Telecommunications Networking

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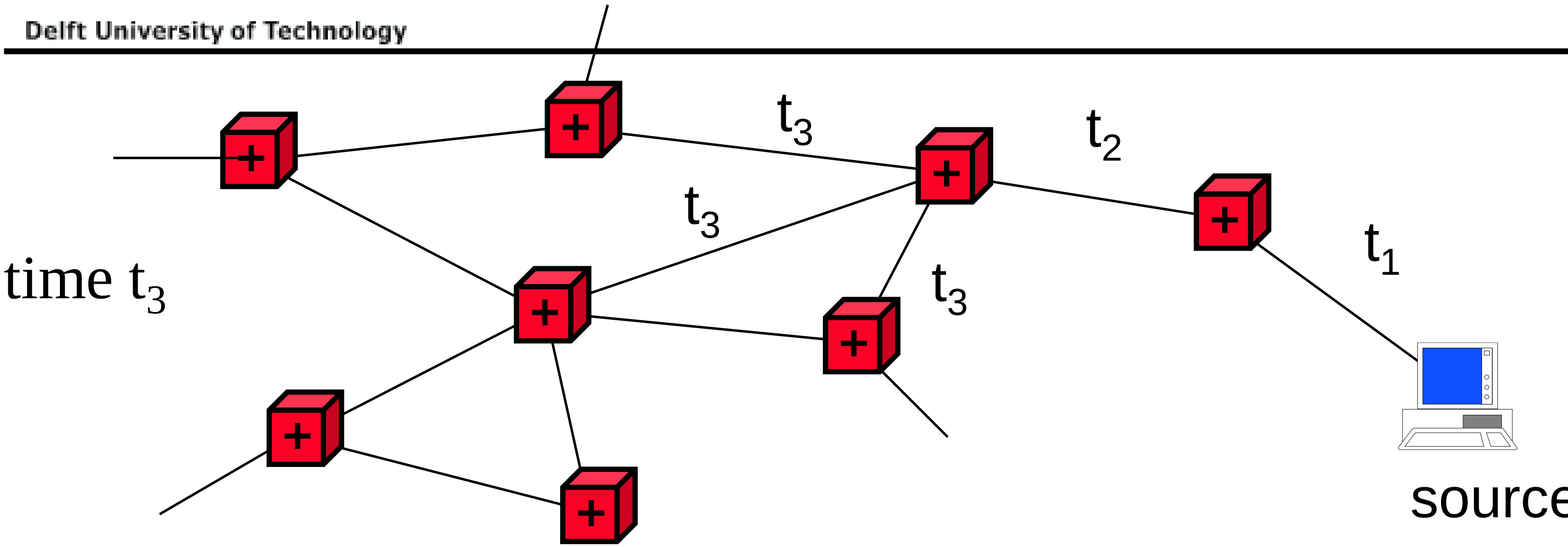
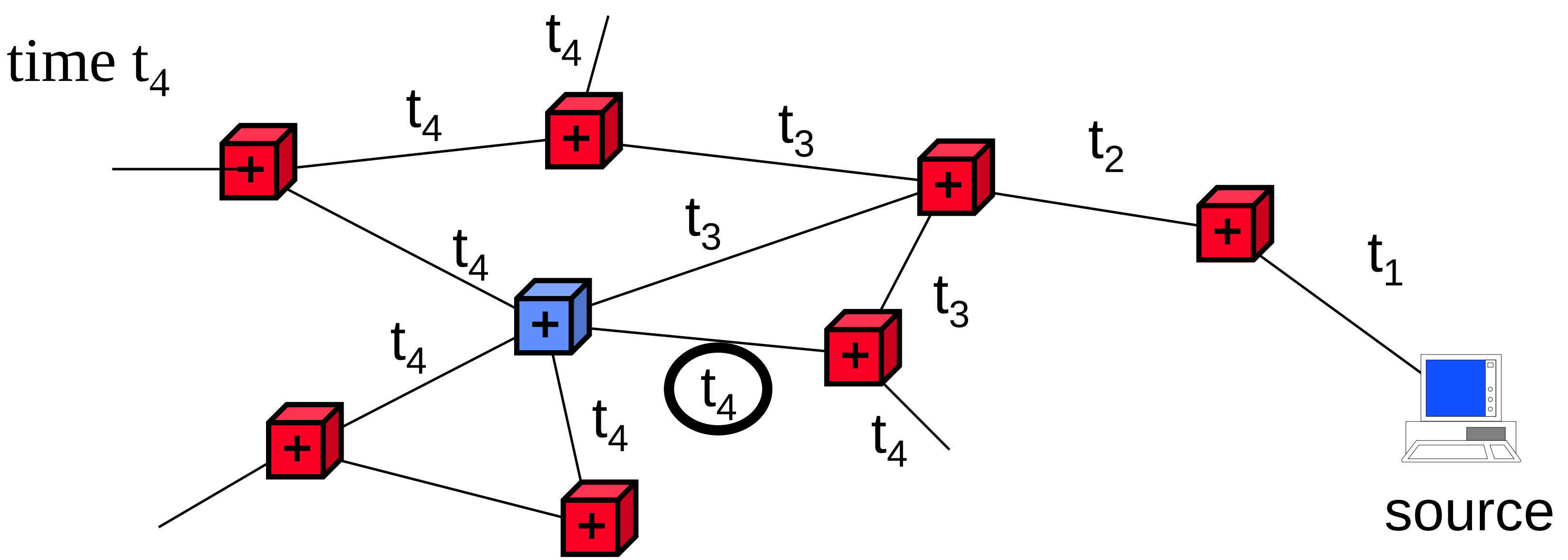
1. Introduction
2. Local Area Networking
3. Error Control and Retransmission Protocols
4. Architectural Principles of the Internet
5. Flow Control in Internet: TCP
6. Routing Algorithms
7. **Routing Protocols**
8. The principles of ATM
9. Traffic Management in ATM
10. Scheduling
11. Quality of Service
12. Quality of Service routing
13. Peer-to-peer networks

