Optical and Transport Networks

Prof. Stefano Bregni **V Exam 2018-19 – 13 September 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.

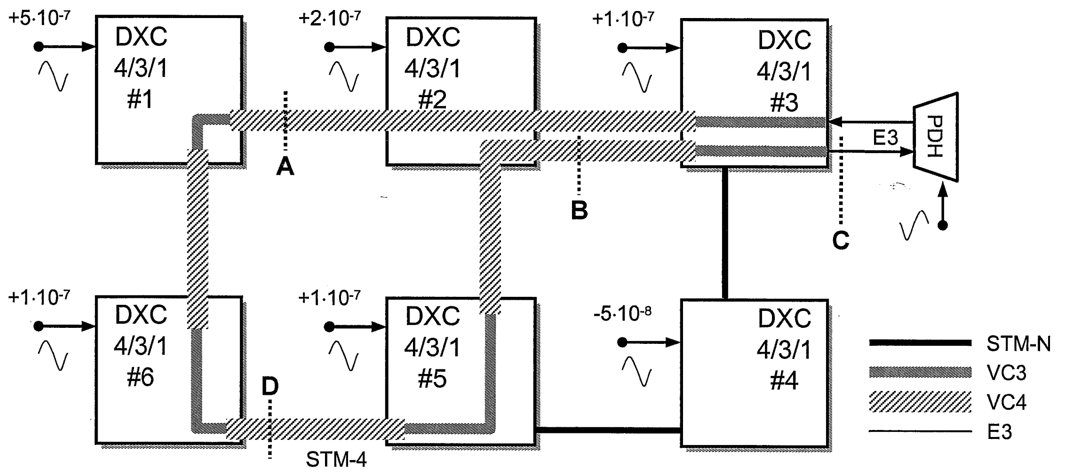
Problem 1

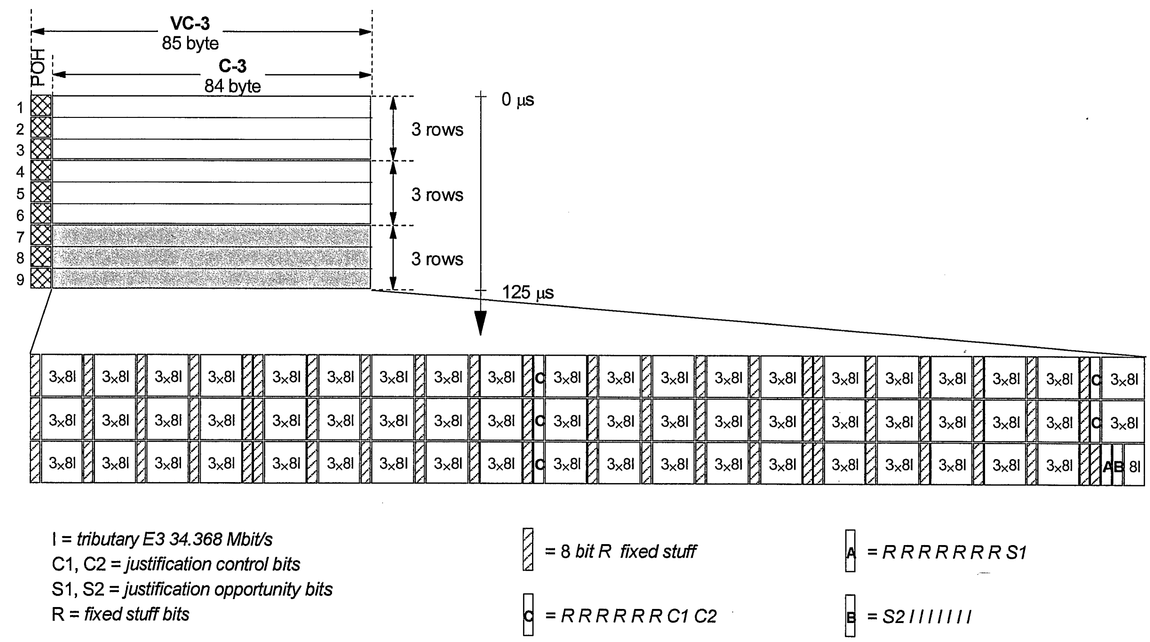
(Solve on this sheet in the space provided) (6 points)

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 = 85×9 bytes, period = 125 μs, TU3 justification size = 1 byte, maximum TU3 justification rate = 2 kHz. Characteristic parameters of VC4 are recalled: size = 261×9 bytes, period = 125 μs, AU3 justification size = 3 byte, maximum AU3 justification rate = 2 kHz.

