data rate : noiseless : nyquist bit rate
levels
$2B \cdot \log_{10}(M)$

noisy : Shannon capacity:
$B \log_2(1 + SNR)$

- Shannon capacity gives the upper limit, whereas the nyquist formula gives the number of levels needed
- apply the shannon capacity formula to find the upper limit, then choose a lower limit and apply the nyquist formula to find the number of levels

+ main parameters:
  - bandwidth : range of frequencies (Mbps)
  - throughput : actual amount of data passed (Mbps)
  - latency
  - bandwidth-delay product

◦ propagation time : time for signal to travel from one point to another
- transmission time (propagation delay) : the amount of time for one bit

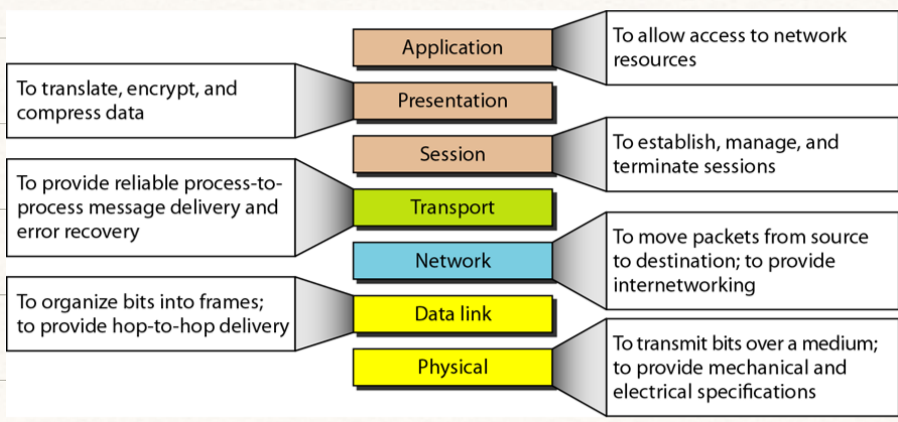
22/10 exam

mid preparations:

Chapter 2

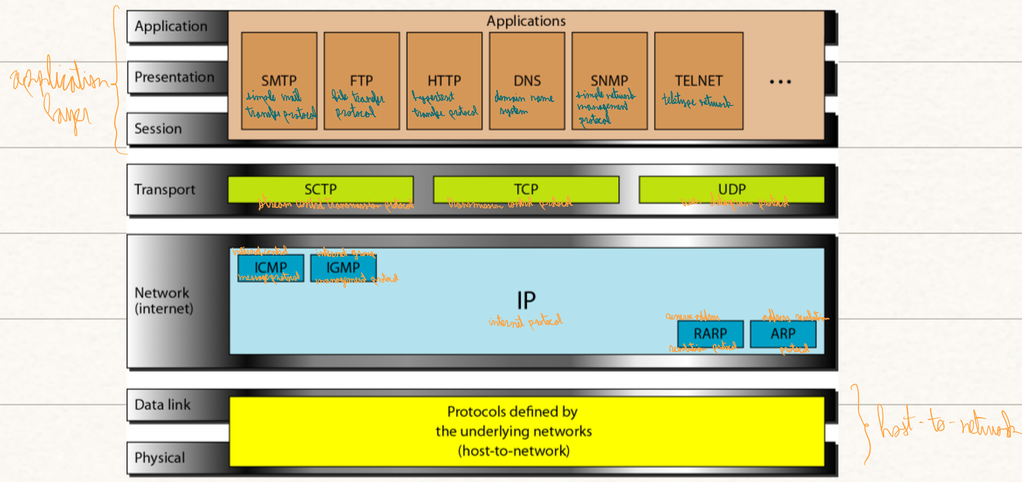
+ layers of OSI (open systems interconnection) model:
  1- physical 2- data link 3- network 4- transport 5- session
  6- presentation 7- application
  trailer added here
  - header added in every layer

- physical layer: responsible for movements of individual bit from one hop to next
- data link: responsible for moving frames between nodes (hops)
- network layer: responsible for delivering individual packets from source to destination
- transport layer: responsible for delivering messages from one process to another
- session layer: responsible for synchronization and dialog control
- presentation layer: responsible for translation, compression, and encryption
- application layer: provides services to end user



+ layers of TCP/IP suite : (originally four, five when compared to OSI)

- original : host-to-network, internet, transport, and application
- compared to OSI : physical, data link, network, transport, application



- four levels of addresses : physical, logical, port, and specific
  (data link and physical layers / network layer / transport layer / application layer)
- most local networks use 48-bit (6-byte) physical address written as 12 hexadecimal digits
  (4 bits → 1 hexadecimal)
  - every byte is separated by colon (:)
- physical address changes every hop ; logical, port, and specific addresses don't change
- port address is 16-bits represented as one decimal number

