Computer Networks 1

(Mạng Máy Tính 1)

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Lecture 5: Network Layer

Reference:

Chapter 5 - "*Computer Networks*",

Andrew S. Tanenbaum, 4th Edition, Prentice Hall, 2003.

Contents

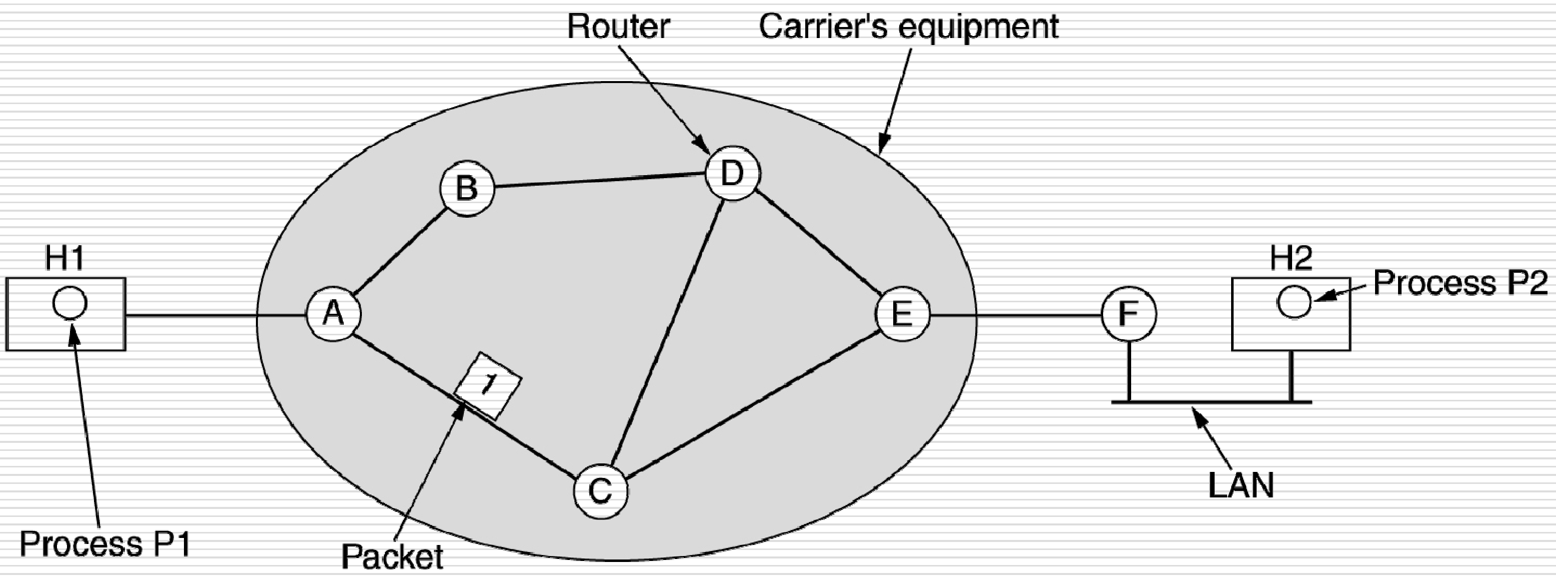
- The network layer design issues
- Routing algorithms
- Congestion control algorithms
- Quality of services
- Internetworking
- The network layer in the Internet

Network Layer Design Issues

- Store-and-Forward Packet Switching
- Services Provided to the Transport Layer
- Implementation of Connectionless Service
- Implementation of Connection-Oriented Service
- Comparison of Virtual-Circuit and Datagram Subnets

Store-and-Forward Packet Switching – Router

The environment of the network layer protocols.



Services Provided to the Transport Layer

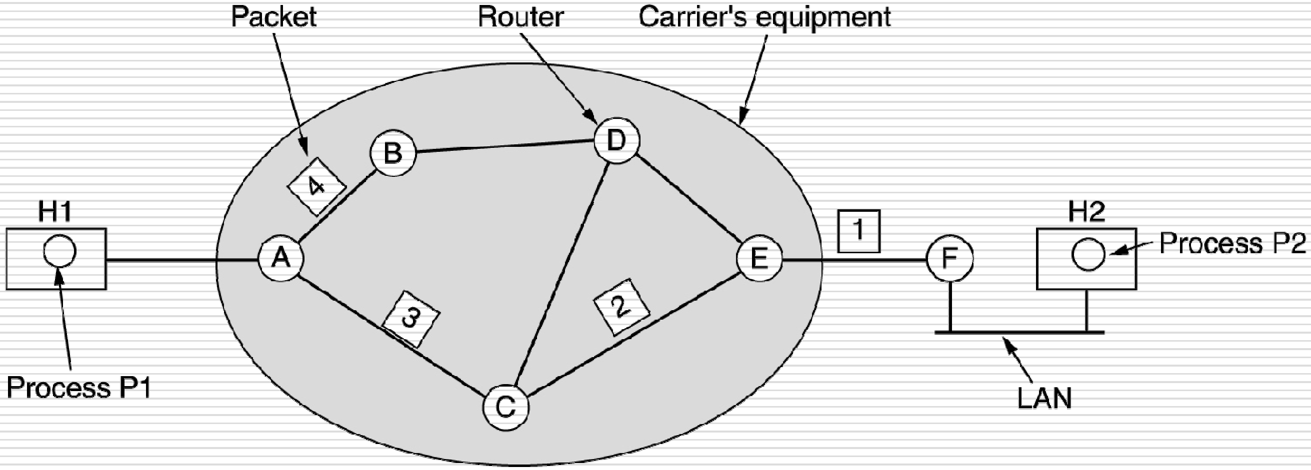
- Network layer provides services to the transport layer
- Goals of network layer services
  - Independent of router technology
  - The transport layer should be shielded from the number, type and topology of routers
  - Network addresses available to the transport layer should be uniformed and even across LANs and WANs

Two Classes of Services in the Network Layer

- Connection less service
  - Packets are called datagrams
  - The subnet is called a datagram subnet
  - Packets may arrive at the destination by multiple paths
- Connection oriented service
  - The connection is called Virtual Circuit
  - The subnet is called a virtual circuit subnet
  - All packets arrive at the destination by the same route

Implementation of Connectionless Service

Routing within a diagram subnet.

