Optical and Transport Networks

Prof. Stefano Bregni **II Exam 2019-20 – 19 February 2020**

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.

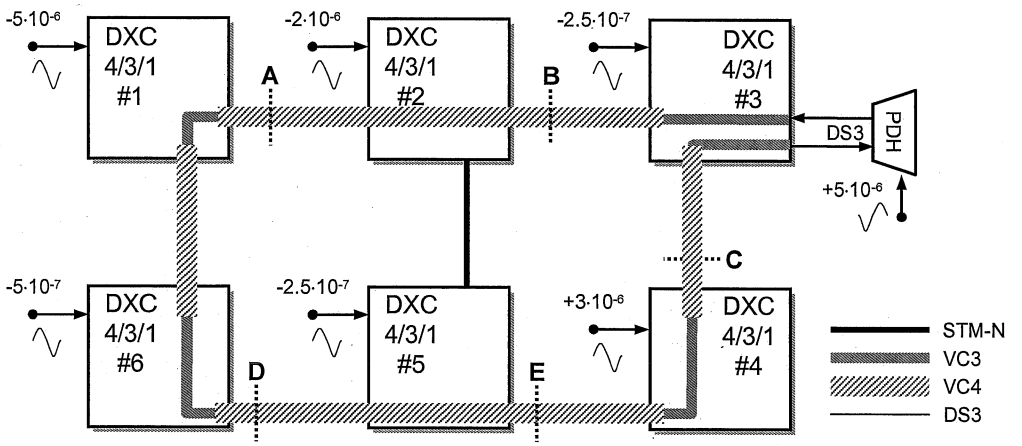
Problem 1

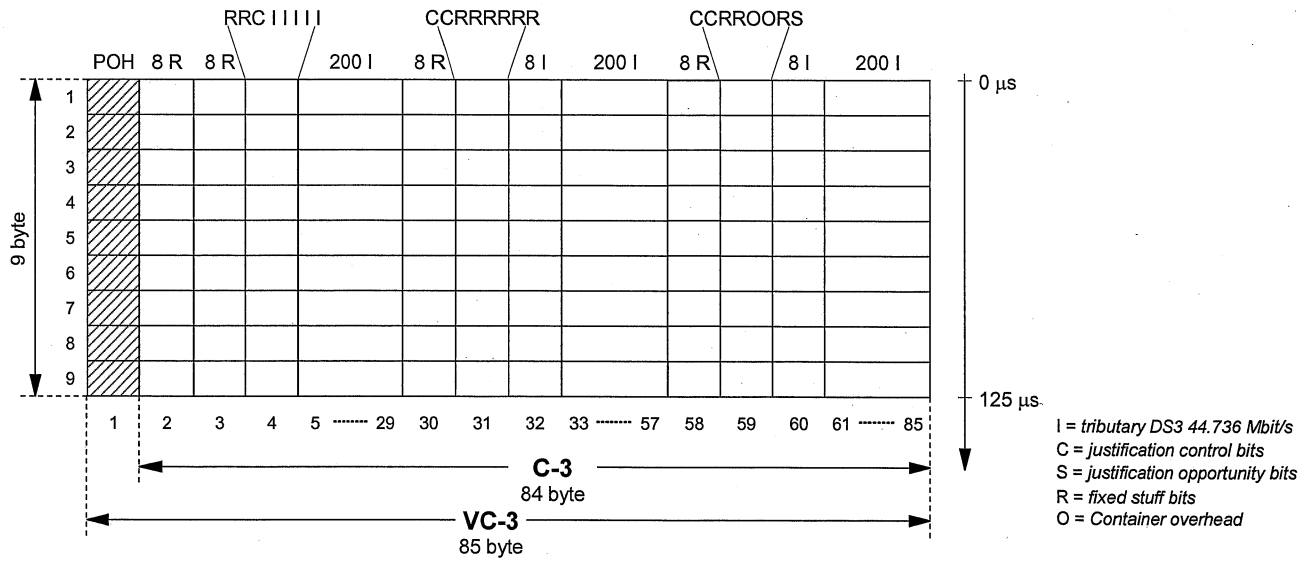
(Solve on this sheet in the space provided) (6 points)

Consider the network of DXC 4/3/1 elements in figure below, where all links are bidirectional. Links between DXCs are STM-1 (f_0 = 155.520 Mbit/s). Each Network Element (NE) is synchronized by an external reference, of which either the fractional frequency deviation $\Delta f/f_0$ from the nominal value f_0 = 2.048 MHz or the absolute frequency is given.

