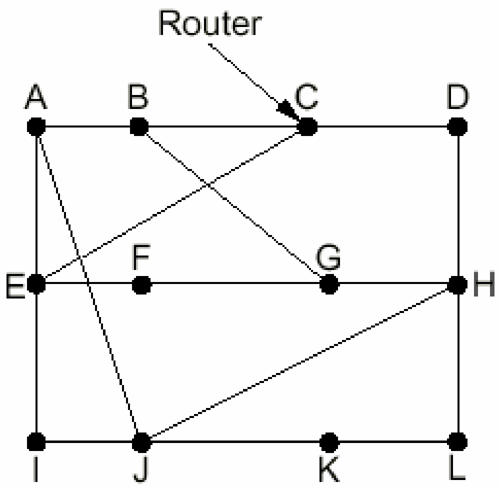
Network Layer(8)

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		

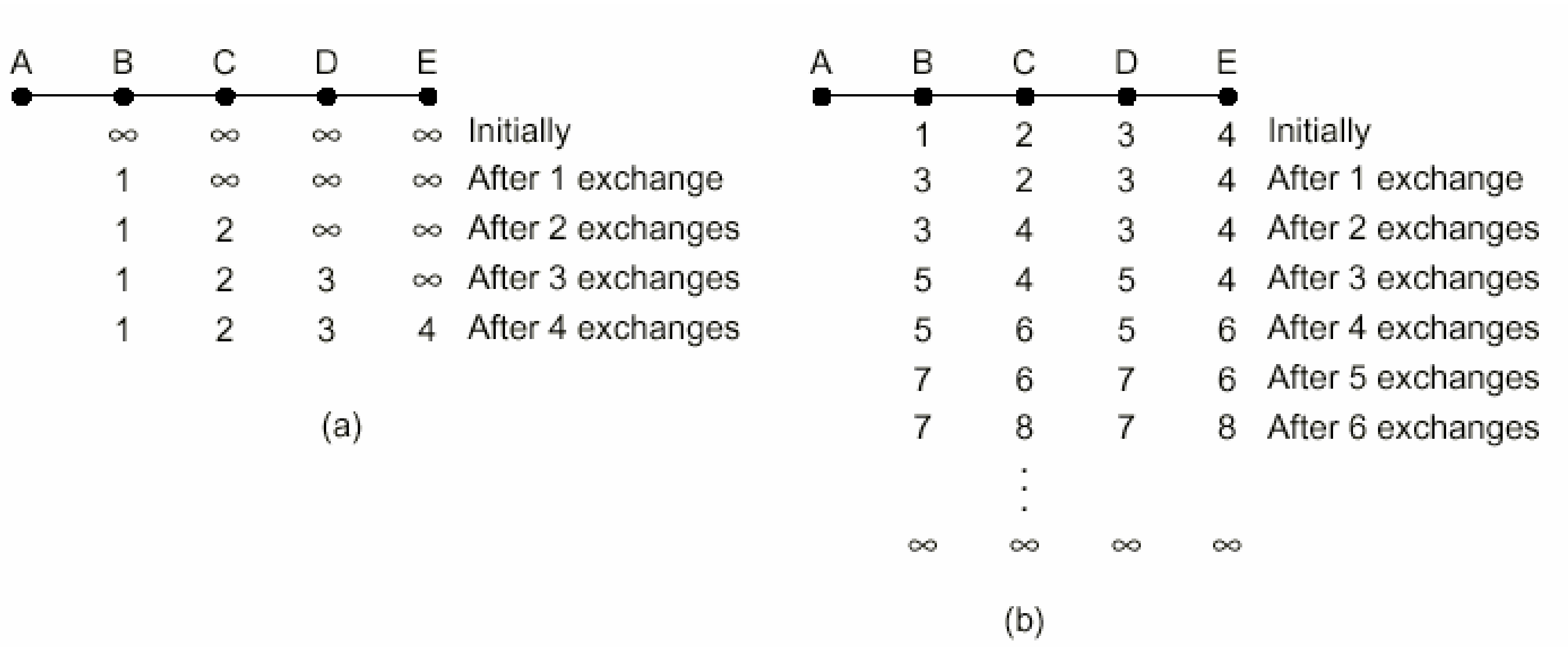
Vectors received from J's four neighbors

New routing table for J

(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?

