

# Optical and Transport Networks

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IV Exam 2018-19 – 15 July 2019

Last and first name:

(capital letters)

(signature)

Matriculation number:

NB: In any exercise, any answer not justified adequately, even with few words, will not be considered.

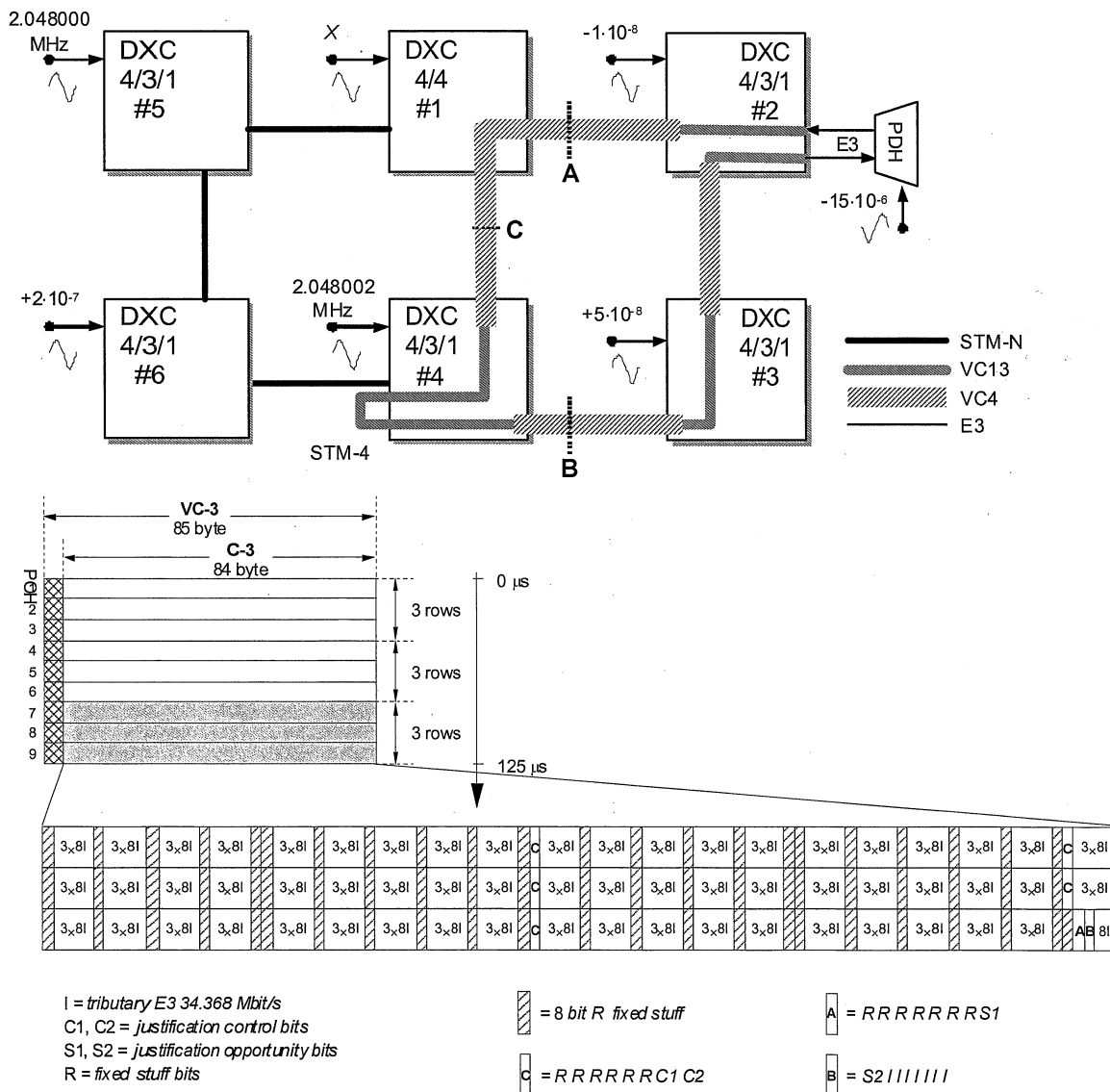
## Problem 1

(Solve on this sheet in the space provided) (6 points)

Consider the network of DXC 4/4 and 4/3/1 elements in figure below, where all links are bidirectional. Links between DXCs are STM-4 ( $f_0 = 622.080$  Mbit/s). Each Network Element (NE) is synchronized by an external reference, of which either the fractional frequency deviation from the nominal value  $f_0 = 2.048$  MHz or directly the absolute frequency is given.