For your convenience, the asynchronous mapping scheme of DS3 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 a DS3 port of DXC #3, generates a DS3 link (f_0 = 44.736 MHz), which follows the path indicated with the black thin line in figure. The DS3 circuit is transported (asynchronous mapping) via the LO VC3 path indicated with the grey line in figure (3-2-1-6-5-4-3). 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, 6-5-4, 4-3).





a) Compute the justification ratio ρ (as fraction of justification opportunity bits occupied by significant bits) in the VC3 transiting at interface C from DXC #4 to DXC #3. *(2 points)*

$$44{,}736 \text{ Mb/s}\,(1+5\cdot10^{-6}) = (1-2{,}5\cdot10^{-7})\,(621+\rho)\,9\cdot8000 \text{ bit/s}$$

$$\rightarrow \rho = 0{,}3366$$

b) Compute every how many seconds AU4 pointer justifications do happen at interface E (i.e., the inter-justification period), in the direction from DXC #5 to DXC #4, specifying also their sign (POS/NEG) *(2 points)*

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

In the AU4 p.p. of NE #5: $\Delta f = f_{VC4}(-5\cdot10^{-7}+2{,}5\cdot10^{-7}) = -37.584$ Mb/s

1 AU4 jmt every $\frac{24 \text{ bit}}{37.584 \text{ bit/s}} = 0{,}638\,5$ sec (POS)

c) 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) *(2 points)*

No jmt

AU/TU

d) Discuss whether, and under what conditions, the pointer activity at interface A (in the direction from DXC #2 to DXC #1) may be affected by a diurnal wander introduced by the link supplying the external synchronization signal to DXC #3 *(2 points)*

TU: no

AU: maybe

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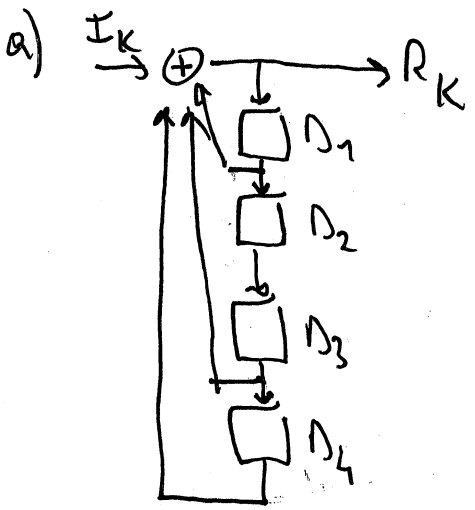
Problem 2

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

a) Draw the scheme of a self-synchronizing scrambler with characteristic polynomial $P(x) = 1+x+x^3+x^4$, fed with all "0"s and utilized as PRBS generator. Denote the bit sequence at the input as $\{I_k\} = \{0, 0, \ldots\}$ and the sequence at the output as $\{R_k\}$.

b) Initialize the delay cells D_i ($i = 1, 2, 3, 4$) as $\{1, 0, 0, 0\}$ at the initial step $k = 0$. Calculate the PRBS sequence $\{R_k\}$ generated at the output, highlighting its periodicity. What is its period P? What is the maximum period that we could expect from this scrambler?

a)



b)

K	I_K	D_{1K}	D_{2K}	D_{3K}	D_{4K}	R_K
0	0	1	0	0	0	1
1	0	1	1	0	0	1
2	0	1	1	1	0	0
3	0	0	1	1	1	0
4	0	0	0	1	1	0
5	0	0	0	0	1	1
6	0	1	0	0	0	1