Flooding


time t_3
t_3
t_2
t_3
t_1
t_3
source


time t_4
t_4
t_4
t_3
t_2
t_3
t_4
t_1
t_3
t_4
t_4
t_4
t_4
source

Flooding (dis)advantages

- Simple and robust
- Use of all paths assures shortest time

- Disadvantage: overhead (many duplications)
- Remedies (to stop the process):
  - TTL
  - Sequence numbers
  - Selective flooding: trees

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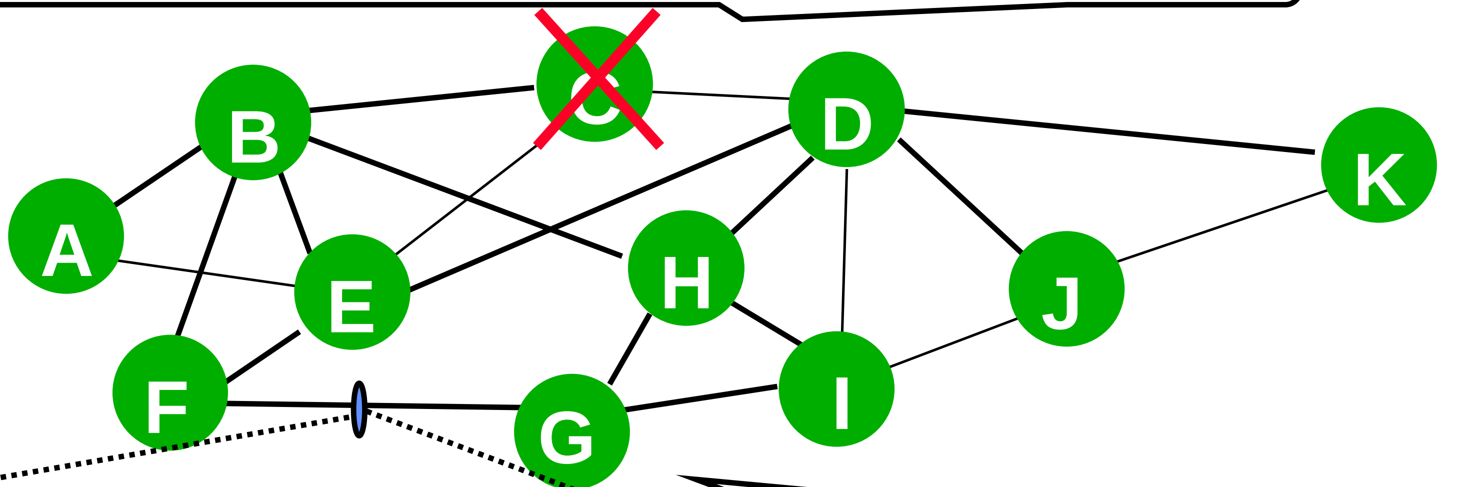
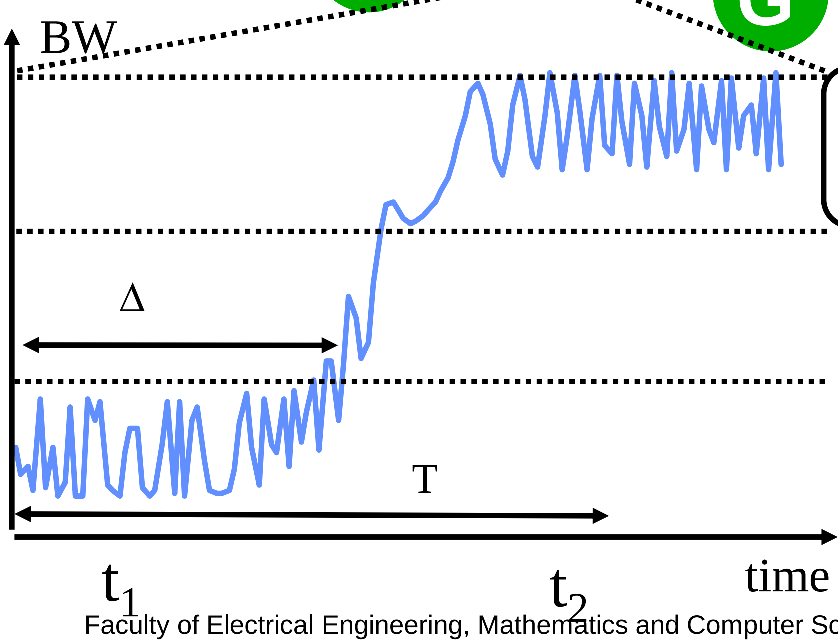
Topology Changes