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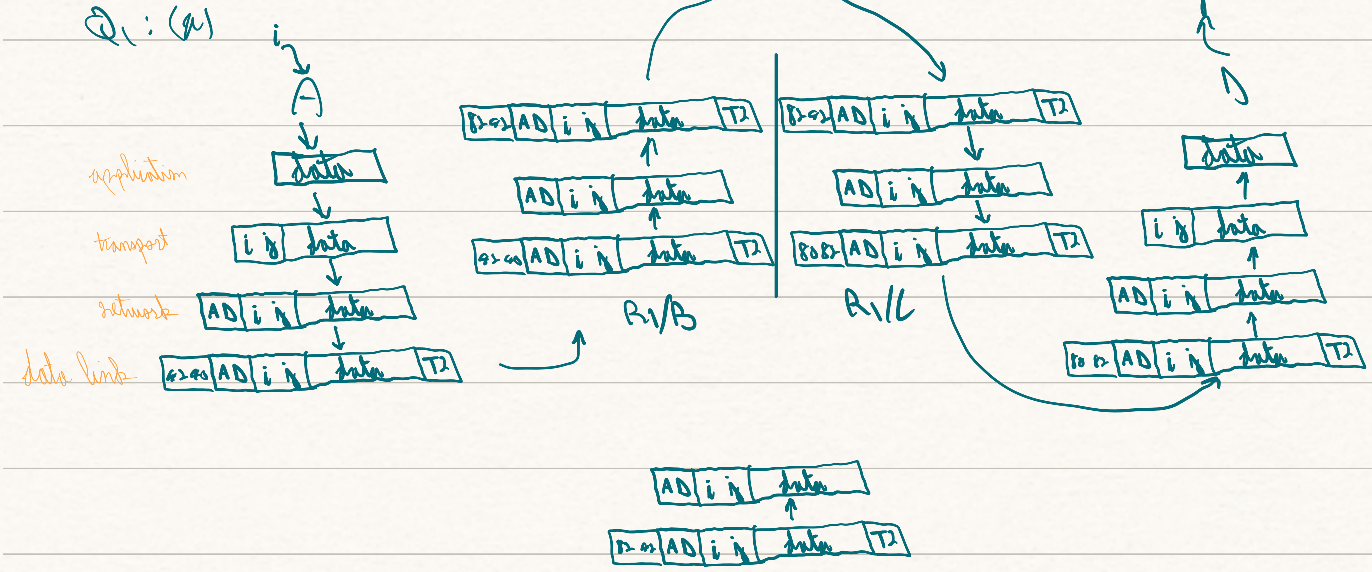
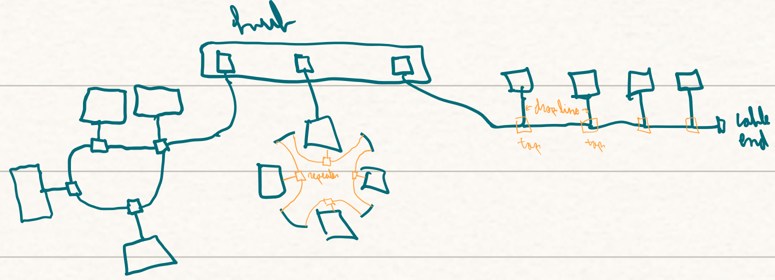
first exam spring 2020/2021

Q1 : (a)



(b)



Q1) (a)

1- data link layer addresses change every hop since it is responsible for moving frames between nodes. *(physical addressing)* Whereas, network layer addresses don't change since this layer is responsible for delivering individual packets from source to destination *(logical addressing)*

data link protocols are defined by the underlying network. *(supports all standard)* IP protocol includes ICMP, IGMP, RARP, ARP

2-

3- twisted pair has better performance in noise and crosstalk

in parallel pair, each wire is affected differently by noise and cross talk

- receiver gets no unwanted signal with twisted pair

4- data elements are what we want to send, signal elements are what we can send

data element is the smallest entity that represents a piece of information, signal element is the shortest unit (time-wise) of a digital signal

scrambling technique *(to maintain synchronization with trail of zeros)*

bipolar 8 zero substitution — *V: same polarity as previous pulse, B: opposite polarity*

5- B8ZS substitutes 8 consecutive zeros with 000VB0VB

high density bipolar order 3

HDB3 substitutes 4 consecutive zeros with B00V *(equal + and -)* or 000V *(unequal + and -)* if the pulse sequence after the last substitution had an equal number of + and - amplitude or not respectively

6- 8B6T → 8 digital elements and 6 signal elements *(3 levels)* *(self synchronizing due to redundant data)* → $r = \frac{4}{3}$ *(no DC)*, bandwidth $= \frac{3N}{4}$ *(average signal rate $= \frac{3N}{8}$, bit rate)*

4D-PAM5 → smaller bandwidth $(\frac{N}{8})$, self sync., no DC *(4 wires)* *(five levels)*

7- ARP: address resolution protocol, retrieves physical address of receiver from logical *(IP → MAC; logical, physical)*

RARP: reverse address res. prot., retrieves logical address from physical *(MAC → IP; physical, logical)*

8- guided: coaxial, twisted pair, waveguide/optical / contains signal inside physical limits of medium

unguided: microwave, radio waves, infrared / signal is not confined, no conductor needed

9- line-of-sight : higher frequency >30MHz / straight line

sky propagation: (2-30MHz), greater distance than ground prop. with lower power

10- step: density and n constant from center to end of core

graded: density and n decreases radially from core center, higher bandwidth than step

(b)

1- line-coding technique to transmit high speed data over copper wires, channel is partitioned into sub-channels called tones by making each tone orthogonal to others thereby allowing overlap of BW

2- when voltage level is constant (due to trail of 1s or 0s in some coding) the spectrum creates a very low frequency component called DC component which desync system

4- occurs in non-return to zero schemes, receiver assumes average of signal is baseline and uses this as reference for other signals. with a long trail of 'high' value signals, this average will increase making it difficult to decode accurately

5- a solution to maintaining sync. with trail of zeros without increasing number of bits

7- ———

connectionless and directional but fast

8- UDP: process to process protocol that only adds port addresses and some error control simpler

- TCP: more reliable connection based provides full transport layer services, slower

9- computer, internet connection, email address, etc.

