DATA COMMUNICATIONS AND NETWORKING

Solved Examples

References:

STA: Stallings, Data and Computer Communications, 6th ed.
TAN: Tannenbaum, Computer Networks, 4th ed.)

1. Given the following information, find the minimum bandwidth required for the path:
FDM Multiplexing
Five devices, each requiring 4000 Hz.
200 Hz guard band for each device.

Solution:

No. of devices = 5.

No. of guard bands required between these is 4.

Hence total bandwidth = (4000 x 5) + (200 x 4)
= 20.8 KHz.

2. An end system sends 50 packets per second using the User Datagram Protocol (UDP) over a full duplex 100 Mbps Ethernet LAN connection. Each packet consists 1500B of Ethernet frame payload data. What is the throughput, when measured at the UDP layer?

Solution:

Frame Size = 1500B

Packet has the following headers:

IP header (20B)

UDP header (8B)

Total header in each packet = 28B

Total UDP payload data is therefore 1500-28 = 1472B.

Total bits sent per second = 1472 x 8 x 50 = 588800 bps or **588 kbps.**

3. Imagine the length of a 10Base-5 cable is 2500 metres. If the speed of propagation in a thick co-axial cable is 60% of the speed of light, how long does it take for a bit to travel from the beginning to the end of the cable? Ignore any propagation delay in the equipment. (Speed of light = 3 x 10^8 metres / sec)

Solution:

Speed of propagation = 60% x c
= 60 x 3 x 10^8 / 100
= 18 x 10^7 metres / sec.

So it would take a bit 2500 / 18 x 10^7 = 13.9 μsecs

4. Given a channel with an intended capacity of 20 Mbps. The bandwidth of the channel is 3MHz. What signal-to-noise ratio is required in order to achieve this capacity? (STA, Problem 3.17, Pg. 100)

Solution:

According to Shannon's Capacity formula (Stallings, 6th ed., page 96), the maximum channel capacity (in bps) is given by the equation:

$$C = B \log_2(1 + SNR)$$

Where B is the bandwidth and SNR is the signal-to-noise ratio.

Given B = 3 MHz = 3×10^6 Hz, and

C = 20 Mbps = 20×10^6 bps,

So,

$$20 \times 10^6 = 3 \times 10^6 \log_2(1 + SNR)$$
$$\log_2(1 + SNR) = 20 / 3 = 6.667$$
$$1 + SNR = 102$$

Hence, SNR = 101

(Note, SNR can also be written as S/R to indicate that it is the signal-to-noise ratio)

6. A digital signaling system is required to operate at 9600 bps. (a) If a signal element encodes a 4-bit word, what is the minimum required bandwidth of the channel? Repeat part (a) for the case of 8-bit words. (STA, Problem 3.14, Pg. 100)

Solution:

(a) By Nyquist's formula, the channel capacity is related to bandwidth and signaling levels by the equation $C = 2B \log_2 M$, where M is the number of discrete signal or voltage levels

Here C = 9600 bps, $\log_2 M = 4$ (because a signal element encodes a 4-bit word)

$$2B = C / \log_2 M$$
$$B = C / (2 \times \log_2 M)$$
$$B = 9600 / (2 \times 4)$$
$$B = 9600 / 8$$

Hence, B = 1200 Hz.

(b) For this case, take $\log_2 M = 8$ (because a signal element encodes a 8-bit word)

Proceeding in a similar way, we get B = 600 Hz.

7. What is the channel capacity for a teleprinter channel with a 300 Hz bandwidth and a signal-to-noise ratio of 3 DB? (STA, Problem 3.13, Page 100)

Solution:

Using Shannon's equation: $C = B \log_2(1 + SNR)$ we have

B = 300 Hz and SNR (in dB) = 3,

Therefore, $SNR = 10^{0.3}$ (Ref STA, pg 96)

$C = 300 \log_2(1 + 10^{0.3})$

$C = 300 \log_2(2.995)$

C = 474 bps

8. Suppose that data are stored on 1.44 Mbyte floppy diskettes that weight 30 g each. Suppose that an airliner carries 10^4 kg of these floppies at a speed of 1000 km/h over a distance of 5000 km. What is the data transmission rate in bits per second of this system? (STA, Problem 4.1, Page 127) [Note: I have taken disk capacity as 1.44 MB instead of 1.4 MB as given in STA]

Solution:

First calculate the time for which data was carried:

Speed = distance / time

So time = distance / speed

Time = 5000 km / 1000 kmph = 5 hrs.

