15	1

Split horizon

A

dest	link	cost
A	local	0
B	13	3
D	13	1
C	13	3
E	13	2

from A:
dest cost
A 0



D

dest	link	cost
D	local	0
A	13	1
B	13	∞
C	16	∞
E	16	∞

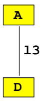
- Split horizon cuts the process of counting to infinity

Split horizon

A

dest	link	cost
A	local	0
B	13	∞
D	13	1
C	13	∞
E	13	∞

from D:
dest cost
D 0
B,C,E ∞



D

dest	link	cost
D	local	0
A	13	1
B	13	∞
C	16	∞
E	16	∞

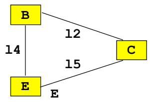
- Split horizon cuts the process of counting to infinity

Split horizon may fail

from E:
dest cost
A ∞
B 1
C 1
D ∞

B

dest	link	cost
B	local	0
A	14	∞
C	12	1
E	14	1
D	14	∞

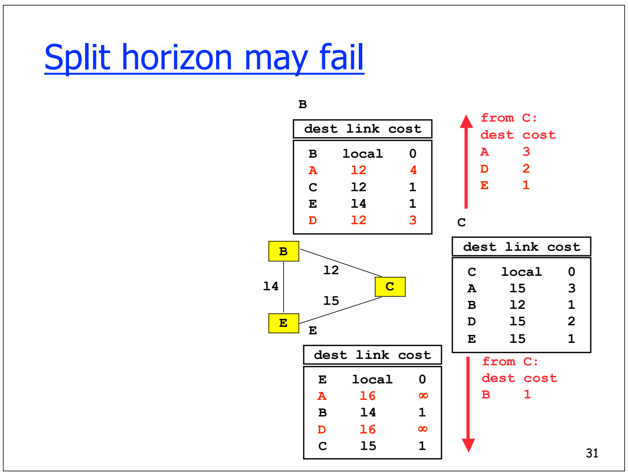


E

dest	link	cost
E	local	0
A	16	∞
B	14	1
D	16	∞
C	15	1

C

dest	link	cost
C	local	0
A	15	3
B	12	1
D	15	2
E	15	1



Split horizon may fail

B

dest	link	cost
B	local	0
A	12	4
C	12	1
E	14	1
D	12	3

from C:

dest	cost
A	3
D	2
E	1

C

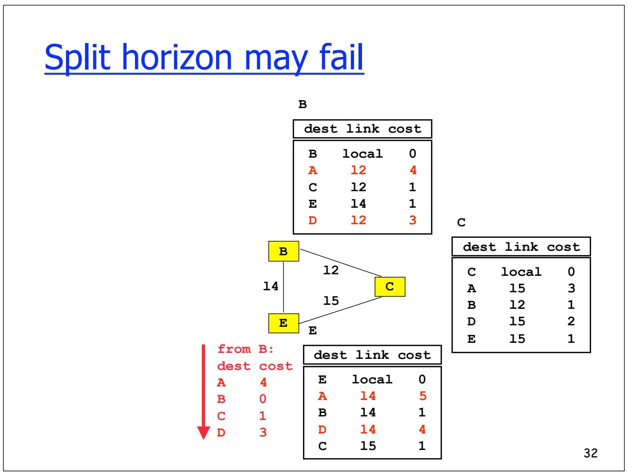
dest	link	cost
C	local	0
A	15	3
B	12	1
D	15	2
E	15	1