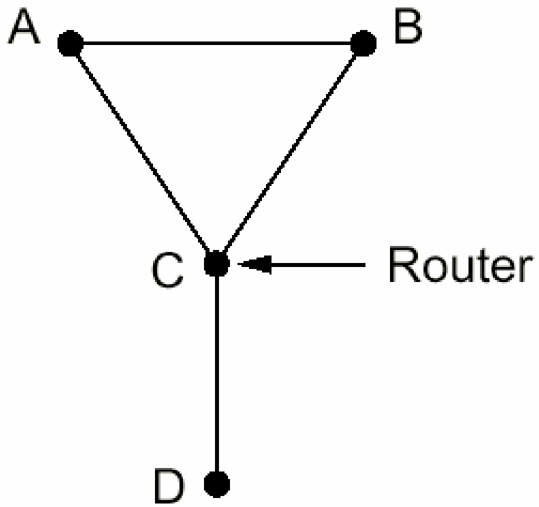
The Split Horizon Hack (Poisoned Reverse)

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

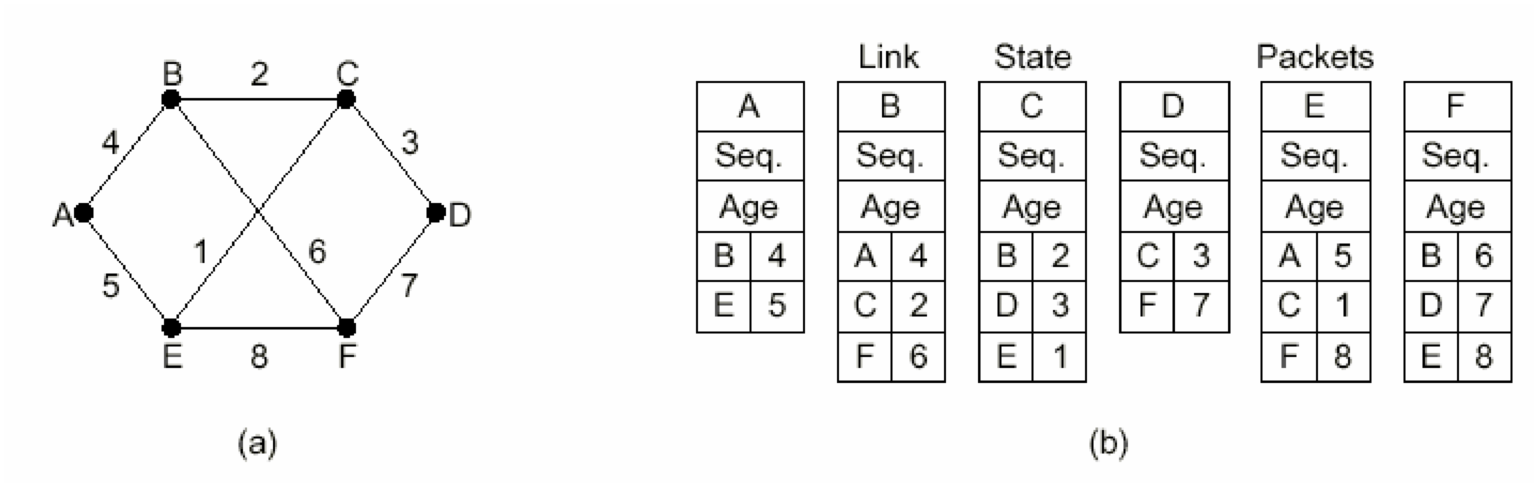
Idea:

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.

Network Layer(11)

Example of building Link State Packets



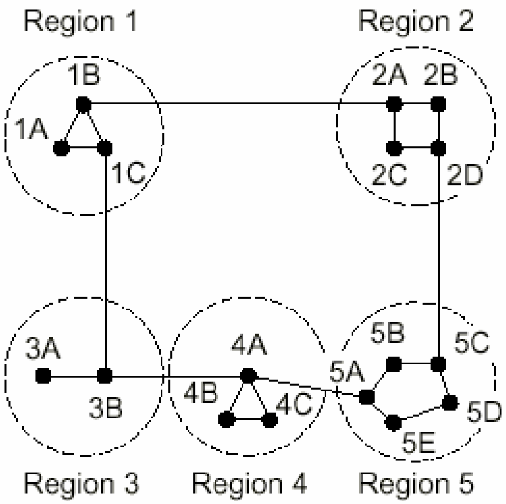
The principle of Link State Routing is widely used in actual networks (e.g. IP).

