1. Consider a MPLS switch that has 16 slots and each slot can house an interface card with 16 Gigabit Ethernet ports. At the input port the Label mapping unit will strip the Ethernet and MPLS frames from the incoming packet and replace them with an internal frame structure containing, e.g., connection id, new MPLS label and internal switching label. The total overhead of the frame is 64 bits and the contents of the label are fetch from Connection table memory.

   The Traffic policing unit ensures that no connection exceeds its reserved capacity. It uses the internal switching label to fetch per connection data, updates the data and writes it back to memory.
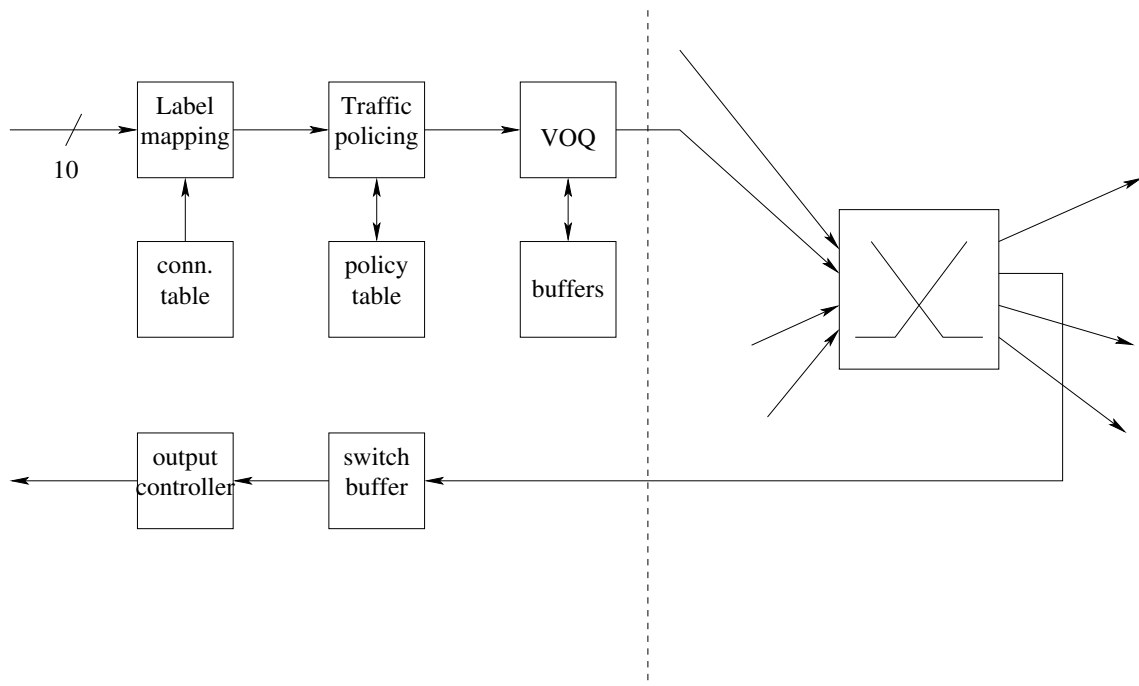
   Virtual output queueing unit is used to provide the actual buffering in the system. Each packet is first written into buffer memory (containing one queue per output port) and read when the it is scheduled for switching.

   The switching matrix utilises 3.125 MHz LVDS pairs to minimise the signal count and provide compact switch size.

   At the output port the switch buffer just adapts the internal switch line speed to external line speed. The Output controller forms the MPLS-over-Ethernet frame using the information transported in the switching frame.

   The design goal is that each port can manage full speed traffic when the average IP datagram length is 100 octets or more.

   (a) What is the required memory speed for Connection table and policy table memories? What is the required memory throughput for VOQ buffer memory?

   (b) If the memory devices that are to be used for VOQ memory have access speed of 6 ns, what is the most suitable power-of-2 memory bus width?

   (c) What is the required clock speed for 16 LVDS pair POS-Phy4 interfaces between units?

   (d) At switching matrix 8B10B coding is used to provide synchronisation and basic error detection. How many signal pairs are required per slot and what is the size of the switch?

   (e) What is the required speed of the switch buffer at the output port?

