
UDP
User Datagram
Protocol

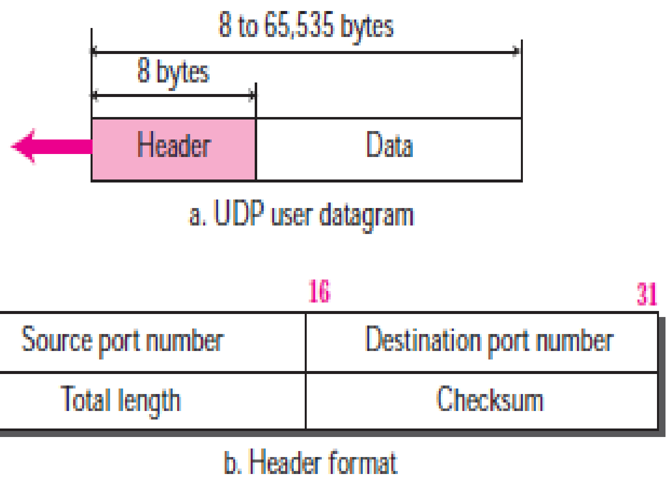
User Datagram Protocol (UDP)

UDP – An Introduction

- Connectionless service
- Unreliable transport protocol.
- No flow control / No Acknowledgement
- Process to Process communication
- Powerless
- It uses minimum of over heads
- No reliability is obtained using UDP
- Less interaction between sender and receiver

User Datagram Protocol (UDP)

USER DATAGRAM



User datagram hearde format

- Above picture depicts user data gram format
- UDP packets are called user datagrams(messages)
- It has fixed size header of 8 bytes

User Datagram Protocol (UDP)

UDP Datagram various fields

- Source Port Number:
  - 16 bits long – port ranges from 0-65535.
  - This port number will be used by the source host for identification.
- Destination Port Number:
  - 16 bits long.
  - Used by the process running on the Destination machine.
  - Application level service on end machine

User Datagram Protocol (UDP)

UDP Datagram various fields

- Length:

UDP length=IP length – IP headers Length

  - Length field specifies the entire length of UDP packet (including header).
  - It is 16-bits field and minimum value is 8-byte, i.e. the size of UDP header itself.
  - A user datagram is encapsulated in an IP datagram.

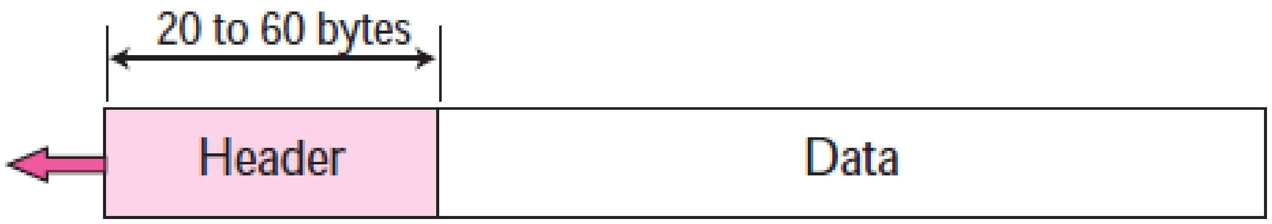
- Checksum:
  - This field is used to detect errors over the entire user datagram (header plus data)

TCP Header

Transmission Control Protocol (TCP)

TCP Segment

- A packet in TCP is called a ***Segment***
- ***Segment – Format***
  - Header - 20 to 60 Bytes
    - In case of no options Header is of size 20 bytes
    - When options are used Header size extends up to 60 Bytes
  - Data from application program

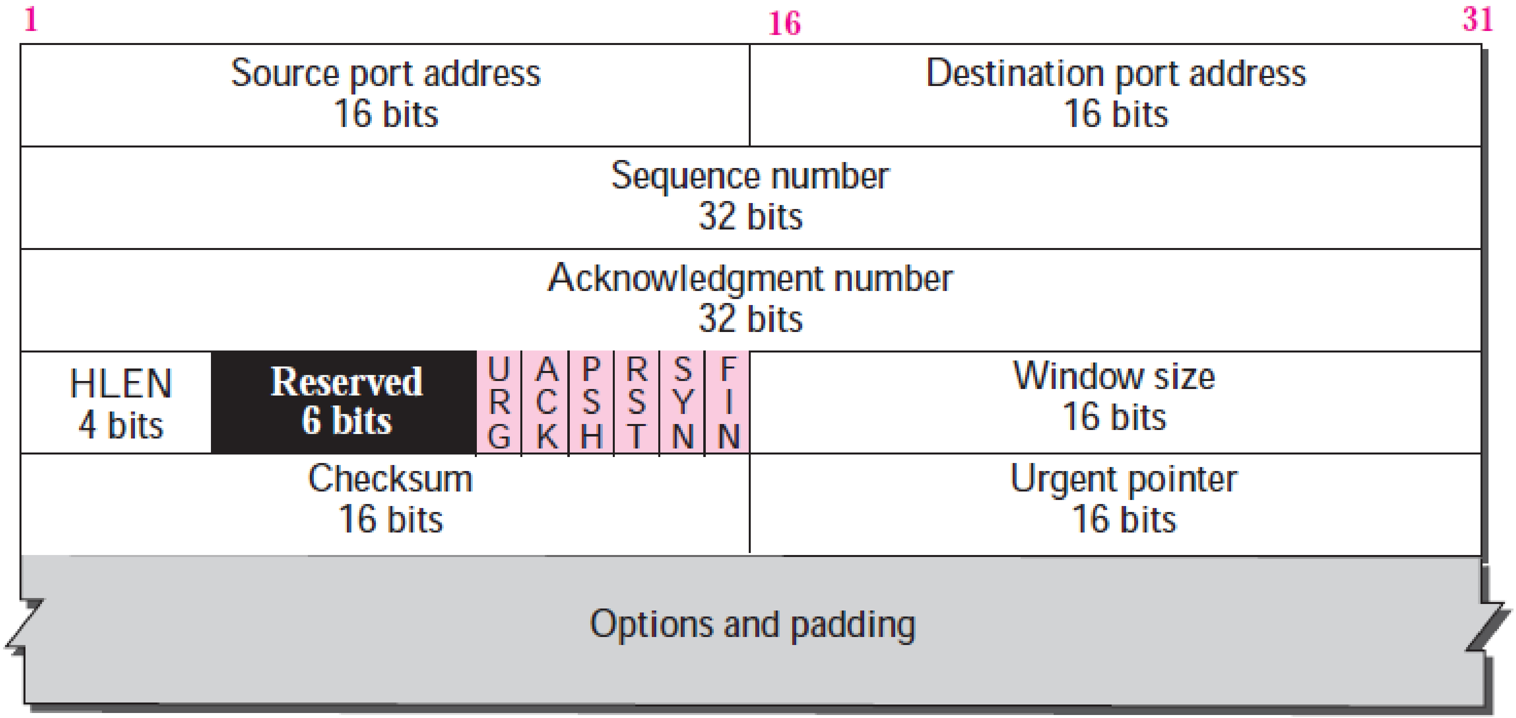


Format of Segment

Transmission Control Protocol (TCP)

TCP Header

- Size of TCP Header varies from 20 to 60 bytes



Format of TCP Header

Source: Behrouz A. Forouzan, “TCP IP Protocol Suite ” 4th edition, 2010, McGraw-Hill ISBN: 0073376043

Transmission Control Protocol (TCP)

TCP Header Contd…

- The various fields of TCP header are as follows:

i. Source Port Address
ii. Destination Port Address
iii. Sequence Number
iv. Acknowledgement Number
v. Header Length
vi. Reserved

vii. Control
viii. Window Size
ix. Urgent Pointer
x. Options
xi. Checksum

Transmission Control Protocol (TCP)

TCP Header Contd…

i. *Source Port Address*

- 16 bit Field
- Defines port number of application program in host sending the segment

ii. *Destination Port Address*

- 16 bit Field
- Defines port number of application program in host receiving the segment

iii. *Sequence Number*

- 32 bit field
- Defines number of first byte of data contained in Segment
- Each byte is numbered for connectivity reasons
- Sequence number provides information regarding the first byte of segment to destination host

Transmission Control Protocol (TCP)

TCP Header Contd...

iv. Acknowledgement Number

- 32 bit Field
- Defines the byte number the receiver expects to receive from senders
- If ‘n’ bytes are received from sender ‘n+1’ is sent as acknowledgement number
- Acknowledgment and Data go hand in hand

v. Header Length

- 4 bit Field
- Indicates number of 4 byte words in Header
- Value of header length varies between 5 (5 x 4 = 20) and 20 (20 x 4 = 60)

vi. Reserved

- 6 bit field
- Reserved for future use

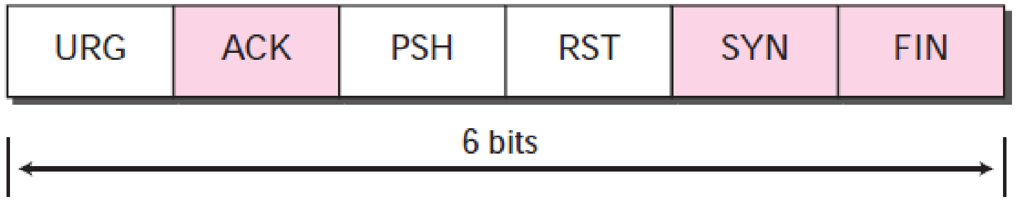
Transmission Control Protocol (TCP)

TCP Header Contd…

vii. Control

- 6 bit Field
- Defines 6 unique control bits / flags
- Can be set one / more at a time
- Enables
  - Flow Control
  - Connection Establishment, Termination and Abortion
  - Mode of TCP Data transfer

URG: Urgent pointer is valid
ACK: Acknowledgment is valid
PSH: Request for push
RST: Reset the connection
SYN: Synchronize sequence numbers
FIN: Terminate the connection



Control Field of TCP Header

Source: Behrouz A. Forouzan, “TCP IP Protocol Suite ” 4th edition, 2010, McGraw-Hill ISBN: 0073376043

Transmission Control Protocol (TCP)

