Integration of Routing and Switching

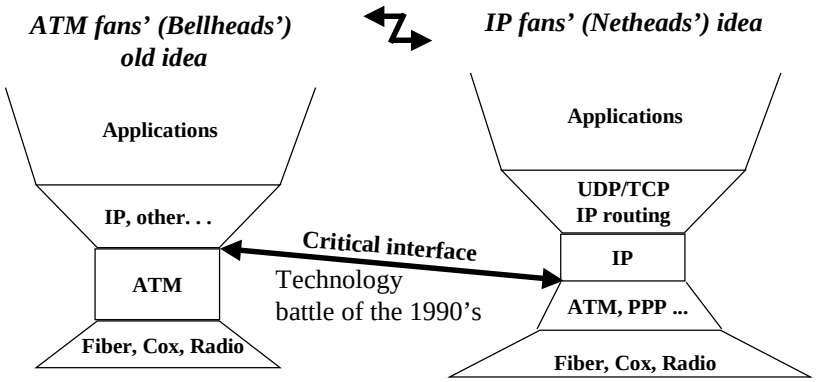
Label Switching & IP switching

The goal is to avoid executing packet forwarding algorithm for each and every packet and replace it with switching in hardware. The result is faster and less expensive IP network with Integrated Traffic Engineering Mechanisms.

- Motivation
- History
- Principle of Label swapping and its properties (MPLS)
- Label Distribution Protocol
- Traffic management and MPLS

LUE uudet specsit!

ATM vs IP as the integrating layer



IP -switching and label switching are manifestations of the technology (and business) battle on the critical IP/ATM = packet/circuits -interface.

Basic problem of all *IP over ATM solutions* is the huge nrof flows and their small size

- A Flow is a sequence of packets from a source address or prefix to a destination address or prefix possibly with a certain UDP/TCP source and destination ports. Cmp. packets sent in a TCP-session.
- Average length of a flow in the Internet seems to be < 10 000 octets
- On 1 Gbit/s wirespeed we have
  - 12500 = nrof flows that are created and disappear each second
  - 450 M flows created and disappear/h in a router with 10 ports
  - 100…1000 -fold too much for each flow to be treated like a “phone call”.

Many attempts to adapt IP to underlaying ATM

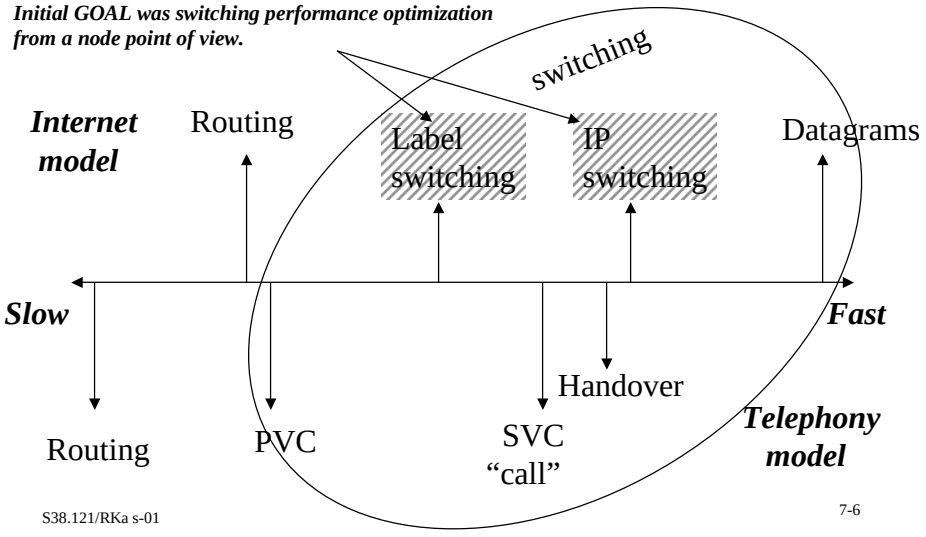
- Classical IP over ATM
- LANE - LAN Emulation
- MPOA = LANE extended to WAN (wide area)
  - destinations far away in an ATM network can be attached into an IP network by establishing virtual connections to them (=by making an “ATM-call”) based on traffic or connectivity needs

All these architectures suffer from Complex Architecture, in-efficiency and poor scalability.

