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CERTIFICATION COURSES

COMPUTER NETWORKS AND INTERNET PROTOCOLS

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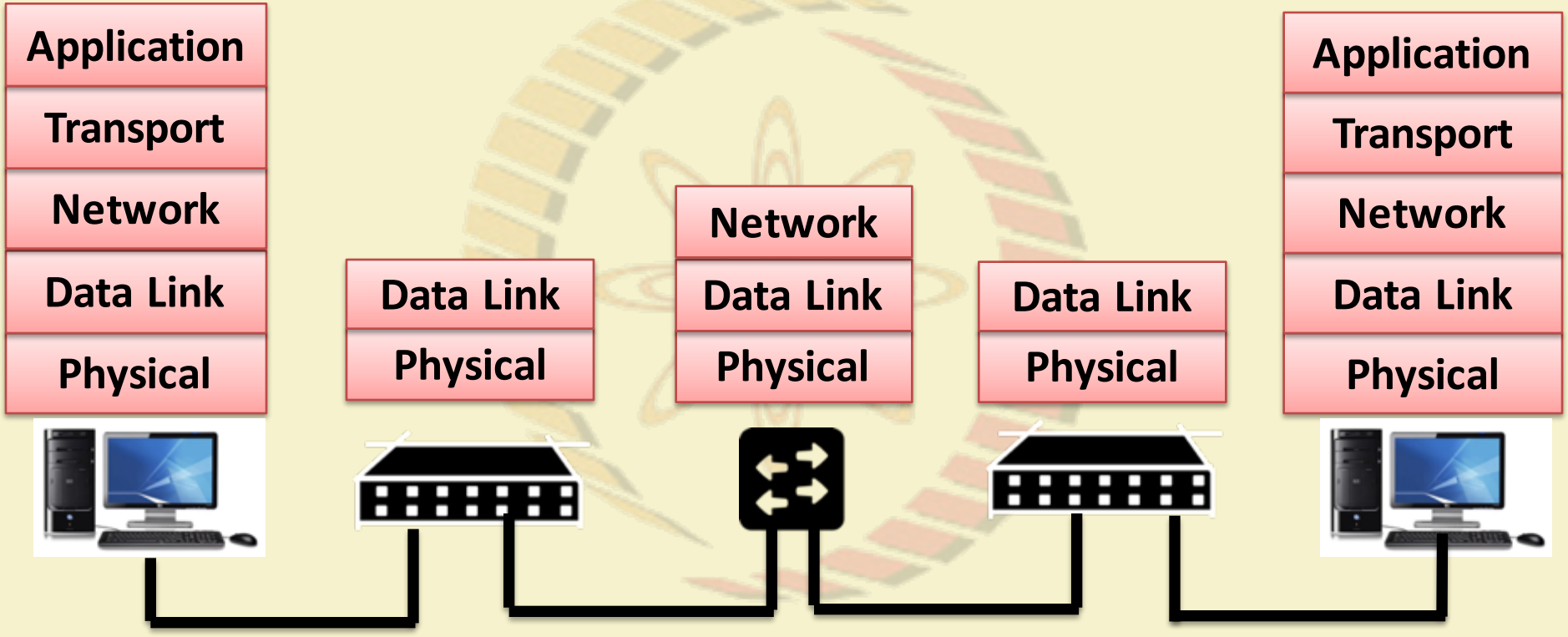
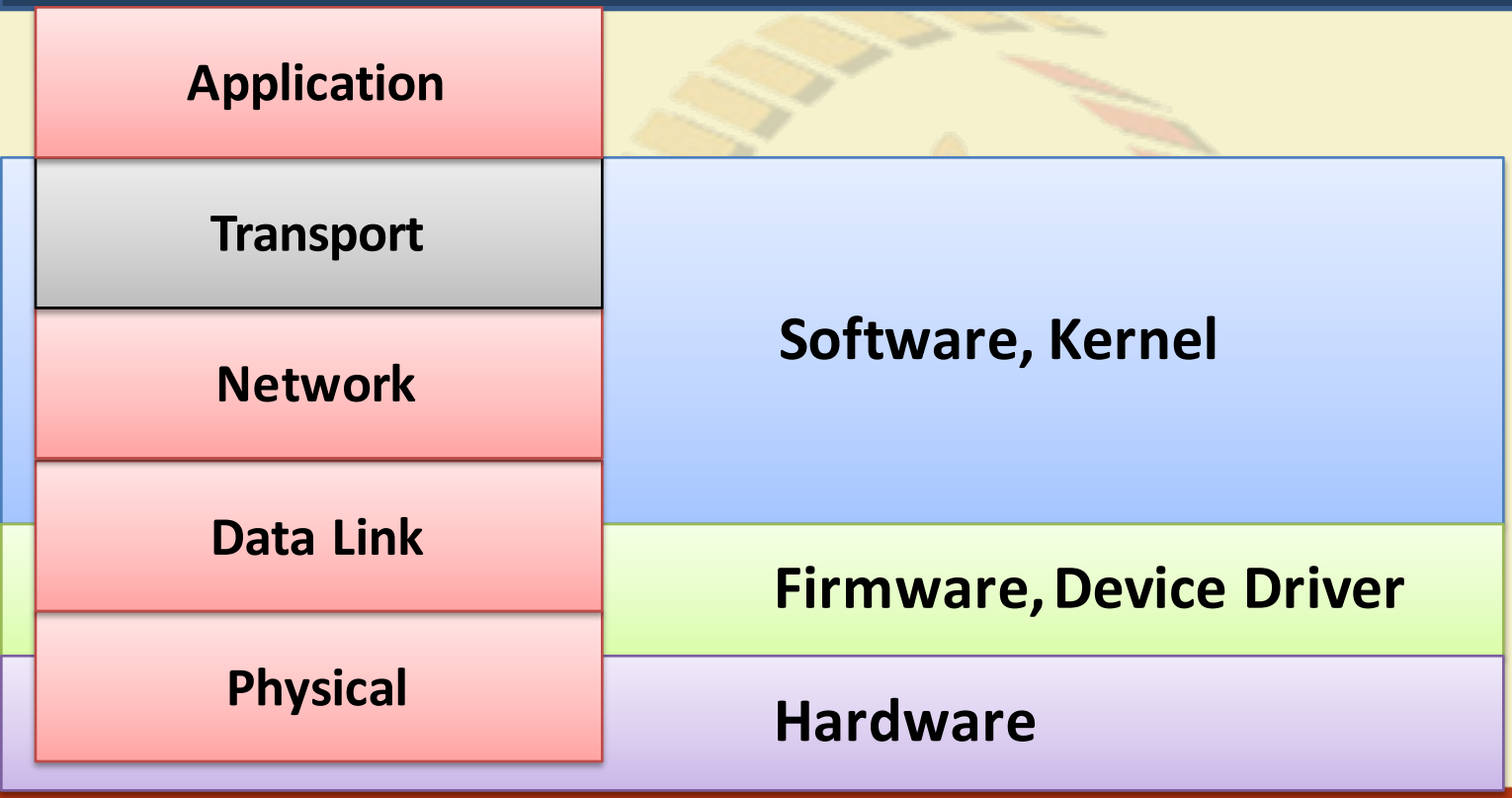
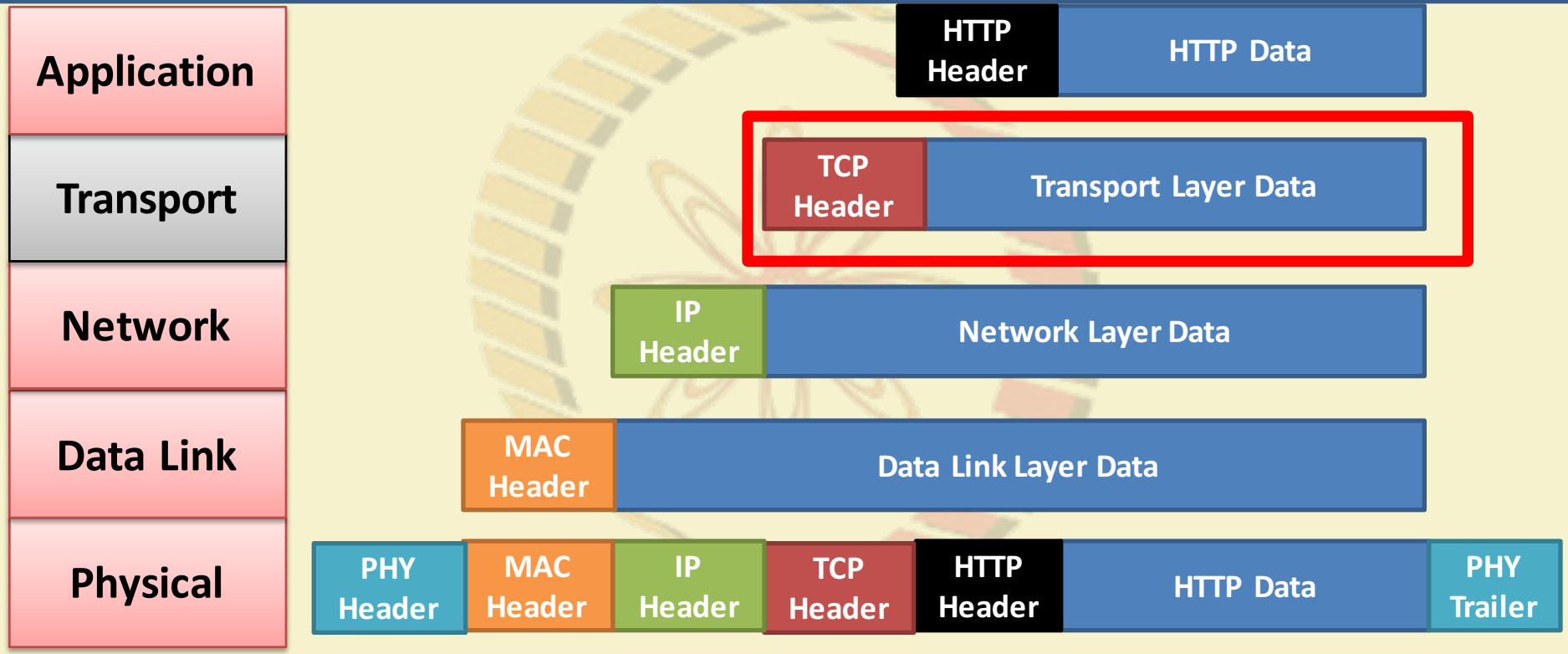
Transport Layer - I (Services)



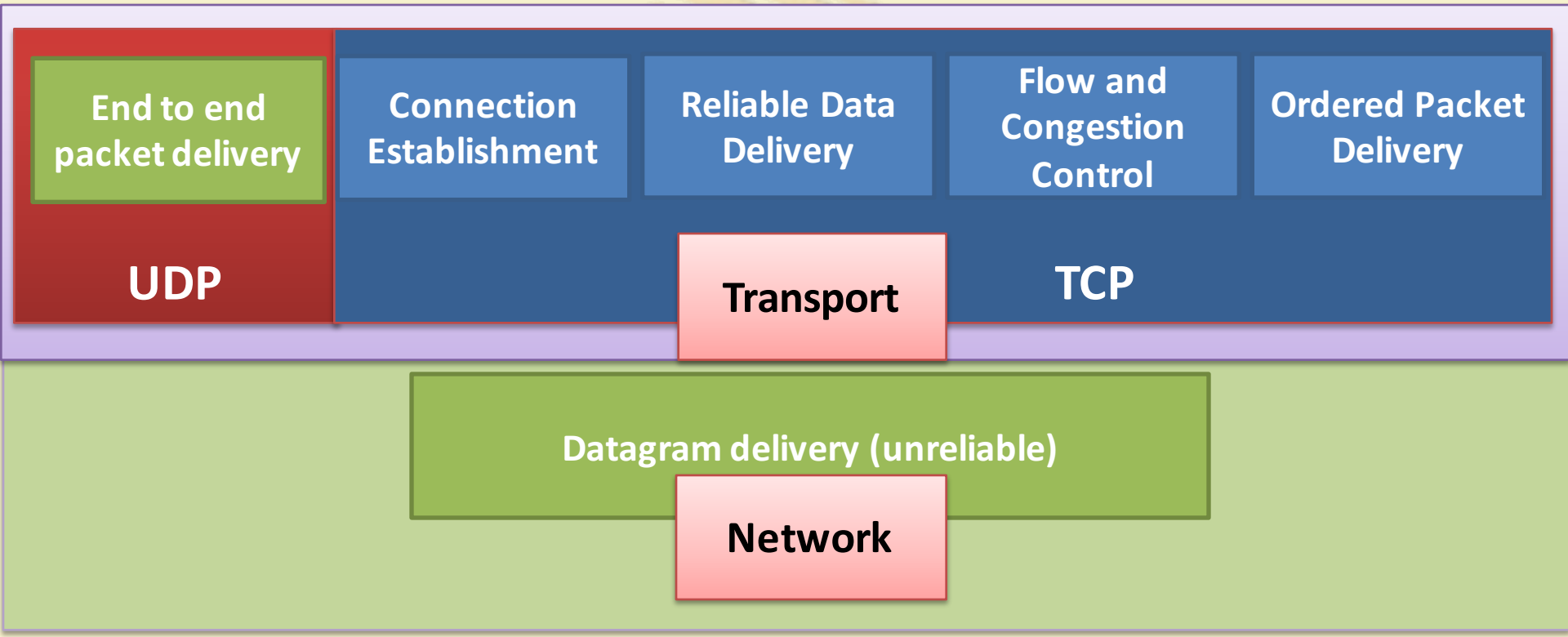
Protocol Stack Implementation in a Host



How Application Data Passes Through Different Layers



Transport Layer Services




thank you!

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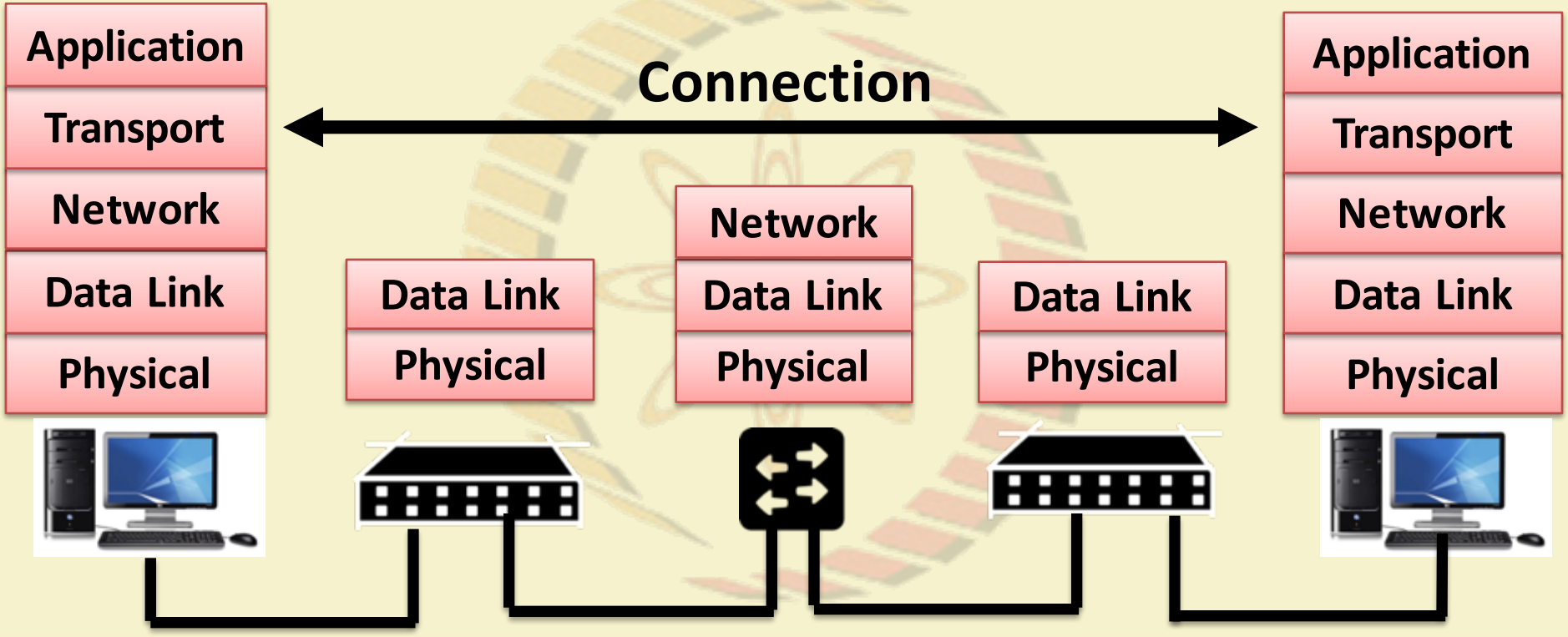
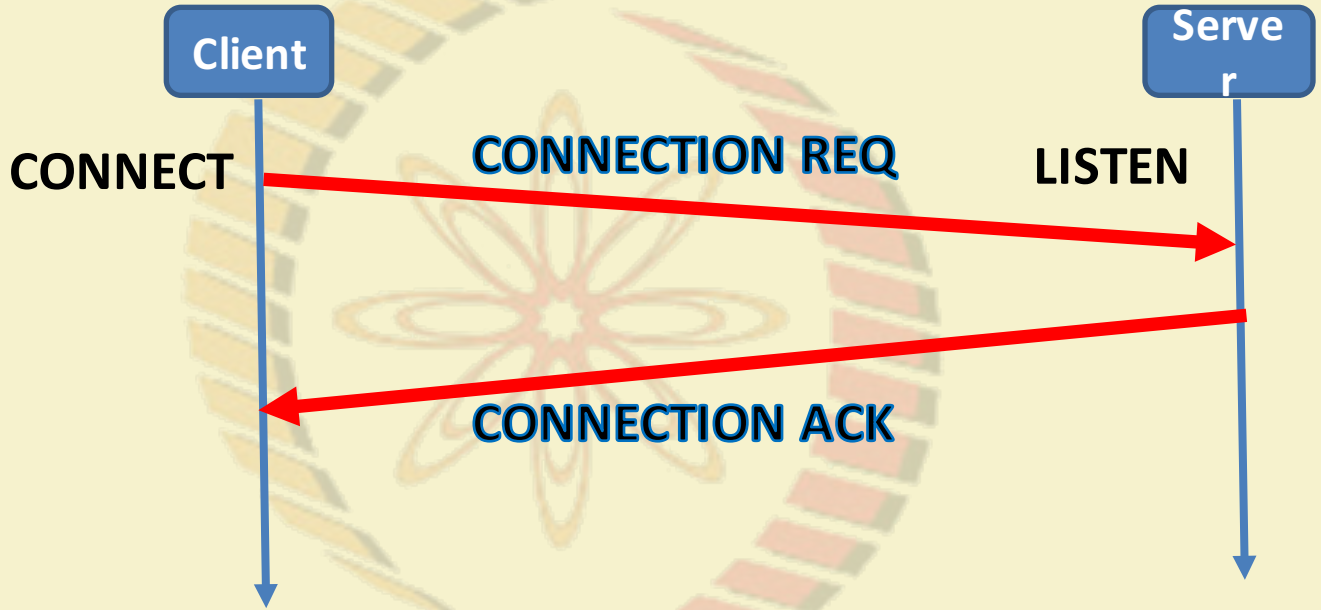
Transport Layer - II (Connection I)



Connection Establishment



- This is a simple primitive for connection establishment – but does this work good?

