Optical and Transport Networks

Prof. Stefano Bregni **III Exam 2018-19 – 24 June 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.

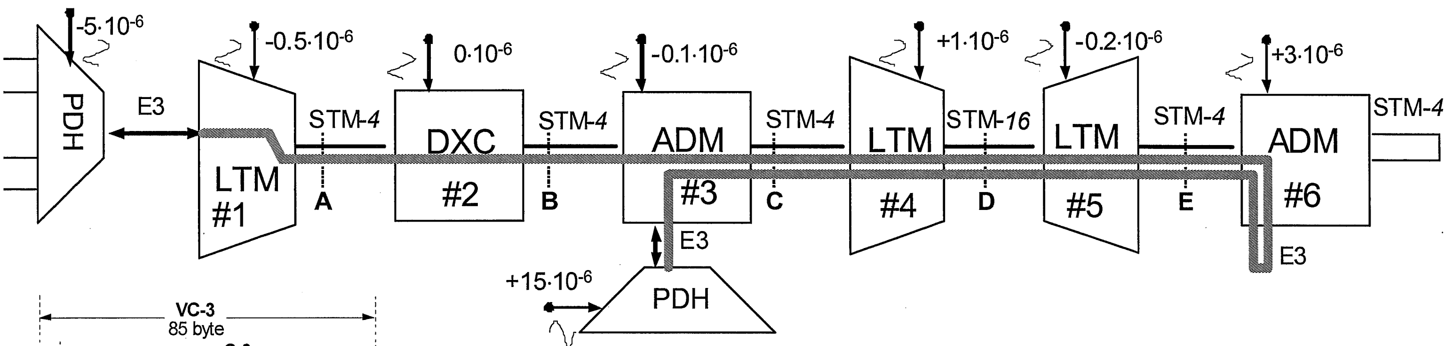
Problem 1

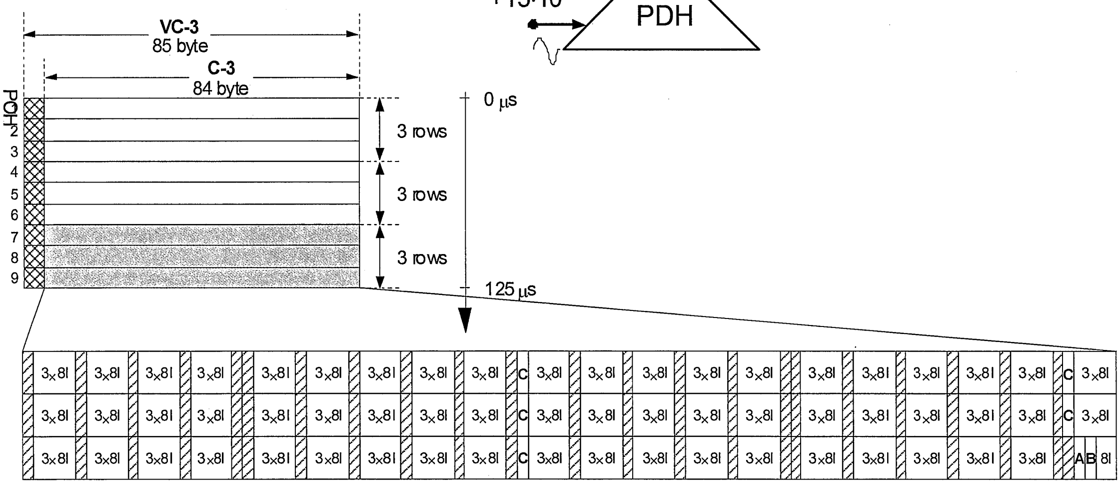
(Solve on this sheet in the space provided) (6 points)

Consider the SDH system in figure below, where all links are bidirectional. Links between Network Elements (NEs) are STM-N (f_0 = N·155.520 Mbit/s). Each 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 LTM #1, generates a bidirectional E3 link (f_0 = 34.368 MHz), which follows the path indicated in figure. The E3 circuit is transported (asynchronous mapping) via two LO VC3 paths (1-2-3-4-5-6, 6-5-4-3) transported in its turn via three HO VC4 paths (1-2-3, 3-4-5-6, 6-5-4-3). The E3 is demapped and remapped in the second LO VC3 path at ADM #6.





