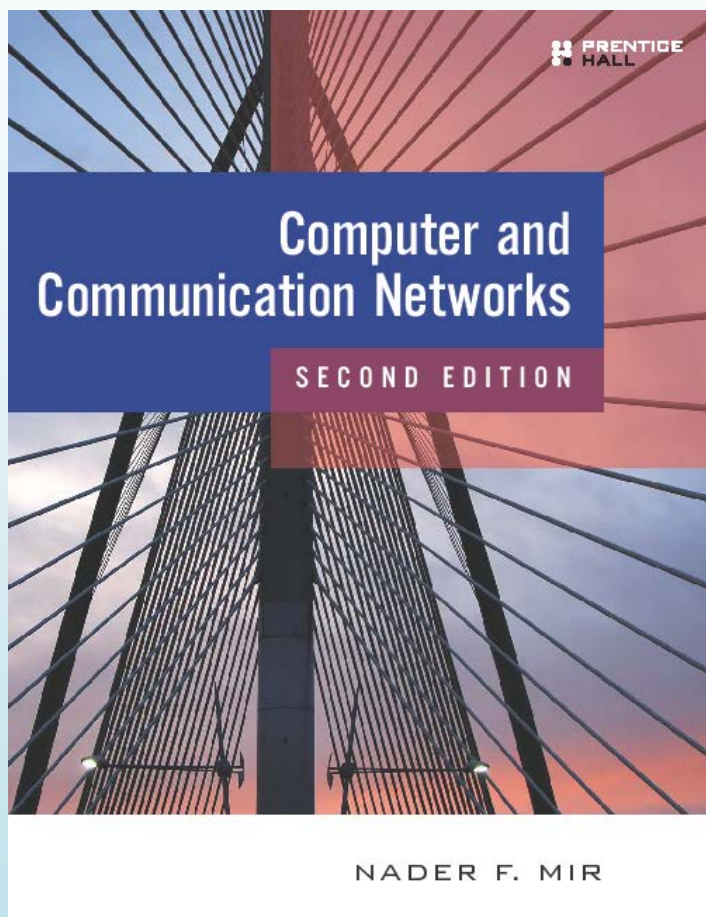


# Solution Manual for Computer and Communication Networks 2<sup>nd</sup> Edition

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Prepared for Instructors

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# Contents

## Preface

## Part I: Fundamental Concepts

- Chapter 1: Packet-Switched Networks
- Chapter 2: Overview of Networking Devices
- Chapter 3: Data Links and Link Interfaces
- Chapter 4: Local Area Networks and Networks of LANs
- Chapter 5: Wide-Area Routing and Internetworking
- Chapter 6: Multicast Routing and Protocols
- Chapter 7: Wireless Wide Area Networks and LTE Technology
- Chapter 8: Transport and End-to-End Protocols
- Chapter 9: Basic Network Applications and Management
- Chapter 10: Network Security

## Part II: Advanced Concepts

- Chapter 11: Network Queues and Delay Analysis
- Chapter 12: Advanced Router and Switch Architectures
- Chapter 13: Quality of Service and Scheduling in Routers
- Chapter 14: Tunneling, VPNs, and MPLS Networks
- Chapter 15: All-Optical Networks, WDM, and GMPLS
- Chapter 16: Cloud Computing and Network Virtualization
- Chapter 17: Software-Defined Networking (SDN) and Beyond
- Chapter 18: Voice over IP (VoIP) Signaling
- Chapter 19: Media Exchange and Voice/Video Compression
- Chapter 20: Distributed and Cloud-Based Multimedia Networking
- Chapter 21: Mobile Ad-Hoc Networks
- Chapter 22: Wireless Sensor Networks

# Preface

The first version (update) of the solution manual, updated on January 3, 2015, for the second edition of Computer and Communication Networks, ISBN: 0133814742, is hereby provided to instructors. For any exercise marked with “N/A,” the solution will be provided in the upcoming updated versions. Normally, every year the solution manual is updated. Please check the web page of the textbook in the Pearson Prentice Hall site and click on “Resources” to obtain the latest version of this solution manual. For any questions related to this solution manual, please directly contact the author. For effective educational learning purposes, instructors are kindly requested not to allow any student to access this solution manual.

## UPDATES ON TEXTBOOK

The second edition of the textbook is reprinted time to time when is sold out. Typically, every year there is a run of reprints. Some minor updates (if any) are incorporated into the future book’s reprints.

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## HOW TO CONTACT THE AUTHOR

Please feel free to send me any feedback at the Department of Electrical Engineering, Charles W. Davidson College of Engineering, San Jose State University, San Jose, California 95192, U.S.A, or via e-mail at [nader.mir@sjsu.edu](mailto:nader.mir@sjsu.edu). I would love to hear from you, especially if you have suggestions for improving the textbook and its solution manual. I will carefully read all review comments. You can find out more about me at [www.engr.sjsu.edu/nmir](http://www.engr.sjsu.edu/nmir). I hope that you enjoy the text and that you receive from it a little of my enthusiasm for computer communications and networks.

