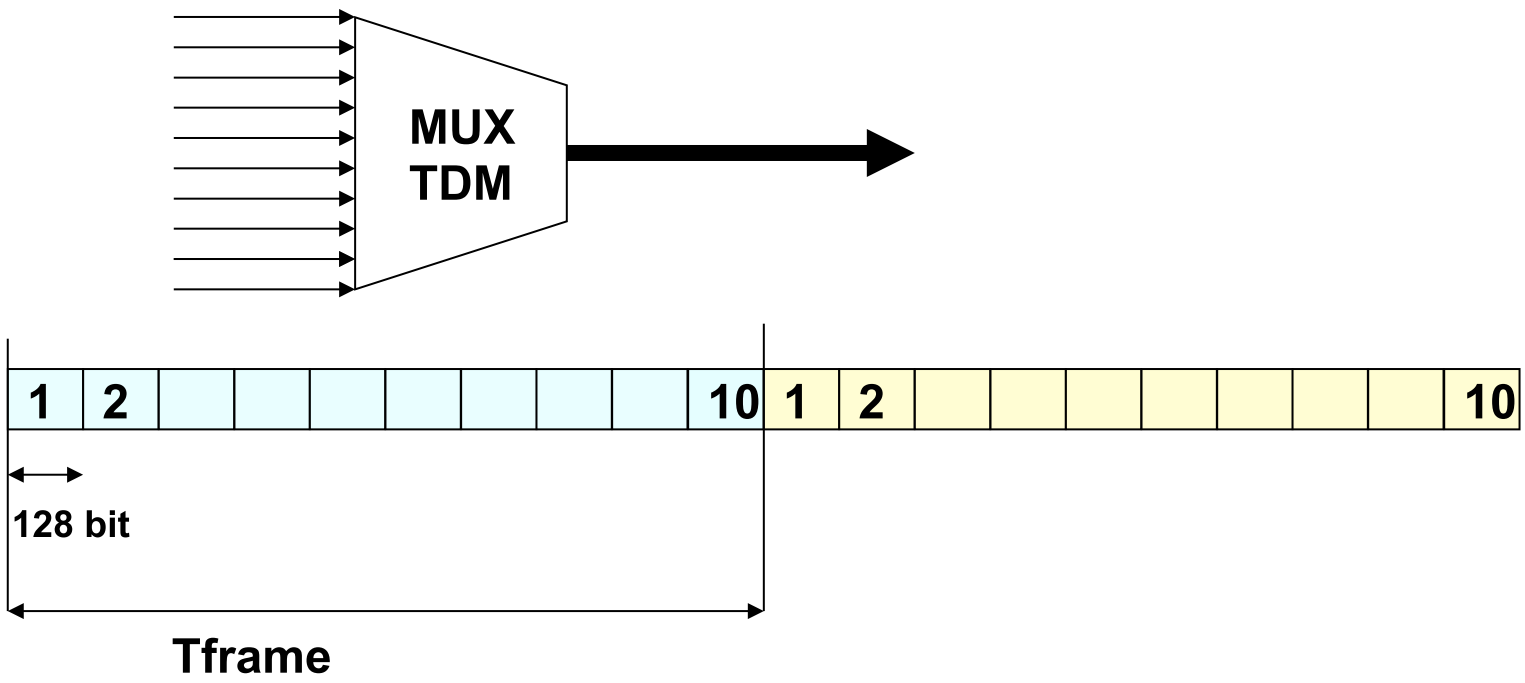
Politecnico di Milano
Scuola di Ingegneria Industriale e dell’Informazione

E2
Multiplexing

Exercise 1

A TDM multiplexing system has a frame with 10 slots and in each slots 128 bits area transmitted. The number of multiplexed flows is equal to 10 and each flow has a rate of 64 kb/s. Calculate the rate of the multiplexed flow and the frame duration.

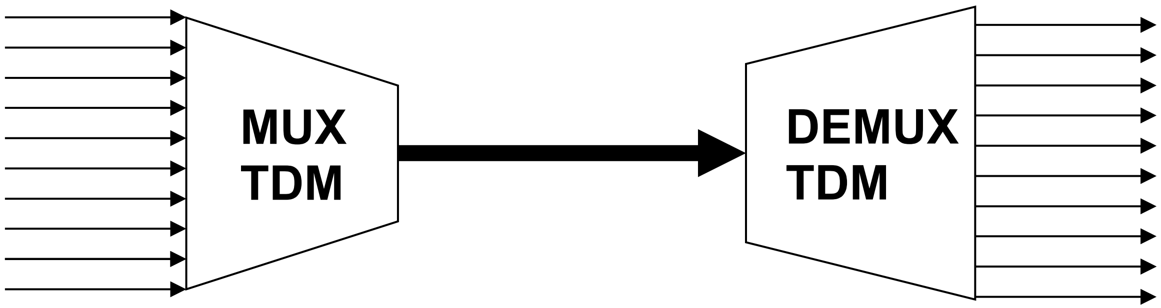


Exercise 1 - Solution

- First approach:
  - Multiplexed flow rate is V = 64 [Kb/s] x 10 = 640 [kb/s]
  - Frame duration is 128 [bits] x 10 / 640 [Kb/s] = 2 ms
- Second approach:
  - Frame duration can also be computed as: T_f=128[bit] / 64[Kb/s] = 2ms
  - Multiplexed flow rate V= 128 [bit] x 10 / 2 [ms] = 640 [Kb/s]