I = *tributary E3 34.368 Mbit/s*
C1, C2 = *justification control bits*
S1, S2 = *justification opportunity bits*
R = *fixed stuff bits*

= *8 bit R fixed stuff*

C = *R R R R R R C1 C2*

A = *R R R R R R R S1*

B = *S2 I I I I I I I*

a) Compute the justification ratio ρ (as fraction of justification opportunity bits occupied by dummy bits) in the VC3 generated at LTM #1.

$$34{,}368\ \text{Mb/s}\,(1-5\cdot10^{-6})\ \text{Mb/s} = 8000\ \text{Hz}\,(1-5\cdot10^{-7})\,(1433-2\rho)\cdot 3$$

$$\Rightarrow \rho = 0{,}503222$$

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

NO justifications

c) 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 #6, specifying also their sign (POS/NEG)

In the AU pointer processor in #5: $\Delta f = f_{VC4}(-10^{-7}+2\cdot10^{-7}) =$

$= +15{,}0336\ \text{bit/s}$

1 just. AU4 every $\dfrac{24\ \text{bit}}{15{,}0336\ \text{bit/s}} =$

$= 1{,}5964\ \text{sec (NEG)}$

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

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

In the TU3 pointer processor in #3: $\Delta f = f_{VC3}(-0{,}5\cdot10^{-6}+10^{-7}) =$

$= -19{,}584\ \text{bit/s}$

1 just TU3 every $\dfrac{8\ \text{bit}}{19{,}584\ \text{bit/s}} =$

$= 0{,}4085\ \text{sec (POS)}$

$f_{VC3} = \dfrac{85\cdot9\cdot8\ \text{bit}}{125\,\mu s} = 48{,}96\ \text{Mb/s}$

Problem 2
(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, $\nu_0 = 10$ Hz)

$$\nu(t) = \nu_0 + \frac{1}{\nu_0 t^2}$$

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

$$\Phi(t) = 2\pi \int_1^t \nu(\tau)\,d\tau = 2\pi\left[\nu_0 t - \frac{1}{\nu_0 t}\right]_1^t = 2\pi\left[\nu_0 t - \frac{1}{\nu_0 t} - \nu_0 + \frac{1}{\nu_0}\right] =$$

$$= 2\pi\nu_0(t-1) + \frac{2\pi}{\nu_0}\left(1\,\text{Hz} - \frac{1}{t}\right)$$

b) Evaluate the *Time Interval* measured by this clock and its *Time Interval Error* in 1 s ≤ t ≤ 3 s, that is TI(t, τ) and TIE(t, τ), for t = 1 s, τ = 2 s.

$$T(t) = \frac{\Phi(t)}{2\pi\nu_0} = (t-1) + \frac{1}{\nu_0^2}\left(1\,\text{Hz} - \frac{1}{t}\right)$$

$$TI(t,\tau) = T(t+\tau) - T(t)$$

$$TIE(t,\tau) = TI(t,\tau) - \tau$$

$$TIE(1,2) = TI(1,2) - 2 \simeq 6{,}67\text{ ms}$$

$$TI(1,2) = T(3) - T(1) = T(3) =$$

$$= 2\text{ sec} + \frac{1}{(10\text{ Hz})^2}\left(1\,\text{Hz} - \frac{1}{3\text{ sec}}\right) =$$

$$= 2{,}00667\text{ sec}$$

c) Evaluate the *Time Error* TE(t) measured by this clock in t = 2 s.

$$TE(t) = T(t) - t = -1 + \frac{1}{\nu_0^2}\left(1\,\text{Hz} - \frac{1}{t}\right)$$

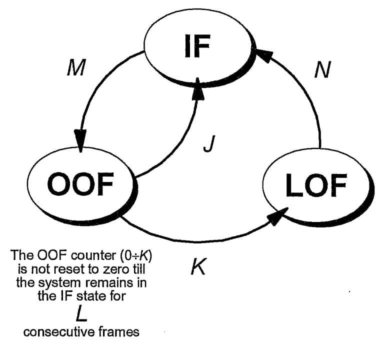
$$TE(2) = -1 + \frac{1}{(10\text{ Hz})^2}\left(1\,\text{Hz} - \frac{1}{2\text{ sec}}\right) = -0{,}995\text{ sec}$$