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)

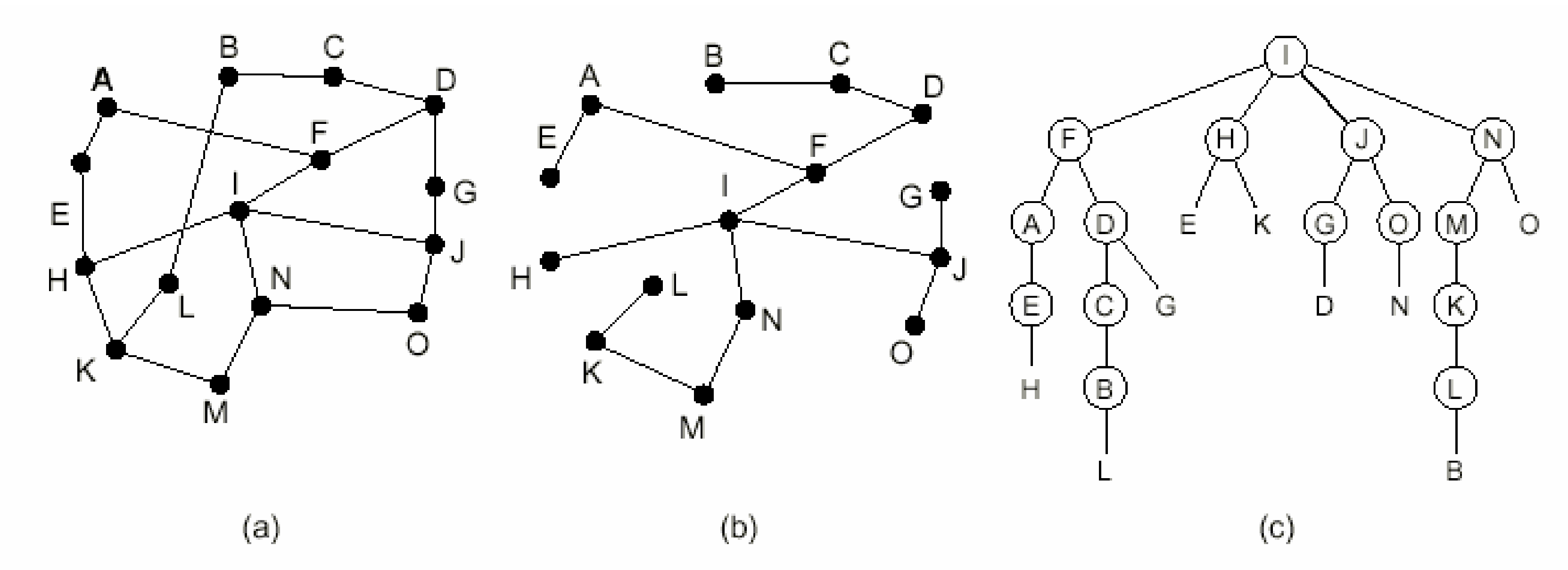
Network Layer(16)

Broadcast Routing

Possible methods:

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

Example of reverse path ordering



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

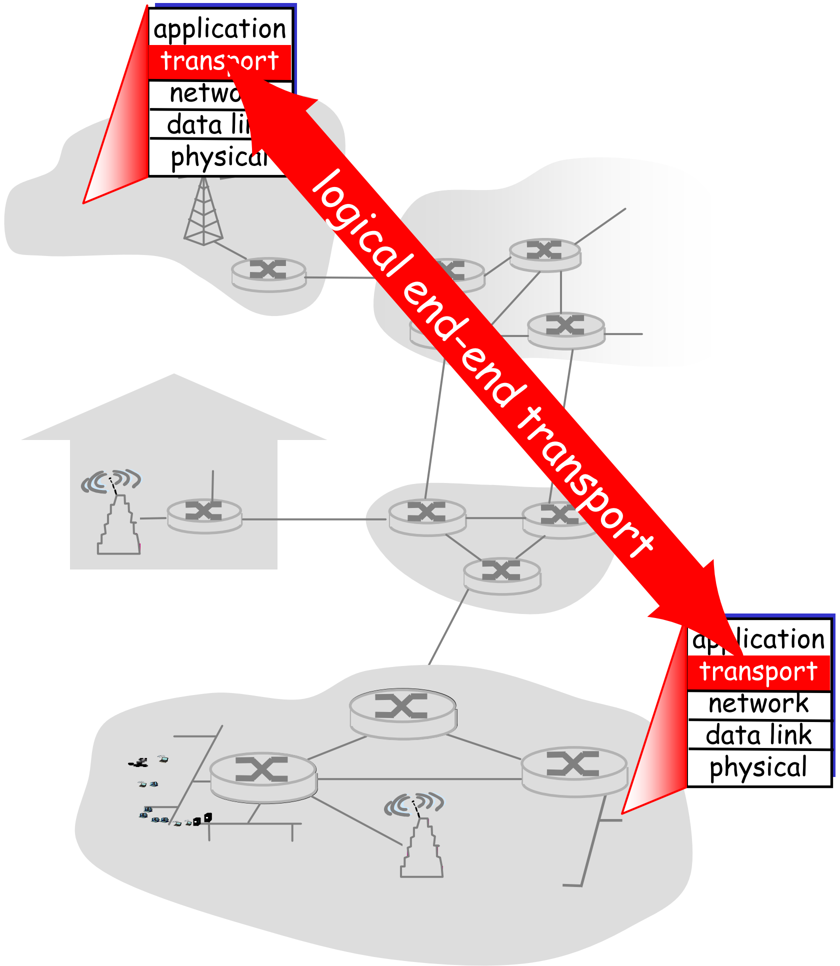
Network Layer(21)