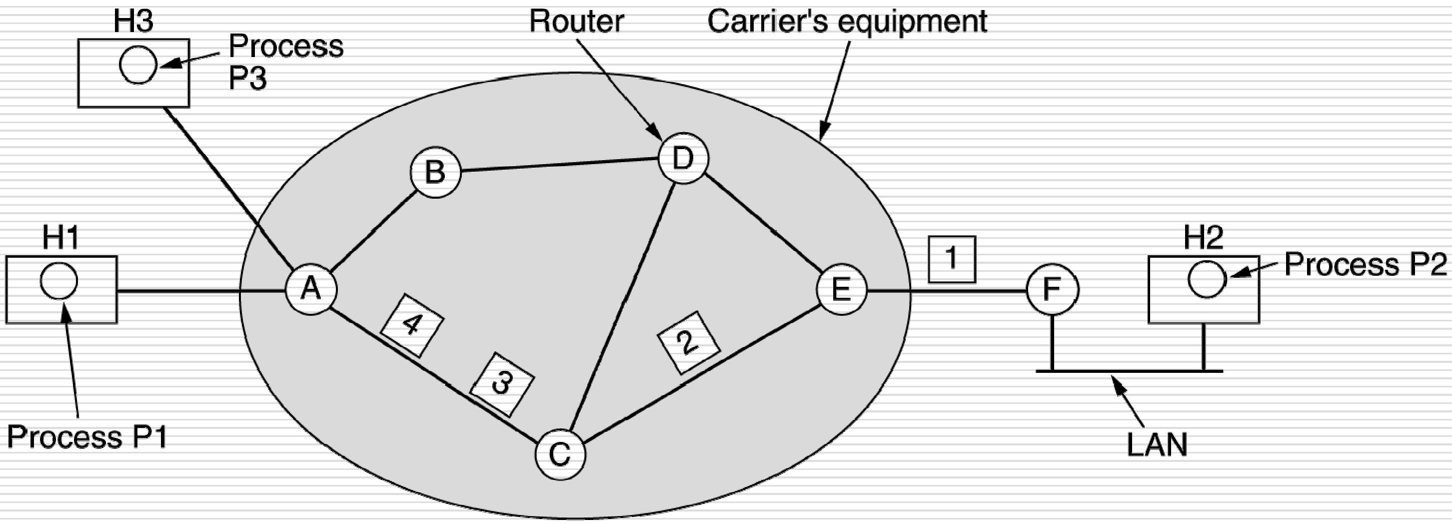


A's table initially (Dest.)	(Line)	A's table later (Dest.)	(Line)	C's table (Dest.)	(Line)	E's table (Dest.)	(Line)
A	–	A	–	A	A	A	C
B	B	B	B	B	A	B	D
C	C	C	C	C	–	C	C
D	B	D	B	D	D	D	D
E	C	E	B	E	E	E	–
F	C	F	B	F	E	F	F

Dest. Line

Implementation of Connection-Oriented Service

Routing within a virtual-circuit subnet.



A's table

In		Out	
H1	1	C	1
H3	1	C	2

C's table

A	1	E	1
A	2	E	2

E's table

C	1	F	1
C	2	F	2

Comparison of Virtual-Circuit and Datagram Subnets

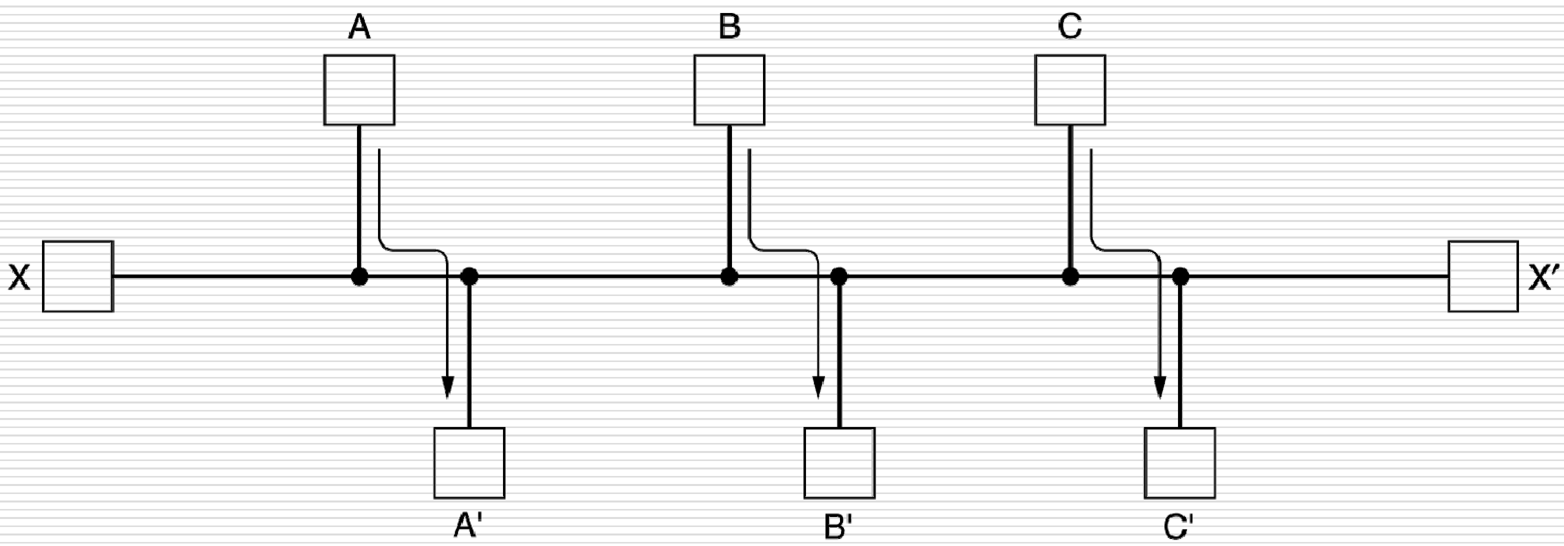
Issue	Datagram subnet	Virtual-circuit subnet
Circuit setup	Not needed	Required
Addressing	Each packet contains the full source and destination address	Each packet contains a short VC number
State information	Routers do not hold state information about connections	Each VC requires router table space per connection
Routing	Each packet is routed independently	Route chosen when VC is set up; all packets follow it
Effect of router failures	None, except for packets lost during the crash	All VCs that passed through the failed router are terminated
Quality of service	Difficult	Easy if enough resources can be allocated in advance for each VC
Congestion control	Difficult	Easy if enough resources can be allocated in advance for each VC