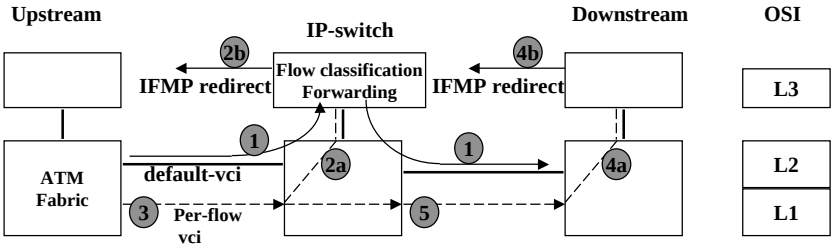
What's wrong in a pure IP network?

- Can not guarantee or even assure Quality of Service.
- Packet forwarding with longest match destination prefix search is a rather slow operation
  - can be turbo-charged with HW but the question of adaptability to protocol changes remains
- Routing based on Shortest Paths Only limits operator's capability to manage the traffic in the network and use network resources efficiently
  - Because there is no route pin-down, it is difficult to implement alternative routing.

Routing and switching are mechanisms for mapping traffic to network resources



IP switching reduces router load by connecting part of the traffic directly thru the ATM fabric



1. IP switches work as routers. IP-packets are carried on the default VCI. In addition the node run the Flow Classification program.
2. Flow Classifier has detected a flow, 2a - IP-switch reserves a dedicated upstream VCI for the flow. 2b - IP switch sends IFMP redirect message to upstream neighbor.
3. Upstream IFMP-node starts forwarding remaining packets of the flow onto that VCI. The first packet on the VCI acts as an acknowledgement to IFMP redirect message.
4. Downstream IP-switch/router has also detected the flow and sends a redirect message.
5. IP-switch thruconnects the flow in the ATM Fabric (Processor is out of loop).

Properties of IP switching (a' la IPSILON)

- Several flow types
  - source IP-address, destination-IP-address + many packets
  - source IP-address, destination-IP address, TCP/UDP-ports
- Flow packets have their own encapsulation
- Last downstream IFMP -node which pops the packet to its processor, sets the packet TTL to the right value.
- IP -switching is a *traffic driven end-to-end* solution
- Approximately 70 - 80% of packets can be mapped to flows and switched

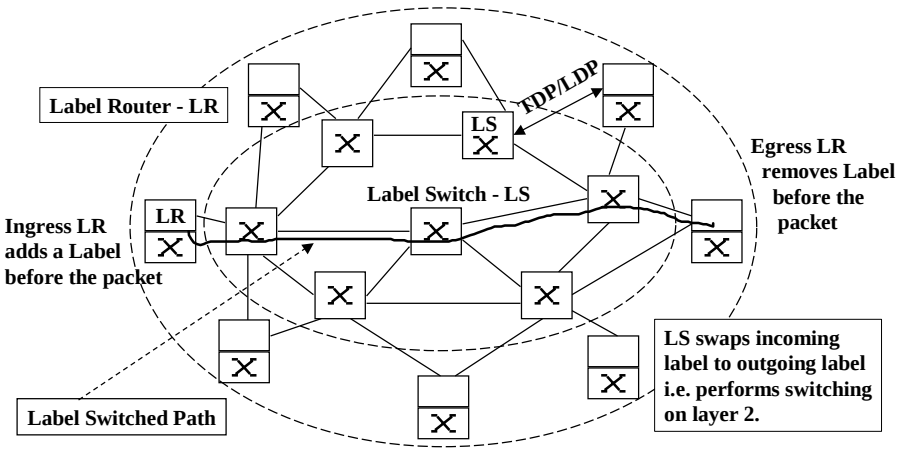
IP switching by IPSILON forced forward several competing solutions

- Cisco: Tag Switching
- IBM: ARIS - Aggregate route based IP switching
- Toshiba: CSR - Cell switch router
- Juha Heinänen: SITA - Switching IP through ATM

Added value is topology driven switching - whole routes are mapped to virtual paths/circuits in the underlaying link layer.