Now 1.44 Mbytes = 1.44 x 10^6 x 8 bits = 11.52 x 10^6 bits

Each floppy weighs 30 gm, and total load (of floppies) carried is 10^4 kg = 10^7gms.

Hence, number of floppies carried = 10^7 gms / 30 gms = 333333

Now each floppy contains 11.52 x 10^6 bits and so 333333 floppies will contain

11.52 x 10^6 x 333333 bits = 3839996 x 10^6 bits

Now calculate data transmission speed:

Data transmission speed = data carried in bits / time

Data transmission speed = 3839996 x 10^6 bits / (5 hrs x 60 mins x 60 secs)

= 213.3 x 10^6 bits/sec

= 213.3 Mbps.

9. Television channels are 6 MHz wide. How many bits/sec can be sent if four-level digital signals are used? Assume a noiseless channel. [TAN, Problem 3, Page 177]

Solution:

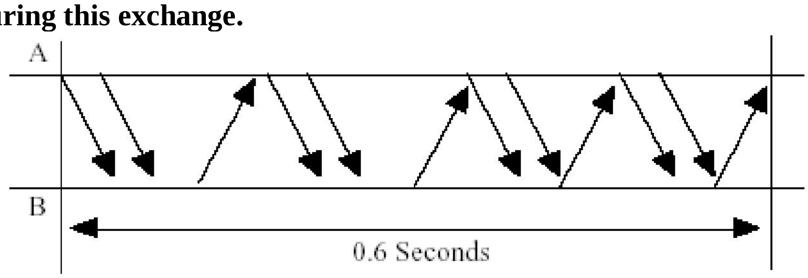
Bandwidth = 6 MHz (given) = 6 x 10^6

Using Nyquist's Theorem,

$$C = 2B \log_2 M$$
$$C = 2 \times 6 \times 10^6 \times \log_2 4$$
$$C = 24 \text{ Mbps}$$

Hence, C = 24 Mbps

10. The following frame transition diagram (figure 1) shows an exchange of Ethernet frames between two computers, A and B connected via a 10BT Hub. Each frame sent by Computer A contains 1500 B of Ethernet payload data, while each frame sent by Computer B contains 40 B of Ethernet payload data. Calculate the average utilization of the media during this exchange.



Solution:

No. of frames from A = 8.

Ethernet MAC Frame Payload = 1500B

Total A Frame Size = 8 B (Preamble) + 14 B (Mac) + 1500 B + 4 B (CRC-32)
Total A Frame Size = 8+14+1500+4 = 1526 Bytes = 12208 bits

No of Frames from B = 4
Total B Frame Size = 40B
Total B Frame Size = 8 B (Preamble) + 14 B (Mac) + 40 + 6 B PAD + 4 B (CRC-32)
= 8+ 60 + 4 = 72 B = 576 b

(We have ignored the Inter Frame Gap (IFG) which could be included as overhead).

Hence, total utilized bandwidth in this period
= 12208 x 8 + 576 x 4
= 97664 + 2304
= 99968
Utilization = 99968 / (0.6 x 10^7) = 1.7 %
[The factor 10^7 appears because the Ethernet typically operates at 10 Mbps]

11. A client program sends one UDP packet with 100 B of data each second to a server and receives a corresponding reply also with 60 B of data. The client and server are connected by an Ethernet LAN. Calculate the total number of bits sent via the Ethernet network by this program in each second. From the number of bits per second calculate the utilization, given that Ethernet typically operates at 10 Mbps.

Solution:

1 UDP message sent per second, with 1 reply received per second.

Each message contains:

MAC-Preamble (8 bytes) + MAC Header (14 bytes) + IP Header (20 bytes) + UDP (8 bytes) + UDP Payload (60 bytes) + CRC-32 (4 bytes)

Total sent per second = (8+14+20+8+60+4) * 8 * 2= 912 * 2 bps = 1824 bps

Total per second= 1824 bits /sec

Assume 10 Mbps Ethernet operation.

Utilization = (Total bits per sec / clock rate) * 100 = (1824 / 10 x 10^6) x 100 = 0.018 %

Hence, utilization = 0.018 %

12. A TCP session sends 10 packets per second over an Ethernet Local Area Network (LAN). Each packet has a total size of 1480 B (excluding the preamble and cyclic redundancy check (CRC)). Calculate the size of the headers, and hence the TCP payload data. What therefore is the TCP throughput of the session?

