Advanced Computer Networks

Internal routing - distance vector protocols

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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

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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)

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Routing protocols

	Internet	ISO
IGP	distance vector: RIP, RIP v2, IGRP	
	link state: OSPF	IS-IS
	dual: EIGRP	
EGP	EGP (obsolete)	
	BGP	IDRP
host	ICMP Redirect	IS-ES

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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

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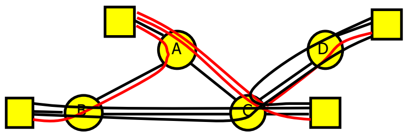
Traffic matrix



	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				

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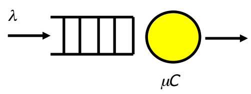
Traffic

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



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

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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

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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)

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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

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Bellman-Ford algorithm

- Bellman-Ford algorithm
  - node i knows cost $c(i,k)$ to its immediate neighbours ($+\infty$ 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 $D(i,n) = +\infty$ otherwise
  - node i receives from neighbour k latest values of $D(k,n)$ for all n (distance vector)
  - node i computes the best estimates $D(i,n) = \min_k (c(i,k) + D(k,n))$

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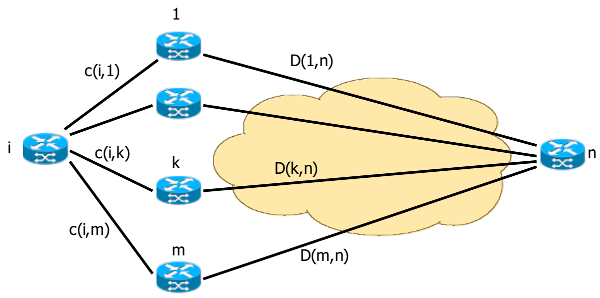
Bellman-Ford algorithm



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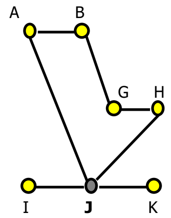
Example of Bellman-Ford



	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

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Distance vector example

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

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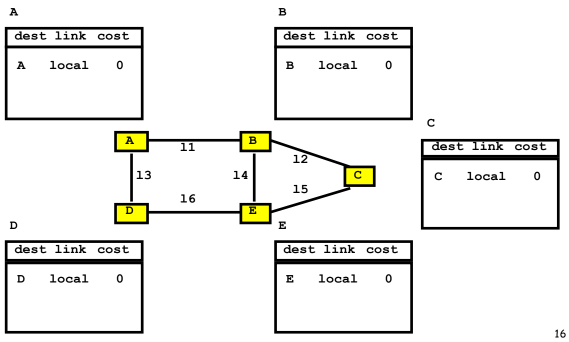
Initialization



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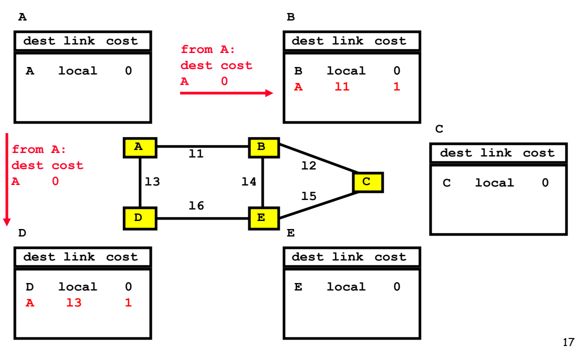
Distance vector announcement



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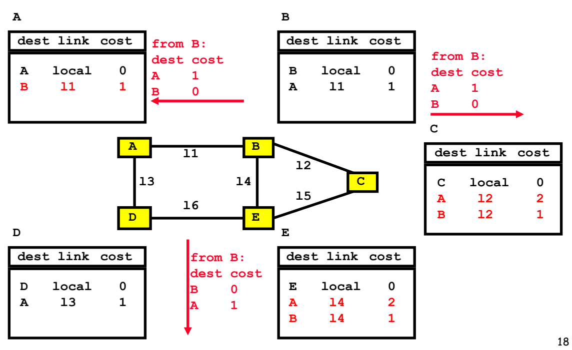
Distance vector announcement



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Distance vector announcement

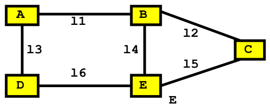
A

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

B

dest	link	cost
B	local	0
A	11	1

from D:
dest cost
D 0
A 1



C

dest	link	cost
C	local	0
A	12	2
B	12	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

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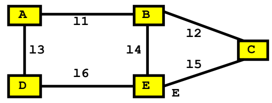
Final

