Politecnico di Torino

Exercises on Ethernet Standards

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Contents

License

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Part I.

Exercises

1. Exercises

1.1. Exercise 1

Given an Ethernet network, answer to the following questions:

1. Estimate the maximum theoretical diameter of an Ethernet v.2.0 (10 Mbps) network.
2. Indicate and motivate the differences between Ethernet v.2.0 and IEEE 802.3 with respect to the maximum allowed diameter of the network.

1.2. Exercise 2

Estimate the maximum theoretical diameter of:

1. A Fast Ethernet network.
2. A Gigabit Ethernet network.

1.3. Exercise 3

Given an Ethernet v.2.0 network, answer to the following questions:

1. Calculate the maximum throughput (in Mb/s) obtainable at layer-1.
2. Calculate the maximum throughput (in Mb/s), considering only the valid data at Ethernet level (i.e., without Preamble, SFD and Inter-Frame Gap).
3. Calculate the maximum throughput (in Mb/s) obtained by any layer-3 protocol.
4. Calculate the maximum efficiency of the network (defined as the ratio between the maximum amount of layer-3 data and the total data sent).

1.4. Exercise 4

Evaluate the maximum throughput (in Mb/s) obtained over a Gigabit Ethernet network when each station sends only one frame at a time, considering both the L2 and L3 throughput.

1.5. Exercise 5

Evaluate the maximum throughput (in Mb/s) obtained over a Gigabit Ethernet network when each station sends the maximum allowed amount of continuous data according to the Burst Mode defined by the standard, considering only the valid data at Ethernet (L2) level. Assume that hosts generate only frames of the maximum size.

1.6. Exercise 6

Assuming a Gigabit Ethernet network, answer to the following questions:

1. Evaluate the throughput (in Mb/s) obtained by any layer-3 protocol, assuming that a station sends a total of 4278 bytes of L3 data, which is then encapsulated at L2 using the minimum frame and sent one frame at a time.
2. Repeat the previous exercise assuming that the station sends the maximum allowed amount of continuous data according to the Burst Mode defined by the standard, using the minimum frame size.
3. Comment briefly the differences, if any, between the results.

1.7. Exercise 7

An host is currently involved into a VoIP session, where the voice uses the PCM-64 codec (64Kbps). Assuming that:

1. the host sends a new packet every 40ms
2. voice is encapsulated directly in RTP, which is then encapsulated in UDP
3. the data-link layer is a 10Mbps Ethernet
4. each protocol has the standard value of the header length

Determine, for each packet, *(a)* the amount of bytes that actually contain voice samples, *(b)* the size of the header of each protocol that is supposedly present in that packet, and *(c)* the total number of bytes of the protocol headers determined above. Determine also the efficiency of the encapsulation (in %).

1.8. Exercise 8

Assuming that an host on a Gigabit Ethernet is currently transmitting as fast as possible a continuous stream of IP packets whose length is 100bytes, and assuming that the station does not make use of the burst mode, calculate:

1. the maximum amount of IP traffic that we can generate on that network
2. the efficiency, in percentage, of this transmission.

1.9. Exercise 9

A station S has to send data on a FastEthernet network. However, the channel appears busy due to another station that is currently transmitting its data.

Calculate the maximum amount of time that the station has to wait before trying to get access to the channel[1].

Repeat the exercise in case of a Gigabit Ethernet station.

[1]We suppose that the station S does not generate any collision on the channel.

Part II.

Solutions

2. Solutions

2.1. Solution for exercise 1

1. The minimum Ethernet v.2.0 frame size is 64 bytes. Considering also the Preamble (7 bytes) and the Start Frame Delimiter (1 byte), we can argue that the minimum amount of information transmitted over the link for each packet is *(7+1+64) bytes=72 bytes=576 bits*. However, the collision must be detected within 575 bits, because the transmission of 576 bits leads to a valid frame.

   Note that the Preamble (max 7 bytes) might not be considered in this evaluation because of the possible variable nature of its length. In fact, this field may be shortened by each hub encountered by the frame, which uses the Preamble to synchronize its receiver clock with the transmitter. In this cast the maximum number of allowed bits will be 519 (the 512 bits of the minumum Ethernet frame, plus 8 bits of the Starting Frame Delimiter, minus 1 bit). However the IEEE 802.3 standard still considers the preamble, so we do the same.

