Networking and Future Internet

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Contents

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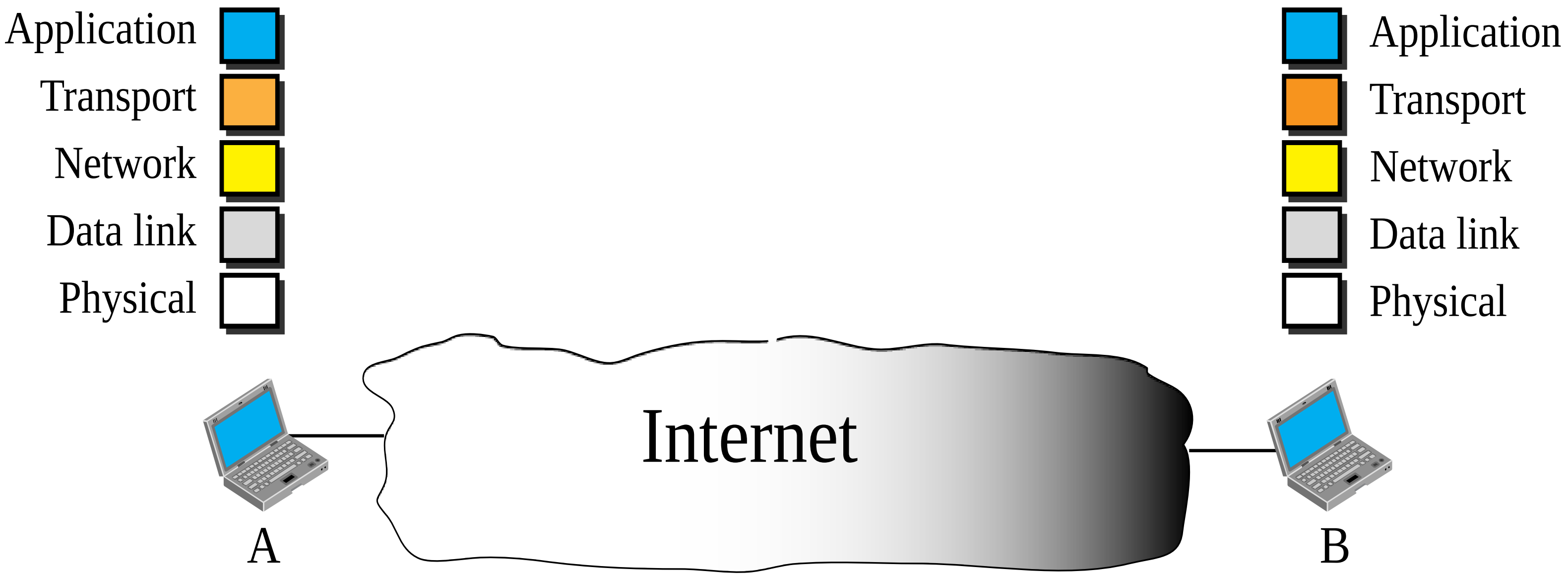
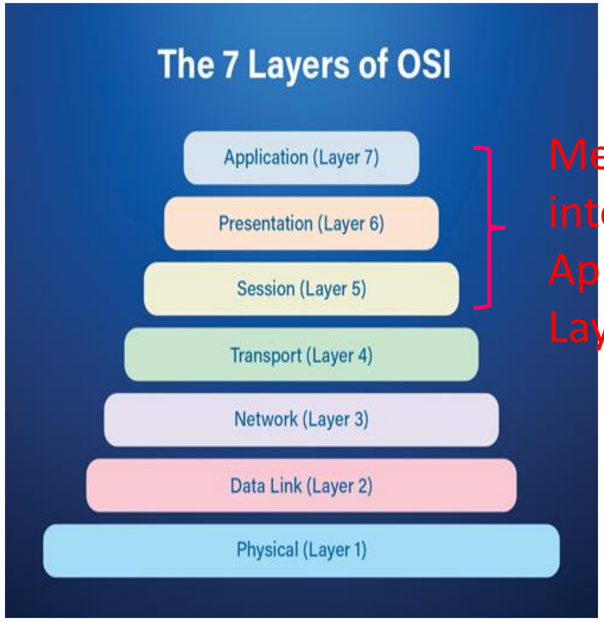
1. Networking AND Network Layer

- At the conceptual level, we can think of the global Internet as a black box network that connects millions of computers

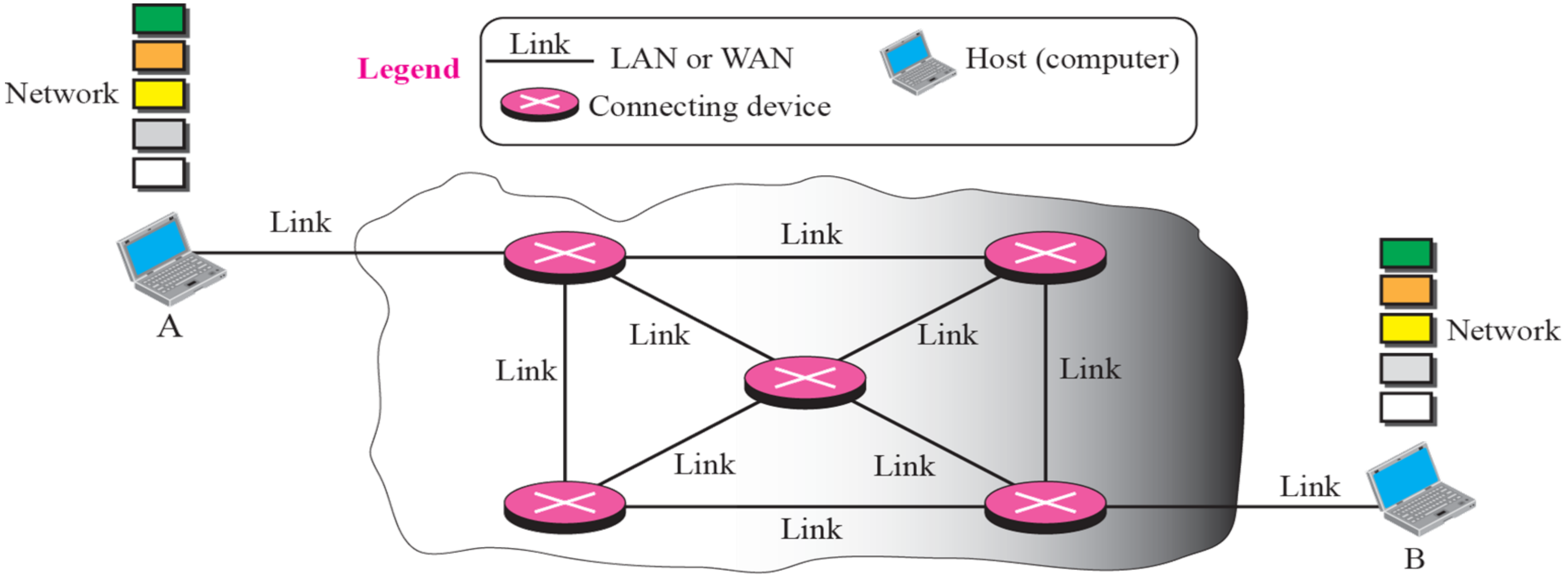




Merged into Application Layer

Internet as a combination of LAN and WANs

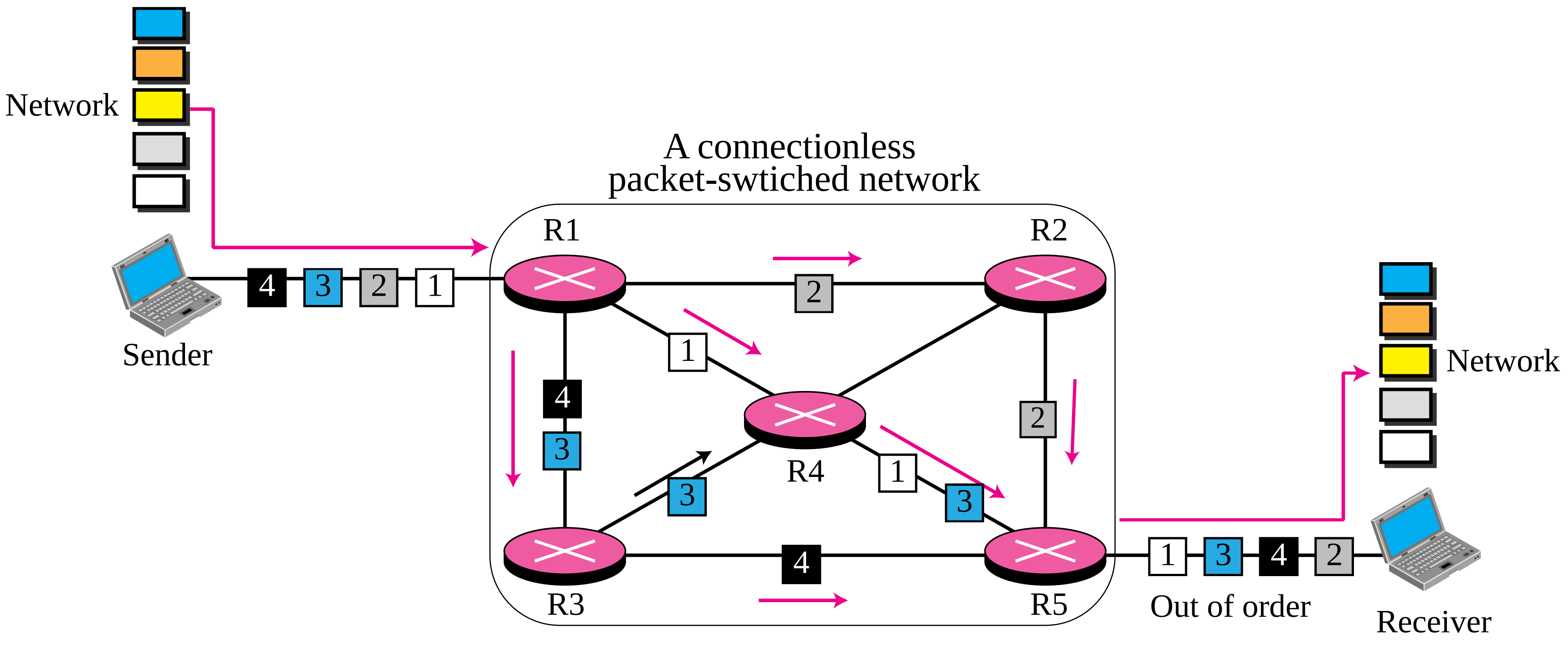
- Internet is made of many networks (or links) connected together through the connecting device
- Internet is an internetwork, a combination of LANs and WANs



An internet as a combination of links and connecting devices

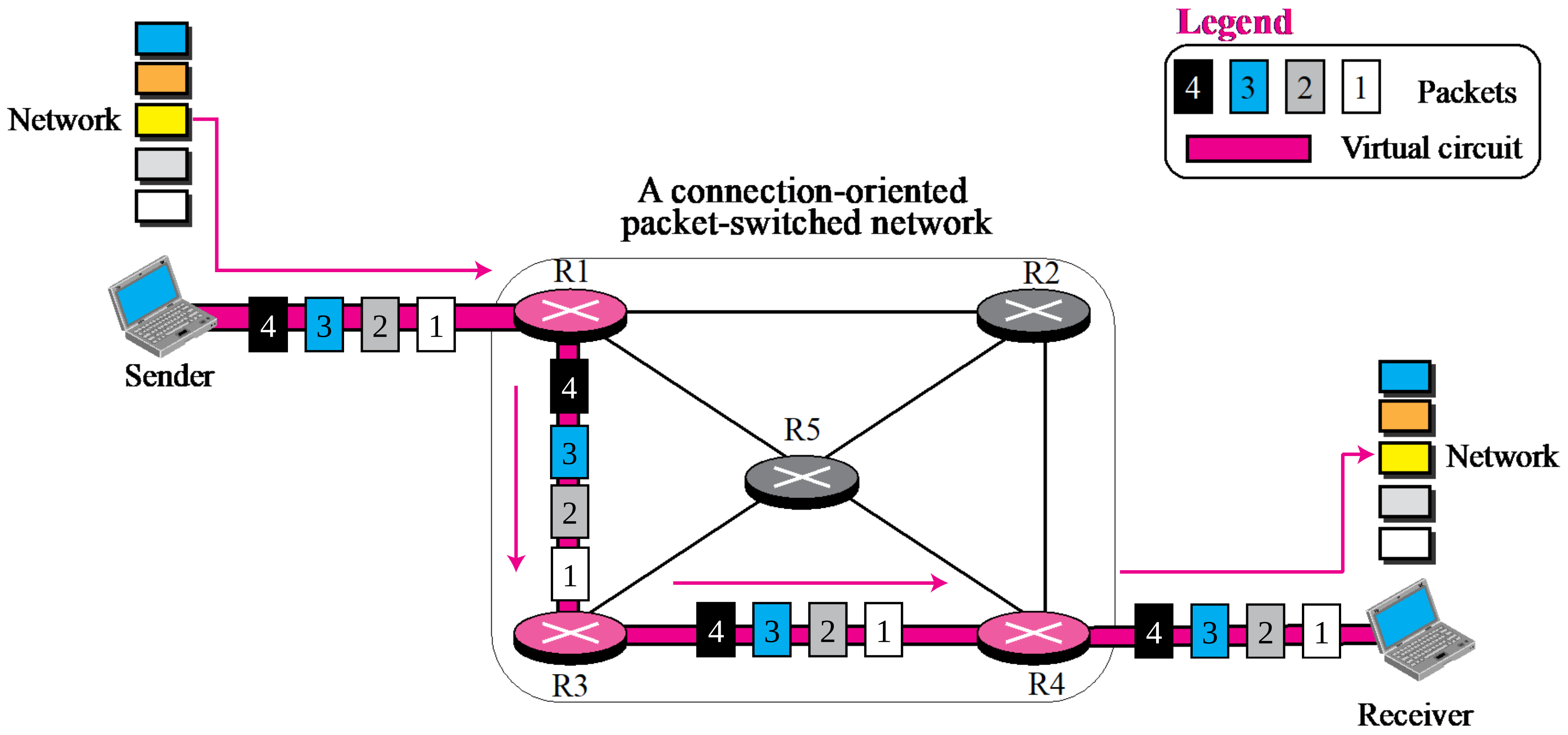
Connectionless Packet-Switched Network

- Each packet is routed based on the information contained in its header
  - There is no relationship between packets
- The switches in this type of network are called as a *routers*