Solution:

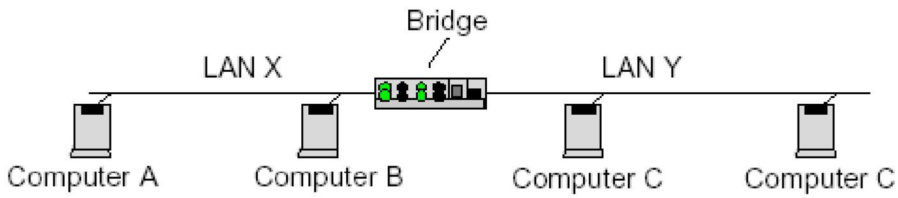
First we determine the protocol headers which contribute to the PDU size:

MAC Header (14 bytes) + IP Header (20 bytes) + TCP(20 bytes) + TCP Payload (? bytes)

Next determine the size of the payload:
Payload = 1480 - (14+20+20) = 1426 B

Throughput = number of useful (data) bits transferred by a layer using the services of the layer below.
= 1426 x 8 x 10
= 114 kbps.

13. A small Local Area Network (LAN) has four computers A, B, C and D connected in the following topology:



(a) The computer A sends a graphics file of size 10 MB simultaneously to computers B, C, and D using Unicast packets constructed by the Universal Datagram Protocol (UDP). Calculate the utilization of LAN X, given that each frame carries 1024 B of UDP payload data, and transmission is at 50 packets per second to each destination.

(b) What is the utilization on LAN Y?

Solution:
(a) All packets travel on LAN X.

Each packet has the following protocol headers (PCI):
MAC-Preamble (8 bytes) + MAC Header (14 bytes) + IP Header (20 bytes) + UDP(8bytes) + UDP Payload (1024 bytes) + CRC-32 (4 bytes)

[The inter-frame gap may also be considered as overhead, which will yield a slightly higher answer.]
Total size = (8 + 14 + 20 + 8 + 1024 + 4) x 8 = 8624 bits

50 UDP message sent per second to 3 computers = 150 UDP messages/second
Assume 10 Mbps Ethernet operation.
Total utilization = 8624 x 150 / (10 x 1000 000 x 100) =13%

(b) This is different, since this is unicast transmission, the bridge will not forward packets from A to B. It will however forward packets from A to B and C. The utilization on LAN Y is therefore: 2/3 of 13%, i.e. 9%.

14. A computer on a 6-Mbps network is regulated by a token bucket. The token bucket is filled at the rate of 1 Mbps. It is initially filled to capacity with 8 Mbps. Hw long can the computer transmit at the full 6 Mbps?

Solution:
Suppose for time *t*, the computer can transmit at the full 6 Mbps.

Then 6t = 8 + t
Hence, t = 1.6 sec

15. A group of N stations share a 56 kbps pure (unslotted) aloha channel. Each station has one (NEW) packet arriving every 100 seconds and packets are 1000 bits long. What is the maximum value of N that the channel can accommodate? [TAN, Problem 2, Page 338]

Solution:

The required data rate is
N * (1000 bits per packet) * (1 packet/100 seconds) = 10 N bps.

Since, efficiency = 18%,

With unslotted aloha, the available data rate is 0.18 * 56,000 bps = 10,080 bps.

Rate required = rate available
⇨ 10 N = 10080
⇨ N <= 1008 stations.

16. A system has a n-layer protocol hierarchy. Applications generate messages of length M bytes. At each of the layers, an h-byte header is added. What fraction of the network bandwidth is filled headers?

Solution:
Given: (1) n-layered protocol.
(2) Each layer adds a h – byte header.

Hence, the total number of header bytes per message is *hn*.

So the relative space wasted on header is *hn/M*.

17. A simple telephone system consists of two end offices and a single toll office to which each end office is connected by a 1-MHz full-duplex trunk. The average telephone is used to make four calls per 8-hour workday. The mean call duration is 6min. Ten percent of the calls are long-distance (i.e., pass through the toll office). What is the maximum number of telephones an end office can support? Assume 4 kHz per circuit.

Solution:
Each telephone makes 0.5 calls/hour at 6 minutes each. Thus, a telephone occupies a circuit for 3 min/hour. Twenty telephones can share a circuit. Since 10% of the calls are long

distance, it takes 200 telephones to occupy a long-distance circuit full time. The interoffice trunk has 1,000,000/4000 = 250 circuits multiplexed onto it. With 200 telephones per circuit, an end-office can support 200x250 = 50,000 telephones.