   Given the transmission time for a single bit (0.1 μs in a 10 Mbps network), the time needed to transmit this data is:

   $$575 \text{ bits} \times 0.1\ \mu s/bit = 57.5\ \mu s.$$

   Since (i) data have to reach the outmost station of the network before the sender finishes to transmit and (ii) the sender has to be able to eventually detect a collision, the transmitted signal has to reach the outmost station in $57.5\ \mu s/2 = 28.75\ \mu s$. Since the propagation speed of an electromagnetic signal on the physical medium is about 200,000 Km/s, we can argue that the maximum extension of an Ethernet network is approximately:

   $$200{,}000\ Km/s \times 28.75\ \mu s = 5750\ m.$$

   Note that this is an upper bound of the requested value as the exercises does not consider tolerances that are usually important in real network scenarios. Furthermore, it has to be considered that the maximum network diameter proposed is several standards is shorter than this theoretical value because of the physical limitations of the adopted medium, which limit the maximum network extension more than the CSMA-CD protocol.

2. The sum of the minimum frame size (64 bytes) and the amount of additional bytes required to send a frame through the network (Preamble, Start Frame Delimiter) is 72 bytes for both Ethernet v.2.0 and IEEE 802.3. Hence, there are no differences between Ethernet v.2.0 and 802.3 concerning the maximum allowed diameter.

2.2. Solution for exercise 2

Fast Ethernet

In a Fast Ethernet network the transmission time of a single bit is 10 times shorter than on an Ethernet network and it is equal to 0.01μs. Therefore, the theoretical maximum extension is reduced to (5750 / 10) = 575 m.

Gigabit Ethernet

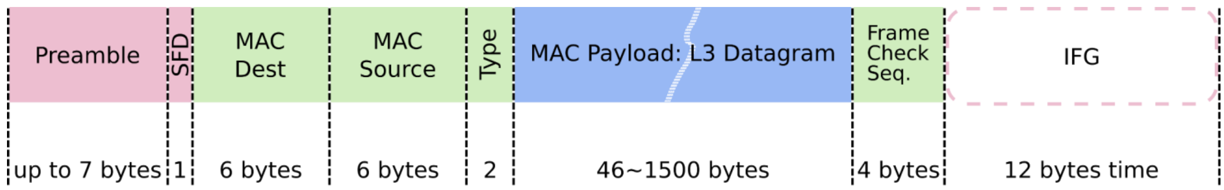
Gigabit Ethernet defines the Carrier Extension function in order to enlarge the minimum duration of a transmission (including the Preamble and Start Frame Delimiter fields), so that:

$$data+extension=4096\ bits$$

Given its bit time equal to 1 ns (100 times shorter than Ethernet) and that the collision should happen within the collision window (hence not later than the 4095th bit), this results in a total transmission time of 4.159 μs. This leads to a maximum diameter, when the CSMA/CD algorithm is used, of:

$$200{,}000\ Km/s \times 4.159\ \mu s \div 2 = 415.9\ m$$

2.3. Solution for exercise 3



Throughput at layer 1

The throughput obtainable at layer 1 in an Ethernet network is equivalent to the maximum number of bits supported by this technology, i.e. 10 Mbps.

Please note that this number does not depend on the modulation used on the physical channel. For instance, Fast Ethernet can transport up to 125 Mbps at the physical layer, but part of these bits are user for better robustness. Therefore, the net throughput on that network (i.e., the maximum amount of data that can be generated by the upper layer that drives the physical channel) is equal to the maximum allowed bit rate, i.e. 100Mbps, independently from the modulation in use.

Throughput at layer 2

The maximum throughput at L2 include only the Ethernet headers and is achieved when the maximum frame is used (in order to limit the overhead of the additional headers).

The wanted result can be obtained by considering that the maximum allowed frame on an Ethernet is 1518 bytes, and that the transmission of a frame must include also the following fields (which represent the overhead):

- Preamble (7 bytes)
- Start Frame Delimiter (1 byte)
- Inter-Frame Gap (silence, but equivalent to an occupancy of 12 bytes of the channel)

These headers account for 20 additional bytes, which will lead to the following maximum throughput at L2:

$$\frac{1518 bytes}{(1518+20) bytes} \times \textit{10 Mbps} = \textit{9.87 Mbps}$$

Efficiency

The maximum performance of a network is achieved when the overhead of the other headers is minimized, i.e., when packets with the maximum size are transmitted.