Connection-Oriented Packet Switched Network

- Each packet is forwarded through virtual path



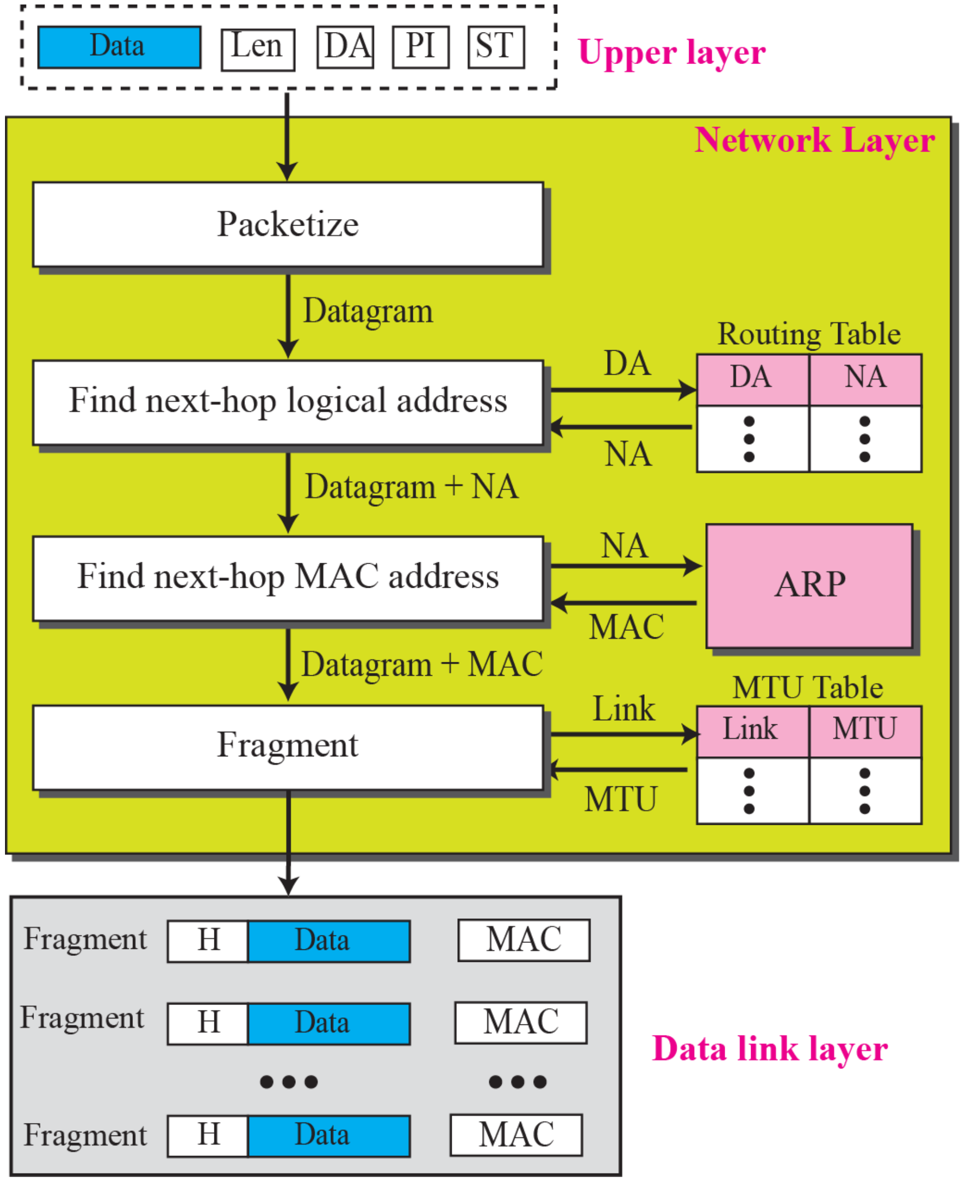
3 Phases of Connection-Oriented Service

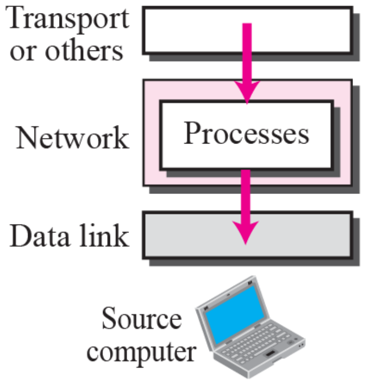
- Setup Phase
  - A router creates an entry for virtual circuit
  - A request packet carries the source and destination address
  - An acknowledgement packet completes the entries in the switching tables
- Data Transfer Phase : the network-layer packets belonging to one message can be sent one after another
- Teardown Phase
  - After sending all packets to destination, source sends a special packet called a *teardown*
  - A destination responds with a *confirmation*
  - All routers delete the corresponding entry from their tables

Service Provided at the Source Computer

- Packetizing
  - Encapsulate the data coming from the upper layer in a datagram
- Finding Logical Address of Next Hop
  - Consult a routing table to find the logical address of the next hop
- Finding MAC Address of Next Hop
  - Using ARP(Address Resolution Protocol)
- Fragmentation
  - When the datagram is bigger then MTU(Maximum Transmission Unit) datagram needs to be fragmented to smaller units before being passed to the data link layer

Services Provided at the Source Computer





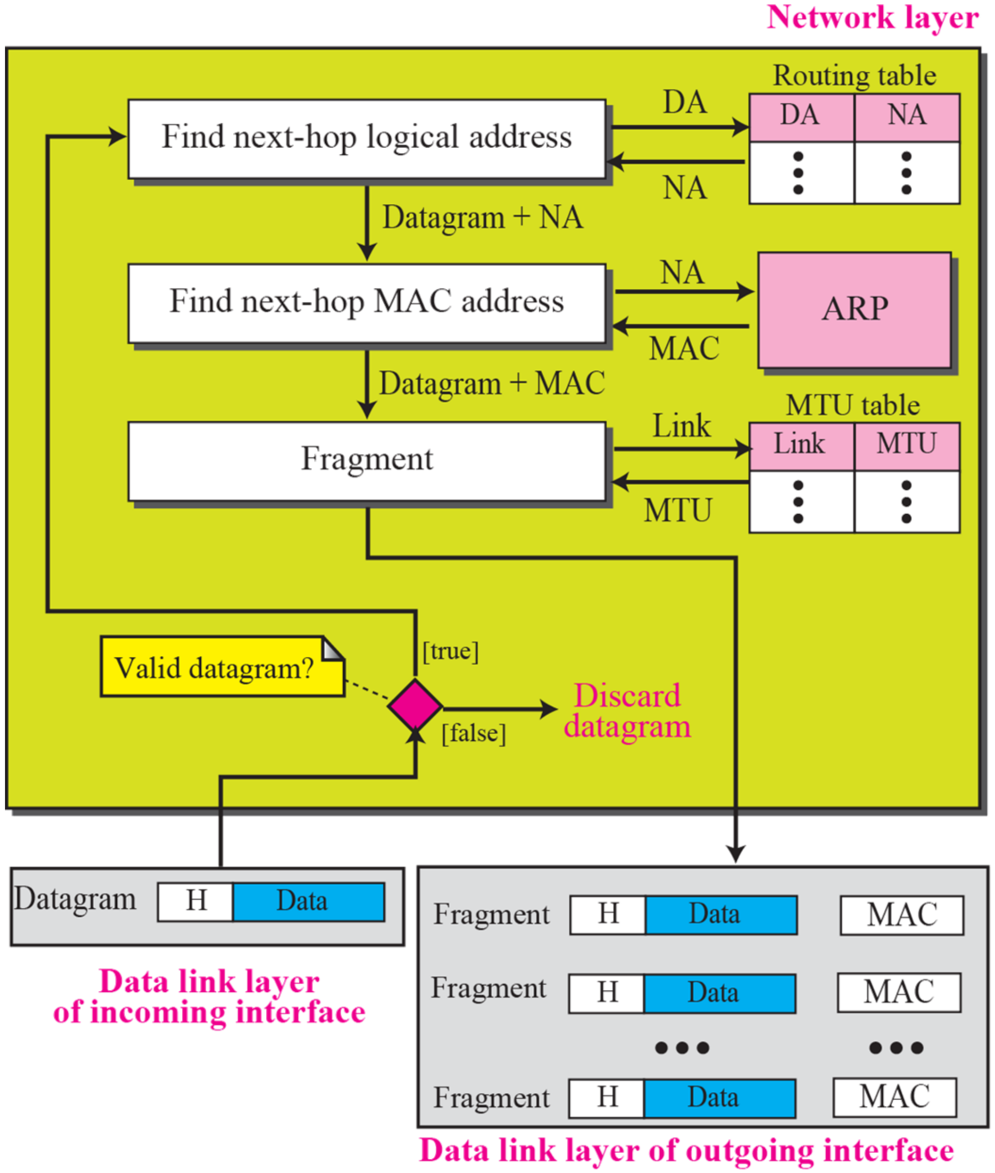
Legend

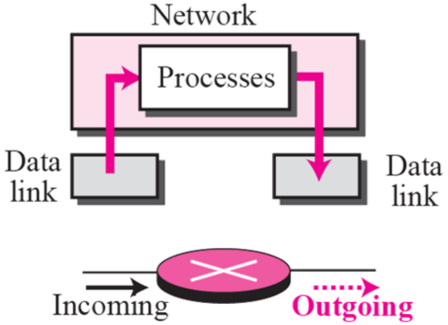
Data	Upper layer data
DA	Destination logical address
SA	Source logical address
PI	Protocol ID
ST	Service type
NA	Next-hop logical address
MAC	Next-hop MAC address
MTU	Maximum Transfer Unit
H	Datagram header
Len	Length of data

Services Provided at Each Router

- A router is involved with two interfaces (the incoming interface and the outgoing interface)
- Finding next-hop logical address
- Finding next-hop MAC address
- Fragmentation

Processing at Each Router





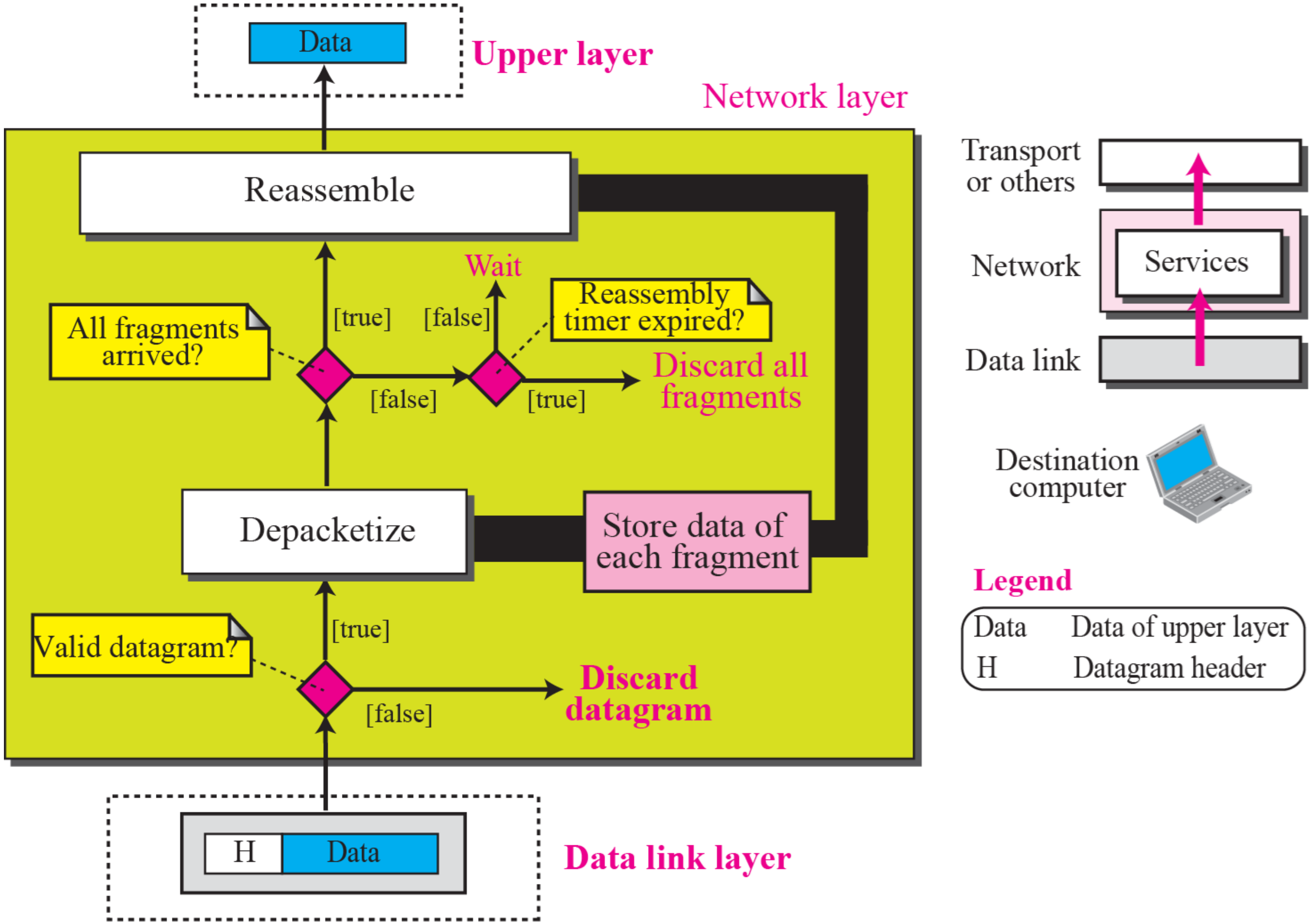
Legend

Data	Upper layer data
DA	Destination logical address
NA	Next-hop logical address
MAC	Next-hop MAC address
MTU	Maximum Transfer Unit
H	Datagram header