Slow variations on time scale: failures, joins/leaves of nodes



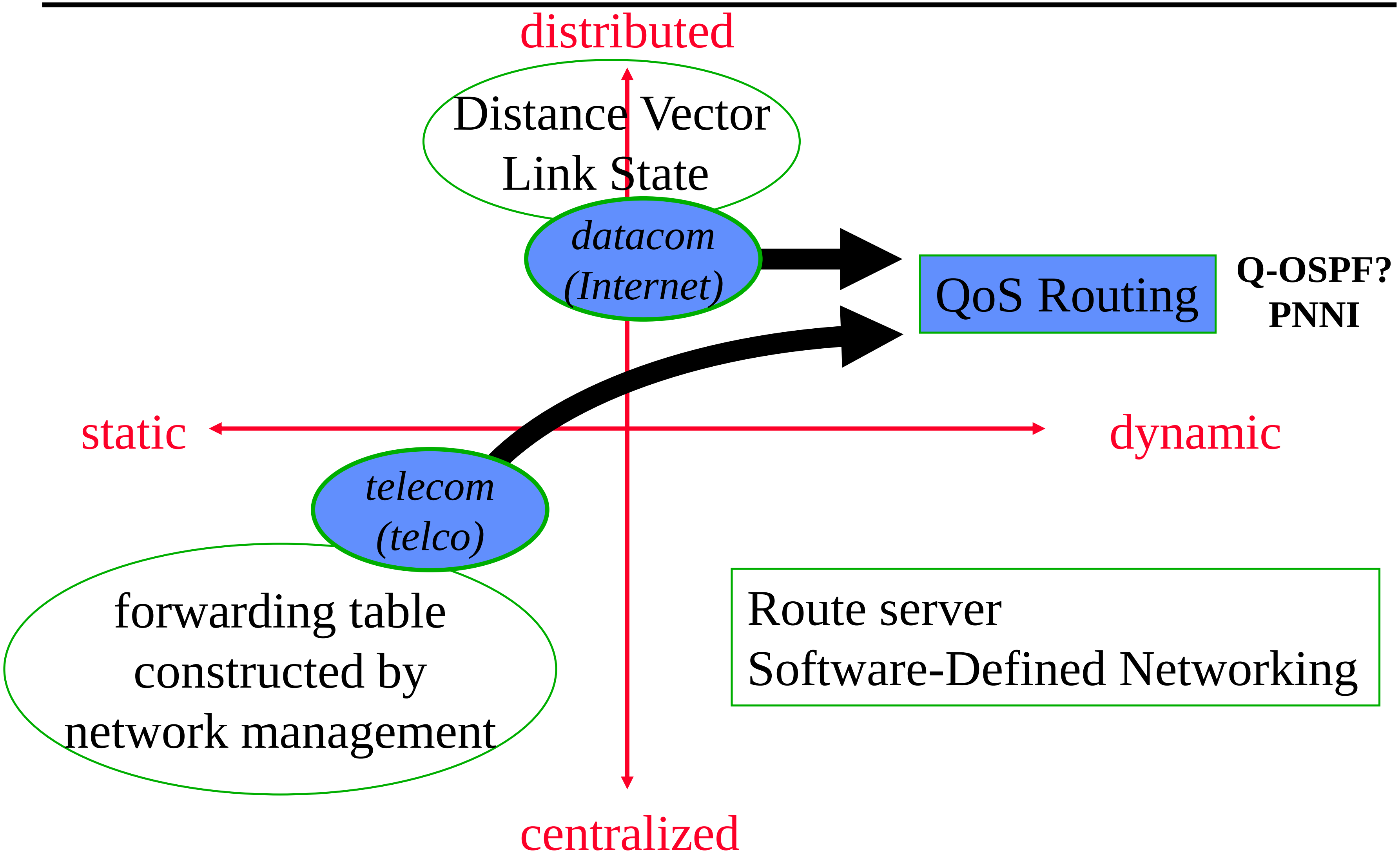
Rapid variations on time scale:
metrics coupled to state of resources