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2. Consider a two node FT-FR broadcast and select network that uses fixed-frame scheduling to allocate the network capacity. The traffic matrix is

$$\Gamma = \left[\begin{array}{cc} 1 & \pi \\ 1 & 1 \end{array} \right]$$

where $\gamma_{i,j}$ denotes the traffic intensty from i to j. Minimum number of time slots neccessary to create a collisionless schedule is

$$L_{min} = \max_{ij} \left(\left\lceil \frac{\bar{T}}{C} \right\rceil, \left\lceil \frac{\mathcal{T}_i'}{\alpha_i} \right\rceil, \left\lceil \frac{\mathcal{R}_j'}{\beta_i} \right\rceil \right),$$

where $\bar{T}$ is the total amount of traffic, C the number of channels, $\mathcal{T}_i'$ traffic send by node i, α_i the number of transmitters in node i, $\mathcal{R}_j'$ traffic received by node j and β_j the number of receivers in node j.

The number of required time-slots for each traffic flow can be found out by decomposing Γ to a scalar part and to a matrix where elements are relative prime numbers. If any $\gamma_{i,j}$ is not a rational number, such element has to be approximated by a suitable rational number $\gamma_{i,j}' > \gamma_{i,j}$

Approximate π by 22/7 and determine the minimum frame length L_{min} for perfect scheduling. How much capasity is wasted?

3. Consider an optical network using fixed-frame scheduling for packet traffic. The traffic load from station i to j is 0.5, the frame length $L = 100$, frame time $F = 125\,\mu$s and there is one time slot allocated for $i \to j$ traffic. Determine the fiber distance at which the propagation delay in fiber equals the average system delay $\bar{D}$. Take the speed of light in the fiber to be $2 \cdot 10^8$ m/s.

   You may assume that the arrival process is a Poisson process and that the average waiting time in the queue is given by

   $$\left(\frac{\rho}{2\mu}\right)\left(\frac{1}{1-\rho}\right)$$

   where ρ is traffic intensity and μ is service rate.

4. In broadcast and select network (i.e., broadcast star) capacity can be allocated dynamically. The efficiency of channel allocations depends on the structure of the nodes and the allocation scheme that is used. Consider a 4-node FT-TT network with fixed frame length. The queue in each node contain 4 frames which are:

   - Node 1 – $[1,2]_1, [1,3]_1, [1,2]_2, [1,3]_2$
   - Node 2 – $[2,4]_1, [2,3]_1, [2,4]_2, [2,4]_3$
   - Node 3 – $[3,1]_1, [3,4]_1, [3,1]_2, [3,3]_1$
   - Node 4 – $[4,1]_1, [4,2]_1, [4,1]_2, [4,3]_1$

   (in the shown order). Find out the schedules for

   (a) Tell-and-go capacity allocation; when a node has something to send, i.e., queue is non-empty, it first send a message (through a separate signalling channel) to all destination stations and then, without waiting a reply, it sends the frame in first free slot. If there is more than one frame destined to a particular destination station at the same time slot, it can tune only to a single wavelenght and receive a single frame. How many frames are lost?

   (b) Lossless scheduling; conflicts are avoided by using reservations, i.e., only one source can send a frame to a particular destination in each time slot. The First Come First Served (FCFS) queue dicipiline is maintained, i.e., the frames have to be sent in order.

   (c) Perfect scheduling; FCFS is not maintained but there is one queue for each destination in each source station and the frames can be sent out of order.

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5. Compare two approaches in upgrading an existing single channel SDH transmission system. One approach is to install new fiber and new single channel SDH transmission systems in parallel, i.e., one channel per fiber. Another approach is to use installed fiber and upgrade its capacity using WDM technology. As there is an existing infrastructure (e.g., cabinets for repeaters or amplifiers), only the fiber installation and equipment costs have to be considered.

Assume that installation of new fiber cable costs 1,500 euro/km and the price of the cable is 2 euro/m for 8-pair cable and 3 euro/m for 16 pair cable. Furthermore, each single channel SDH transmission line requires a repeater after each 25 km fiber span. Assume that a repeater costs 7,000 euro.

A WDM transmission system requires at each end of the system one multichannel WDM (de)multiplexer and for each channel one transponder (a WDM transponder, placed before WDM multiplexer, converts the optical signal in to a form that is suitable for WDM network), e.g., 8 transponders for 8 channel system. Furthermore, an EDFA is required after each 50 km fiber span. Assume that one transponder costs 12,000 euro and one amplifier costs 90,000 euro. The costs for 8- and 16-channel WDM (de)multiplexers are 60,000 and 110,000 euro, respectively.

Draw figures showing the logical structure of both transmission systems. At which transmission line length it becomes cheaper to install WDM based system (consider both 8 and 16 channel cases)?