University of Applied Sciences and Arts
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Broadband techniques:
SDH, ATM, MPLS,
Mobile and Satellite networks

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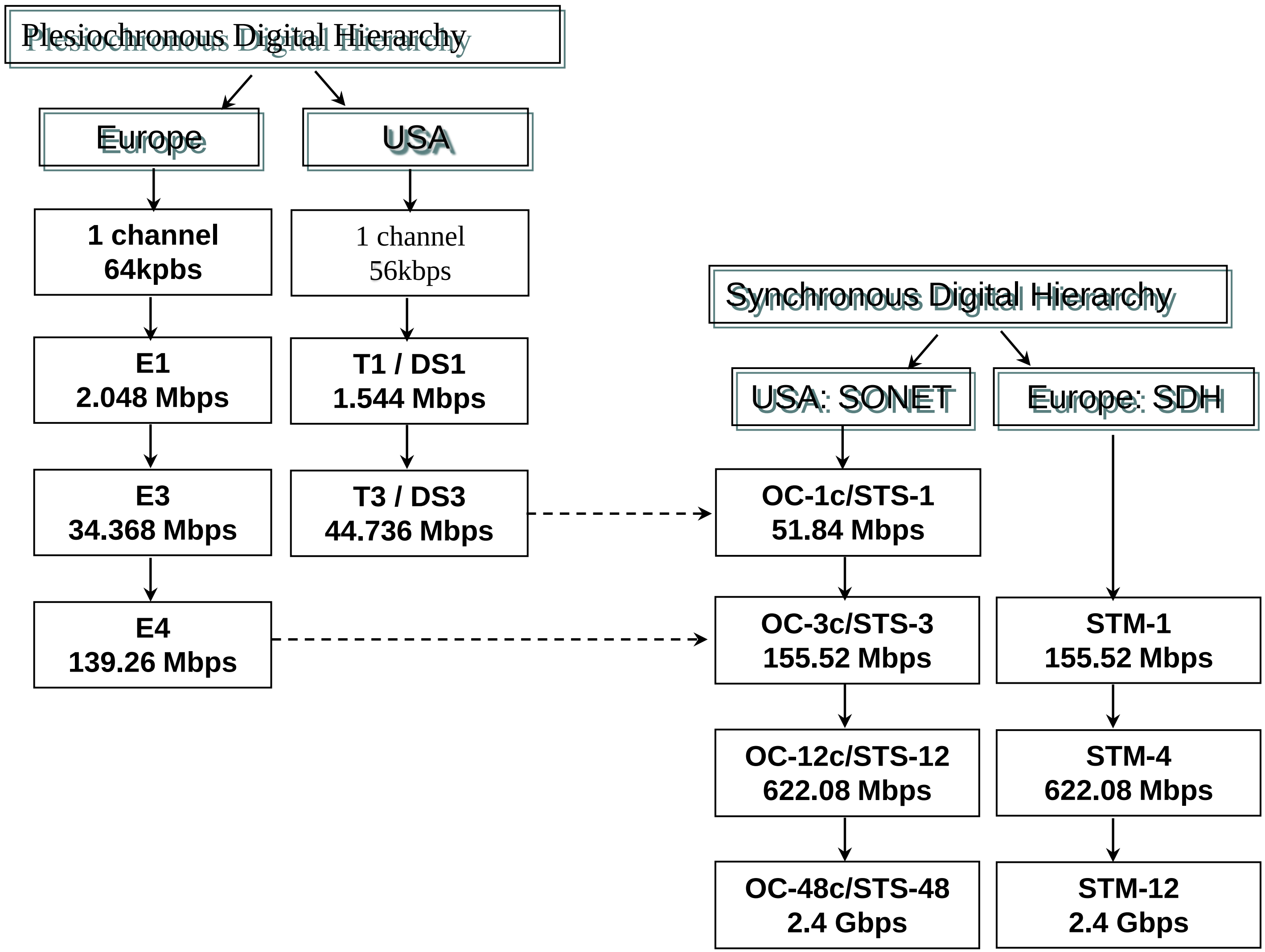
Synchronous Digital Hierarchy (SDH)

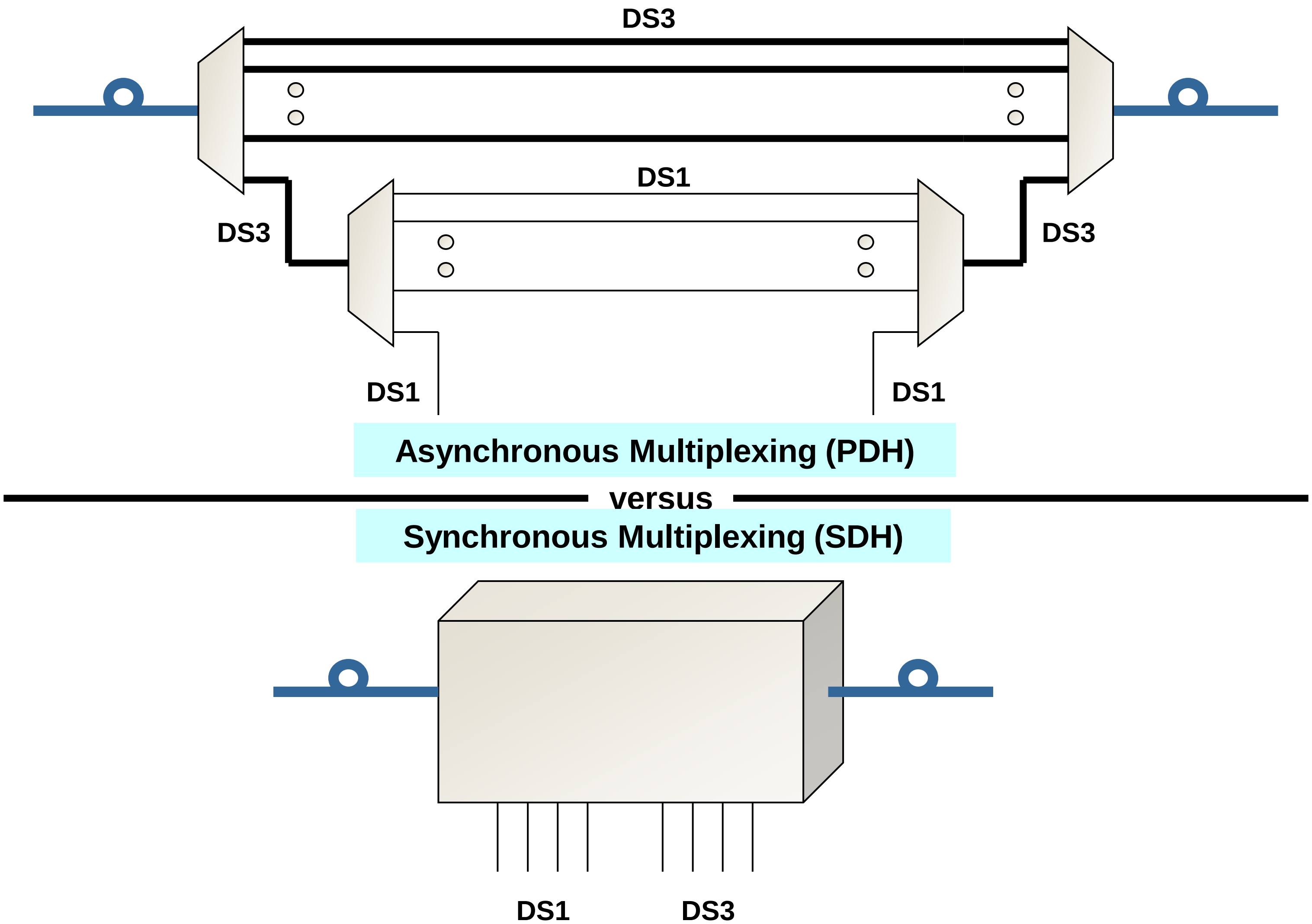
Digital Hierarchies



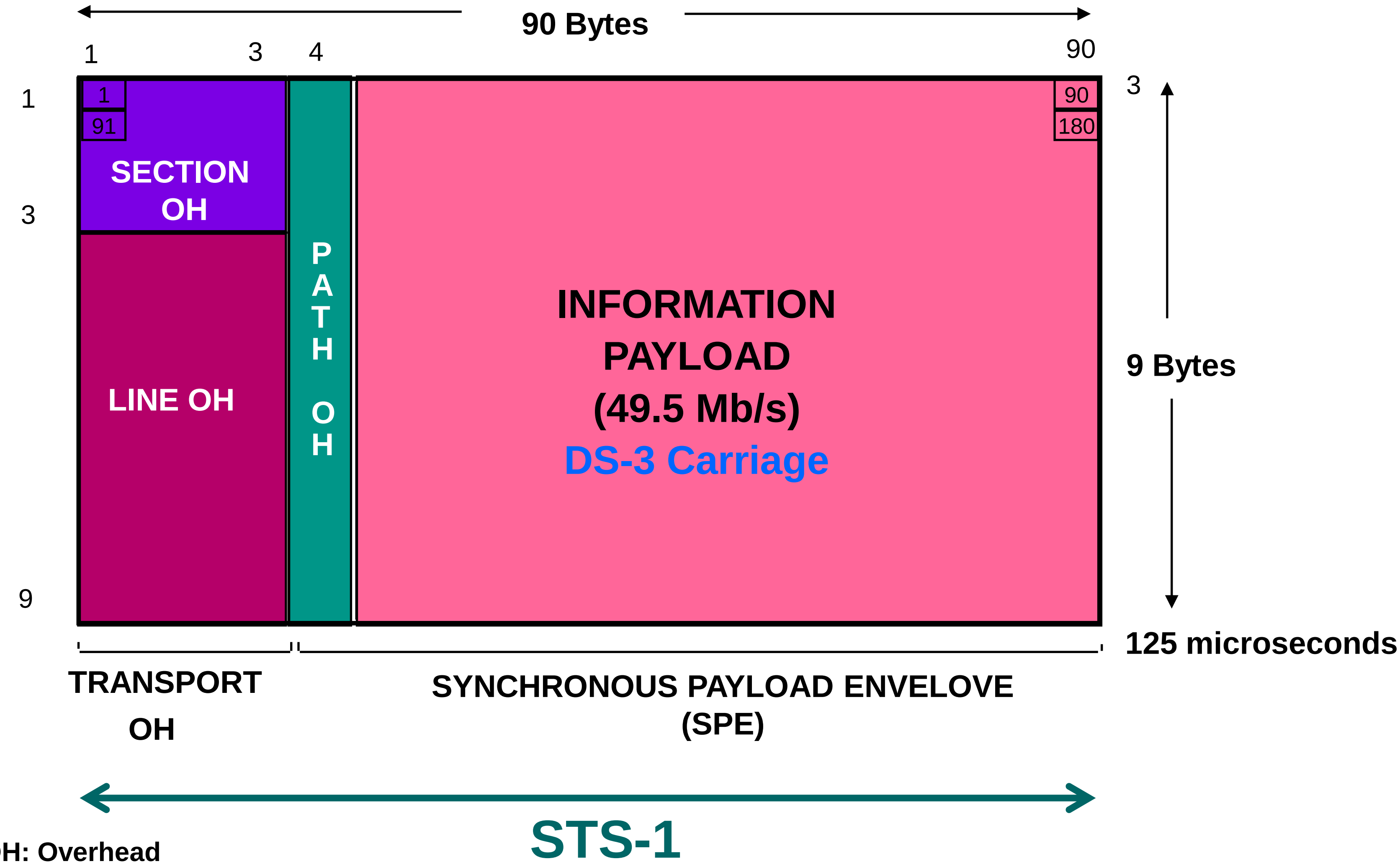
SONET / SDH simplifies Multiplexing

Advantage:

- ***PDH needs 4 pieces of equipment required to access a single DS1***
- ***SONET allows this to happen in one***

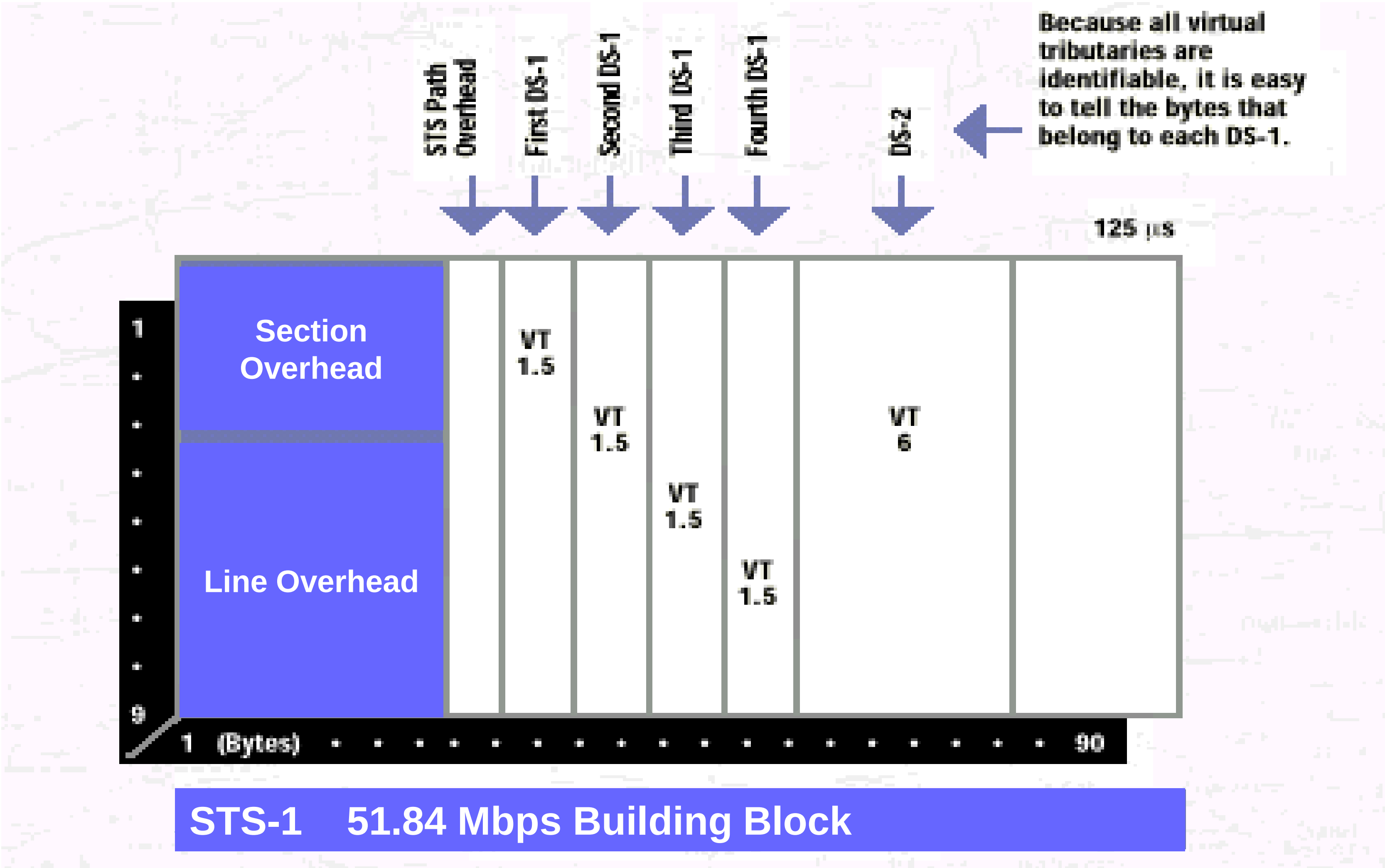


STS-1: The Fundamental Building Block



OH: Overhead

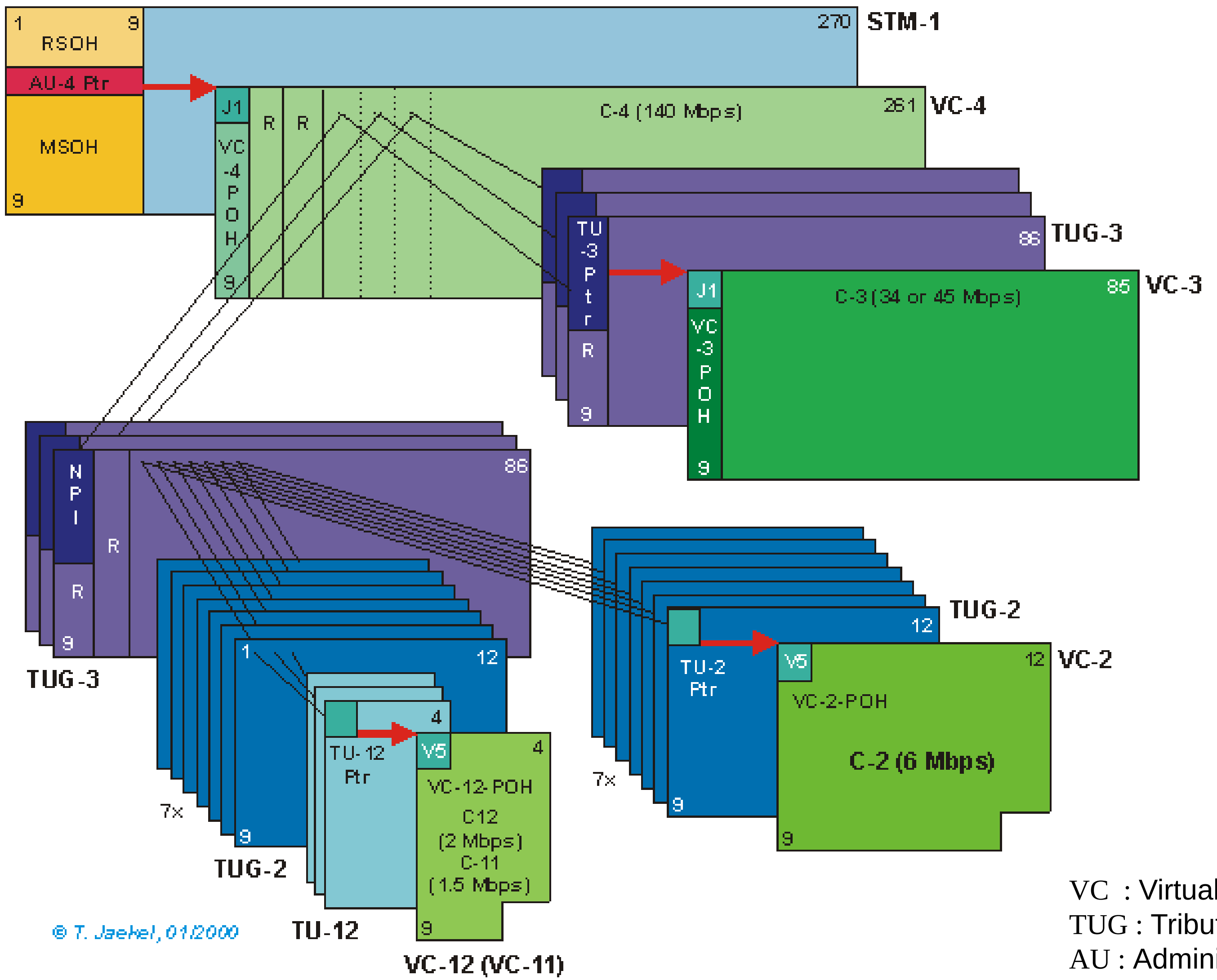
Multiplexing into an STS-1



Container mapping

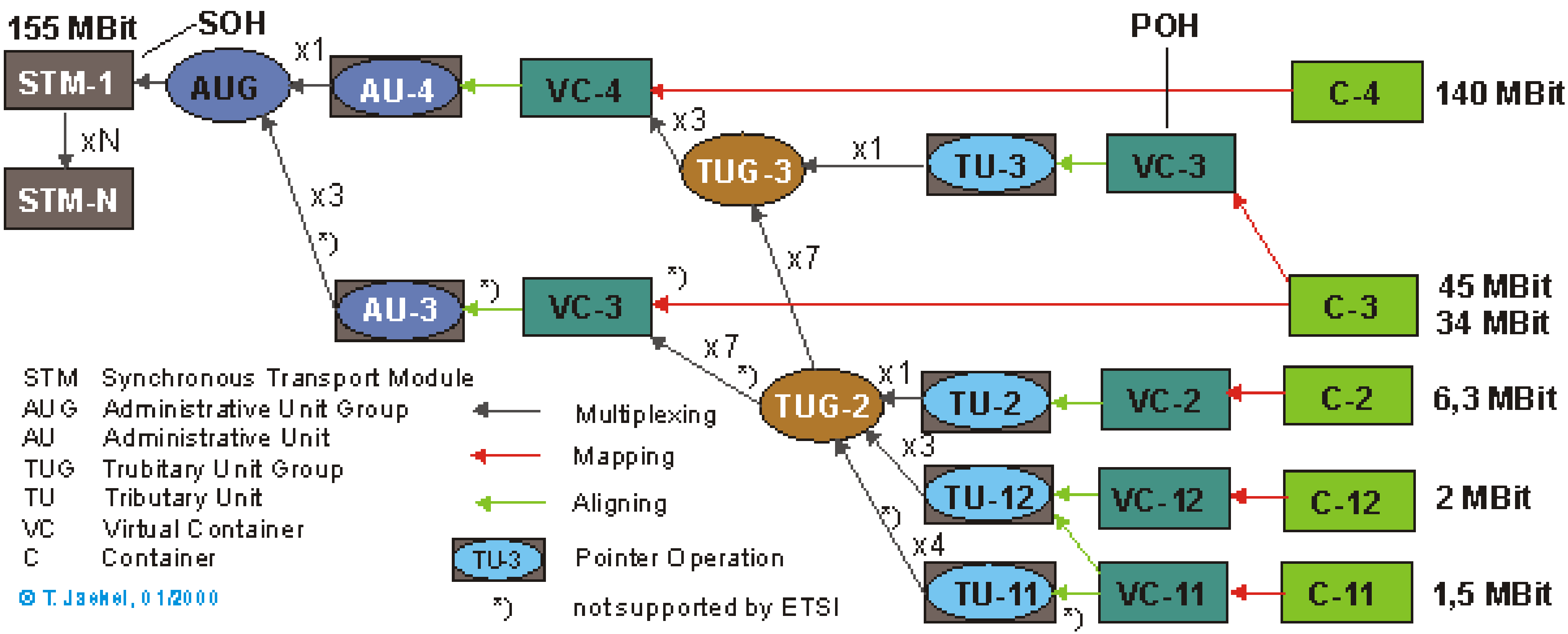
- Almost all PDH and SDH signals are possible. Each signal is packed into a Container.
- By adding the POH-Bytes, the Container becomes a Virtual Container VC. The POH-Bytes are called VC-POH.
- A Tributary Unit Group (TUG) consists of many VC grouped in the Payload. This is done through byte-wise multiplexing.
- An Administrative Unit (AU) completes the matting: AT are realized adding AU4-Pointers to Container or to Tributary Unit.
- Finally, the SOH-Bytes are added and the SDH-Frame is complete.
- Thanks to the multiplexing, the definition of Container types and byte-wise multiplexing with synchronous clock allows easy extraction of the signal (Drop function) or adding new signals (Add function).