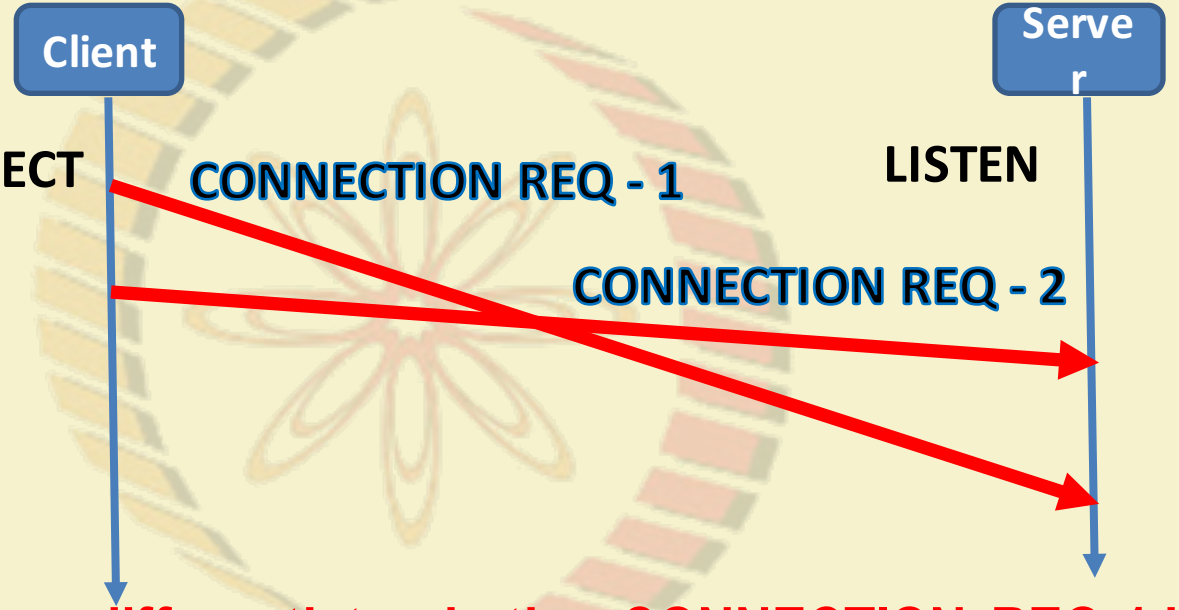
Connection Establishment

- Consider a scenario when the network can lose, delay, corrupt and duplicate packets (the underline network layer uses unreliable data delivery)

- Consider retransmission for ensuring reliability – every packet uses different paths to reach the destination

- Packets may be delayed and got struck in the network congestion, after the timeout, the sender assumes that the packets have been dropped, and retransmits the packets

Connection Establishment



It may happen that the server has crashed and reinitiated the connection. So distinguishing between these two is essential

- How will the server differentiate whether CONNECTION REQ-1 is a new connection request or a duplicate of the CONNECTION REQ-2?

Connection Establishment

- **Protocol correctness versus Protocol performance – an eternal debate in computer networks …**

- Delayed duplicates create a huge confusion in the packet switching network. A major challenge in packet switching network is to develop **correct** or **at least acceptable** protocols for handling delayed duplicates

Connection Establishment – Handling Delayed Duplicates

- **Solution 1: Use Throwaway Transport Address (Port Numbers)**
  - Do not use a port number if it has been used once already – Delayed duplicate packets will never find their way to a transport process
  - Is this solution feasible?

- **Solution 2: Give each connection a unique identifier chosen by the initiating party and put in each segment**
  - Can you see any problem in this approach?

Connection Establishment – Handling Delayed Duplicates

- **Solution 3:** Devise a mechanism to kill off aged packets that are still hobbling about (Restrict the packet lifetime)
  - Makes it possible to design a feasible solution

Connection Establishment – Handling Delayed Duplicates

- Three ways to restrict packet lifetime
  - **Restricted Network Design** – Prevents packets from looping (bound the maximum delay including congestion)
  - **Putting a hop count in each packet** – **initialize to a maximum value and decrement each time the packet traverses a single hop (most feasible implementation)**
  - **Timestamping each packet** – define the lifetime of a packet in the network, need time synchronization across each router.

Connection Establishment – Handling Delayed Duplicates

- Design Challenge: We need to guarantee not only that a packet is dead, but also that all acknowledgements to it are also dead

Connection Establishment – Handling Delayed Duplicates

- Let us define a maximum packet lifetime T – If we wait a time T secs after a packet has been sent, we can be sure that all traces of it (packet and its acknowledgement) are now gone

- Rather than a physical clock (clock synchronization in the Internet is difficult to achieve), let us use a virtual clock – **sequence number generated based on the clock ticks**

Connection Establishment – Handling Delayed Duplicates

- **Label segments with sequence numbers that will not be reused within T secs.**

- The period T and the rate of packets per second determine the size of the sequence number – **at most one packet with a given sequence number may be outstanding at any given time**

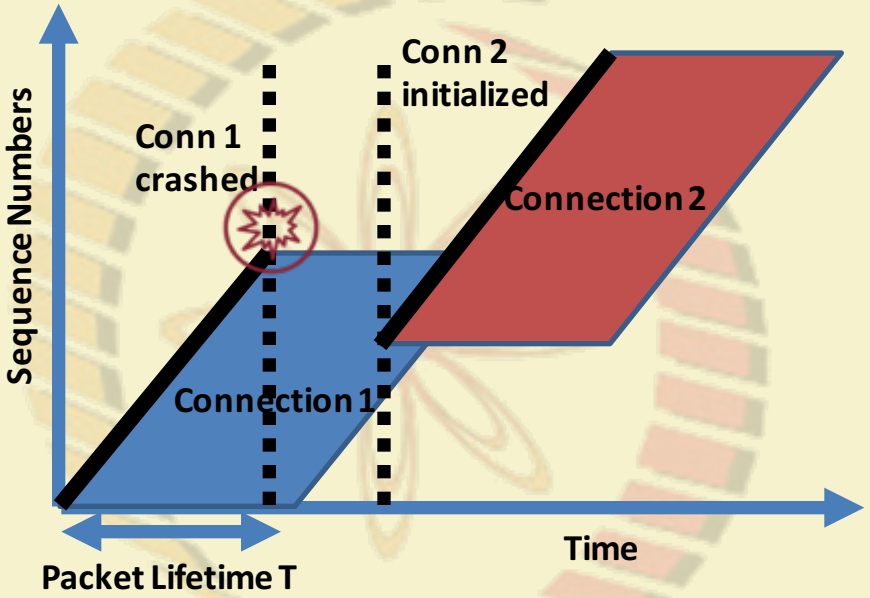
Sequence Number Adjustment

- **Two important requirements (*Tomlinson 1975, Selecting Sequence Numbers*)**
  - **R1.** Sequence numbers must be chosen such that a particular sequence number never refers to more than one byte (for byte sequence numbers) at any one time
  - **How to choose the initial sequence number**

Sequence Number Adjustment

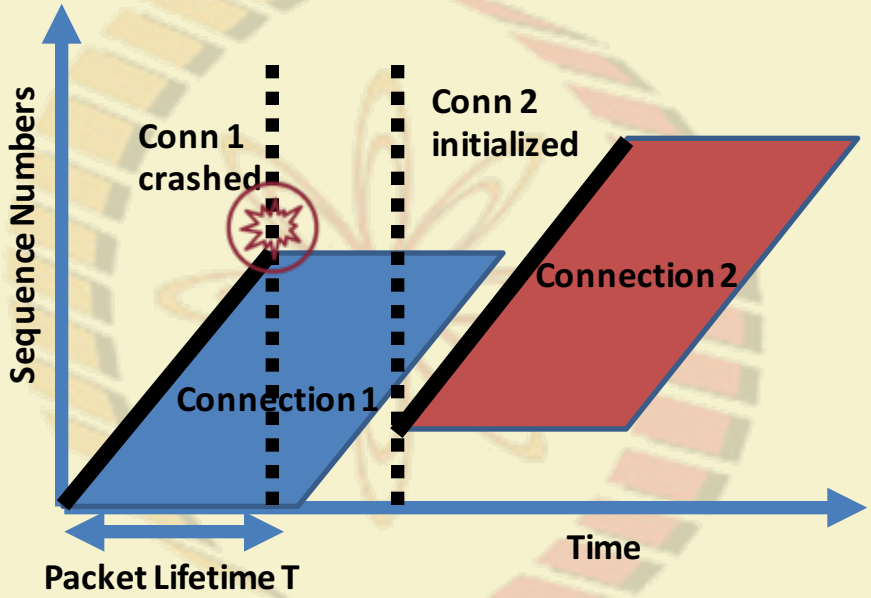
- **Two important requirements (*Tomlinson 1975, Selecting Sequence Numbers*)**
  - **R2:** The valid range of sequence numbers must be positively synchronized between the sender and the receiver, whenever a connection is used
  - **Three way handshaking followed by the flow control mechanism – once connection is established, only send the data with expected sequence numbers**

Initial Sequence Number during Connection Establishment



- A Delayed duplicate packet of connection 1 can create a confusion for connection 2

What We Ideally Want? Either …



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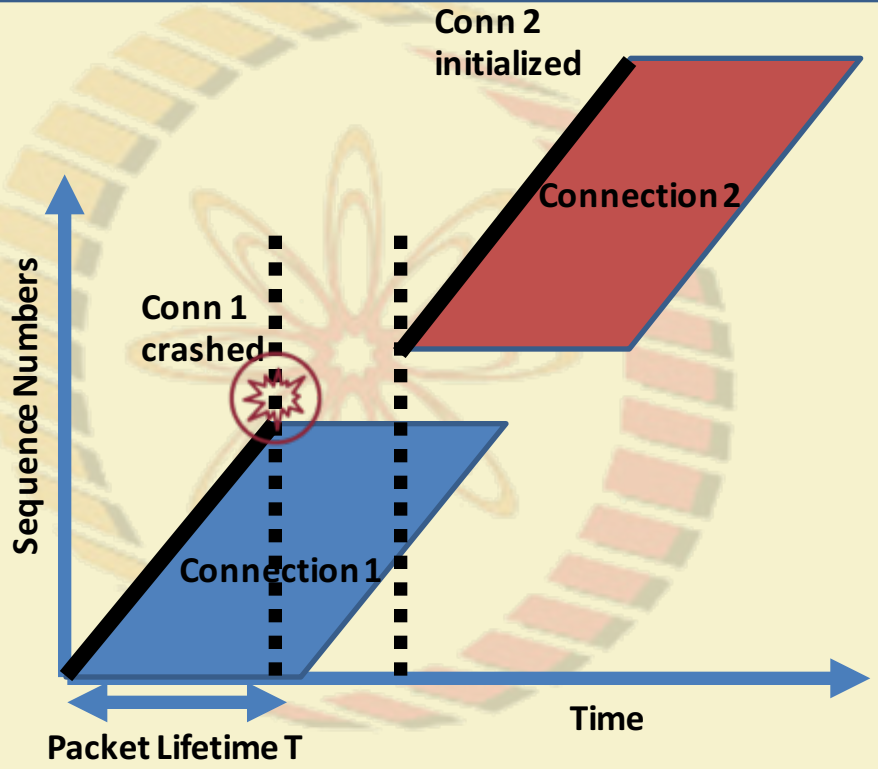


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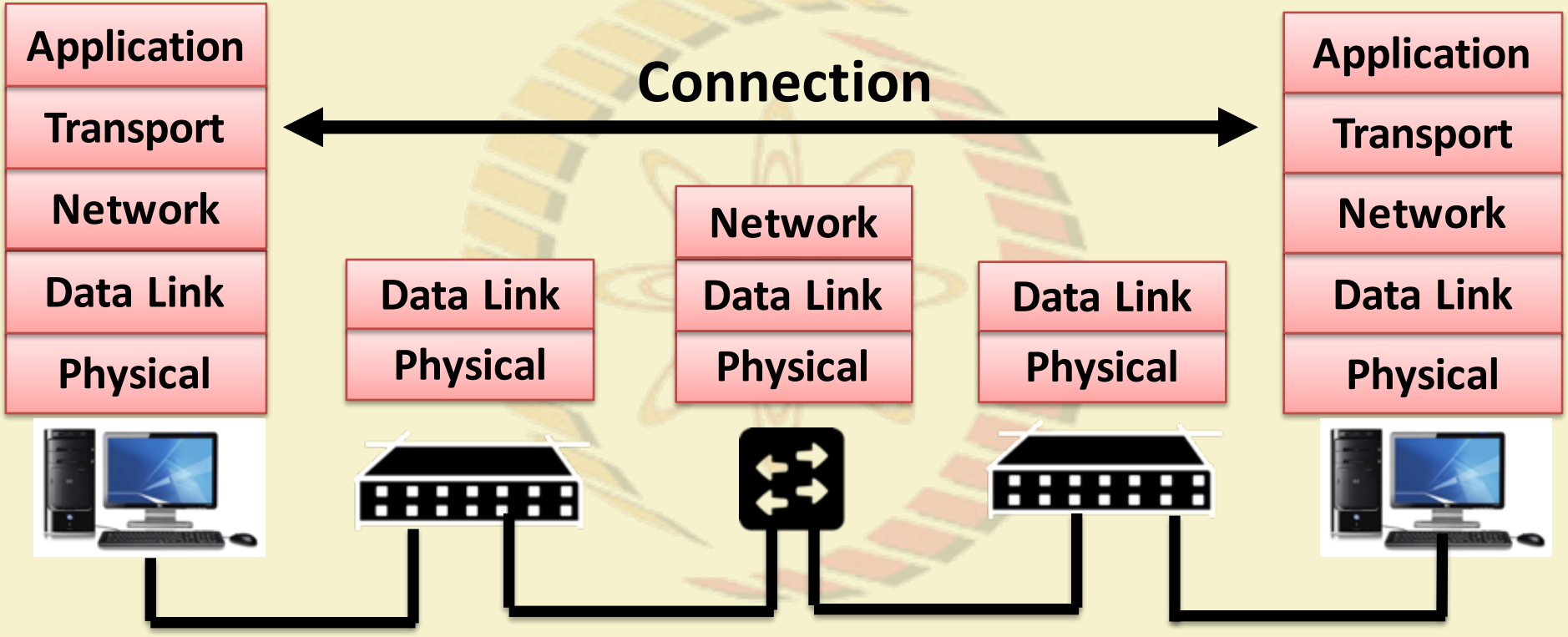
Transport Layer - III (Connection II)



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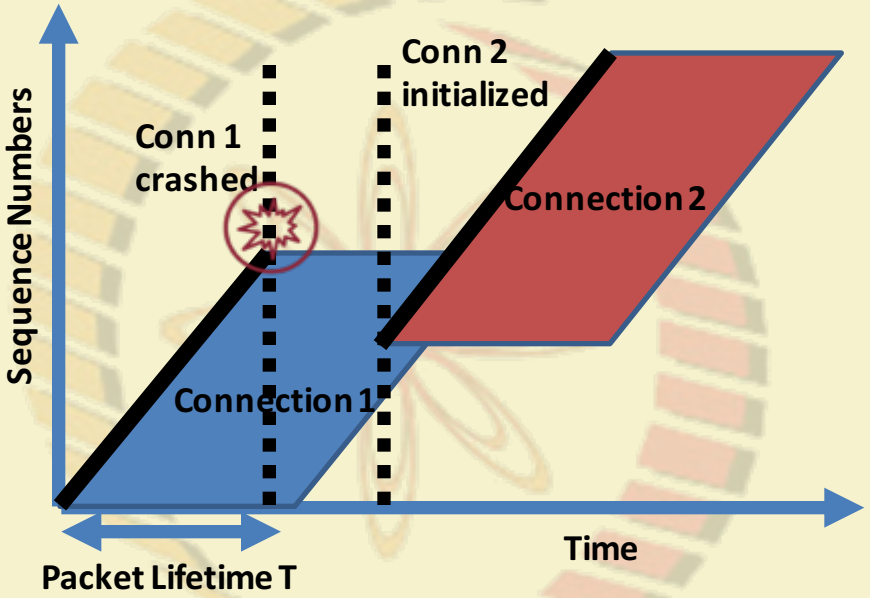

