Network Layer(3)

Routing algorithms

Responsible for deciding which output line an incoming packet should be transmitted on. The goal is to find an optimal path based on a given metric.

Two major classes of routing algorithms:

- nonadaptive
- adaptive

Possible metrics for determining optimality of a path:

- number of hops
- geographic distance
- bandwidth
- average traffic (load)
- communication cost
- mean queue length
- measured delay

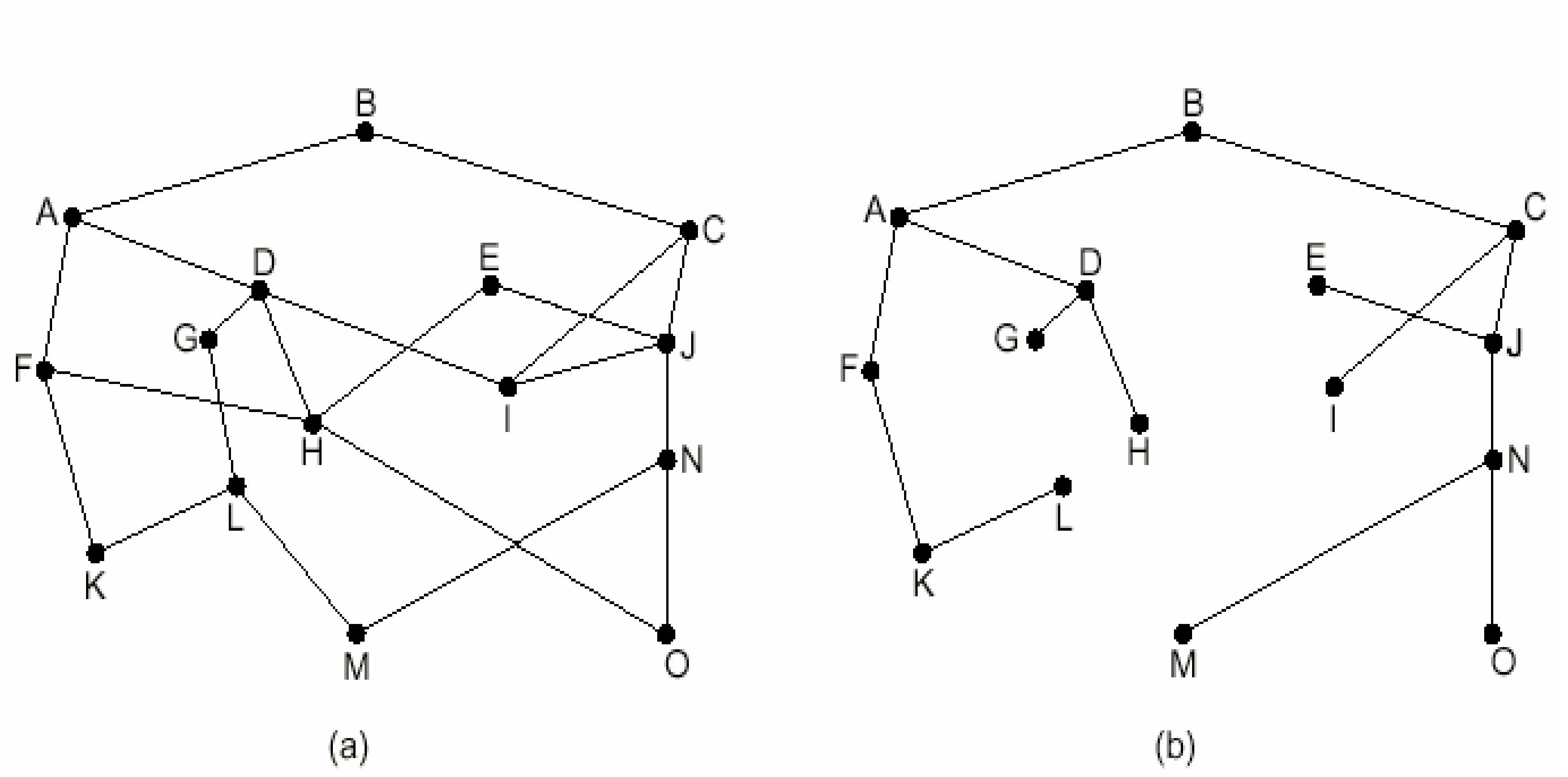
Network Layer(4)

The Optimality Principle:

If router J is on the optimal path from router I to router K, then the optimal path from J to K also follows the same route

---> The set of optimal routes from all sources to a given destination form a tree rooted at the destination.