E

dest	link	cost
E	local	0
A	16	∞
B	14	1
D	16	∞
C	15	1

from C:

dest	cost
B	1



Split horizon may fail

B

dest	link	cost
B	local	0
A	12	4
C	12	1
E	14	1
D	12	3

C

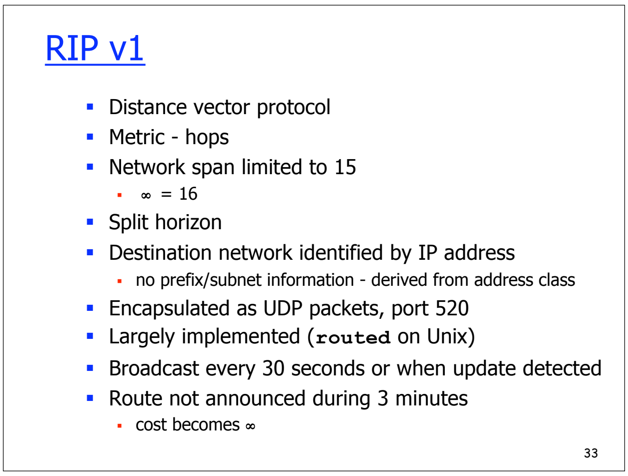
dest	link	cost
C	local	0
A	15	3
B	12	1
D	15	2
E	15	1

from B:

dest	cost
A	4
B	0
C	1
D	3

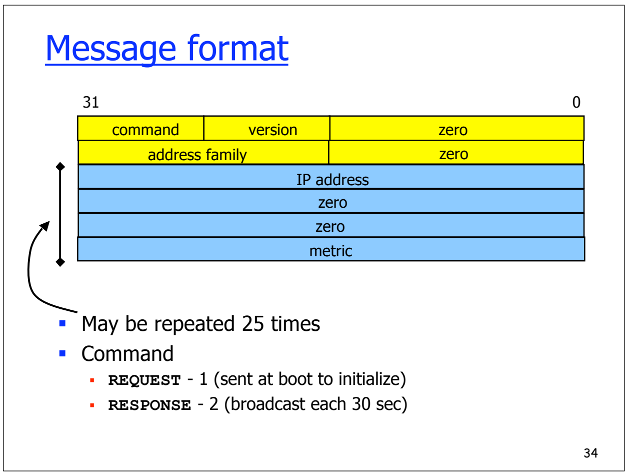
E

dest	link	cost
E	local	0
A	14	5
B	14	1
D	14	4
C	15	1



RIP v1

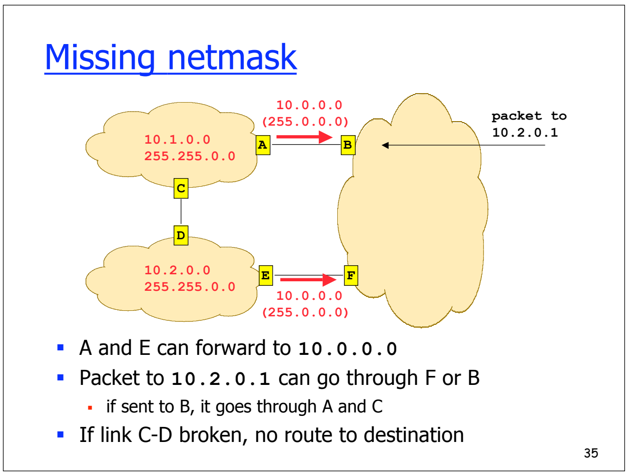
- Distance vector protocol
- Metric - hops
- Network span limited to 15
  - ∞ = 16
- Split horizon
- Destination network identified by IP address
  - no prefix/subnet information - derived from address class
- Encapsulated as UDP packets, port 520
- Largely implemented (`routed` on Unix)
- Broadcast every 30 seconds or when update detected
- Route not announced during 3 minutes
  - cost becomes ∞