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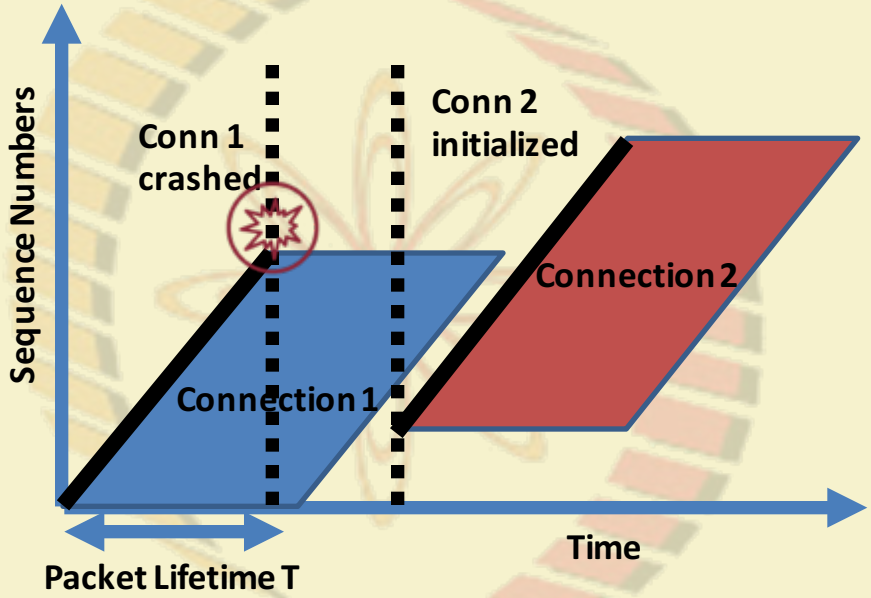

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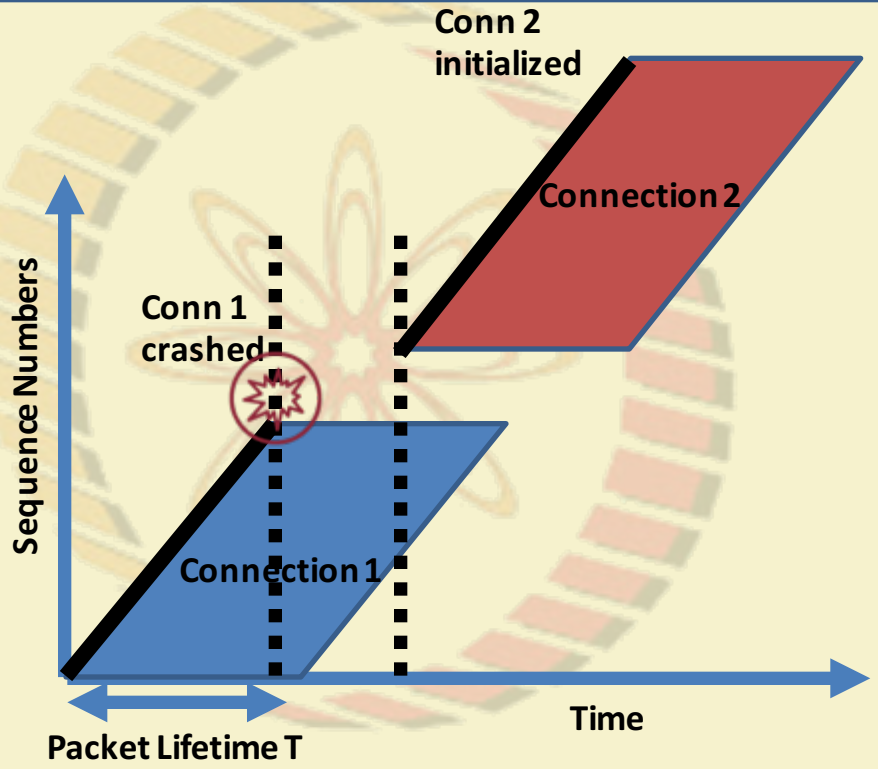

Connection Establishment – Handling Delayed Duplicates

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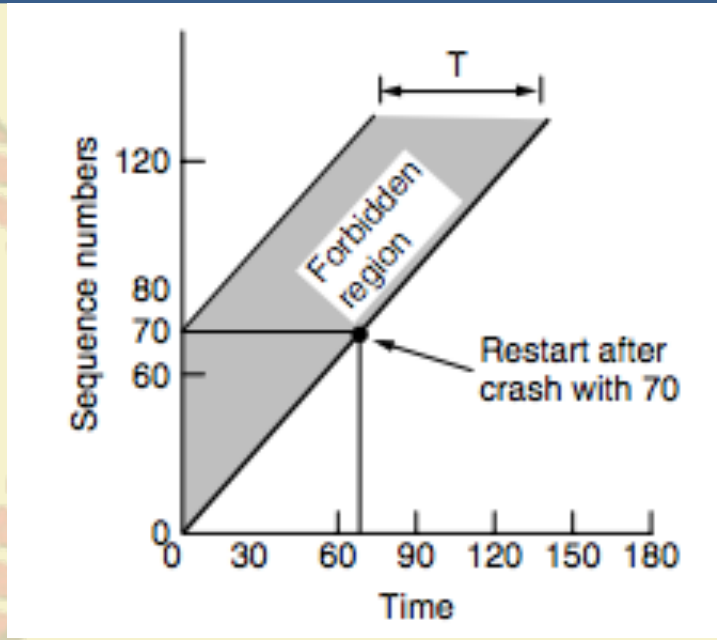
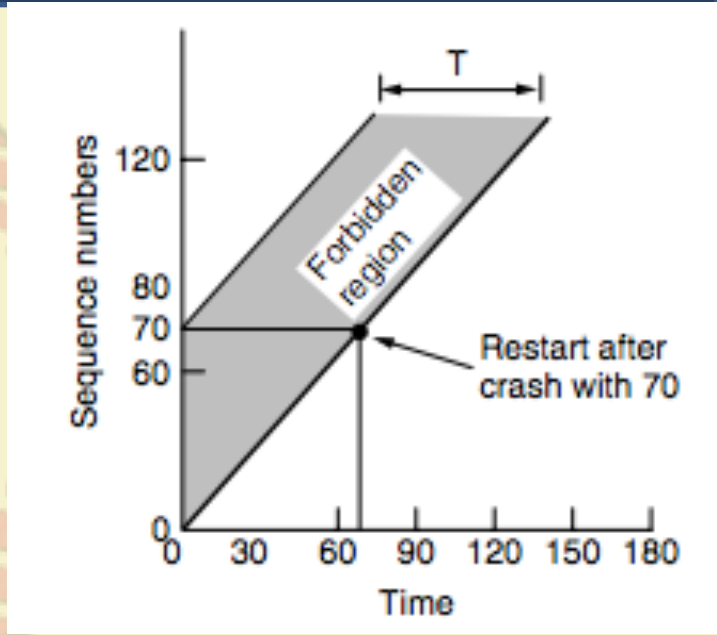


Source: Computer Networks (5th Edition) by Tanenbaum, Wetherell

Connection Establishment – Handling Delayed Duplicates

- For a crashed device, the transport entity remains idle for a duration T after recovery, to ensure that all packets from the previous connection are dead – **not a good solution**



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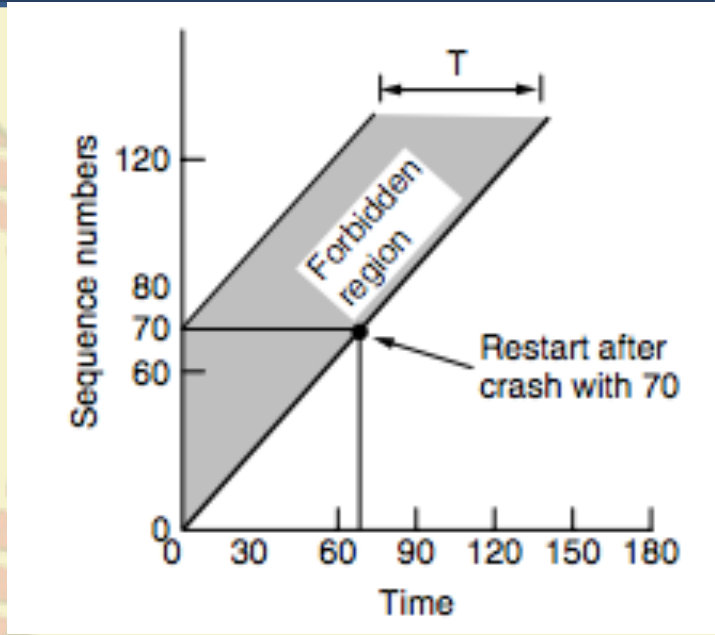
Connection Establishment – Handling Delayed Duplicates

- **Adjust the initial sequence numbers properly -** A host does not restart with a sequence number in the forbidden region, based on the sequence number it used before crash and the time duration T.



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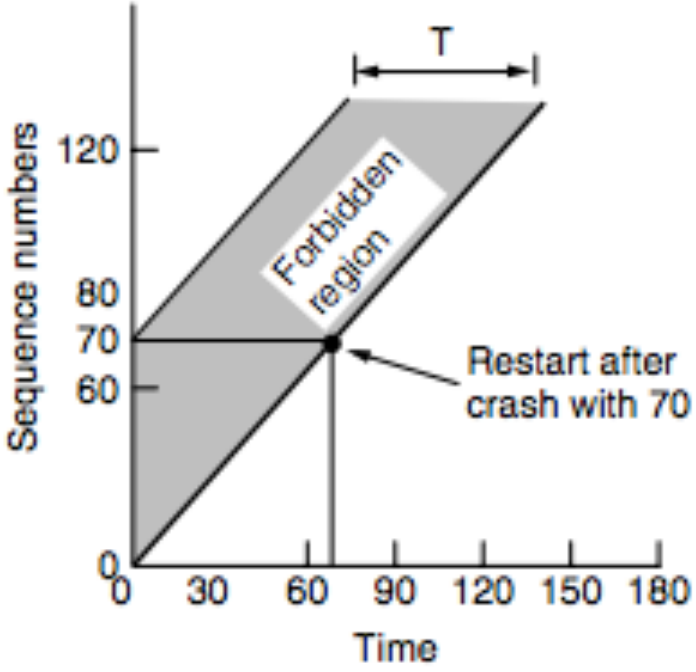
Packet Sequence Numbers are Out of the Forbidden Region

Two possible source of problems

1. A host sends too much data too fast on a newly opened connection



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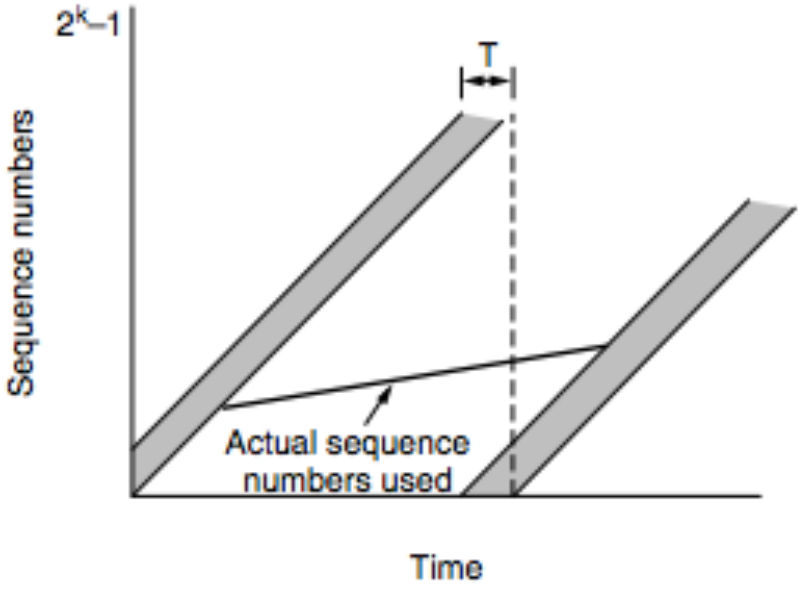
Two possible source of problems

2. The data rate is too slow that the sequence number for a previous connection enters the forbidden region for the next connection



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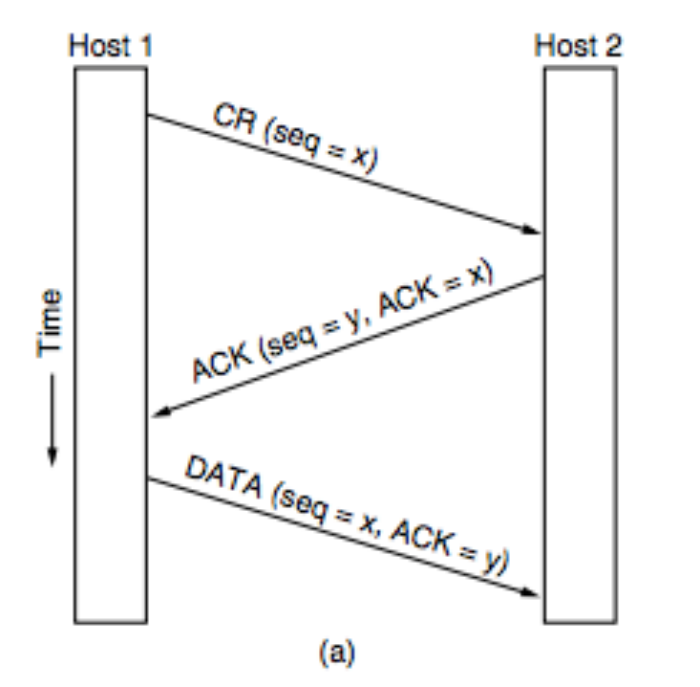
Adjusting the Sending Rate based on Sequence Numbers

- The maximum data rate on any connection is one segment per clock tick
  - Clock ticks (inter-packet transmission duration) is adjusted based on the sequences acknowledged – **ensure that no two packets are there in the network with same sequence number**
  - **We call this mechanism as self-clocking (used in TCP)**
  - Ensures that the sequence numbers do not warp around too quickly (RFC 1323)

Adjusting the Sending Rate based on Sequence Numbers

- **We do not remember sequence number at the receiver:** Use a **three way handshake** to ensure that the connection request is not a repetition of an old connection request
  - The individual peers validate their own sequence number by looking at the acknowledgement (ACK)
  - **Positive synchronization among the sender and the receiver**

Three Way Handshake



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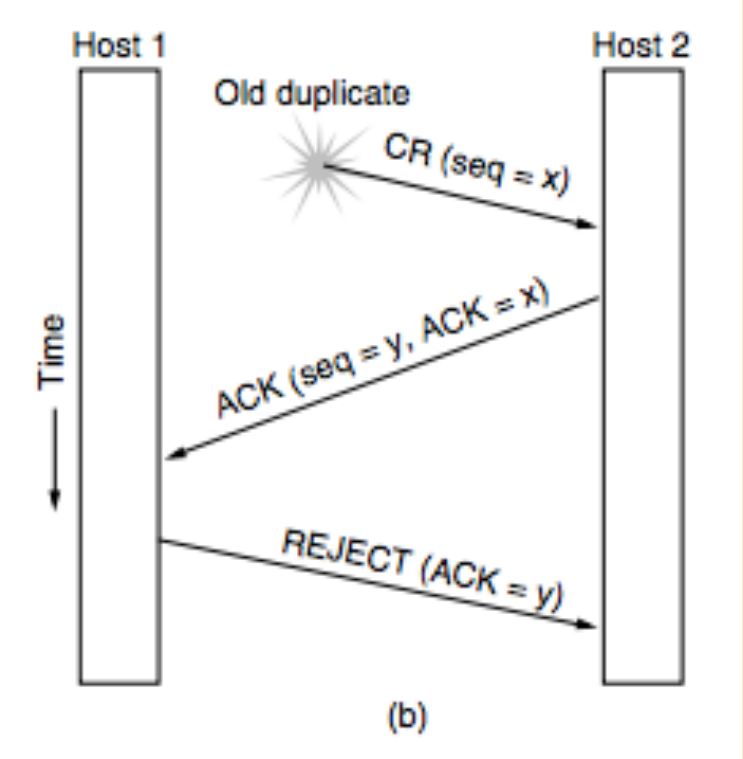
- By looking at the ACK, Host 1 ensures that Sequence number x does not belong to the forbidden region of any previously established connection
- By looking at the ACK in DATA, Host 2 ensures that sequence number y does not belong to the forbidden region of any previously established connection