TENDENCY towards incomplete Routing information

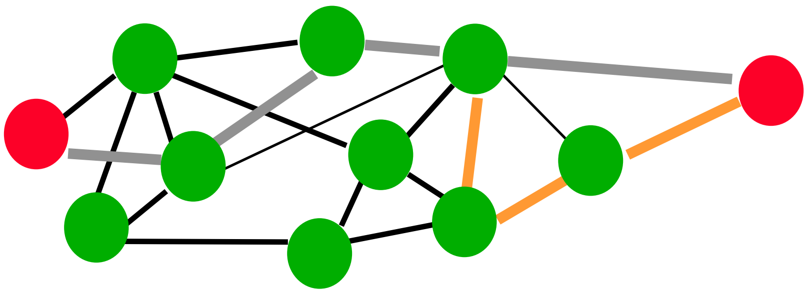
- resource coupling (QoS)
- hierarchical networks (info condensation)

Routing Protocols: Classification and Evolution



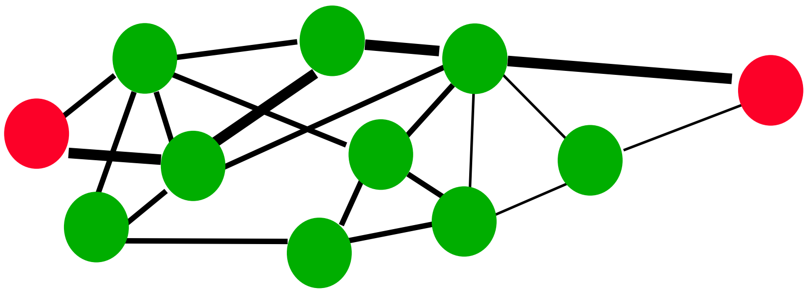
Single Parameter Routing

- HOP BY HOP ROUTING



  - each node computes (sub)path from itself to destination
  - routing consistency requires that all nodes use same routing algorithm
  - flexible, robust, CL
  - only single parameter routing
  - Best Effort (OSPF, RIP)

- SOURCE ROUTING



  - source computes entire path
  - signaling required (CO) or storage of complete path in every packet
  - loop free
  - general multiple parameter routing
  - QoS Routing (PNNI)

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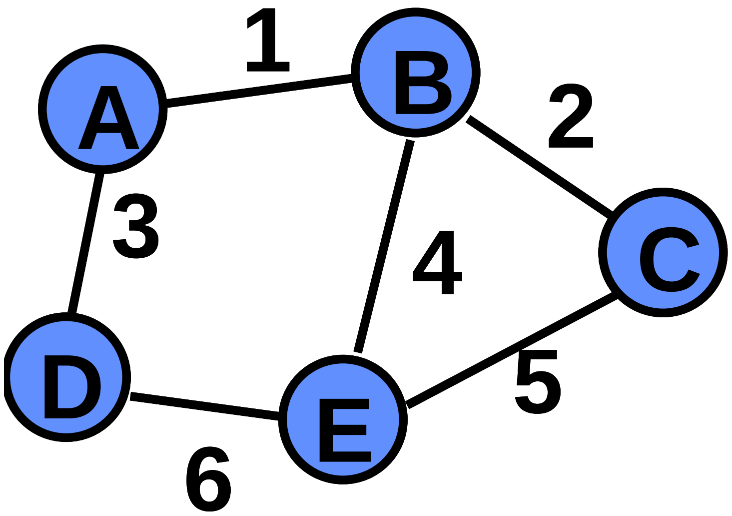
Basic distributed routing protocol families in Internet

- distance vector protocols (RIP; Bellman-Ford)
  - flood list of distances to neighbors
  - maintain list of shortest distances
  - protocol itself constructs forwarding table
  - simple but vulnerable
- link state protocols (OSPF; Dijkstra)
  - flood topology information
  - maintain entire map of network
  - local routing algorithm computes forwarding table
  - more robust but more complex

RIP

- RIP (Routing Information Protocol): distance vector family
- cold start: fully distributed routing
- Artifacts: loops
  - bouncing effect
  - count to infinity
- Heuristics to prevent dynamic side-effects