For your convenience, the asynchronous mapping scheme of E3 into VC3 is given. Characteristic parameters of VC3 are recalled: size =  $85 \times 9$  bytes, period =  $125 \mu\text{s}$ , TU3 justification size = 1 byte, maximum TU3 justification rate = 2 kHz. Characteristic parameters of VC4 are recalled: size =  $261 \times 9$  bytes, period =  $125 \mu\text{s}$ , AU3 justification size = 3 bytes, maximum AU3 justification rate = 2 kHz.

A PDH multiplexer, synchronized by an autonomous reference and connected to an E3 port of DXC #2, generates a bidirectional E3 link ( $f_0 = 34.368$  MHz), which follows the path indicated with the black thin line in figure. The E3 circuit is transported (asynchronous mapping) via the LO VC3 path indicated with the grey line in figure (2-1-4-4-3-2). The LO VC3 path is transported in its turn via HO VC4 paths indicated with wider grey lines in figure (2-1-4, 4-3, 3-2).



- a) Compute the justification ratio  $\rho$  (as fraction of justification opportunity bits occupied by dummy bits) in the VC3 generated at DXC #2.

$$34,368 (1 - 15 \cdot 10^{-6}) \text{ Mb/s} = 8000 \cdot (1 - 10^{-9}) (1433 - 2\rho) 3$$

$$\Rightarrow \rho = 9510733$$

- b) Be informed that the AU4 pointer justifications at interface C, in the direction from DXC #1 to DXC #4, happen once every 10 s and are positive. Then, compute the fractional frequency deviation  $X = \Delta f/f_0$  from the nominal value  $f_0$  of the reference synchronizing DXC #1. (2 points)

In the AU4 pointer processor in #1:  $\Delta f = f_{VC4} (-10^{-9} - X)$

To have 1 AU4 jst (Pos) every 10 sec:

$$\Delta f = \frac{-24 \text{ bit}}{10 \text{ sec}} \rightarrow X \approx +0,6 \cdot 10^{-8}$$

$$f_{VC4} = 155,520 \frac{267}{270} \text{ Mb/s}$$

- c) Compute every how many seconds AU4 pointer justifications do happen at interface B (i.e., the inter-justification period), in the direction from DXC #4 to DXC #3, specifying also their sign (POS/NEG)

NO justification

- d) Compute every how many seconds TU3 pointer justifications do happen at interface B (i.e., the inter-justification period), in the direction from DXC #4 to DXC #3, specifying also their sign (POS/NEG)

In the TU3 pointer processor in #4:  $\Delta f = f_{VC3} (-10^{-9} - \frac{2,048002}{2,048} + 1)$

$$= -68,3 \text{ bits/s}$$

1 TU3 jst. every  $\frac{8 \text{ bit}}{68,32 \text{ bits/s}} = 0,1165 \text{ sec}$

POS

$$f_{VC3} = \frac{85 \cdot 9,8 \text{ bit}}{125 \mu\text{s}} = 48,96 \text{ Mb/s}$$

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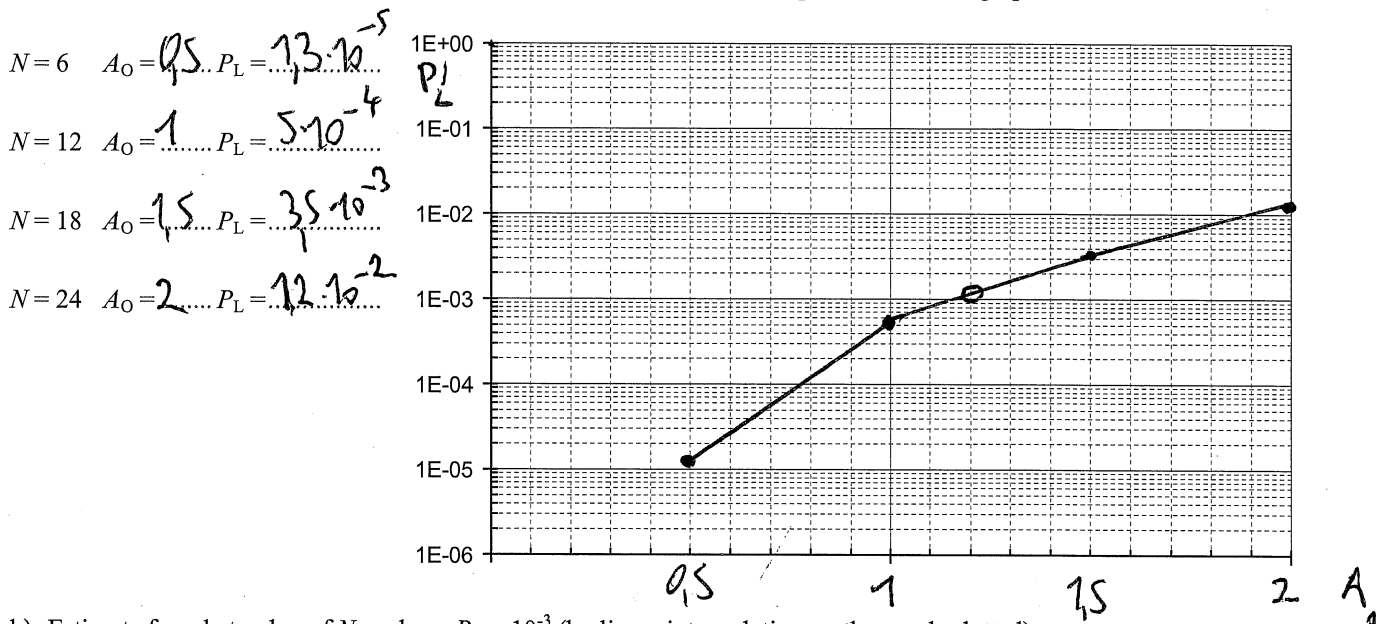
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Problem 2