CONNECTION REQUEST is a Delayed Duplicate

Source: Computer Networks (5th Edition) by Tanenbaum, Wetherell



CONNECTION REQUEST and ACK both are Delayed Duplicates

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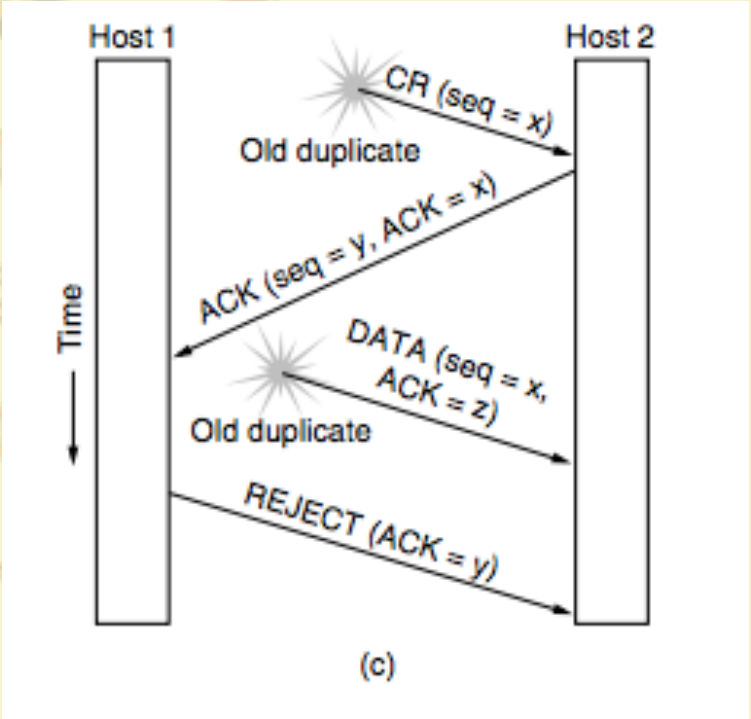
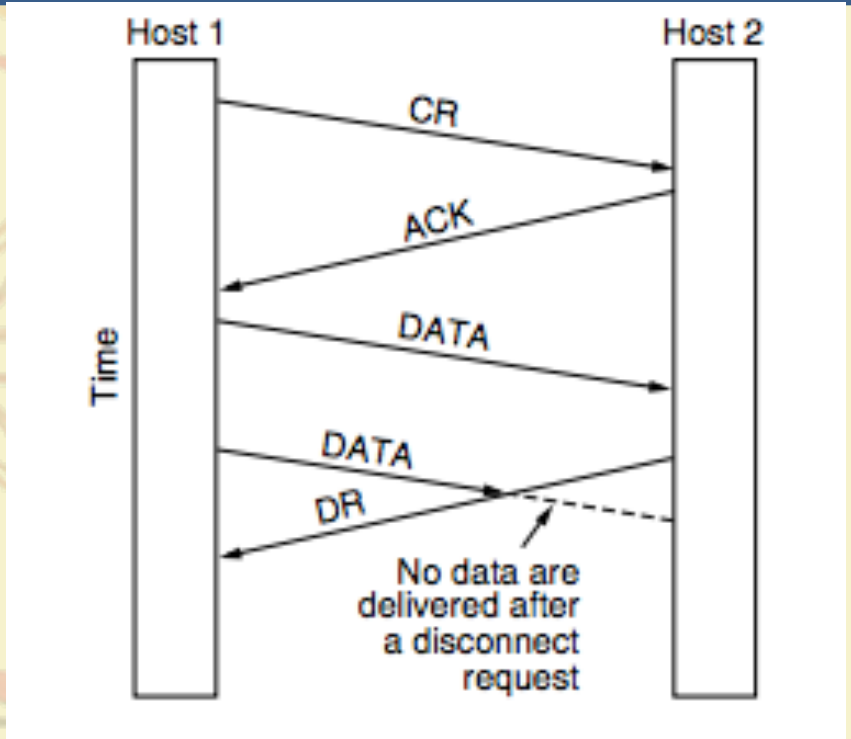


Connection Release – Asymmetric Release

- When one party hangs up, the connection is broken
- This may results in data loss



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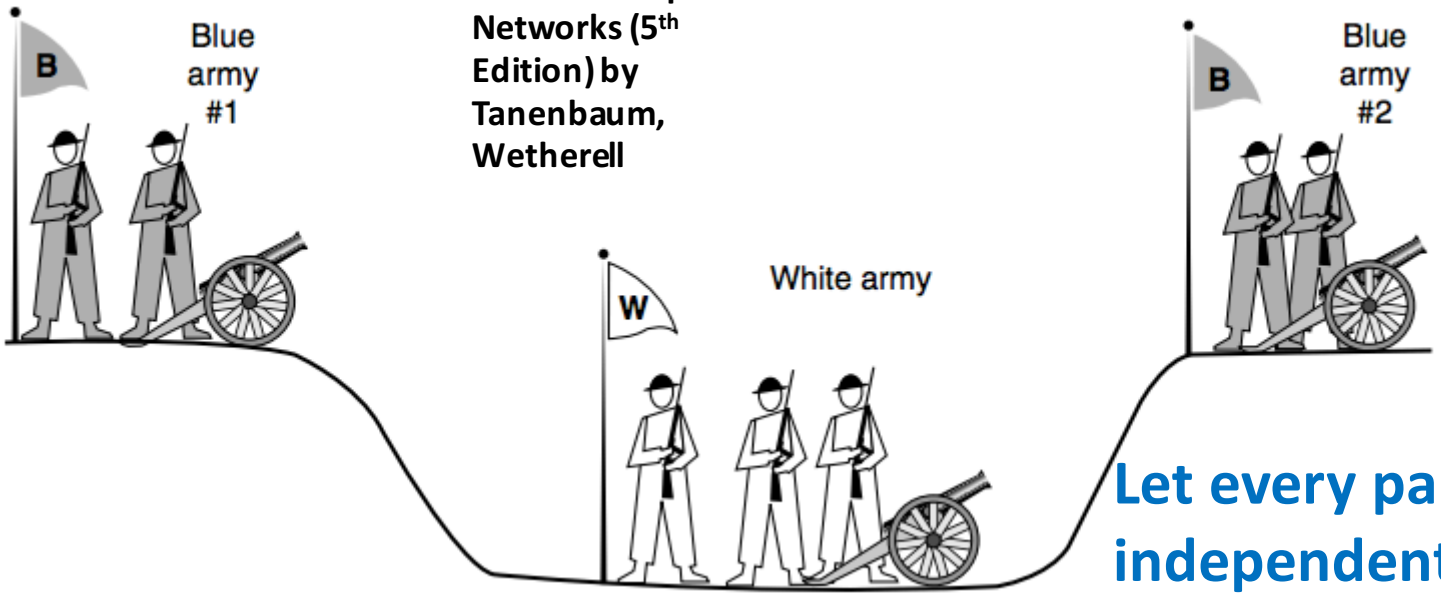
Connection Release – Symmetric Release

- Treats the connection as two separate unidirectional connections and requires each one to be released separately
- Does the job when each process has a fixed amount of data to send and clearly knows when it has sent it.
- What can be a protocol for this?
  - **Host 1: “I am done”**
  - **Host 2: ”I am done too”**
- **Does this protocol work good always?**

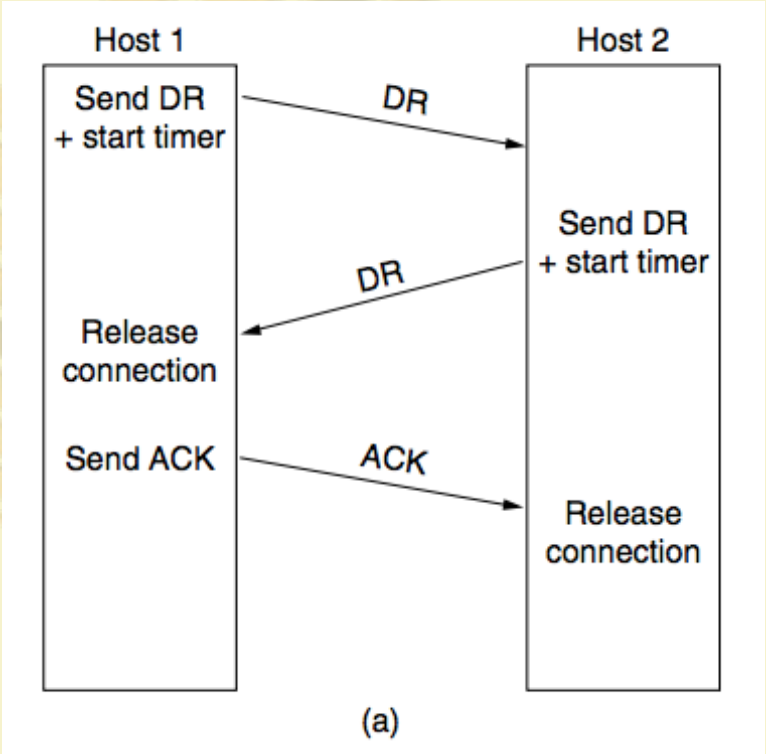
The Two Army Problem



Let every party take independent decisions

No protocol exists to solve this

Connection Release



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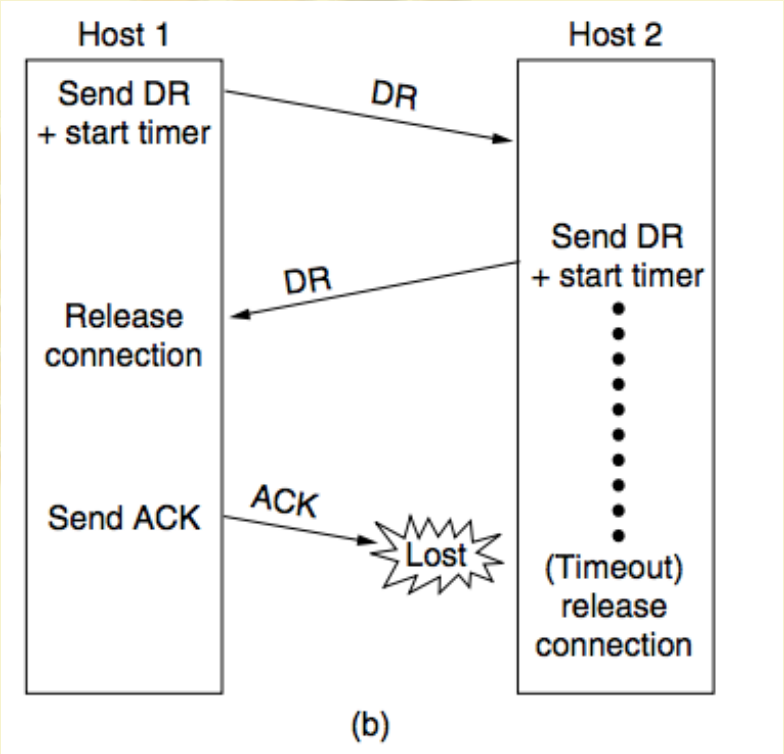
Connection Release – Final ACK Lost



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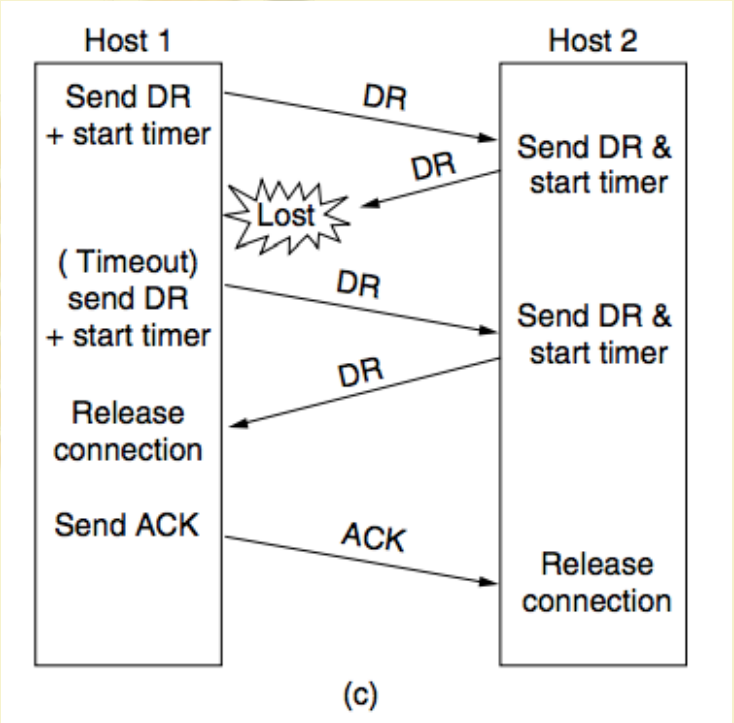
Connection Release – Response Lost



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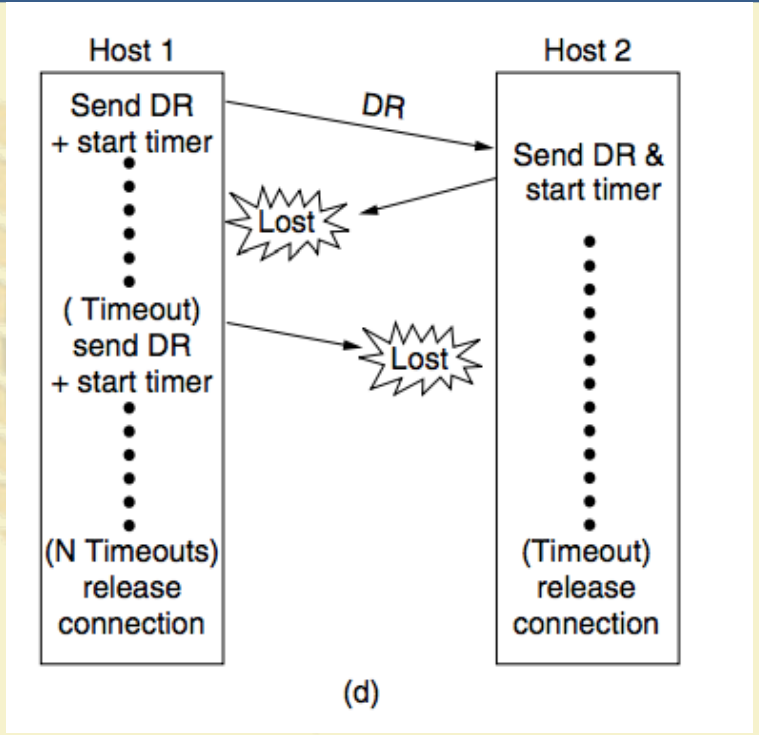
Connection Release – Response Lost and Subsequent DRs Lost



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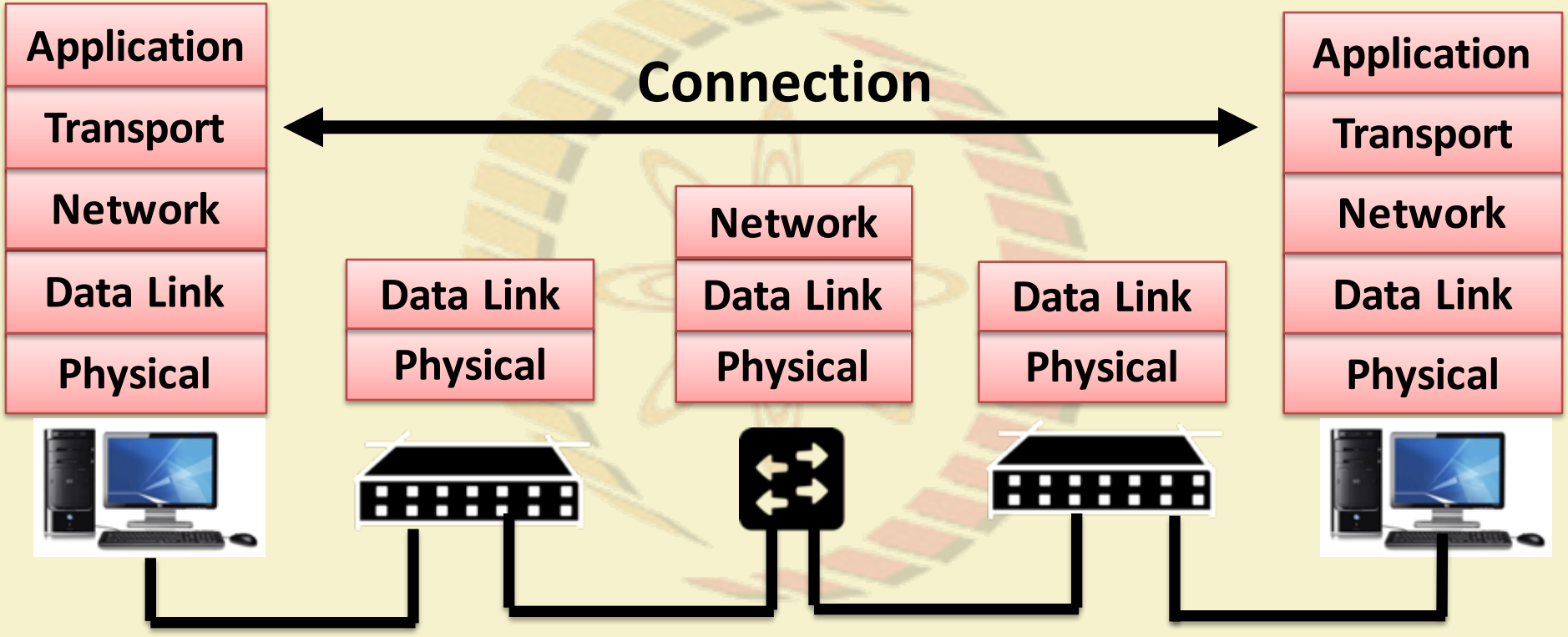