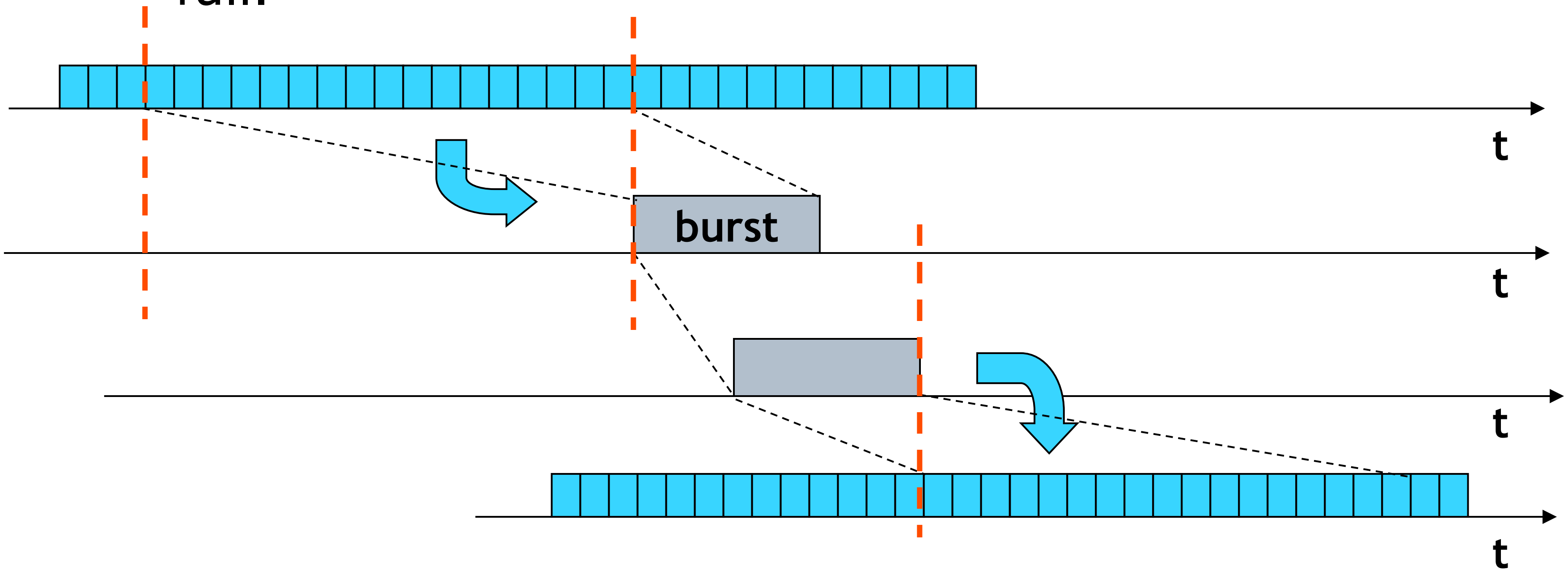
Exercise 2

- Considering the scenario in previous exercise, calculate the delay experience by the first and the last bit of the *burst* from when they arrive at the multiplexing system till when they are picket from the reception buffer, assuming a *store and forward* approach (bits are transmitted when the entire burst is received).

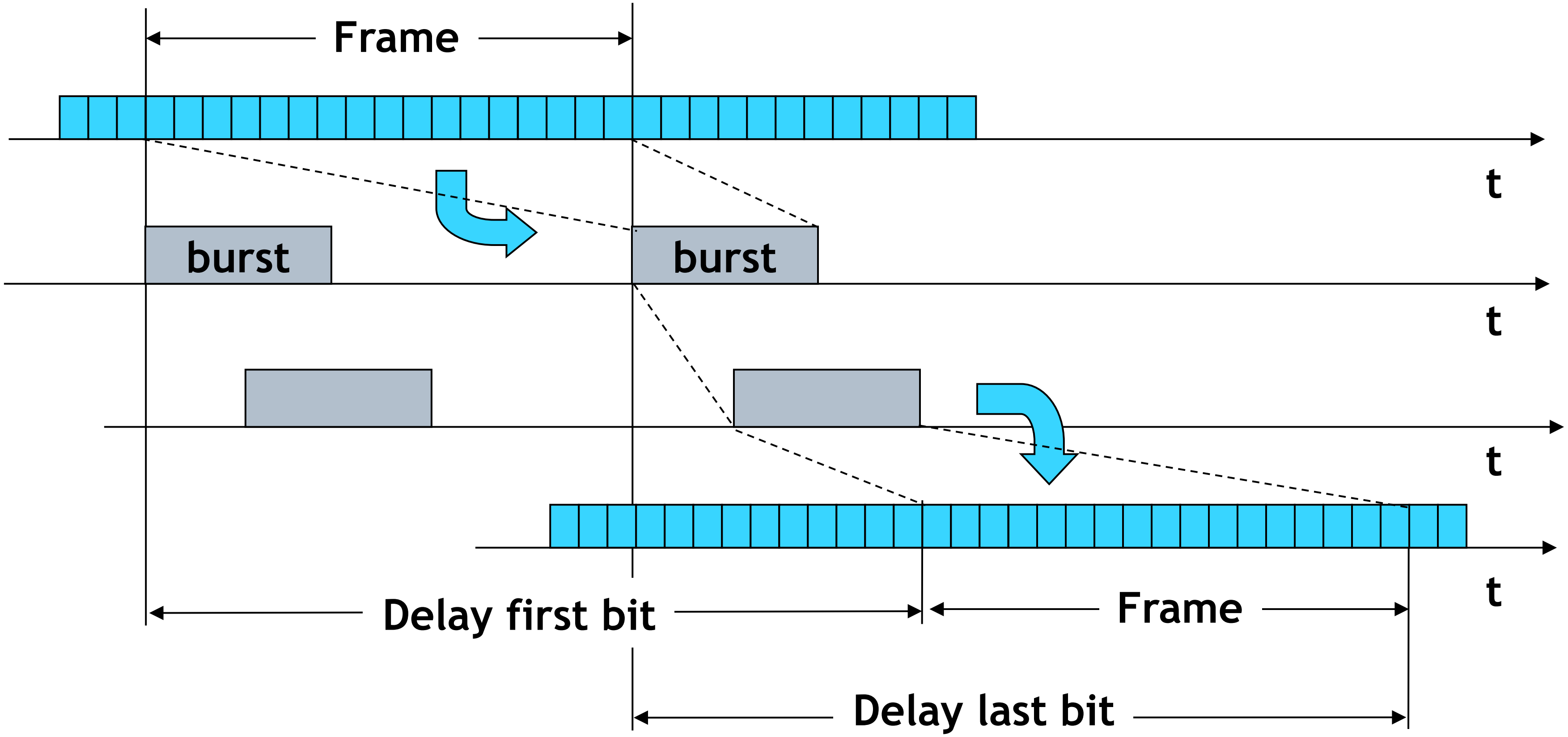


Exercise 2 - Solution

- At the beginning of each slot the register of 128 bits is emptied and the bust transmitted. At receiver the transmission starts when the register is completely full.