TCP Header Contd…

viii. Window Size

- 16 bit Field
- Maximum Window Size: 65, 535 bytes
- Defines Window size of sending TCP
- Determined by Receiver
- Referred as (*rwnd*)
- Sender must adhere to the window size fixed by the receiver

ix. Urgent Pointer

- 16 bit field
- Used only if urgent data is part of segment
- Valid only when urgent flag is set

x. Options

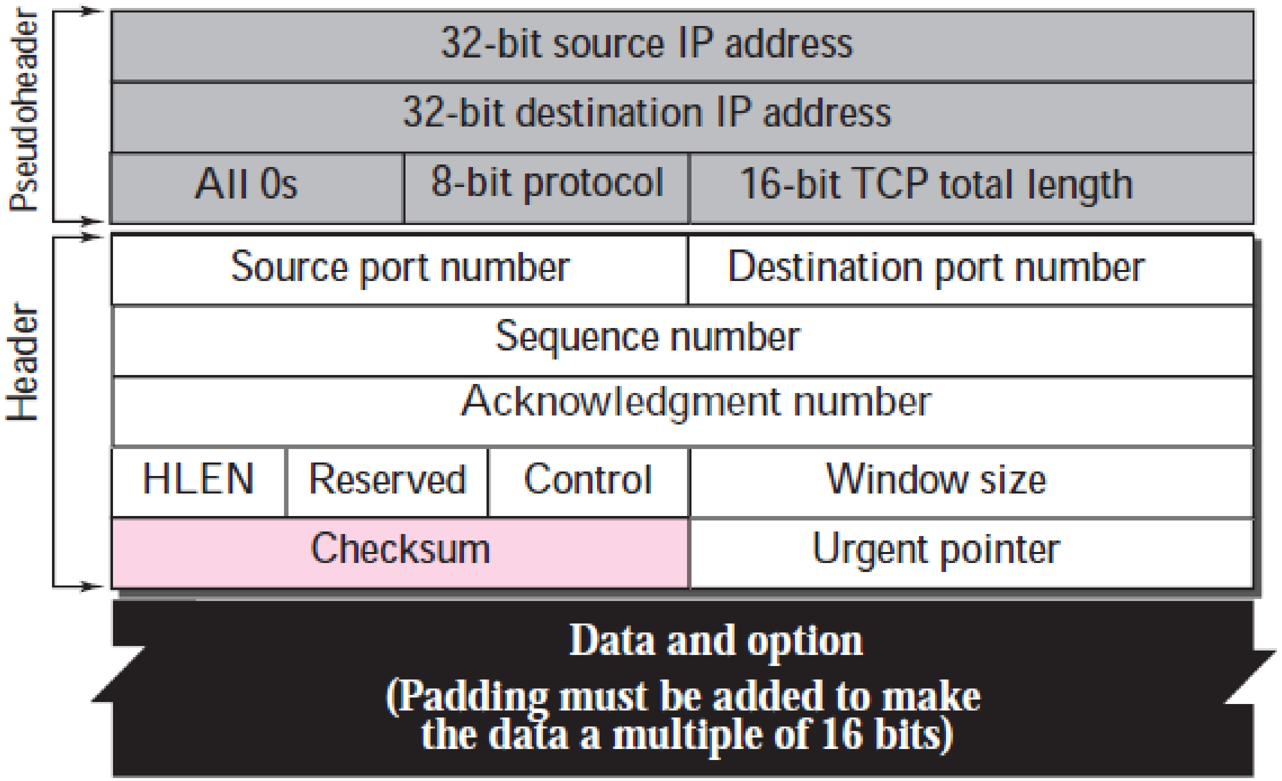
- Can accommodate up to 40 bytes of optional information

Transmission Control Protocol (TCP)

TCP Header Contd…

xi. Checksum

- 16 bit field
- Mandatory in TCP
- Detects error over entire TCP
- Pseudoheader added to segment



Pseudoheader Added to the TCP Datagram

Source: Behrouz A. Forouzan, "TCP IP Protocol Suite " 4th edition, 2010, McGraw-Hill ISBN: 0073376043

A TCP Connection

Transmission Control Protocol (TCP)

A TCP Connection

- Connection Oriented Protocol
- Virtual path established between source and destination
- TCP Segments sent and received over Virtual path
  - Enables retransmission of Lost / Damaged segments
  - Waits for segments arriving out of order
- Phases of TCP Connection
  1. Connection Establishment
  2. Data Transfer
  3. Connection Termination

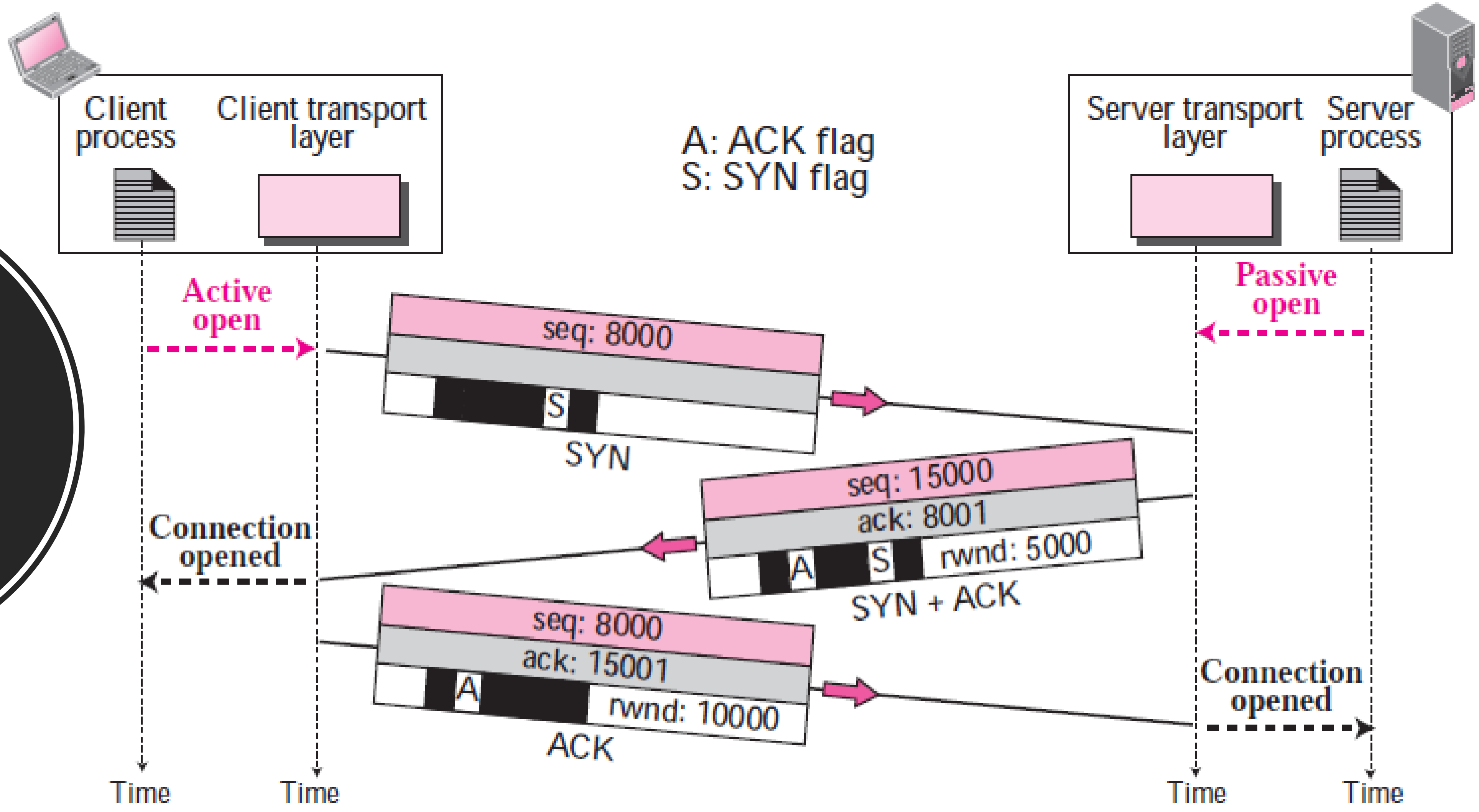
Transmission Control Protocol (TCP)

A TCP Connection Contd...

i. Connection Establishment

- Transmission mode in TCP: ***Full-Duplex***
- Simultaneous transfer of data between Sender and Receiver
- Mutual approval of Communication between sender and receiver mandatory before data transfer
- Connection establishment performed through ***3-Way Handshaking***
  - ***Passive Open*** – Server program informs TCP that it is ready to accept connection
  - ***Active Open*** – Client program intending to connect to a Server informs TCP

Connection Establishment using 3-way Handshaking



Source: Behrouz A. Forouzan, “TCP IP Protocol Suite ” 4th edition, 2010, McGraw-Hill ISBN: 0073376043

Transmission Control Protocol (TCP)

A TCP Connection Contd…

i. Connection Establishment Contd…

- ***Step 1***
  - Client is in active open mode
  - Client sends first SYN segment and sets flag to SYN
  - ***Initial Sequence Number (ISN)*** : 8000 (Random Number) sent to Server
  - SYN segment (Control Segment) carries no data
  - SYN segment consumes one Sequence number
  - ***Note:*** No ACK / Window Size sent along with ISN

Transmission Control Protocol (TCP)

A TCP Connection Contd…

i. Connection Establishment Contd…

- ***Step 2***
  - Server sends second segment (SYN + ACK) and sets flag to SYN & ACK
    - **ACK** - Server acknowledges receipt of first segment from Client
    - **SYN** – Segment for communication from Server to Client
      - New Sequence Number : ***15000*** (Random Number)
      - Acknowledgement Number for Segment from client: ***8001*** (Inc. by 1)
      - Window Size (***rwnd***): Set to ***5000*** by Server (to be used by Client)
    - (SYN+ACK) segment consumes one Sequence number

Transmission Control Protocol (TCP)

A TCP Connection Contd…

i. Connection Establishment Contd…

- **Step 3**
  - Client sends third segment (ACK) and sets ACK flag
    - **ACK** – Client acknowledges receipt of second segment from Server
      - Sequence Number : ***8000*** (Used in first Segment)
      - Acknowledgement Number for Segment from Server: ***15001*** (Inc. by 1)
      - Window Size (***rwnd***) : Set to ***10000*** by Client (to be used by Server)
    - (ACK) segment consumes no Sequence number

Transmission Control Protocol (TCP)

A TCP Connection Contd…

i. *Connection Establishment Contd…*

- *Synchronous Flooding Attack*
  - Type of Denial of Service Attack (DoS)
  - Malicious attackers send large count of SYN segments to a Server
  - SYN segments pretend to come from various Clients using different IP Address
  - Server assumes that Clients are in active open mode and allocates resources
  - Server Sends SYN + ACK segments to fake clients and waits for response
  - Server runs out of resources and is unable to accept connection requests from legitimate clients

Transmission Control Protocol (TCP)

A TCP Connection Contd…

i. *Connection Establishment Contd…*

- ***Simultaneous Open***
  - Client and Server issues active open mode (Rare Phenomenon)
  - SYN + ACK segment sent from Client to Server and vice versa