RIP example



Nodes are capable of relaying packets
Purpose is to compute routing tables
Each node has unique address A, B, C, D, or E
Links are symmetric, have a unique number and have a cost (mostly costs are 1 for shortest hopcount paths)

Cold Start

0. Initial Condition

To	Link	Cost
A	local	0

1. A receives on link 1 the distance vector B = 0 and on link 3 D=0

To	Link	Cost
A	local	0
B	1	1
D	3	1

2. A floods on other links the distance vector A = 0, B = 1, D=1

Cold Start

3. A receives on link 1 the distance vector C = 1, E = 1
4. A receives on link 3 the distance vector E = 1, C = 2

To	Link	Cost
A	local	0
B	1	1
C	1	2
D	3	1
E	1	2

message 3

No change

To	Link	Cost
A	local	0
B	1	1
C	1	2
D	3	1
E	1	2

message 4

New distance on same link should always be used.

Line break

Link 1 between A and B breaks

1. A sends via link 3 the distance vector B = INF
2. A receives on link 3 the distance vector D = 0, E = 1, B = 2, C = 2

To	Link	Cost
A	local	0
B	1	1
C	1	2
D	3	1
E	1	2

old

To	Link	Cost
A	local	0
B	1	INF
C	1	INF
D	3	1
E	1	INF

transient

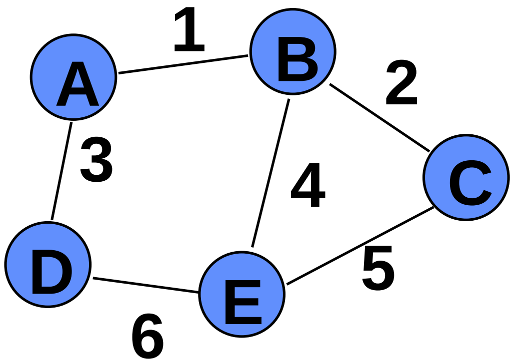
To	Link	Cost
A	local	0
B	3	3
C	3	3
D	3	1
E	3	2

new

Bouncing effect

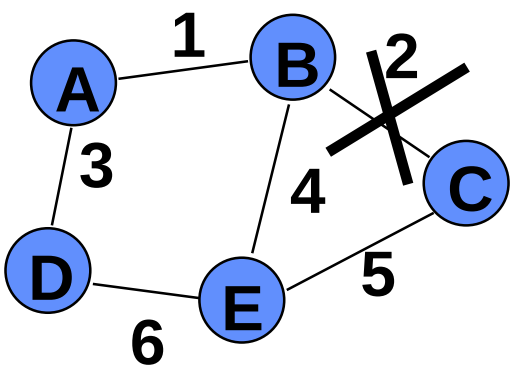
Cost of all links is 1 except E-C is 9

1)



From	Link	Cost
A to C	1	2
B to C	2	1

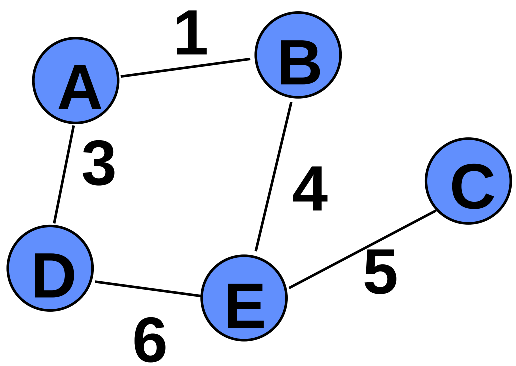
2)



From	Link	Cost
A to C	1	2
B to C	2	INF

Bouncing effect

3) A sends, just before B floods its distances, to B and D



From	Link	Cost
A to C	1	2
B to C	1	3

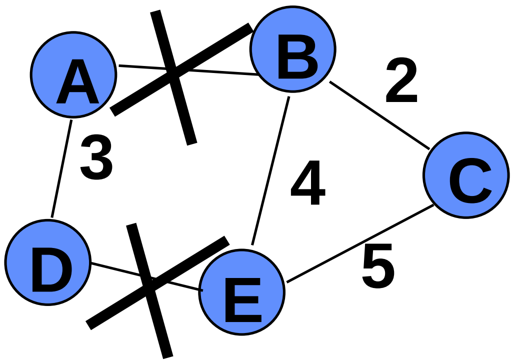
4) B floods its distances to A, who updates its entry to C

From	Link	Cost
A to C	1	4
B to C	1	3

LOOP: **BOUNCING**
Stops after A to C reaches 10

Count to infinity

1)



From	Link	Cost
D to E	6	INF

2) A sends: A = 0, E = 2 and D updates table

From	Link	Cost
D to E	3	4
D to E	3	6

3)

4)

5)

From	Link	Cost
A to E	3	5
A to E	3	7

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Heuristic remedies for looping

- Split horizon: if node A is routing packets bound to destination X through node B, it makes no sense for B to try to reach X through A. Thus, it makes no sense for A to announce to B that X is only a short distance from A.
- Triggered updates: flood information as soon as a change has occurred.
- Hold-down: after the metric for a route entry changes, the router accepts no updates for the route until the hold-down timer expires.