A PDH multiplexer, synchronized by an autonomous reference and connected to an E3 port of DXC #3, 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 (3-2-1-6-5-2-3). The LO VC3 path is transported in its turn via HO VC4 paths indicated with wider grey lines in figure (3-2-1, 1-6, 6-5, 5-2-3).





a) The justification ratio (as fraction of justification opportunity bits occupied by dummy bits) in the VC3 generated at DXC #3 is $\rho = 0.510$. What is the frequency [Mbit/s] of the output E3 signal at interface C?

$f_{E3} = (1+10^{-7}) \cdot 8000 \cdot 3 \cdot (1433 - 2 \cdot 0{,}51)$ bit/s $= 34{,}3675$ 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 #2 to DXC #3, specifying also their sign (POS/NEG)

$f_{VC4} = 155{,}520$ Mb/s $\frac{261}{270} = 150{,}336$ Mb/s

In the AU p.p. in #2:

$\Delta f = f_{VC4}(-10^{-7}) = -15{,}0336$ mb/s

1 just AU4 every $\frac{24 \text{ bit}}{\Delta f} = 1{,}59$ sec (POS)

d) Compute every how many seconds TU3 pointer justifications do happen at interface A (i.e., the inter-justification period), in the direction from DXC #2 to DXC #1, specifying also their sign (POS/NEG)

No justifications

d) Compute every how many seconds TU3 pointer justifications do happen at interface D (i.e., the inter-justification period), in the direction from DXC #6 to DXC #5, specifying also their sign (POS/NEG)

No justifications

Optical and Transport Networks
Prof. Stefano Bregni **V Exam 2018-19 – 13 September 2019**
Last and first name: *(capital letters)*
(signature)
Matriculation number:

Problem 2

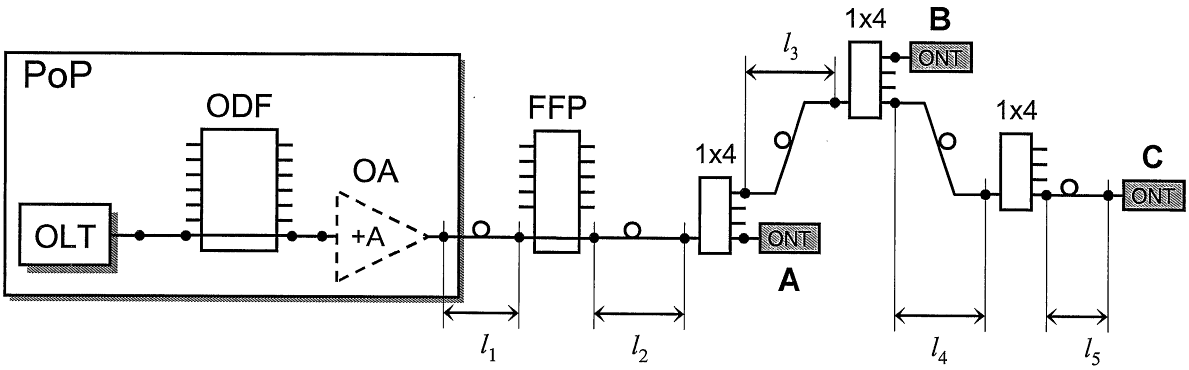
(Solve on this sheet in the space provided) (6 points)

Consider a Passive Optical Network reaching up to 512 users at variable distances from the Optical Line Termination (OLT) via a variable number of 1×8 splitters, with an asymmetric tree topology according to the scheme in figure.

The line from the OLT is cross-connected via an Optical Distribution Frame (ODF) to the PON. An Optical Amplifier (OA), if needed, may be added after the ODF at the Point-of-Presence (PoP). After a first single feeder fibre segment with length l_1, another ODF (Fibre Flexibility Point, FFP) cross-connects to the PON. The fibre segments between the FFP and the following splitters have length l_2, l_3, l_4, l_5, respectively. The length of other segments of fibres connecting network elements is negligible. The Optical Network Terminations (ONT) can be connected at the output of any splitter at the three stages (A, B, C).

Assume the following data for the PON elements:

- fibre with attenuation $\alpha = 0.5$ dB/km;
- $l_1 = 4$ km, $l_2 = 2$ km, $l_3 = 2$ km, $l_4 = 2$ km, $l_5 = 1$ km;
- OLT transmission power $P_{TX} = -3$ dBm;
- 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 $P_{RX} > -33$ dBm, with at least 3 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 as in figure.

$$DPL = P_{Rx/A} - P_{Rx/C} = \alpha(l_3 + l_4 + l_5) + \alpha_c \cdot 5 + 2(\alpha_s + 9)\ dB =$$

$$= 25\ dB$$

b) Evaluate the power P_{RX} [W] received by the farthest ONT in position C without OA.

$$P_{RxC} = P_{TX} - \alpha_c \cdot 12 - 3(\alpha_s + 9) - \sum_1^5 l_i = -44,5\ dBm$$

$$= 35,5\ mW$$

c) Evaluate the OA gain $+A$ [dB] (excluding the additional attenuation $2\alpha_c$ introduced by its two couples of connectors), which is necessary in order to meet the receiver sensitivity of ONT in position C guaranteeing the 3-dB safety margin.