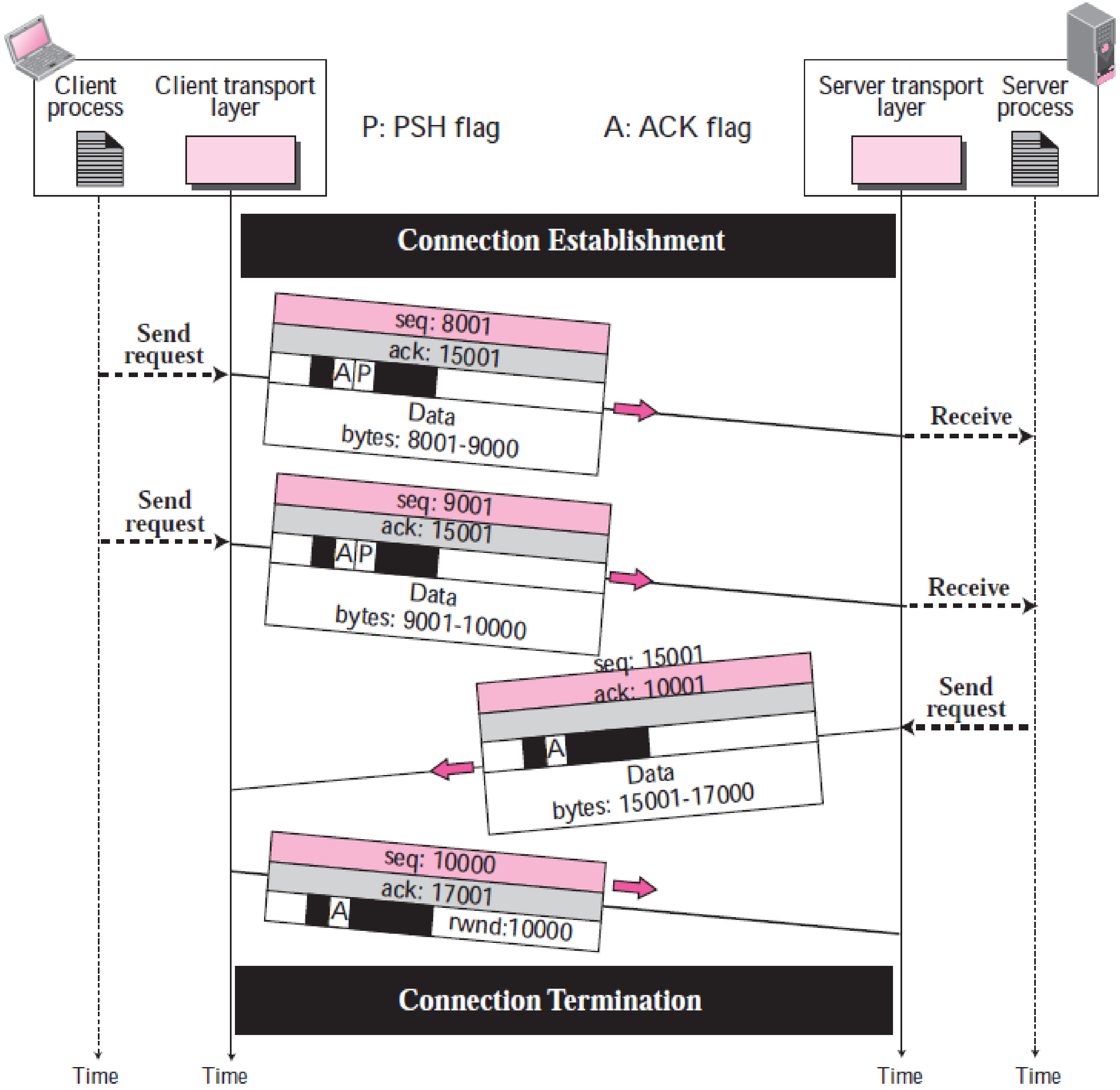
Transmission Control Protocol (TCP)

A TCP Connection Contd…

ii. TCP Data Transfer

- Data transfer is bidirectional after connection is established
- Data and acknowledgements can be sent between client and server bidirectionally
- ***Example (After Connection Establishment)***
  - Client transmits 2000 bytes of data in 1st and 2nd segment to the Server
    - Push flag (PSH) & ACK flags set for Data Segments sent by client
    - ***Segment 1:*** seq(8001), ack(15001), A & P flags set, Data bytes (8001-9000)
    - ***Segment 2:*** seq (9001), ack (15001), A & P flags set, Data bytes (9001 – 10000)

- Server sends 2000 bytes of data in the 3rd segment
- ***Segment 3:*** seq (15001), ack (10001), A flag set, Data bytes (15001 – 17000)
  - ACK flag set & SYN flag not set for data segments sent by server
- ***Segment 4:*** seq (10001), ack (17001), A flag set, rwnd (10000)



Data Transfer in TCP

Source: Behrouz A. Forouzan, "TCP IP Protocol Suite " 4th edition, 2010, McGraw-Hill ISBN: 0073376043

Transmission Control Protocol (TCP)

A TCP Connection Contd...

ii. TCP Data Transfer Contd...

- ***Flexibility of TCP***
  - Sending TCP uses buffer to store incoming data stream from applications
  - Receiving TCP uses buffer to store arriving data and send to applications
  - Disadvantage: Delayed delivery of data
- ***Pushing Data***
  - Sending TCP creates an segment and transfers immediately by setting PSH bit
  - PSH bit indicates that receiving TCP must deliver the received data segment to application program immediately

Transmission Control Protocol (TCP)

A TCP Connection Contd…

ii. TCP Data Transfer Contd…

- Data presented from application program to TCP as stream of bytes
  - Consecutive positions assigned to each byte of data
- **Exception:** Application program needs to send Urgent bytes that needs to be specially treated (With top priority)

- ***Solution: Urgent Data***
  - Send a data segment by setting the URG bit
  - Urgent data inserted at segment beginning by the sending TCP
  - End of the urgent data in segment indicated by urgent pointer field in header

Transmission Control Protocol (TCP)

A TCP Connection Contd…

ii. TCP Data Transfer Contd…

- Segment with URG bit is received by the receiving TCP
- Receiving TCP informs receiving application of the segment with URG bit

Transmission Control Protocol (TCP)

A TCP Connection Contd…

iii. TCP Connection Termination

- Connection termination initiated by the Client by default
- However, Server can also choose to close the TCP connection with client
- Options for connection termination
  - a) 3-way Handshaking
  - b) 4-way Handshaking with Half-Close Option

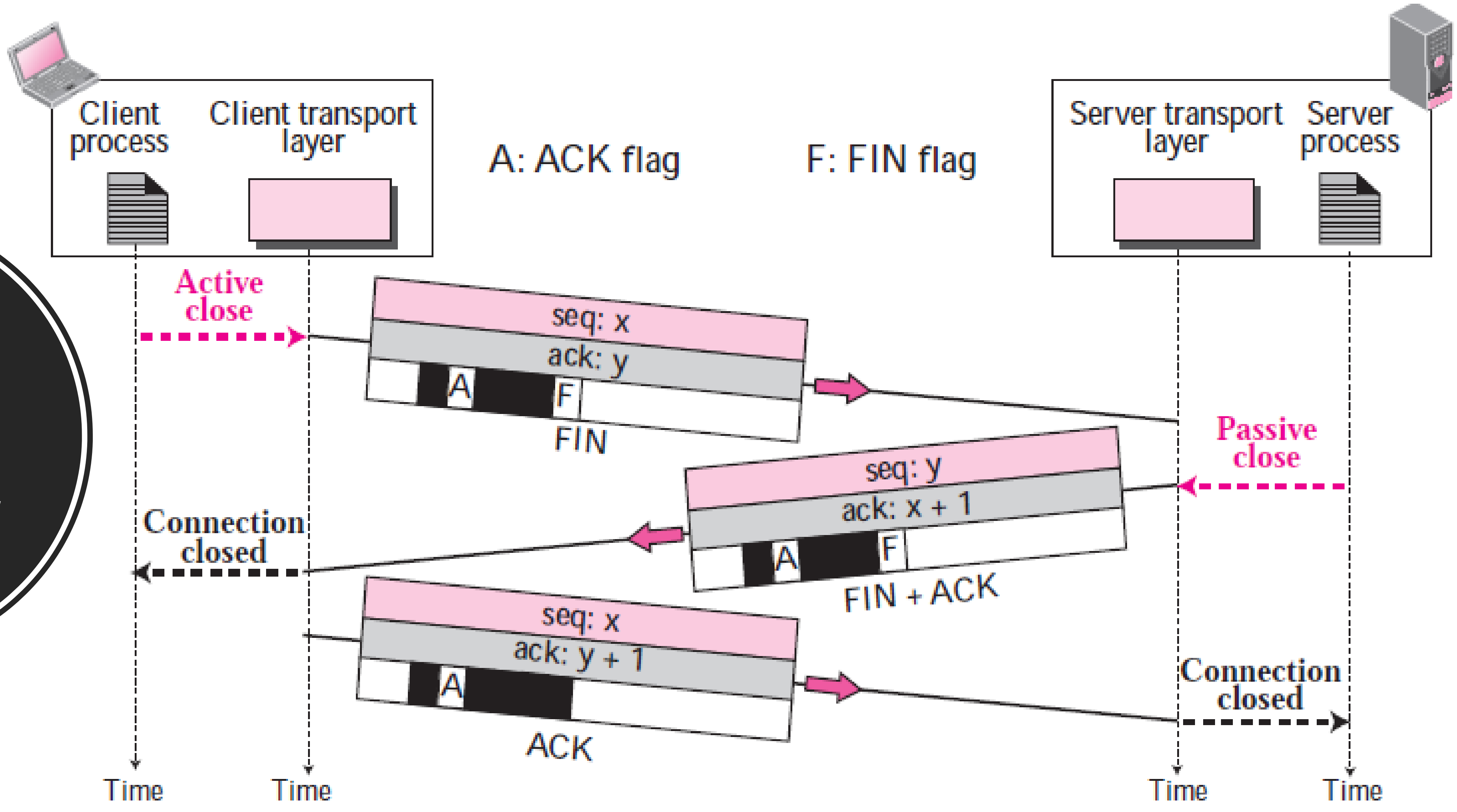
Transmission Control Protocol (TCP)

A TCP Connection Contd…

a) *Connection Termination using 3-way Handshaking*

- ***Passive Close*** – Server program informs TCP that it is ready to close connection
- ***Active Close*** – Client program intending to close connection to a Server informs TCP
- ***Step 1***
  - Client process sends close command to Client TCP
  - Client TCP sends 1st Segment (FIN) with FIN flag and ACK flag set
  - FIN Segment consumes one sequence number (if it carries no data)
  - Note: FIN segment may carry last chunk of data also

Connection Termination using 3-way Handshaking



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Transmission Control Protocol (TCP)

d) A TCP Connection Contd…

a) Connection Termination using 3-way Handshaking

- ***Step 2***
  - Server TCP sends 2nd segment (FIN + ACK) to confirm receipt of FIN segment
  - Server announces connection closing from its side
  - 2nd Segment may contain last chunk of data
- ***Step 3***
  - Client TCP sends 3rd segment (ACK) that confirms FIN receipt from Server
  - Acknowledgment number – Sequence number + 1
  - 3rd Segment cannot carry data