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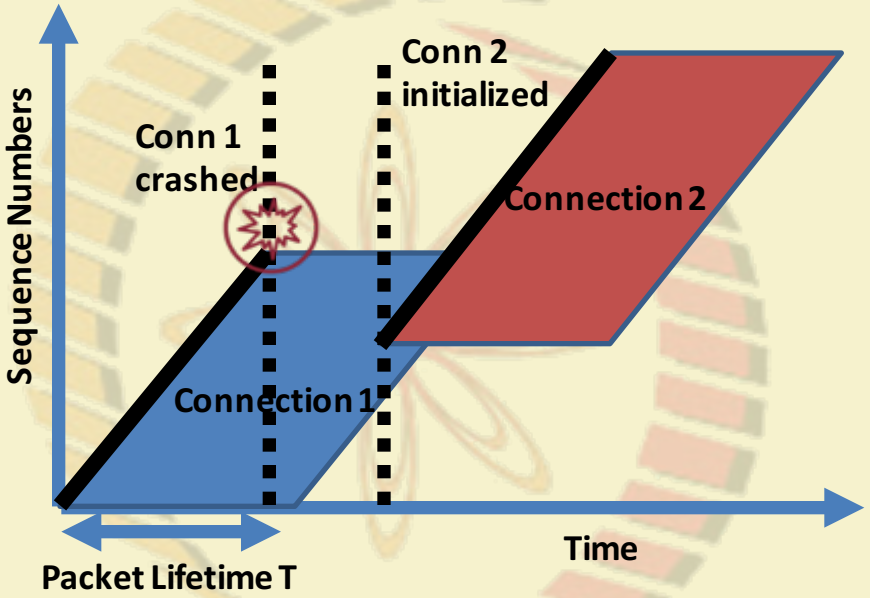

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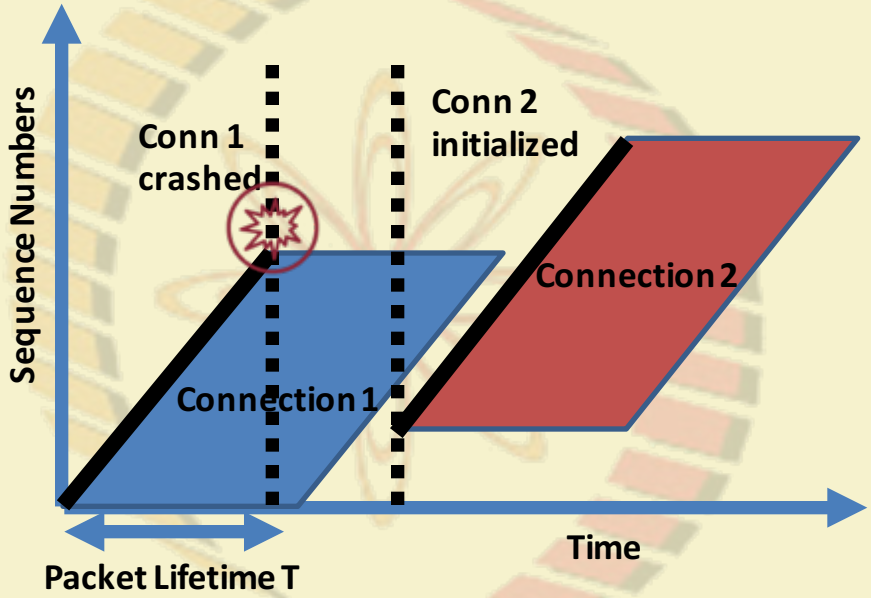

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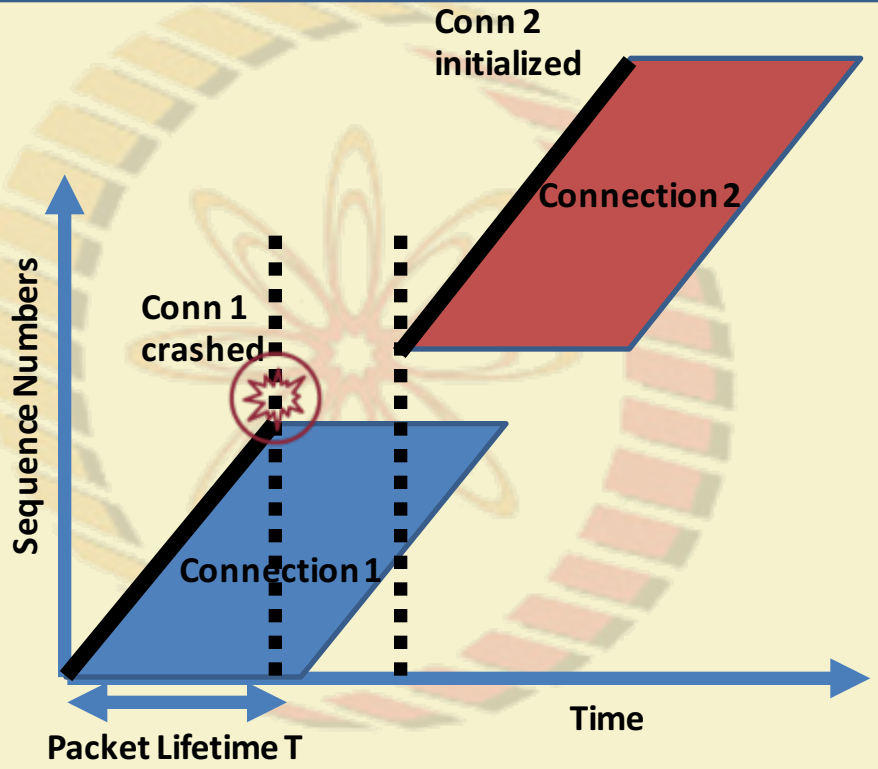

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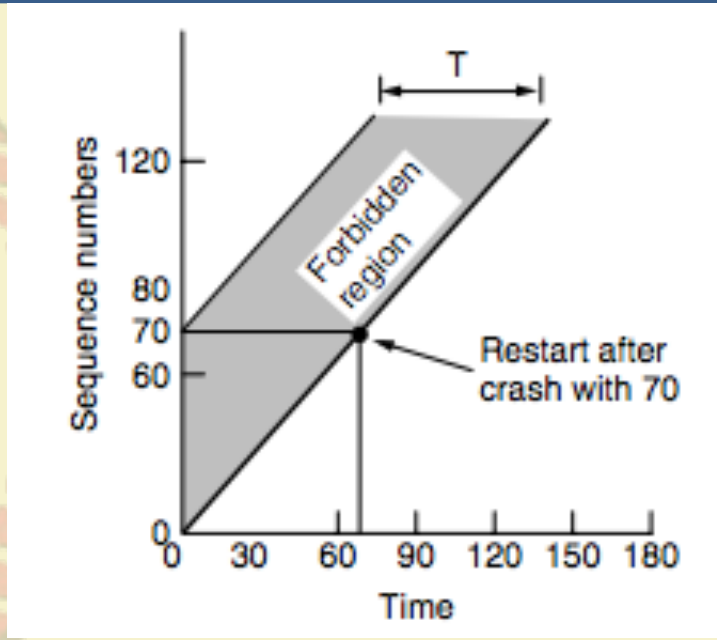

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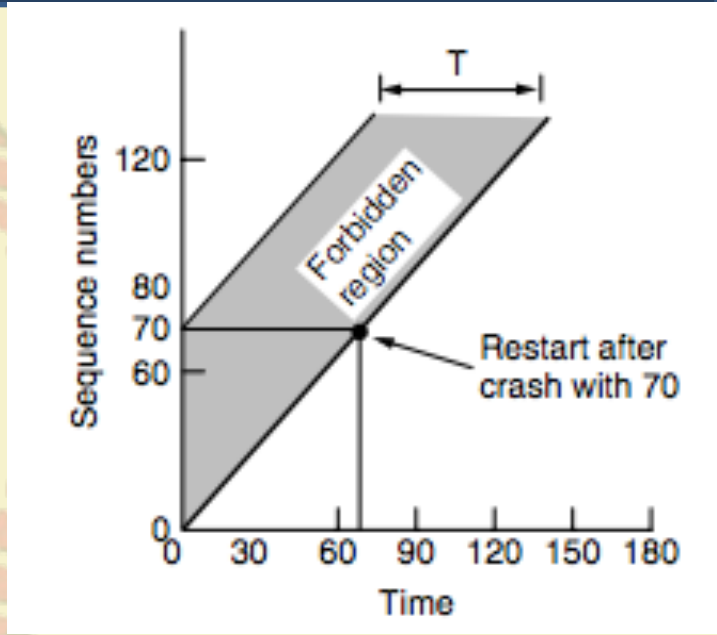

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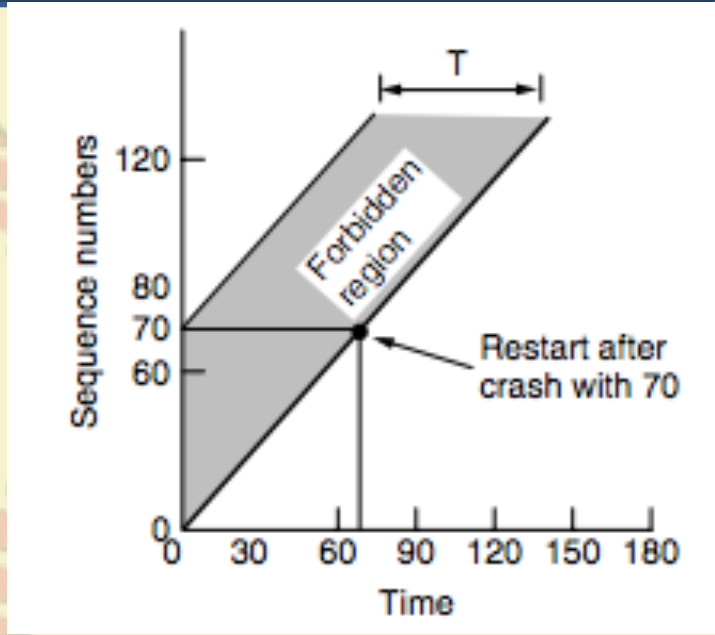

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Packet Sequence Numbers are Out of the Forbidden Region

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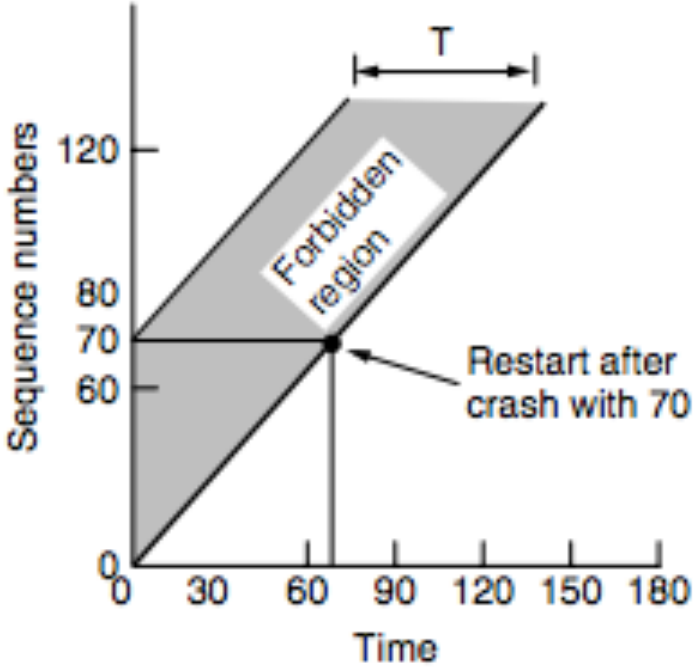

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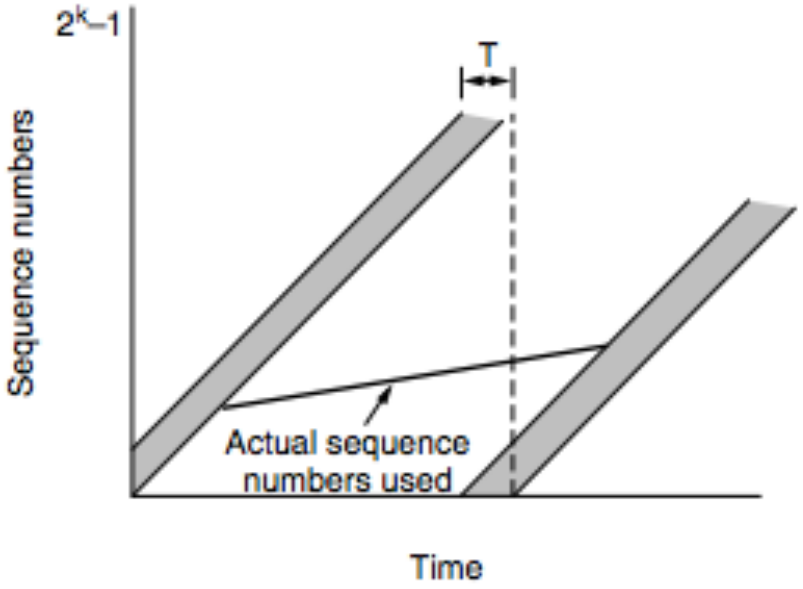

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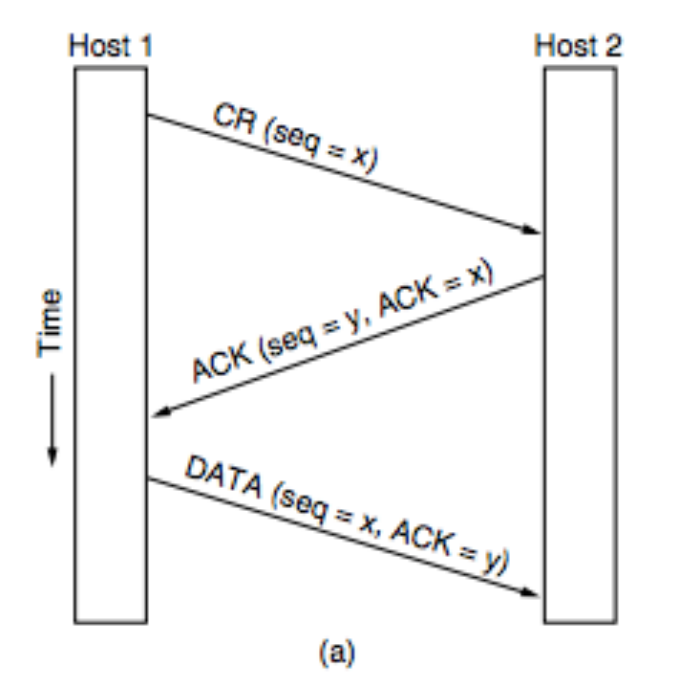
Three Way Handshake



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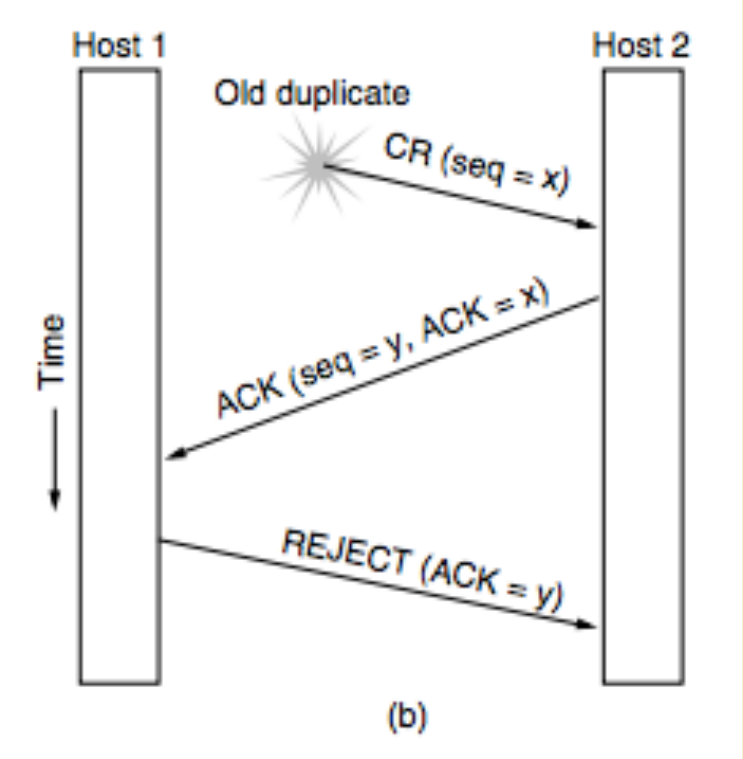
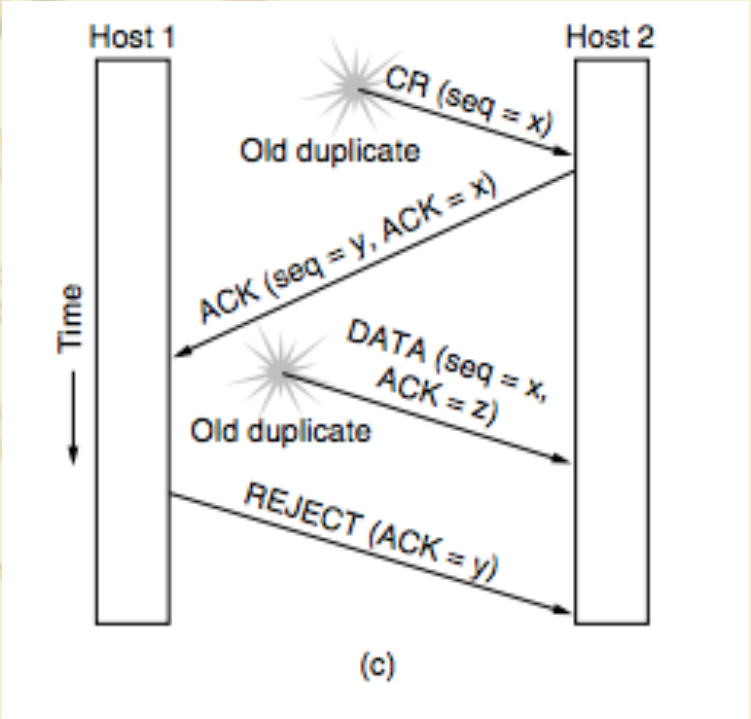
Source: Computer Networks (5th Edition) by Tanenbaum, Wetherell