Services Provided at the Destination Computer

- Reassemble the fragment (Validating each datagram)
- Deliver the data to upper layer
- Set a reassembly timer, if the timer is expired, all data fragments are destroyed and an error message is sent that all the fragmented datagram need to be resent

Processing at the Destination Computer



Note

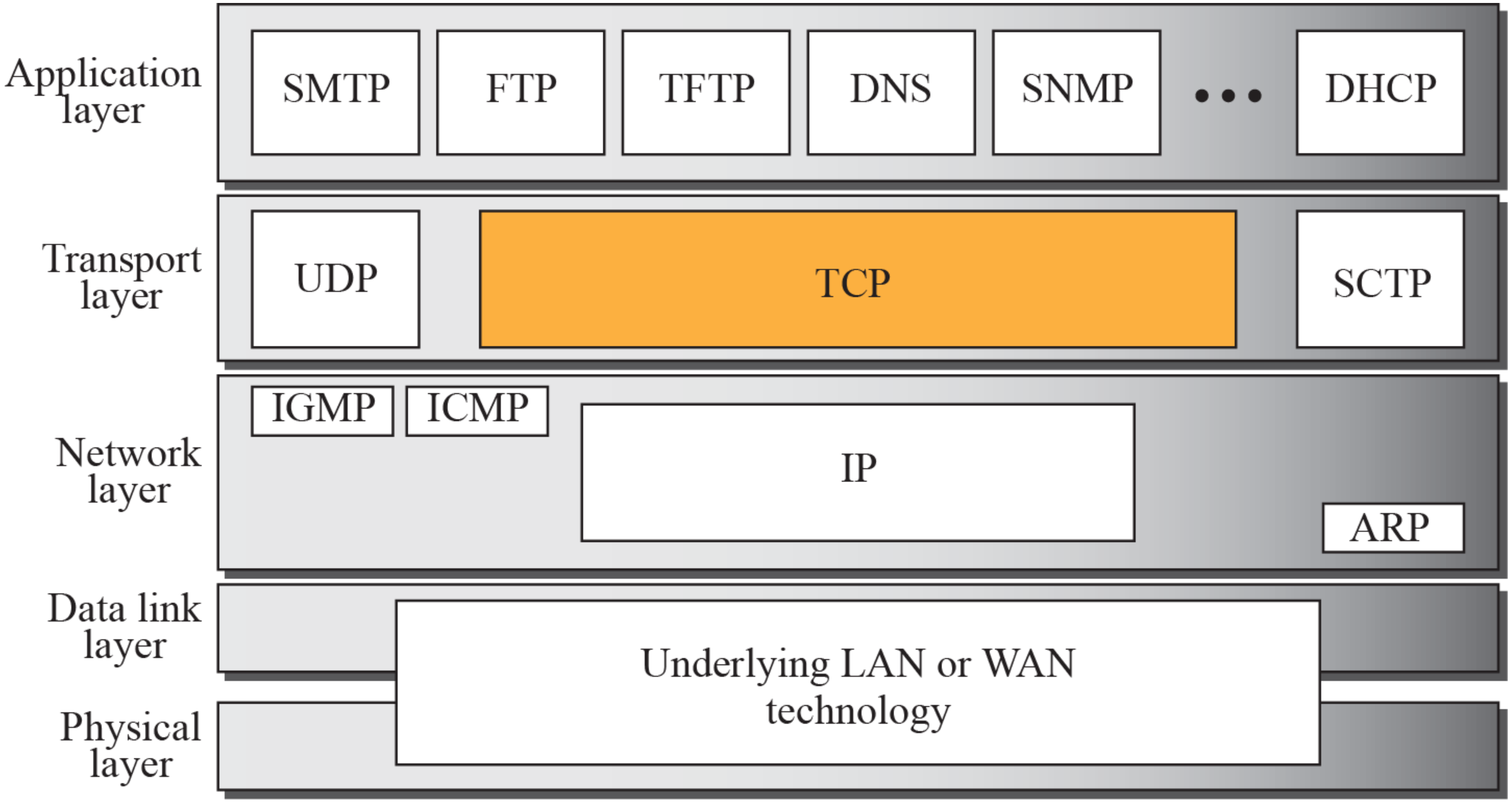
No flow control is provided for the current version of Internet network layer

Summary for Networking and Network

- At the conceptual level. We can think of the global Internet as a black box network.
- The Internet, however, is not one single network; it is made of many networks (or links) connected together through the connecting devices.
- The network layer is designed as a packet-switched network. Packet-switched network can provide either a connectionless service or a connection-oriented service.
- When the network layer provides a connectionless service, each packet traveling in the Internet is an independent entity;
- In a connection-oriented service, there is a virtual connection between all packets belonging to a message.
- In a connectionless service, the packets are forwarded to the next hop using the destination address in the packet. In a connection-oriented service, the packets are forwarded to the next hop using a label in the packet.
- In a connection-oriented network, communication occurs in three phases: setup, data transfer, and teardown. After connection setup, a virtual circuit is established between the sender and the receiver in which all packets belonging to the same message are sent through that circuit.
- We discussed existing services at the network layer in the Internet including addressing, services provided at the source computer, services provided at the destination computer, and services provided at the each router.
- We also discussed some issues related to the network layer, services that are normally discussed for the network layer, but they are either partially implemented at the network layer or not implemented at all. Some of these services, such as routing and security are provided by other protocols in the Internet.

2. TCP

- TCP/IP protocol suite



- Stream Data Service (stream transport layer service)
  - The sending TCP

    1) accepts a stream of characters from sending application program

    2) creates packets called *segments*, of appropriate size extracted from the stream

    3) sends segments across the network

  - The receiving TCP

    1) receives segments, extracts data from segments

    2) orders segments if they have arrived out of order

    3) delivers segments as a stream of characters to the receiving application program

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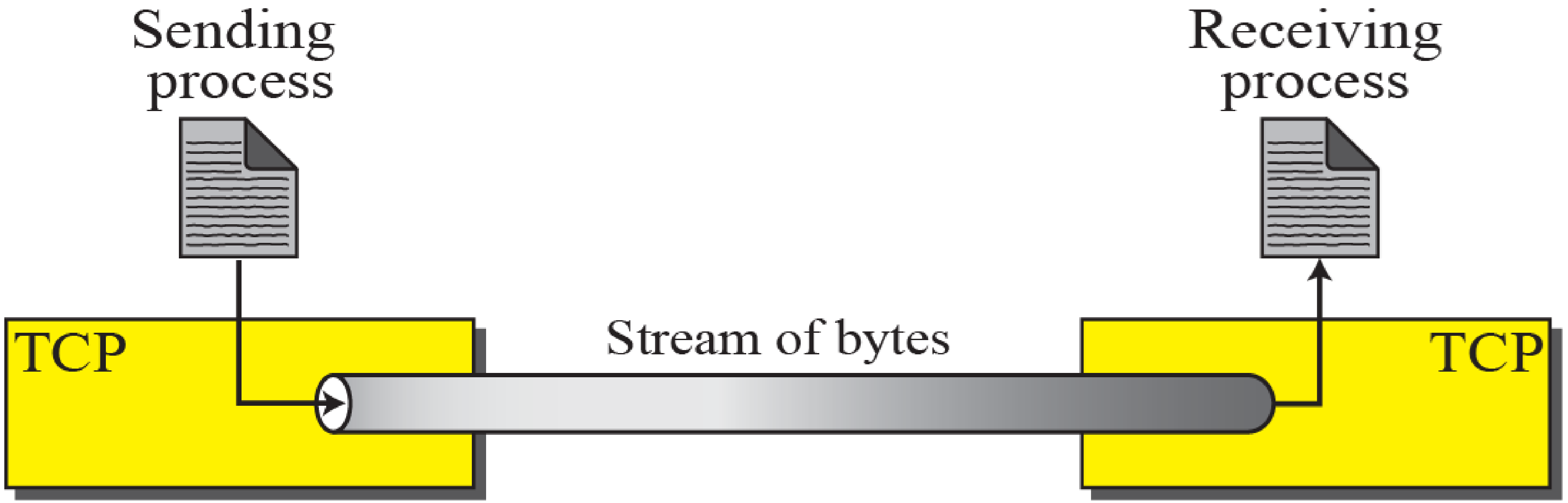
Stream Delivery (cont'd)



Sending and receiving buffers

- For stream delivery,
  - the sending and receiving TCPs use buffers
    - the sending TCP uses sending buffer to store the data coming from the sending application program.
      - the sending application program *writes* data to the buffer of the sending TCP
    - the receiving TCP receives the segments and stores them in a receiving buffer
      - the receiving application program uses the read operation to read the data from the receiving buffer.
      - Since the rate of reading can be slower than the rate of receiving, the data is kept in the buffer until the receiving application reads it completely.

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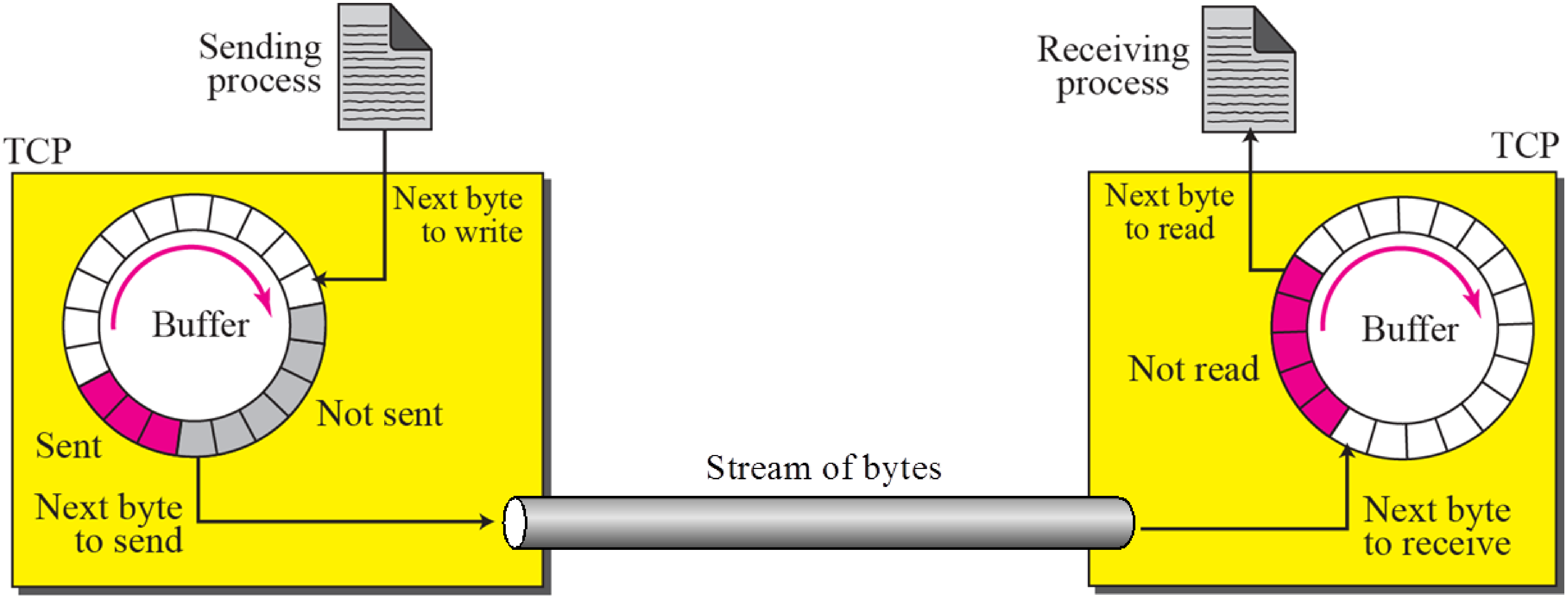
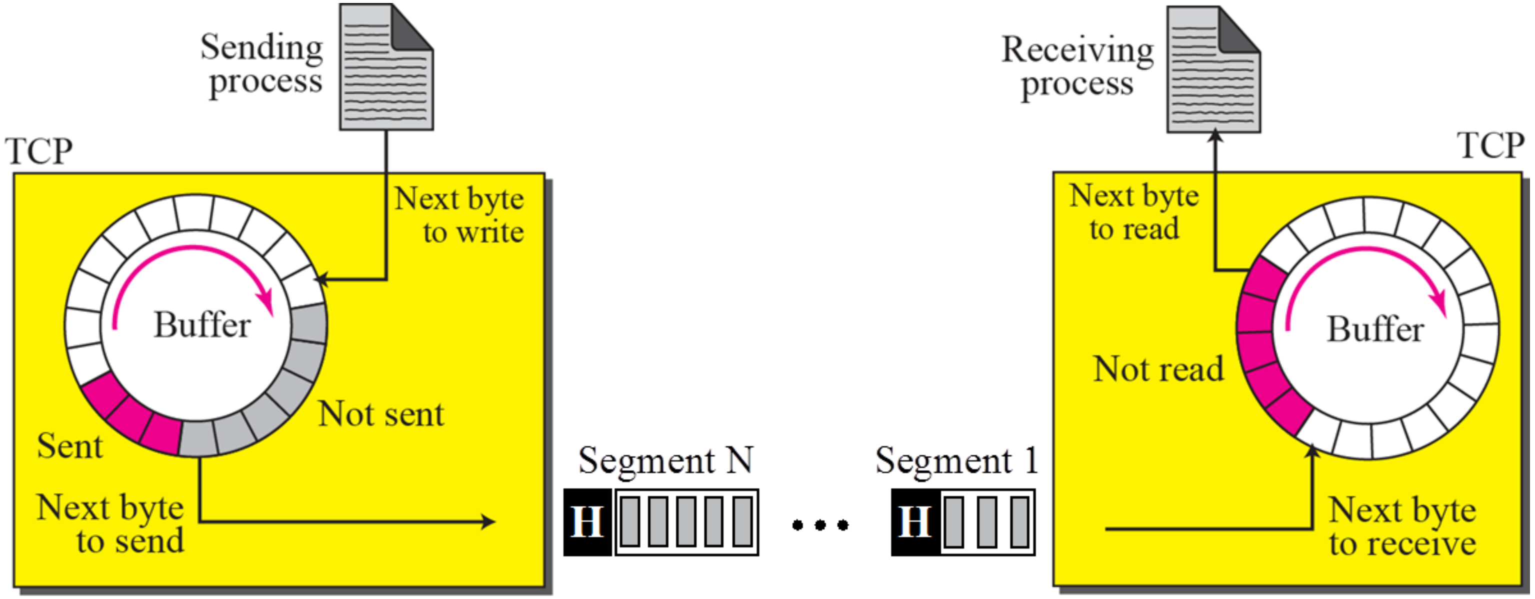
Sending and receiving buffers (cont'd)