Routing Algorithms

- To route packets from a source to a destination
- Distinction between routing and forwarding
  - Routing: make decision on which route to use
  - Forwarding: use routing tables to send packets
- Two class of algorithms
  - Nonadaptive (static)
  - Adaptive

Fairness vs Optimality

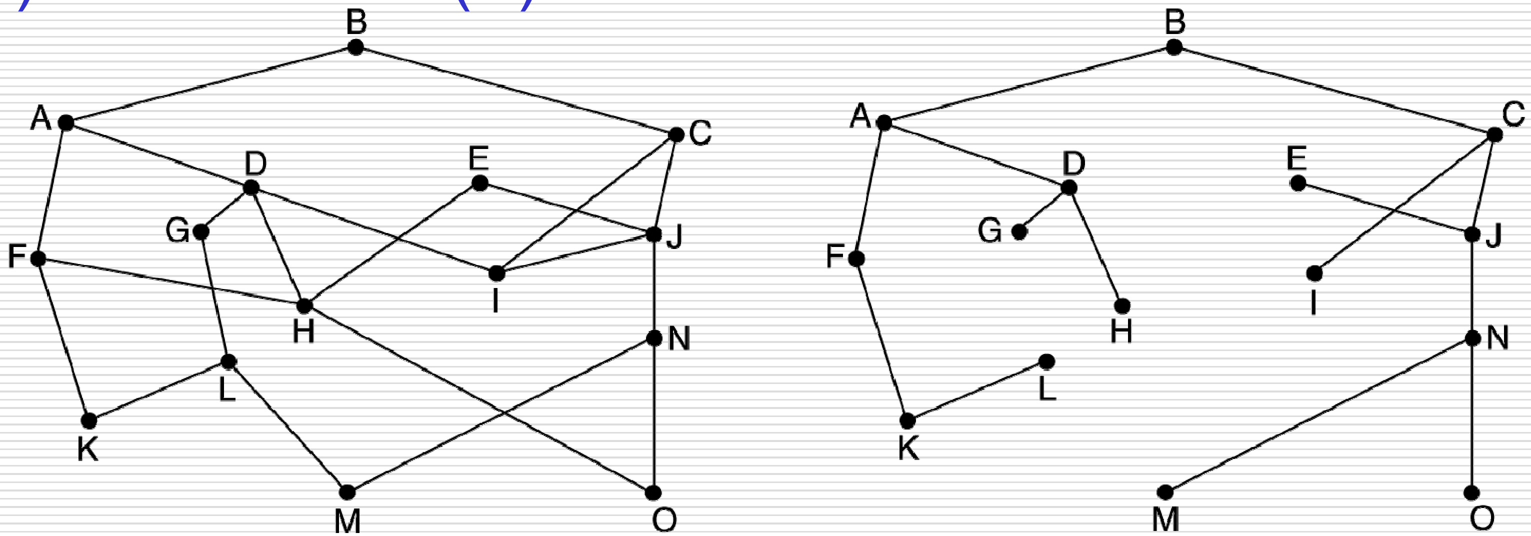
Conflict between fairness and optimality.



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 is also on the same route.

(a) A subnet. (b) A sink tree for router B.



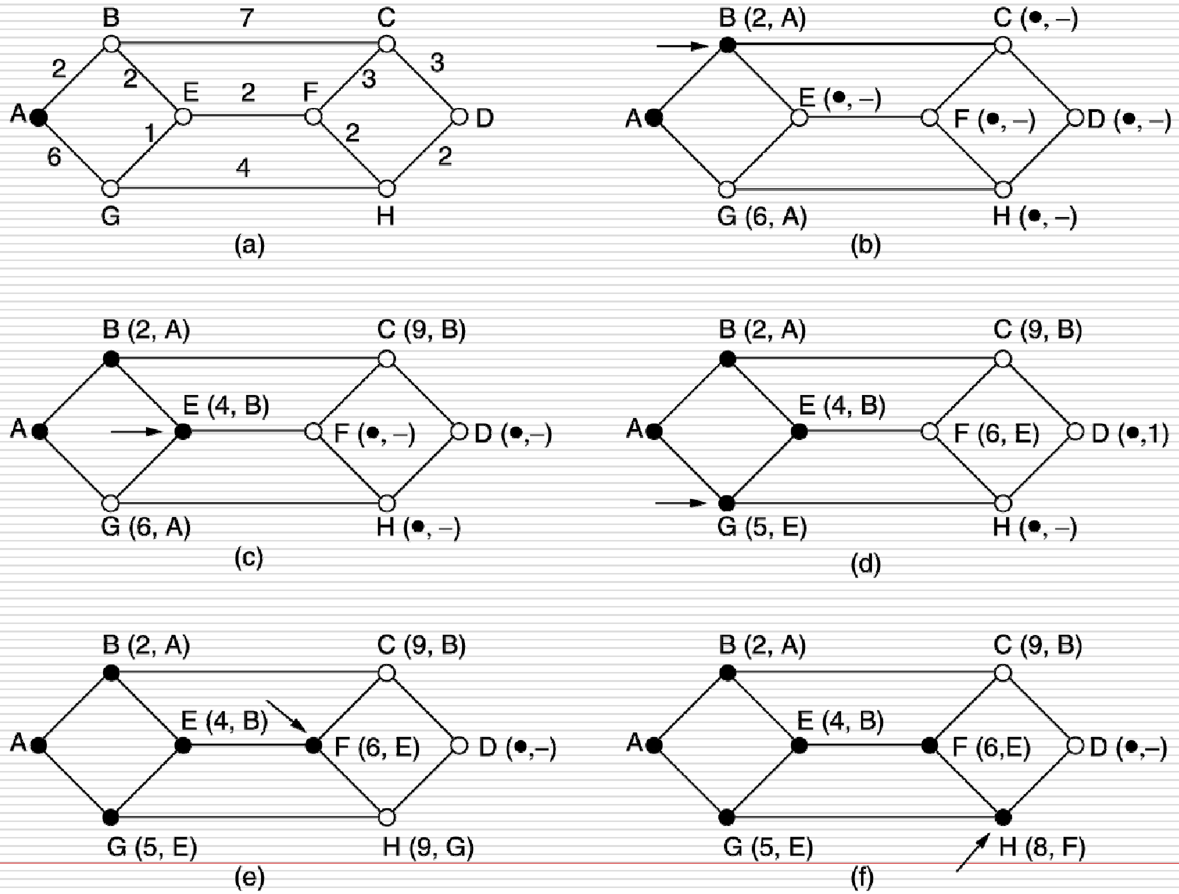
(a) (b)