Container mapping



VC : Virtual Container.
TUG : Tributary Unit Group
AU : Administrative Unit

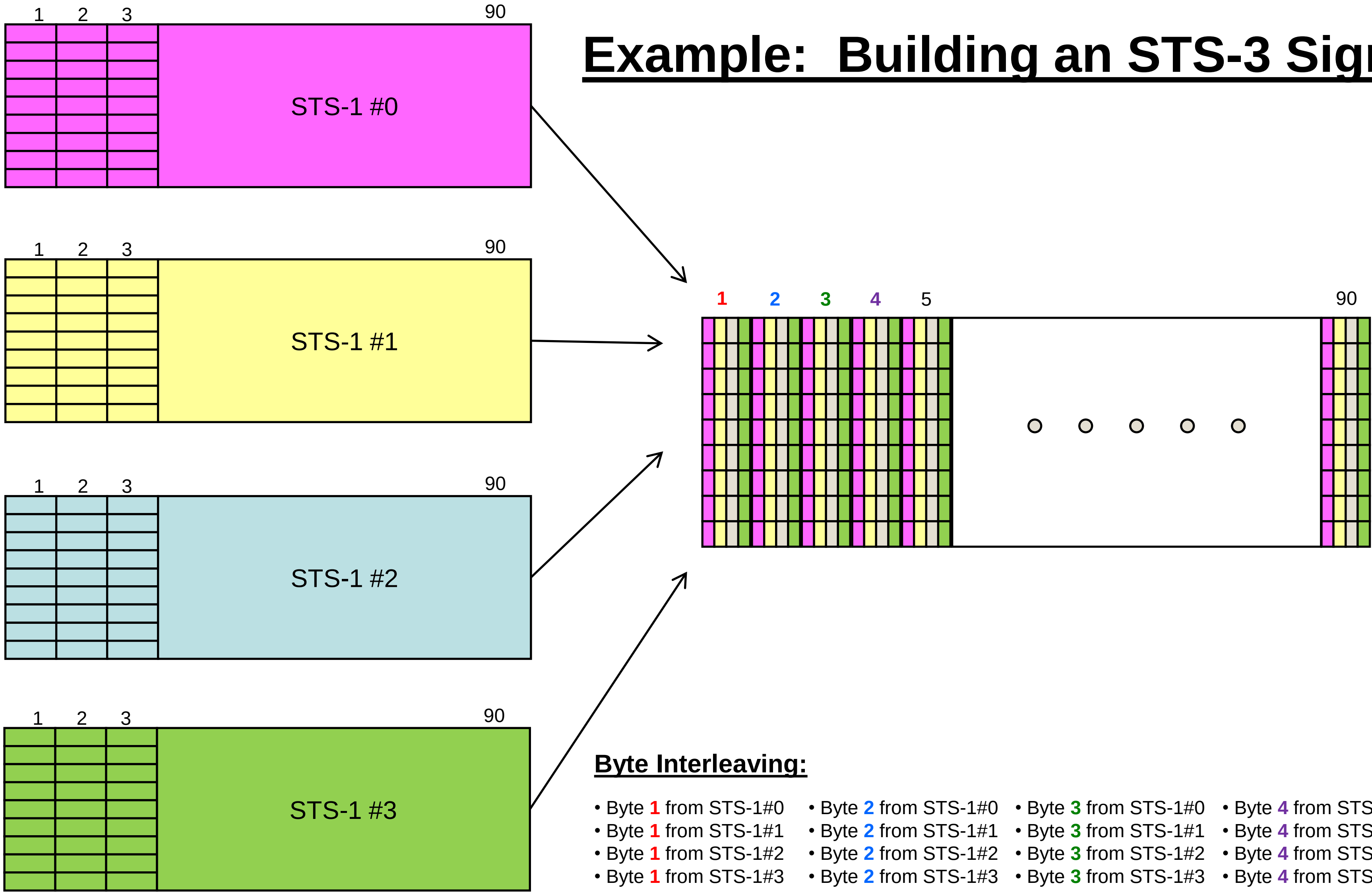
Container mapping



STM1 = 155 MBit/s (electrical/optical data communication),
STM4 = 622 MBit/s (optical data communication),
STM16 = 2,4 GBit/s (optical data communication),
etc.

Building Higher Rate Signals

Example: Building an STS-3 Signal

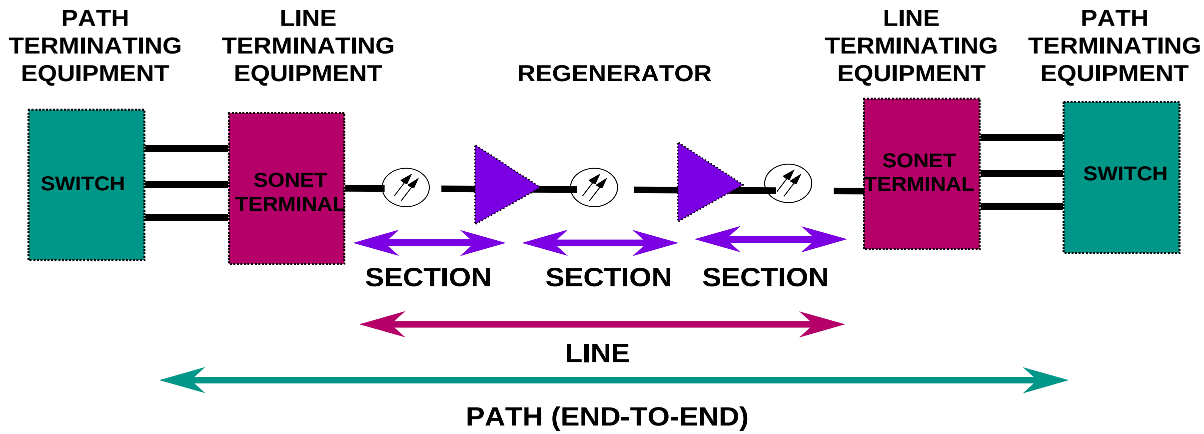


Byte Interleaving:

- Byte 1 from STS-1#0
- Byte 1 from STS-1#1
- Byte 1 from STS-1#2
- Byte 1 from STS-1#3
- Byte 2 from STS-1#0
- Byte 2 from STS-1#1
- Byte 2 from STS-1#2
- Byte 2 from STS-1#3
- Byte 3 from STS-1#0
- Byte 3 from STS-1#1
- Byte 3 from STS-1#2
- Byte 3 from STS-1#3
- Byte 4 from STS-1#0
- Byte 4 from STS-1#1
- Byte 4 from STS-1#2
- Byte 4 from STS-1#3

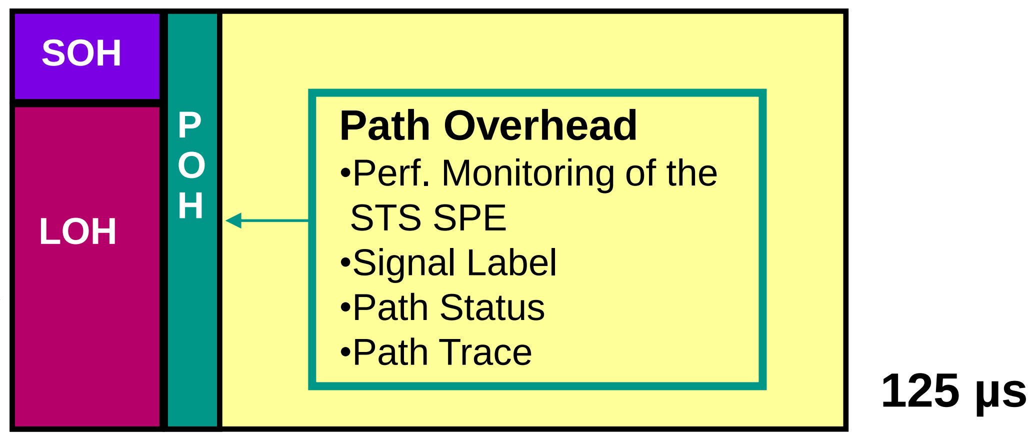
...

Standardized OAM&P



Section Overhead
- •Perf. Monitoring
- •Local Orderwire
- •Data communication channels
- •Framing

Line Overhead
- •Perf. Monitoring of individual STS-1
- •Express Orderwire
- •Data Channels for OAM&P
- •Pointer
- •Protection Switching
- •Line AIS
- •Line FERF

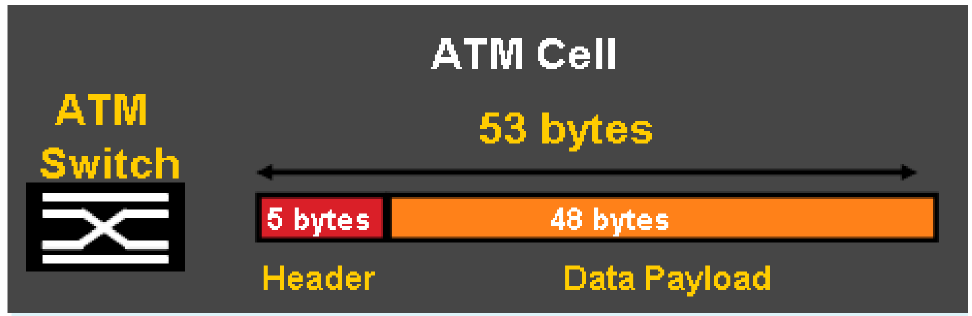


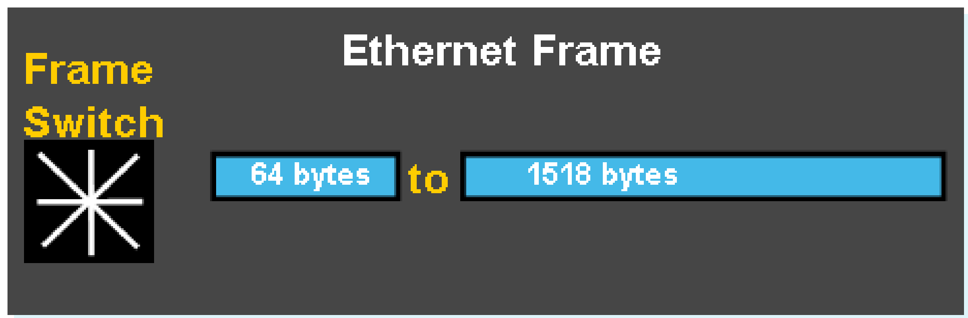
SONET Overhead Structure Permits
- **efficient & accurate fault isolation**
- **site to site communication**
- **centralised remote provisioning & performance monitoring**