$$A - 2\alpha_c \geq -33 \text{ dBm} + 3 \text{ dB} - (-44{,}5 \text{ dBm}) = 14{,}5 \text{ dB}$$

$$\rightarrow A = 15{,}5 \text{ dB}$$

d) Evaluate the maximum total distance $L = \sum_{i=1}^{5} l_i$, which can be covered including an OA with gain $A = +19$ dB (excluding the additional attenuation $2\alpha_c$ introduced by its two couples of connectors), meeting the receiver sensitivity and safety margin of the ONT.

$$P_{Rx\,K} \geq -30 \text{ dBm}$$

$$P_{TX} + (A - 2\alpha_c) - \alpha_c \cdot 12 - 3(\alpha_s + 9) - \alpha L \geq -30 \text{ dBm}$$

$$\alpha L \leq +9 \text{ dBm} \rightarrow L \leq 18 \text{ Km}$$

Optical and Transport Networks

Prof. Stefano Bregni — **V Exam 2018-19 – 13 September 2019**

Last and first name: *(capital letters)*

(signature)

Matriculation number:

Problem 3

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

Consider a group of $m = 8$ telephone circuit lines loaded by Pascal Traffic with $A_O = 8$ Erl, $\sigma_O^2 = 12$ (VMR = 1.5). The channel group is modelled as a pure loss queuing system without buffer: a call request is served if at least one line is available, otherwise is rejected and gets lost (i.e., the user gives up, or BCC).

Apply the *Wilkinson's Equivalent Random Traffic Method* and compute:

a) the equivalent Poisson traffic A_{Oe} (with $\sigma_{Oe}^2 = A_{Oe}$) and the number of lines m_e of the fictitious channel group overflowing (approximately) the given Pascal traffic with A_O, σ_O^2;

b) the traffic A_L [Erl] lost by the group of $m = 8$ lines loaded by the given Pascal Traffic with $A_O = 8$ Erl, $\sigma_O^2 = 12$;

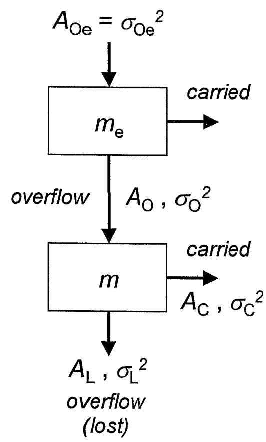
c) the traffic A'_L [Erl] lost by the group of $m = 8$ lines loaded by a Poisson Traffic with $A_O = 8$ Erl and $\sigma_O^2 = A_O$.

For you convenience, some key formulas are attached.

- Erlang-B Formula: $E_{1,m}(A_o) = \dfrac{\frac{A_o^m}{m!}}{\sum_{k=0}^{m} \frac{A_o^k}{k!}}$ $\qquad E_{1,m}(A_o) = B_m(A_o) = \dfrac{A_o B_{m-1}(A_o)}{m + A_o B_{m-1}(A_o)}$

- Wilkinson's Overflow Traffic: $\begin{cases} A_O = A_{Oe} E_{1,m_e}(A_{Oe}) \\ \sigma_O^2 = A_O \left[1 - A_O + \dfrac{A_{Oe}}{1 + m_e + A_O - A_{Oe}} \right] \end{cases}$

$$A_{Oe} = (1 + m_e + A_O) \frac{\sigma_O^2 + A_O^2 - A_O}{\sigma_O^2 + A_O^2}$$



Target: $A_0 = 8$ $\sigma_0^2 = 12$

m_e	$A_{oe}(m_e, A_0, \sigma_0^2)$	$\hat{A}_0(m_e, A_{oe})$	$\Delta = \hat{A}_0 - A_0$
1	8,947	8,0478	0,0478
2	9,8421	8,04188	0,04188
...	...	...	...
5	12,526	8,0173	
6	13,4210	8,0072	
7	14,3158	7,9963	MIN
8	15,2105	7,984	

$$\Rightarrow \left| \begin{array}{l} A_{oe} = 14{,}3158 \quad (= \sigma_{oe}^2) \\ m_e = 7 \end{array} \right.$$

b) $A_L = A_{oe} \cdot E_{1,m+m_e}(A_{oe}) = 2{,}2625$ Erl

$$E_{1,\underbrace{m+m_e}_{15}}(\underbrace{A_{oe}}_{14{,}3158}) = 0{,}1580$$

c) $A_L' = A_0 E_{1,m}(A_0) = 1{,}8845$ Erl

Optical and Transport Networks

Prof. Stefano Bregni **V Exam 2018-19 – 13 September 2019**

Last and first name: *(capital letters)*

(signature)