Segments

- The IP layer, as a service provider for TCP, needs to send data in packets, not as a stream of bytes
- At the transport layer, TCP groups a number of bytes together into a packet called a segment.
  - TCP adds a header to each segment and delivers the segment to the IP layer for transmission

TCP Segments



TCP Features

- Numbering System
- Flow Control
- Error Control
- Congestion Control

Numbering System

- Byte numbers
  - All data bytes being transferred in each connection are numbered by TCP.
  - The numbering starts with a randomly generated number.
  - Number range for first byte : $0 \sim 2^{32} - 1$
    - If random number is 1,057 and total number 6,000bytes, the bytes are numbered from 1,057 to 7,056
  - Byte numbering is used for flow and error control

Numbering System (cont'd)

- Sequence number
  - After the bytes have been numbered, TCP assigns a sequence number to each segment that is being sent.
  - Sequence number for each segment is number of the first byte carried in that segment.

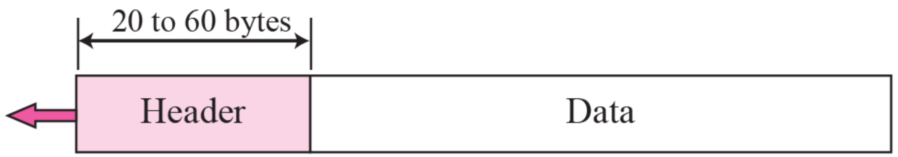
Suppose a TCP connection is transferring a file of 5,000 bytes. The first byte is numbered 10,001. What are the sequence numbers for each segment if data are sent in five segments, each carrying 1,000 bytes?

Solution

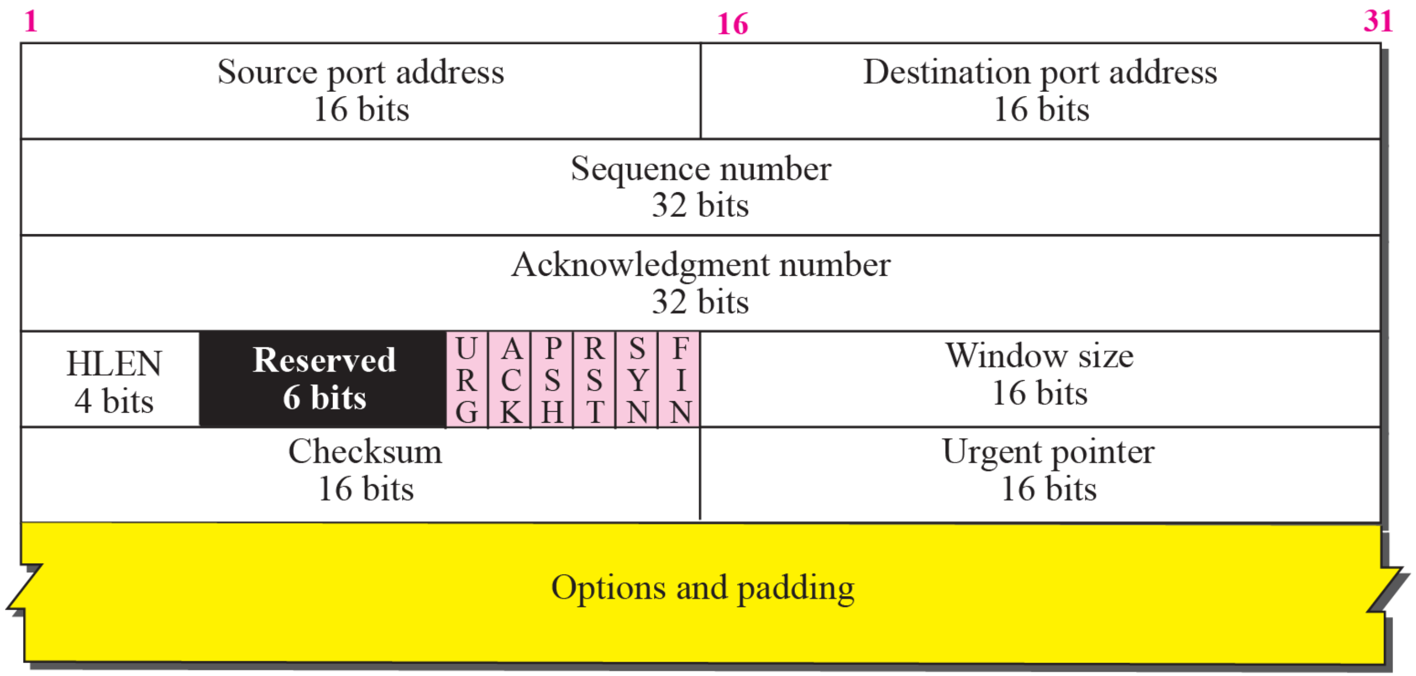
The following shows the sequence number for each segment:

Segment 1	→	Sequence Number:	10,001	Range:	10,001	to	11,000
Segment 2	→	Sequence Number:	11,001	Range:	11,001	to	12,000
Segment 3	→	Sequence Number:	12,001	Range:	12,001	to	13,000
Segment 4	→	Sequence Number:	13,001	Range:	13,001	to	14,000
Segment 5	→	Sequence Number:	14,001	Range:	14,001	to	15,000

- TCP Segment Format



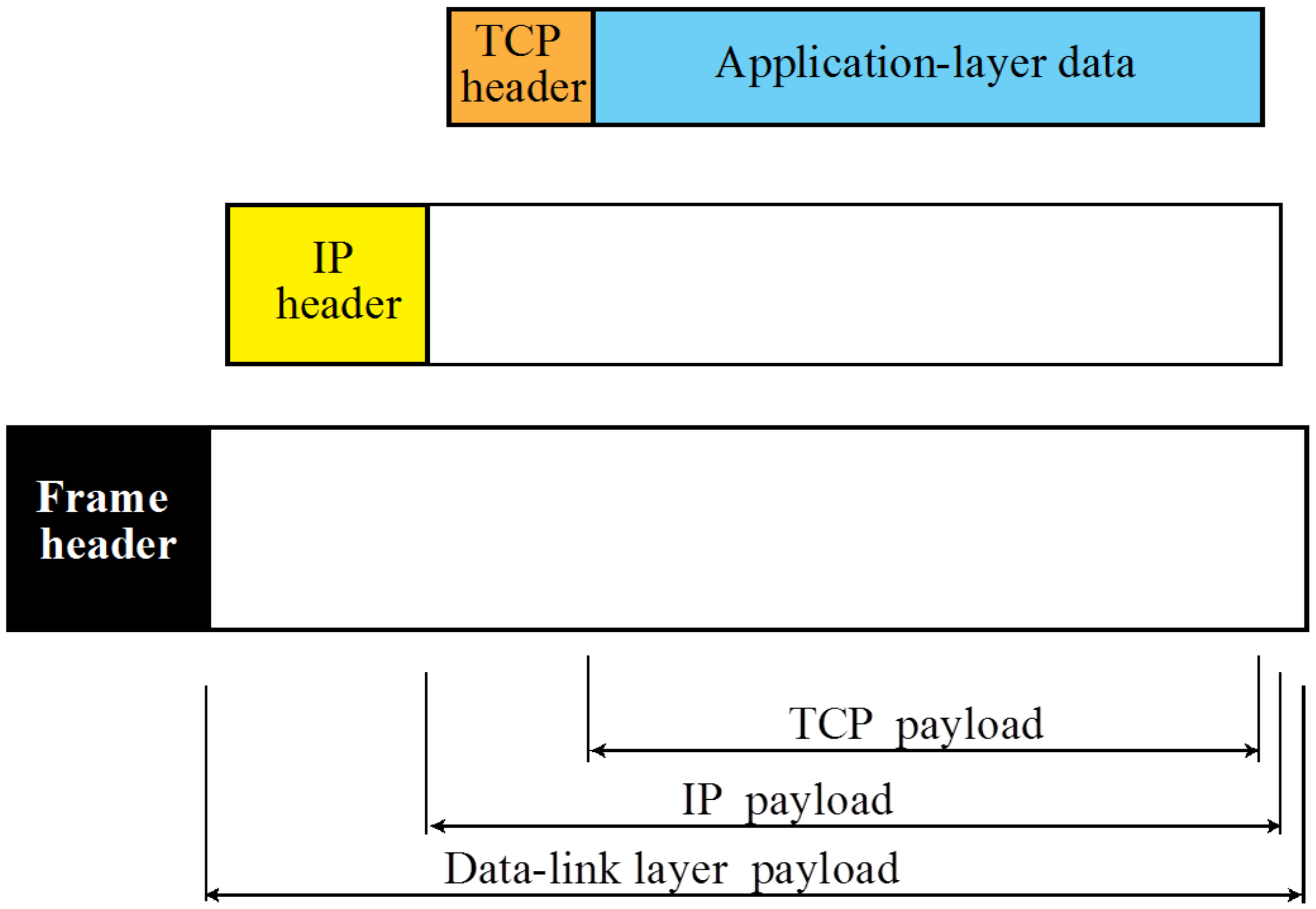
a. Segment



b. Header

Encapsulation

- A TCP segments is encapsulated in an IP datagram



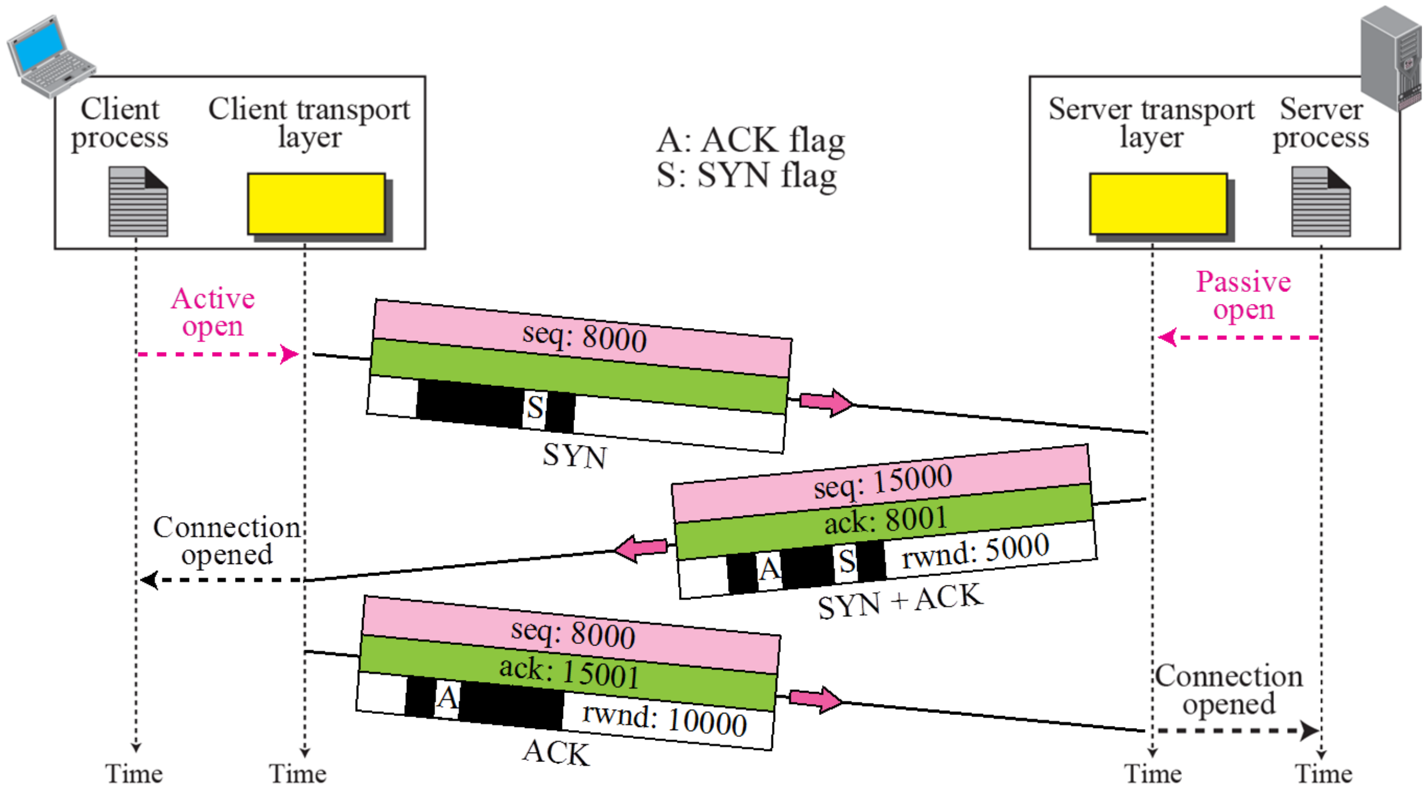
A TCP Connection

- TCP is connection-oriented
  - Establishes a virtual path between the source and destination
  - TCP connection is virtual, not physical
- TCP uses the services of IP to deliver individual segments to the receiver, but it controls the connection itself
- If a segment is lost or corrupted, it is retransmitted