RIP summarized

- simple and adequate for small, reliable (link failures are rare) networks
- inadequate for large and complex networks:

slow convergence

↓

network is left too long in transient state

↓

loops may occur

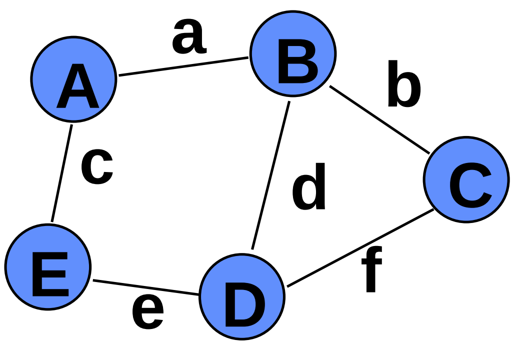
↓

leading to temporary congestion

Link-state protocols

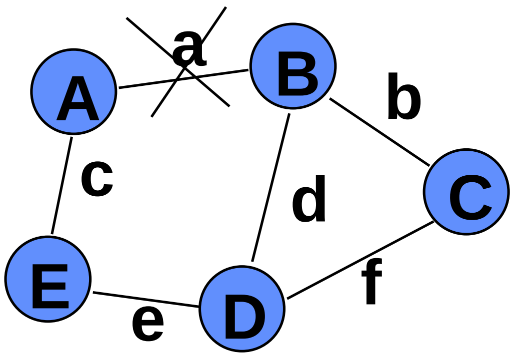
- First developed for ARPANET to overcome the problems with distance vector protocols.
- Nodes all maintain a map of the network that will be updated quickly after a topology change.
- If all nodes have the same map and algorithm, loops cannot occur.
- OSPF developed by IETF for Internet.

OSPF: Link State Database



From	To	Link	Cost	Num
A	B	a	1	1
A	E	c	5	1
B	A	a	1	1
B	C	b	3	1
B	D	d	3	1
C	B	b	3	1
C	D	f	7	1
D	B	d	3	1
D	C	f	7	1
D	E	e	8	1
E	A	c	5	1
E	D	e	8	1

OSPF: Link State Database



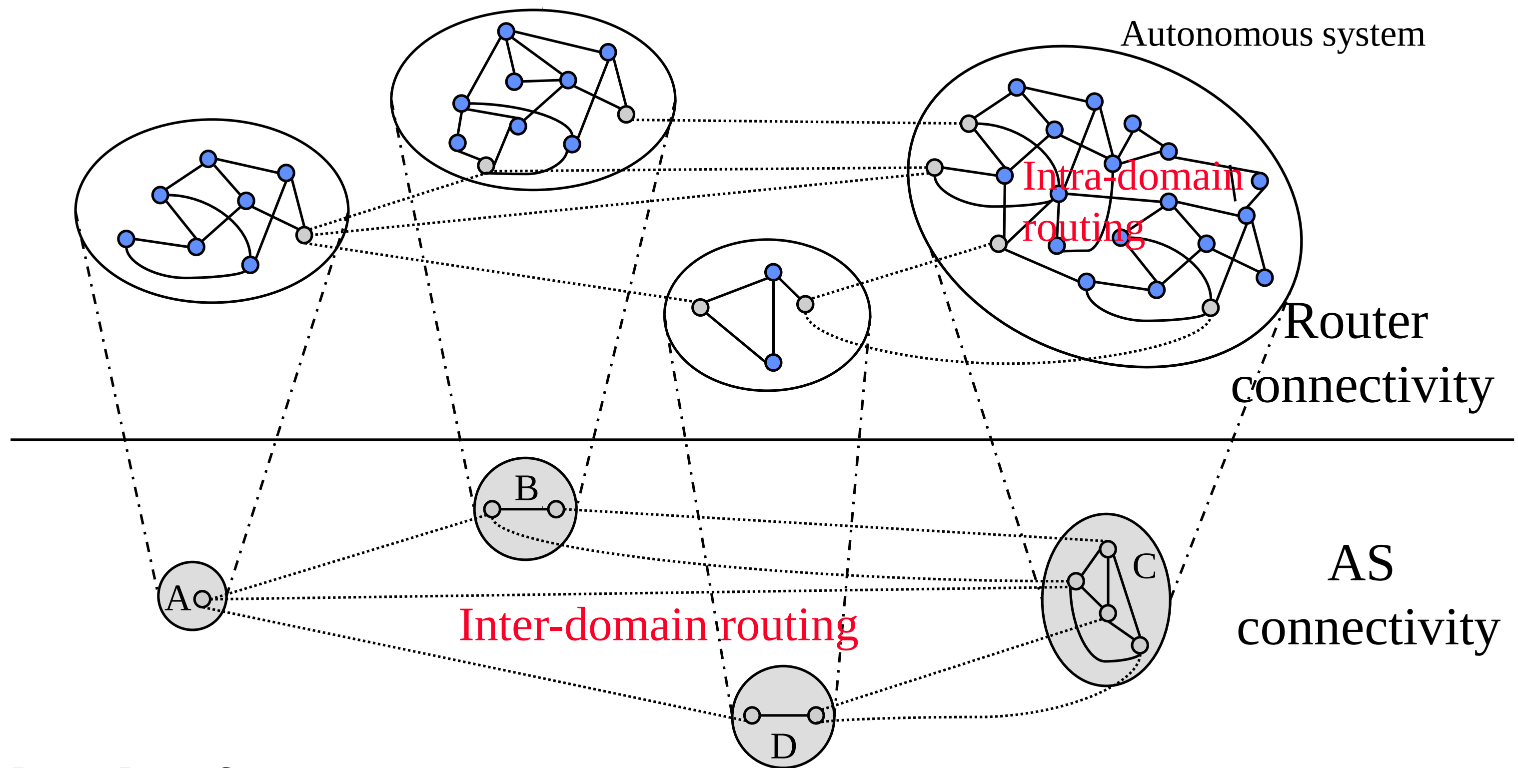
A broadcasts:
From A to B, link a, cost = INF, num =2
(modulo numbering)