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

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Link failure

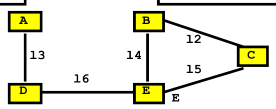
A

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	∞

from A:
dest cost
A 0
B,C,E ∞
D 1



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	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

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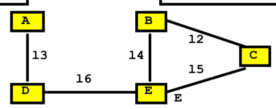
Link failure

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

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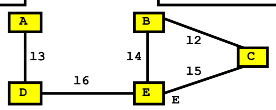
Final state after failure

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

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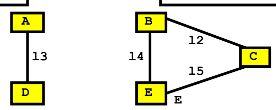
Equal link costs - link failures

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	16	∞
C	16	∞
E	16	∞

E

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

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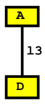
Counting to infinity

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

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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

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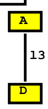
Example of split horizon

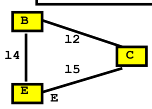
A

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	∞
C	16	∞
E	16	∞

E

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

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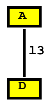
Split horizon

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	16	∞
C	16	∞
E	16	∞

- Split horizon cuts the process of counting to infinity

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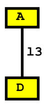
Split horizon

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	16	∞
C	16	∞
E	16	∞

- Split horizon cuts the process of counting to infinity

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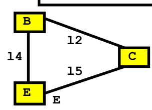
Split horizon may fail

from E:

dest	cost
E	0
A	∞
C	1
D	∞

B

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



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

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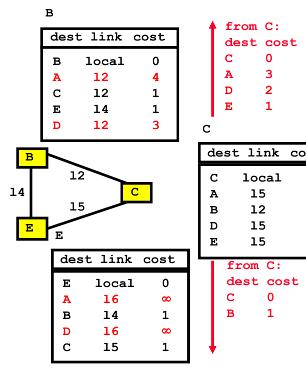
Split horizon may fail



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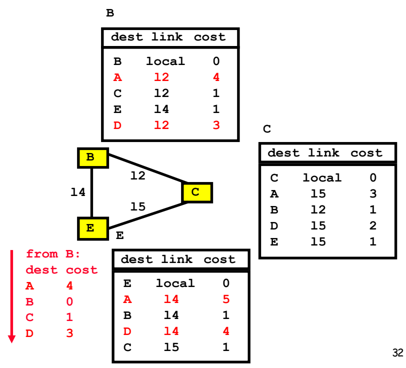
Split horizon may fail



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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 ∞

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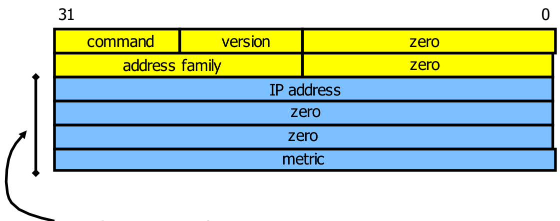
Message format



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

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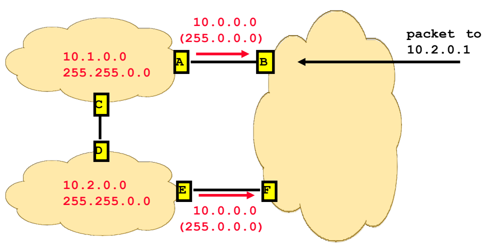
Missing netmask



- 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

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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

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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)

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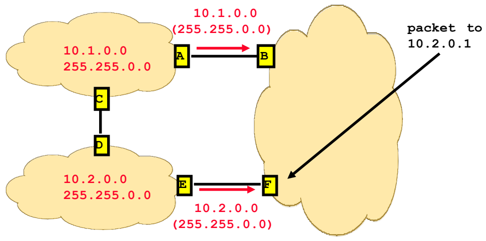
Announcing netmasks



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

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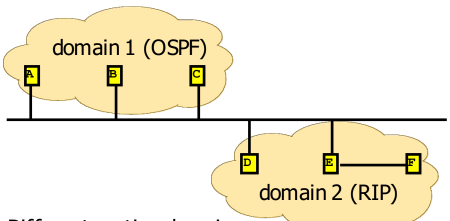
Routing domains



- 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**

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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"
}
```

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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			

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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"
}
```

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IGRP (Interior Gateway Routing Protocol)

- Proprietary protocol by CISCO
- Metric that estimates the global delay
- Maintains several routes of similar cost
  - load sharing
- Takes into account netmasks
- No limit of 15
  - number of routers included in messages
- Broadcast every 90 sec

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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 $\neq$ 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

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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

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