Common Routing Algorithms

- The Optimality Principle
- Shortest Path Routing
- Flooding
- Distance Vector Routing
- Link State Routing
- Hierarchical Routing
- Broadcast Routing
- Multicast Routing
- Routing for Mobile Hosts
- Routing in Ad Hoc Networks

Shortest Path Routing

- Use Dijkstra algorithm



Flooding

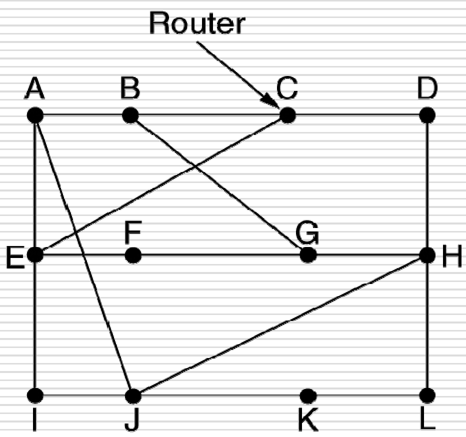
- Incoming packets are sent to every outgoing lines
- Generate vast numbers of duplicates
- Alternatives for improvement
  - Tracking packets sent
  - Use TTL (time-to-live)
  - Selective flooding
- Not practical in most applications

Distance Vector Routing (1)

- Also known as Bellman-Ford and Ford-Fulkerson algorithm
- Originally was used in ARPANET
- Used in Internet under RIP
- Each router having a table of the best known distance to each destination and the preferred outgoing line to get there
- Periodically, a router exchanges its table with its neigbors
- Then, all routers recalculate their tables

Distance Vector Routing (2)

(a) A subnet. (b) Input from A, I, H, K, and the new routing table for J.



(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)

Distance Vector Routing (3)

The count-to-infinity problem

a) initially, all routers are down

b) Initially, all routers are up, then A is down

A	B	C	D	E	
	•	•	•	•	Initially
	1	•	•	•	After 1 exchange
	1	2	•	•	After 2 exchanges
	1	2	3	•	After 3 exchanges
	1	2	3	4	After 4 exchanges

(a)

A	B	C	D	E	
	1	2	3	4	Initially
	3	2	3	4	After 1 exchange
	3	4	3	4	After 2 exchanges
	5	4	5	4	After 3 exchanges
	5	6	5	6	After 4 exchanges
	7	6	7	6	After 5 exchanges
	7	8	7	8	After 6 exchanges
		⋮			
	•	•	•	•	

(b)

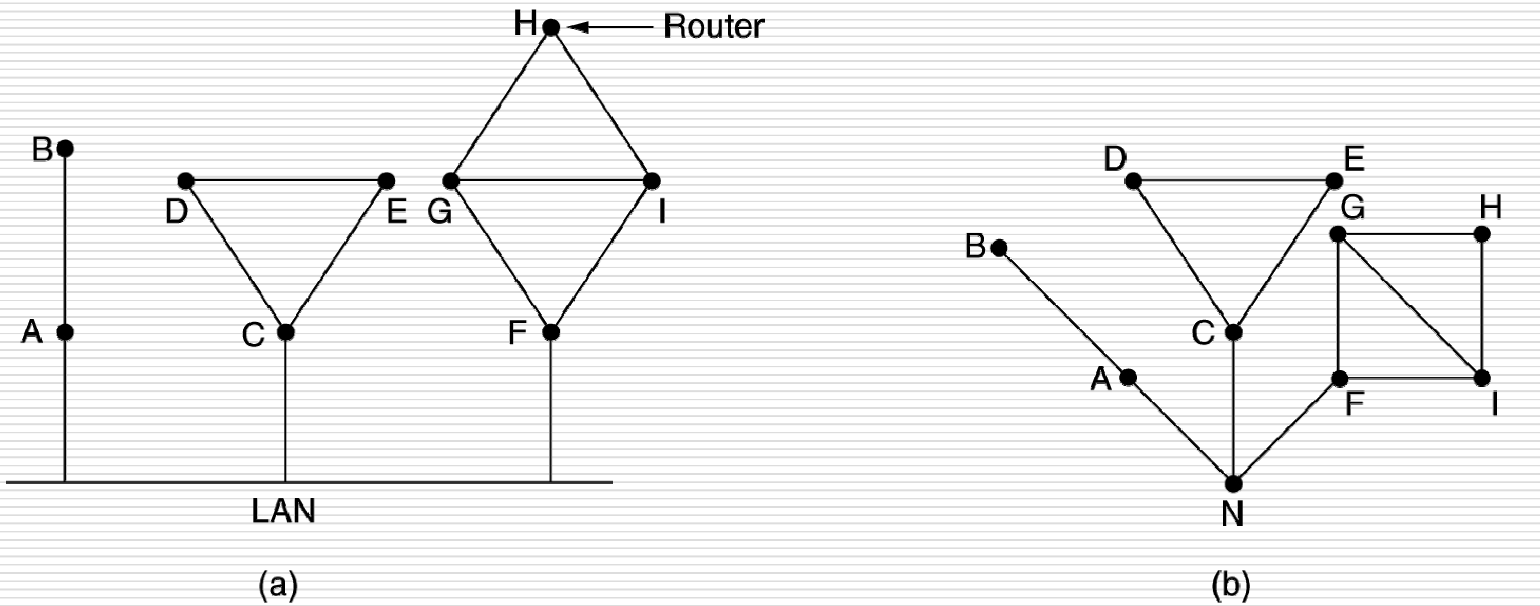
Link State Routing

Each router must do the following:

- Discover its neighbors, learn their network address.
- 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.
- Compute the shortest path to every other router.