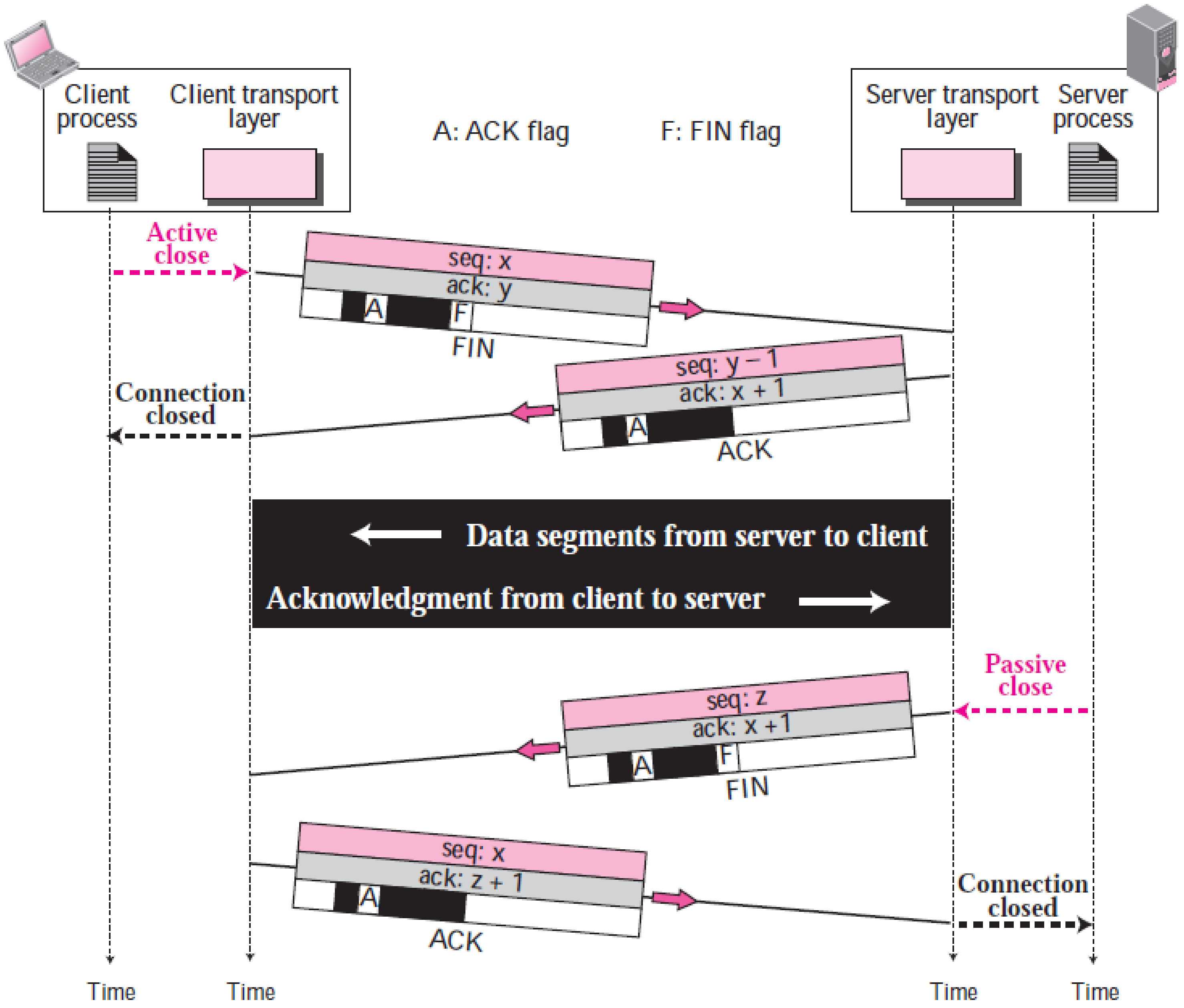
Transmission Control Protocol (TCP)

A TCP Connection Contd…

b) *Half Close Connection Termination*

- ***Half Close –*** In client / Server communication if one can stop sending data while the other can send data it is called an Half-Close
  - The Client or Server can issue a Half-Close request
- Example – Sorting
  - Client sends data for sorting to Server
    - Client closes connection in Client-Server direction
  - Server receives data from client & keeps connection open
    - Till Sorting is completed & result sent back to Client

Half-Close



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Transmission Control Protocol (TCP)

A TCP Connection Contd...

iv. TCP Connection Reset

- Reset Flag (RST) - Denies connection / Aborts connection / Terminates existing idle connection
  - ***Denying Connection***
    - Client requests to a non-extent server port
    - Server sends segment with RST flag set and denies request
  - ***Aborting Connection***
    - Client / Server TCP aborts existing connection by sending RST segment to abort connection

Transmission Control Protocol (TCP)

A TCP Connection Contd…

iv. TCP Connection Reset Contd…

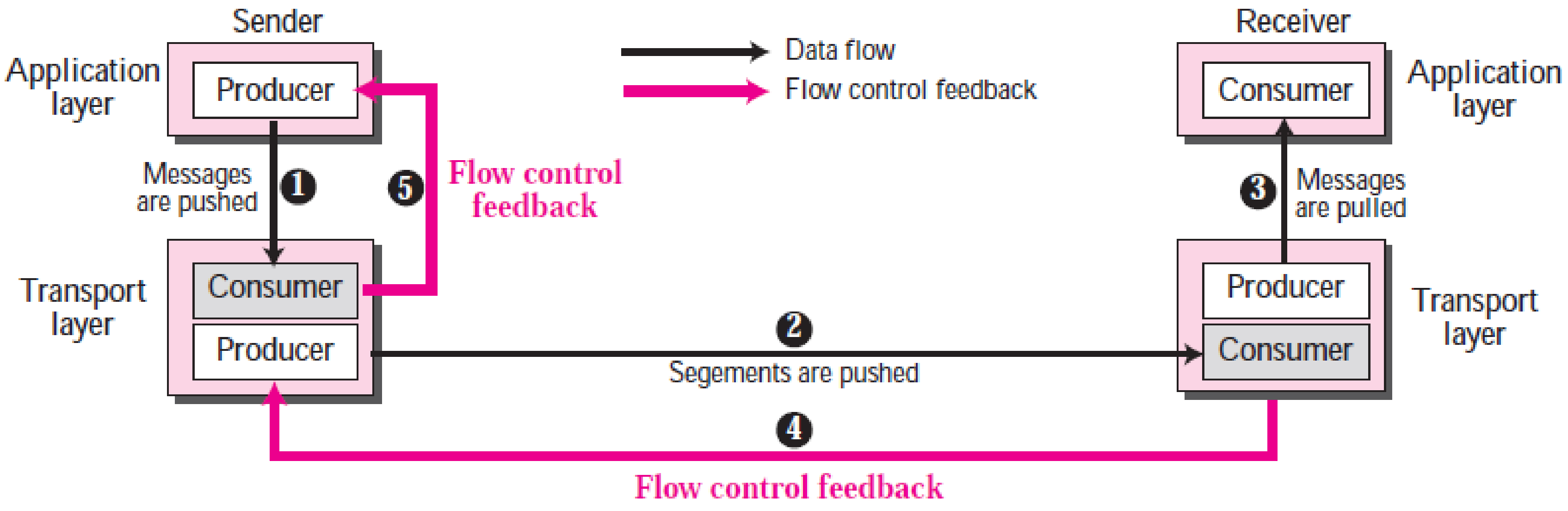
- ***Termination Idle Connection***
  - Client finds server idle or vice versa
  - Client / Server sends RST segment to terminate connection
  - Similar to abort

TCP Flow Control

Transmission Control Protocol (TCP)

TCP Flow Control

- Creates a balance between rate of data production and the rate of data consumption
- ***Assumption:*** Channel between sender & receiver is error-free



Data Flow and Flow Control Feedbacks in TCP

Source: Behrouz A. Forouzan, “TCP IP Protocol Suite ” 4th edition, 2010, McGraw-Hill ISBN: 0073376043

Transmission Control Protocol (TCP)

TCP Flow Control Contd…

1) Messages are pushed from the Sending application to TCP Client
2) Message segment from TCP Client is pushed to TCP Server
3) Messages are pulled by receiving application from TCP Server
4) Flow control feedback is sent from TCP server to TCP client
5) TCP client forwards the flow control feedback to sending application

- ***Opening and Closing Windows***
  - Buffer size of sender & receiver is fixed during connection establishment
  - Window sizes of Sender / Receiver is controlled and adjusted by TCP Server
  - Opening / Closing / Shrinking of client window is controlled by receiver

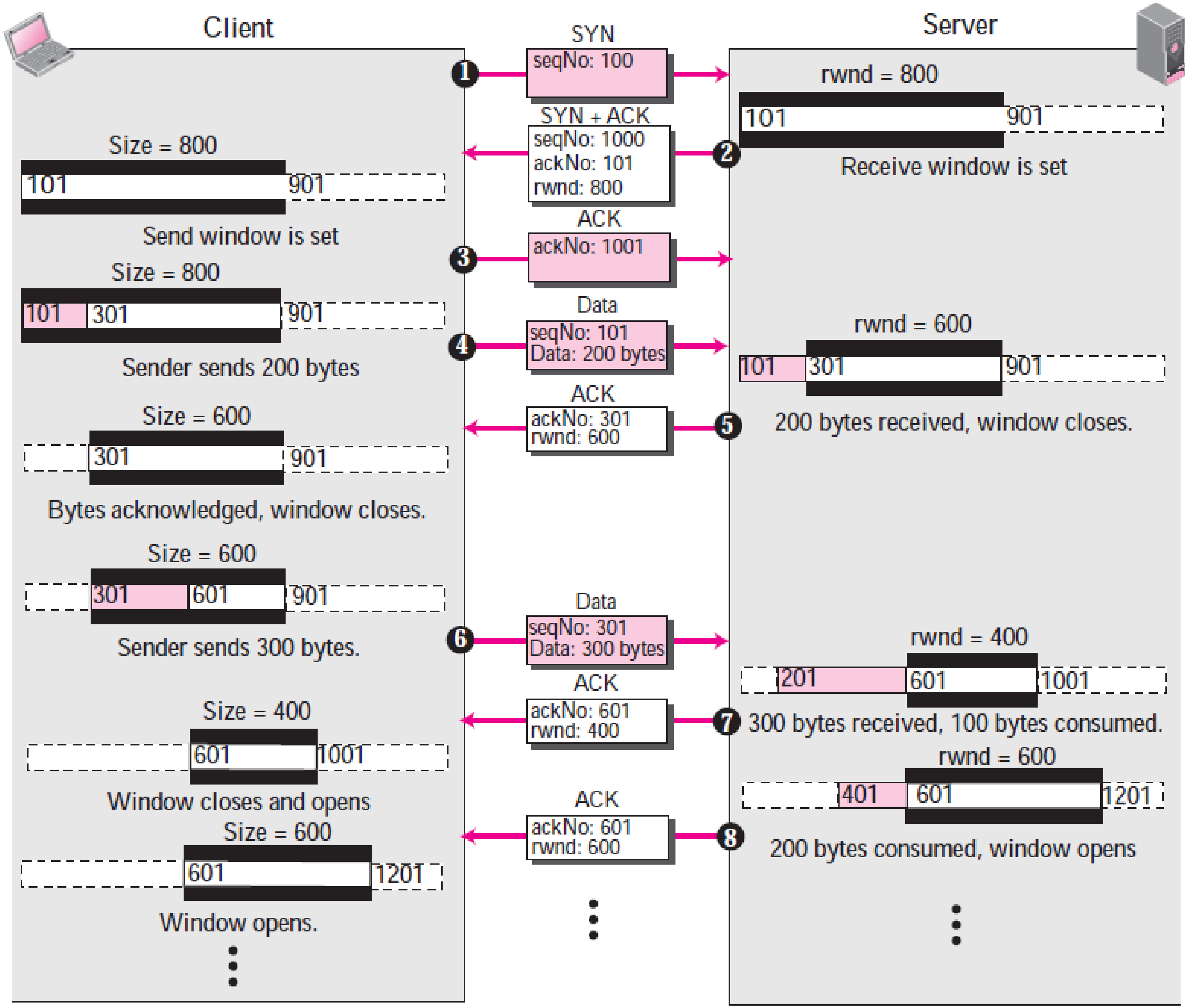
Transmission Control Protocol (TCP)