*—Nader F. Mir  
San Jose, California*

P A R T

# I

## Fundamental Concepts

# Packet-Switched Networks

1.1. Total distance =  $\ell = 2(\sqrt{3,000^2 + 10,000^2}) = 20,880.61$  km.

Speed of light =  $c = 2.3 \times 10^8$  m/s.

(a) propagation delay =  $t_p = \frac{\ell}{c} = \frac{20,880.61 \text{ km}}{2.3 \times 10^8 \text{ m/s}} = 90.8$  ms

(b) Number of bits in transit during the propagation delay  
 =  $(90.8 \text{ ms}) \times (100 \times 10^6 \text{ b/s})$   
 = 9.08 Mb

(c) 10 bytes = 80 bits  
 2.5 bytes = 20 bits, then:

$$T = t_f(\text{transfer time, data}) + t_f(\text{transfer time, ACK}) + t_p(\text{data}) + t_p(\text{ACK})$$

$$= \frac{80\text{b} + 20\text{b}}{100 \times 10^6 \text{ b/s}} + 2 \times 90.8\text{ms} = 181.7 \text{ ms}$$

1.2. Total distance =  $\ell = 2(\sqrt{(30/1000)^2 + 10,000^2}) \approx 20,000$  km.

Speed of light =  $c = 2.3 \times 10^8$  m/s.

(a)  $t_p = \frac{\ell}{c} = \frac{20,000 \text{ km}}{2.3 \times 10^8 \text{ m/s}} = 87$  ms

(b)  $100 \text{ Mb/s} \times 0.087 \text{ s} = 8.7 \text{ Mb}$

(c) Data :  $\frac{(10 \text{ B}) \times 8 \text{ b}}{100 \text{ Mb/s}} + t_p = 0.79 \mu\text{s} + 0.087 \text{ s}$

Ack:  $\frac{(2.5 \text{ B}) \times 8 \text{ b}}{100 \text{ Mb/s}} + t_p = 0.19 \mu\text{s} + 0.087 \text{ s}$

Total time  $\approx 1 \mu\text{s}$  (transfer) + 0.173 s (prop.)

1.3. Assuming the speed of transmission at  $2.3 \times 10^8$  :

(a) Total Delay:  $D = (n_h - 1)t_p + [n_p + (n_h - 2)]t_f + n_h t_r$

(b)  $t_{p1} = \frac{50 \text{ miles} \times 1600 \text{ m/miles}}{2.3 \times 10^8 \text{ m/s}} = 0.35 \text{ ms}$

$t_{p2} = \frac{400 \text{ miles} \times 1600 \text{ m/miles}}{2.3 \times 10^8 \text{ m/s}} = 2.8 \text{ ms}$

The packet of size 10,000 bytes includes the header of size 40 bytes. Therefore:

Number of packets =  $n_p = \frac{200\text{MB}}{10,000\text{B} - 40\text{B}} = 20,080$ .

$t_f = \frac{10,000 \text{ B/packets} \times 8 \text{ b/B}}{100 \text{ Mb/s}} = 0.8 \text{ ms/packets}$

$D = [(2-1)0.35 + (3-1)2.8] + [20,080 + (5-2)]0.8 + 5 \times 0.2 \times 10^3 \approx 16.66 \text{ s}$

Note that for this exercise we assumed the processing time is provided per packet (and not collectively for all packets. Thus we multiplied the last term by 5)

1.4.

$D_p = [n_p + (n_h - 2)]t_{f1} + n_h t_{r1} + (n_h - 1)t_p$

$D_c = 3([1 + (n_h - 2)]t_{f2} + n_h t_{r2} + (n_h - 1)t_p)$

$D_t = D_p + D_c = 4(n_h - 1)t_p + (n_p + n_h - 2)t_{f1} + 3(n_h - 1)t_{f2} + n_h(t_{r1} + 3t_{r2})$

1.5.

Number of packets =  $n_p = \frac{200\text{MB}}{10,000\text{B} - 40\text{B}} = 20,080$ .

$D_t = D_p + D_c$

$t_{p1} = \frac{50 \text{ miles} \times 1600 \text{ m/miles}}{2.3 \times 10^8 \text{ m/s}} = 0.35 \text{ ms}$

$$t_{p2} = \frac{400 \text{ miles} \times 1600 \text{ m/miles}}{2.3 \times 10^8 \text{ m/s}} = 2.8 \text{ ms}$$

(a) Here,  $t_r$  is defined as the processing time for each packet. Therefore,  $t_r = 0.2$ . Also,

$$\begin{aligned} n_p &= 1 \\ d_{\text{conn-req}} &= d_{\text{conn-accept}} \\ &= (n_h - 1)t_p + [n_p + (n_h - 2)]t_f + n_h t_r \\ &= [(2 - 1)0.35 + (3 - 1)2.8] \text{ ms} + [1 + (5 - 2)] \frac{500 \text{ b/packet}}{100 \text{ mb/s}} + 1 \times 0.2 \text{ s} \approx 0.2 \text{ s} \end{aligned}$$

We notice here that the large processing delay has dominated.

