**NATIONAL UNIVERSITY OF SINGAPORE**
**FACULTY OF ENGINEERING**

**EXAMINATION FOR**

(Semester II: 2020/2021)

**EE5134 OPTICAL COMMUNICATIONS AND NETWORKS**

April/May 2021 - Time Allowed: **2** Hours

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INSTRUCTIONS TO CANDIDATES:

1. This paper contains **FOUR (4)** questions and comprises **FIVE (5)** pages.
2. Each question carries **25** marks
3. This is an **OPEN BOOK** examination. NO copy and paste or copying from Internet sources or other sources is allowed. The answers should be yours, in your own words and hand writing.
4. Programmable Calculators are **NOT** allowed.
5. You should NOT consult with any other person during the Exam.
6. Abide by the code of conduct and rules stated in the declaration form, sign and submit it along with your answers.
7. Only handwritten answers on papers are allowed. Typewritten answers or use of devices like tablets are not allowed. Write your answers on fresh sheets of paper. Please start each question (Q1, Q2, Q3, and Q4) on a new page. Clearly indicate the part, e.g. Q1(a) on the left margin.
8. Write your matriculation number on every page.
9. Scan/ Photo each page and compile into one PDF file in the given order: cover page, signed declaration form, and your answers.
10. Name your file: <matric number>-<module code>.pdf (e.g.: A1234567R-EE5134).
11. Upload the PDF file to the folder corresponding to your group, “EE5134 Exam Paper Group no” at LumiNUS.

**Q.1**

(a) Consider a unidirectional WDM physical ring network with five nodes connected as $0\rightarrow1\rightarrow2\rightarrow3\rightarrow4\rightarrow0$. It is required to create six lightpaths for the node pairs $P_1$: <0,2>, $P_2$: <0,1>, $P_3$:<3,0>, $P_4$:<2,3>, $P_5$: <1,4>, and $P_6$: <4,0>.

(i) Route the lightpaths using shortest-path-first heuristic with fixed-order wavelength assignment policy, and list the path and wavelength chosen for each lightpath in the table format as shown below. Determine the number of wavelengths required.

| Lightpath $P_i$ | Path | Wavelength |
|---|---|---|
| | | |

(ii) Develop a better heuristic with fixed-order wavelength assignment policy, and list the path and wavelength chosen for each lightpath in the table format as shown below. Your heuristic should require fewer wavelengths than that used in part (i) above. Explain the intuitive reason why your heuristic is doing better.

| Lightpath $P_i$ | Path | Wavelength |
|---|---|---|
| | | |

(iii) Construct a path graph and assign wavelengths for lightpaths using graph coloring method. Verify that this method requires the same number of wavelengths as in part (ii) above.

(iv) It is required to route 0.4, 0.5, and 0.6 units of client traffic flows for the node pairs (0,3), (2,1) and (1,2), respectively, through shortest paths over the virtual topology. Determine the route traversed by each traffic flow and load carried by each lightpath. Tabulate the results in the format below. Calculate the congestion and average weighted number of (virtual) hops.

| Traffic flow | route | hop |
|---|---|---|
| | | |

| Lightpath $P_i$ | Load |
|---|---|
| | |

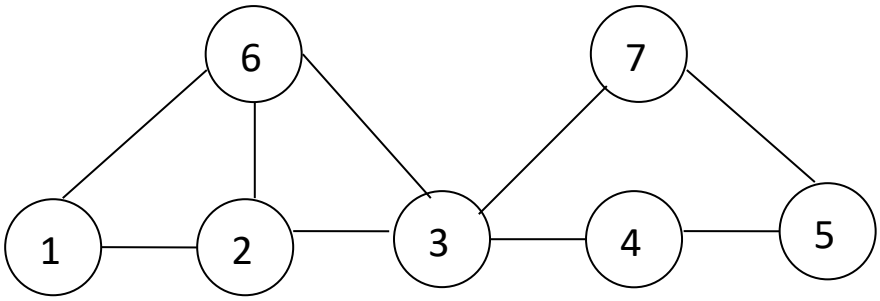
(20 marks)

(b) Briefly describe one advantage and one disadvantage of parallel route search when compared to sequential route search with forward wavelength reservation.