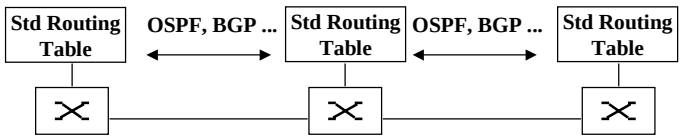
IETF started to create order in chaos with its -
MPLS - MultiProtocol Label Switching activity.

In topology driven Label Switching a full mesh VCC network is established on a Label Switched Domain



A Label Switched network in action: phase 1

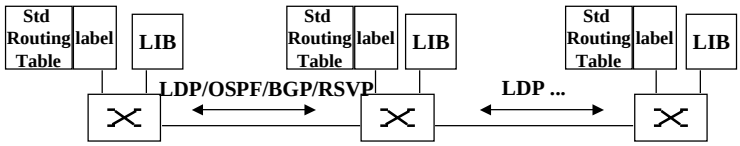
1. Label Routers and Label Switches work as any Router (as OSPF, BGP, etc protocol nodes) - we call them Label Switching Routers.



A Label Switched network in action: phase 2

2. LR and LS (or LSR)

- **use the Routing Table created normally by routing protocols to set labels**
- **distribute labels using routing, RSVP or LDP -protocols.**
- **LR builds Label Information Base from received info.**

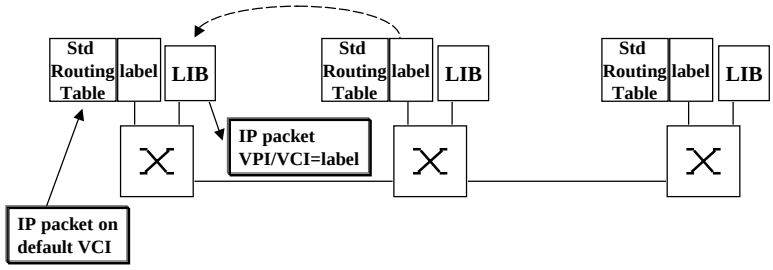


- ***MPLS group has published a DRAFT LDP spec (last 10/99?).***

Label Switched network in action: ph. 3

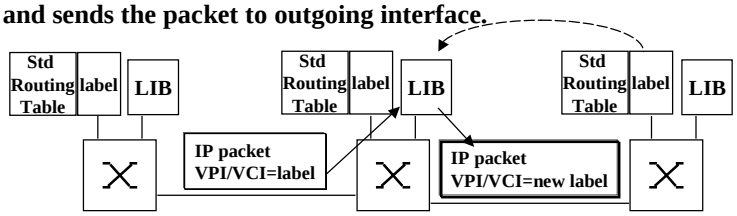
3. When Ingress-LR receives a packet from outside the LS-Domain,

- **it analyses the packet header, performs layer 3 services,**
- **fetches outgoing interface from Routing Table and Label from LIB,**
- **adds Label prior to packet header and send the packet to next LS.**

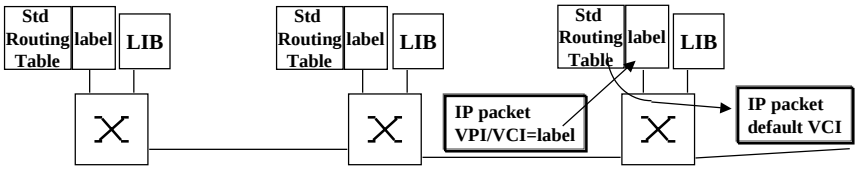


Label Switched network in action: ph. 4, 5

4. LS receives Label packet on layer 2, swaps incoming to outgoing Label and sends the packet to outgoing interface.



5. Egress LR removes label from packet and routes the packet based on IP packet header.



Many transport mechanisms for Labels are specified - Label Switching is independent of MAC -layer

Label can be transported:

- **as part of MAC header (e.g. ATM VPI/VCI)**
- **as part of network layer header (flow label in IPv6)**
- **in the header of a new "shim" layer between MAC-layer and network layer: In fact this is the method used in European pilot deployments!**

⇨ *Efficient manipulation of Labels requires HW-support of Label Switching:*
- *In ATM label switching = ATM-switching in ATM fabric.*

Labels may be bound to packets based on many criteria

- **A Label may be bound (by LDP) with a set of IP addresses called FEC - Forwarding Equivalence Class.**
  - **All packets in one FEC receive the same MPLS treatment**
  - **A FEC can be, for example, an IP address prefix (0…32 bits).**
  - **A FEC can be also IP address of a Host (this has higher priority)**
  - **(also proposed: FEC is a multicast -address and Label is associated with a multicast tree)**
- **We talk about Flow Granularity.**