TCP Flow Control Contd…

Scenario – TCP Flow Control

- ***Segment 1***
  - Connection request – (SYN) segment from client to server
  - Initial Sequence Number (ISN): 100 (Next byte to Arrive : 101)
  - Server allots buffer size = 800 (Assumption)
  - Server allots Window size (rwnd) = 800
- ***Segment 2***
  - (ACK + SYN) segment from Server to Client
  - Set ACK no = 101 & Buffer Size = 800 bytes

Flow Control – A Scenario



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Transmission Control Protocol (TCP)

TCP Flow Control Contd…

Scenario – TCP Flow Control

- ***Segment 3***
  - ACK segment sent from client to server
- ***Segment 4***
  - Client sets window size to 800 (since rwnd from server is 800)
  - Client process pushes 200 bytes of data to TCP client
  - TCP client creates data segment with bytes (101-300) and sends to Server
  - Client window adjusted
    - Shows 200 bytes as sent but no ACK received from Server

Transmission Control Protocol (TCP)

TCP Flow Control Contd…

Scenario – TCP Flow Control

- Shows 200 bytes as sent but no ACK received from Server
- Server stores 200 bytes in buffer & closes receive window
- Server indicates the next expected byte as 301
- ***Segment 5***
  - Server acknowledges receipt of 200 bytes from client & reduces rwnd to 600
  - Client receives acknowledgement and resizes window size to 600
  - Client closes the window (101-300) from left to right
  - Client indicates the next byte to send as 301

Transmission Control Protocol (TCP)

TCP Flow Control Contd…

Scenario – TCP Flow Control

- ***Segment 6***
  - Client pushes 300 more bytes to the server (Seq. No = 301 & Data = 300 bytes)
  - Server stores 300 bytes in buffer
  - 100 bytes of data are pulled by the Client process
  - So, Window size is reduced by 100 bytes to the left & opened by 100 bytes to the right
  - Overall, TCP client window size is reduced by 200 bytes
  - Now, Receiver window size (rwnd) = 400

Transmission Control Protocol (TCP)

TCP Flow Control Contd…

Scenario – TCP Flow Control

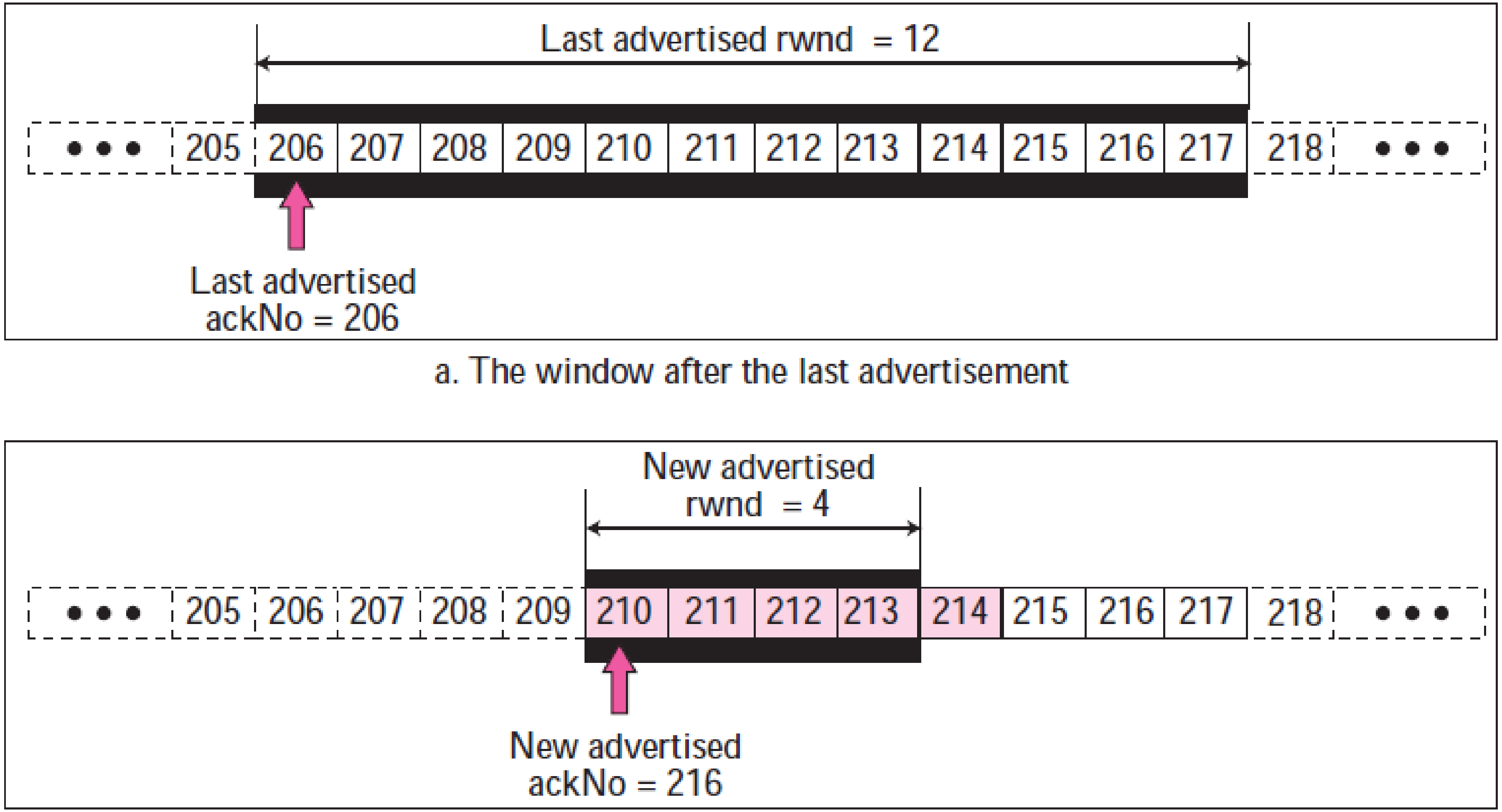
- ***Segment 7***
  - TCP Server acknowledges receipt of 300 bytes and sets window size (rwnd) = 400 & TCP Client reduces window size to 400
  - Sender windows closes by 300 bytes from the left and opens by 100 bytes to the right
- This process continues until all the data segments are sent from server to client and connection gets closed

Transmission Control Protocol (TCP)

TCP Flow Control Contd…

- ***Shrinking of Windows***
  - Shrinking : Decreasing window size i.e., right wall moves towards the left
  - Sender window may shrink based on rwnd value defined by receiver
  - Receiver window cannot shrink
  - ***Illustration***
    - Upto 205 bytes of data received and acknowledged by sender
    - Last advertised rwnd = 12 (Window size) & last advertised ACK No = 206
      - Data can be sent from byte 206 to byte 217 (Since rwnd = 12)
    - New advertised rwnd = 12 (Window size) & new advertised ACK No = 210

The window after the new advertisement; Window has shrunk



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TCP Flow Control Contd…

- ***Shrinking of Windows Contd…***
  - Shrinking of window has occurred from byte 217 to byte 213 (Window had moved from right to left
  - Shrinking can be prevented by the relation given below:

New ACK number + new rwnd > = Lask ACK Number + Last rwnd

  - To prevent shrinking,
    - Wait until enough buffer locations are available in its window

Transmission Control Protocol (TCP)

TCP Flow Control Contd…

- ***Silly Window Syndrome***
  - Occurs when either the sending process creates data slowly (or) the receiving process consumes data slowly (or) both
  - Silly window syndrome sends / receives data in small segments thus resulting in poor efficiency
  - ***Example***
    - A 42 byte TCP datagram is needed to send Segment with 2 bytes of data
    - Overhead : 42 / 2 ⇒ Network capacity used inefficiently

Transmission Control Protocol (TCP)

TCP Flow Control Contd…

- ***Silly Window Syndrome Created by Sender***
  - Sending TCP creates syndrome since sending application program creates data slowly i.e., 1 byte at an instance
  - ***Suggestions***
    - Prevent sending TCP from transmitting data byte by byte
    - Sending TCP made to wait & collect data to send data in larger block
    - ***Disadvantage:*** Waiting too long delays the process
  - ***Solution***
    - Nagle's Algorithm

Transmission Control Protocol (TCP)

TCP Flow Control Contd...