(5 marks)

**Q.2**

(a) Consider a WDM network as shown in the figure below. A lightpath is set up from node 1 to node 5 on the path 1-2-3-4-5. List one set of possible backup paths for the cases of (i) failure-independent path-based protection and (ii) failure-dependent path-based protection.




(5 marks)

(b) Consider a hypothetical signaling protocol for EPON in which OLT assigns slots for the ONUs in a round-robin fashion for upstream operation. Here, OLT assigns x slots each to ONU1, ONU2, and so on, in a round robin fashion. Upon receiving the slot assignment, ONU1 transmits data for a maximum of x slots depending on how much data it needs to transmit. Upon completion, it notifies the OLT which then assigns x slots to ONU2. This procedure is repeated with other ONUs. Briefly discuss one advantage and one disadvantage of this protocol when compared with the MPCP protocol.

(5 marks)

(c) A burst scheduling algorithm called Least Used Channel First (LUCF) chooses the wavelength channel on which least number of bursts are currently active among the possible wavelength channels for a new burst. Show with an example that LUCF performs poorly when compared to the Latest Available Unscheduled Channel (LAUC) scheduling algorithm. In your example, choose a burst-switching node with 2 wavelengths $w_0$ and $w_1$ per fiber and three bursts, and show that LAUC can schedule all the three bursts, but LUCF can schedule only the first two bursts.

(5 marks)

(d) Consider a wavelength-convertible WDM network with 6 wavelengths per fiber and each node having conversion capability of degree 2. Suppose that a wavelength is occupied on a fiber with probability 0.15. The above event is assumed to be independent of the use of other wavelengths on the fiber and is also independent of the use of the same and other wavelengths on other fibers.

(i) What is the equivalent multi-fiber network for the above convertible network from the perspective of blocking performance?

(ii) Use the above equivalence and calculate the blocking probability of a request for a 3-hop path (i.e., a path traversing 3 links).

(10 marks)

**Q.3**

(a) Calculate the transmission distance for a fiber link with an attenuation of 0.52 dB/km, under the condition that the power launched in is 1.2 mW, and power at the output is 48 μW.

(5 marks)

(b) Assume a multimode step-index fiber with a **core diameter** of 84 μm and a relative index difference $\Delta = 1.5\%$. It works at 850 nm wavelength. Its core index is 1.47. Estimate

(i) The normalized frequency of the fiber

(5 marks)

(ii) The number of guided modes.

(5 marks)

(c) List out different types of **dispersions in optical fiber**, and explain the cause of each type.

(5 marks)

(d) An optical fiber has a length of 1.2 km. It is a multimode step-index fiber, with $n_1 = 1.48$, $n_2 = 1.465$, and $\Delta = 0.01$. Calculate the model delay of this optical fiber.

(5 marks)

**Q. 4**

(a) Explain **three key optical processes** within a semiconductor laser. (hint: can use figures/drawings to explain).

(5 marks)

(b) A DFB laser has a Bragg grating period of 221 nm. Its waveguide has an effective refractive index of 3.5. Calculate its Bragg wavelength (assuming a **first order grating**).

(5 marks)

(c) A silicon-based PIN photodiode has a light receiving area with diameter of 0.42 mm. Under the radiation at 700 nm with intensity of 0.12 $mW/cm^{-2}$, the photodiode generates a photocurrent of 74 nA.

(i) Calculate its responsivity.

(5 marks)

(ii) Find its quantum efficiency at 700 nm

(5 marks)

(d) A silicon-based APD has a quantum efficiency of 0.7 at 830 nm under M=1. The APD is then biased to work under M=120. Calculate its photocurrent with incident optical power of 8 nW.

(5 marks)

**Appendix**

Speed of light in vacuum = $3\times10^{8}$ m/s,
Electric charge = $1.6\times10^{-19}$ C,
1eV = $1.6\times10^{-19}$ J
Planck's constant = $6.63\times10^{-34}$ J·s,
Boltzmann constant = $1.38\times10^{-23}$ J/K
Room temperature = 300 K

**END OF PAPER**