From	To	Link	Cost	Num
A	B	a	INF	2
A	E	c	5	1
B	A	a	INF	2
B	C	b	3	1
B	D	d	3	1
C	B	b	3	1
C	D	f	7	1
D	B	d	3	1
D	C	f	7	1
D	E	e	8	1
E	A	c	5	1
E	D	e	8	1

OSPF: link state family

- All nodes maintain a map of the network
- Quickly update after any topology change
  purpose: synchronized copy of the link state in all nodes of network
- recommended by IAB as a replacement for RIP
- OSPF properties:
  - Secured flooding and fast, loopless convergence of link state
  - Dijkstra's shortest path algorithm (as default)
  - precise (multiple) metrics
  - multiple paths (any routing problem can be computed)
  - can take the ToS fields into account

Two-level Routing Hierarchy



- Two levels of routing in Internet:
  - Intra-domain routing (interior gateway protocols): RIP and OSPF routing within one AS (also IS-IS,...)
  - Inter-domain routing (exterior gateway protocols): EGP and BGP glue together different ASs (also IDRP,...)

Border Gateway Protocol (BGP)

- Fundamental Internet routing protocol: the heart of the Internet’s global connectivity
  - glue between ASs
  - complex protocol
  - only unicast
- Distance vector protocol enhanced with path vectors
  - Path vector contains entire path (list of ASs)
- ‘shortest path’: based on policies, not part of BGP
- Exchange of routing table via TCP
- Current scaling: problematic
  - RIB grows large
  - CIDR looses initial efficiency (aggregation)

Example BGP Table (RIB)

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```
TIME: 08/28/01 15:02:05
TYPE: TABLE_DUMP/INET
VIEW: 0
SEQUENCE: 0
PREFIX: 3.0.0.0/8
FROM: 192.65.184.3 AS513
ORIGINATED: 08/28/01 12:42:08
ORIGIN: IGP
ASPATH: 513 209 701 80
NEXT_HOP: 192.65.184.3
STATUS: 0x1

TIME: 08/28/01 15:02:05
TYPE: TABLE_DUMP/INET
VIEW: 0
SEQUENCE: 1
PREFIX: 3.0.0.0/8
FROM: 64.211.147.146 AS3549
ORIGINATED: 08/28/01 12:41:54
ORIGIN: IGP
ASPATH: 3549 701 80
NEXT_HOP: 64.211.147.146
COMMUNITY: 3549:2256 3549:30840
STATUS: 0x1

TIME: 08/28/01 15:02:05
TYPE: TABLE_DUMP/INET
VIEW: 0
SEQUENCE: 2
PREFIX: 3.0.0.0/8
FROM: 193.148.15.85 AS3257
ORIGINATED: 08/28/01 11:30:59
ORIGIN: IGP
ASPATH: 3257 701 80
NEXT_HOP: 193.148.15.85
STATUS: 0x1
```

main body of entries skipped