Asynchronous Transfer Mode (ATM)

ATM (Asynchronous Transfer Mode)

- 25 Mbps, 155 Mbps, 622 Mbps or 2.4 Gbps
- Cell-based vs. frame transmissions
  - 53 byte cells
- Negotiated service connection
  - End-to-end connections
  - Virtual circuits
- Switch-based
- Dedicated capacity
- Is NOT an IEEE-Standard





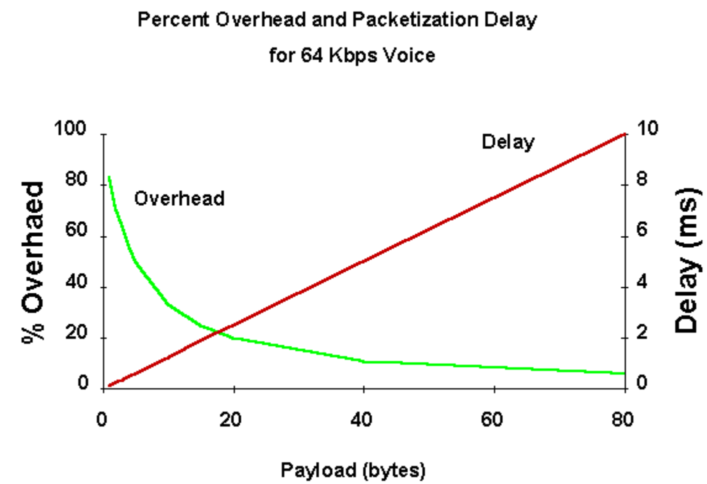
ATM

- ATM is a fast packet oriented transfer mode based on asynchronous time division multiplexing and it uses fixed length(53 bytes) cells. Each ATM cell consists of 48 bytes for information field and 5 bytes for header.

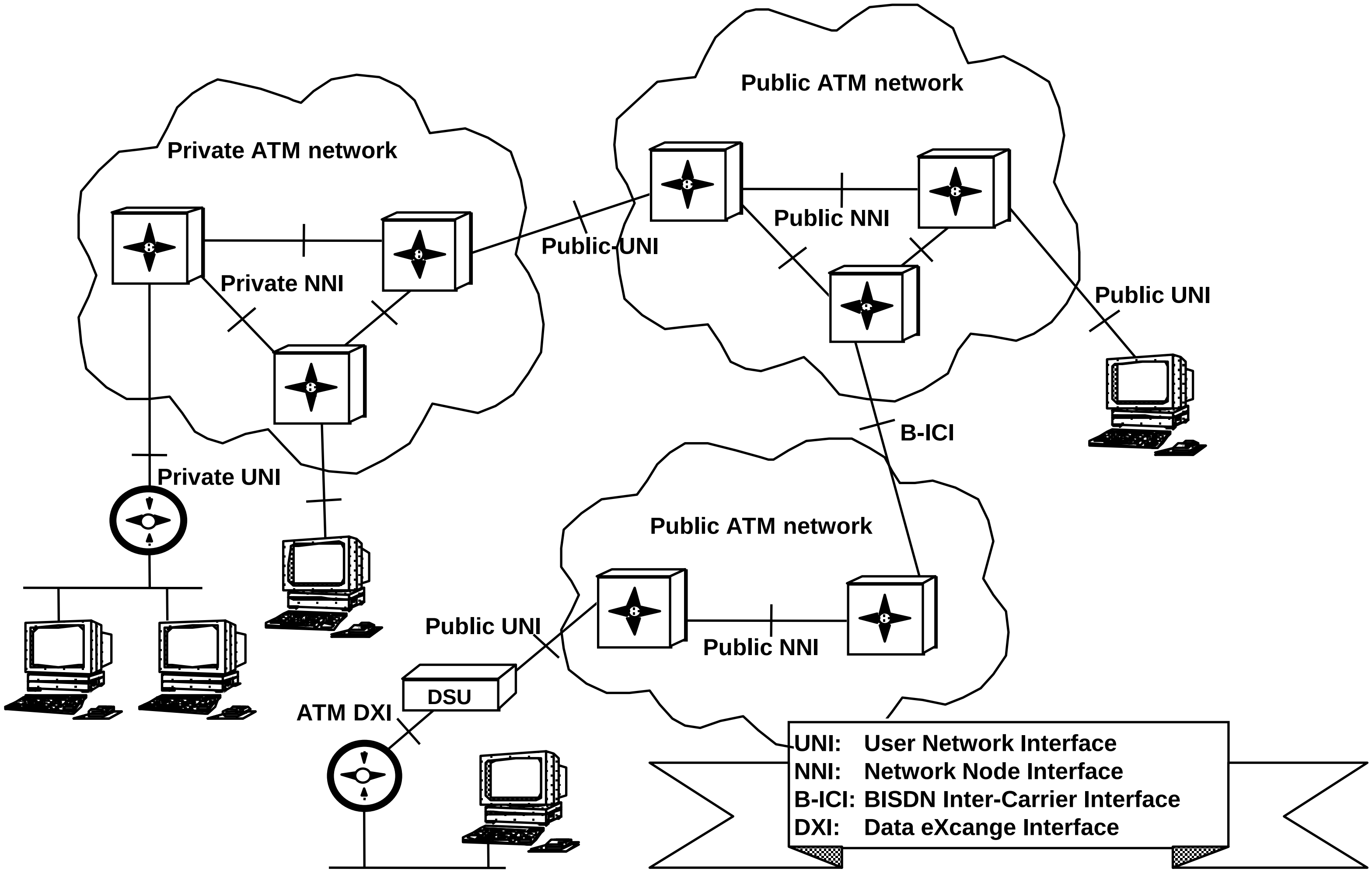
  - 53 byte cells (48 byte data and 5 byte header)
  - Why small cells?
  - Why 48 bytes?

The choice of cell dimensions

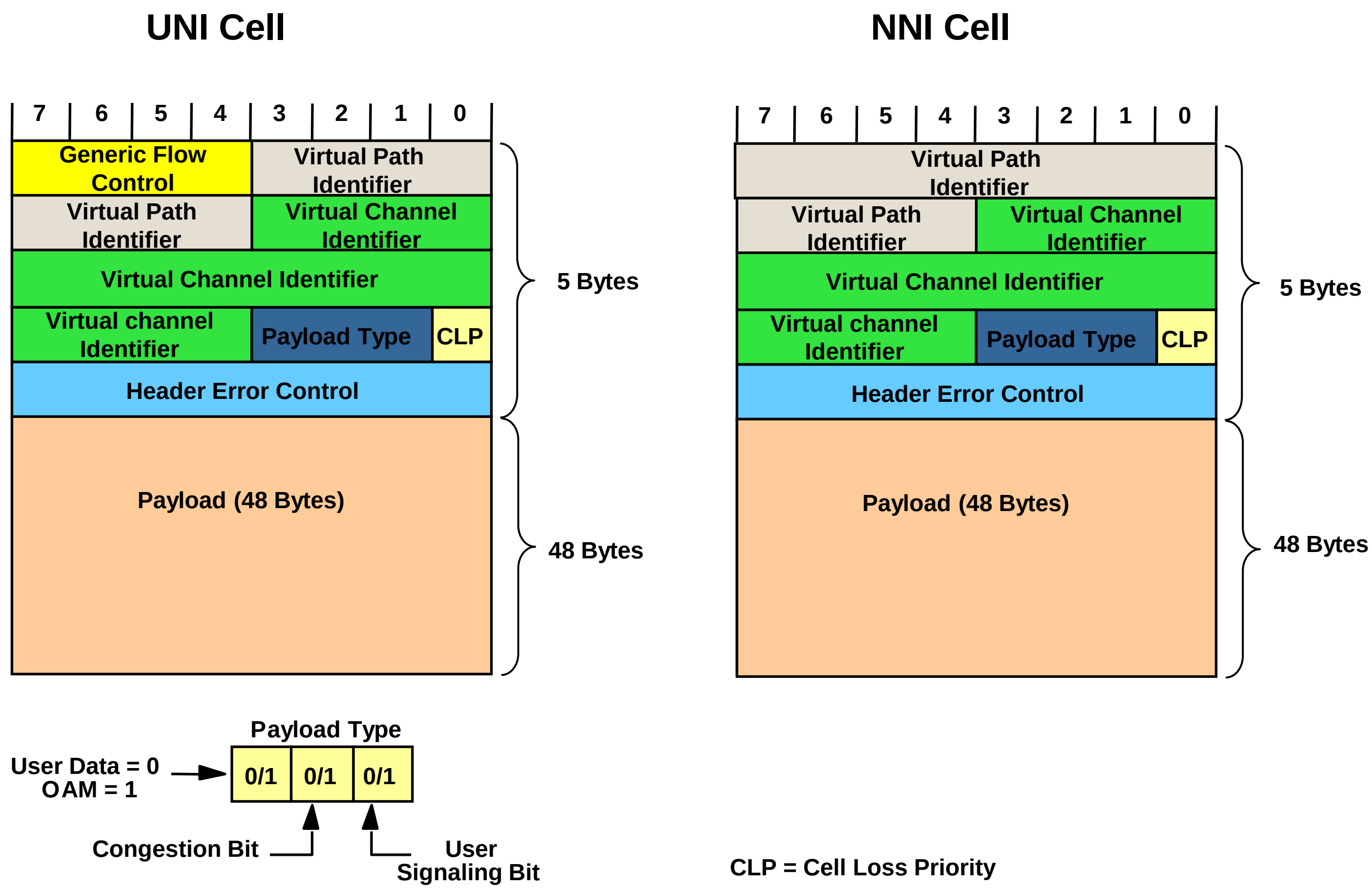
- Small dimension
  - Between 16 and 64 bytes
- Europe: 32 + 4 byte
  - Reduced delays on “slow” lines
- US: 64 + 5 bytes
  - Reduced overhead
  - No delay problems, “fast” lines existes already
- The tradeoff
  - 48 bytes payload + 5 bytes header = 53 bytes ATM cell