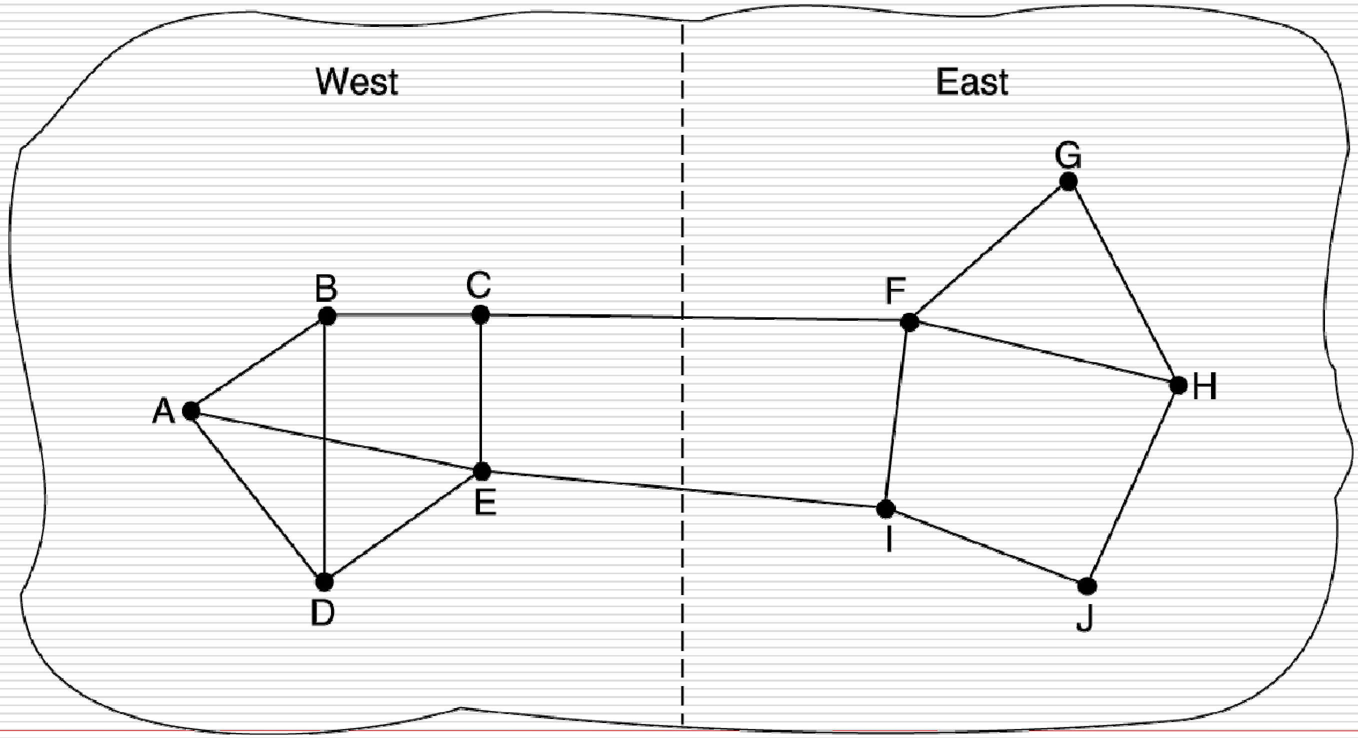
Learning about the Neighbors

(a) Nine routers and a LAN. (b) A graph model of (a).



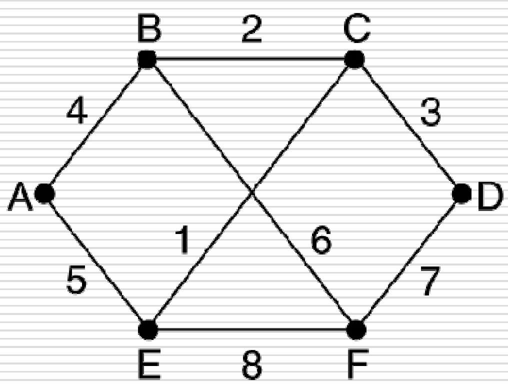
Measuring Line Cost

A subnet in which the East and West parts are connected by two lines.



Building Link State Packets

(a) A subnet. (b) The link state packets for this subnet.



(a)

Link State Packets

A		B		C		D		E		F	
Seq.		Seq.		Seq.		Seq.		Seq.		Seq.	
Age		Age		Age		Age		Age		Age	
B	4	A	4	B	2	C	3	A	5	B	6
E	5	C	2	D	3	F	7	C	1	D	7
		F	6	E	1			F	8	E	8

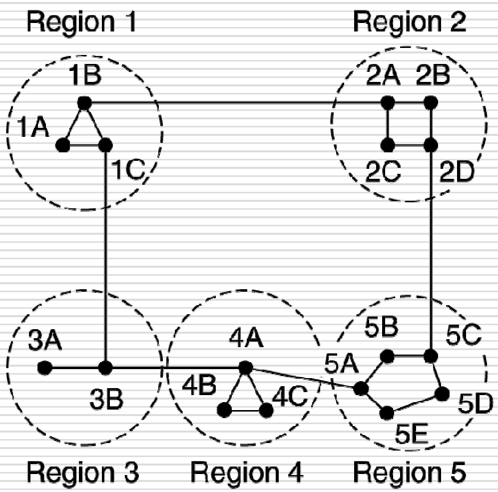
(b)

