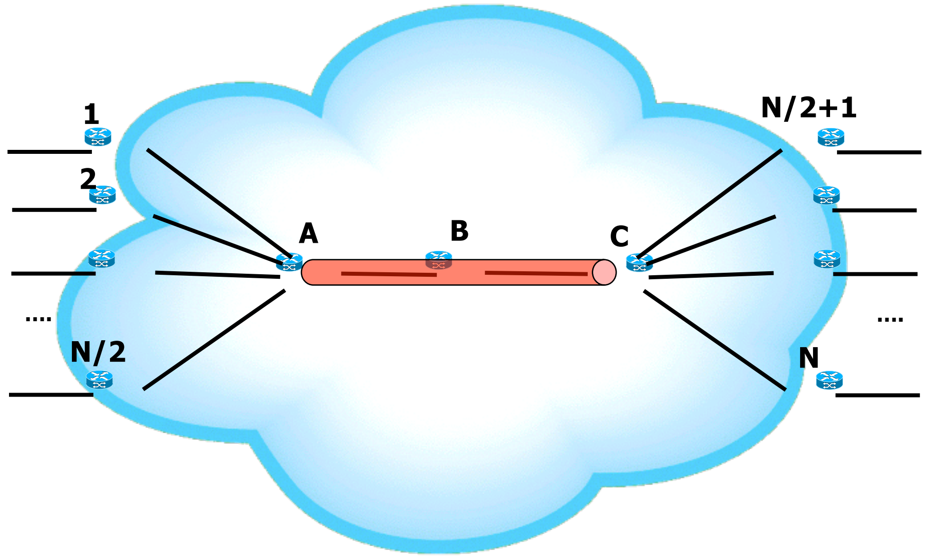
Exercise 1

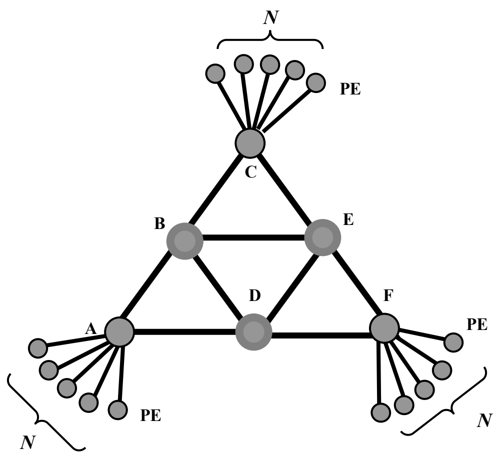
Compute the number of LFIB entries for the following LSRs: PEs, A, B and C, and the following cases:

a) No merging in the network
b) Merging in the network
c) Merging in the network and the tunnel showin in the figure between the LSRs A and C.



Exercise 2

In the MPLS network shown in the figure below all LSPs has been established automatically using LDP following a shortest path approach in order to achieve a full connectivity among all the PEs (border) LSRs. The link layer is Gigabit Ethernet and none of the nodes implements penultimate hope popping.



1. Assuming that the network do not implement LSP merging, compute the total number of forwarding entries (NHLFE) that the next nodes should have in order to achieve full connectivity among the PEs (full mesh). Take into account that the LSPs are unidirectional

Node A:
Node B:
Node PE:

2. Assume the network implements LSP merging. Compute the total number of forwarding entries (NHLFE). Counts each label merging n-to-1 as n forwarding entries.

Node A:
Node B:
Node PE:

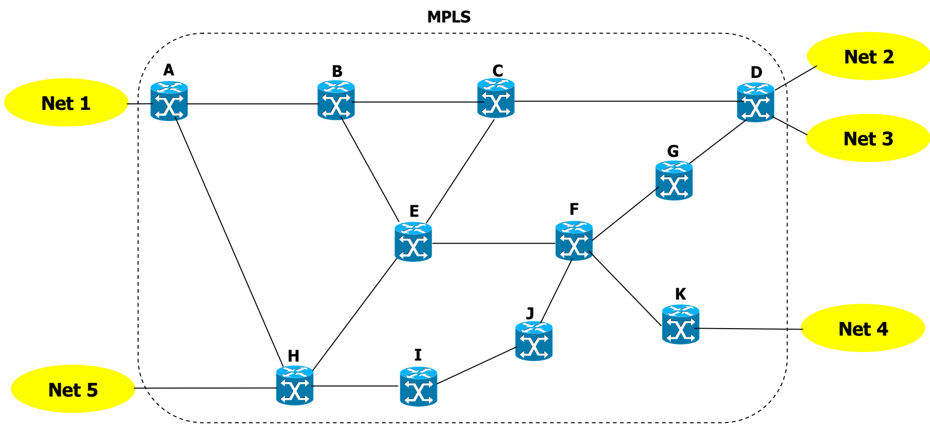
3. Assume the network implements LSP merging, and, in addition, the network manage wants to reduce the forwarding tables for nodes B, D, E, setting up the next bidirectional tunnels: A-C, A-F, C-F, and routing all LSPs that cross nodes B, D and E through those tunnels. Compute the total number of forwarding entries (NHLFE). Counts each label merging n-to-1 as n forwarding entries.