Summary:

- it provides service to the transport layer
- its main job is routing packets from the source to the destination
  - static routing algorithms include e.g.
    - shortest path routing
    - flooding
  - dynamic routing algorithms (used by most actual networks) include
    - distance vector routing
    - link state routing
  - other important routing topics are e.g.
    - hierarchical routing
    - broadcast routing

Transport services and protocols

- provide *logical communication* between app processes running on different hosts
- transport protocols run in end systems
  - send side: breaks app messages into segments, passes to network layer
  - rcv side: reassembles segments into messages, passes to app layer
- more than one transport protocol available to apps
  - Internet: TCP and UDP



Transport vs. network layer

- *network layer:* logical communication between hosts
- *transport layer:* logical communication between processes
  - relies on, enhances, network layer services

Household analogy:

12 persons sending letters to 12 persons

- processes = persons
- hosts = houses
- transport protocol = Ann and Bill
- network-layer protocol = postal service

Transport Layer(3)

Two principal alternatives:

- protocol is connection-oriented (setup required) and reliable, like the telephone system (TCP)
- protocol is connectionless (no setup required) and unreliable, like the postal system (UDP)

Two basic philosophies for organizing the layer:

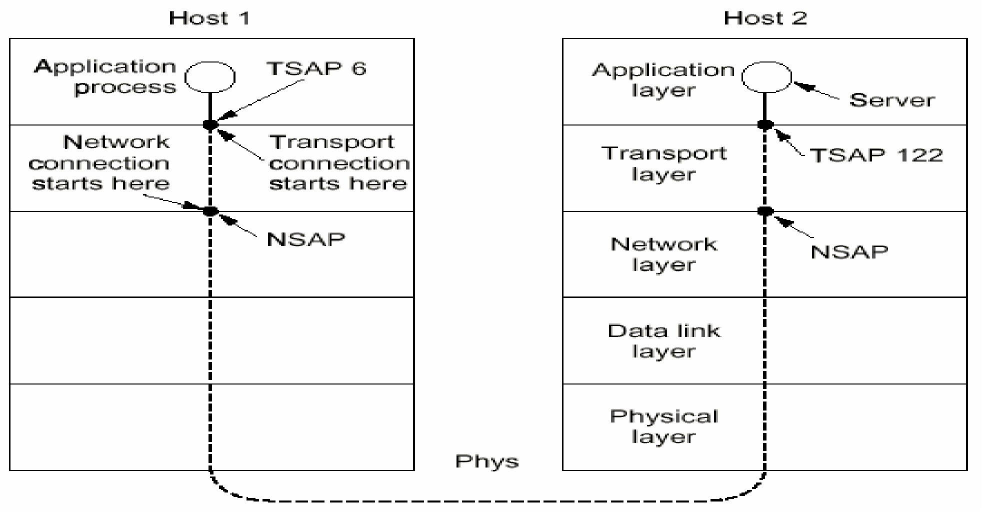
- virtual circuits (identity of the connection)
- datagram (identity of the independent packet)