Distributing the Link State Packets

The packet buffer for router B in the previous slide

Source	Seq.	Age	Send flags A	Send flags C	Send flags F	ACK flags A	ACK flags C	ACK flags F	Data
A	21	60	0	1	1	1	0	0	
F	21	60	1	1	0	0	0	1	
E	21	59	0	1	0	1	0	1	
C	20	60	1	0	1	0	1	0	
D	21	59	1	0	0	0	1	1	

Hierarchical Routing



(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

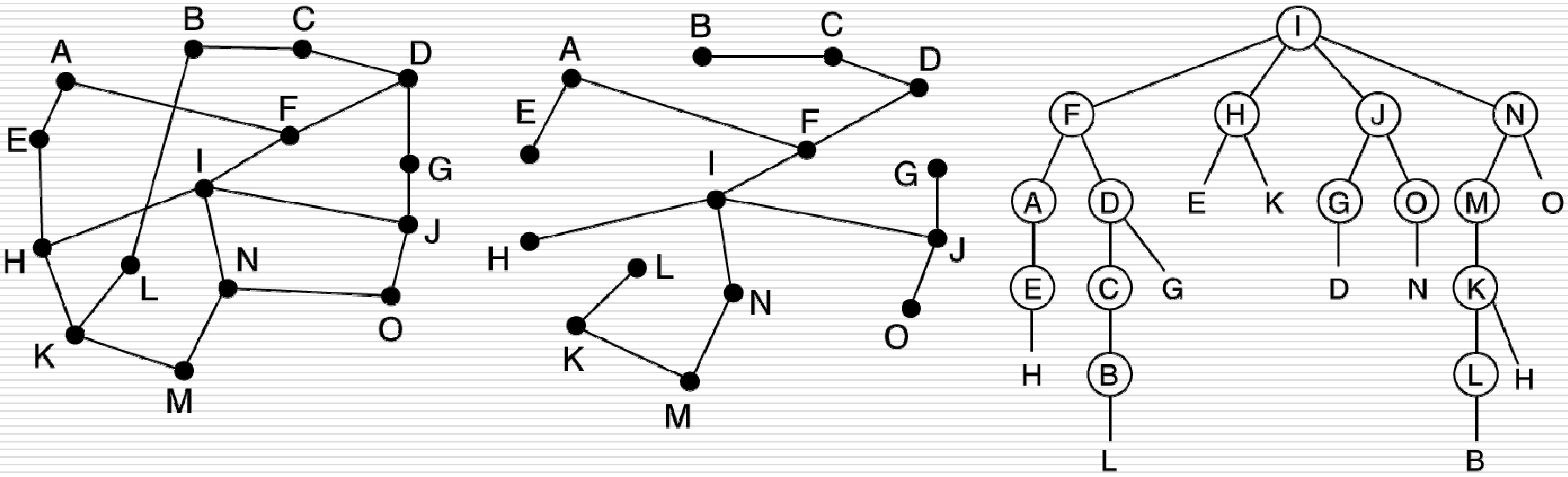
(b)

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)