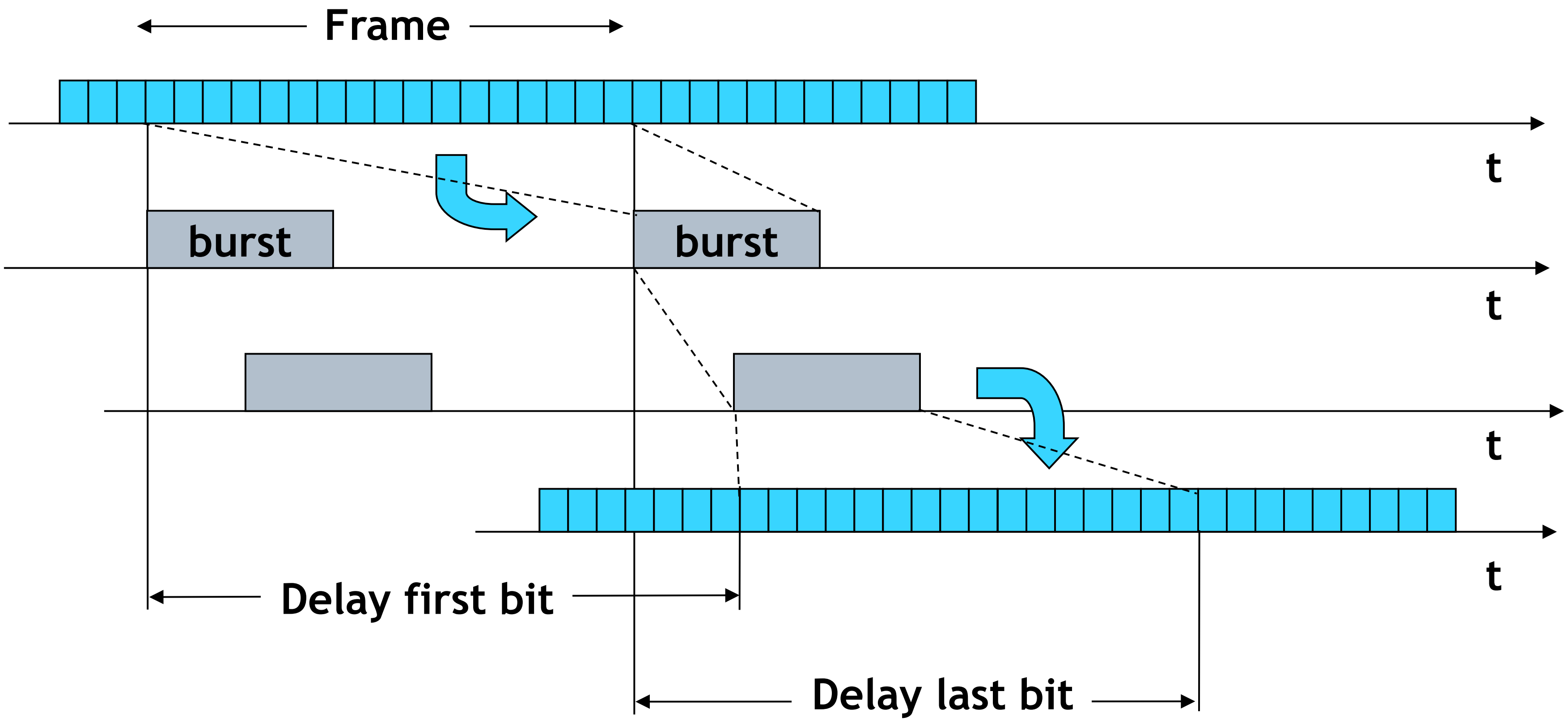


Exercise 2-Solution



Delay is constant for all bits and equal to: Frame duration + Transmission time (+ propagation delay) = 2.2 ms

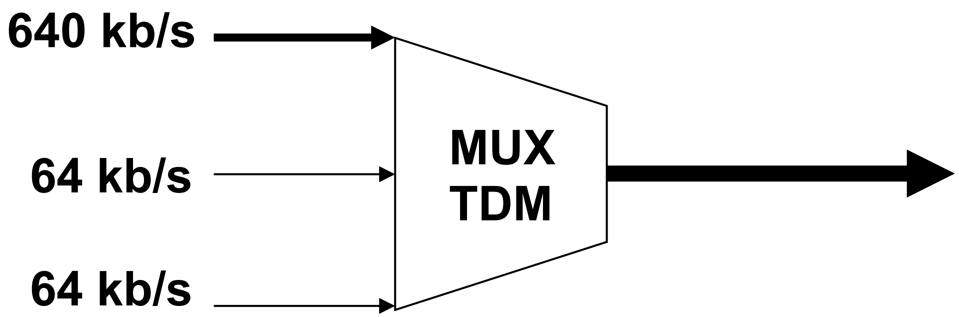
Exercise 2 - Solution



If receiver start transmitting when it receives the first bit (cut through), total delay is equal to Frame time (+ propagation delay) – We save the transmission time

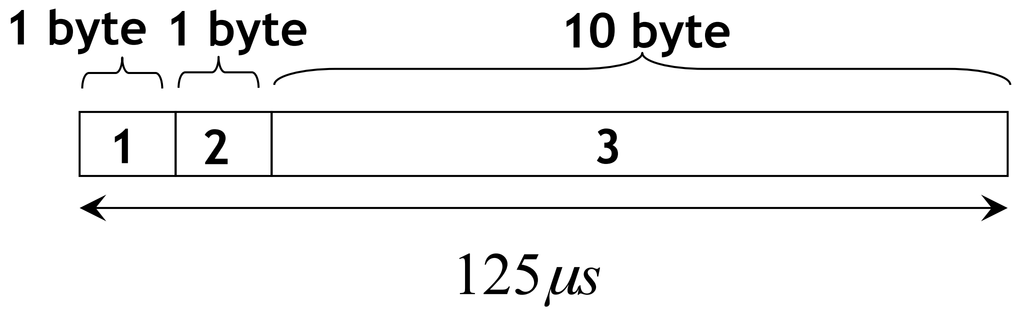
Exercise 3

- Two 64 kb/s flows and a 640 kb/s flow are multiplexed together according to a TDM scheme. Assuming as multiplexing unit 8 bits, calculate the duration of the shortest possible frame, its structure, and the multiplexed flow rate.
- Same as before but with multiplexing unit of 1 bit.