Comparison of datagram and virtual circuit protocols

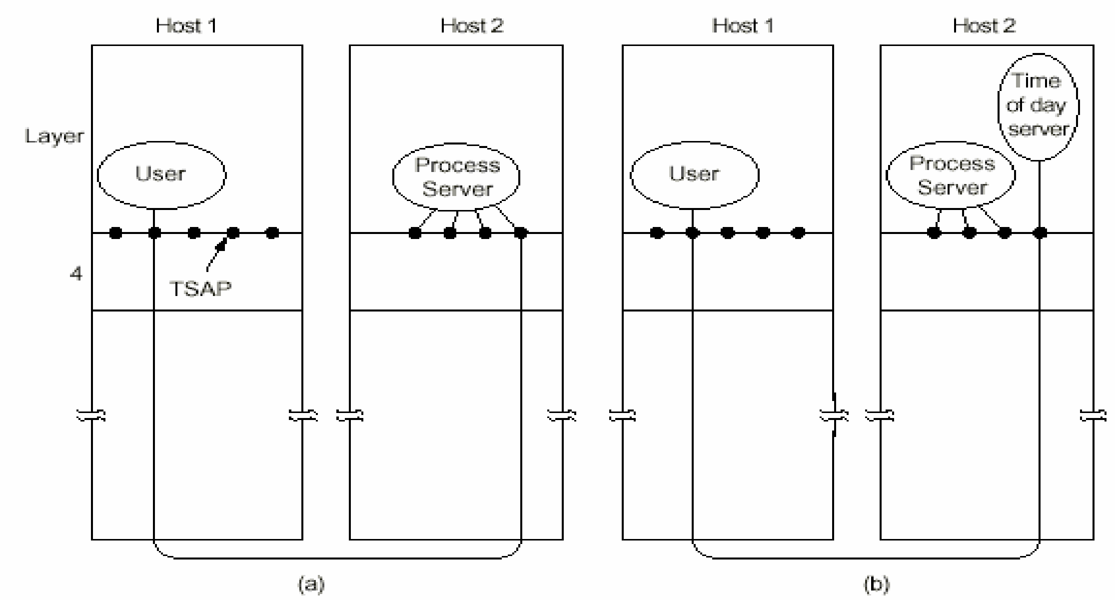
Issue	Datagram subnet	VC subnet
Circuit setup	Not needed	Required
Addressing	Each packet contains the full source and destination address	Each packet contains a short VC number
State information	Subnet does not hold state information	Each VC requires subnet table space
Routing	Each packet is routed independently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

Transport Layer(5)

Addressing (first approach)



Addressing (second approach)



Transport Layer(6)

Establishing a Connection

Problem:

How to prevent that duplicates being delayed and, therefore, outdated packets lead to a wrongly established new connection

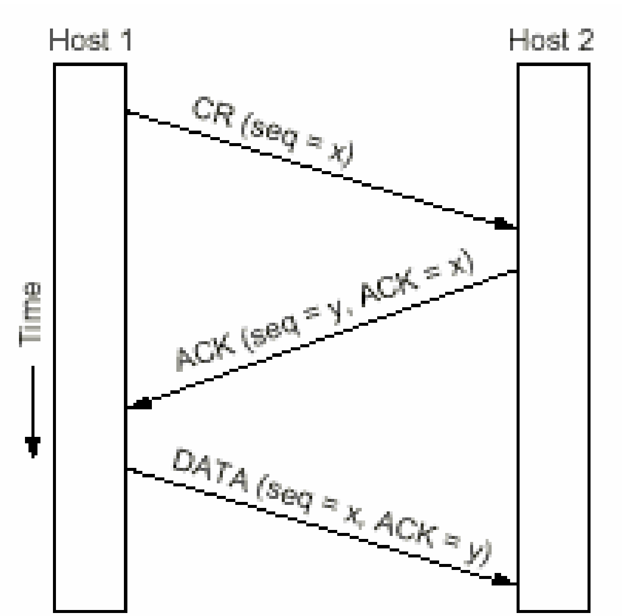
Solution:

Getting both sides (sender and receiver) to agree on a unique initial sequence number

Implementation:

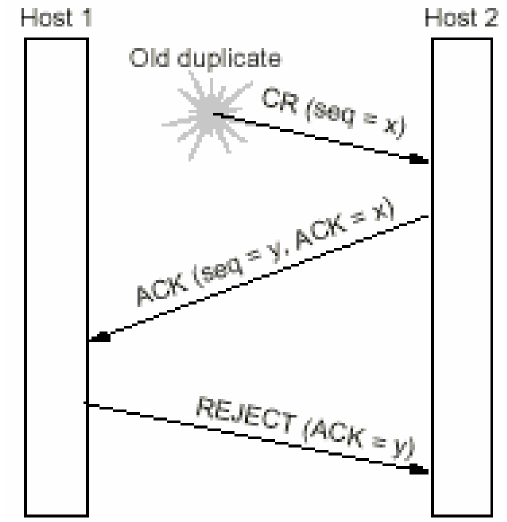
The three-way handshake (also adopted in TCP)

Normal operation



Transport Layer(8)

Duplicate CR (Connection request)



Duplicate CR and ACK