ATM Network: structure and components

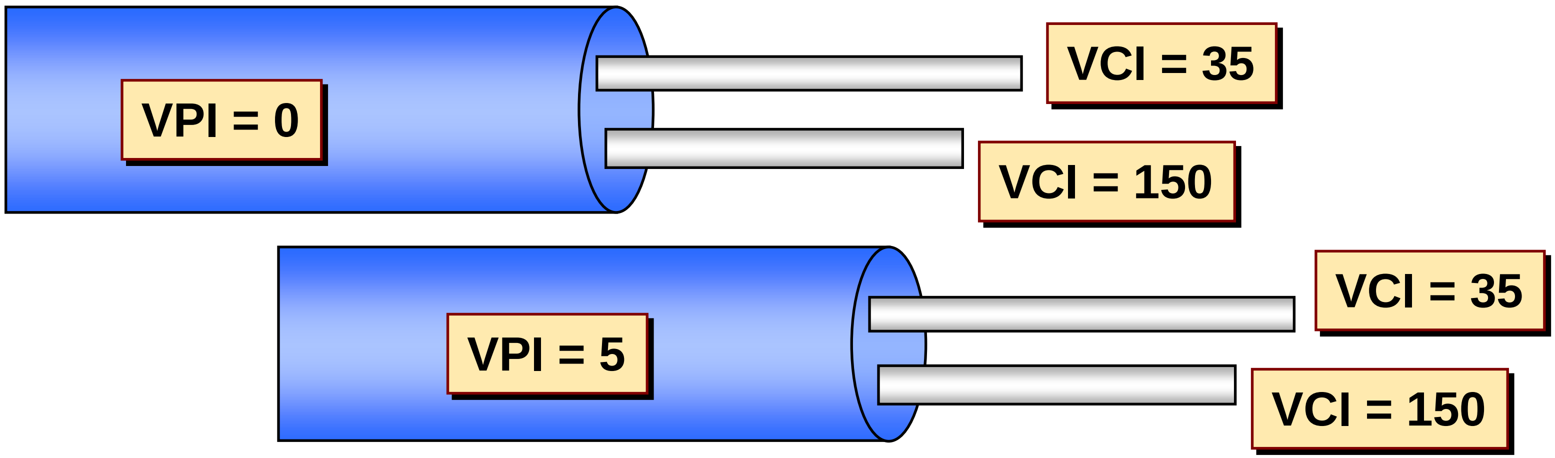


Cell Format



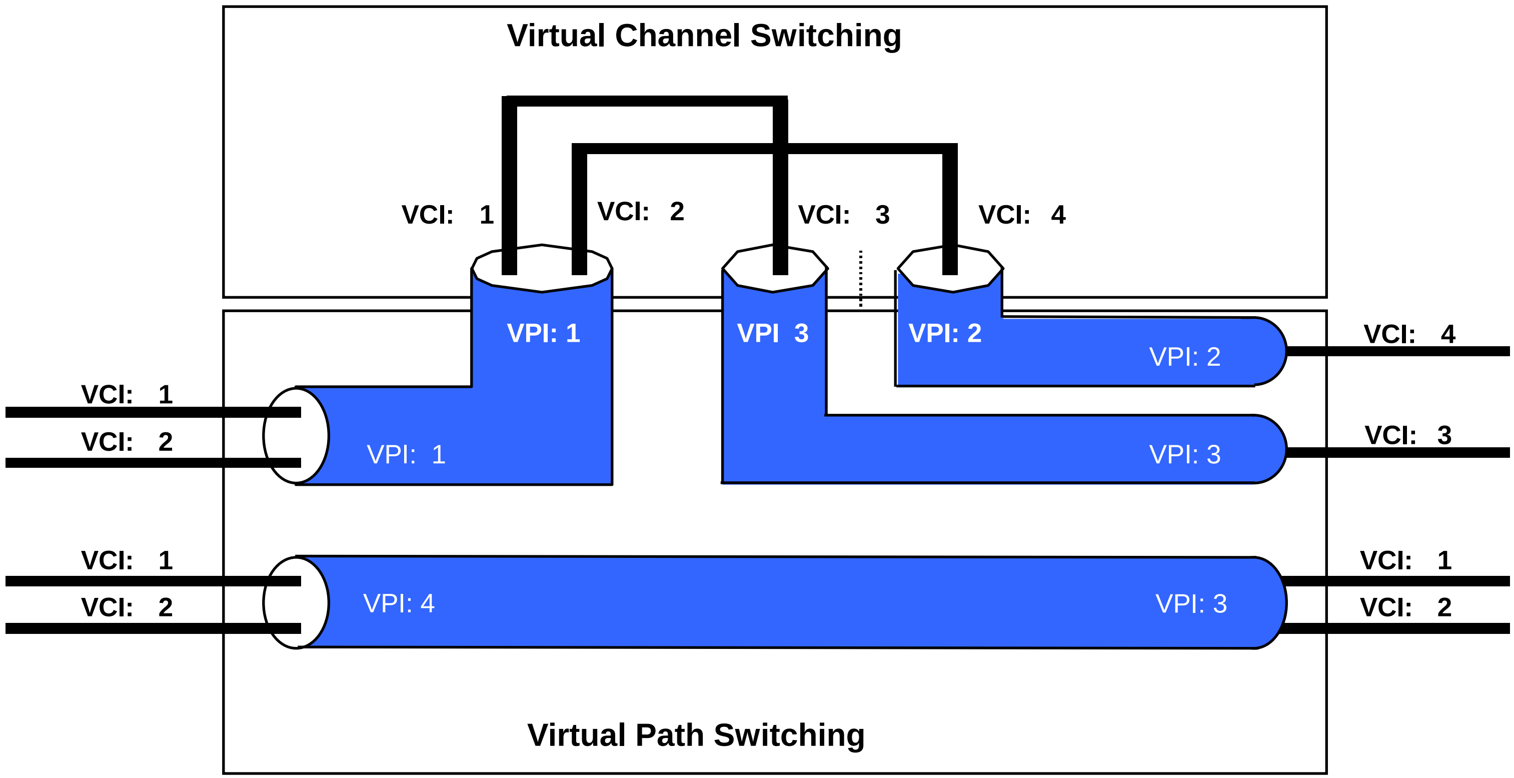
CLP = Cell Loss Priority

Virtual Channels and Virtual Paths



- **Each virtual channel has a Virtual Path Identifier (VPI) and a Virtual Channel Identifier (VCI)**

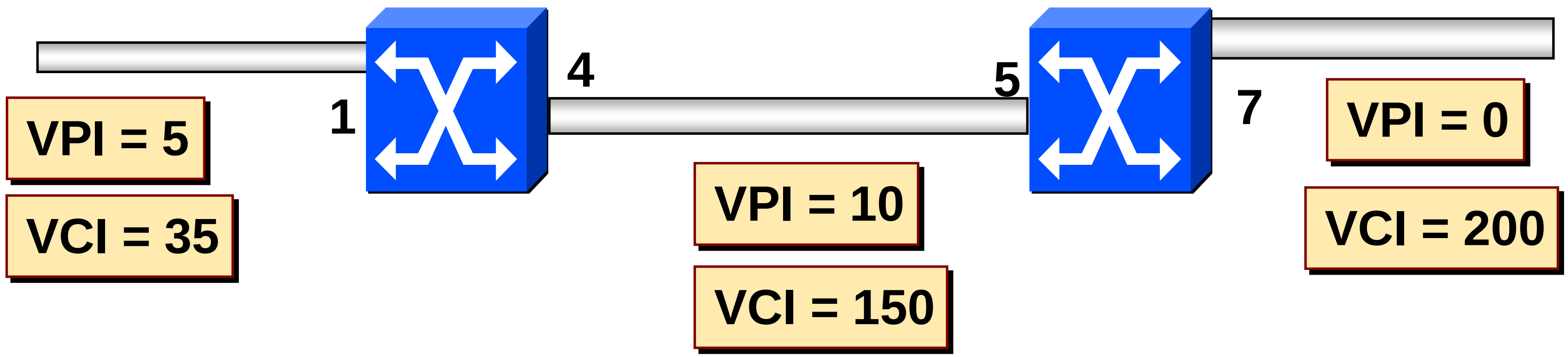
“Virtual Path” e “Virtual Channel”



Virtual Circuits (VC)

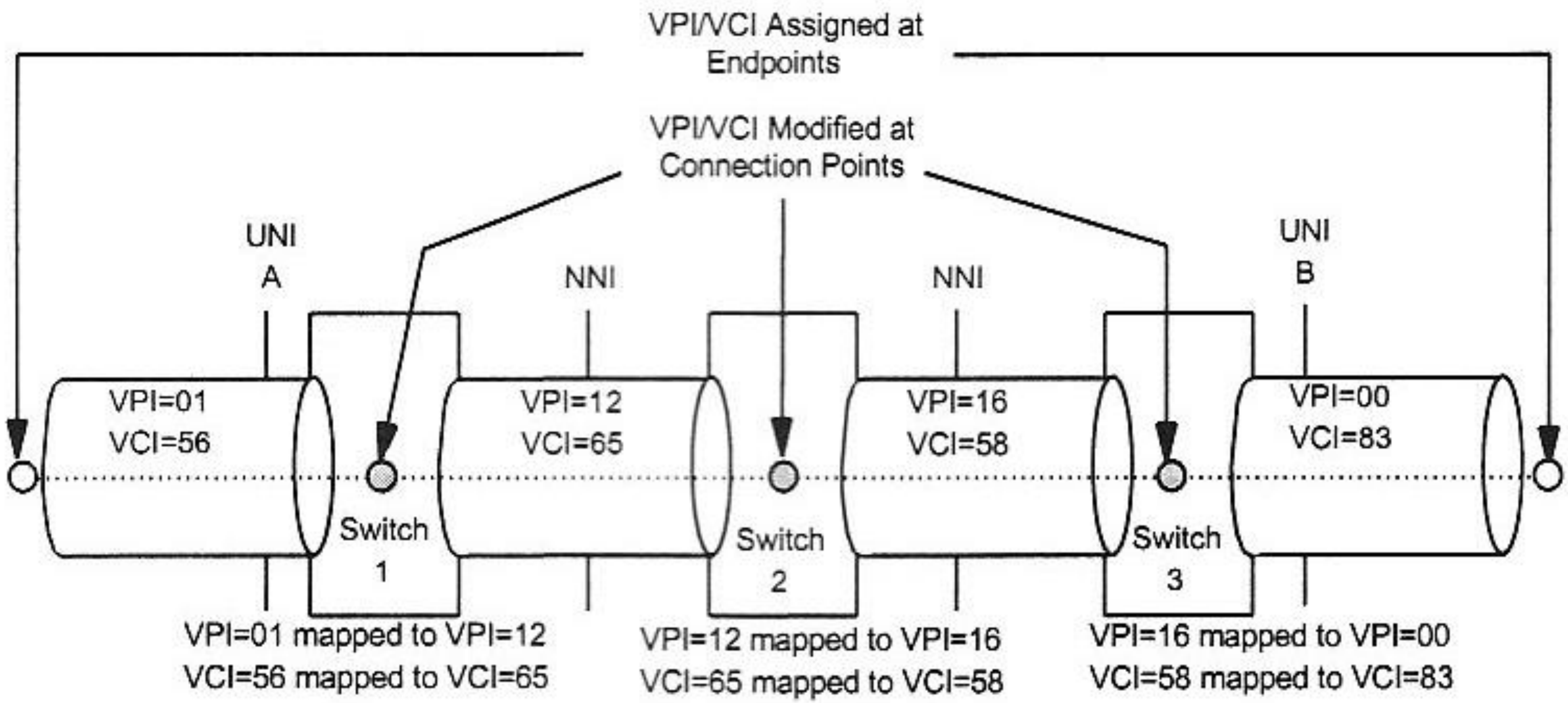
IN			OUT		
1	5	35	4	10	150

IN			OUT		
5	10	150	7	0	200



- A virtual circuit is an end-to-end connection consisting of multiple links and VPI, VCI pairs
- Permanent virtual circuits are established manually by creating the lookup table at each switch
- Switched virtual circuits are established automatically by the User-Network Interface (UNI) signaling