Exercise 3 - Solution

Frame structure:



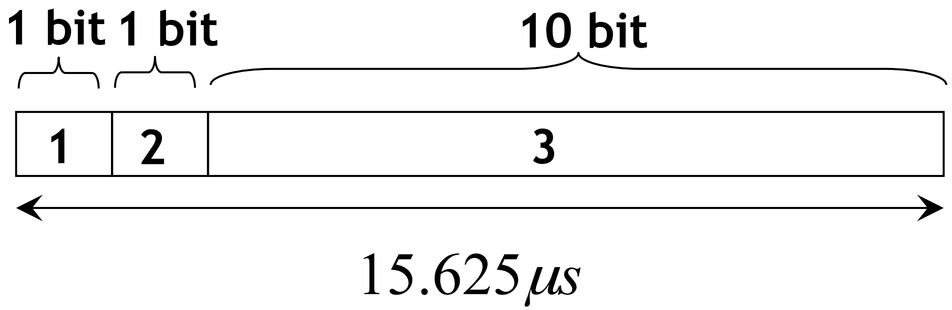
Frame duration= $\dfrac{1\ byte}{8\ kbyte/s} \equiv 125\mu s$

Multiplex flow rate = $\dfrac{12 \times 8\ bit}{125\ \mu s} \equiv 768\ kbit/s$

Also 2 x 64 + 640=768 *kb/s*

Exercise 3 - Solution

Frame structure:



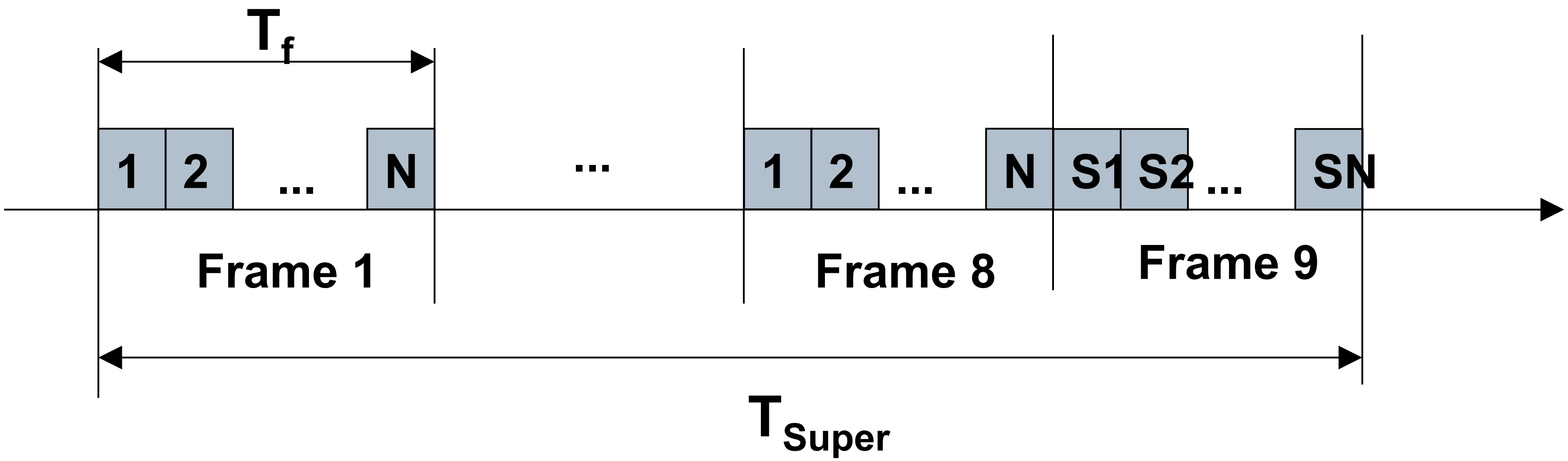
Frame duration $= \dfrac{1\,bit}{64\,kbit/s} \equiv 15.625\mu s$

Muliplexed flow rate $= \dfrac{12\,bit}{15.625\,\mu s} \equiv 768\,kbit/s$

Exercise 4

- *N* voice flows at 64 kb/s are multiplexed together with 8 bits per burst. The same N slots of the frame are also used to transmit a signaling flow of 8 kb/s per voice channel. To this purpose a multi-frame structure is adopted.
- Calculate duration of the frame and multi-frame.