(Solve on this sheet in the space provided) (5 points)

$N$  persons make a call, or attempt to call, on the average once every 1 hour, supposedly at random Poisson times using their mobile phones. The duration of calls is random, with unknown distribution and average 5 minutes. Telephones are all connected to the same radio base station, linked to the network by a backhaul link carrying 6 lines (single telephone circuits). To evaluate the probability  $P_L$  that a call is rejected, use the Erlang-B  $E_{1,m}(A_0)$  formula.

a) Evaluate the probability  $P_L$  for  $N = 6, 12, 18, 24$ . Write the values and plot them on the graph below.



b) Estimate for what value of  $N$  we have  $P_L \approx 10^{-3}$  (by linear interpolation on the graph plotted)

$$A_0 \approx 1.18 \quad N = 14 \quad (P = 1.09 \cdot 10^{-3})$$

c) How many lines are needed with  $N = 24$ , in order to make the probability that a call is rejected lower than  $10^{-4}$ ? (by computation of the formula)

$$A_0 = 2 \quad m \quad B_m(A_0)$$

|    |                     |
|----|---------------------|
| 6  | $1.2 \cdot 10^{-2}$ |
| 7  | $3.4 \cdot 10^{-3}$ |
| 8  | $0.8 \cdot 10^{-3}$ |
| 9  | $1.9 \cdot 10^{-4}$ |
| 10 | $3.8 \cdot 10^{-5}$ |

$\Rightarrow$

**Problem 3**

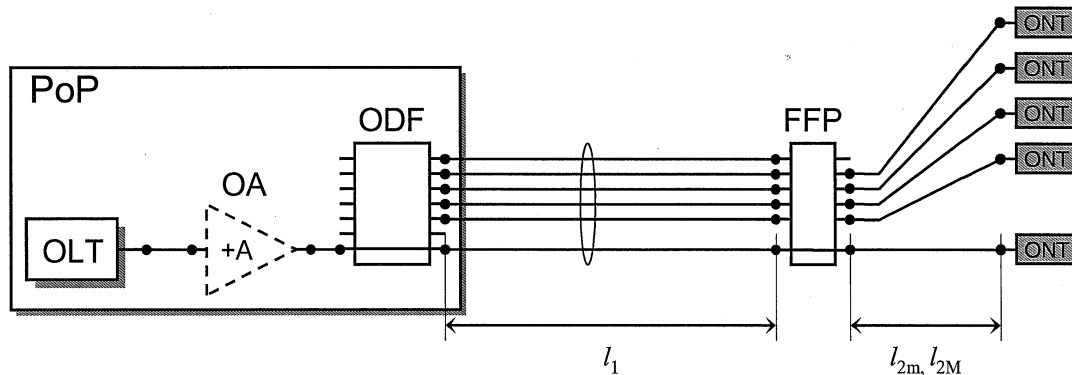
(Solve on this sheet in the space provided) (6 points)

Consider a Point-to-Point (P2P) network reaching up to 128 users at variable distances from the Ethernet Optical Line Termination (OLT) according to the scheme in figure.

The line from the OLT is cross-connected via an Optical Distribution Frame (ODF) to the user lines. An Optical Amplifier (OA), if needed, may be added before the ODF at the Point-of-Presence (PoP). After a first feeder fibre segment with length  $l_1$ , another ODF (Fibre Flexibility Point, FFP) cross-connects to the users. The fibre segments between the FFP and the users have variable length from minimum  $l_{2m}$  to maximum  $l_{2M}$ . The length of other segments of fibres connecting network elements is negligible.