- ***Nagle's Algorithm for Silly Window Syndrome Created by Sender***

  i. First segment of data sent by sending TCP irrespective of the size of segment

  ii. Data is accumulated in buffer by sending TCP until acknowledgment is received from receiving TCP (or) enough data accumulated to send a segment

  iii. Repeat step 2 until transmission completes

- Nagle's algorithm works based on speed of application program and the network speed
  - Faster the application program larger the segment size
- ***Advantage:*** Simple to implement

Transmission Control Protocol (TCP)

TCP Flow Control Contd…

- ***Silly Window Syndrome Created by Receiver***
  - Syndrome created when serving application consumes slowly
  - ***Example***
    - 1 KB data blocks created by sending application
    - 1 byte of consumed at a time by receiving application
    - Once sending window buffer is full, window size (rwnd) becomes 0
  - ***Solution 1:*** Clarks's Solution
    - Send ACK as data segment arrives
    - Set rwnd = 0 iff receive buffer is half empty (or) there is enough space

Transmission Control Protocol (TCP)

TCP Flow Control Contd…

- ***Silly Window Syndrome Created by Receiver Contd…***
  - ***Solution 2:*** Delayed Acknowledgment
    - Acknowledgement is withheld when segment arrives
    - Receiver waits for space in incoming buffer before acknowledging
    - Delayed ACK prevents sending TCP from sliding
    - Delayed ACK reduces network traffic
    - Note: ACK not to be delayed by more than 500 ms

TCP Error Control

Transmission Control Protocol (TCP)

TCP Error Control

- TCP – Reliable Transport layer Protocol
- Entire data stream to be delivered without error / loss / duplication
- Reliability is provided by TCP using Error Control
- Error Control includes:
    - Finding and resending corrupted segments
    - Resending lost segments
    - Storing out-of-order segments till missed segments arrive
    - Discarding duplicate segments
- Error control achieved by: Checksum, Acknowledgement and Time-out

Transmission Control Protocol (TCP)

TCP Error Control Contd…

a) Checksum

- TCP uses 16-bit mandatory checksum field
- Checksum field associated with each segment
  - Checks for corrupted segment
- Invalid Checksum: Segment discarded by receiving TCP & considered lost

Transmission Control Protocol (TCP)

TCP Error Control Contd…

b) Acknowledgement

- Acknowledgement segments (ACK) carry no data & confirms data segment receipt
- Types : Cumulative and Selective Acknowledgment
- ***Cumulative Acknowledgment (ACK)***
  - 32-bit ACK field used
  - Acknowledges segments cumulatively (sets ACK flag to 1)
  - No feedback provided for discarded, lost or duplicate segments
- ***Selective Acknowledgement (SACK)***
  - Reports out of order & duplicate segments

TCP Error Control Contd…

b) Acknowledgement Contd…

- No provision for SACK in TCP header
- SACK included as part of options field in the TCP header

- ***Rules for Generating Acknowledgments***

1) When data is sent from sender to receiver, ACK provides the next Seq. No expected to be received
    - This results in less traffic and less segments between sender and receiver
2) In case of one in-order segment remaining, receiver needs to delay sending ACK segment. Network traffic is thus reduced.

Transmission Control Protocol (TCP)

TCP Error Control Contd…

b) Acknowledgement Contd…

3) At no point of time there should be more than two in-order segments unacknowledged. (Thwarts unnecessary retransmission)
4) Receiver acknowledges (ACK) an higher out-of-order sequence number immediately leading to fast retransmission of next segment
5) Receiver sends ACK when a missing segment arrives. Segments reported as missing are thus informed to the receiver
6) Receiver discards duplicate segment & sends ACK indicating the next in-order segment. Lost ACK segment problems are thus solved.

Transmission Control Protocol (TCP)

TCP Error Control Contd…

c) Retransmission of Segments

- When retransmission occurs?
  - Expiry of retransmission timer (or)
  - Sender receives more than 2 duplicate ACK's for 1st segment
- ***Retransmission after RTO***
  - One retransmission time-out (RTO) maintained by sending TCP for each connection
  - In case of time-out, timer is restarted by TCP & first segment of Queue is sent
  - This version of TCP is called ***Tahoe***

Transmission Control Protocol (TCP)

TCP Error Control Contd…

c) Retransmission of Segments Contd…

➢ ***Retransmission after 3 Duplicate Segments***

- ➢ Also called as Fast Retransmission & followed by most implementations
- ➢ TCP version called as ***Reno***
- ➢ If 3 identical duplicate ACK's along with the original ACK are received for a segment, the next segment is retransmitted
- ➢ Note: Retransmission does not wait for time-out in this case

Transmission Control Protocol (TCP)

TCP Error Control Contd…

d) Out-of-Order Segments

- Out-of-Order segments are not discarded by TCP
- TCP flags such segments as out-of-order and store them temporarily until missing segments arrive
- TCP makes sure that data segments are delivered in sequence to the process

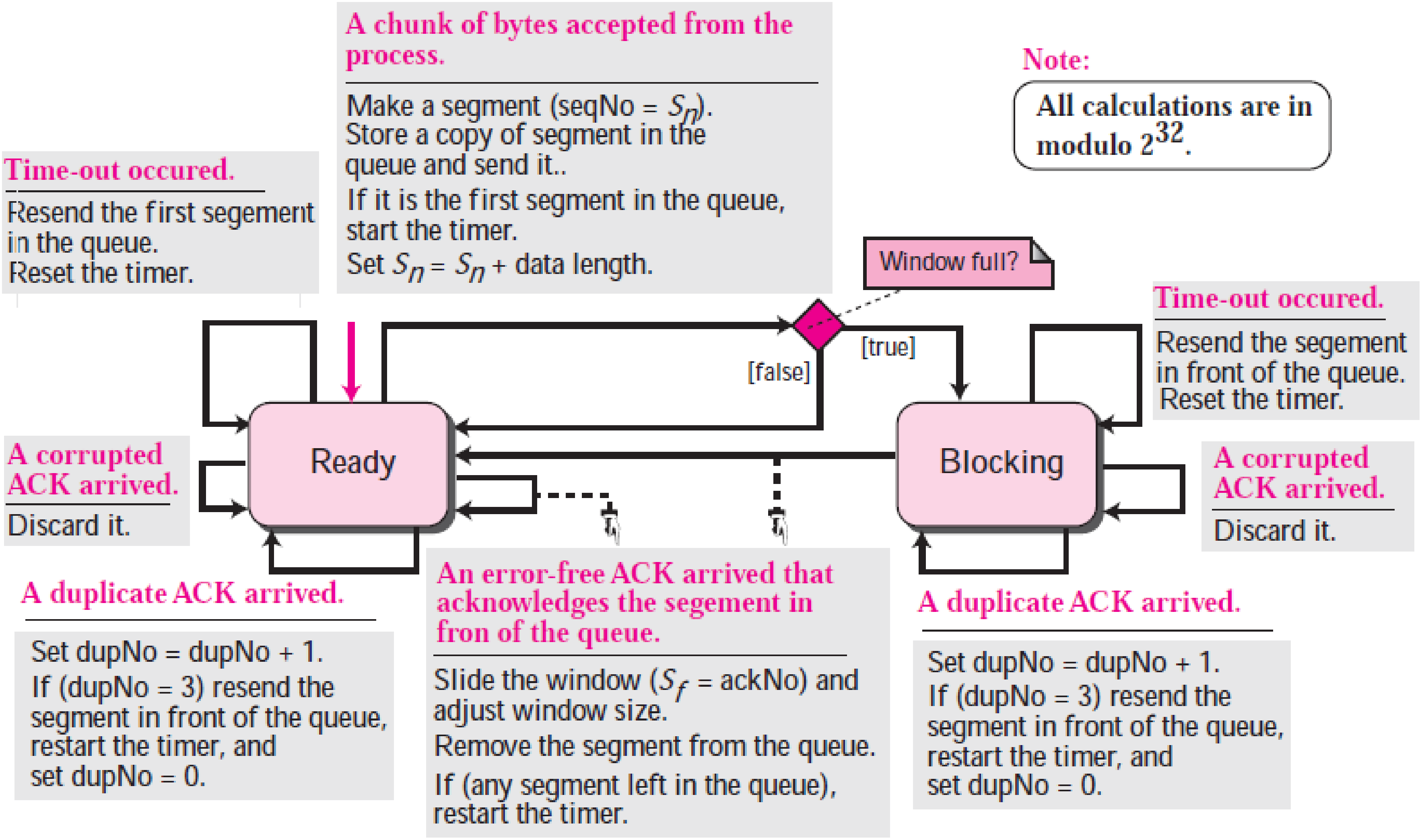
Transmission Control Protocol (TCP)

TCP Error Control Contd…

e) FSM for Data Transfer in TCP

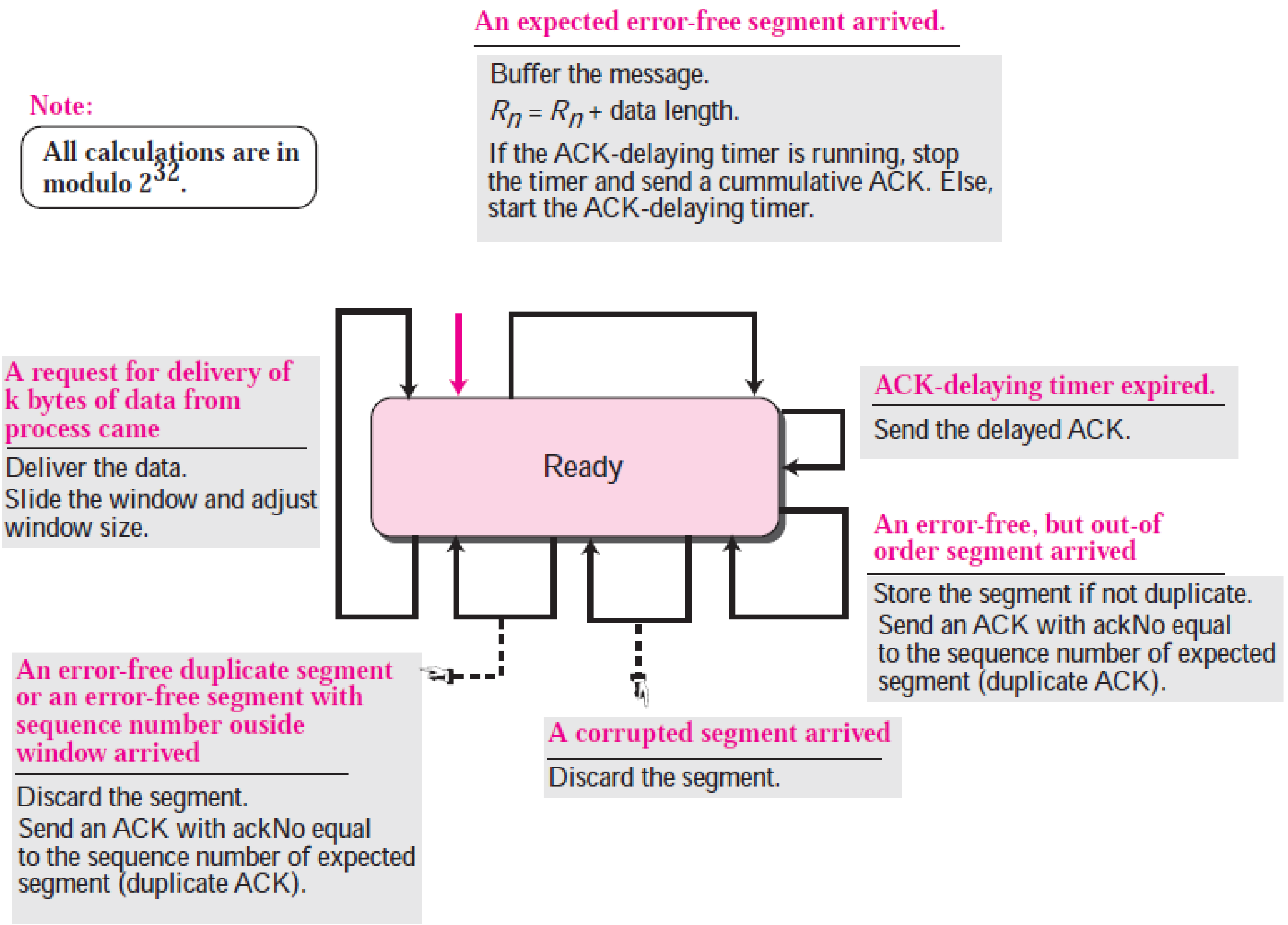
- FSM – Finite State Machine
- Similar to Selective repeat and Go Back-N protocol
- ***Sender-side & Receiver Side FSM***
  - ***Assumption :*** Unidirectional communication
  - ***Ignored Parameters:*** Selective ACK and Congestion Control
  - Nagle's algorithm / Windows shutdown not included in FSM
  - ***Advantage:*** Fast transmission policy using 3 duplicate ACK segments
  - ***Bi-directional FSM :*** Complex and more practical