(b)  $d_{\text{conn-release}} \approx 0.2 \text{ s}$

(c) Since  $t_r$  is defined as the processing time for each packet, then  $t_r = 20,080 \times 0.2 = 4,016 \text{ s}$ . Here, for the same reason as above, the large total processing delay has dominated.

$$\begin{aligned} D_p &\approx n_h t_r = 5 \times 4,016 = 20,090 \text{ s} \\ D_c &= d_{\text{conn-req}} + d_{\text{conn-accept}} + d_{\text{conn-release}} = 0.2 + 0.2 + 0.2 = 0.6 \end{aligned}$$

$$D_i = D_p + D_c = 20,090 + 0.2 \times 3 = 20,090.6 \text{ s}$$

This result is a clear indication of traffic congestion

1.6.

$$s = 10^9 \text{ b/s}$$

$$n_h = 10 \text{ nodes}$$

$$t_r = 0.1 \text{ s}$$

10,000 B of data is broken up to two chunks leading to two packets:

$$\text{Packet1 size} = 9,960 \text{ (data)} + 40 \text{ (header)} = 10,000 \text{ B}$$

$$\text{Packet2 size} = 2,040 \text{ (data)} + 40 \text{ (header)} = 2,080 \text{ B}$$

Transfer delay:

For data packets,  $P1$  (Packet1) and  $P2$  (Packet2):

$$t_{f1-P1} = \frac{10,000 \text{ B} \times 8 \text{ b/B}}{10^9 \text{ b/s}} = 8 \times 10^{-5} \text{ s}$$

$$t_{f1-P2} = \frac{2,080 \text{ B} \times 8 \text{ b/B}}{10^9 \text{ b/s}} = 16.64 \times 10^{-6} \text{ s}$$

For signaling packets:

$$t_{f2} = \text{transfer times for control packets} = \frac{500 \text{ b}}{10^9 \text{ b/s}} = 5 \times 10^{-7} \text{ s}$$

Propagation delay:

$$t_p = \frac{\ell}{c} = \frac{500 \text{ miles} \times 1.61 \times 10^3 \text{ m}}{2.3 \times 10^8 \text{ m/s}} = 3.5 \times 10^{-3} \text{ s}$$

(a) request + accept time:

$$t_1 + t_2 = 2([n_p + (n_h - 2)]t_{f2} + (n_h - 1)t_p + n_h t_r) = 2.06 \text{ s}$$

(b)  $t_3 = \frac{1}{2}(t_1 + t_2) = 1.03 \text{ s}$

(c) In the timing chart, we assume that packets are transmitted in the order of their sizes starting with the longest ( $P_1$  appears first and then  $P_2$  in the timing chart). Therefore,  $P_1$  is dominant over  $P_2$  when parallel transmission over nodes happen. So for transfer time, we have a situation in which  $n_p + (n_h - 2) - 1$  of  $P_1$ s and one last  $P_2$  are calculated:

$$\begin{aligned} D_p &= [n_p + (n_h - 2) - 1]t_{f1-P1} + (1)t_{f1-P2} + n_h t_r + (n_h - 1)t_p \\ &= 1.5 \times 10^{-4} \text{ s} + 1 \text{ s} + 3.15 \times 10^{-2} \text{ s} = 1.031 \text{ s} \end{aligned}$$