Problem 3

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

Consider the standard SDH frame alignment algorithm, represented by the diagram below ($K = 12$, $N = 12$). A frame aligner operates on a test STM-1 framed signal at input, with random content everywhere in all frames except the alignment word, which consists of X bits during hunting and $Y = 8$ bits during maintenance. The test signal is affected by random transmission errors on the line, uncorrelated and with rate $\varepsilon = 10^{-3}$.

a) Compute the probability P_1 that the system, being aligned but in Out-of-Frame state, moves to the Loss-of-Frame state due to the random transmission errors.



$$P_1 = \left[1-(1-\varepsilon)^8\right]^{12} \cong (8\varepsilon)^{12} \cong 6\cdot 10^{-26}$$

b) Let P_2 be the probability that the system, being in state Loss-of-Frame, gains correct alignment (IF) due to simulation of the alignment word by the random payload. Evaluate the number of bits X, which are necessary to have $P_2 < 10^{-30}$.

$$P_2 = \left(\frac{1}{2^X}\right)^{12} \qquad \frac{1}{2^{12X}} < 10^{-30} \qquad 12X > 30 \log_2 10 \qquad X > \frac{30}{12} \Big/ \log_{10} 2$$

$$\Rightarrow X \geq 9$$

c) Let P_3 be the transition probability that the system moves from being correctly aligned (IF) to Out-of-Frame in M frame periods due to the random transmission errors. How much should we change the length of the alignment word Y, to keep the same P_3 if ε is doubled?

$$P_3 = \left[1-(1-\varepsilon)^Y\right]^n \qquad \left[1-(1-\varepsilon)^Y\right]^n = \left[1-(1-2\varepsilon)^{\hat{Y}}\right]^n$$

$$(1-\varepsilon)^Y = (1-2\varepsilon)^{\hat{Y}}$$

$$\rightarrow \hat{Y} = Y \frac{\log(1-\varepsilon)}{\log(1-2\varepsilon)} \cong Y \frac{1}{2}$$

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Problem 4

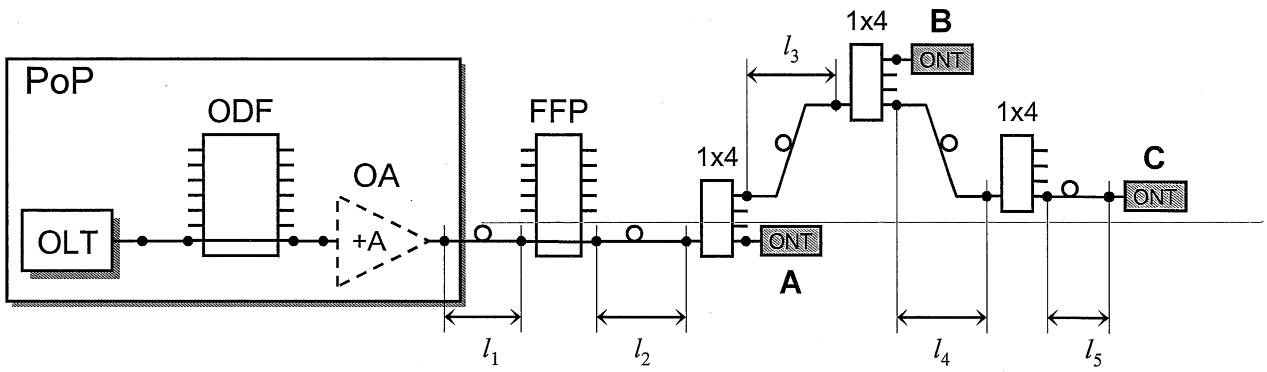
(Solve on this sheet in the space provided) (6 points)

Consider a Passive Optical Network reaching up to 64 users at variable distances from the Optical Line Termination (OLT) via a variable number of 1×4 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 $\alpha = 0.3$ dB/km;
- $l_1 = 1$ km, $l_2 = 500$ m, $l_3 = 3$ km, $l_4 = 3$ km, $l_5 = 3$ km;
- OLT transmission power $P_{TX} = 0$ 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 $P_{RX} > -27$ 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 *Differential Path Loss* [dB] between ONTs at position A and ONTs at positions B, C.