Tables in a Label Switch are

Routing Table

Prefix	Next hop	Label
prefix1	Node 1	Label 1
. . .	. . .	. . .
prefix*n*	Node *m*	Label *p*

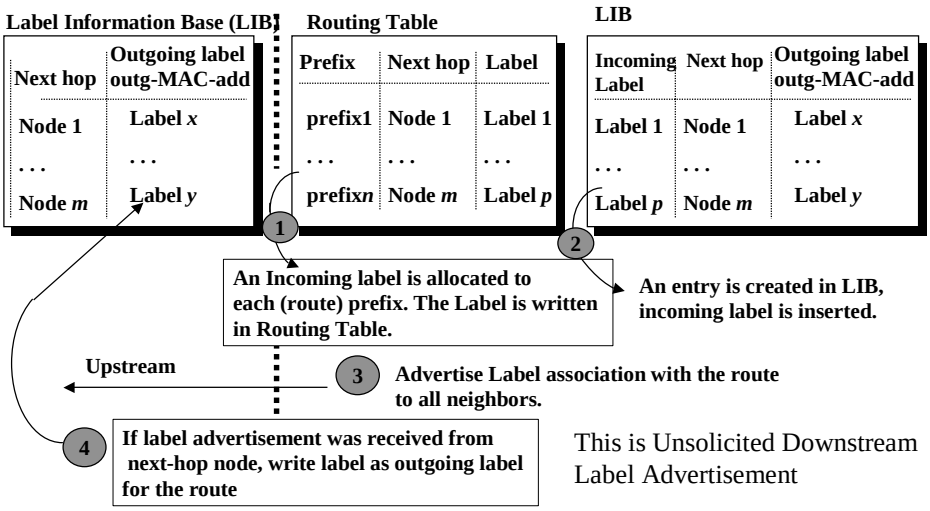
Label Information Base (LIB)/node or/incoming port)

incoming label	Next hop	Outgoing label outgoing-MAC-add
label1	Node 1	Label *y*
. . .	. . .	. . .
label*p*	Node *m*	Label *x*

If outgoing label = VCI, LIB entry will also carry TTL-decrement = length of Label Switched Path (nrof of hops), so that TTL can be set to the right value prior to sending in the ingress router.

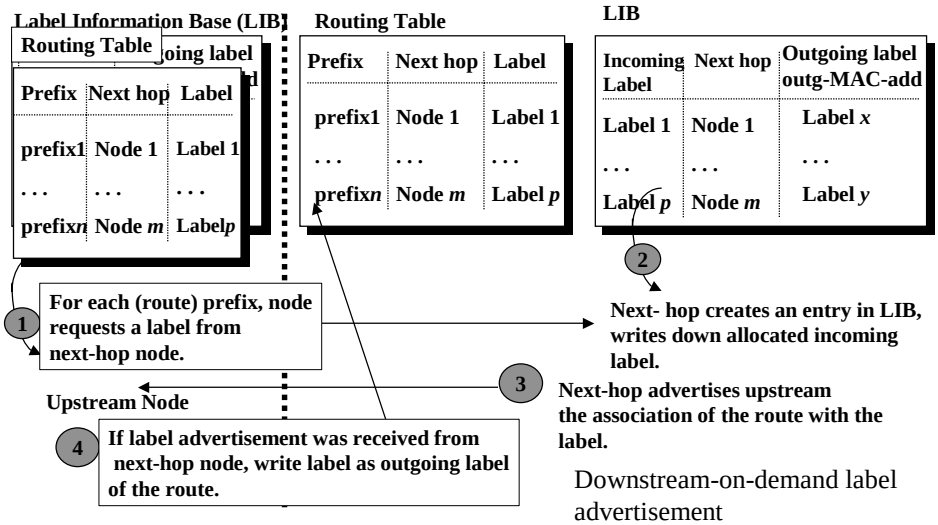
Label allocation mode can be Downstream on-demand or Unsolicited Downstream

These a ways to advertise labels



This is Unsolicited Downstream Label Advertisement

On-demand Label Allocation in action:



Downstream-on-demand label advertisement

Two modes of Label Switched Path control in a network

- Independent LSP Control Mapping: advertise when
  - for each new FEC in FIB, when advertisement arrives unsolicited from downstream
  - Upstream LR sends Label Request about known FEC
  - next hop of FEC changes and loop prevention is on
  - attributes of the label switched path change
  - reception from downstream AND (upstream label has not been allocated or loop prevention or attributes of LSP have changed)

  --> Nodes work autonomously and label binding progresses as a random process

- Ordered LSP Control Mapping - is the alternative

Ordered LSP Control Mapping - Label binding is always initiated by Egress node

- Downstream LR advertises, when one of the following conditions is satisfied:
  - Egress node of a FEC detects a new FEC
  - Upstream node sends request about known FEC and LR is the egress of that FEC or it has already set the downstream label
  - Next hop of FEC changes and Loop prevention is on
  - LSP attributes change
  - A label advertisement arrives from downstream AND (
    a) upstream label has not been set OR
    b) loop prevention is on OR
    c) LSP attributes have changed)

Label Retention modes

- Conservative Label Retention Mode
  - If labels are distributed unsolicited, they may arrive from many neighbors for a particular FEC. Only the label received from next hop of that FEC is retained
  - saves label space, but slows down recovery when route is changed
- Liberal Label Retention Mode
  - labels received from any neighbor are retained. In on-demand mode, more labels may be requested than actually are needed right now
  - speeds up route recovery but consumes label space

Route selection in an MPLS network can be hop-by-hop or explicit

MPLS architecture supports

1. ***hop-by-hop routing - traditional for packet networks***
2. ***Explicit routing*: Ingress or Egress node of the MPLS domain computes the route thru the domain e.g. based on configuration (policy) or network state information.**
3. **Explicit routes require new label bindings and distribution. If explicit route is based on state information (e.g. a-la PNNI), the result is *adaptive routing*.**
4. **An LSP is built either hop-by-hop or explicitly. Mixed paths can lead to loops and therefore not supported.**

Label Distribution Protocol (LDP) is one of methods to distribute, request and release labels

UUSI: LUE http://www.ietf.org/rfc/rfc3036.txt *(2001)*

- Many network protocols are supported (IPv4, IPv6, IPX ...)
- LDP opens, monitors and closes TCP-sessions dynamically between peer LSR - Label Switching Routers.
- One LDP session corresponds to one TCP -session. An LDP-session is responsible for a certain label space.
- LDP is symmetric. Label information may be distributed in both directions.

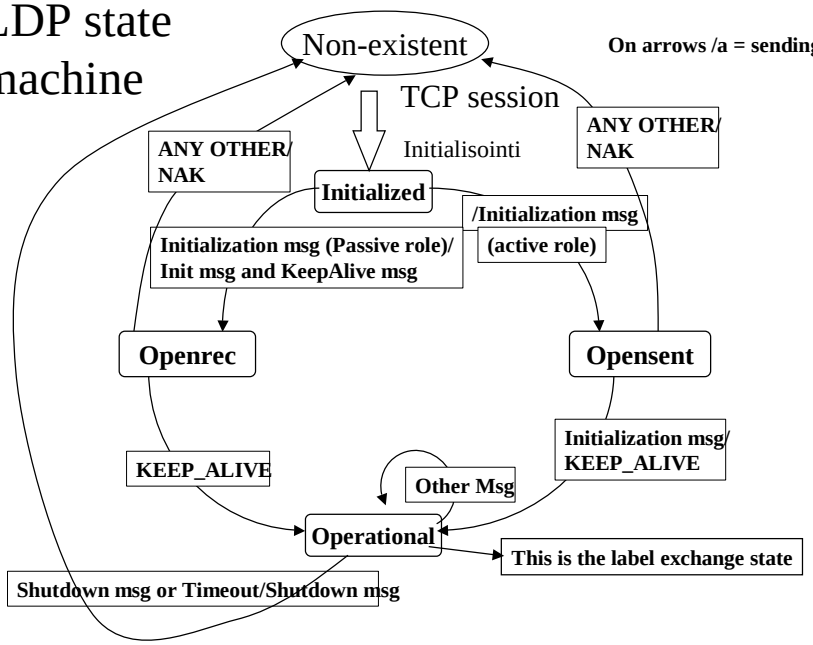
LDP maintains a dynamic VCC configuration for optimization of routing