Q3 : (a) nyquist : $\boxed{2B \cdot \log_2 L}$

capacity : $\boxed{C = B \log_2 (1+SNR)}$

upper limit : $5020000 \cdot \log_2 (1501) = 52.96$ Mbps

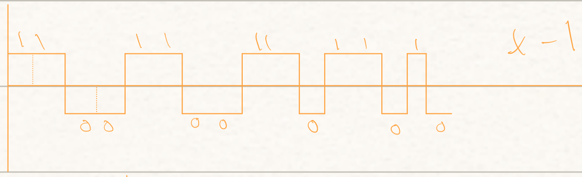
(b) $C = 26.63$ Mbps , when SNR is very high : $C = B \times \frac{SNR_{dB}}{3}$

(C)

average signal rate = $N/2$

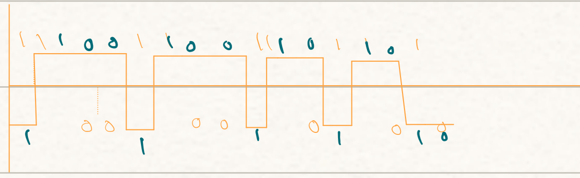
both have DC problem

1 -

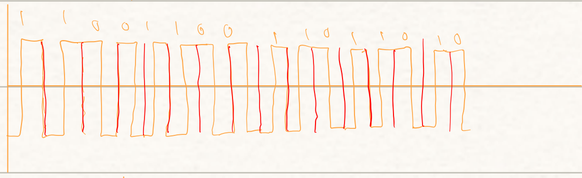


$x - 1$

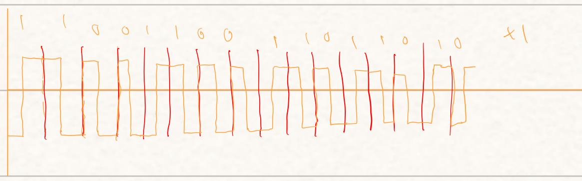
2 - inverts if next bit is 1



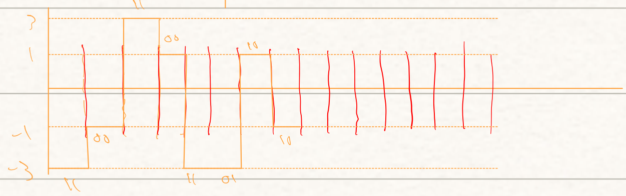
3 - 1 ↑ 0 ↓ double bandwidth of NRZ



4 - inverts direction double bandwidth of NRZ



5 -



Q4 : (a) $\frac{4000}{100 \text{ Mbps}} \rightarrow 4 \times 10^{-5}$

last bit leaves

arrives after own bandwidth delay

arrives after 10 ns

| - - - | → time 4×10^{-5} A 100 Mbps B

40

$10\,ns + \frac{D}{S} > 4 \times 10^{-5}$

$\rightarrow D > 7997$

assuming $S = 2 \times 10^8$ for wire

(b) transmission time $= \frac{20 \times 8 \times 10^6}{4 \times 10^6} = 40\,s$

total time: propagation time + trans. time $= \frac{1}{4 \times 10^6} + \frac{385000 \times 10^3}{3 \times 10^8} = 1.283\,s$

Q6) 1- presentation, 2- session, 3- data link, (transport) 4- session

5- presentation, (or session) 6- data link, 7- physical, 8- transport, 9- application,

10- physical, 11- transport, 12- data link and transport, 13- network,

14- physical, 15- transport, 16- data link, 17- data link, 18- application,

19- presentation, 20- physical

questions from book:

chapter 8 :

Q1: switching allows connecting multiple devices in a network. switches can create temporary connections, therefore they are more practical than buses and more efficient than star

Q2: three traditional switching methods: circuit switching, packet switching, and message switching

most common today

Q3: approaches to packet switching: datagram or virtual circuit

Q4: - in a circuit switched network, data is not packetized, instead data flows continually through the same channel

- in a packet switched network, data is packetised such that each packet becomes an independent entity with its respective addressing info.

Q5: defines source and destination

Q6: defines virtual circuit number

P1: a) $\frac{1000}{1\times10^6} + \frac{5000\times10^3}{2\times10^8}$ + delay for setup and teardown $= 104$ ms

- setup is assumed to be a two-way communication whereas teardown is one way

→ total delay for setup and teardown: $3 \cdot \left[\frac{1000}{1\text{Mbps}} + \frac{5000\times10^3}{2\times10^8}\right] = 78$ ms

b) $0.078 + \frac{5000\times10^3}{2\times10^8} + \frac{100000}{1\text{Mbps}} = 203$ ms c) 1.103 s

P2: 1 → $\frac{3200\text{k}}{2\times10^8} + 3 + 20 + 20 = 59$ ms

2 → 91.5 ms | 3 → 114 ms

P3: a) the channel is maintained for the whole transfer phase

b) setup and teardown phases don't exist in datagram network

each packet is independent, thus routing is done individually

c) in a virtual circuit network, end-to-end addressing during setup and teardown phases are required to make the corresponding entry in the switching table.

during transfer phase, each packet carries a virtual circuit identifier to determine which virtual circuit that packet follows

P6: datagram requires source and destination i.e two addresses

virtual circuit requires input port, output port, input virtual circuit identifier, output VCI

since VCI is a local number thus two different input and output ports may use the same VCI

- VCI is unique only in relation to a port -> (port, VCI) unique

Chapter 7:

Q1: below physical layer, controlled by physical

Chapter 8:

Q1: digital-to-digital: line coding, scrambling, block coding

Q2: data element is smallest entity that represents info / what we need to send — carried

signal element is shortest unit of digital signal / what we can send — carrier

Q3: data rate: bps, signal rate: baud, number of signals/s

Q6: include timing info in data with transitions

Q8: provides redundancy and ensures sync and error det.

