Question 1

Assume that a network topology is described by directional graph $G(N, L)$, where each link $l = (b, e) \in L$ begins at node $b \in N$, ends at node $e \in N$, and has length W_l. There are $|R|$ requests, where request $r = (s, d) \in R$ originates from source node $S(r) = s \in N$, terminates at destination node $D(r) = d \in N$, and requires transmission rate B_r. Some nodes are nominated for grooming sites using a suitable heuristic approach. The non-grooming source and destination nodes of a request should home on an adequate grooming site through backhaul connections for possible grooming operations.

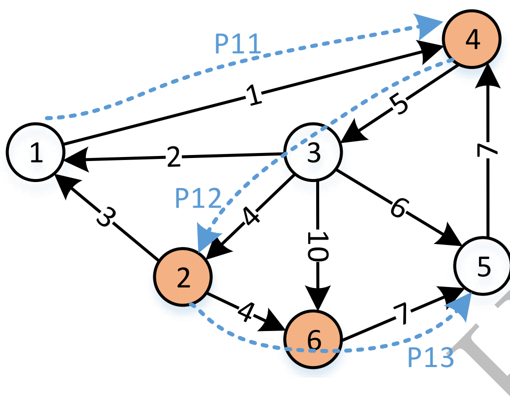

Figure 1: A sample network topology in which grooming sites are highlighted. The route of a sample request with its two backhaul parts is shown.

(a) Propose a heuristic approach for locating $|K| \leq |N|$ grooming sites.

(b) Write an optimization problem formulation to route the traffic requests such that the overall length of backhaul connections is minimized.

(c) Assume that the grooming site $k \in N$ can accept at most G_k (input/output) backhaul connections. Upgrade your formulation to take this constraint into account.

(d) What happens if the constraint on the grooming capacity G_k cannot be assured? Upgrade your formulation to allow minimum violation of the grooming capacity constraint.

Question 2

A 1550-nm wavelength optical system shown in Fig. 2 has three spans of single-mode optical fiber, and three optical amplifiers each with 6 dB noise figure. Each amplifier has 20 dB optical gain but the length of each fiber span is different, they are 80, 120, and 50 km, respectively.

Question 2 continued on next page...

The fiber attenuation is 0.25 dB/km. The signal optical power emitted from the transmitter is 10 mW.

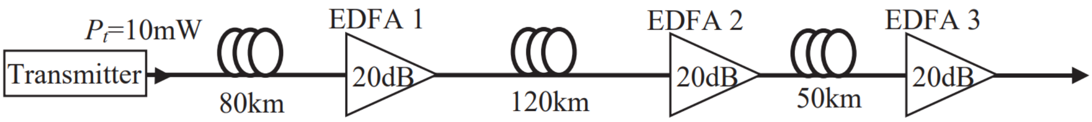

Figure 2: An optical link with inline amplification.

(a) What is the optical noise power spectral density at the output of the laser EDFA (in the unit of dBm/nm)?

(b) If there is a narrowband filter at the output of the last EDFA at the optical signal wavelength with $B_o = 0.1$ nm optical bandwidth, what is the optical signal-to-noise ratio (OSNR) at the system output? (Here OSNR is defined as the ratio between signal optical power and the optical noise power within the bandwidth of the optical filter)

Question 3

Assume that 135 (identical and independent) services are multiplexed onto a 100 Gb/s wavelength. Each service can be represented by an ON/OFF model, where a service is ON with probability 0.6. When the service is ON, the requested service rate is 1 Gb/s.

(a) What is the probability that the intended offered load exceeds the wavelength bit rate? Let P equal this probability.

(b) On average, how full is the 100 Gb/s wavelength?

(c) Next, consider the scenario where these same services are multiplexed onto 10 Gb/s wavelengths. How many services can be multiplexed onto one 10 Gb/s wavelength such that the probability that the intended offered load exceeds the wavelength bit rate is no higher than P?

(d) With this number of services on a 10 Gb/s wavelength, on average, how full is the wavelength?

Question 3 continued on next page...

(e) What is the statistical multiplexing gain in the 100 Gb/s scenario versus the 10 Gb/s scenario (for the level of P calculated above)?

Question 4

Consider the bidirectional topology graph of Fig. 3. The network carries three protected directional requests from sources 5, 4, and 6 to the destinations 2, 2, and 1, respectively. For each request, the working and protection paths create the minimum-hop pair of maximally link-disjoint paths. Each path should be routed continuously over a wavelength subject to wavelength non-overlapping and continuity constraints.

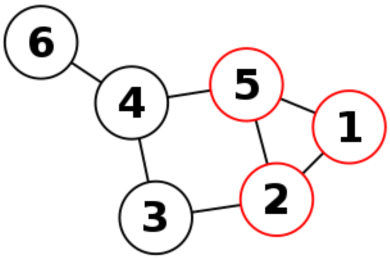

Figure 3: A bidirectional topology graph.

(a) Determine the working and protection paths of each request?

(b) Draw the corresponding conflict graph.

(c) Use the conflict graph to determine a range for the required number of wavelengths to route the requests. What is the minimum number of required wavelength?

Question 5

Write the rate equations for a two-level system, showing that a steady-state population inversion cannot be achieved by using direct optical pumping between levels 1 and 2.