$$DPL_{AC} = P_{RX/A} - P_{RX/C} = \alpha(l_3 + l_4 + l_5) + 5\alpha_c + 2(\alpha_s + 6) \quad [dB]$$
$$= 19{,}2 \text{ dB}$$

$$DPL_{AB} = P_{RX/A} - P_{RX/B} = \alpha(l_3) + 2\alpha_c + (\alpha_s + 6) = 8{,}9 \text{ dB}$$

b) Evaluate the power P_{RX} [W] received by the farthest ONT in position C with OA having gain $A = +8$ dB.

$$P_{RX/C} = P_{TX} + A - 14\alpha_c - 3(\alpha_s + 6) - \alpha \sum_{1}^{5} l_i = -23{,}15 \text{ dBm}$$

$$= 4{,}8\ \mu W$$

c) Evaluate the maximum total distance $L = \sum_{i=1}^{3} l_i$, which could be covered with only the first two stages and including an OA with gain $A = +15$ dB, meeting the receiver sensitivity and safety margin of the ONT at position B.

$$P_{RX/B} \geq -21 \text{ dBm}$$

$$P_{TX} + A - 11\alpha_c - 2(\alpha_s + 6) - \alpha L \geq -21 \text{ dBm}$$

$$\Rightarrow L \leq 55 \text{ Km}$$

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Problem 5

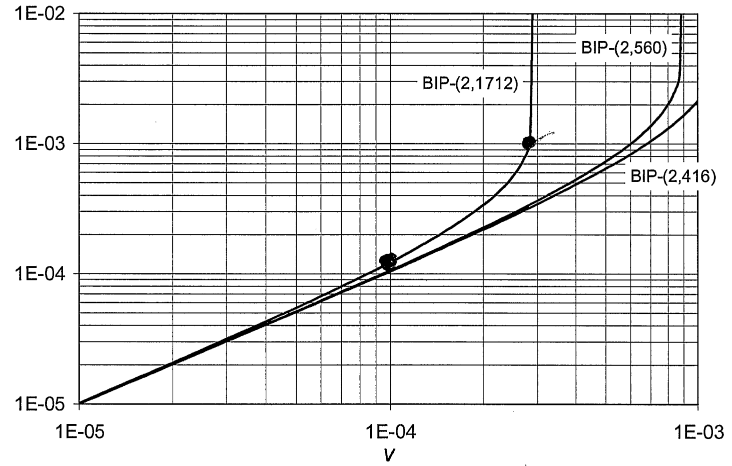
(Answer on this sheet in the space provided) (13 points)

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

1) The figure below plots the calibration curves $\varepsilon(v)$ for adjusting BER estimates of bits 1, 2 of byte V5 of VC-11, VC-12 and VC-2. *(3 points)*

a) Why the parity violation rate v detectable by BIP (2, 1712) cannot be larger than ~$3 \cdot 10^{-4}$?

b) Under the error rate BER = 10^{-4} on the transmission line, what is the approximate parity violation rate detected by the byte V5 of VC-2? And for BER = 10^{-3}?



$v \simeq 2{,}9 \cdot 10^{-4}$ $(\varepsilon = 10^{-3})$

$v \simeq 10^{-4}$ $(\varepsilon = 10^{-4})$

2) Outline the principle of *Virtual Concatenation* (what is different from Contiguous Concatenation?) enhanced by *Link Capacity Adjustment Scheme.* *(2 points)*

3) Outline the principles of one-way vs. two-way schemes for synchronization over packet-switched networks. Are they suitable for frequency and/or time synchronization? *(2 points)*

4) For what reason the ONUs of a PON must be synchronized by the OLT? What happens if the clock of an ONE has a frequency offset from the OLT? *(3 points)*

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5) For what reason, and under what circumstances, the probability of *time congestion* (Block Probability) in a bundle of lines serving phone calls is higher than the probability of *call congestion* (Call Loss Probability)? *(3 points)*