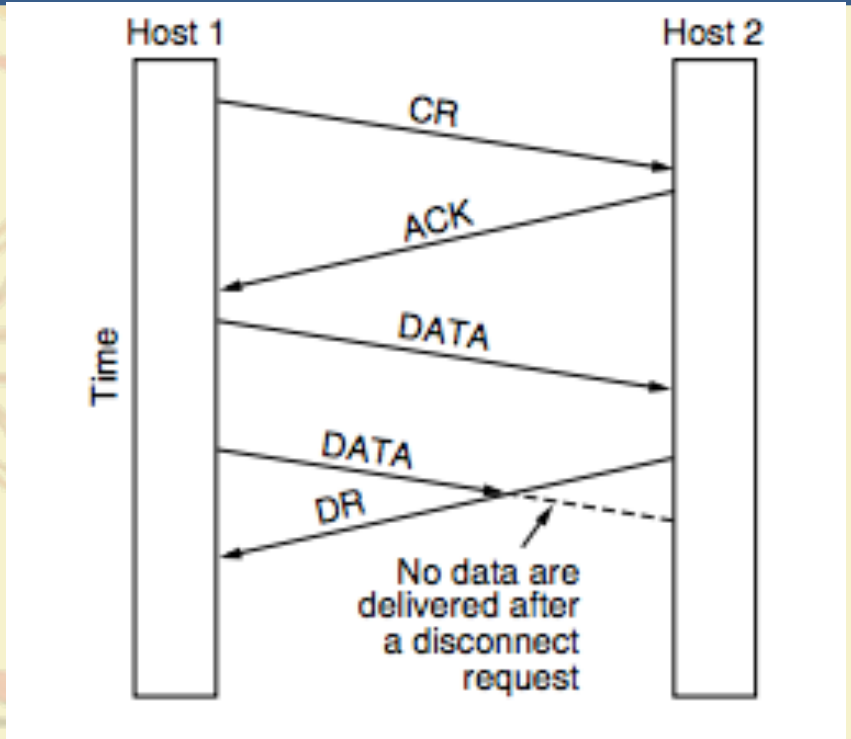
CONNECTION REQUEST and ACK both are Delayed Duplicates

Source: Computer Networks (5th Edition) by Tanenbaum, Wetherell



Connection Release – Asymmetric Release

- When one party hangs up, the connection is broken
- This may results in data loss

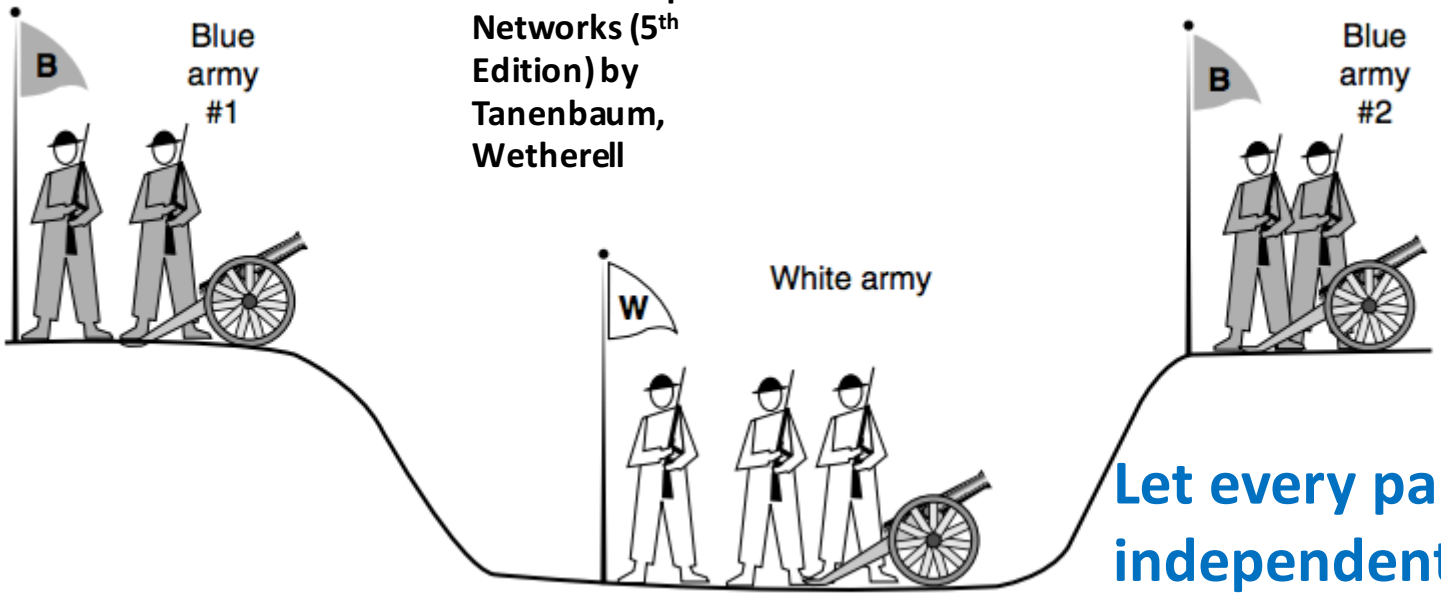


Source: Computer Networks (5th Edition) by Tanenbaum, Wetherell

Connection Release – Symmetric Release

- Treats the connection as two separate unidirectional connections and requires each one to be released separately
- Does the job when each process has a fixed amount of data to send and clearly knows when it has sent it.
- What can be a protocol for this?
  - **Host 1: “I am done”**
  - **Host 2: ”I am done too”**
- **Does this protocol work good always?**

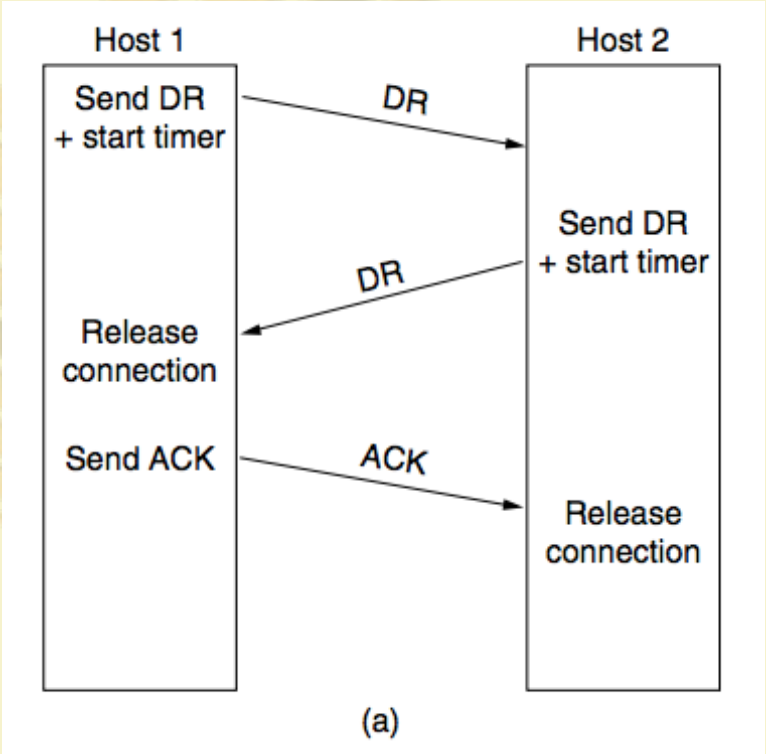
The Two Army Problem



Let every party take independent decisions

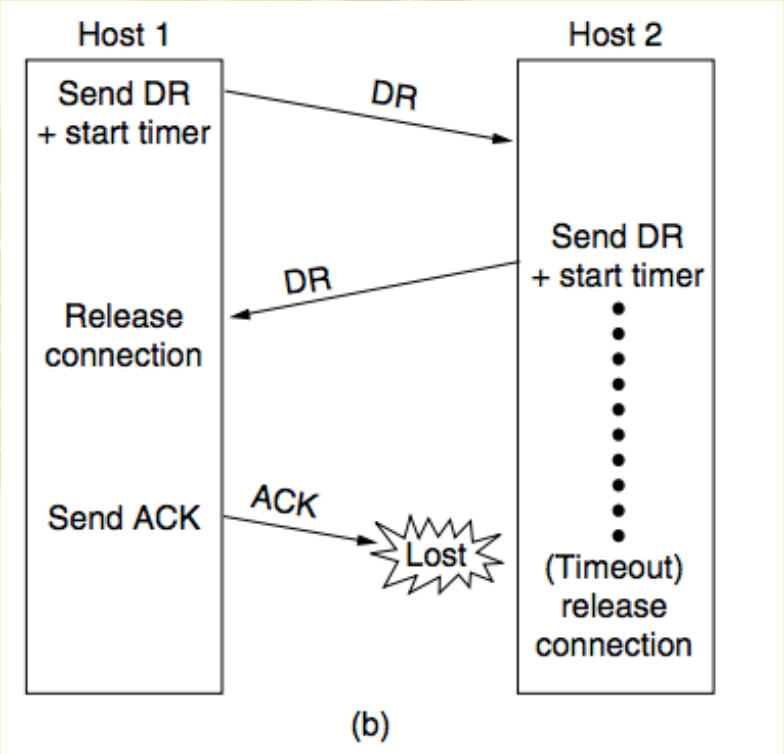
No protocol exists to solve this

Connection Release



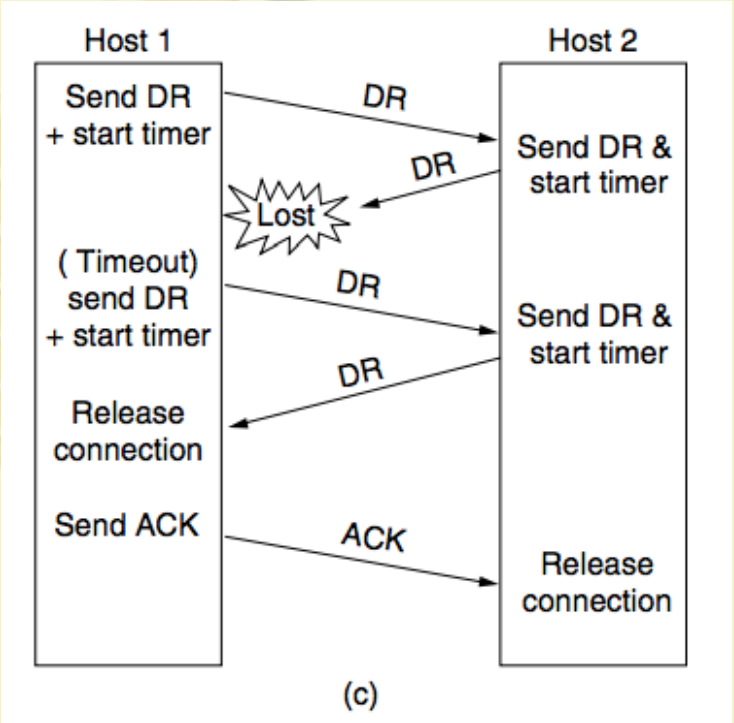
Source: Computer Networks (5th Edition) by Tanenbaum, Wetherell

Connection Release – Final ACK Lost



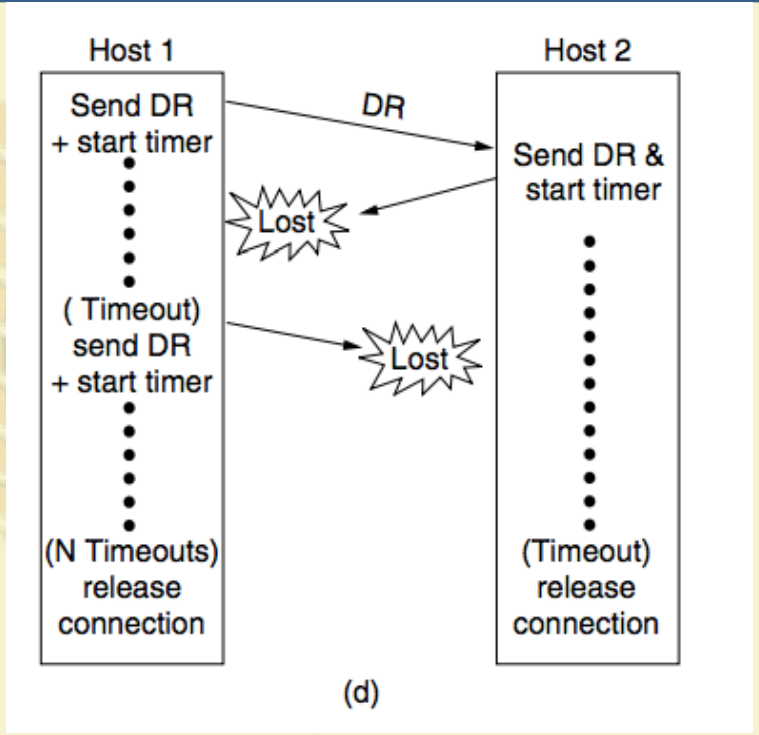
Source: Computer Networks (5th Edition) by Tanenbaum, Wetherell

Connection Release – Response Lost



Source: Computer Networks (5th Edition) by Tanenbaum, Wetherell

Connection Release – Response Lost and Subsequent DRs Lost



Source: Computer Networks (5th Edition) by Tanenbaum, Wetherell


thank you!

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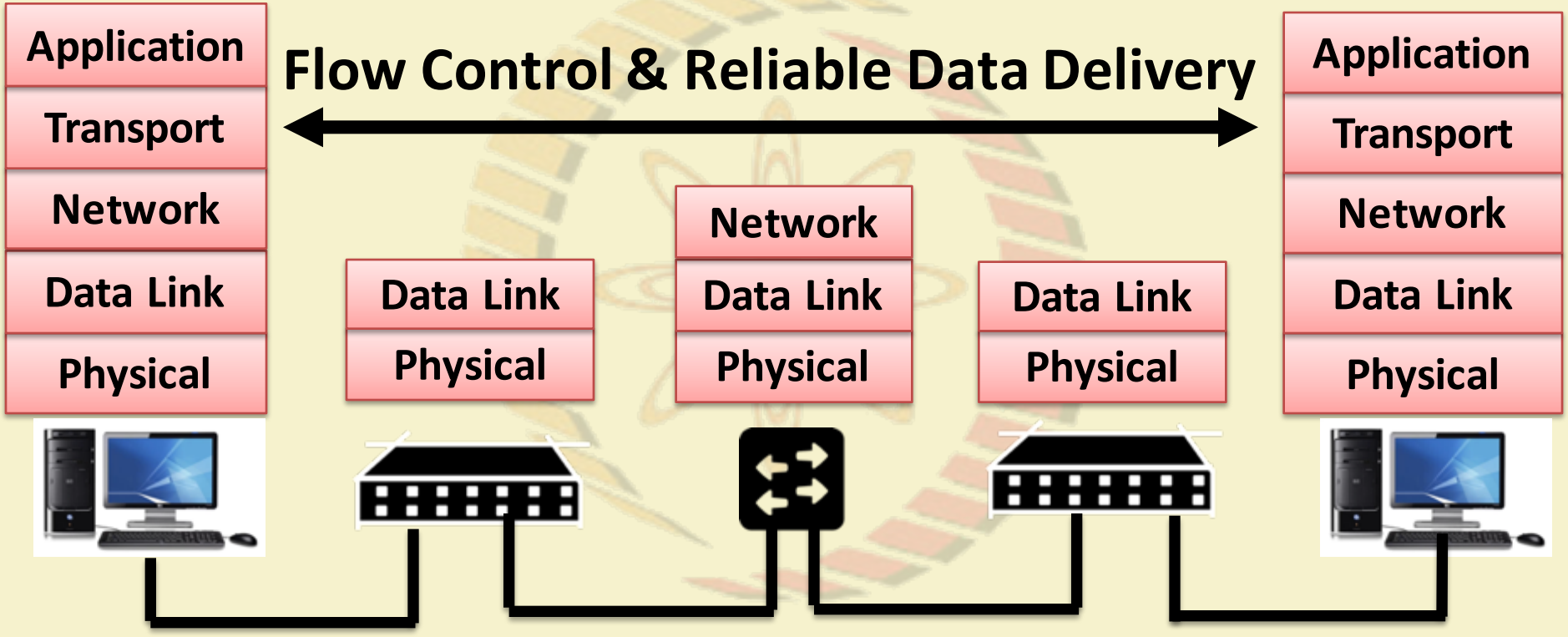
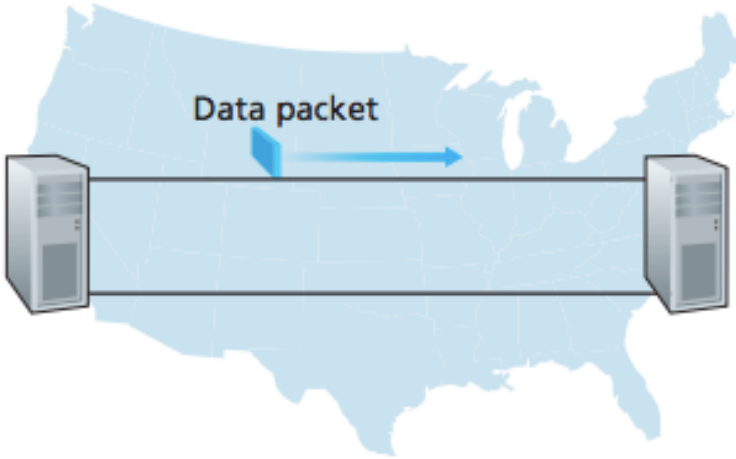
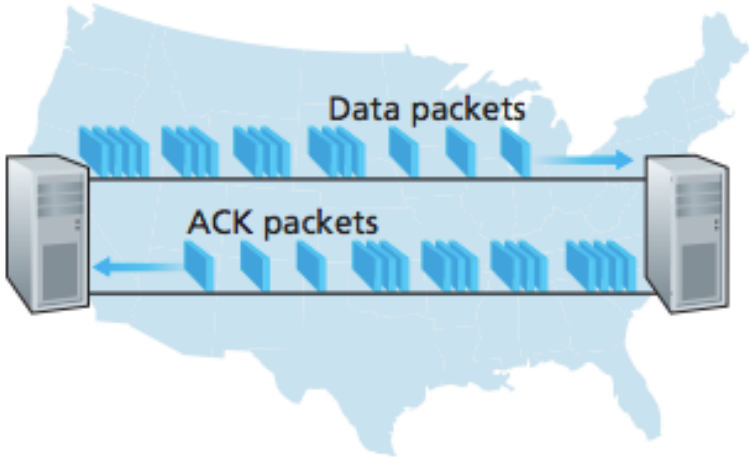
Transport Layer - V (Sliding Window Protocols)