$$D_c = t_1 + t_2 + t_3 = 3.09 \text{ s}$$

$$D_t = D_p + D_c = 1.03 + 3.09 = 4.1 \text{ s}$$

1.7. See Figure 1.1



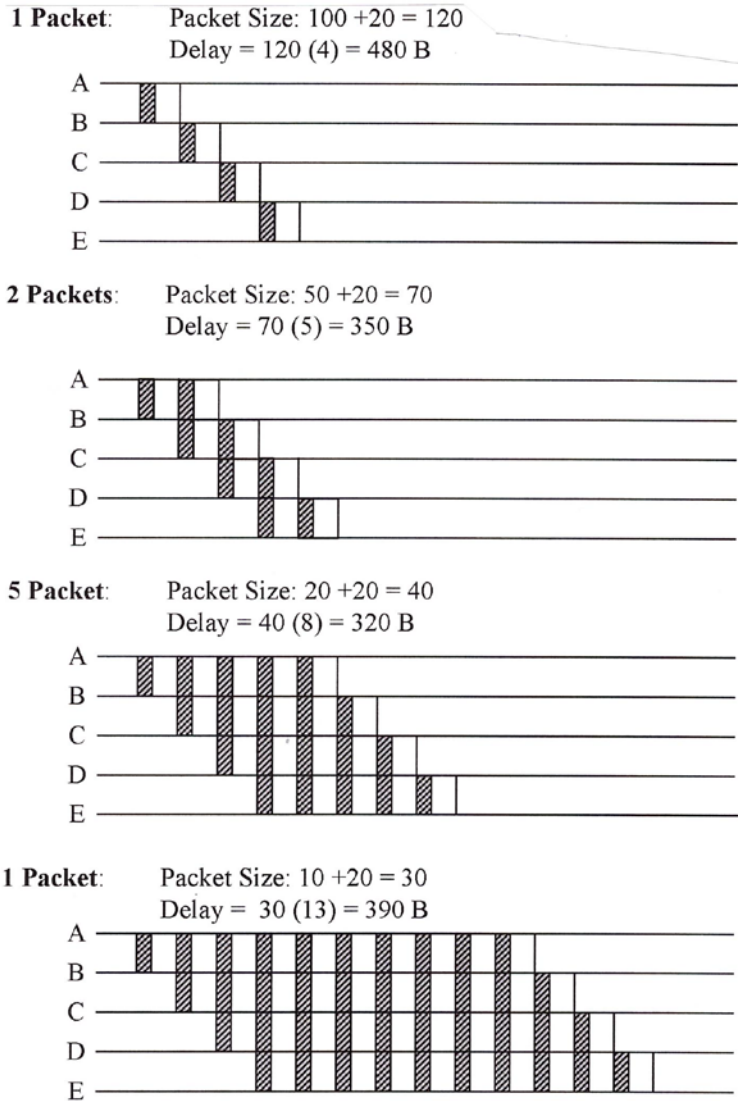


FIGURE 1.1. Solution to exercise 1.7.

1.8.

$$d + h = 10,000 \text{ b,}$$

$$\rho_d = 72\%,$$

$$\frac{h}{d} = 0.04,$$

$$s = 100 \text{ Mb/s,}$$

(a)  $h = 0.04d$  then:  $\frac{d}{d+h} = 0.96.$

Since:  $\rho_d = \rho \frac{d}{h+d}$  then:  $0.72 = \rho 0.96$

$\Rightarrow \rho = 0.74$

(b)  $\mu = \frac{s}{h+d} = \frac{100 \times 10^6 \text{ b/s}}{10 \times 10^3 \text{ b}} = 10 \times 10^3 = 10,000 \text{ packets/sec}$

(c)  $\lambda = \rho\mu = 0.74 \times 10,000 = 74,000$

$\bar{D} = \frac{1}{10,000 - 74,000} = 0.38 \text{ ms}$

(d)  $\bar{D}_{\text{opt}} = \frac{h}{s} \left( \frac{\sqrt{\rho_d}}{1 - \sqrt{\rho_d}} \right)^2$

$d+h = 10,000h / d = 0.04$

$\Rightarrow h = 384 \text{ b}$

$\bar{D}_{\text{opt}} = 0.12$

1.9.

$s = 100 \text{ Mb/s}$

$\rho = 80\%$

(a)  $\rho = \frac{\lambda}{\mu}$

$\Rightarrow 0.8 = \frac{8000}{\mu}$

$\Rightarrow \mu = 10,000 \text{ packets/s}$

$\mu = \frac{s}{h+d} \Rightarrow 10,000 = \frac{100 \times 10^6}{h+d}$

$\Rightarrow h+d = 10,000 \text{ b}$

(b)  $\rho_h = 0.008$  and  $\rho_h = \rho \frac{h}{d+h}$

$\Rightarrow d+h = 100h$

$\Rightarrow h = 100 \text{ b}$ , and  $d = 9900 \text{ b}$ .

(c)  $\rho_h = 0.008$

$\rho_d = \rho - \rho_h = 0.8 - 0.008$

$\Rightarrow \rho_d = 0.792$

$d_{\text{opt}} = h \left( \frac{\sqrt{\rho_d}}{1 - \sqrt{\rho_d}} \right) = 809 \text{ bits}$