Node A:
Node B:
Node PE:

4. In the case of bullet 3) provide a description (as detailed as possible) for the content of an ethernet frame carrying a UDP/IP datagram captured in the link A-B. Show the relative position of the headers for layer 2, 3 and MPLS. Indicate the nodes adding each of the lables.

Exercise 3

The following figure shows an ISP core network based on MPLS technology with LSP merging and their connection to networks Net1...Net5



Routing protocols: OSPF inside and BGP outside (to connect Net1..Net5). Label assignment is control driven, and LDP is the label distribution protocol. All the necessary LSPs have been automatically created using the shortest paths with the number of hops as metric.

a) Assume the link C-D goes down and that:
- Link failure detection time by the LSRs on each side of it is 15 ms
- The time since a node's OSPF process knows of a link failure (due to a level 2 event or an OSPF LSA), updates its routing table, builds the message, sends it, and its neighbors receive it, is always 10 ms.
- It is possible to send control messages (OSPF,LDP) simultaneously through several links..
- The time the LDP takes to: react to a change in the routing table (such change takes 10ms since the event notifying the link is down is triggered), update the LFIB and send and LDP message (if required) is negligible.

a.1) Determine the network recovery time for the LSR D's outgoing traffic, assuming the LDP is configured as downstream-on-demand, ordered, with conservative label retention.

a.2) Repeat the previous exercise if the LDP is configured as downstream-unsolicited, independent, with conservative label retention.

a.3) Repeat the previous exercise in case the label retention mode is liberal.
Note: In this mode, C can receive mappings from D and E and store boths. Same happens with B, when it receives mapping from E and C; and F from E and G (this last one it is used).

b) Design an optimum (smallest no of hops) prefixed protection LSP that solves the problem of the C-D link failure described in a). Describe the forwarding tables in each of the LSRs used only for the LSP that would transport the outgoing traffic in D. Use Penultimate-Hop- Popping

c) Assume that all the links speed is 1Gb/s. Given the following traffic matrix (in Mb/s) previously the link C-D is down

Destino \ Origen	Net1	Net2	Net3	Net4	Net5
Net1	-	400	200	50	100
Net2	400	-	50	50	100
Net3	200	50	-	50	100
Net4	50	50	50	-	500
Net5	100	100	100	500	-

c.1) Define the LSPs to be established with traffic engineering to ensure that same traffic matrix can run after the link is down (if it is possible). It is not required to indicate symmetric LSPs..

Path	Mb/s cursados

c.2) Is it possible to establish those LSPs automatically? Describe what extensions for which protocol are required, and show an example of a message to establish one of the LSPs listed in the previous question,

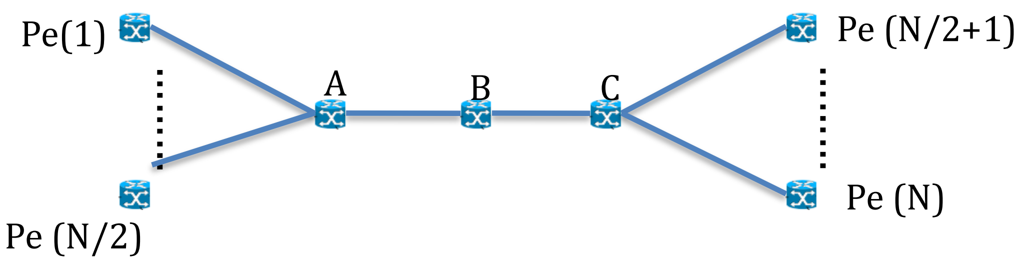
Ejercicio 4

Given the MPLS network of the figure, where N=4 , fill out the LFIB of node A in the cases:

I. Merging is disabled in the network.
II. Merging enabled.
III. Merging and a biderectional tunnel A-C is configured for all LSPs traversing A-C.