18. A channel has a bit rate of 4kbps and a propagation delay of 20 msec. For what range of frame sizes does stop-and-wait give an efficiency of at least 50 percent?

Solution:

Efficiency will be 50% when the time to transmit the frame equals the round trip propagation delay. At a transmission rate of 4bits/ms, 160 bits takes 40 ms. For frame sizes above 160 bits, stop-and-wait is reasonably efficient.

19. A message is split into 10 packets, each of which has 80% chance of arriving undamaged. Assuming no error control, how many attempts to send the message are required for the entire message to arrive intact?

Solution:

P(all correct) = $0.8^{10} \sim 0.1$

Therefore the average number of attempts is 1/P ~ **10**

20. Suppose five devices are connected to a statistical time division multiplexer and that each produces output as shown here. Construct the frame that the multiplexer sends.

Solution:

0	A_3	0	A_2	A_1
B_4	B_3	0	B_2	B_1
0	C_2	0	0	C_1
D_5	D_4	D_3	D_2	D_1
0	0	E_2	0	E_1

The frames which are sent are

$A_1B_1C_1D_1E_1$
$A_2B_2D_2$
D_3E_2
$A_3B_3C_2D_4$
B_4D_5

21. Suppose we want to devise a single-bit error-correcting Hamming code for a 16-bit data string. How many parity bits are needed? How about for a 32-bit data string.

Solution:
The number of bits actually transmitted is the number of data bits plus the number of parity bits. If we have 16 data bits and only use 4 parity bits, then we would have to transmit 20 bits. Since there are only 16 combinations that can be constructed using 4 parity bits, this is not enough. With 5 parity bits, we must transmit 21 bits. Since there are 32 combinations that can be constructed using 5 parity bits, there will be enough combinations to represent all single-bit errors.

With 32 data bits, using 5 parity bits will not be enough since we would have to transmit 37 data bits and 5 parity bits only allows 32 combinations. With 6 parity bits, we have to transmit 38 data bits. Since 6 parity bits gives 64 combinations, there will be enough combinations to represent all single-bit errors.

Random Thoughts

1. Consider the following definitions.

R - transmission rate (bits/second)
S - signal speed (meters/second)
D - distance between the sender and receiver (meters)
T - time to create (build) one frame (microseconds)
F - number of bits in a frame
N - number of data bits in a frame
A - number of bits in an acknowledgement
P - percentage of time that bit are in the channel.

(i) Since R is the transmission rate, the amount of **time required to transmit one bit** is 1/R .

(ii) Since there are F bits in a frame, **time required to transmit the whole frame** is F/R.

(iii) The bits must then travel the channel. Since D is the length of the channel and S is the speed of the signal, the **time required to travel the channel** is D/S.

So after the last bit is transmitted it requires D/S time to get to the receiver.

(iv) **Time required for a frame to be sent is:**
time to create a frame + time to transmit a whole frame + time reqd. by the last bit to travel
= T + F/R + D/S.

(v) Similarly the **time required for an acknowledgement** is T + A/R + D/S.

(vi) In the **unrestricted** protocol a new frame is built as soon as the last one is sent. So the time required to build a new frame is T + F/R.

(vii) **For stop-and-wait** time required to build a new frame is
T + F/R + D/S + T + A/R + D/S.

(viii) The **time required to transmit a frame** is F/R + D/S.

(ix) Let P be the **percentage of time that bits** are in the channel.

With the unrestricted protocol we have:
P = (F/R) * 100 / (T + F/R)

With the stop and wait protocol we have:
P = (F/R + D/S) * 100 / (T + F/R + D/S + T + A/R + D/S)

(x) **Effective data rate:** It is defined as the number of data bits sent per unit time. It is found by dividing the number of data bits by the elapsed time between sending two frames.

For the unrestricted protocols the effective data rate is N/(T + F/R),
For the stop and wait protocol, it is N/(T + F/R + D/S + T + A/R + D/S).

2. Efficiency of Token Ring Network

In a Token Ring Network, we don't have to worry about contention.

We define the **percent utilization** as

U = 100* (time to send a frame)/(time to send a frame + time to send a token).

Usually the time to send a token is small compared to the time to send a frame, so percent utilization is close to 100%.