Stop and Wait versus Sliding Window (Pipelined)



a. A stop-and-wait protocol in operation



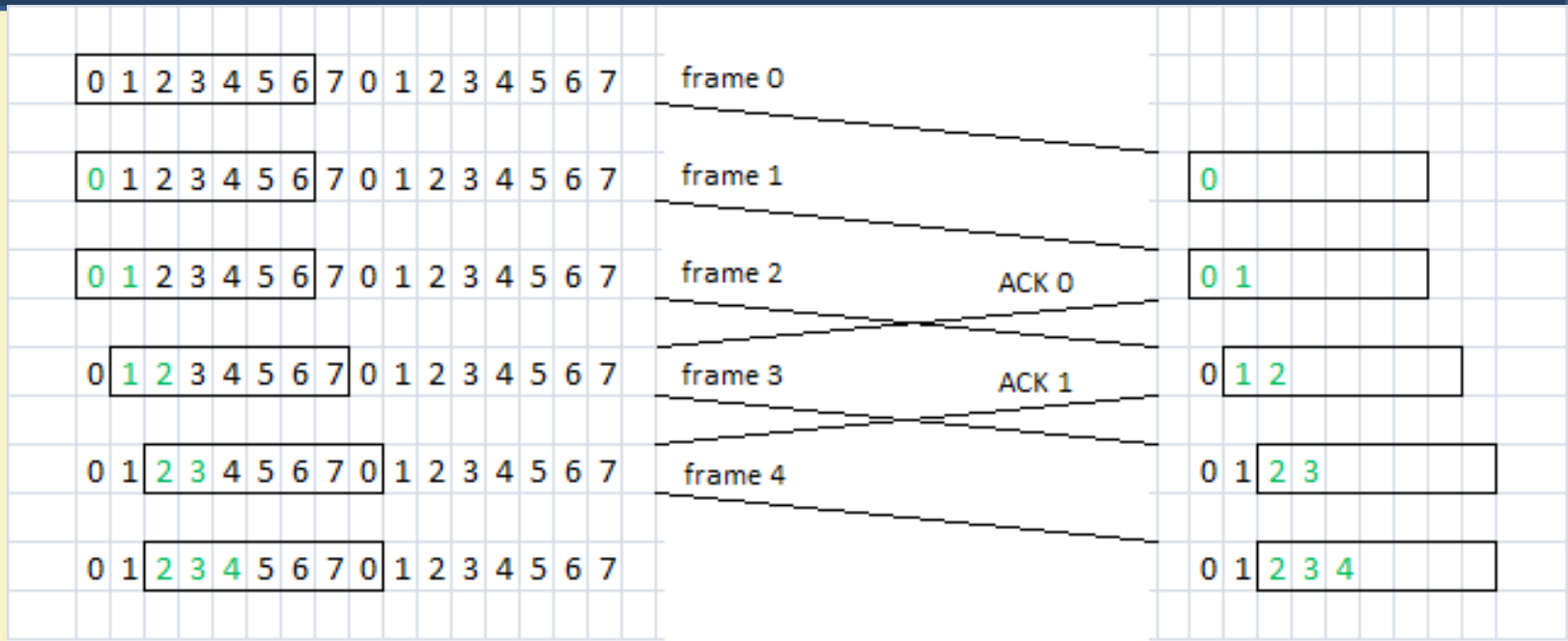
b. A pipelined protocol in operation

Source: Computer Networks, Kurose, Ross

Sliding Window Protocols

- Each outbound segment contains a sequence number – from 0 to some maximum (2^n-1 for a n bit sequence number)
- The sender maintains a set of sequence numbers corresponding to frames it is permitted to send (**sending window)**
- The receiver maintains a set of frames it is permitted to accept (**receiving window)**

Sliding Window Protocols – Sending Window and Receiving Window



Sliding window Protocol

Source:
http://ironbark.xtelco.com.au/subjects/DC/lectures/13/

Sliding Window for a 3 bit Sequence Number

Source: Computer Networks (5th Edition) by Tanenbaum, Wetherell

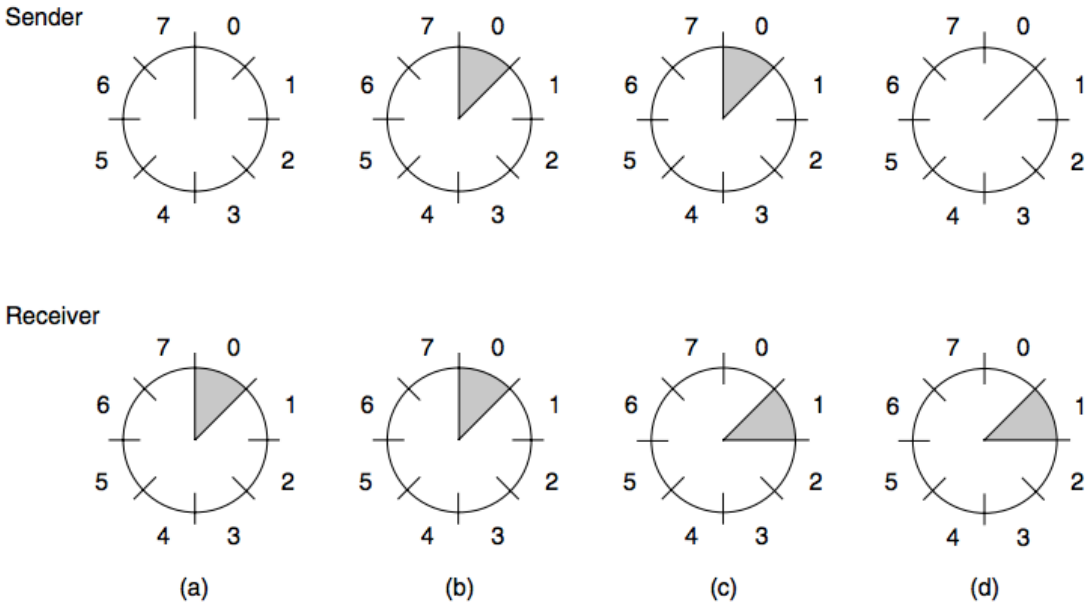
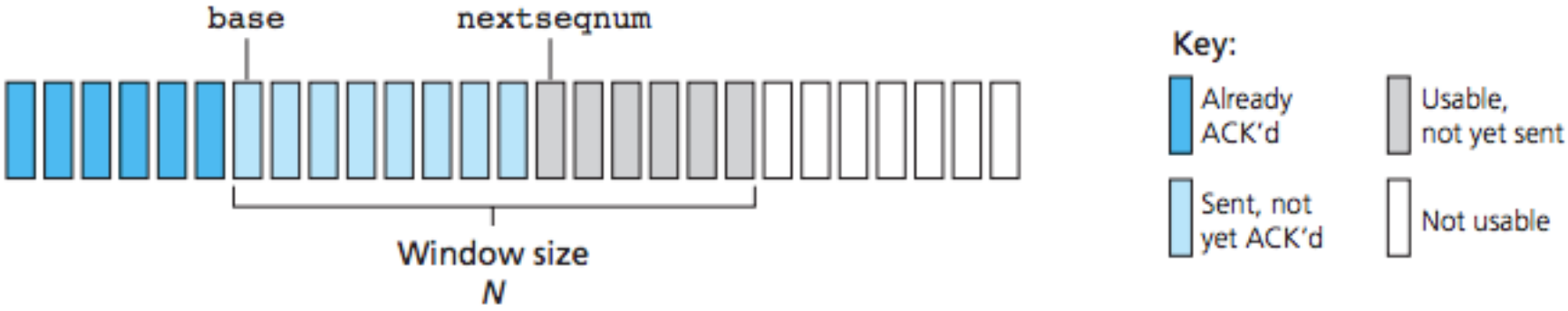


Figure 3-15. A sliding window of size 1, with a 3-bit sequence number. (a) Initially. (b) After the first frame has been sent. (c) After the first frame has been received. (d) After the first acknowledgement has been received.

Sliding Window Protocols in Noisy Channels

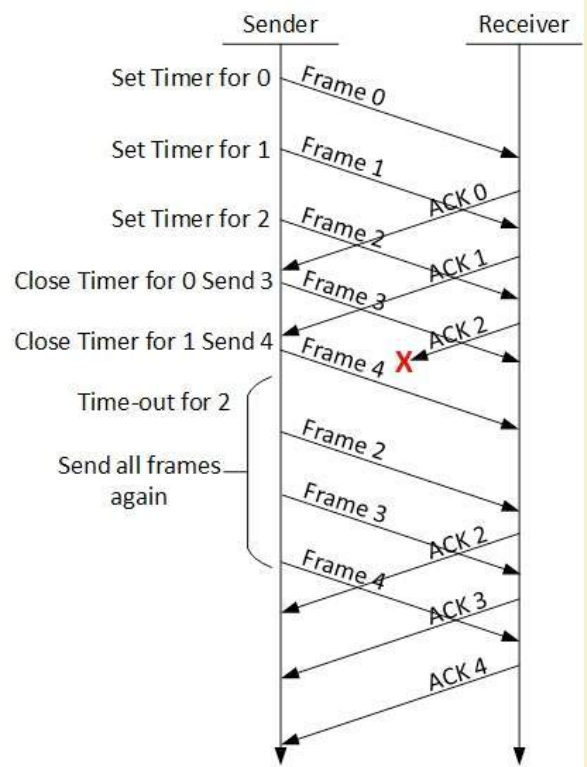
- **A timeout occurs if a segment (or the acknowledgment) gets lost**
- **How does the flow and error control protocol handle a timeout?**
- **Go Back N ARQ:** If segment N is lost, all the segments from segment 0 (start of the sliding window) to segment N are retransmitted
- **Selective Repeat (SR) ARQ:** Only the lost packets are selectively retransmitted
  - **Negative Acknowledgement (NAK) or Selective Acknowledgements (SACK):** Informs the sender about which packets need to be retransmitted (not received by the receiver)

Go Back N ARQ – Sender Window Control



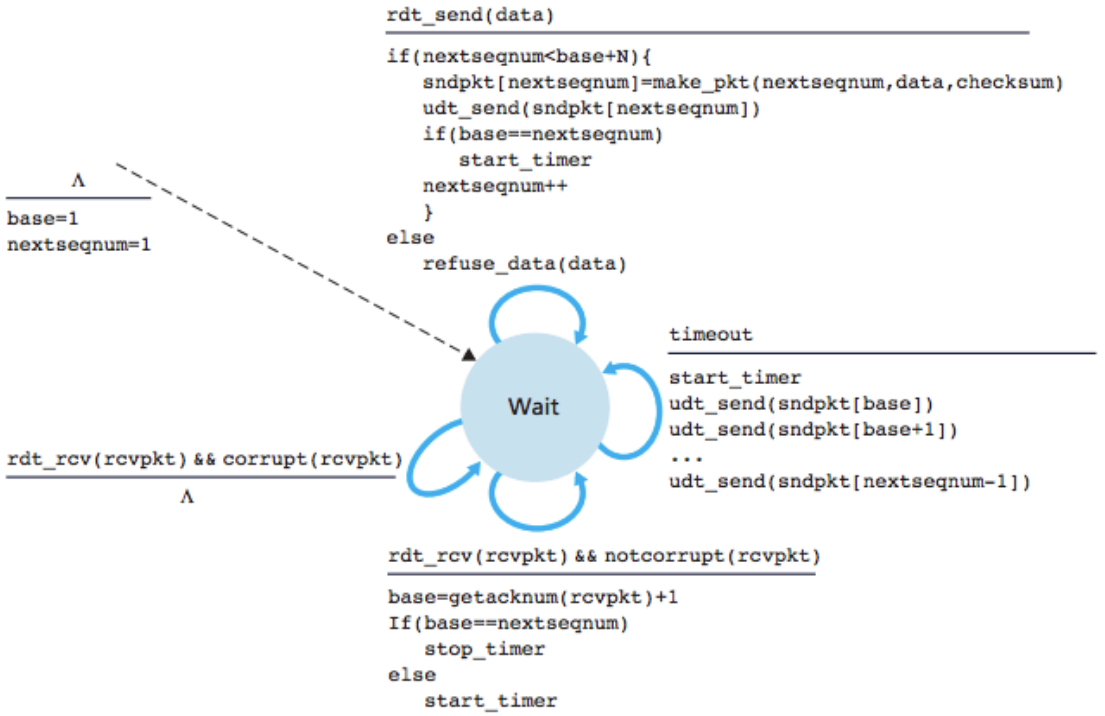
Source: Computer Networks, Kurose, Ross

Go Back N ARQ



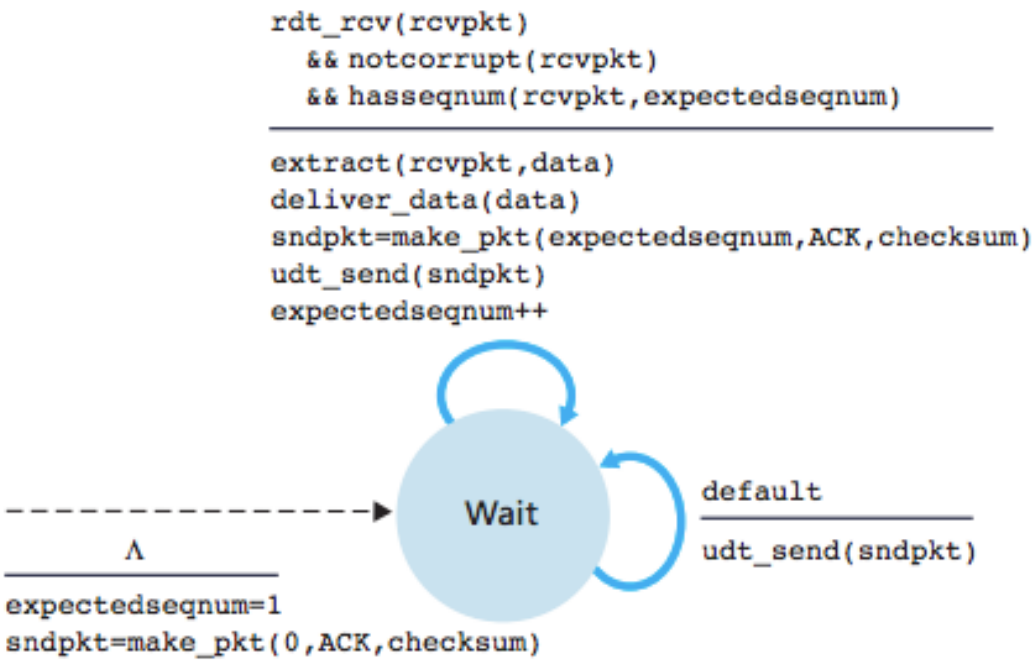
Source
https://www.tutorialspoint.com/data_communication_computer_network/data_link_control_and_protocols.htm