The wanted result can be obtained by considering that the maximum allowed payload on an Ethernet is 1500 bytes, and that the transmission of a frame must include also the following fields (which represent the overhead):

- Preamble (7 bytes)
- Start Frame Delimiter (1 byte)
- Destination MAC address (6 bytes)
- Source MAC address (6 bytes)
- Protocol Type (2 bytes)
- Cyclic Redundant Code (4 bytes)
- Inter-Frame Gap (silence, but equivalent to an occupancy of 12 bytes of the channel)

All these headers lead to a total length of 1538 bytes. Hence, we can conclude that the maximum efficiency of the network when transporting L3 traffic is

1500 bytes/1538 bytes=97.53 %,

Throughput at layer 3

The maximum throughput can be easily calculated from the efficiency above:

10 Mbps × 97.53 %=9.753 Mbps

2.4. Solution for exercise 4

Gigabit Ethernet maintains backward compatibility at frame level with Ethernet v.2.0, hence the figure 1 is still valid, with two remarks:

- **Carrier Extension:** Slot time is extended, bringing the minimum duration of a Gigabit Ethernet frame to 512 bytes-time, sending proper filling sequence after the FCS if the total length of the frame is less then 512 byte. Anyway, as we are interested in the maximum throughput, which can be obtained with the impact of the additional headers is minimized, we can assume that each sent frame is 1518 bytes long, hence Carrier Extension is not present in those frames.

- **Frame Bursting:** Each station could send more than a frame without releasing the channel. In this way only the first frame of a burst is possibly subject to Carrier Extension. Sending only one frame at a time, Frame Bursting is not enabled in this exercise.

Therefore the maximum L3 throughput of a Gigabit Ethernet network in the conditions above is

$$\frac{1500 bytes}{(1518+20) bytes} \times \textit{1 Gbps} = \textit{975.3 Mbps}$$

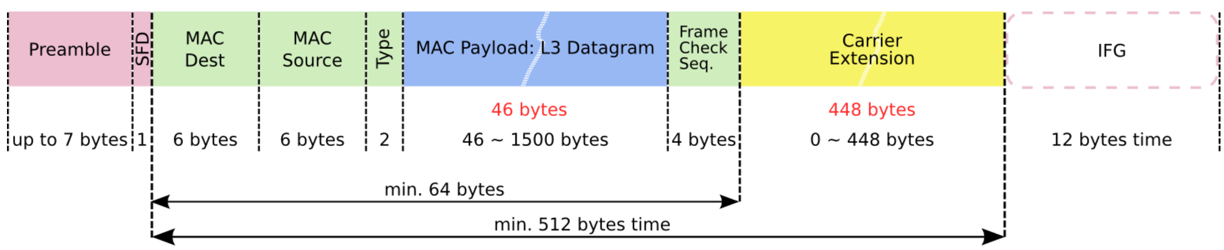
or, considering the L2 throughput,

$$\frac{1518 bytes}{(1518+20) bytes} \times \textit{1 Gbps} = \textit{987 Mbps}$$

2.5. Solution for exercise 5

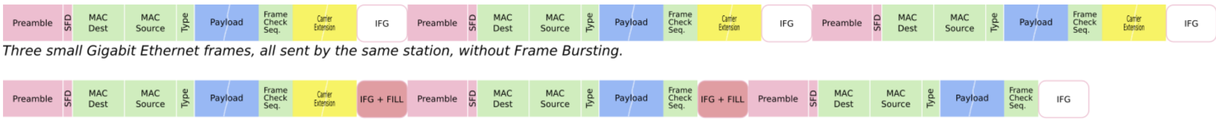
Frame Bursting does not reduce the time used by each frame transmitted on the channel, and the channel occupancy in these conditions is exactly the same as the previous exercise. Hence the maximum throughput is exactly the same evaluated in the previous exercise.

2.6. Solution for exercise 6



1. The minimum payload length in a Gigabit Ethernet network is 46 bytes (as in Ethernet and Fast Ethernet), hence 93 frames (64 bytes long) are needed to send all the L3 data. As reported in figure 2, for each frame, a sequence of padding symbols (448 bytes long) is added, due to the Carrier Extension Mode, to reach the minimum duration of a Gigabit Ethernet Frame (512 bytes). Hence the requested throughput is:
$$\frac{93 \times 46 bytes}{93 \times (64+448+20) bytes} \times \textit{1 Gbps} = \textit{86,47 Mbps}$$
2. With Frame Bursting only the first frame of a burst is possibly subject to Carrier Extension. According to the standard the frame burst limit is 8192 byte-time plus the exceeding size of the last frame started during the burst and the related IFG: the 93rd frame begins after
$$\textit{(64+448+20) bytes} + \textit{91} \times \textit{(64+20) bytes} = \textit{8176 bytes-time}$$
and concludes the burst which is 8260 bytes-time long.
Therefore the requested throughput is:
$$\frac{93 \times 46 bytes}{(64+448+20) bytes + 92 \times (64+20) bytes} \times \textit{1 Gbps} = \textit{517,92 Mbps}$$