- LDP session has a keep-alive timer.
- LDP-session is closed if label information is not received during keep-alive time.
- When session is closed, all labels with that peer are released.
- Alternatives to LDP are
  - label carriage in routing protocol (OSPF, BGP) messages
  - RSVP - Resource reSerVation Protocol

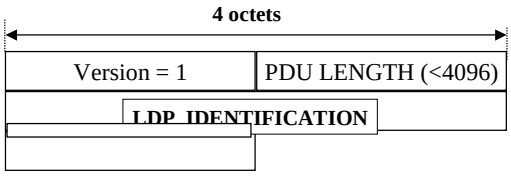
LDP runs mainly on TCP between peer nodes

- Peers are detected by sending Discovery message on UDP to “allRouters in sub-net” -address to find all immediate neighbor peers OR by sending the message to a known IP address of an LSR
  - in the latter case the peer is an LSR farther away in the network to which a nested LSP will be set up.
- All other messages are sent over TCP

LDP state machine

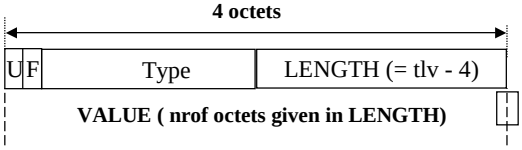


LDP messages carry TLV info elements



LDP header

LDP_identification contains: sender's (router-id) IP-address + number of LDP instance in the LSR (2 bytes). The latter uniquely identifies the label space of the sender.

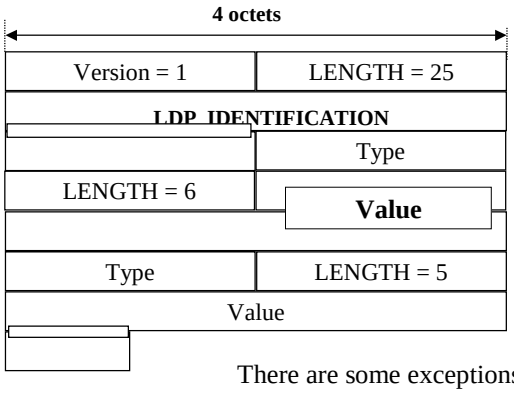


TLV structure

T - Type, L - Length, V- Value
Value may carry other TLV structs

U - Unknown TLV: 0 - Notify originator; Ignore entire msg; 1 - ignore this TLV
F - Forward unknown TLV-bit: U=1,F=1 --> unknown TLV is forwarded

Example LDP message



There are some exceptions to the TLV style of coding all information for achieving more compact coding.

FEC - Forwarding Equivalence Class TLV

00	(FEC) 0x0100	Length
FEC Element 1		
. . .		
FEC Element n		

FEC Element Types:
Wild Card 0x01 - Label withdraw, release
Prefix 0x02 - Address prefix
Host Addr 0x03 - IP address of a Host

00	Gen Label 0x0200	Length
Label		

Label can in practice be e.g. in ATM: VPI+VCI (12+16 bits) or FR DLCI (10, 17 or 23 bit)

LDP message types are

Notification	- Serious and non-serious errors
Hello	- Maintenance of peer relationships (Immediate and addressed neighbors)
Initialization	- Initialization of an LDP session
KeepAlive	- Refreshing the session
Address	- Contains LSR I/f address list
Address Withdraw	- To withdraw an advertisement
Label Mapping	- Setting up label bindings
Label Request	- Requesting labels from downstream
Label Abort Request	- Request to abort a pending request
Label Withdraw	- to Break binding between labels and FECs
Label Release	- To release labels previously requested or received

Traffic driven vs. topology driven packet switching

Traffic driven

- *end-to-end* hop-by-hop solution
- scalability for Internet backbone =? reason: millions of flows/link
- policy based QoS for a small part of the traffic seems easy to add