$P = 6$

$P \leq 15$

Problem 3

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

Let $s(t)$ be a non-ideal timing signal generated by a clock with instantaneous frequency ($t \geq 1$ s, $\nu_0 = 1$ Hz)

$$\nu(t) = \nu_0\left(1+\frac{T}{t}\right)$$

a) Derive the analytical expression of the timing signal $s(t) = A$ sen $\Phi(t)$ knowing that $\Phi(1) = 0$.

$$\Phi(t) = 2\pi \int_1^t \nu(t)\,dt = 2\pi\nu_0\left[t + T\log t\right]_1^t = 2\pi\nu_0\left(t - 1 + T\log t\right)$$

b) On what instant of ideal time t the *Time Error* of this clock is TE(t) = 0?

$$TE(t) = T(t) - t = T\log t - 1 \qquad T(t) = \frac{\Phi(t)}{2\pi\nu_0}$$

$$TE(t) = 0 \text{ per } \log t = 1/T \quad t = e^{1/T}$$

c) For what value of the parameter T the timing signal $s(t)$ at time $t = 2$ s has the same *Total Phase* as the ideal timing signal?

$$1 + T\log 2 = 2 \rightarrow T = \frac{1}{\log 2} \qquad TE(2) = 0$$

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Problem 4

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

200 persons make a call, or attempt to call, on the average once every T at random Poisson times using their mobile phones. The duration of calls is random, with unknown distribution and average 5 minutes. Phones are all connected to the same radio base station, linked to the network by a backhaul link carrying $m = 8$ single telephone lines.

To evaluate the probability P_L that a call is rejected, use the Erlang-B $E_{1,m}(A_O)$ formula:

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

What is the minimum value of T (approximately), in order to make the probability P_L that a call is rejected lower than 1%?

$$A_o = 200 \frac{5'}{T} = \frac{1000}{T} \quad T\,[\text{min}]$$

$m=8$	A_o [Erl]	$B_m(A_o)$
	5	~0,07
	4	~0,03
	3	~0,008
	3,5	~0,017
	3,125	~0,00996

$\Rightarrow A_o < 3{,}125$ Erl

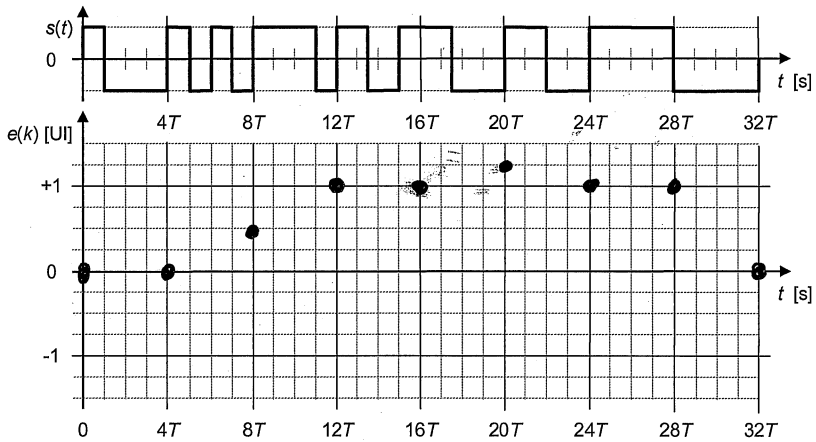
$T > 320$ min (5h20')

Problem 5

(Answer on this sheet in the space provided) (15 points)
NB: In any exercise, any answer not justified adequately, even with few words, will not be considered.