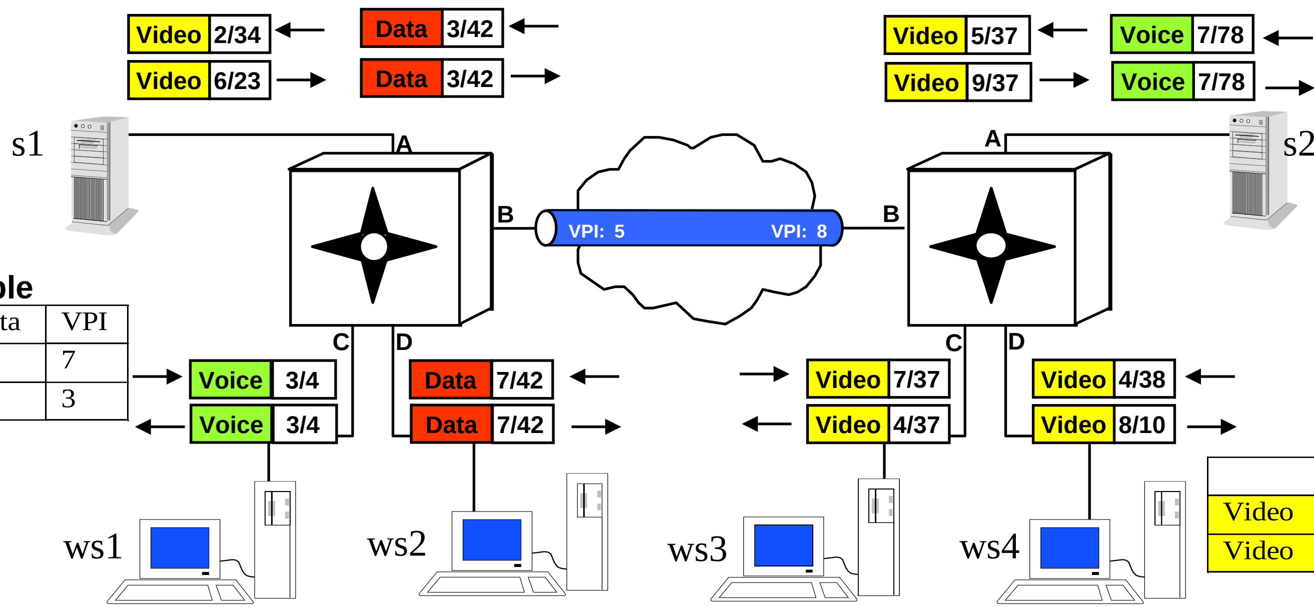
VPI e VCI



VPI/VCI Assigned at Endpoints
VPI/VCI Modified at Connection Points
UNI A
NNI
NNI
UNI B
VPI=01
VCI=56
VPI=12
VCI=65
VPI=16
VCI=58
VPI=00
VCI=83
Switch 1
Switch 2
Switch 3
VPI=01 mapped to VPI=12
VCI=56 mapped to VCI=65
VPI=12 mapped to VPI=16
VCI=65 mapped to VCI=58
VPI=16 mapped to VPI=00
VCI=58 mapped to VCI=83

Switching di Celle

Video	↔	s1	ws4
Data	↔	s1	ws2
Voice	↔	s2	ws1
Video	↔	s2	ws3



Virtual Paths Connection Table

	Porta	VPI	Porta	VPI
Data	A	3	D	7
Data	D	7	A	3

Virtual Paths Connection Table

	Porta	VPI	Porta	VPI
Video	A	5	C	4
Video	C	7	A	9

Virtual Channels Connection Table

	Porta	VPI/ VCI	Porta	VPI/ VCI
Video	A	6/23	B	5/24
Video	B	5/37	A	2/34
Voice	C	3/4	B	5/4
Voice	B	5/4	C	3/4

Virtual Channels Connection Table

	Porta	VPI/ VCI	Porta	VPI/ VCI
Video	B	8/24	D	8/10
Video	D	4/38	B	8/37
Voice	B	8/4	A	7/78
Voice	A	7/78	B	8/4

ATM Service Classes

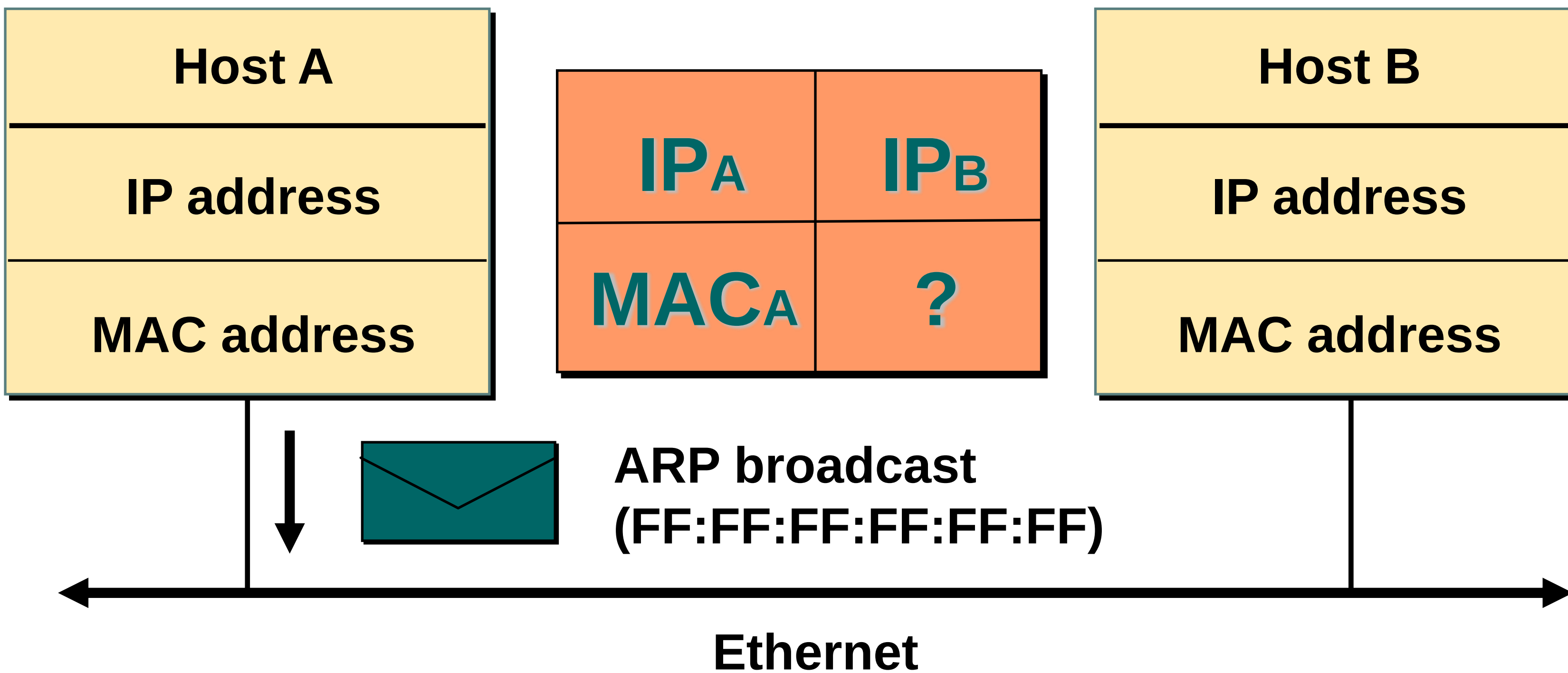
Service	Class A	Class B	Class C	Class D
Time compenstation	required		not required	
Bit Rate	constant	variable		
Connection Mode	connection oriented			connectionless
Example	circuit emulation	compressed video, audio	connection oriented data transfer	connectionless data transfer
AAL T ype	Type 1	Type 2	Type 3 /4 or 5	

ATM Internetworking (1): Encapsulation

- Multiprotocol Encapsulation over ATM Adaptation Layer 5 (RFC 1483)
  - Basic “encapsulation” method

From “IP over Ethernet” to ATM LANE

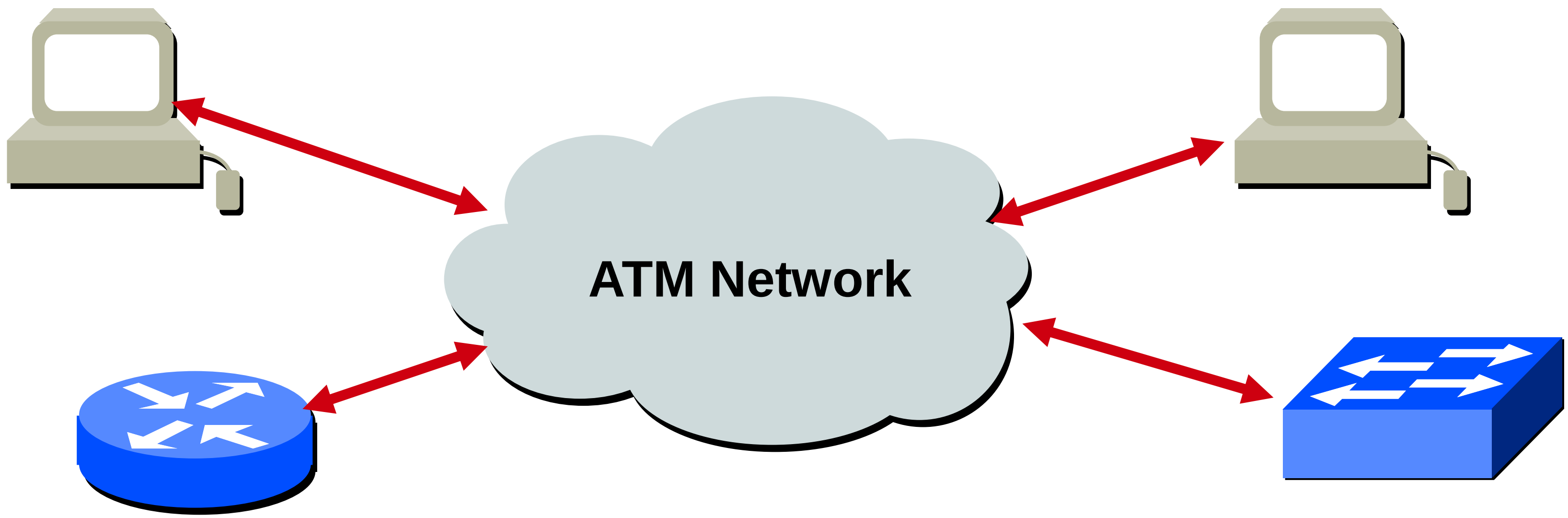
- Each host has an IP address and a MAC address
- A broadcasts an ARP for B’s MAC address



Key Mechanisms of IP over Ethernet

- A protocol or mechanism to resolve addresses between the network layer and the data link layer (ARP)
- A mechanism that supports broadcasting and multicasting
  - Ethernet achieves this by using a broadcast MAC address and group-specific multicast addresses. Token Ring uses a functional address to support broadcasts.