Q9: long zero level with other levels

Q10:

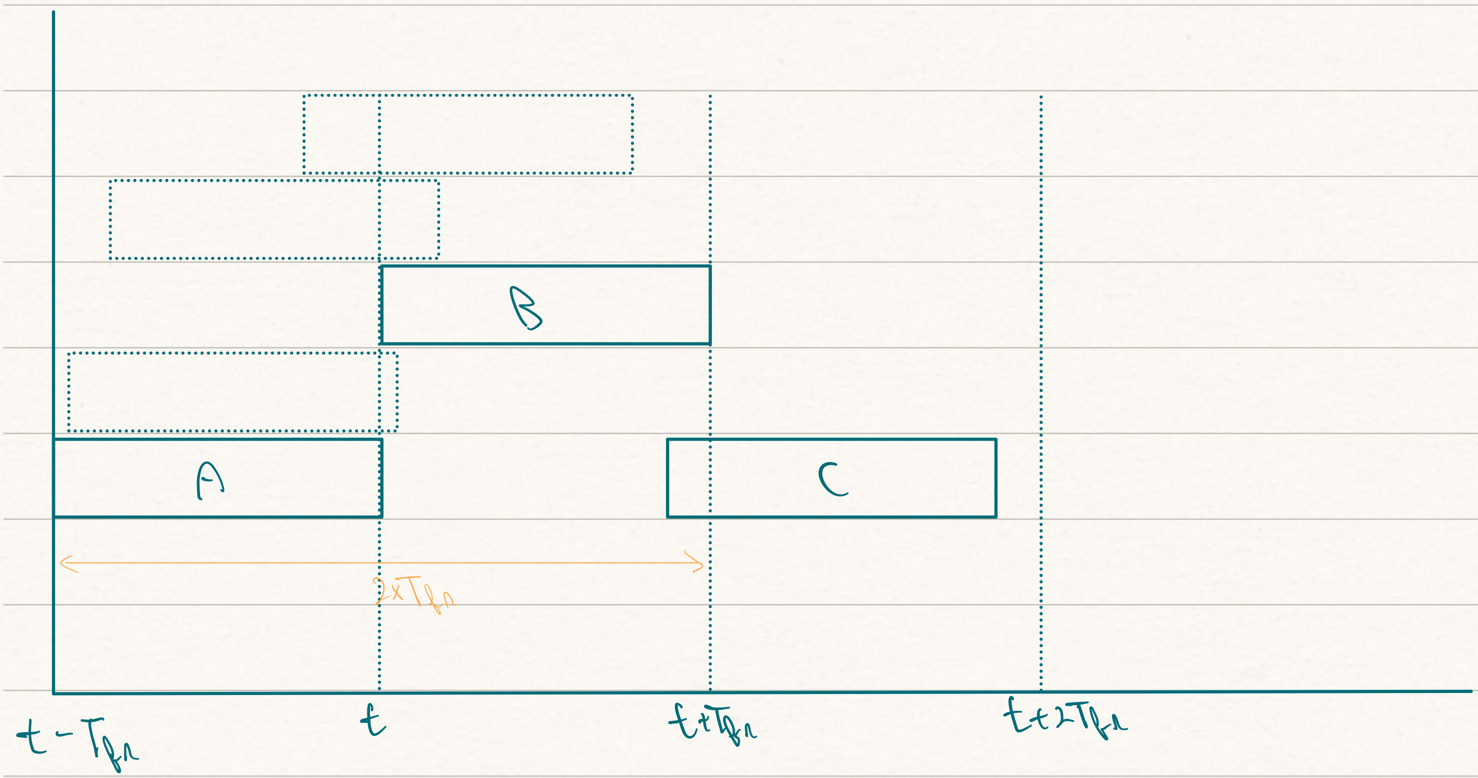
Chapter 10:

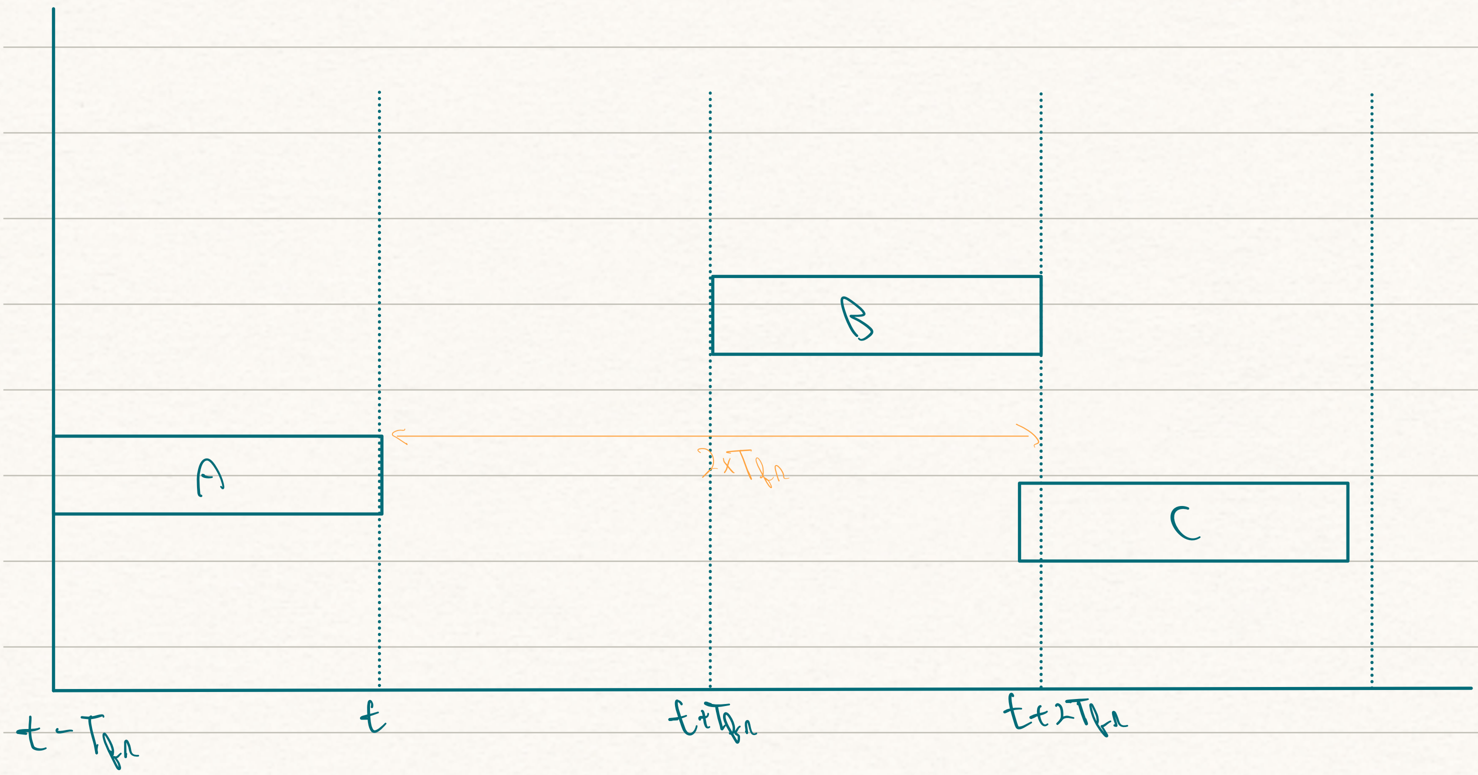
* forward error correction: receiver tries to correct corrupted codeword
* error detection by retransmission: the corrupted message is discarded when an error is detected and the sender needs to retransmit

* linear block code : data placed into codeword blocks in which the XOR operation between any two codewords gives another codeword
* cyclic code : a category of linear block codes in which the rotation of any codeword results in another codeword.

Chapter 11 : 1/12/2022

- flag : to identify end and beginning of frame, delimiter
+ Questions :





data link layer functions: data link control and media access control

Chapter 12 summary:

- data link can be viewed as two layers: upper layer is data link control, and lower layer is for resolving access to shared media
- many protocols to handle access to shared link, three categories: 1- random access 2- controlled access, 3 - channelization
- in random access, no station has control over another
- ALOHA allows multiple access to shared medium. collisions occur if two stations send at same time. collision with any bit of frame makes data garbled
- CSMA developed to minimise chance of collisions. stations sense medium before using through one of the following methods: I-persistent, P-persistent and nonpersistent
  - → I-persistent: station keeps sending same data until it is acknowledged
  - → p - persistent: p is probability of success, system only sends data if channel is

available. otherwise, system waits a backoff time

→ nonpersistent: system sends data once and doesn't resend regardless of success

- CSMA/CD: modifies CSMA to handle collisions
  frame is sent again if collision is detected
- CSMA/CA: to avoid collisions in wireless networks
  collisions avoided: interframe space, contention window, and acks
- in controlled access, stations consult each other to see who has the right to send. station cannot send unless authorized by others
  controlled-access methods: polling, token passing, and reservation
- FDMA: bandwidth divided into bands each reserved for a station
- TDMA: station has entire bandwidth of channel for certain time slot
- CDMA: different codes

8 9 11 12 13

check syllabus — check syllabus for second

8 (- first material) 9 first section, 10 first section

all 11 all 12

second preparation:

block coding:

datawords + redundant bits = codewords

$k + r \qquad n$

- since more codewords possible than datawords $(2^n > 2^k)$, and every dataword matched to one codeword, then $2^n - 2^k$ codewords not used.

+ to detect error: 1- receiver has list of valid codewords, 2- codeword changed to invalid codeword.

Second 2021:

Q1: 1- control field for I-frames contains bits that define the sequence number of the frame and, in case of piggybacking, the number of the ack. additionally, one of the bits identifies the frame as an I-frame.

on the other hand, S-frames' control fields first signify that the frame is an S-frame. the ack. or nak number is also contained here (in case piggybacking is not possible). finally, the control field defines the type of S-frame (RR, RNR, REJ, SREJ)

2- in bit stuffing, a single bit breaks up a sequence of five ones following a zero so that they are not mistaken for a flag. This is done by stuffing a zero after the fifth one.

byte stuffing requires insertion of 8 bits, which are called an escape character to inform the receiver that the next byte is a flag or a valid data sequence with the same pattern.

3- + go-back-N: receiver window size = 1
sender window size = $2^m - 1$
- if frame is lost, all subsequently sent frames must be resent
- etc.