Exercise 4 - Solution



- Signaling flows are 8 times slower. So we must have 1 slot assigned to signaling every 8 slots of voice.
- Each voice send 8 x 8 bits per Super-Frame (T_{Super}):

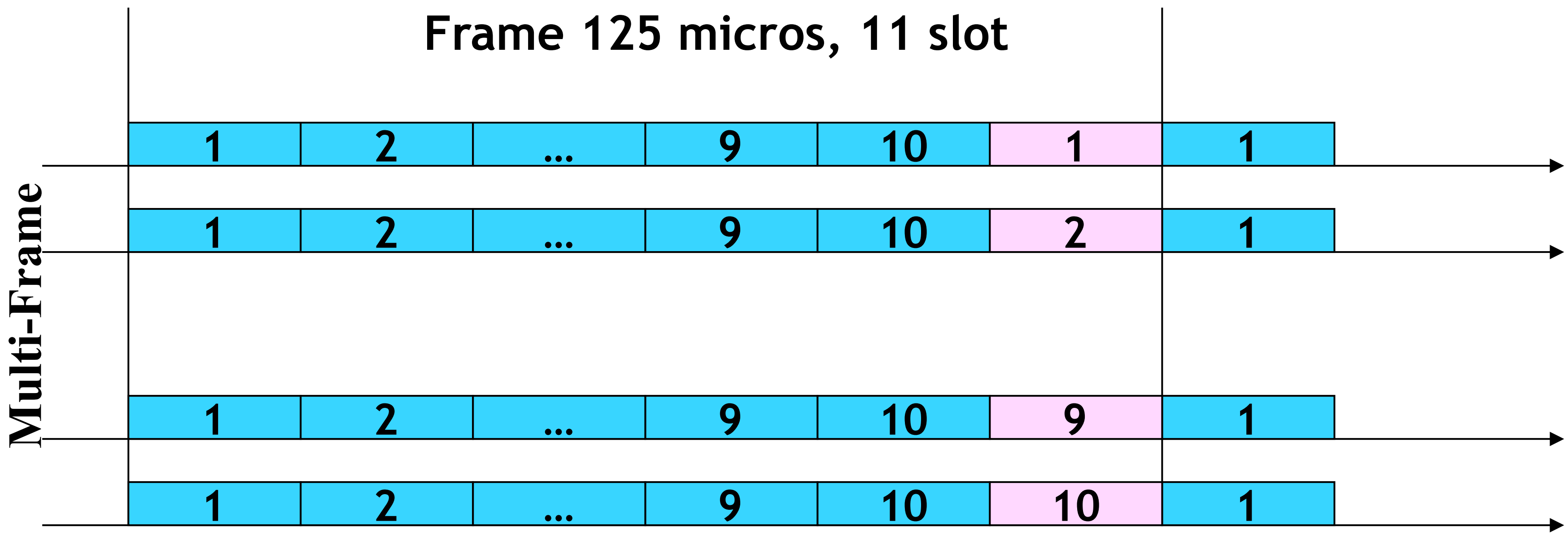
$$T_{Super} = \frac{8 \cdot 8\, bit}{64\, kbit/s} = 1\, ms \qquad T_f = \frac{T_{Super}}{9} = 111\, \mu s$$

Exercise 5

- 10 voice flows at 64 kb/s are time multiplexed together on a multiplex flow that can be configured in N channels with 8 bits per burst. At each flow a signaling channel must be added. Consider the following cases:
  - Signaling channel has a rate of 6.4 kb/s
  - Signaling channel has a rate of 8 kb/s and fractions of the multiplex channel can be used with minimum waste of resources
  - Signaling channel has a rate of 8 kb/s and it shares the slot with the voice channel using a multi-frame structure.
- For all cases calculate the number N of channels, the frame duration, the multi-frame duration (if applicable) and the multiplexed flow rate.

Exercise 5 - Solution (a)

- Signaling required in total 64 kb/s, which is equivalent to an additional channel/slot.
- The additional slot can be assigned to the signaling channel of each voice channel according to a super-frame structure with 10 frames per super-frame

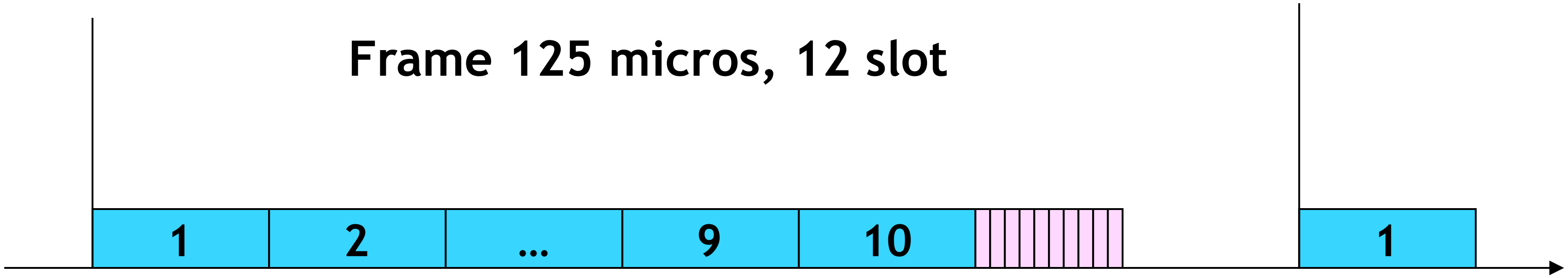


Exercise 5 - Solution (a)

- Frame duration is: $$T_f = \frac{8 \text{ bits}}{64 \text{ kb/s}} = 125 \mu s$$
- Multi-frame duration is: $$T_{\text{super}} = 125 x 10 = 1,25 ms$$
- The multiplexed flow rate is: $$V = 64 \text{ kb/s} \cdot 11 = 704 \text{ kb/s}$$

Exercise 5 - Solution (b)