Example of a sink tree



Network Layer(7)

Distance Vector Routing

Idea:

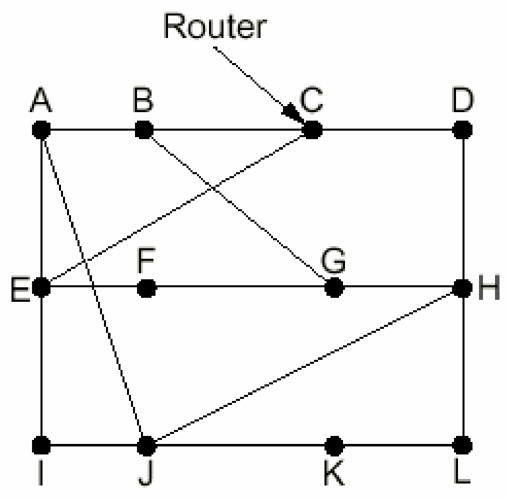
Each router maintains a table (vector) giving a periodically updated best known path length to each destination and which output line to use to get there

Used in early versions of

- ARPANET
- Internet (RIP)
- DECnet
- Novell´s IPX
- AppleTalk
- Cisco routers

Network Layer(8)

Example of the updating process



(a)

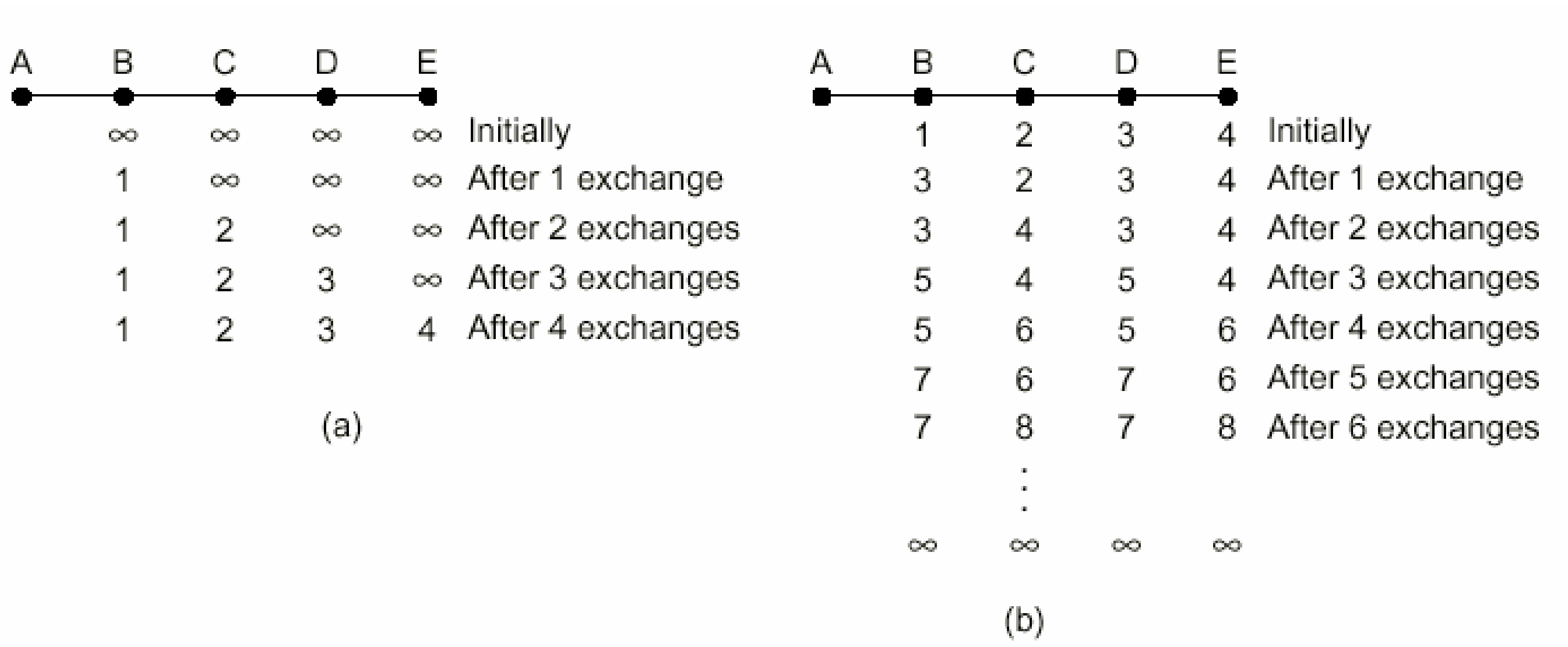
To	A	I	H	K	New estimated delay from J	Line
A	0	24	20	21	8	A
B	12	36	31	28	20	A
C	25	18	19	36	28	I
D	40	27	8	24	20	H
E	14	7	30	22	17	I
F	23	20	19	40	30	I
G	18	31	6	31	18	H
H	17	20	0	19	12	H
I	21	0	14	22	10	I
J	9	11	7	10	0	–
K	24	22	22	0	6	K
L	29	33	9	9	15	K
	JA delay is 8	JI delay is 10	JH delay is 12	JK delay is 6	New routing table for J	

Vectors received from J's four neighbors

(b)

Network Layer(9)

Example of the count-to-infinity problem



Main problems:

- The algorithm often takes too long to converge to infinity
- How to define infinity?