$(d+h)_{\text{opt}} = h + d_{\text{opt}} = 100 + 809$

$$\Rightarrow (d+h)_{\text{opt}} = 909 \text{ b}$$

$$(d) \bar{D}_{\text{opt}} = \frac{h}{s} \left( \frac{1}{1-\sqrt{\rho_d}} \right)^2$$

$$\Rightarrow \bar{D}_{\text{opt}} = 8.2 \times 10^{-5} \text{ s}$$

1.10. See Figure 1.2.

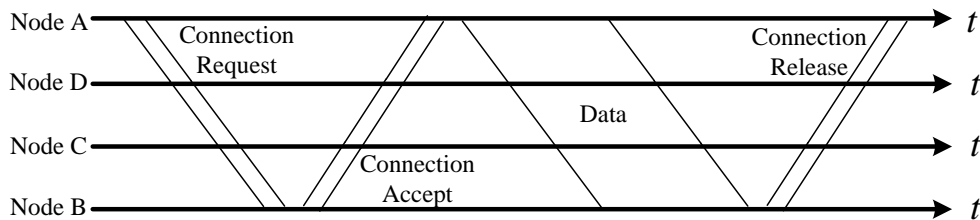


FIGURE 1.2 Signaling delay in connection-oriented packet-switched environment

1.11.

$$D = \frac{d+h}{s[1-\rho_d/d(d+h)]}$$

$$(a) \frac{\partial D}{\partial h} = 0$$

$$\text{Thus: } h_{\text{opt}} = \frac{d(1-2\rho_d)}{2\rho_d}$$

(b) Queueing delay

1.12.

(a) Address:

127.156.28.31 =  
 0111 1111 . **1001 1100** . **0001 1100** . 0001 1111  
 Mask:  
 255.255.255.0 =  
 1111 1111 . **1111 1111** . **1111 1111** . 0000 0000  
 Class A  
 Subnet ID: 1001 1100 0001 1100=39964

(b) Address:

150.156.23.14 =  
1001 0110 . 1001 1100 . **0001 0111** .0000 1110  
Mask:  
255.255.255.128 =  
1111 1111 . 1111 1111 . 1111 1111 . 1000 0000  
Class B  
Subnet ID: 000101110 = 46

(c) Address:

150.18.23.101 =  
1001 0110 . 0001 0010 . **0001 0111** . 0110 0101  
Mask:  
255.255.255.128 =  
1111 1111 . 1111 1111 . 1111 1111 . 1000 0000  
Class B  
Subnet ID: 000101110 = 46

---

1.13.

(a) IP: 1010 1101 . 1010 1000 . **0001 1100** . 0010 1101

Mask: 1111 1111 . 1111 1111 . 1111 1111 . 0000 0000  
Class B  
Subnet ID=00011100=28

(b) A packet with IP address 188.145.23.1 using mask pattern 255.255.255.128

IP: 1011 1100 . 1001 0001 . **0001 0111** . 0000 0001  
Mask: 1111 1111 . 1111 1111 . 1111 1111 . 1000 0000  
Class B  
Subnet ID=000101110=46

(c) A packet with IP address 139.189.91.190 using a mask pattern 255.255.255.128

IP: 1000 1011 . 1011 1101 . **0101 1011** . 1011 1110  
Mask: 1111 1111 . 1111 1111 . 1111 1111 . 1000 0000  
Class B  
Subnet ID=010110111=183

---

1.14.

IP1: **1001 0110 . 0110 0001 . 0001 1100** . 0000 0000  
IP2: **1001 0110 . 0110 0001 . 0001 1101** . 0000 0000  
IP3: **1001 0110 . 0110 0001 . 0001 1110** . 0000 0000

New IP (CIDR): 150.97.28.0/22

---

1.15.

Address:

141.33.11.0/22 = **1000 1101 . 0010 0001 . 0000 1011 . 0000 0000**  
141.33.12.0/22 = **1000 1101 . 0010 0001 . 0000 1100 . 0000 0000**  
141.33.13.0/22 = **1000 1101 . 0010 0001 . 0000 1101 . 0000 0000**  
141.33.8.0/21

---

16.

(a) 191.168.6.0

1011 1111 . 1010 1000 . 0000 0110 . 0000 0000  
1111 1111 . 1111 1111 . 1111 1110 . 0000 0000  
Result:  
1011 1111 . 1010 1000 . 0000 0110 . 0000 0000 = 191.168.6.0/23

(b) 173.168.28.45

1010 1101 . 1010 1000 . 0001 1100 . 0010 1101  
1111 1111 . 1111 1111 . 1111 1110 . 0000 0000  
Result:  
1010 1101 . 1010 1000 . 0001 1100 . 0000 0000 = 173.108.28.0/23

(c) 139.189.91.190

1000 1011 . 1011 1101 . 0101 1011 . 1011 1110  
1111 1111 . 1111 1111 . 1111 1110 . 0000 0000  
Result:  
1000 1011 . 1011 1101 . 0101 1010 . 0000 0000 = 139.189.90.0/23

---

1.17. N/A

---

1.18.

180.19.18.3: 1011 0100 . 0001 0011 . 0001 0010 . 0000 0011

(a) 180.19.0.0/18:

**1011 0100 . 0001 0011 . 0000 0000 . 0000 0000**  
180.19.3.0/22:  
**1011 0100 . 0001 0011 . 0000 0011 . 0000 0000**  
180.19.16.0/20:  
**1011 0100 . 0001 0011 . 0001 0000 . 0000 0000**

(b) The longest match is 180.19.16.0/20.