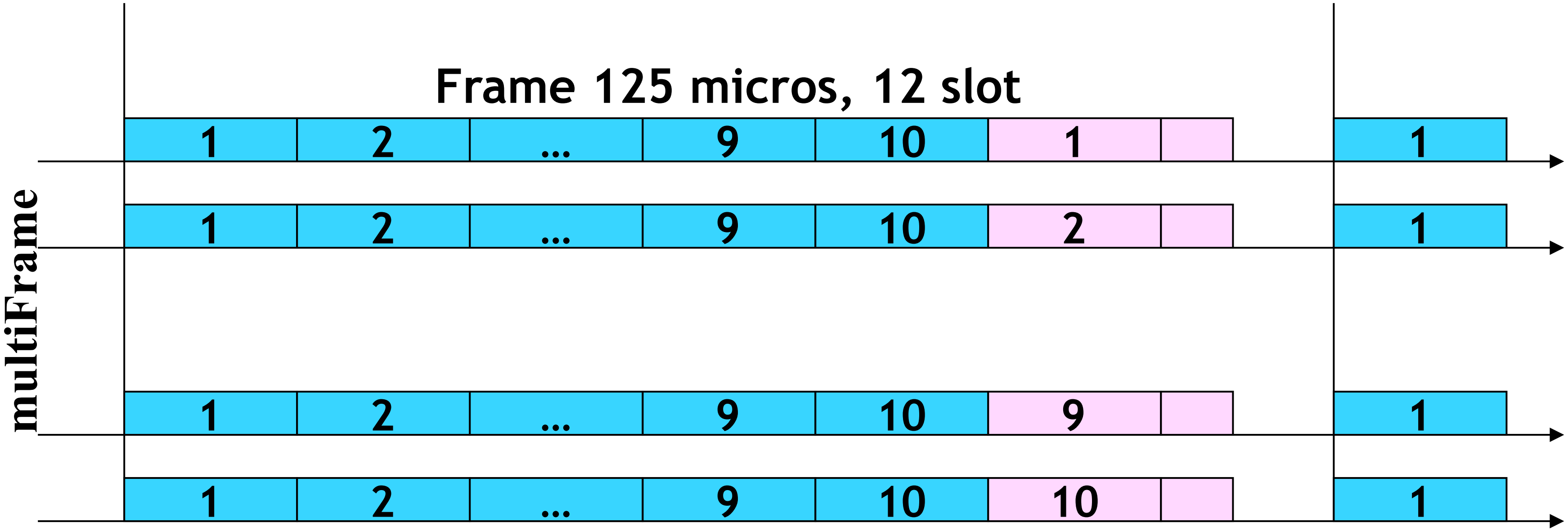
- In this case signaling requires in total 80 kb/s, which are equivalent to 1,25 channels.
- Therefore we need to ass two more channels and some resources will be wasted (N=12).
- Out of 16 bits of the two additional channels, 10 can be assigned to the 10 signaling channel, and the last 6 bits are empty.



Multipex rate is 12 x 64= 768 kb/s

Exercise 5 - Solution (b)

- Another possibility is to use multi-frame, with 10 bits per frame assigned to a signaling channel at a time. But the final results is similar and resources are wasted in any case.

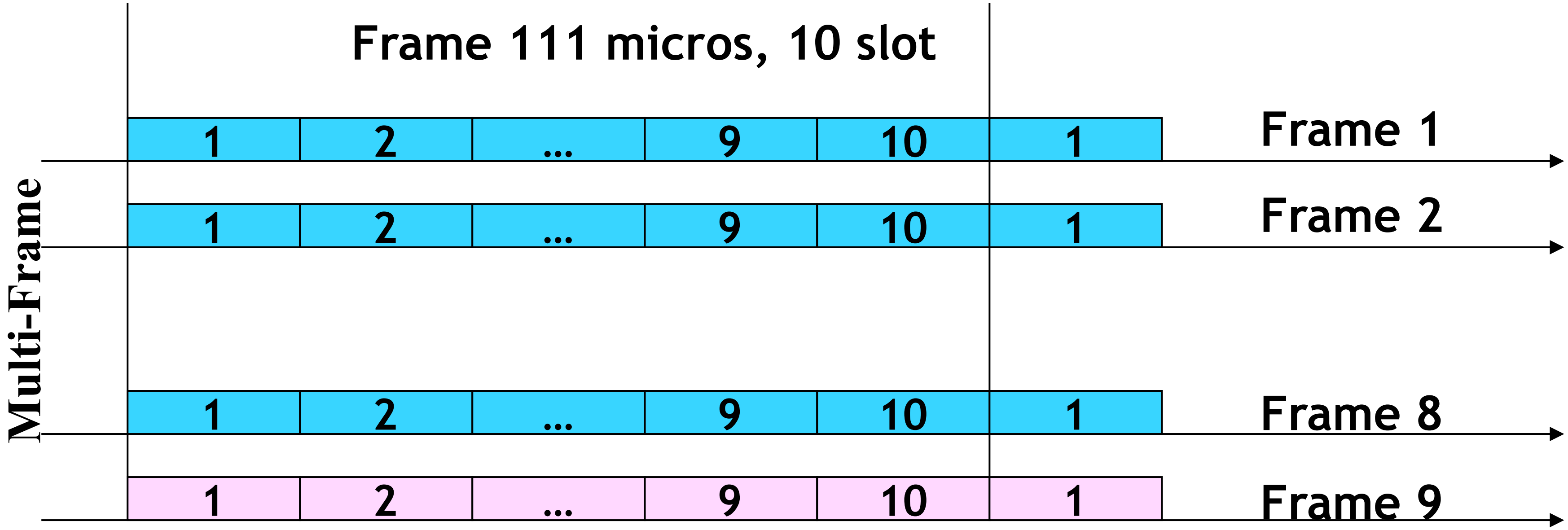


Multiplex rate is 12 x 64= 768 kb/s

Exercise 5 - Solution (c)

- In this case we have a Frame with N=10 and each slot is assigned to the voice channel and its signaling channel using a multi-frame.
- Since the signaling channel rate is 1/8 of the voice channel, we need a multi-frame of 9 frames, where first 8 are assigned to voice and last one to signaling.
- Since voice can use 8 out of 9 frames, the frame duration must be reduced so as the channel rate remains constant

Exercise 5 - Solution (c)