Simplified FSM for TCP Sender Side



Source: Behrouz A. Forouzan, “TCP IP Protocol Suite ” 4th edition, 2010, McGraw-Hill ISBN: 0073376043

Simplified FSM for TCP Receiver Side



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TCP Congestion Control

Transmission Control Protocol (TCP)

TCP Congestion Control

- Congestion window and congestion policy handles TCP congestion

a) Congestion Window

- Client window size (rwnd) decided by the available buffer space of Server
- Ignored entity in deciding window size : Network Congestion
- Sender window size determined by,
  - rwnd (receiver advertised window size) &
  - cwnd (Congestion window size)

Actual window size = min (rwnd, cwnd)

TCP Congestion Control Contd…

TERMINOLOGIES & ABBREVIATIONS USED

- ***rwnd* –** Sender Window Size
- ***cwnd* –** Congestion Window Size
- ***ssthresh* –** Slow Start Threshold
- ***MSS* –** Maximum Segment Size
- ***ACK* –** Acknowledgement
- ***RTT* –** Round Trip Time
- ***RTO* –** Retransmission Time-out

Transmission Control Protocol (TCP)

TCP Congestion Control Contd…

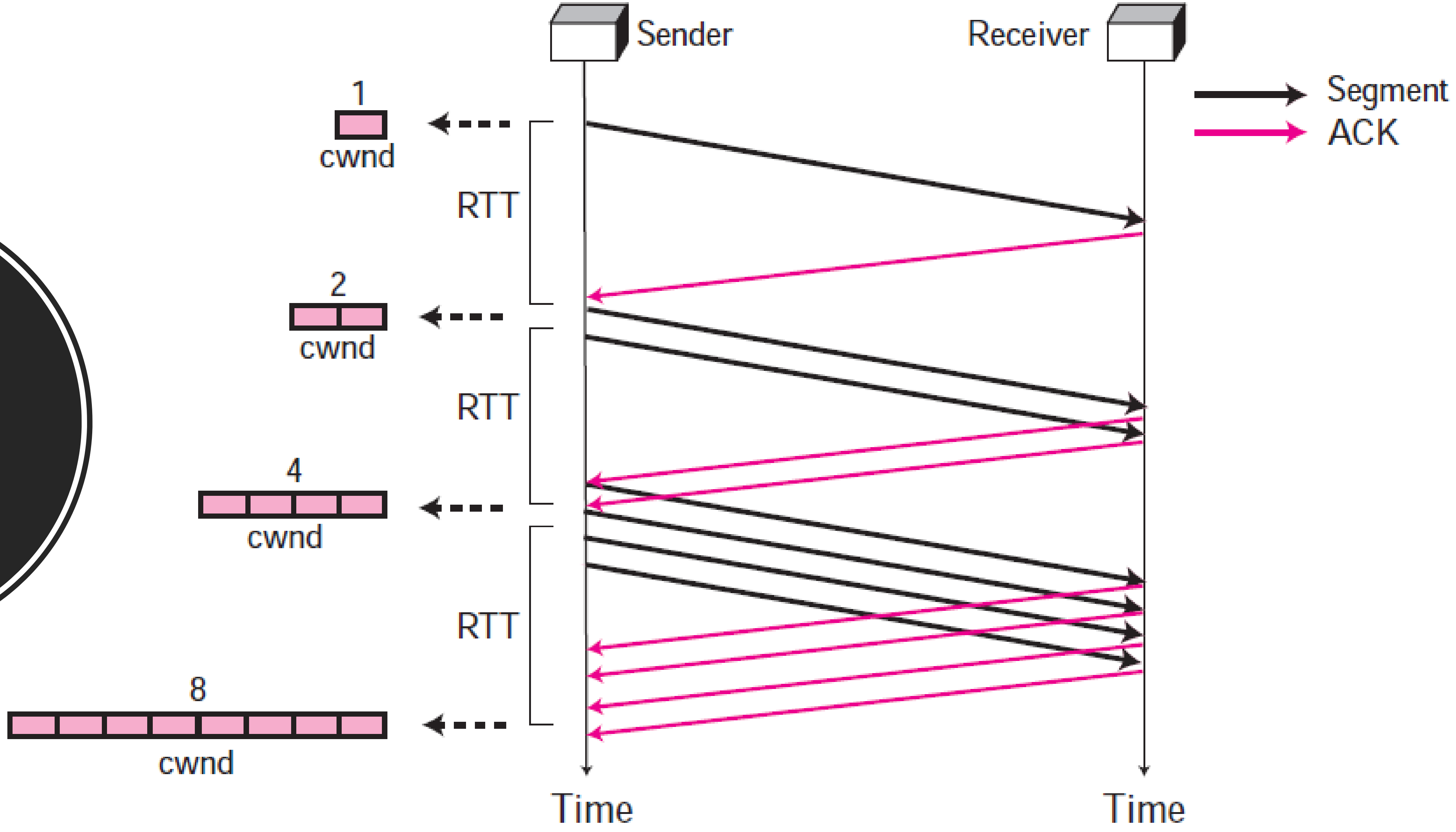
b) Congestion Policy

- Three phases : Slow Start, Congestion avoidance & Congestion detection

i. Slow Start (Exponential Increase)

  - ***Assumption:*** rwnd > cwnd
  - cwnd initialized to one Maximum window size (MSS)
  - On arrival of each ACK, cwnd increases by 1
  - Algorithm starts slowly & grows exponentially
  - Delayed ACK policy is ignored
  - ***Note:*** Consider each segment is individually acknowledged

Slow Start, Exponential Increase



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Transmission Control Protocol (TCP)

TCP Congestion Control Contd...

b) Congestion Policy

i. Slow Start (Exponential Increase) contd...

- Initial value of cwnd = 1 MSS

No of MSS sent	No of Segments Acknowledged	RTT	cwnd in MSS
Nil	Nil	-	1
1	1	1	$1 \times 2 = 2 \Rightarrow 2^1$
2	2	2	$2 \times 2 = 4 \Rightarrow 2^2$
4	4	3	$4 \times 2 = 8 \Rightarrow 2^3$
8	8	4	$8 \times 2 = 16 \Rightarrow 2^4$

Transmission Control Protocol (TCP)

TCP Congestion Control Contd…

b) Congestion Policy

i. Slow Start (Exponential Increase) contd…

- For Delayed Acknowledgements
  - If multiple segments are acknowledged accumulatively, cwnd increases by 1
  - ***Example:*** if ACK = 4 them cwnd = 1
  - Growth is exponential but not to the power of 2
  - Slow start stops with a threshold value ***ssthresh***
    - It stops when ***window size = = ssthresh***

Transmission Control Protocol (TCP)

TCP Congestion Control Contd…

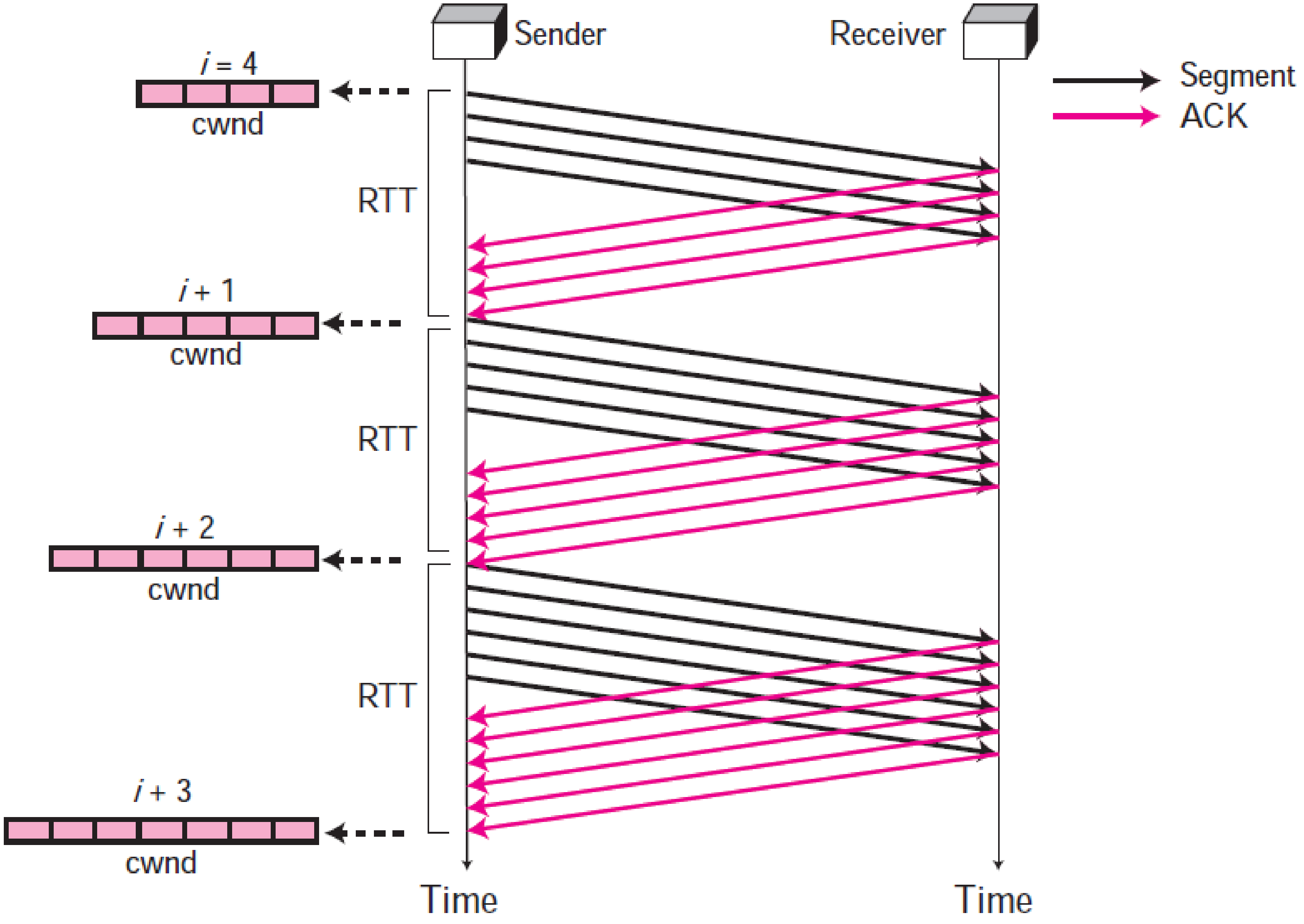
b) Congestion Policy

ii. Congestion Avoidance : Additive Increase

- Slow start increases congestion window size (cwnd) exponentially
- Congestion avoidance increases cwnd additively
- Additive phase begins when slow start reaches ssthresh i.e. cwnd = I
- Increase in cwnd is based on RTT & not on number of ACK's