+ selective-repeat: receiver window size = sender window size = 2^{m-1}
- lost frame can be resent individually upon receipt of Nak.

4- PAP: user sends username and password, simple

CHAP: system sends challenge packet to which user applies predefined procedure to solve. user then sends solution with password and system compares to grant or deny access

more secure, require more processing

5- ADSL: lower data rate, uses existing local loops

HDSL: higher data rate without repeaters, two twisted pairs

6- reservations: time is divided into intervals, station reserves time slot before transmitting, stations "take permission" from all other stations to reserve.

polling: a primary station asks each secondary station, in order, if it has data to send. if not, the station sends a Nak and the primary station polls the rest. otherwise, the secondary station sends data and the primary acknowledges its receipt.

Thus, the primary acts as the initiator and controls all transmission

7- non-persistent: station sends frame immediately if line is idle otherwise station waits a random amount of time and senses again.

p-persistent: station continuously senses. when channel becomes idle and transmission success probability is p, station sends.

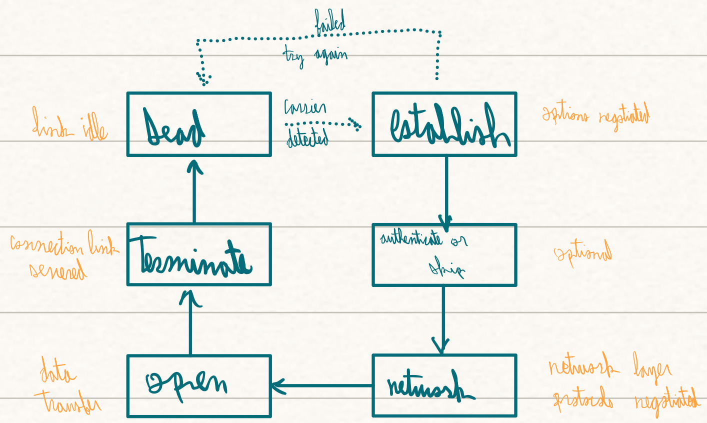
if probability of successful transmission is 1-p, station waits until next time slot and sends if line is idle. The channel in this method is divided into slots.

8 - N/A

Q2: 1- a scheme in which the message words are split into blocks of codewords where each message word has k bits and codeword has n bits the block coding scheme should allow error detection and correction. Thus, n must be greater than k.

2- a technique where tasks are started before an acknowledgement of the completion of previous tasks is received (or before previous task has ended). This improves efficiency.

3-



4 - carrier sense multiple access where collision is avoided by using an interframe space, defining a contention window, and waiting for ack

5 - a signal sent by any station that detects a collision to all other stations informing them of the collision

6 - modulation technique combining QAM and FDM used in ADSL

7 - replaces the modem and packetizes data.

8 - ADSL that does not require installation of splitters at the user's premises thereby making ADSL more practical as modem can be plugged directly into phone jack

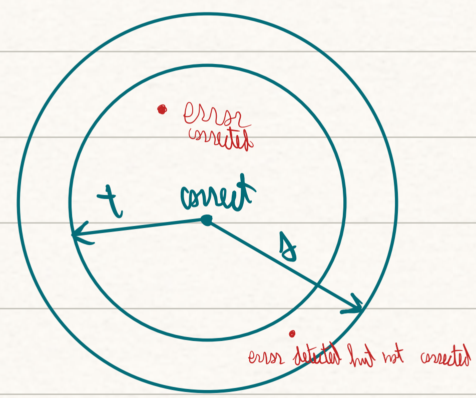
9 - Counting scheme in which numbers repeat without adding digits:

modulo - 5 : 0 → 4 : 0, 1, 2, 3, 4, 0, 1, ...

10 - N/A

11 - a circle with radius t is drawn around the correct codeword any codeword that lies in the bounds of the circle or on the circle is considered equal to the codeword in the center. moreover, any codewords not equal to the codeword in the center but still lie within the circle are detected as erroneous

for t errors corrected, 2t detected



12 - a message from the receiver to the sender informing them of the missing frame and requesting retransmission

13- to reduce frame size

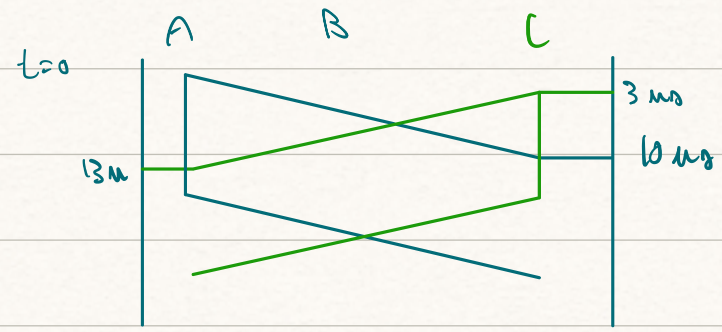
Q3: a) 1- $d_{min} = s+1 = 4$

2- $d_{min} = 2t+1 = 7$

3- detection of 4 → $d_{min} = 5$, correction of three → $\boxed{d_{min} = 7}$

4 - detection of six requires more than correction of three → $d_{min} = 7$

b)



1- 13 us

2- 10 us

3- 100 Mbps → 700 bits in 7 us

4- 1300 bit

incorrect

Chapter 19:

+ blocks in classful addressing:
  - in class A: first bit (MSB) is zero. next seven reserved for block number → $\overset{\text{blocks}}{0-127}$