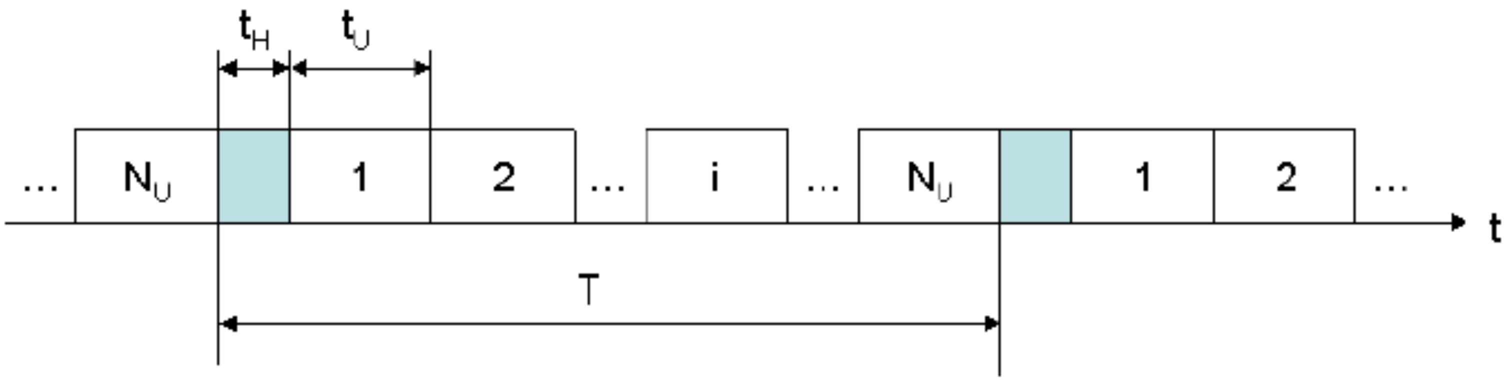


Exercise 5 - Solution (c)

- The 8 bytes transmitted on a multi-frame are generated in 125 x 8 = 1000 μs. This must be also the multi-frame duration.
- Frame duration is then 1000/9= 111.11 μs.
- Multiplex rate is (10 x 8)/(1000/9) =720 kb/s
- Or equivalently to 10 x (64 +8) kb/s =720 kb/s since we don’t waste resources

Exercise 6

- A link with a rate of F_L = 40 Mbit/s is connected through a TDM-MUX to a number of source stations. Dimension the system so as to guarantee at each station a rate of F_U = 155 kb/s, assuming that additional resources are required for signaling with a number of additional bits per frame C_H equal to 50% of the information bits per frame C_U transmitted by each station.
  - Calculate the maximum number of stations N_U.
  - Transmission system requires that each station cannot stay idle without transmitting bits for more than t_s = 64.125 μs. Considering figure below, calculate t_U, CU, C_H e T.



Exercise 6 - Solution

Multiplex rate must be:

$$F_L \geq N_U F_U + F_H \qquad \textbf{(1)}$$

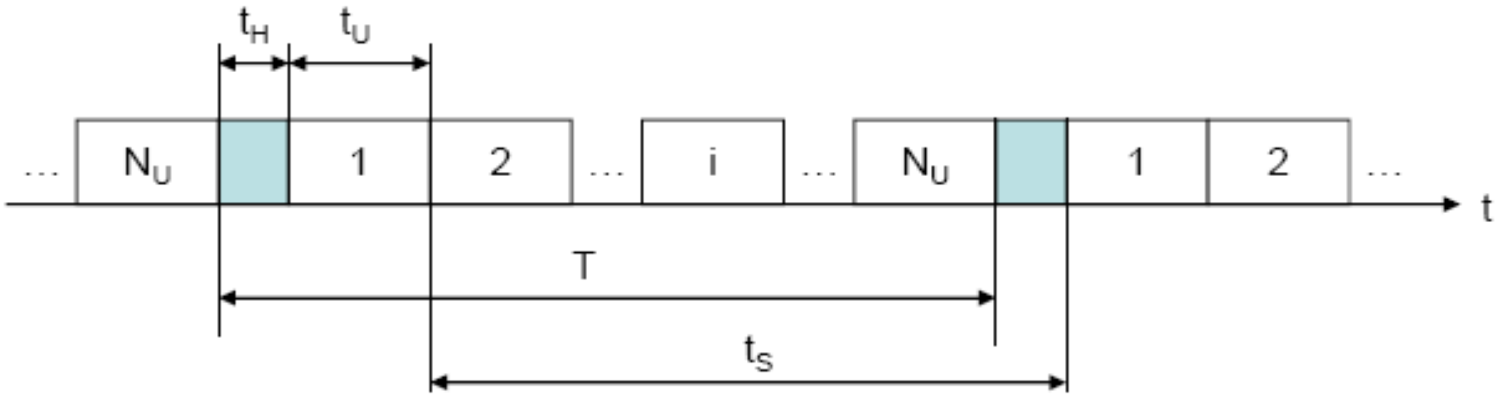
In each frame, the number of signaling bits C_H must be $C_U/2$, then:

$$F_H = C_H / T = C_U / (2T) = F_U / 2 \qquad \textbf{(2)}$$

Replacing (2) in (1) and solving by N_U, we get:

$$N_U \leq \frac{F_L - F_U / 2}{F_U} = \frac{40[Mb/s] - 77{,}5[kb/s]}{155[kb/s]} = 257{,}5$$