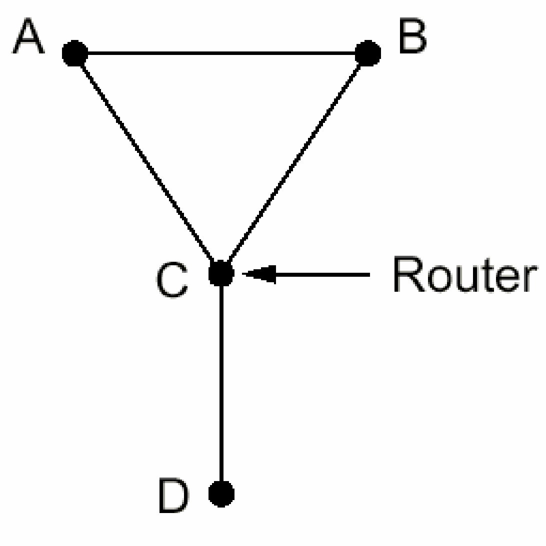
The Split Horizon Hack (Poisoned Reverse)

Idea:

The distance to A is reported as infinity on the line that packets for A are sent on

Network Layer(10)

Example where split horizon fails



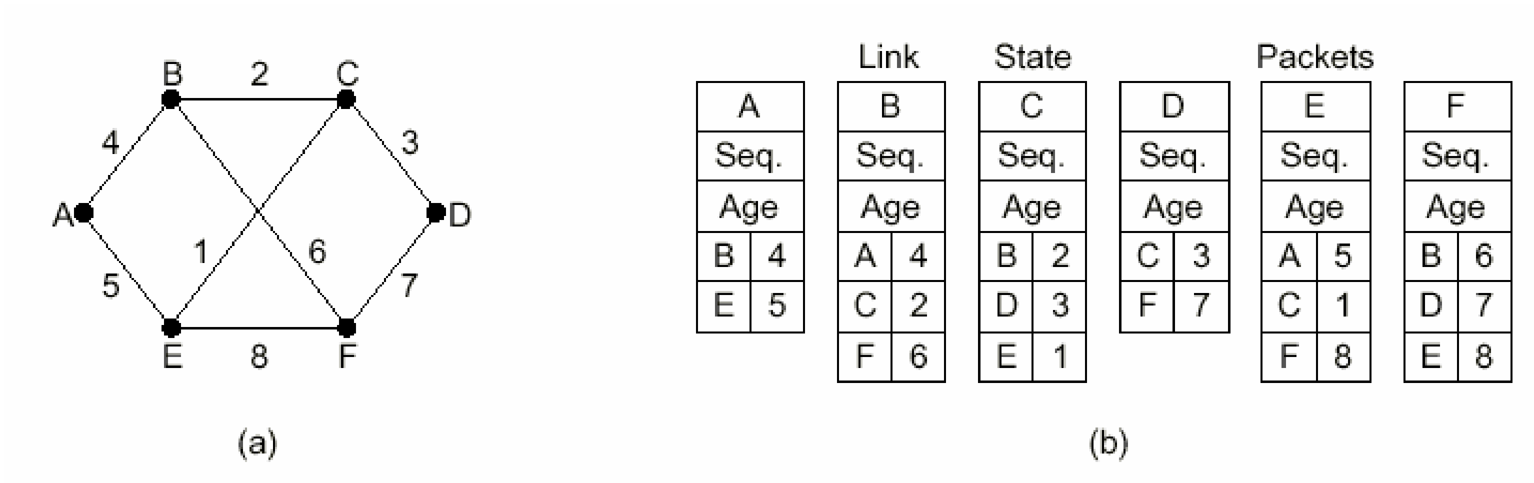
Link State Routing

Principle behind:

Each router must

- discover its neighbors and learn their network addresses.
- measure the delay or cost to each of its neighbors.
- construct a packet telling all it has just learned.
- send this packet to all other routers using flooding.
- compute the shortest path to every other router using shortest path algorithm (constructing sink tree).