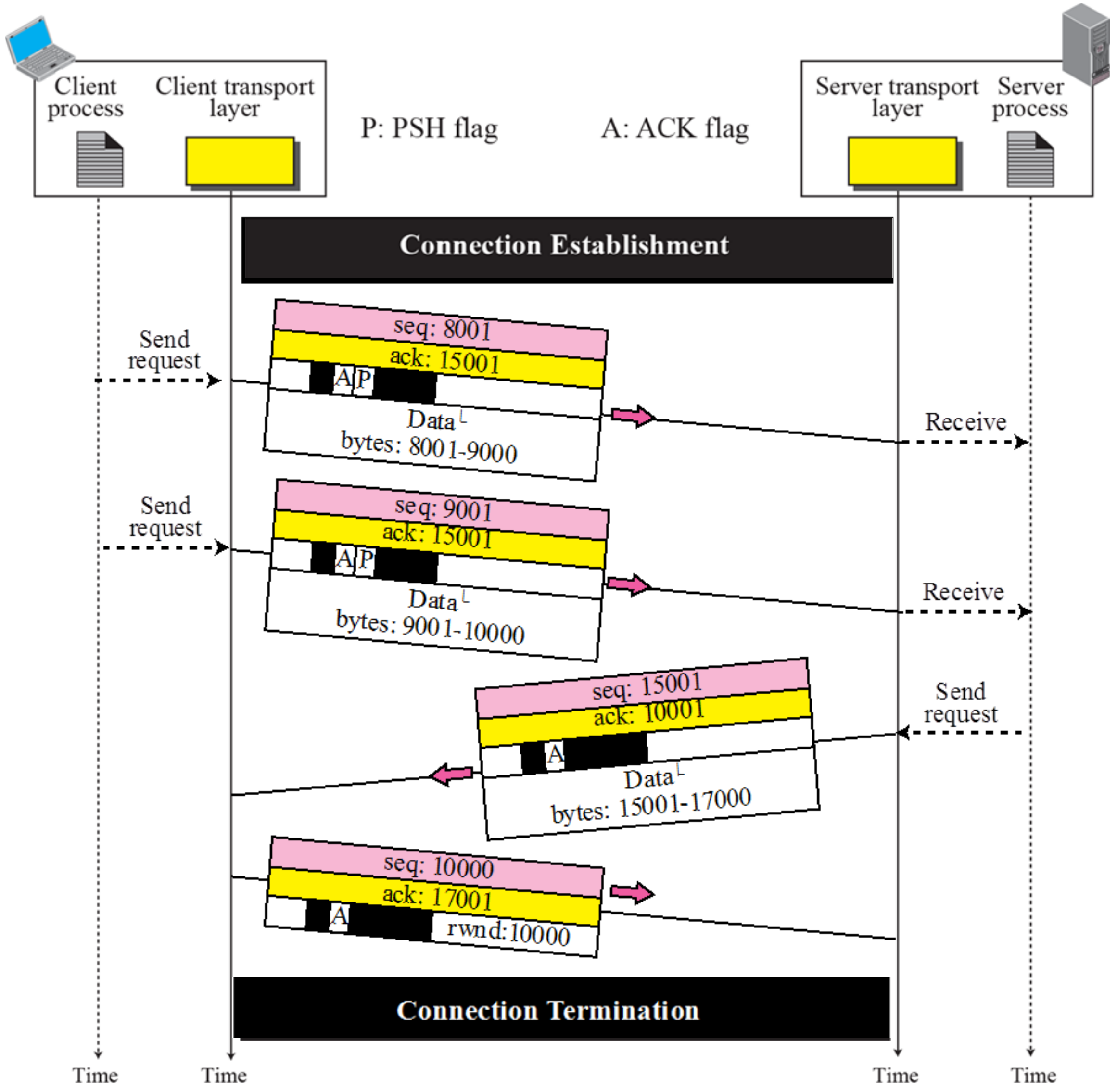
Connection Establishment using Three-way Handshake

- The server program tells its TCP to make a *passive open*

  The Client program issues a request for an *active open.*



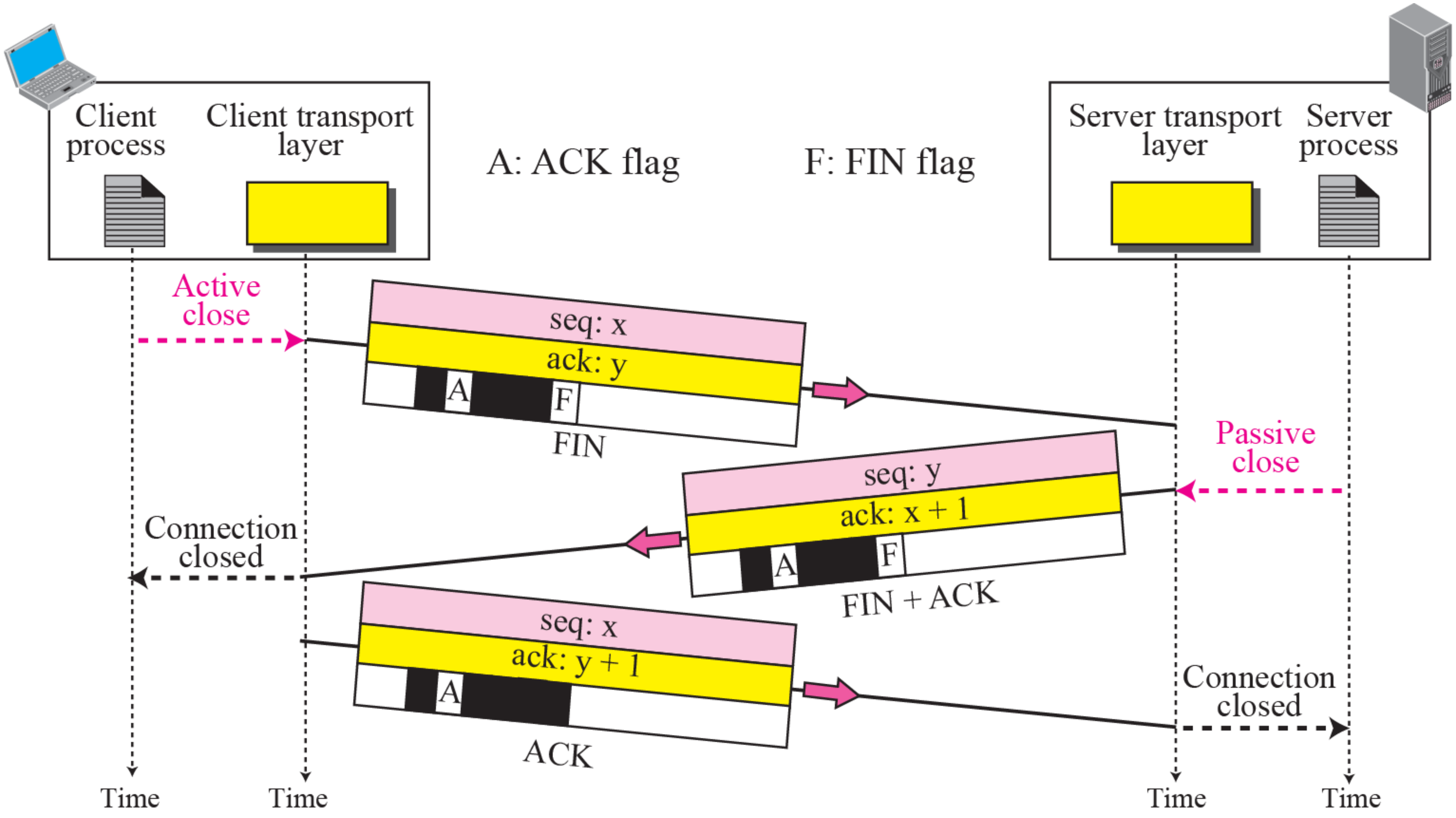
Data Transfer



Data Transfer (cont'd)

- Urgent data
  - To send urgent data
  - Use of URG bit set by sending TCP
  - Receiving TCP extracts the urgent data from the segment using urgent pointer

Connection Termination using Three-way Handshake



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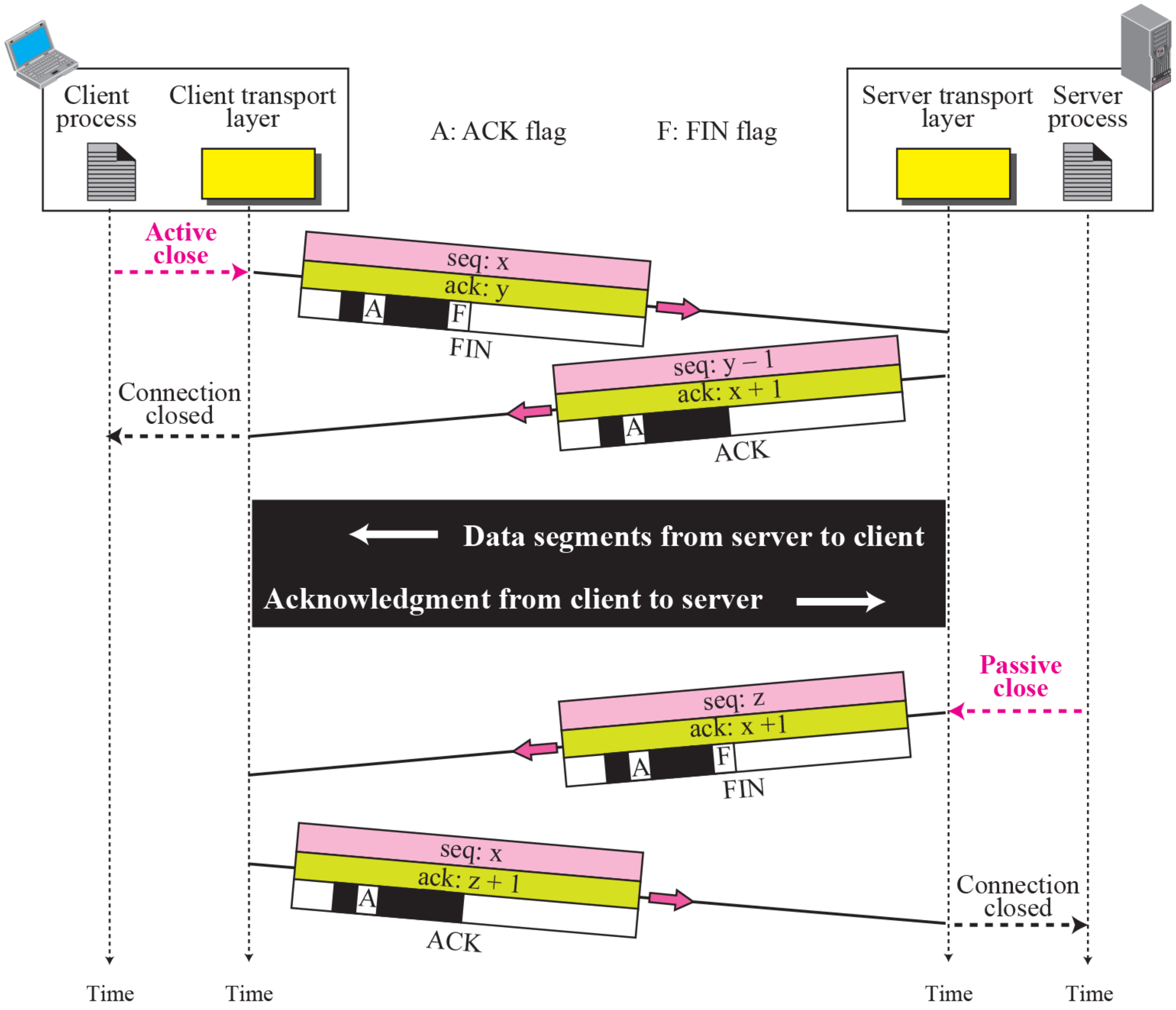
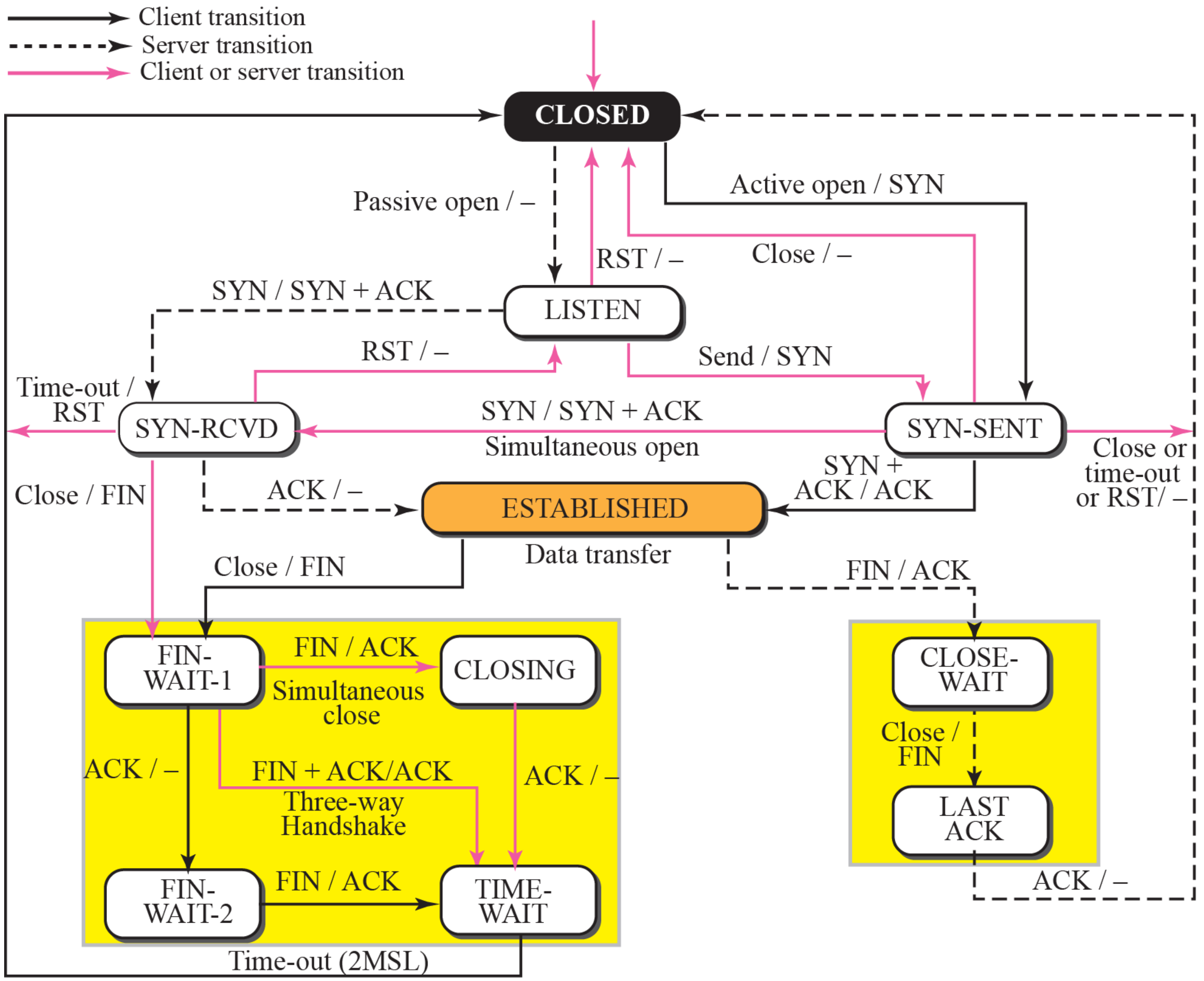
Half-Close