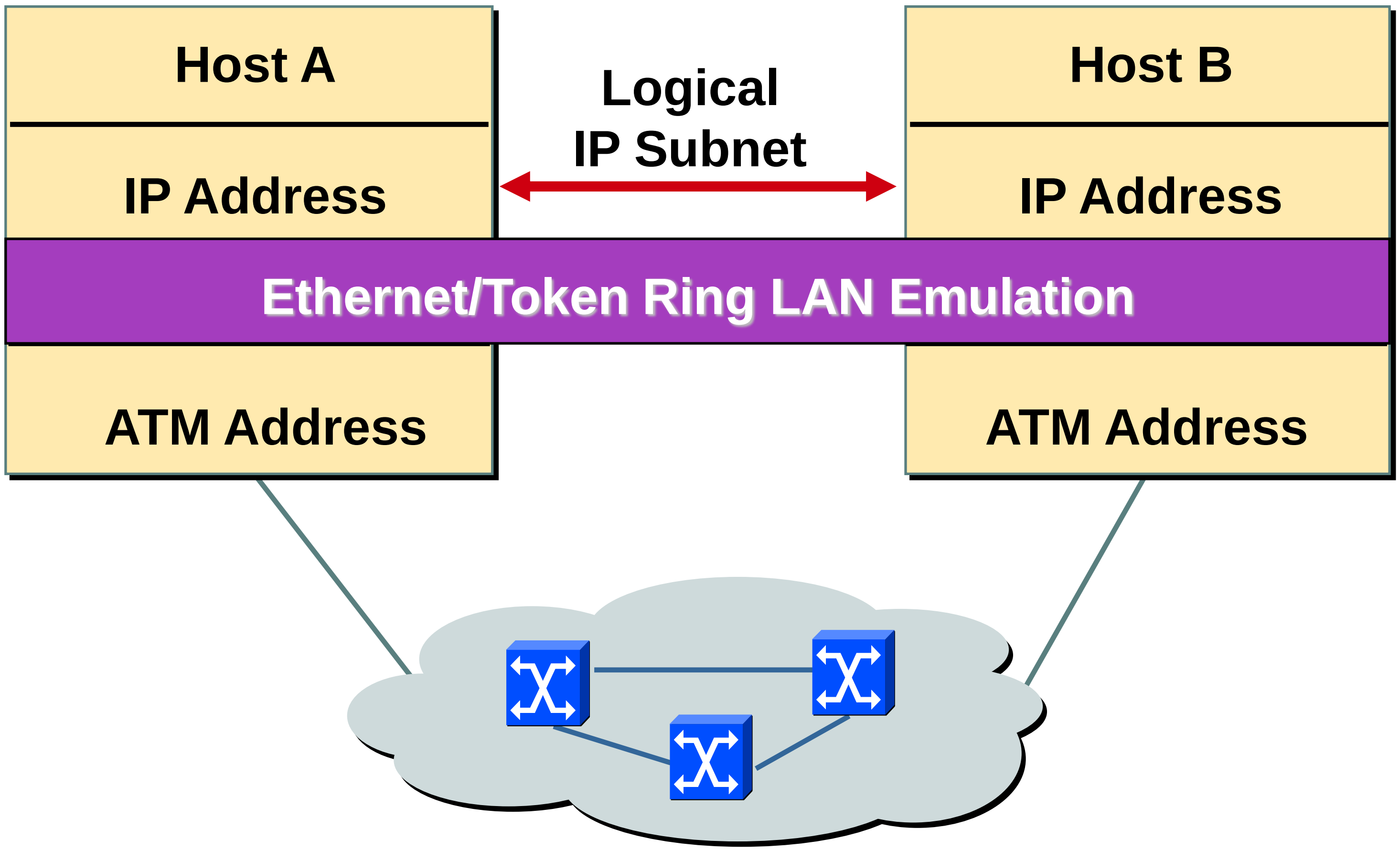
Moving to ATM—Challenges



- **Non-Broadcast Multiple Access fabric (NBMA)**
- **Address resolution**
- **Broadcasting**
- **Configuration**

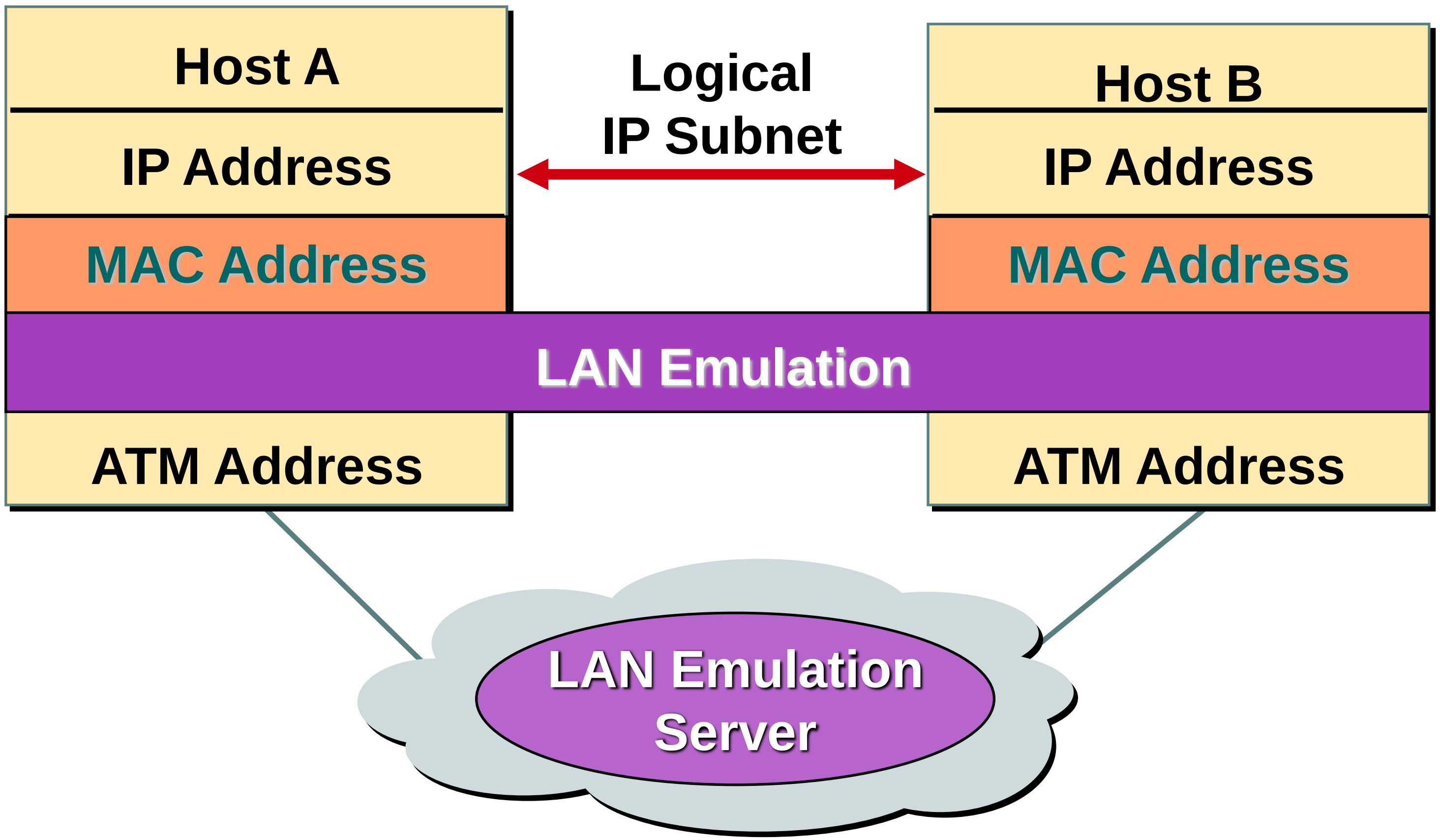
Moving to ATM—LANE Approach

- **LANE hides ATM from the network layer by emulating an Ethernet or Token Ring**