Assume the following data for the P2P network elements:

- fibre with attenuation  $\alpha = 0.5$  dB/km;
- $l_1 = 1$  km,  $l_{2m} = 100$  m,  $l_{2M} = 10$  km;
- OLT transmission power  $P_{TX}$ ;
- splitter insertion loss  $\alpha_s = 1$  dB;
- power loss by each couple of optical connectors  $\alpha_c = 0.5$  dB (connections marked with dots in figure);
- sensitivity of ONT receivers  $P_{RX} > -27$  dBm, with at least 6 dB of safety margin to be guaranteed;
- optional OA gain  $+A$  [dB] (excluding the additional attenuation  $2\alpha_c$  introduced by its two couples of connectors);



- a) Evaluate the maximum *Differential Path Loss* [dB] between ONTs.

$$DPL = \Delta l \alpha = (9,9 \text{ km}) \cdot (0,2 \text{ dB/km}) = 1,98 \text{ dB}$$

- b) Evaluate the minimum OLT transmission power  $P_{TX}$  [W] necessary to reach the farthest ONT (without OA).

$$P_{TX} - 6\alpha_c - (l_1 + l_{2M})\alpha - 6 \text{ dB} \geq -27 \text{ dBm}$$

$$\Rightarrow P_{TX} \geq -12,5 \text{ dBm} \quad (\approx 56 \mu\text{W})$$

- c) Evaluate the total length of fibers [km] deployed to reach 128 users with the P2P network according to the scheme in figure, if the length of fibers between the FFP and the users is uniformly distributed.

$$128 \left( l_1 + \frac{l_{2m} + l_{2M}}{2} \right) = 761,6 \text{ km}$$

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**Problem 4***(Solve on this sheet in the space provided) (6 points)*

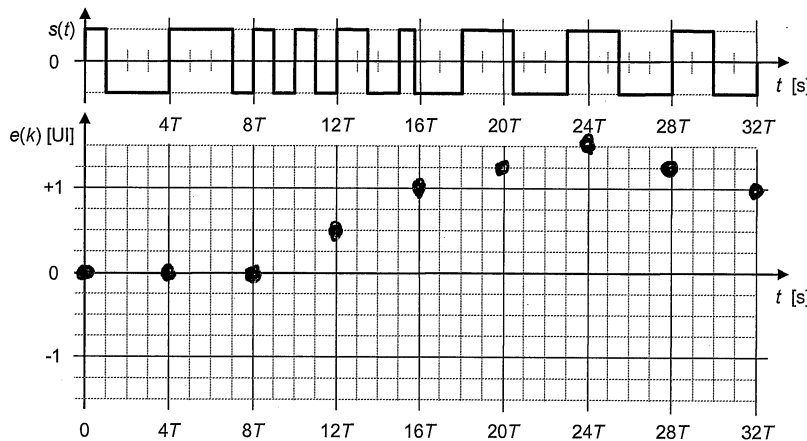
- a) Describe the principle of a Phase-Locked Loop (PLL) and its main components. Specify what makes it a non-linear system. Explain what approximation is made to study its linear model.

- b) Describe the *closed-loop transfer function* of a *second-order PLL*, specifying what are the input and output quantities and the general behaviour of the transfer function, even without giving the exact formula. What is its time constant (describe with words)?

- c) What is the *free-run mode* of a slave clock? What is the *hold-over mode* of a slave clock?



- 2) Let  $s(t)$  be the square timing signal  $s(t)$  plotted in figure and with nominal frequency  $\nu_0 = 1/(4T)$  Hz. (3 points)
- Plot the jitter values  $e[k]$  measured in [UI], at significant instants  $t_k = k(4T)$  of the ideal timing signal with frequency  $\nu_0$ , starting from the initial point  $e[0] = 0$ , with the convention that positive jitter denotes time advance.
  - What is its average frequency over the interval  $(0, 32T)$ ?



$$\overline{\nu} = \frac{9}{32T} \text{ Hz}$$

- 3) What is efficiency of payload utilization in the case of transport of 1 Gb/s Ethernet over SDH with and without VCAT? Consider the case of virtual and contiguous concatenation of VC-4, evaluate the net capacity of the concatenated VC-4s and then the utilization efficiency in the two cases. (2 points)

Net capacity VC-4:  $155.520 \text{ Mb/s} \cdot \frac{260}{270} = 149.760 \text{ Mb/s} (C_{44})$

VC-4-16c:  $C_{44} \cdot 16 = 2404.8 \text{ Mb/s} \rightarrow \eta = 41.7\%$

VC-4-7V:  $C_{44} \cdot 7 = 1048.32 \text{ Mb/s} \rightarrow \eta = 95.4\%$

- 4) What is the application of PTP in mobile networks? For what reason it should be used instead of NTP or GPS? (2 points)



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5) Explain and discuss the graph below.

(3 points)