Go Back N ARQ – Sender



Source: Computer Networks, Kurose, Ross

Go Back N ARQ – Receiver

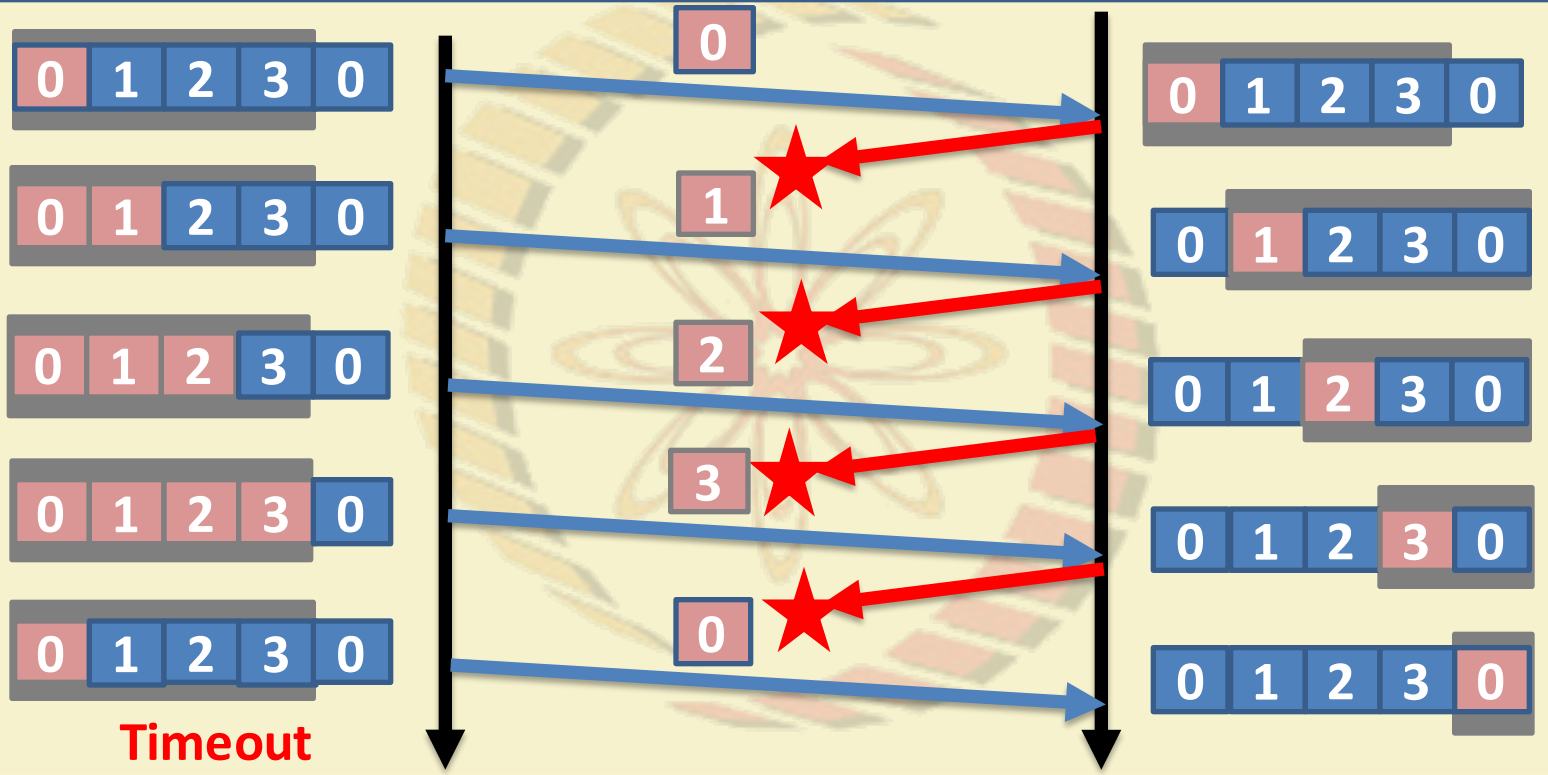


Source: Computer Networks, Kurose, Ross

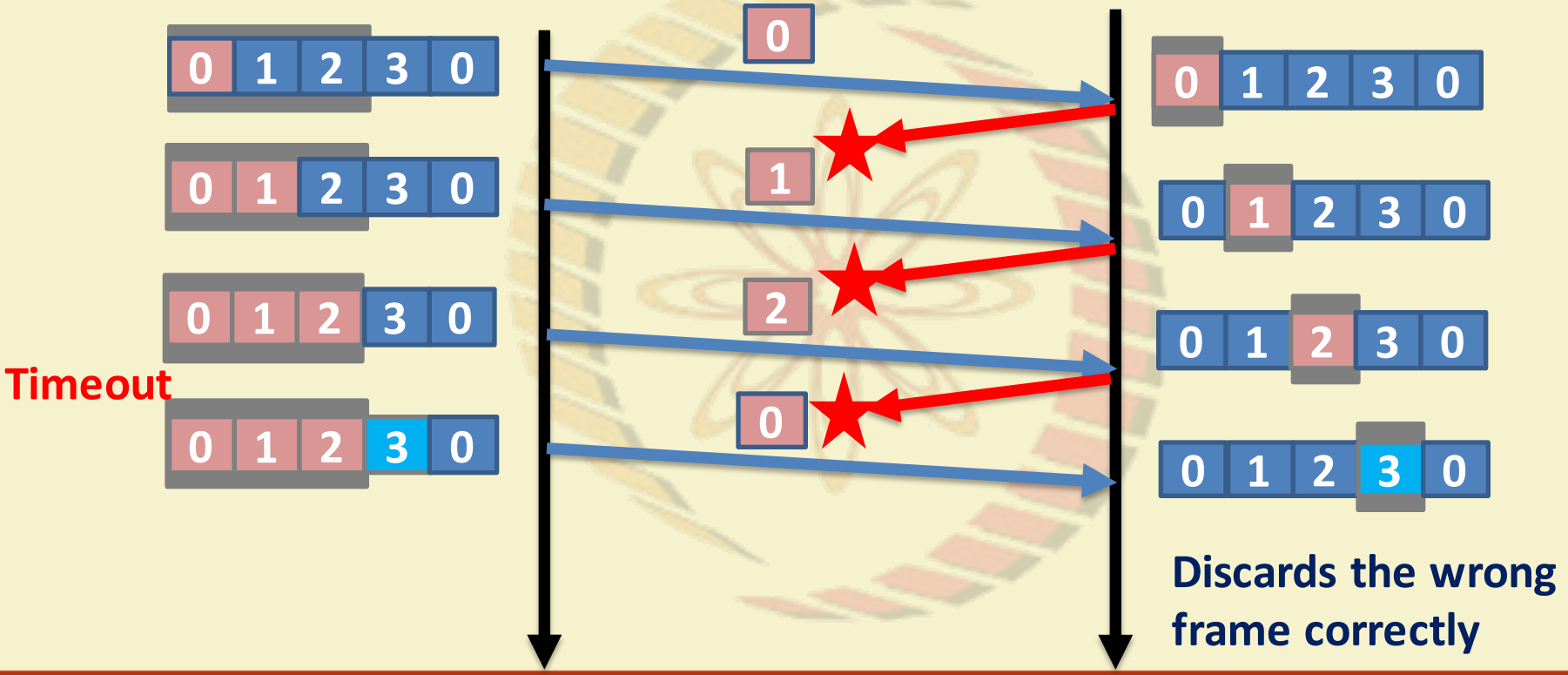
Go Back N ARQ – A Bound on Window Size

- **Outstanding Frames –** Frames that have been transmitted, but not yet acknowledged
- **Maximum Sequence Number (MAX_SEQ): MAX_SEQ+1** distinct sequence numbers are there
  - **0,1,…,MAX_SEQ**
- **Maximum Number of Outstanding Frames (=Window Size): MAX_SEQ**
- **Example:** Sequence Numbers (0,1,2,…,7) – 3 bit sequence numbers, number of outstanding frames = 7 **(Not 8)**

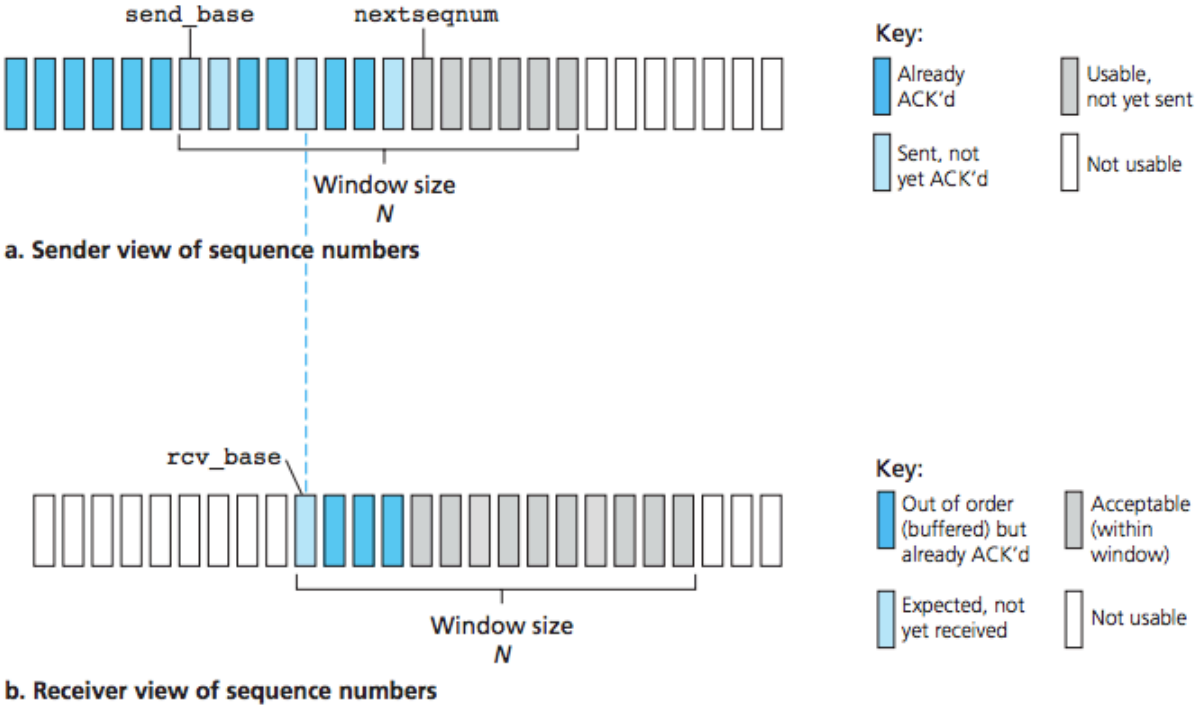
Go Back N ARQ (MAX_SEQ = 3, Window Size = 4)



Go Back N ARQ (MAX_SEQ = 3, Window Size = 3)

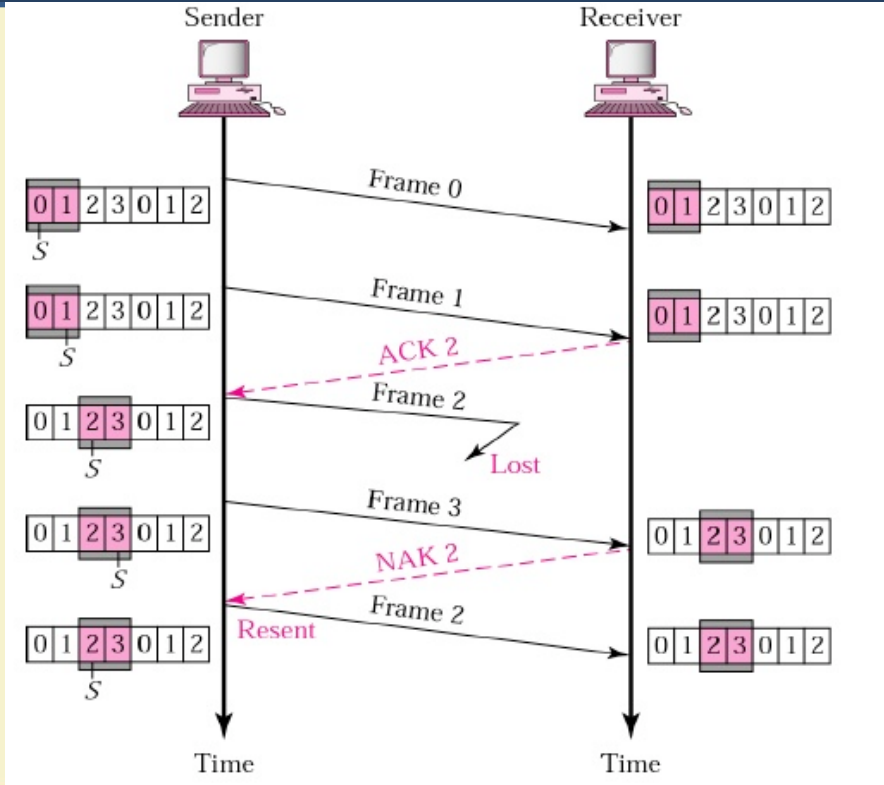


Selective Repeat (SR) – Window Control



Source: Computer Networks, Kurose, Ross

Selective Repeat ARQ



Source: Computer Networks, Tanenbaum

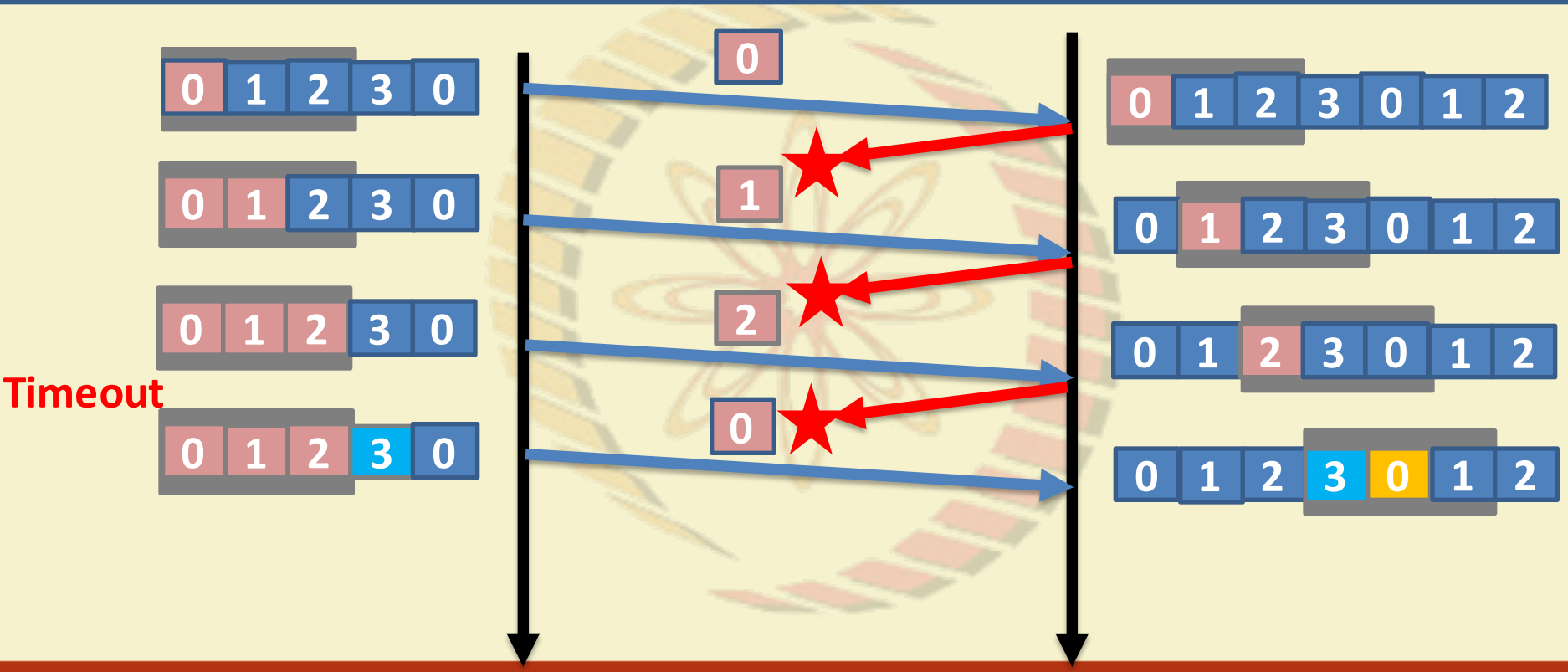
Selective Repeat – A Bound on Window Size

- **Maximum Sequence Number (MAX_SEQ): MAX_SEQ+1** distinct sequence numbers are there
  - **0,1,…,MAX_SEQ**

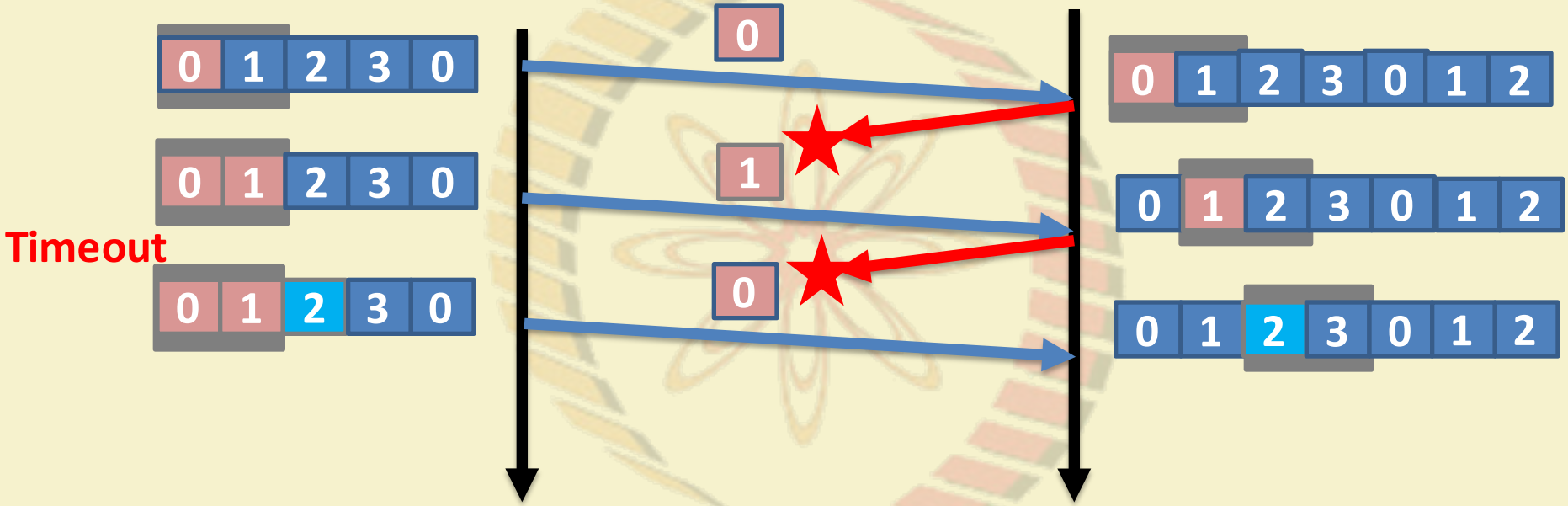
- **Maximum Number of Outstanding Frames (=Window Size): (MAX_SEQ+1)/2**

- **Example:** Sequence Numbers (0,1,2,…,7) – 3 bit sequence numbers, number of outstanding frames (window size) = 4

Selective Repeat (MAX_SEQ = 3, Window Size = 3)



Selective Repeat (MAX_SEQ = 3, Window Size = 3)



Discards the wrong frame correctly


thank you!