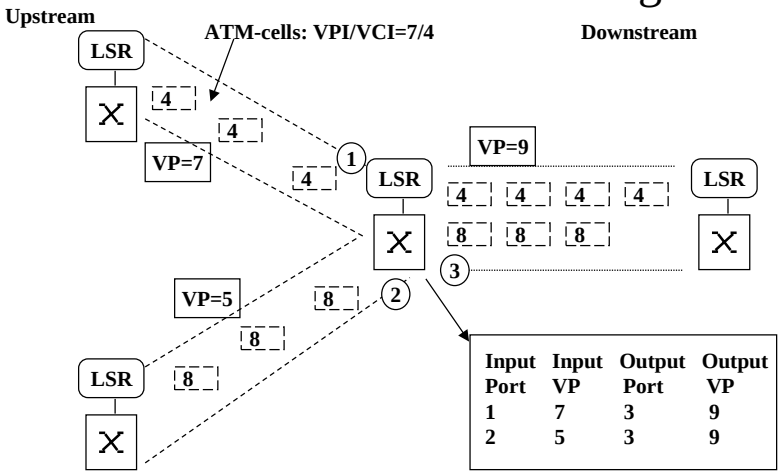
Topology driven

- label domain wide *hop-by-hop and explicit* routing and traffic management solution
- label and routing properties are background operations as compared to user traffic => layer 2 determines top performance
- How large can a label switched domain really be?

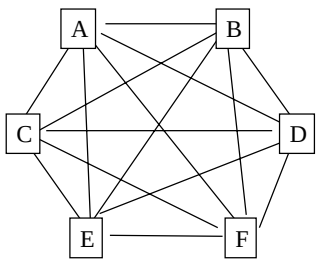
Independent of ATM - both approaches are possible also directly on top of Packets-over-Sonet (POS) - this leads to new kind of label switching hardware.

How easy is it to add QoS support in to MPLS networks?

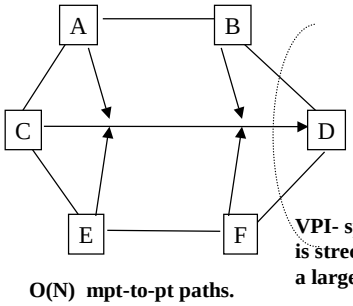
Issue 1: On an LSP Virtual Paths to destination need to merge



Merging virtual paths will reduce the use of label space and nrof LSPs



N x (N-1) -paths
N = nrof routes



O(N) mpt-to-pt paths.
Scales better

VPI- space is streched for a larger domain

VC merge

VC - virtual connection (“ATM-call”)

Routing loops in a label switched network need to be either detected or prevented

- **Label paths follow routing information produced by IP routing.**
- **If loops are possible on IP-layer, the same applies to label switching layer.**
- **Counter measures are needed:**
  - **Path vector (LDP-message route) can be transferred in LDP messages**
  - **…**

Traffic management requirements for MPLS

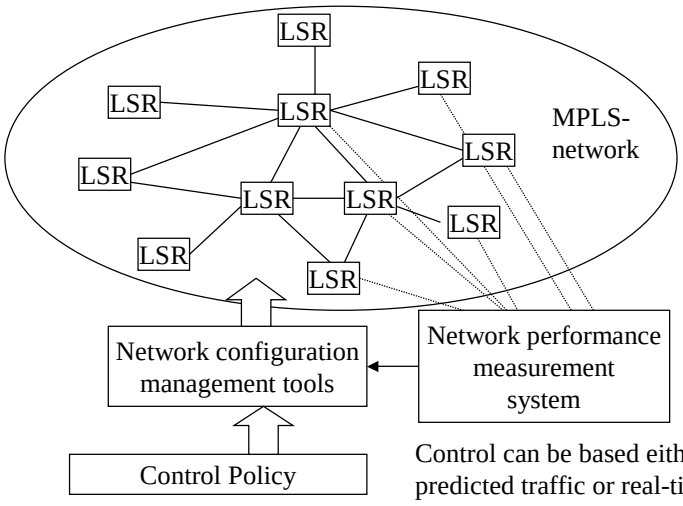
RFC 2702: “Requirements for Traffic Engineering over MPLS”, 28 s, 9/99.

Traffic Engineering (TE) is concerned with **performance optimization of operational networks**. TE encompasses the application of technology and scientific principles to the **measurement, modeling, characterization and control of Internet traffic** and the application of such knowledge and techniques **to achieve specific performance objectives**.
Measurement and Control are the aspects of TE that concern MPLS.