RTT	cwnd in MSS
1	i
2	i + 1

Congestive avoidance, Additive Increase



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Transmission Control Protocol (TCP)

TCP Congestion Control Contd…

b) Congestion Policy

iii. Congestion Detection : Multiplicative Decrease

- Size of Cwnd must be decreased in case of congestion
- Retransmission occurs during missing segments / lost segments
- Retransmission helps identify whether congestion has occurred or not
- Retransmission occurs when
  - There is RTO Time-out
  - On receipt of three duplicate ACK’s
- Note: In both cases, ssthresh is reduced by half (Multiplicative decrease)

TCP Congestion Control Contd…

b) Congestion Policy

iii. Congestion Detection : Multiplicative Decrease Contd…

a) Time-out increases possibility of congestion. TCP reacts as follows:

- Ssthresh set to half the value of rwnd
- Cwnd initialized to 1
- Slow start phase is initiated again

b) Three duplicate ACK's indicates a weaker possibility of Congestion. Also called as fast transmission & fast recovery. TCP reacts as follows:

- Ssthresh set to half the value of rwnd

Transmission Control Protocol (TCP)

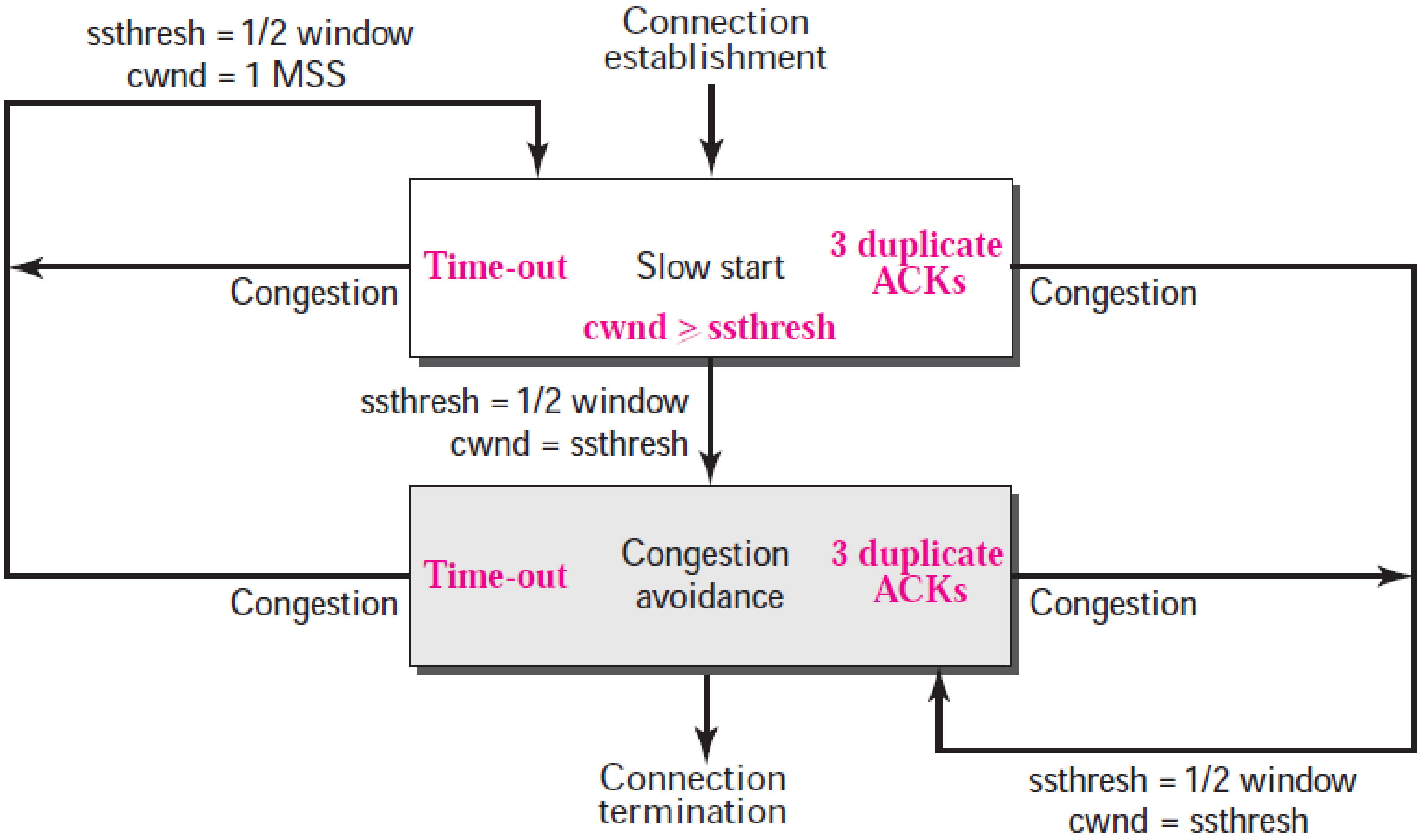
TCP Congestion Control Contd…

b) Congestion Policy

iii. Congestion Detection : Multiplicative Decrease Contd…

- Cwnd = ssthresh
- Congestion avoidance phase is initiated again

TCP Congestion Policy : A Summary



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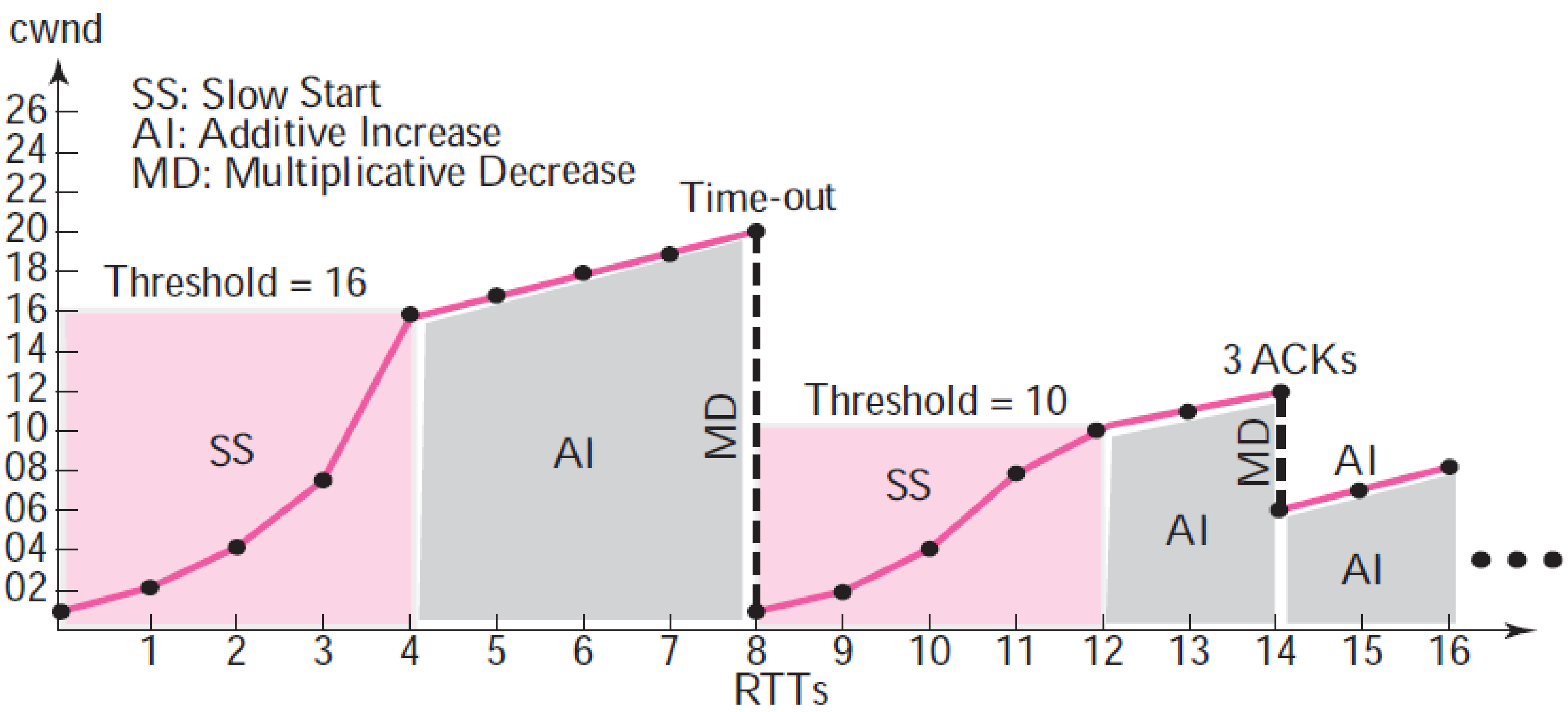
Transmission Control Protocol (TCP)

TCP Congestion Control Contd…

Summarization with Example

- Assumptions
  - Maximum window Size (MSS) = 32
  - Threshold (ssthresh) = 16
- TCP moves to slow start
  - rwnd starts from 1 and and grows exponentially till it reaches ssthresh (16)
- Additive increase increases rwnd from 16 to 20 (one by one)
  - When rwnd = 20, time-out occurs
- Multiplicative Decrease: ssthresh reduced to 10 (half the window size)

Congestion Example



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Transmission Control Protocol (TCP)

TCP Congestion Control Contd…

Summarization with Example Contd…

- New ssthresh = 10
- TCP moves to Slow start again
  - rwnd starts from 1 and and grows exponentially till it reaches new ssthresh (10)
- Additive increase increases rwnd from 10 to 12 (one by one)
- 2 duplicate ACK’s are received by the sender
- Multiplicative Decrease: ssthresh reduced to 6 (half the window size)