Client process
Client transport layer
A: ACK flag
F: FIN flag
Server transport layer
Server process
Active close
seq: x
ack: y
A
F
FIN
seq: y – 1
ack: x + 1
A
ACK
Connection closed
Data segments from server to client
Acknowledgment from client to server
Passive close
seq: z
ack: x +1
A
F
FIN
seq: x
ack: z + 1
A
ACK
Connection closed
Time
Time
Time
Time

State Transition Diagram

- To keep track of all the different events happening during connection establishment, connection termination, and data transfer, the TCP software is implemented as a finite state machine.

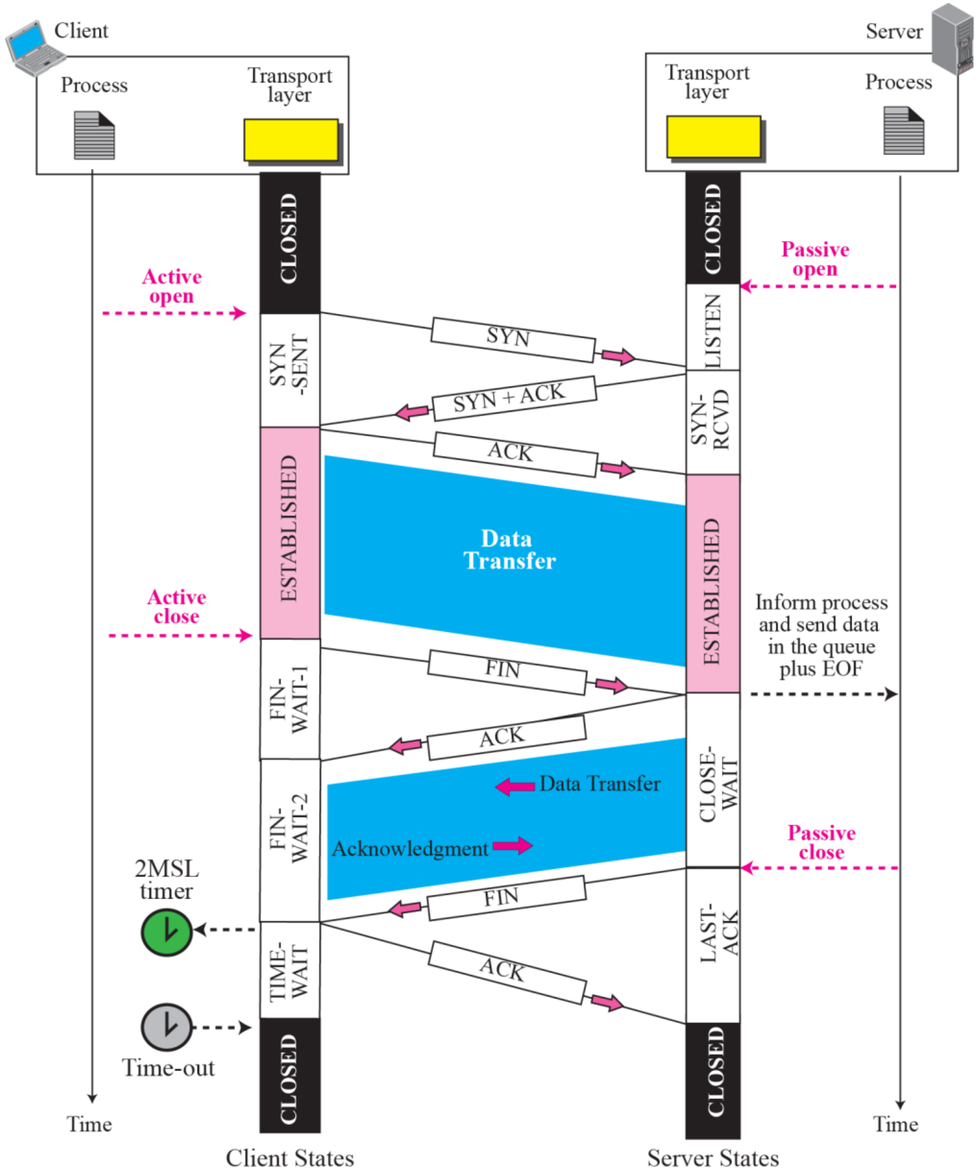
State Transition Diagram (cont'd)



State for TCP

State	*Description*
CLOSED	No connection exists
LISTEN	Passive open received; waiting for SYN
SYN-SENT	SYN sent; waiting for ACK
SYN-RCVD	SYN+ACK sent; waiting for ACK
ESTABLISHED	Connection established; data transfer in progress
FIN-WAIT-1	First FIN sent; waiting for ACK
FIN-WAIT-2	ACK to first FIN received; waiting for second FIN
CLOSE-WAIT	First FIN received, ACK sent; waiting for application to close
TIME-WAIT	Second FIN received, ACK sent; waiting for 2MSL time-out
LAST-ACK	Second FIN sent; waiting for ACK
CLOSING	Both sides decided to close simultaneously

Time-line diagram for Transition Diagrams



Error Control

- TCP is a reliable transport layer protocol
  - Application program that delivers a stream of data to TCP relies on TCP to deliver the entire stream to the application program on the other end *in order, without error, and without any part lost or duplicated.*
- Error control in TCP is achieved through the use of three tools
  - Checksum
  - Acknowledgment
  - Time-Out

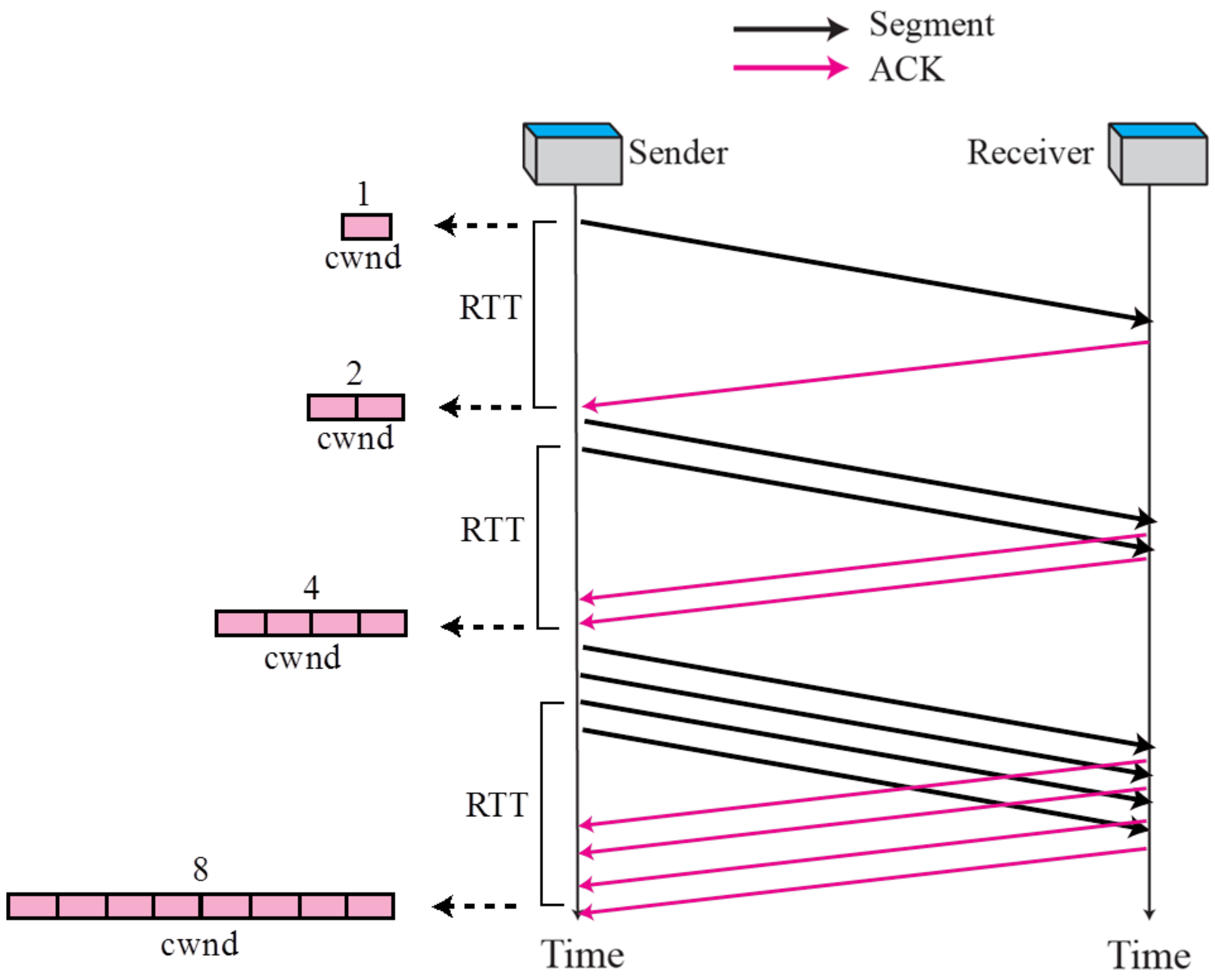
Congestion Control

- Congestion in a network may occur if the load on the network is greater than the capacity of the network
- Congestion control refers to the mechanism and techniques to control the congestion and keep the load below the capacity
- Congestion in a network or internetwork occurs because routers and switches have queues.

Congestion Control (cont'd)

- Congestion window
  - Today, TCP protocols include that the sender's window size is not only determined by the receiver but also by congestion in the network
  - Actual window size = minimum (rwnd, cwnd)

Slow Start, Exponential Increase



Congestion Control (cont'd)

- In the slow start algorithm, the size of the congestion window increases exponentially until it reaches a threshold.