Performance Objectives or traffic management are divided

- Traffic oriented
  - improve quality of service offered to traffic streams
  - reduce packet loss, delay, jitter
  - maximization of traffic carried by the network
  - fulfillment of Service Level Agreements (SLA)
- Resource oriented
  - optimization of resource usage
  - avoiding overload in one part of the network while another part of the network is lightly loaded - when traffic matrix and network dimensioning do not match well.

Traffic management model in MPLS



Control can be based either on predicted traffic or real-time measurement.

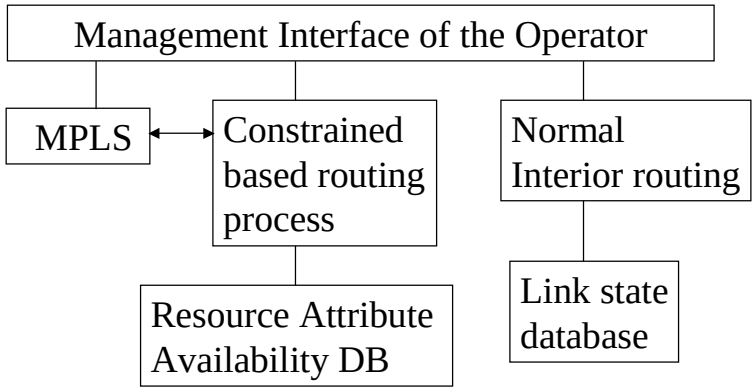
Shortest path routing can cause traffic management problems

- Shortest paths of too many traffic streams can merge on a single link or on a single router interface
- Offered traffic or traffic demand on a link can be larger than link capacity
- at the same time, it is possible that there is a feasible alternative route for the excess traffic so that the demand could be met.

Benefits of IP over ATM and FR include

- In FR and ATM -networks it is possible to set up an arbitrary logical topology that is shown to IP-routing layer
  - Constraint based routing at the VC -level
  - Operator configured static virtual paths
  - Minimization of nrof hops seen by IP routing
  - CAC - call admission control
  - traffic shaping and restriction
  - connection recovery (survivability) at VC layer

MPLS target model for traffic management



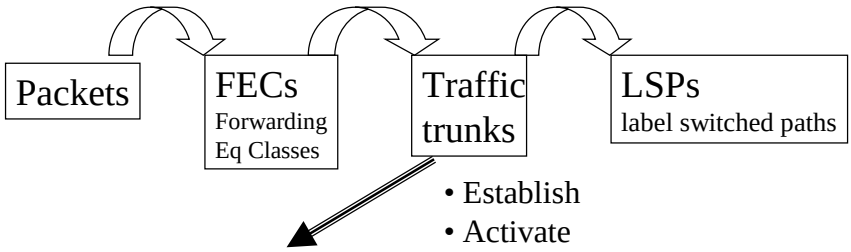
MPLS terminology for traffic management

- Traffic trunk - aggregation of traffic flows of the same class which are placed inside a Label Switched Path
  - object for routing
  - LSP + attributes
- Induced MPLS-graph (leimapolkugraafi)=H = (U, F, d), where $U \subseteq V$ - subset of set of all nodes in the network such that u {$u \in U$} has at least one LSP,
  F - set of LSPs and "d" - set of demands and constraints on LSPs

Attractiveness of MPLS from the traffic management point of view is based on

- Explicit non-shortest path routes are easy to create and maintain manually or using a protocol
- traffic trunks are easy to map to LSPs
- traffic trunks and resources can be described using dynamic attributes - resource attributes constrain the routing of traffic trunks
- traffic streams can be merged and split
- IP-routing+MPLS is simpler (?) for an Operator than IP + independent underlaying ATM or FR network

MPLS traffic management mechanisms



Traffic measurement& statistics

- Establish
- Activate
- Deactivate
- Modify Attributes
- Reroute
- Destroy
- (Policing and traffic shaping)

MPLS summary

- Specification takes a long time. MPLS -group has produced 11 RFCs and 26 Internet Drafts. (Network WG) -another group has produced RFC:n (RFC 2702).
- IPR may slow progress, QoS =?
- Motivation of the work has changed on the way
  - current motivation is enriching routing capabilities and achieving better traffic management in a unified way
  - setting up secure VPNs (virtual networks) using MPLS is also an important goal