Exercise 6 - Solution



We have: $t_S = (N_U - 1)t_U + t_H$

Since: $t_H = t_U / 2$ **we get** $t_S = (N_U - 1/2)t_U$

Solving by t_U $t_U = 0{,}25\mu s$

Therefore

$$C_U = F_L t_U = 10[bit]$$

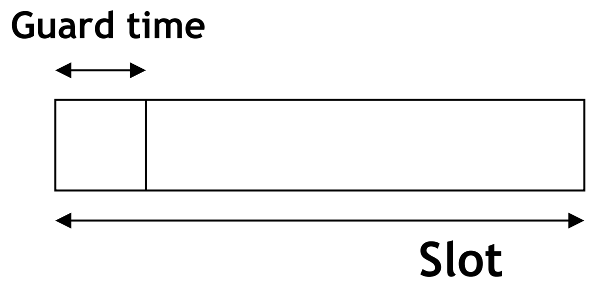
$$C_H = 5[bit]$$

$$T = N_U t_U + t_H = 64{,}375\mu s$$

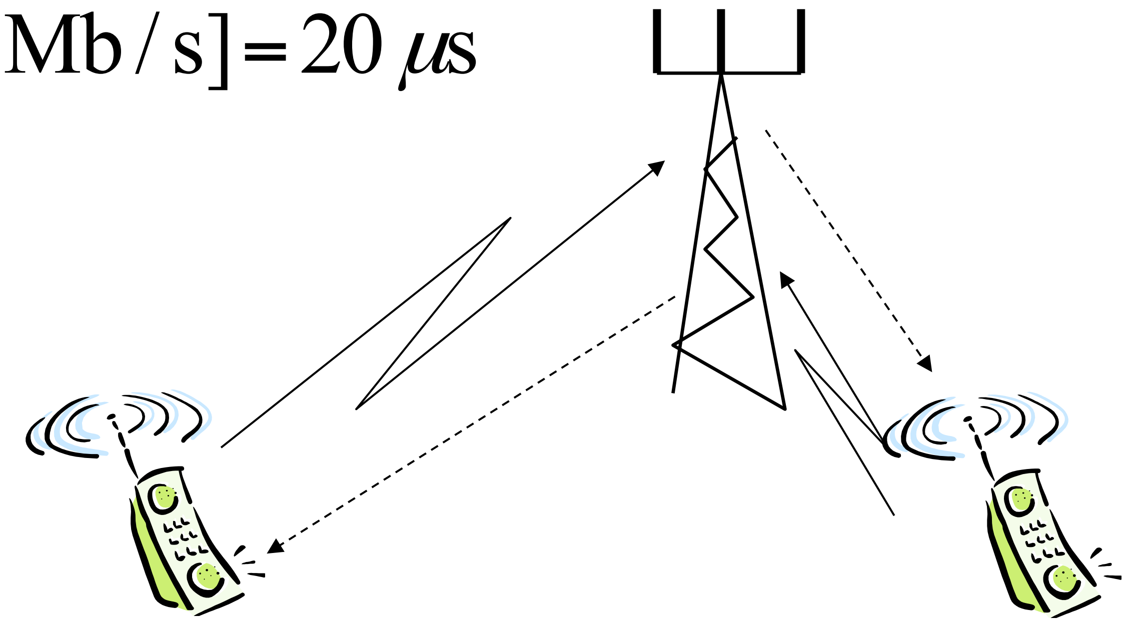
Exercise 7

- In a cellular system carrier rate is 1.6 Mb/s.
- System operates according to a TDMA scheme where in each slot 32 bit-intervals are used as guard time.
- Calculate the guard time.

Exercise 7 - Solution



$$T_G = 32[\text{bit}] \,/\, 1{,}6[\text{Mb/s}] = 20\,\mu s$$



Exercise 8

- A TDMA cellular system has a carrier rate of 2 Mb/s and a maximum range of 1Km.
- Calculate the guard time and the corresponding number of guar bits per slot (assume propagation delay of 3×10^8 m/s).
- Calculate system efficiency assuming a time slot of 666 μs.

Exercise 8 - Solution

- Denoting with R cell range we have

$$T_g = 2\tau = 2\frac{R[m]}{v[m/s]} = \frac{1000[m]}{3\cdot 10^8[m/s]} = 6.6\mu s$$

- The number of guard bits is then:

$$N = 6.6[\mu s]\cdot 2[Mb/s] = 13.2 \text{ bits}$$

- Efficiency is :

$$\eta = \frac{T_s - T_g}{T_s} = \frac{(666-6{,}6)[\mu s]}{666[\mu s]} = 0{,}99$$

Exercise 9

- A TDMA mobile radio system has 100 voice channel per carrier. Each voice channel as a rate of 32 kb/s. Assuming cells of 300 m and an efficiency not smaller than 90%, calculate:
  - Guard time
  - Frame length
  - TDMA *burst* length in bits
  - Carrier rate
- Assume propagation speed of $3x10^8$ m/s.

Exercise 9 – Solution (1)

Denote with τ propagation delay

$$\tau = \frac{R[m]}{v[m/s]} = \frac{300[m]}{3 \cdot 10^8 [m/s]} = 1 \mu s$$

and guard time

$$T_g = 2\tau = 2\mu s$$

Transmission *burst* duration T is such that:

$$\frac{T}{T + 2\tau} \geq 0.9$$

and then $T \geq 18\tau = 18\mu s$

Frame duration T_f, with T= 18 μs is:

$$T_f = 100(18\mu s + 2\mu s) = 2ms$$

Exercise 9 – Solution (2)

The number of bits per frame to be transmitted by each channel is:

$$B = 32[kb/s] \cdot 2ms = 64 \text{ bits}$$

These bits must be transmitted in a *burst* at a rate V such that transmission time is T. Then:

$$V = 64 \text{ bits} / 18\ \mu\text{s} = 3.555 \text{ Mb/s}$$

Exercise 10

- A geostationary satellite TDMA system ues a bust of 10.000 bits at a rate of 34 Mb/s. Distance from earth ranges between 36.000 and 40.000 Km, propagation speed is 300.000 Km/s, and processing delay on the satellite is negligible.
  - Calculate the time slot duration assigned to each station and the efficiency of the system.
  - How many stations can be accommodated with a rate of 2 Mb/s each?

Exercise 10 – Solution

- **Guard time:**

$$\tau_1 = \frac{36000km}{300000km/s} = 0.12s$$ minimum

$$\tau_2 = \frac{40000km}{300000km/s} = 0.133s$$ maximum

$$2\Delta\tau = 2(\tau_2 - \tau_1) = 0.0267s \equiv 26.7\text{ ms}$$

- ***burst* duration is:**

$$T_B = \frac{10000\text{ bit}}{34\text{ Mbit/s}} = 294.118\ \mu s$$

Exercise 10 - Solution

Time slot and efficiency

$$T_{SLOT} = 2\Delta\tau + T_B = 26.99\ ms$$

$$\eta = \frac{T_B}{2\Delta\tau + T_B} = \frac{0.2941}{26.99} = 0.0109$$

b) Frame length is the generation time of 10000 bits at 2 Mb/s, which is 5 ms, bit time slot is 26.99 ms

No station at 2 Mb/s rate can be accommodated by the system