    ∴ size of block $= 2^{\text{remaining bits}} = 2^{24} = 16,777,216$
  - in class B: first two bits reserved for type, 16384 blocks → next 14 bits for block number

    ∴ block size $= 32 - \underset{}{\overset{\text{class type bits}}{2}} - \overset{\text{block number bits}}{14} = 16$ bits $= 65,536$
  - same concept for other types with different number of blocks

1 1 1 1

0 0 0 0 → 16 addresses

first address = 32, last = 47

$11001101 . 00010000 . 00100101 . 0010\underbrace{0111}_{32-28=4 \text{ bits}}$

final IPv6 not included

options and everything up to 546 in

19.2 until address space included (redirection in)

18 out

1 and 2 in

3 out

4, 5, 6, 7, 9, 10, 13 out

8, 11, 12 in

total: 1, 2, 8, 11, 12, 19, 20

$$a^3_n = \frac{K}{\pi}\int_{-\pi}^{\pi} \cos((N-2n)\theta)\cdot T_N \sec(\theta m) \cdot \cos(\theta)\, d\theta$$

$$F = \left|\sum_{n=0}^{M} 2a^3_n \cos((N-2n)\theta)\right| = K\left|T_N \sec(\theta m) \cos(\theta)\right|$$

$$F = a_0^3 + \left|\sum_{n=1}^{M} 2a^3_n \cos((N-2n)\theta)\right|$$

$$K\int \cos[(N-2n)\theta] T_N \sec(\theta m)\cdot \cos\theta \, d\theta$$

final practice:

Q1: 1) the time to live field changes, there may also be changes in the fragmentation and options fields. Any changes in the header will also change the checksum at the router. When fragmentation occurs, there will be change in the total length field, fragment offset, fragment flag (more fragments bit) and identification

2) HLEN = 48 bytes → $\frac{48}{4} = 12 = \boxed{1100}$

3) 1123 (1024 + 99, since 0 inclusive)

4) 25.34.12.56/16 → first 16 bits reserved

→ first address = 25.34.0.0, last address = 25.34.255.255

number of addresses = 2^{16}

Q2: $t_3 - t_1 = \frac{2k}{0.2\times10^6} = 10\ \mu s$

$t_4 - t_2 = 10\ \mu s \rightarrow t_4 = 13\ \mu s$ ∴ A hears at 13 μs

∴ 1) $t_4 = 13\ \mu s$ when A hears

2) $t_3 = 10\ \mu s$ when C hears

3) t bits transmitted = 7 μs → bits = 10M · 7μ = 70 bits

4) t bits transmitted = 13 μs → bits = 130 bits

Q3: (a) 1) data link addresses the physical address of the node connected to the link. This physical address changes at every node.

The network addresses are logical addresses of the source and destination it does not change while traveling

The network layer uses protocols of the IP suite (ICMP, IGMP, ARP, RARP)

whereas the data link layer does not follow a specific protocol

3) the size of both send and receive windows are the same in selective repeat ARQ and they are equal to $2^{m-1} = 2^4 = 16$

4) in subnetting is when an organization divides a block of address between different subnets. the organization is seen to have one address. all messages are sent to a router that connects the organization to the internet and the subnets. the router routes messages to the specific subnet it is meant for and each subnet has its own mask different from the organization's

subnetting is when an address block is divided into smaller blocks with contiguous addresses and each of these smaller block define small networks called subnets. a subnet will have a mask with more 1s

supernetting is when several address blocks (usually C blocks) are added to create a large address block. this decreases the number of 1s in the mask.

(b) 1) CIDR: classless interdomain routing

a method of allocating addresses. The CIDR notation is shown by the /n where n is the number of fixed bits in the mask

2) network address translation: when a large set of addresses exist internally but only one address appears to the internet

the internal addresses need to be unique internally but need not be unique globally

Q4: a) 1: VER ✓ HLEN ✓ total length = $(54)_x$ = 4 + 80 = 84 bytes

header checksum is zero → corrupted not sure!

2: HLEN = 20 → no options

3: flags and fragmentation offset: flags → $\boxed{010}$1 1000 01010000

the don't fragment bit is 1 → no fragments

4: data size = 84 − 20 = 64 bytes

5: time to live: 2×16 = 32 hops

6: identification: 3

b) 1. 11010000 . 0010 0010 . 0011 0110 . 0000 1100

2. 10000001 . 0000 1110 . 0000 0110 . 0000 1000

3. 0111 . 0010 . 0010 0010 . 00000010 . 00001000

c) 1. class C A 1/2 0 → 127 B 1/4 128 → 191 C 1/8 = 192 → 223

2. class B D 1/16 224 → 239 E 1/16 240 → 255

3 class A

Q4: M bit → more fragments if 1, D → don't fragment if 1

1- offset 200 → first bit = 200·8 = 1600

2- last byte = 1600 + 200 − 4×5 − 1 = 1779

3- last since M is zero

Q5: 1. mask is all contiguous ones → A

2. C 3. in classless addressing prefix length defines the mask:

mask = 27 → 2^5 addresses 32

6. $\begin{array}{r} 142 \\ \times\ 64 \end{array}$ = $\begin{array}{r} 1100\ 0000 \\ \times\ 0100\ 0001 \\ \hline 0100\ 0000 \end{array}$ = 64

in 1 block 16M in A

7. in class C → 256 addresses, 65K in B

268 M in D and E

8. 27 → 2^5 last 5 bits

and $\left.\begin{array}{l} 0100\ 1100 \ (76) \\ 1110\ 0000 \end{array}\right\}$ 0100 0000 = 64