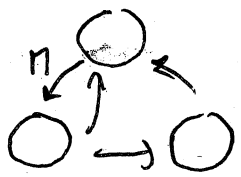
1) Let $s(t)$ be the square timing signal $s(t)$ plotted in figure for $0 \le t \le 32T$. *(3 points)*

- What is its average frequency ν_0 over the interval $(0, 32T)$?
- Plot the jitter values $e[k]$ [UI] of $s(t)$, measured against the ideal timing signal $s_0(t)$ with frequency ν_0 at significant instants $t_k = k/\nu_0$ (i.e., the significant instants of the ideal timing signal $s_0(t)$), starting from the initial point $e[0] = 0$ and with the convention that positive jitter denotes time advance.



$$\nu_0 = \frac{8}{32T} = \frac{1}{4T}\ \text{Hz}$$

2) Consider the standard SDH frame alignment algorithm, represented by a Markov Chain with three states (LOF, OOF, IF). The line signal is affected by random transmission errors, uncorrelated and with bit error rate $\varepsilon = 10^{-6}$. The frame alignment word, checked during maintenance, has length b [bit]. How long should be made the frame alignment word, in order to keep the same probability of transition IF → OOF if the bit error rate doubles? *(3 points)*



$$\left[1-(1-\varepsilon)^b\right]^n = \left[1-(1-2\varepsilon)^x\right]^n$$

$$(1-\varepsilon)^b = (1-2\varepsilon)^x$$

$$1-b\varepsilon \cong 1-2x\varepsilon \rightarrow x \cong b/2$$

$$\left(\text{Valore esatto: } x = b\,\frac{\log(1-\varepsilon)}{\log(1-2\varepsilon)}\right)$$

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3) Consider a GPON, where the clock of an ONU is not synchronized by the OLT but is in free running with frequency offset 1 ppm. *(3 points)*

- What problem is experienced by the user of this ONU?
- What problem is experienced by users of other ONUs?
- If the data bursts transmitted by ONUs last 10 ms and are separated by 1 ms guard times, after how long data would begin to overlap, starting from perfect alignment?

4) Data bursts transmitted (or attempted) by users connected to an urban base station of a mobile network are monitored. Initial times and duration of each burst are recorded. What reasons could be mentioned, to suspect that burst start times cannot be modeled by a Poisson process? What statistical analysis would you perform on the measured data, to confirm or deny that such model holds? *(3 points)*

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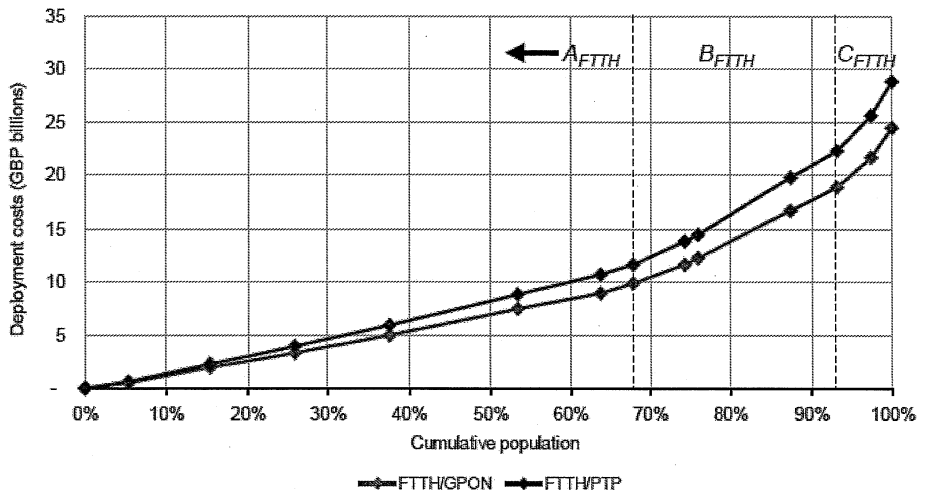
5) Explain and discuss the graph below. *(3 points)*

- What is the meaning of the slope of the curves? Why it is not constant?
- In what country of the world would you expect the slope nearly constant from 0% to 100%?
- Comparing the curves of two countries A and B, I note that in the curves of A the region with linear progression (constant slope) extends from 0% to 80%, while in the curves of B the same region extends only from 0% to 40%. What difference would you infer between the characteristics of the two countries?