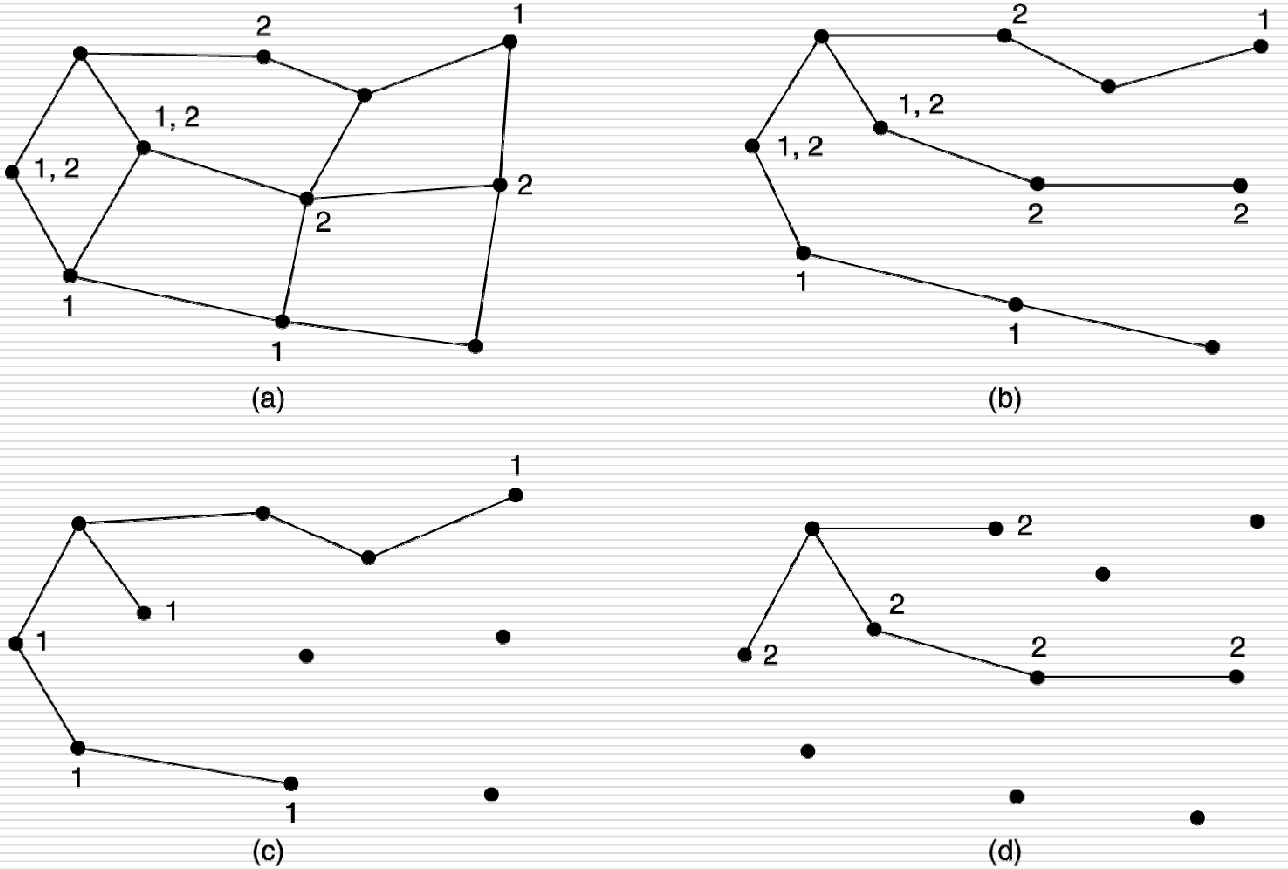
Broadcast Routing



(a) (b) (c)

Reverse path forwarding. (a) A subnet. (b) a Sink tree. (c) The tree built by reverse path forwarding.

Multicast Routing

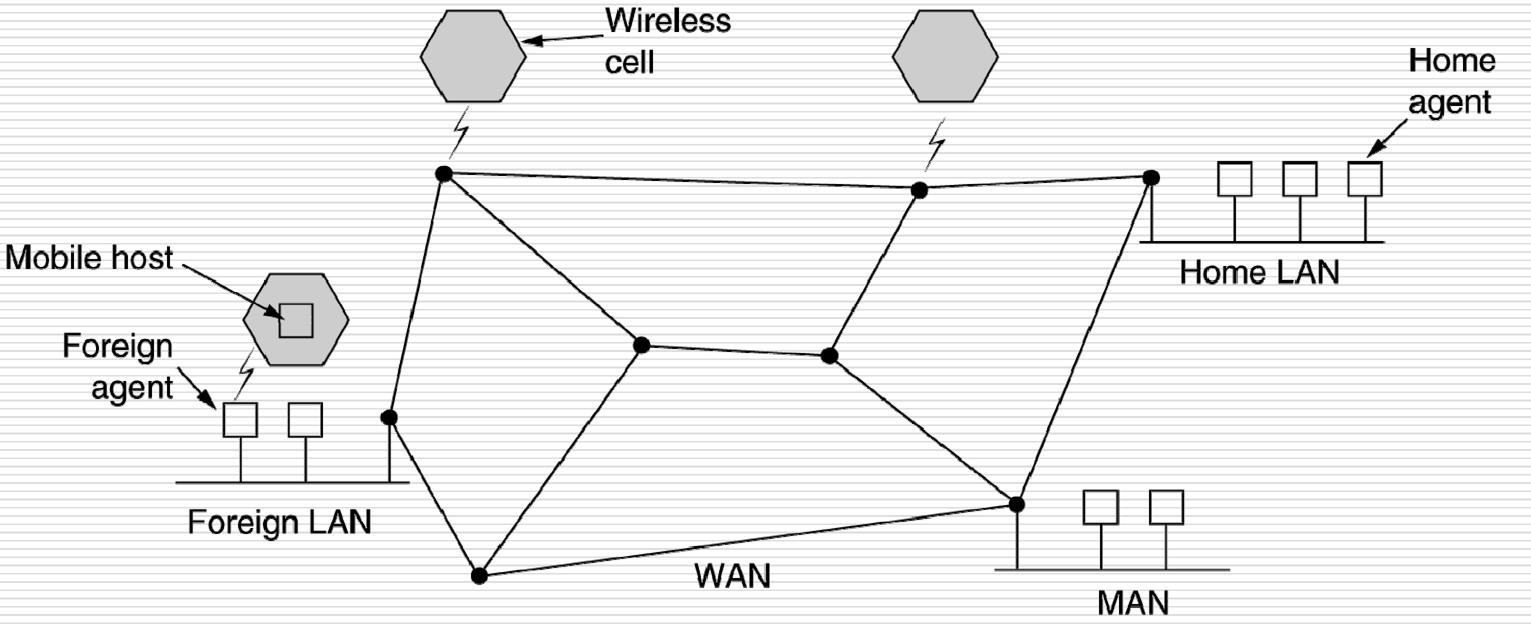


(a) A network. (b) A spanning tree for the leftmost router.

(c) A multicast tree for group 1. (d) A multicast tree for group 2.