9. $\left.\begin{array}{l} 0000\ 0110 \\ 0000\ 0011 \end{array}\right\}$ 111 7

10. fixed length → $\log_2(10) = 3.3 \to 4 = 24$

- identification field same for all fragments

Chapter 20:

- IPv4 unreliable connectionless, responsible for source to dest delivery
- IPv4 packets called datagrams with header 20 → 60 bytes
  max length: $2^{16}-1$ bytes
- MTU: max number of bytes link can encapsulate
- fragmentation: split large datagrams to accommodate MTU
- 40 (max) bytes of options for testing and debugging
- size options: filler between options for alignment, padding, recording route, selection of mandatory route, selection of certain routes, recording processing time

review questions:

1 - delivery of packet in network layer means packet delivered from source to final destination whereas delivery of frame in datalink layer means delivery from node to next node

host-to-host

node-to-node

2 - connectionless: no setup or teardown phases, each datagram independent
only data transfer phase

connection-oriented: setup, teardown, and data transfer
virtual connection established before

IPv4

→ IPv4 and v6 normally connectionless but IPv6 can be connection

3. fragmentation is splitting of large datagrams into smaller to accommodate MTU. IPv4 allows fragmentation at host and routers

4 - the header sections are split into contiguous 16 bit blocks and added (carry is added to next) the complement of the sum is stored changes with every visit (TTL changes)
once received checksum is added if result is zero no error
covers header only, header changes at every hop
other fields have own checksum from higher levels

13 - large MTU accommodates large packages without splitting
reduces processing time in reassembly, fewer lost
small improves transmission efficiency, transmits fast
better for mux

14 - first: $8 \cdot 120 = 960$

20- identification field incremented for next datagram if not fragmented

ver	HLEN	service	total length	identification	frag flag and offset	TTL	protocol	checksum
x 4	5	00	00 54	00 03	58 50	20	06	00 00

→ 32 bits source then 32 bits dest

Chapter 19

- global identification identifies each host and router uniquely using 32 bits to enable delivery of packets host-to-host
- A, B, and C: unicast, D: multi, E: reser
- subnetting: divide network into smaller creating intermediate level of IP or more 1s in mask if classless

+ restrictions on classless:
  - number of addresses 2^x
  - mask needs to be included to define block
  - (value in decimal) of starting address needs to be divisible by number of addresses

3- classful addressing assigns organization a class A, B, or C blocks of addresses which they there

classless: assigns set of contiguous addresses with mask

6- in classless addressing, mask defines (CIDR) number of contiguous 1s that set the prefix

in classless mask used to find first address

default when no subnetting

- network address: first address in block

- NAT: large set of unique addresses internally (but not unique globally) and one address externally

16- A: 0 → 127 , B: 128 → 191 , C: 192 → 223 , D: 224 → 240

18- a) class A → only first byte fixed → netid = 114 , host: 34.2.8

b) class B → first 2 bytes fixed → netid = 132.56

c) class C → first 3 bytes → netid = 208.34.54

20-
AND 00010000 11000000 } 182.44.82.00 first

or 00010000 00111111 } 182.44.82.63

19- ..12.56

AND 0000 1100 . 0011 1000 , 0000 0000 . 00000000 } 25.34.0.0 first

or 1111 1111 . 1111 1111 → 25.34.255.255

21- a) 500 subnets → $\log_2 500 = 9$ more 1s in mask

→ /17

b) $2^{32-17} = 1024 \cdot 32 \approx 32k$

c) first address in subnet 1:

16.0. 0000 0000 (fixed) → 16.0.0.0 , last: 16.0.127.255

d) subnet 500: 500/2 − 1 = 249 last

16.249.128.0 first , 16.244.255.255 last

22. a) 26 b) $2^6 = 64$ c) 130.56.0.0 first , 130.56.0.63

d) 130.56.255.11000000 (192) last 255

23. a) /29 b) 8 c) 211.17.180.0 , 211.17.180.7

d) 211.17.180.255

25. a) 123.56.77.32 AND 00100000 11111 } first = 123.56.77.32

last 00100111 123.56.77.39

b) 200.17.21.1000 0000 AND 0001 1111 } first 128, last: 1001 1111 159

c) 17.34.00010000.0000 0000 first 16.0

1 1111 1111 last 17.255

d) 180.34.66.64 → first last: 180.34.64.69

26. a → /25, b → /28, c → /30

available: 2^{16} = 65 k, needed: 60 k

first address divisible by 128

27. /24

Chapter 12:

- data link: two sublayers: upper data link control, lower shared media

- protocols: random access, controlled-access, channelization

no superior

13: pure aloha → $T_{fr} = \frac{1000}{1m} = 1$ ms

throughput = $G \times e^{-2G}$ for pure Aloha

$G = 10 \cdot 100 \cdot T_{fr} = 1$ → throughput = 13.5%

14. slotted aloha → throughput = $G \times e^{-G} = e^{-1} = 36.8\%$

15. $T_{fr} = \frac{512}{10m} = \frac{x}{100m} = \frac{y}{1G} = \frac{z}{10G}$ → $x = 5120$, $y = 51200$

$z = 512k$

16. $T_{fr} = 2 \times T_p = 2 \times \frac{\text{distance}}{\text{prop speed}} = \frac{\text{frame size}}{\text{data rate}}$

$\therefore$ distance × datarate $= 2600 \cdot 10\,M = x \cdot 100\,M = y \cdot 1G$

$\rightarrow x = 260 \,,\ y = 26$ - -