Matriculation number:

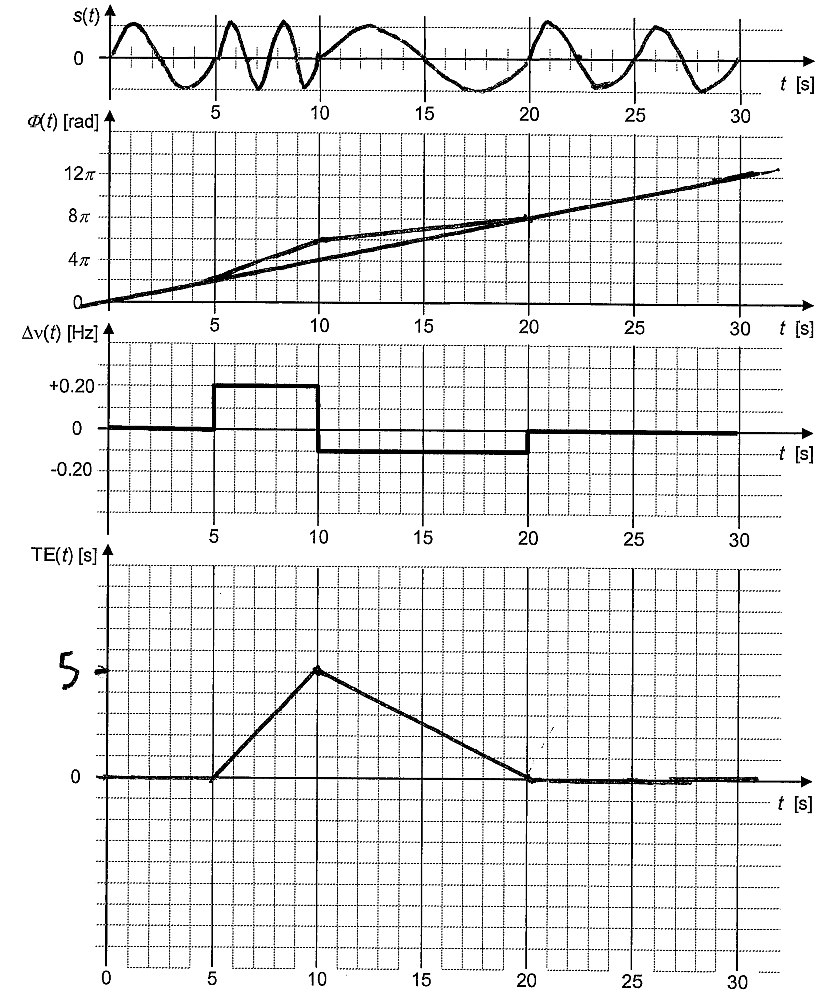
Problem 4

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

a) Let $s(t)$ be a pseudo-sinusoidal timing signal with nominal frequency $\nu_0 = 0.2$ Hz and *instantaneous frequency error* $\Delta\nu(t) = \nu(t) - \nu_0$ as plotted in figure. Plot on the graphs:

- the timing signal $s(t)$;
- the *Total Phase* $\Phi(t)$ of $s(t)$ and of the ideal timing signal with frequency ν_0, both starting from $\Phi(0) = 0$;
- the *Time Error* TE(t) with respect to the ideal timing signal with frequency ν_0, starting from TE(0)=0, with the convention that positive TE denotes time advance. Specify values on the Y axis.

$T_n = \frac{1}{\nu_n} = 5$ sec



b) What is *jitter* of a digital signal? Provide its definition and explain why it may cause bit transmission errors.

c) What is *jitter tolerance*? Suggest a procedure to measure the jitter tolerance at a digital interface of a communication equipment.

Problem 5

(Answer on this sheet in the space provided) (13 points)

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

1) What is PTP? What is its purpose? What is its application in 3G/4G/5G networks? For what reason in these applications it is preferred to NTP? and to GPS? Discuss pros and cons. *(3 points)*

Last and first name: *(capital letters)*
(signature)

Matriculation number:

2) What is *power-law noise*? In communications systems and networks, what empirical data can be found to obey a power-low model? *(3 points)*

3) Describe the principle of TDM/TDMA applied in downstream and upstream transmission in PONs. Explain how collisions are avoided in upstream transmission. Outline how *Dynamic Bandwidth Allocation* is achieved in the TDM/TDMA scheme described. *(3 points)*

Last and first name: *(capital letters)*
(signature)

Matriculation number:

4) Explain the meaning of *greenfield, brownfield, overbuild* deployment of an FTTH infrastructure. Explain pros and cons of *total replacement* vs. *overlay* strategies for network migration to FTTH. *(2 points)*

5) Explain and discuss the graph below, in particular why the slope is increasing moving to right. *(2 points)*