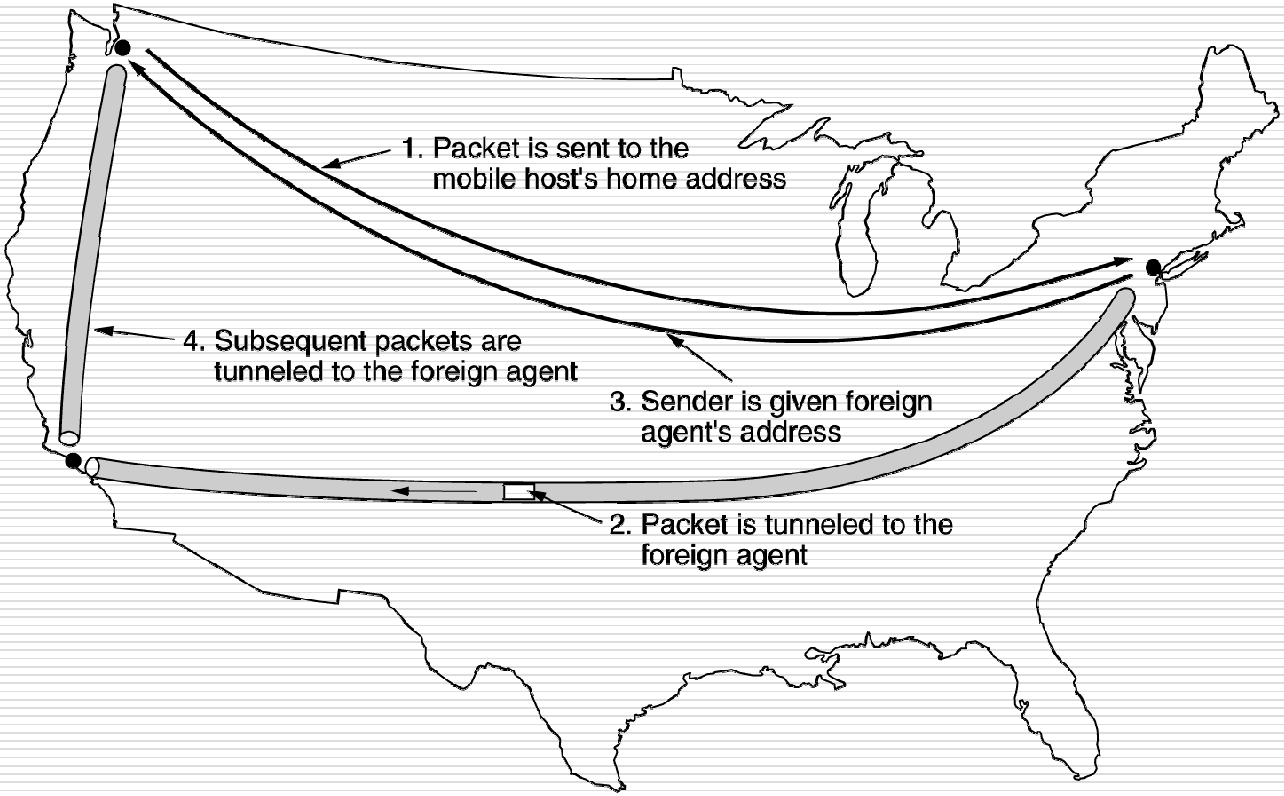
Routing for Mobile Hosts

A WAN to which LANs, MANs, and wireless cells are attached.



Routing for Mobile Hosts (2)

Packet routing for mobile users.

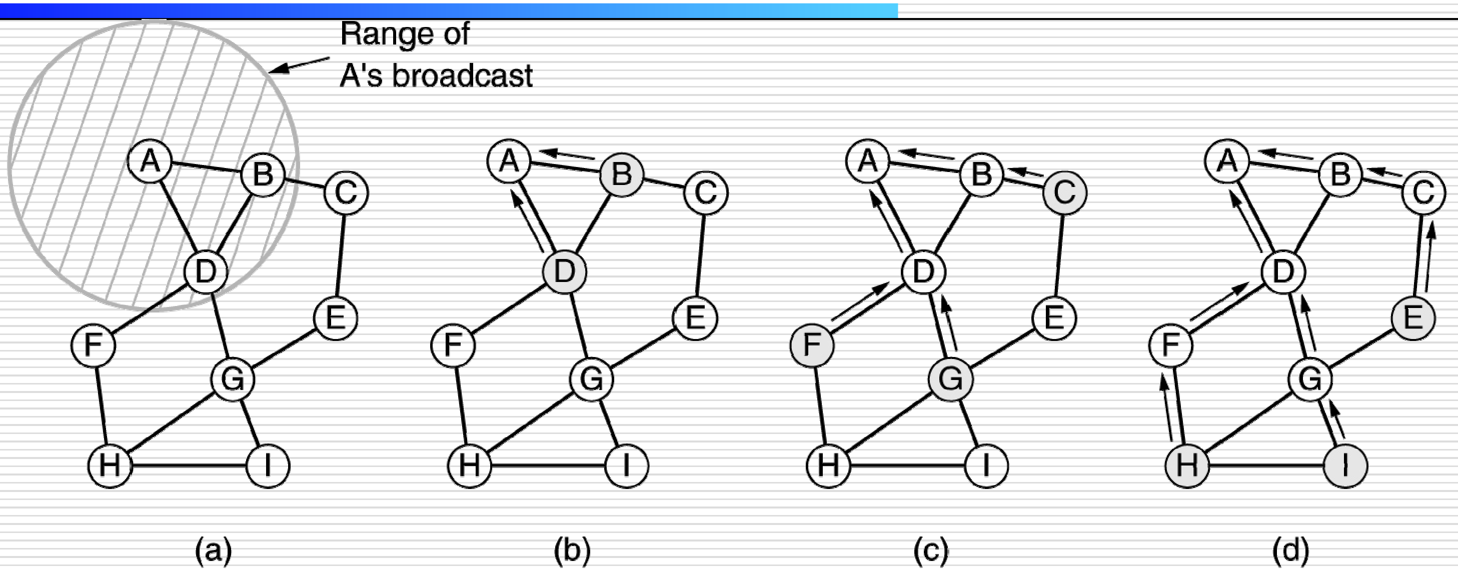


Routing in Ad Hoc Networks

Possibilities when the routers are mobile:

- Military vehicles on battlefield.
  - No infrastructure.
- A fleet of ships at sea.
  - All moving all the time
- Emergency works at earthquake .
  - The infrastructure destroyed.
- A gathering of people with notebook computers.
  - In an area lacking 802.11.

Route Discovery



(a) Range of A's broadcast.

(b) After B and D have received A's broadcast.

(c) After C, F, and G have received A's broadcast.

(d) After E, H, and I have received A's broadcast.

Shaded nodes are new recipients. Arrows show possible reverse routes

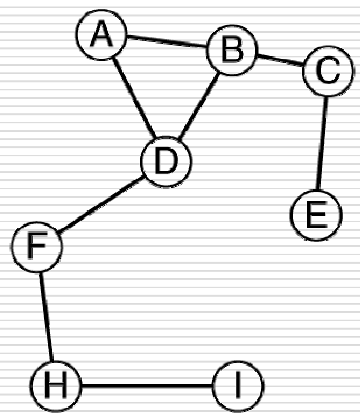
Route Maintenance

(a) D's routing table before G goes down.

(b) The graph after G has gone down.

Dest.	Next hop	Distance	Active neighbors	Other fields
A	A	1	F, G	
B	B	1	F, G	
C	B	2	F	
E	G	2		
F	F	1	A, B	
G	G	1	A, B	
H	F	2	A, B	
I	G	2	A, B	

(a)



(b)