Use the tables to provide answers. Only the tunnel and the LSPs between PEs are considered in this exercise.

Answer in the attached tables filling the following information: Combination source node (could be more than one node) and destination node involved in the traffic referred within the LFIB entry, In Label, LSR operation, Out Label. In case you need it you can use A and C as source/destination nodes.



1. without merging:

Source Node	Destination Node	Input Label	Operation	Output Label

2. With merging

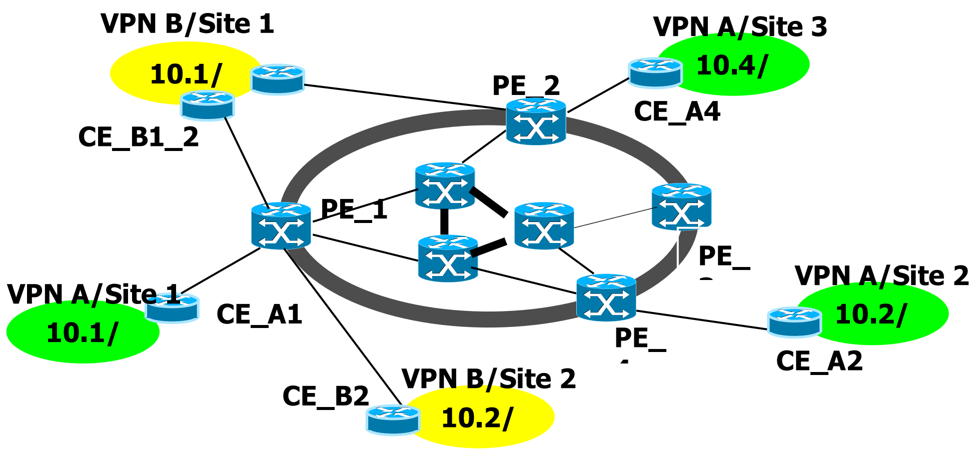
Source Node	Destination Node	Input Label	Operation	Output Label

3. With merging and a tunnel:

Source Node	Destination Node	Input Label	Operation	Output Label

Exercise 5

The enterprises A and B use VPN that include multiple offices geographically distributed. Both enterprises subcontract the VPN to an VPN provider. This provide implements VPN service on top of its network (which means a singe BGP autonomous system) using the RFC 2547 that defines BGP/MPLS VPN level 3 implementation. The figure below shows an schema of the prefix associated to each company, the provider's access routers (PEs), the client routers (CE) and the network topology. The chosen solution uses the following routing protocolos: PEs use BGP with the clients, PEs use iBGP among them, and the internal nodes works using OSPF.



1. What iBGP technique should be used in PE_1 to avoid the VPN A routes become visible to VPN B?

2. Describe how the provider manages the fact that the address space of both companies is overlapped. You should answer:

2.a) How the issue of distributing routes (routing) having as destination network: 10.2.0.0/16 from PE_1 to PE_4 is solve?:
2a.1) when routes are distributed inside the network?
2a.2) when routes are distributed to other PEs?

2.b) How the potention ambiguity in the destination when forwarding a packet inside the network whose source is A-site3 and destination A-site2

cómo se soluciona la posible ambigüedad de destino en el reenvío (forwarding) dentro de la red de un paquete procedente de A-site3 con destino A-site2.

3. Given that the underlaying technolog is GigabitEhternet in the core network, draw an example of the frame which embeds the packet referred in the previous point.
   3.a) In the first hop of the packet within the core network
   3.b) In the last hop of the packet within the core network assuming the network enables Penultimate Hop Popping.

NOTE: You don´t need to provide details of the IP and Ehternet headers. You just need to identify the relative position of the MPLS lables and what is the purpose of each of those lables in the VPN context.

4. Given a stable configuration of the core network IP/MPLS, a new office named A-Site4 is added and it is connected to PE_3.

4.a) Describe what has to be configured en the network elements involved in this aggregation (identify those elements).

4.b) Enumerate the sequential steps happening in the network until the moment all the other A offices can send/receive packets to/from the new office. Perform an estimation of the duration of that process takin into account the following lower bound time required for:

- the processing and updating of e-BGP routes with all the invoved routers is 10ms,
- in the case of i-BGP 4ms,
- RIP/OSPF required time is 5 ms hop by hop
- Establishing the LSP in the network using LDP requires 7ms.
- The diffusion time of the new routes within the local offices is 20ms.
- Take into account that for scalability reasons it is not required to establish new LSPs if the network has previously establish part of those LSPs.