3. The difference between the previous two results shows that Frame Bursting, relieving the huge performance decay introduced by Carrier Extension when dealing with short frames, may bring in a strong improvement in throughput, up to about 600%; the figure 3 exemplifies graphically the improvements brought in by Frame Burst Mode considering a burst composed of three small frames.



Three small Gigabit Ethernet frames, all sent by the same station, without Frame Bursting.

A Frame Burst made of three small Gigabit Ethernet frames.

2.7. Solution for exercise 7

Size of the voice samples

A PCM-64 codec generates a traffic of 64Kbps. Since the text specifies that packets are generated each 40ms, each packet will contain:

$$64Kbps \times 0,040s = \mathit{2560\ bits/packet} = \mathit{320\ bytes/packet}$$

Size of the protocol headers and total number of additional bytes required on the channel

According to the standard encapsulation for the RTP protocol, we have the following header occupancy:

Protocol	Header size
RTP	12 bytes
UDP	8 bytes
IP	20 bytes
Ethernet	18 bytes (+ 20 additional bytes for Preamble, SFD, IFG)
Total	58 bytes headers (+ 20 additional bytes for Ethernet)

Therefore the size of the protocol headers required to send our voice samples is equal to 58 bytes.

However, Ethernet requires 18 additional bytes in order to be able to send that L2 frame (whose length is 320 + 58) on the channel. For this reason, the additional "channel occupancy" for being about to send our 320 bytes voice samples every 40ms will be equal to 78 bytes.

Efficiency of the encapsulation

In percentage, the efficiency of this encapsulation is:

$$\frac{320}{320+78} = \textit{80.4\%}.$$

2.8. Solution for exercise 8

Since the minimum frame generated by this station is $<$ 512 bytes, each Ethernet frame will be enlarged in order to reach at least the minimum size as mandated by the slot time (512 bytes).

Therefore, the occupancy (in terms of bytes) for each IP frame, will be:

7 (Preamble) + 1 (SFD) + 512 bytes (min. ethernet frame) +12 (IFG) = 532 bytes

The efficiency of this transmission is:

$$\frac{IPtraffic}{ChannelOccupancy} = \frac{100bytes}{532bytes} = \textit{18.8\%}$$

The total amount of IP traffic that can be sent on that network will be the following: Gigabit Ethernet throughput $\times$ Efficiency = 1Gbps $\times$ 18.8% = 188 Mbps.

2.9. Solution for exercise 9

The worst case for station S is that the other station just started its transmission, and that the frame has the maximum length.

In this case, the station has to wait for the time required to send that frame (of the maximum size) plus the additional required overheads (Preamble, Start Frame Delimiter, and Inter-Frame Gap):

Maximum waiting time (in bytes): 1 + 7 + 1518 + 12 = 1538 bytes[1]

which, on a FastEthernet network corresponds to:

$$\textit{Maximum waiting time (in } \mu s\textit{): } \frac{1538\times8(bit)}{100\times10^6(bps)} = 123\mu s$$

In case of a Gigabit Ethernet, the maximum frame size is unchanged, but station have the possibility to send in burst mode, which basically behaves like having a longer frame whose size can be up to 8KB + 1 maximum frame - 1 byte.

Therefore, the maximum channel occupancy will be:

Maximum waiting time (in bytes): 8192 + 1538 - 1 = 9729

which, on a Gigabit Ethernet network corresponds to:

[1] In fact, in order to be precise we should consider that the other station already transmitted at least one *bit*, which is what it took the ownership of the channel. However, we omit this in our solution, since it does not have any significant impact on the result.

$$\textit{Maximum waiting time (in } \mu s\textit{):}\ \frac{9729 \times 8}{10^9} = 77.8 \mu s$$

Please remember that the waiting time is referred to the time required to enter into a contention phase for accessing to the physical medium; there are no guarantees whatsoever that after that time the station will be able to transmit its data.