Message format

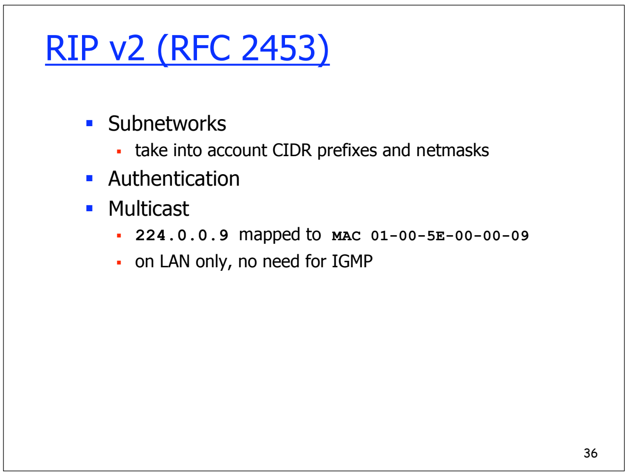
<table>
<tr><td colspan="3">31</td><td>0</td></tr>
<tr><td>command</td><td>version</td><td colspan="2">zero</td></tr>
<tr><td colspan="2">address family</td><td colspan="2">zero</td></tr>
<tr><td colspan="4">IP address</td></tr>
<tr><td colspan="4">zero</td></tr>
<tr><td colspan="4">zero</td></tr>
<tr><td colspan="4">metric</td></tr>
</table>

- May be repeated 25 times
- Command
  - **REQUEST** - 1 (sent at boot to initialize)
  - **RESPONSE** - 2 (broadcast each 30 sec)



Missing netmask

- A and E can forward to `10.0.0.0`
- Packet to `10.2.0.1` can go through F or B
  - if sent to B, it goes through A and C
- If link C-D broken, no route to destination



RIP v2 (RFC 2453)

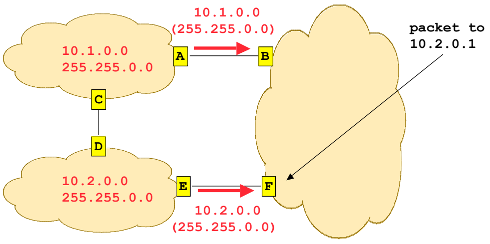
- Subnetworks
  - take into account CIDR prefixes and netmasks
- Authentication
- Multicast
  - `224.0.0.9` mapped to `MAC 01-00-5E-00-00-09`
  - on LAN only, no need for IGMP

Message format

31			0
command	version	unused	
address family		route tag	
IP address			
netmask			
next router			
metric			

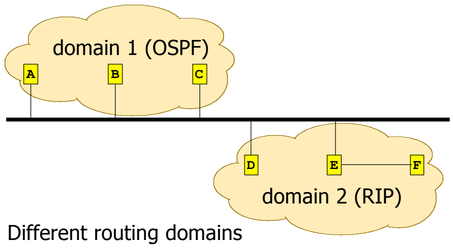
- Command, version unchanged
- One address family - authentication
- Next router
  - used at the border of different routing domains (e.g. RIP and OSPF)
- Route tag
  - for external routes (used by BGP)

Announcing netmasks



- E can forward to `10.2.0.0`
- Packet to `10.2.0.1` can go through F

Routing domains



- Different routing domains
  - e.g. routers under different administrations that run different routing protocols (RIP, OSPF)
- If A wants to send a packet to F, it goes through D and E
- When announcing F, D adds E as **next router**

Simple authentication

31			0
command	version	unused	
xFFFF		authentication type = 2	
password on 16 bytes			

- Configuration of gated (`/etc/gated.conf`)

```
rip yes {
            interface all
            version 2 multicast
            authentication simple "qptszwmz"
}
```

MD5 authentication

31			0
command	version	unused	
xFFFF		authentication type = 3	
packet length		key Id	auth. length
increasing sequence no.			
zero			
zero			
route info			
xFFFF		x01	
seal			

MD5 authentication

- Seal
  - MD5 digest on the message using a shared secret
  - sequence number avoids replay attacks
- Configuration of gated (`/etc/gated.conf`)

```
rip yes {
            interface all
            version 2 multicast
            authentication md5 "qptszwmz"
}
```

Conclusion

- Main distance vector protocols
- Largely deployed (Unix BSD `routed`)
- Simplicity
- Slow convergence
- Not suited for large and complex networks
  - Link State protocols should be used instead