Start → cwnd = 1

After 1 RTT → cwnd = 1 x 2 = 2 → 2^1

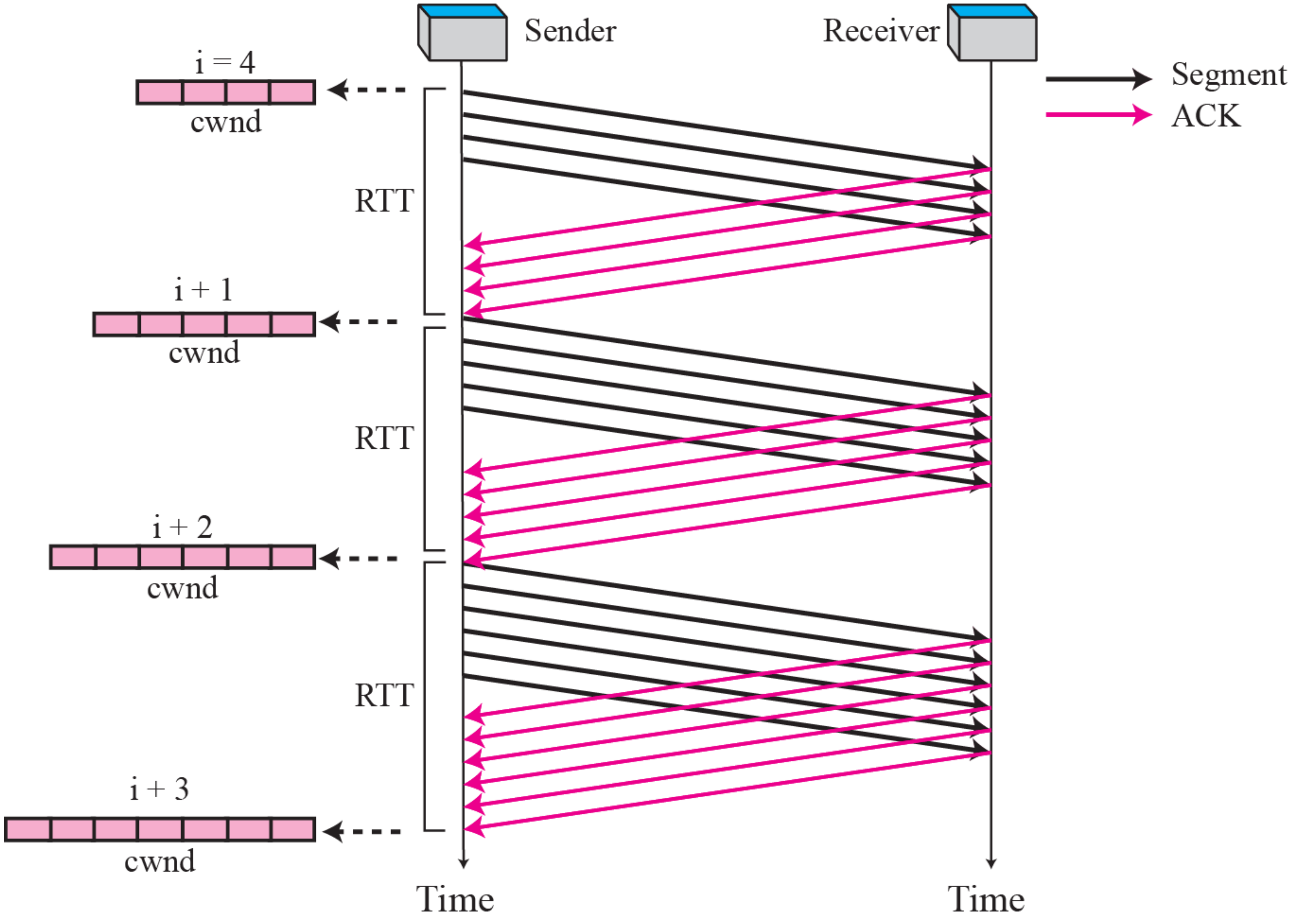
After 2 RTT → cwnd = 2 x 2 = 4 → 2^2

After 3 RTT → cwnd = 4 x 2 = 8 → 2^3

Congestion Avoidance, Additive Increase

- When the size of the congestion window reaches the slow start threshold, in the congestion avoidance algorithm, the size of the congestion window increases additively until congestion is detected

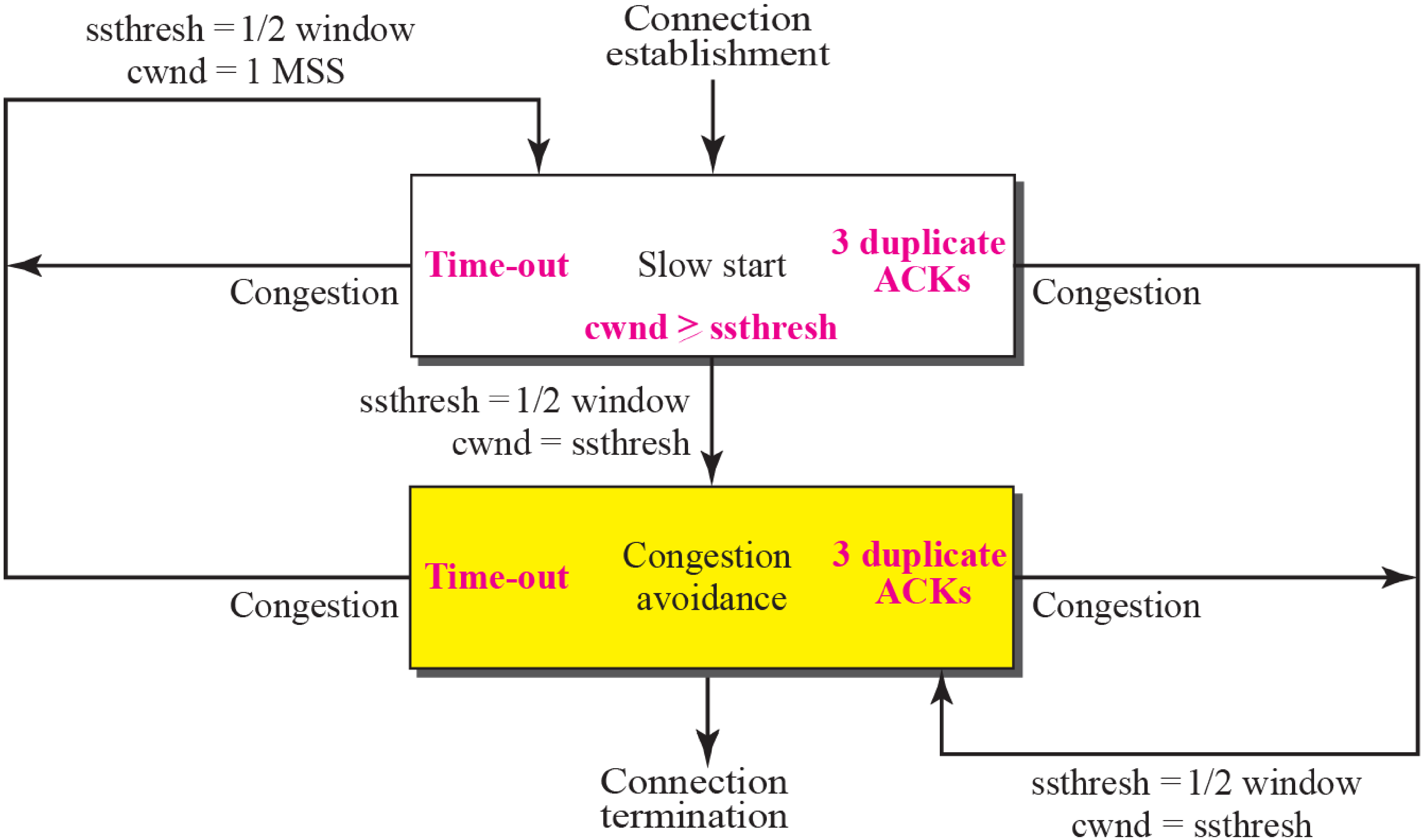
Congestion Avoidance, Additive Increase



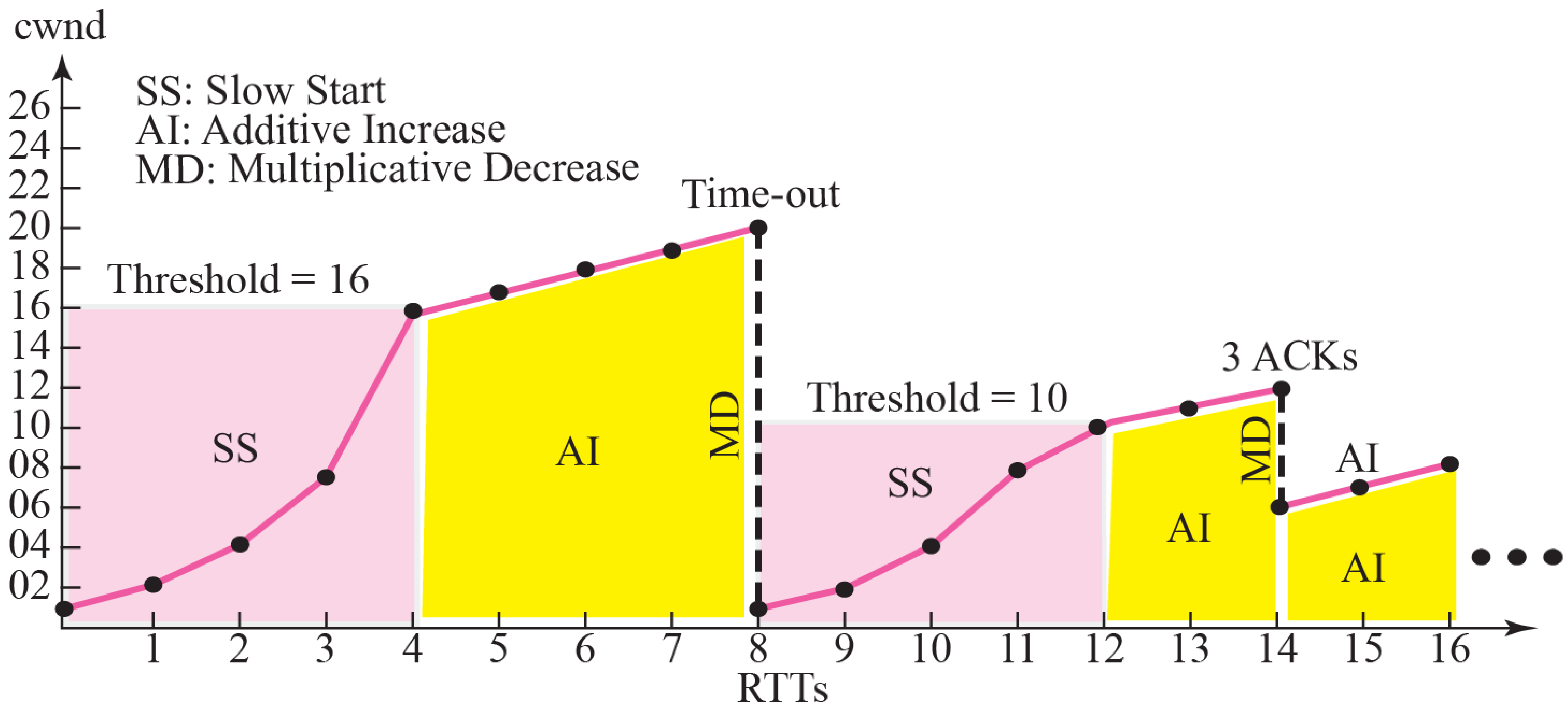
Congestion Detection : Multiplicative Decrease

- Most implementations react differently to congestion detection:
  - If detection is by time-out, a new slow start phase starts.
  - If detection is by three ACKs, a new congestion avoidance phase starts.

TCP Congestion Policy Summary



Congestion Example

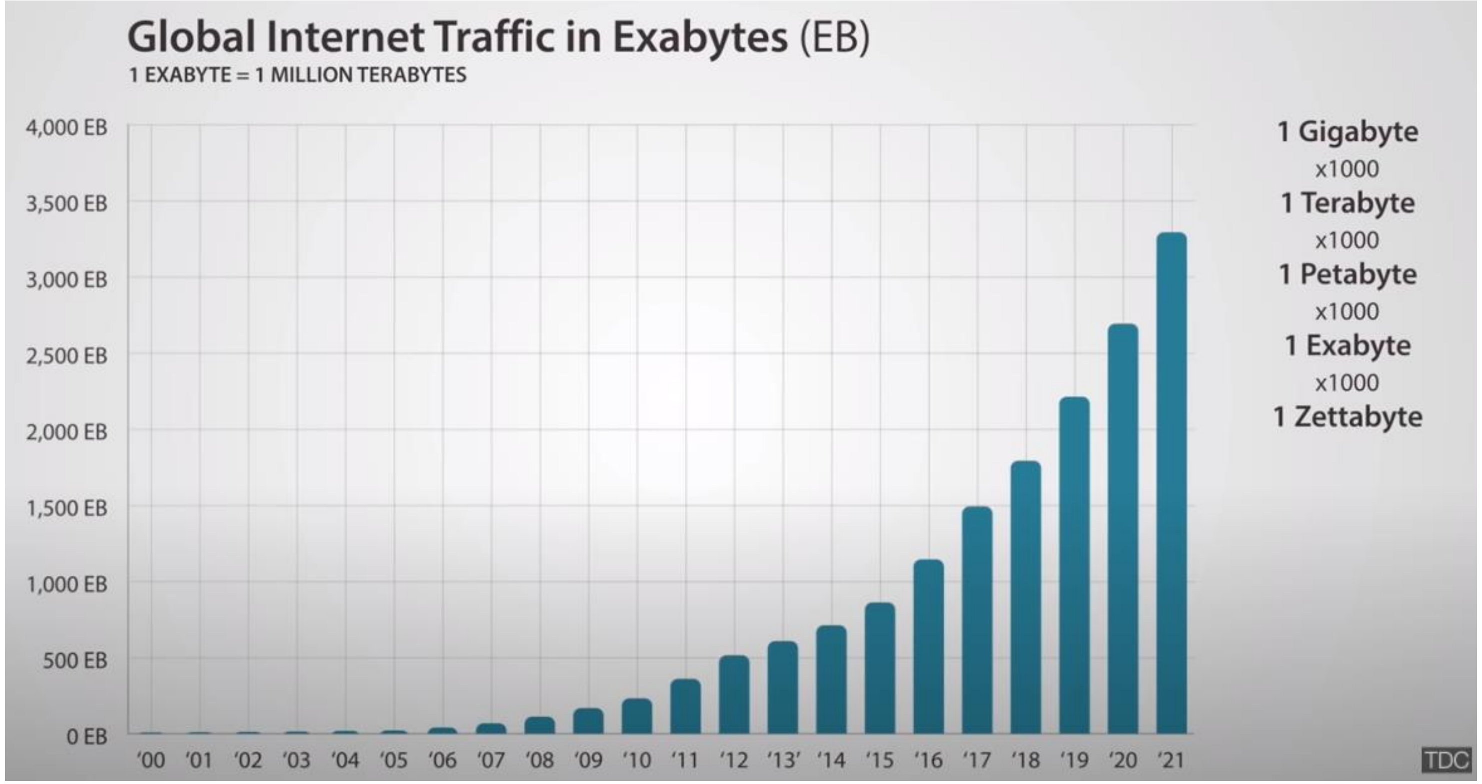


3. Future Internet

Why Future Internet?