---

1.19.

- (a) N1 L11: **1100 0011 . 0001 1001 . 0000 0000 . 0000 0000**  
N2 L13: **1000 0111 . 0000 1011 . 0000 0010 . 0000 0000**  
N3 L21: **1100 0011 . 0001 1001 . 0001 1000 . 0000 0000**  
N4 L23: **1100 0011 . 0001 1001 . 0000 1000 . 0000 0000**  
N5 L31: **0110 1111 . 0000 0101 . 0000 0000 . 0000 0000**  
N6 L33: **1100 0011 . 0001 1001 . 0001 0000 . 0000 0000**

(b) Packet: 1100 0011 . 0001 1001 . 0001 0001 . 0000 0011

L11: 1100 0011 . 0001 1001 . 0000 0000 . 0000 0000  
L12: **1100 0011 . 0001 1001 . 0001 0000 . 0000 0000**  
L12: 1100 0011 . 0001 1001 . 0000 1000 . 0000 0000  
L13: 1000 0111 . 0000 1011 . 0000 0010 . 0000 0000  
L21: 1100 0011 . 0001 1001 . 0001 1000 . 0000 0000  
L22: **1100 0011 . 0001 1001 . 0001 0000 . 0000 0000**  
L23: 1100 0011 . 0001 1001 . 0000 1000 . 0000 0000  
L31: 0110 1111 . 0000 0101 . 0000 0000 . 0000 0000  
L33: **1100 0011 . 0001 1001 . 0001 0000 . 0000 0000**  
Answer=N6

(c) 32-21=11 b

So,  $2^{11} = 2,048$  users

---

1.20.

(a) IPv4 address field has 32 bits

Total number of IP addresses available =  $2^{32}$   
Number of IP addresses per person for 620 million people  
$$= \frac{2^{32}}{620 \times 10^6} = 6.9 \approx 7$$

(b) Number of bits required to serve 620 million people is 30 since  
 $2^{29} \approx 536$  mil < 620 mil <  $2^{30} \approx 1,074$  mil

Thus, CIDR can only have 32-30 = 2 bit as Network ID field as x.x.x.x/2

(c) IPv6 address field has 128 bits:

Total number of IP addresses available =  $2^{128}$   
Number of IP addresses per person for 620 million people  
$$= \frac{2^{128}}{620 \times 10^6} = 5.49 \times 10^{29}$$

---

1.21.

Mask: 255.255.255.240

1111, 1111 . 1111, 1111 . 1111, 1111 . 1111, 0000

(a) 192.5.150.18 => .0001, 0010 = 18  
192.15.15.16 <= .0001, 0000  
=> L3

(b) 129.95.39.10 => .0000, 1010  
129.95.39.0 <= .0000, 0000  
=> L2

(c) 129.95.38.31 => .0000, 1111  
129.95.38.0 <= .0000, 0000  
=> L7

(d)  
=> L4

---

1.22.

(a) 129.95.39.10 = 1000 0001 . 0101 1111 . 0010 0111 . 0000 1010  
Mask = 1111 1111 . 1111 1111 . 1111 1111 . 1000 0000  
Result = 1000 0001 . 0101 1111 . 0010 0111 . 0000 0000  
= 129.95.39.0

Thus: Mask 1 is used. Output port L2 is found.

(b) 129.95.38.16 = 1000 0001 . 0101 1111 . 0010 0110 . 0001 0000  
Mask1 = 1111 1111 . 1111 1111 . 1111 1111 . 1000 0000  
Result = 1000 0001 . 0101 1111 . 0010 0110 . 0000 0000  
= 129.95.38.0

Mask2 = 1111 1111 . 1111 1111 . 1111 1111 . 1100 0000  
Result = 129.95.38.0

Thus: Mask 1 & 2 are used. Output port L4 is found.

Note : IP address assists in the table for L3 but masking result points to L4

(c) 129.95.38.149 = 1000 0001 . 0101 1111 . 0010 0110 . 1001 0101  
Mask 1 = 1111 1111 . 1111 1111 . 1111 1111 . 1000 0000  
Result = 1000 0001 . 0101 1111 . 0010 0110 . 1000 0000  
= 129.95.38.128

Thus: Mask 1 is used. Output port L3 is found

# Overview of Networking Devices

2.1.