```
TIME: 08/28/01 15:02:35
TYPE: TABLE_DUMP/INET
VIEW: 0
SEQUENCE: 38026
PREFIX: 218.67.0.0/17
FROM: 12.127.0.121 AS7018
ORIGINATED: 08/27/01 13:40:42
ORIGIN: INCOMPLETE
ASPATH: 7018 6453 4134
NEXT_HOP: 12.127.0.121
ATOMIC_AGGREGATE
AGGREGATOR: AS4134 202.97.32.22
STATUS: 0x1

TIME: 08/28/01 15:02:35
TYPE: TABLE_DUMP/INET
VIEW: 0
SEQUENCE: 38027
PREFIX: 218.67.0.0/17
FROM: 129.250.0.232 AS2914
ORIGINATED: 08/27/01 13:43:04
ORIGIN: IGP
ASPATH: 2914 6453 4134
NEXT_HOP: 129.250.0.232
MULTI_EXIT_DISC: 0
ATOMIC_AGGREGATE
AGGREGATOR: AS4134 202.97.32.22
COMMUNITY: 2914:420
STATUS: 0x1
```

The syntax is explained in RFC 1771

BGP Path Vector Protocol

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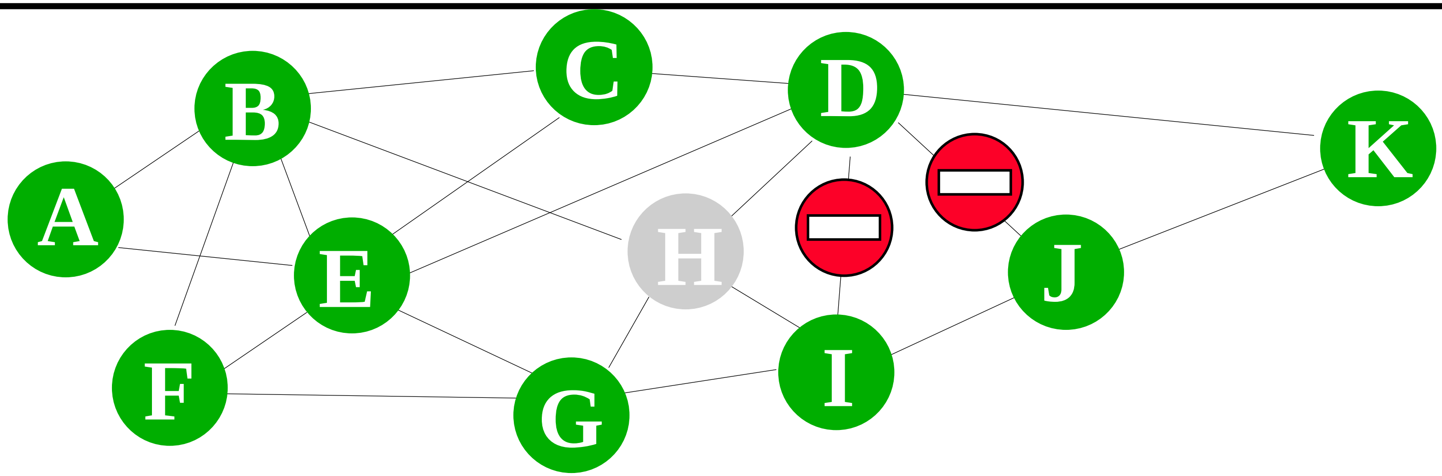

1. H receives the path vector from its BGP-neighbours about K:

   from B: BHIJK   from G: GHDK

   from D: DK   from I : IJK

2. H discards the path from B and from G that runs over itself
3. H uses a module with policy information and link measures and computes a "distance" for each remaining path from H to K
4. The path corresponding to shortest distance is stored in H's routing table.

Example questions Ch. 7

- Explain the difference between intradomain routing and interdomain routing.
- Explain the basic operation of RIP/OSPF/BGP.
- In a fixed network topology, we may distinguish between two types of network changes. Discuss these two types and explain which type of changes is more likely to tend towards incomplete routing information if the network grows.

Partial Examination 2

- Wednesday 29/06/2016
- Content

  Chapters 3, 5 to 7.5, except for footnotes and
  - Fig. 5.7 on p. 118
  - Sec. 5.6 (pp. 122 – 124)
  - Sec. 6.2.4 (pp. 145 – 146)
  - Sec. 6.3.3, 6.3.4 and 6.3.5 (p. 157 - p. 167)
  - Sec. 6.5, 6.6 and 6.7 (pp. 170- 176)
  - Sec. 7.6 and further.
- Closed book
  - Theory: e.g. explain the ARQ protocol used in TCP?
  - Exercise: e.g. compute a minimum spanning tree