- A growing and changing demand
  - For increasing user control of networks/devices/services/applications
  - For interconnecting 'things'-TV/PC/smart phone/sensor/Dron…
  - For convergence: networks/devices/services

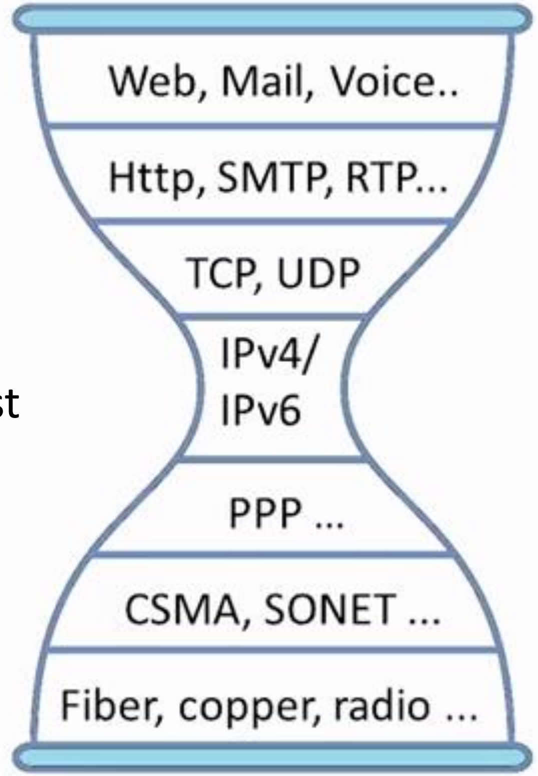
    : Intelligent Transportation System(ITS), Smart Grid, Smart-City, Facebook, YouTube,….
  - Mobility / Security



Why Future Internet?

- Current technologies can be, and need to be improved significantly
  - For scaling up and more flexibility
  - For better security
  - For higher performance and more functionality

Narrow Waist



What is Future Internet? (1)

- Need to resolve the challenges facing today's Internet by rethinking the fundamental assumptions and design decisions underlying its current architecture
- Two principal ways in which to evolve or change a system
  - Evolutionary approach (Incremental)
    - A system is moved from one state to another with incremental patches
    - Software Defined Networking
    - Overlay network
  - Revolutionary approach (Clean-slate)
    - The system is redesigned from scratch to offer improved abstractions and/or performance, while providing similar functionality based on new core principles
    - Information-Centric Networking
- It is time to explore a clean-slate approach
  - In the past 30 years, the Internet has been very successful using an incremental approach
  - Reaching a point where people are unwilling or unable to experiment on the current architecture

Software Defined Networking

- Network control is decoupled from forwarding function and directly programmable
- Nework Intelligence is centralized in a software-based controller.
- Network can be manged, secured and optimized via an automated software.

Overlay Network

- A network which is built on top of another network
- Nodes in overlay neworks are connected by virtual (logical) links
- Locator/ID Separation Protocol (LISP); separate IP address into routing locator and endpoint identifier

Information Centric Networking

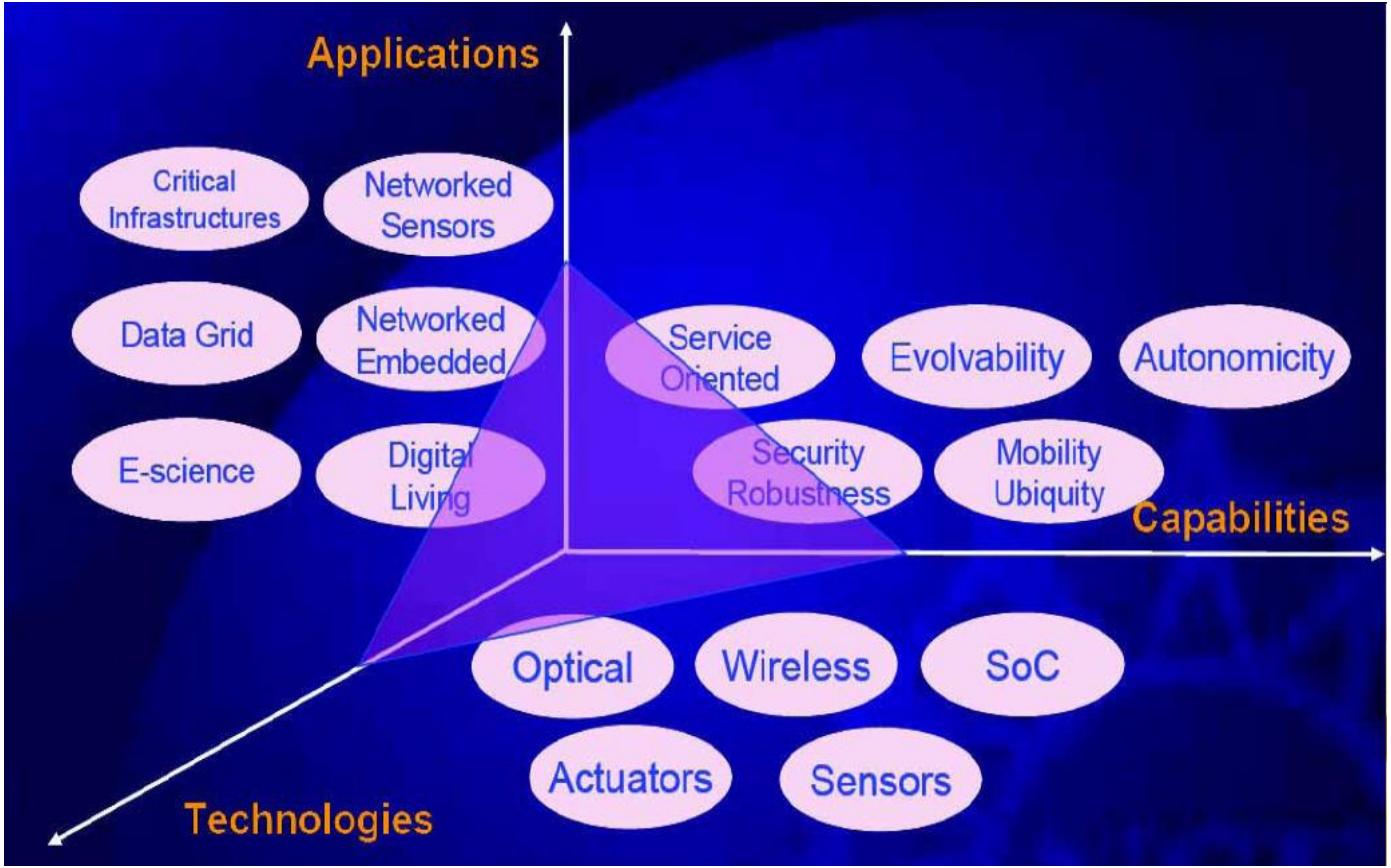
- A clean design of the nework architecture
- Named information is the focal point of the network, rather than hosts
- Content-centric Networking (CCN) – a concrete variation of ICN

What is Future Internet? (2)

- Future Internet?
  - Clean Slate design of the Internet's architecture to satisfy the growing demands
  - Management issues of Future Internet also need to be considered from the stage of design

- Research Goal for Future Internet
  - Performing research for Future Internet and designing new network architectures
  - Building an experimental facility

What is Future Internet? (3)



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History of Internet Growth (1)

- Stage One: Research and Academic Focus (1980-1991)
  - Debate about which protocols will be used (TCP/IP)
  - The National Science Foundation (NSF) took a leading role in research networking
    - NSFNet1: “supercomputer net”
    - NSFNet2: a generalized Internet (thousands of Internet nodes on U.S campus)
  - The Internet Engineering Task Force (IETF) created open standards for the use of the Internet
    - Request for Comments (RFC) standards documents

History of Internet Growth (2)

- Stage Two: Early Public Internet (1992-1997)
  - Federal Networking Council (FNC) made a decision to allow ISP to interconnect with federally supported Internets
  - The National Center for Supercomputing Applications (NCSA) adopted Tim Berners-Lee's work on the World Wide Web
  - Mosaic, Netscape started us down the path to the browser environment today
    - It was watershed development that shifted the Internet from a command-line, e-mail, and file-transfer in the kind of user interface to the browser world of full-screen applications
  - In the fall of 1996, a group of more than thirty University Corporation for Advanced Internet Development (UCAID)
    - Subsequently become known as Internet2

History of Internet Growth (3)

- Stage Three: International Public Internet (1998-2005)
  - The Internet achieved both domestic and international critical mass of growth
  - Fueled by giant bubble in Internet stocks that peaked in 2000 and then collapsed
  - Fiber-optic bandwidth Improvements to gigabit-per-second levels, and price-performance improvements in personal computers
    - xDSL, FTTH, etc.
  - The "bubble" years laid the foundation for broadband Internet applications and integration of voice, data, and video services on one network base

History of Internet Growth (4)

- Stage Four: Challenges for the Future Internet (2006-?)
  - The Internet has become a maturing, worldwide, universal network
  - Debated policy issues: net neutrality
    - Two of the few surviving U.S. telcos intended to levy special surcharges on broadband Internet traffic based on the application and on the company
    - Millions of Internet users
      - Growth in functionality and value of the net could never happened if there had been discrimination in managing packet flow
  - If the telco's well funded campaign succeeds
    - Then Progress toward universal and affordable broadband access would be further delayed

Merits & Demerits of Current Internet

- Merits
  - The original Internet design goal of robustness
    - Network architecture must not mandate recovery from multiple failures, but provide the service for those users who require it
  - Openness: low barrier to entry, freedom of expression, and ubiquitous access
- Demerits
  - "Nothing wrong – just not enough right"
  - Pervasive and diversified nature of network applications require many functionalities
    - Current network architecture doesn't support
  - E.g., TCP variants for high bandwidth delay product networks, earlier work on TCP over wireless networks, and current effort towards cross-layer optimization

Research Institute for Future Internet(1)

- US NSF
  - Future Internet Design (FIND)
  - Global Environment for Networking Innovations (GENI)
- European Commission
  - Future Internet Research and Experimentation (FIRE)
  - EIFFEL's Future Internet Initiative
  - FP7 Projects : http://www.future-internet.eu/activities/fp7-projects.html#c47
  - Goto the EU Future Internet Portal (http://www.future-internet.eu/)
  - Horizon 2020 (http://ec.europa.eu/programmes/horizon2020/)

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Research Institute for Future Internet(2)

- AsiaFI by CJK
- China : NSFC & MOST
  - 973 Fundamental Research Project
  - MOST 863 High-tech Project
  - CNGI Project
- JAPAN
  - NICT's NeW Generation Network (NWGN)
  - Japan Gigabit Network II (JGN2)
  - AKARI Project
- KOREA
  - Future Internet Forum (FIF)

Challenges of the Internet

- Security
  - Worrisome to everyone (user, application developers, operators)
- Mobility
  - Little support for mobile applications and services
- Reliability and Availability
  - ISPs face the task of providing a service which meets user expectations
- Problem analysis
  - Toolset for debugging the Internet is limited
- Scalability
  - E.g., routing system
- Quality of Service
  - It is unclear how and where to integrate different levels of QoS
- Economics
  - How network and service operators continue to make a profit

Requirements of Future Internet

- Highly available information delivery
- Verifiably secure information delivery
- Support for mobility
- Interworking flexibility and extensibility
- Support for a scalable, unified network
- Explicit facilitation of cross-layer interactions
- Distribution of data and control

Conclusions

- Current Internet
  - Root cause of problem: tremendous pace of increase of its use
  - Merits: openness, freedom of expression and ubiquitous access
  - Challenges: mobility, scalability, security & privacy, addressing & identity, robustness, manageability, etc.
- Future Internet
  - Clean slate design of Internet architecture considering security, scalability, mobility, robustness, identity, manageability, etc.
- Research Goal
  - Performing research for Future Internet and designing new network architectures
  - Building an experimental facility
- Propose an integrated architecture of Future Internet
- Investigate possible research topics towards management of Future Internet
  - In a design phase, we can imagine all possible mechanisms to solve the drawbacks of current Internet
  - How can we validate our proposed architecture and management issues?
  - What topic can we focus on?

Future Internet and AI

- How to apply the AI for desiging Futre Internet according to its requirements
  - Highly available information delivery
  - Verifiably secure information delivery
  - Support for mobility
  - Interworking flexibility and extensibility
  - Support for a scalable, unified network
  - Explicit facilitation of cross-layer interactions
  - Distribution of data and control

Q and A

KHU