- (a) Number of channels=  $12 \times 5 \times 10 = 600$
- (b) Capacity=  $600 \times 4 \text{ KHZ} = 2.4 \text{ MHZ}$

2.2. Total output bit-rate of the multiplexer is 160 Kb/s

- (a) Total bit-rate from analog links  
 $= (5 \text{ KHz} + 2 \text{ KHz} + 1 \text{ KHz}) \times 2 \text{ samples/cycle} \times 5 \text{ bits/sample}$   
 $= 80 \text{ Kb/s}$

- (b) Total bit-rate from digital links =  $160 \text{ Kb/s} - 80 \text{ Kb/s} = 80 \text{ Kb/s}$   
 Total bit-rate per digital line =  $\frac{80 \text{ Kb/s}}{4 \text{ lines}} = 20 \text{ Kb/s}$

Pulse stuffing per digital line =  $20 \text{ Kb/s} - 8 \text{ Kb/s} = 12 \text{ Kb/s}$

- (c) For a fair share assignment, the size of channels formed on the frame is proportional to the data rate of that line. Assuming 5-b increments in the length of each channel, we need a total of 3 variable-length channels (10 b + 25 b + 5 b) for the three analog lines, four channels of 10 b long each for the four digital lines, plus a 5 b control channel and a guard bit.



Therefore, the frame size =  $10 + 25 + 5(\text{analog}) + 4 \times 10(\text{digital}) + 5(\text{control}) + 1(\text{guard}) = 86 \text{ b}$

$$\text{Frame rate} = \frac{160 \times 10^3 \text{ b/s}}{86 \text{ b/frame}} = 1,860 \text{ frames/s}$$


---

2.3.

(a) Number of characters are = 1 (sync) + 99 (data) = 100

$$\text{Synchronization bit rate} = \frac{4800 \text{ b/s}}{100} \approx 50 \text{ b/s}$$

Number of 150 b/s terminals

$$= \frac{4800 - (2 \times 600 + 5 \times 300 + 50) \text{ b/s}}{150 \text{ b/s}} = 13.6 \approx 13 \text{ terminals}$$

(b) The number of characters for synchronization is proportional to bit rates. For example, since we need 12 characters for 150 b/s terminals, therefore we need 3 characters for synchronization. Frame format in terms of bits is:

$$\begin{aligned} & 2 \times (12 \text{ char} \times 10 \text{ b/char}) + 5 \times (6 \text{ char} \times 10 \text{ b/char}) + 13 \times (3 \text{ char} \times 10 \text{ b/char}) + \\ & 3 \times 10 \text{ b/char} + 1 \times 10 \text{ b/char} \\ & = 970 \text{ b/frame} \end{aligned}$$


---

2.4.

(a) #bits/frame (total) =  $2 \text{ Mb/s} \times 26 \mu\text{s/frame} = 52 \text{ bits/frame}$

$$\text{\#bits/frame (data)} = 52 \text{ bits/frame} - 10 = 42 \text{ bits/frame}$$

$$\text{\#channels} = n = 42 \text{ bits/frame} \frac{1}{6 \text{ bits/ch}} = 7 \text{ ch/frame}$$

(b)  $P[\text{clipping}] = \sum_{i=n}^{m-1} \binom{m-i}{i} p^i (1-p)^{m-i-1}$

$$m = 10, n = 7, p = 0.9$$

$$P[\text{clipping}] = 0.947$$

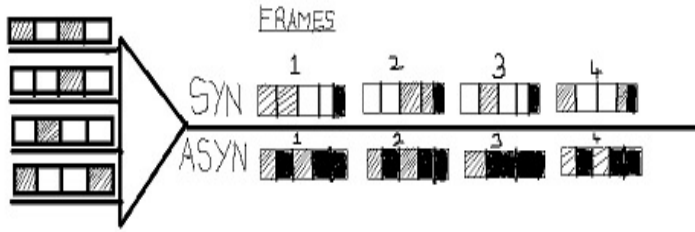

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2.5. N/A

---

2.6.

(a)



(b) Mux Output Rate  
 = 4 lines \* 10 Mb/s = 40 Mb/s

Frame Size =  
 (For Synchronous TDM): 5 ch/frames \* 4 b/ch = 20 b/frames  
 (For asynchronous TDM): Ave: (20+20+12+20)/4 = 18 b/frames

Frame Rate =  
 (For Synchronous TDM): 40 Mb/s / 20 b/frame = 2 Mframes/s  
 (For asynchronous TDM): 40 Mb/s / 18 b/frame = 2.22 Mframes/s

(c) Speed of Clock: (4 lines \* 10 Mb/s) \* 1 cycle/b  
 = 40 M cycles/b  
 = 40 MHz

2.7.