Example of building Link State Packets



(a) (b)

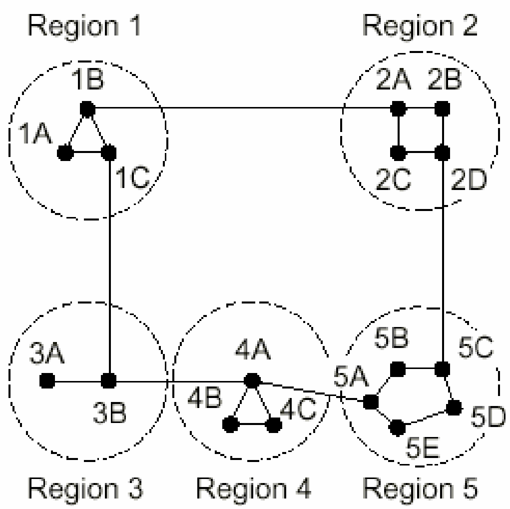
The principle of Link State Routing is widely used in actual networks (e.g. IP).

Hierarchical Routing

Idea:
Routers are divided into (sub)regions, thus making up a multilevel hierarchy.

Network Layer(12)

Example of routing in a two-level hierarchy with five regions



(a)

Full table for 1A

Dest.	Line	Hops
1A	–	–
1B	1B	1
1C	1C	1
2A	1B	2
2B	1B	3
2C	1B	3
2D	1B	4
3A	1C	3
3B	1C	2
4A	1C	3
4B	1C	4
4C	1C	4
5A	1C	4
5B	1C	5
5C	1B	5
5D	1C	6
5E	1C	5

(b)

Hierarchical table for 1A

Dest.	Line	Hops
1A	–	–
1B	1B	1
1C	1C	1
2	1B	2
3	1C	2
4	1C	3
5	1C	4

(c)

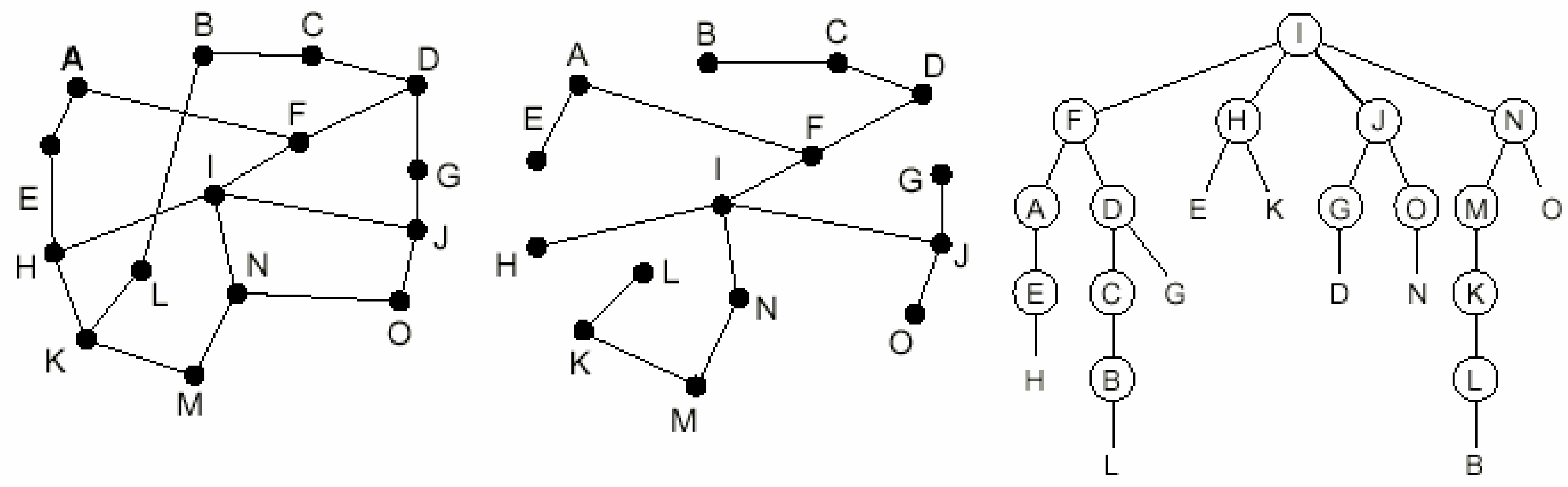
Network Layer(16)

Broadcast Routing

Possible methods:

- the source sends a distinct packet to each destination
- flooding
- **reverse path ordering**

Example of reverse path ordering



(a) (b) (c)

Network Layer(20)

Differences than can occur in the network layer

Item	Some Possibilities
Service offered	Connection-oriented versus connectionless
Protocols	IP, IPX, CLNP, AppleTalk, DECnet, etc.
Addressing	Flat (802) versus hierarchical (IP)
Multicasting	Present or absent (also broadcasting)
Packet size	Every network has its own maximum
Quality of service	May be present or absent; many different kinds
Error handling	Reliable, ordered, and unordered delivery
Flow control	Sliding window, rate control, other, or none
Congestion control	Leaky bucket, choke packets, etc.
Security	Privacy rules, encryption, etc.
Parameters	Different timeouts, flow specifications, etc.
Accounting	By connect time, by packet, by byte, or not at all