(a)  $\rho = \frac{t_a}{t_c + d} = 2/8 = 25\%$

(b) 
$$P_{j=3} = \frac{\binom{m}{j} \left(\frac{t_i}{t_a}\right)^j}{\sum_{i=0}^j \binom{m}{j} \left(\frac{t_a}{t_d}\right)^i} = \frac{\binom{8}{3} \left(\frac{2}{6}\right)^3}{\sum_{j=0}^3 \binom{8}{1} \left(\frac{2}{6}\right)^i} \approx 21\%$$

(c) 
$$B = P_{j=n=4} = \frac{\binom{m}{n} (1/3)^n}{\sum_{i=0}^n \binom{m}{i} (1/3)^i} = \frac{\binom{8}{7} (1/3)^4}{\sum_{i=0}^4 \binom{8}{i} (1/3)^i}$$
  

$$= \frac{70/81}{1+8/3+28/9+56/27+70/81} \approx 9\%$$

(d)  $E[C] = \sum_{j=1}^4 j p_j = 1(0.275) + 2(0.32) + 3(0.213) + 4(0.0889) \approx 1.94$

2.8.

(a)  $m = 4$

$n = 2$

$$\begin{aligned}\text{Prob}[\text{clipping}] = P_c &= \sum_{i=2}^3 \binom{3}{i} \rho^i (1-\rho)^{3-i} \\ &= 10.4\% \text{ for } \rho = 0.2 \\ &= 35.2\% \text{ for } \rho = 0.4 \\ &= 64.8\% \text{ for } \rho = 0.6 \\ &= 89.6\% \text{ for } \rho = 0.8\end{aligned}$$

(b)  $m = 4$

$n = 3$

$$\begin{aligned}\text{Prob}[\text{clipping}] P_c &= \sum_{i=3}^3 \binom{3}{i} \rho^3 (1-\rho)^{3-i} \\ &= 0.0\% \text{ for } \rho = 0.2 \\ &= 6.4\% \text{ for } \rho = 0.4 \\ &= 21.6\% \text{ for } \rho = 0.6 \\ &= 51.2\% \text{ for } \rho = 0.8\end{aligned}$$

(c)  $n = 4$

$P_4 = 100\%$

---

2.9.

$$\rho = \frac{t_a}{t_a + t_d} = 0.9$$

for  $m = 11$  and  $n = 10$ :

$P_c =$  the clipping probability

$$= \sum_{i=n}^{m-1} \binom{m-1}{i} \rho^i (1-\rho)^{m-1-i} = \binom{10}{10} \rho^{10} (1-\rho)^0 = \rho^{10} \approx 0.35$$

---

2.10.

$$\frac{1}{\mu} \left( 1 - \frac{\eta}{\rho} m \right)$$

---

2.11. See Figure 2.1.

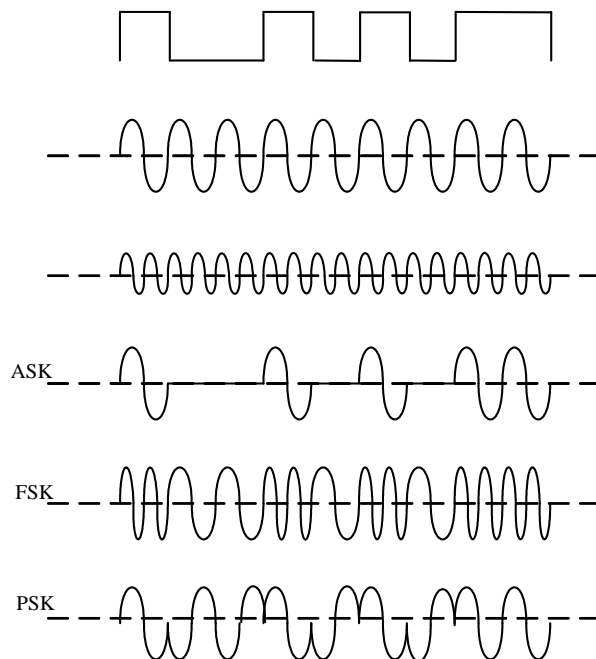


FIGURE 2.1 Modulation techniques in exercise 2.11

2.12.

- (a) Assume a packet incoming at input port of IPP has length of L bits. Then,

$$T = \frac{d + 50}{r} \Rightarrow \frac{\partial T^2}{\partial d \partial r} = 0 \Rightarrow d_{\text{opt}}, r_{\text{opt}}$$

Therefore ways to optimize the transmission delay T are followings:

- Increase transmission rate (r) by reducing clock cycle time of CPU.
- Define value of d to be equal to highest-probability packet length(L).

- (b) For example, if the switch fabric has 5 stages of routing in its internal network, the processing delay mostly depends on AND gate switch time of gates on a fabric. Assume applying CMOS transistors, which are slowest technology for switching transistors, for this switch fabric. Assuming 50-80 ns switch time for CMOS AND gate, the total propagation delay in this switch fabric = 80 ns × 5 stages = 0.4 μs. On the other hand, the delay in IPP (D) mostly depends on packet fragmentation and encapsulation delay time. Typical value of this delay time is about tens or hundreds of milliseconds for a 512-bytes packet.

Therefore processing delay in the switch fabric is not significant compared to delay in IPP.