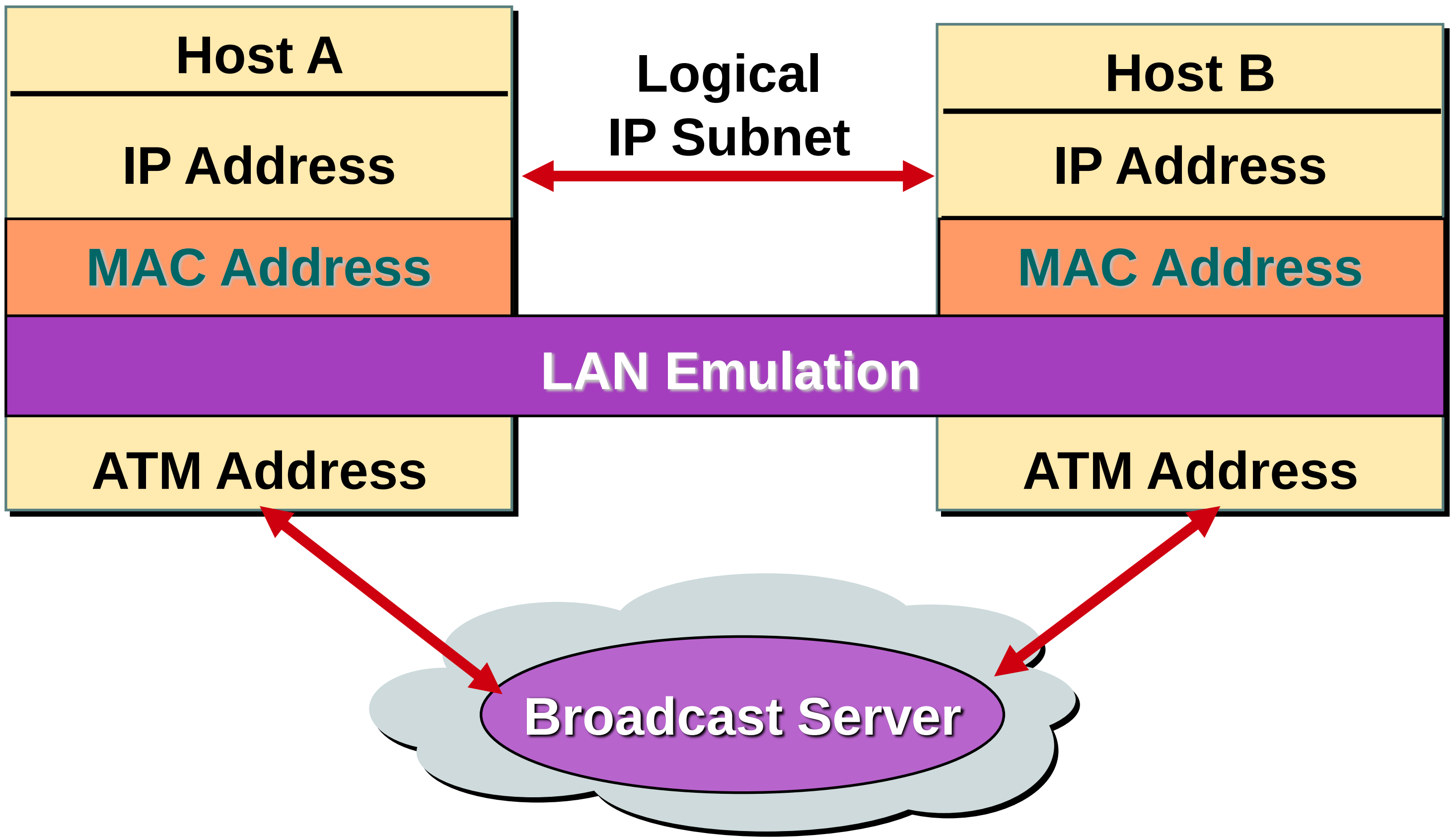
Emulating a LAN over ATM

- Address resolution achieved with an address resolution server—ATM attached hosts running LANE are the clients
- Each LANE host registers its MAC, ATM tuple with the LES



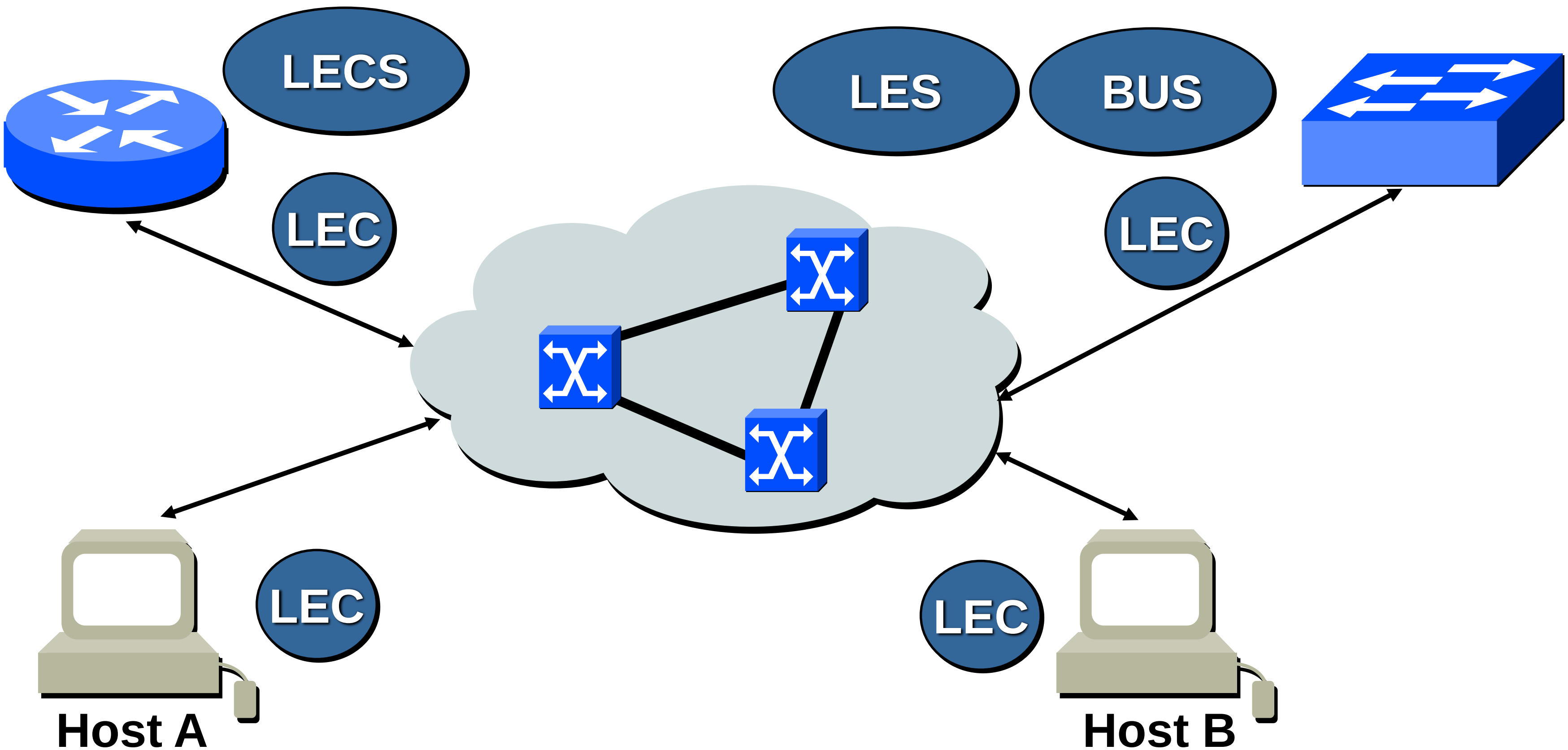
Emulating a LAN over ATM

- Broadcasts are achieved by a using a broadcast server
- The broadcast server is responsible for serializing broadcasts from multiple hosts



Emulated LAN

- An emulated LAN is a broadcast domain (e.g., IP subnet)
- An ELAN consists of at least one LES/BUS and multiple LECs
- Each ELAN can emulate either Ethernet or Token Ring



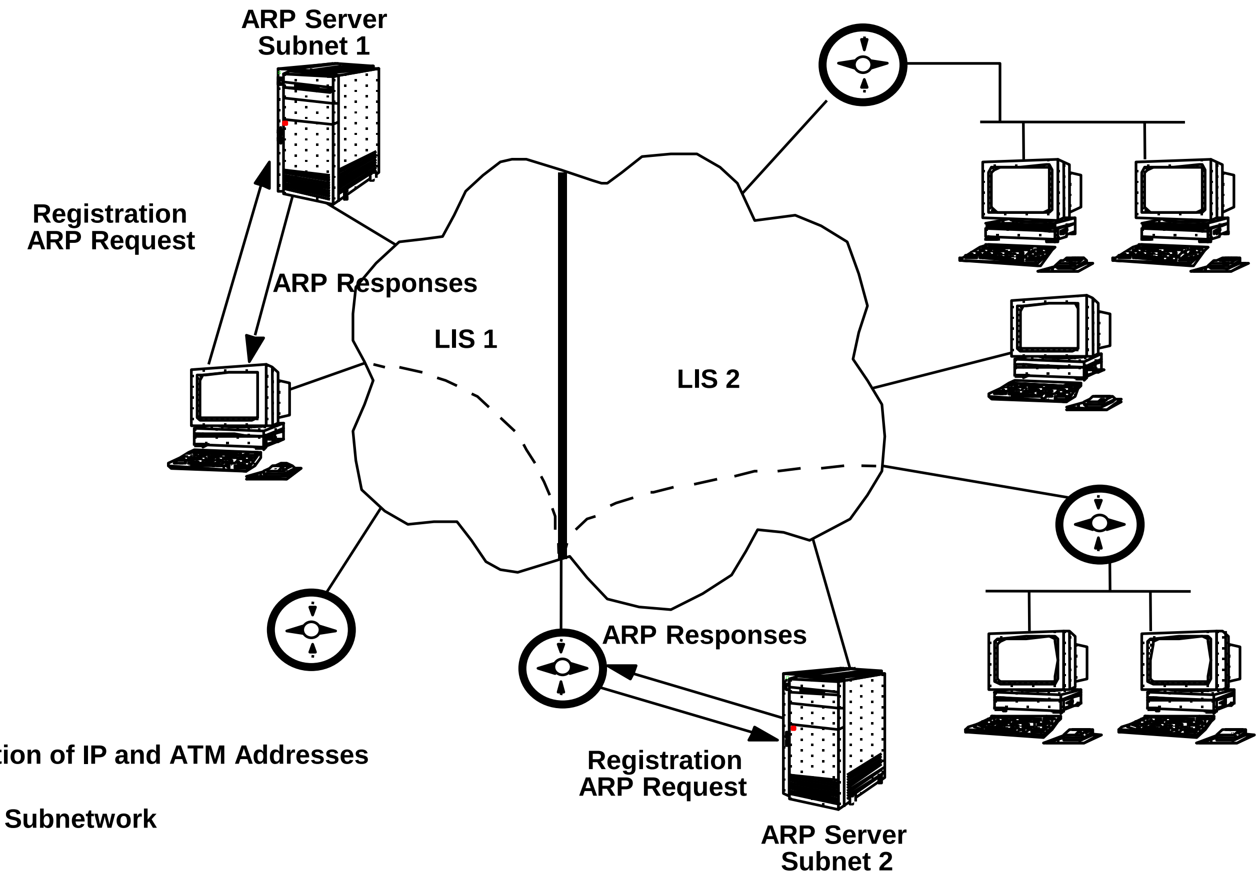
Emulated LANs - components

- LAN Emulation Client (LEC)
  - Embedded within network devices
  - Handles data forwarding and address resolution
  - Main function: providing MAC connectionless service to higher layers
- LAN Emulation Server (LES)
  - Handles address resolution and control information
  - Registers and resolves MAC addresses to ATM addresses

Emulated LANs - components

- Broadcast and Unknown Server (BUS)
  - Carries broadcast or multipoint data
- LAN Emulation Configuration Server (LECS)
  - Dynamically assigns different LECs to different emulated LANs
  - provides the clients with the address of the most appropriate LES
  - maintains a database of the resultant associations

Classical IP and ARP over ATM (RFC 1577)



Address resolution of IP and ATM Addresses

LIS = Logical IP Subnetwork

Summary of LANE Virtual Channel Connections (VCC)

- Configure direct VCC (LECS): Used by the LEC to obtain the LES address for the ELAN it wishes to join
- Control Direct VCC (LES): Used by the LEC to join the ELAN and for LE-ARP requests
- Control Distribute VCC (LES): Used by the LES to forward unresolved LE-ARP requests
- Multicast Send VCC (BUS): Used by the LEC to send broadcast and unresolved unicast traffic
- Multicast Forward VCC (BUS): Used by the BUS to forward broadcast and unresolved unicast traffic received on the Multicast Forward VCC to the remaining LECs
- Data Direct VCC (LEC-LEC): Used for bulk of data traffic

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Multi Protocol Label Switching (MPLS)

Traditional Routing and Switching

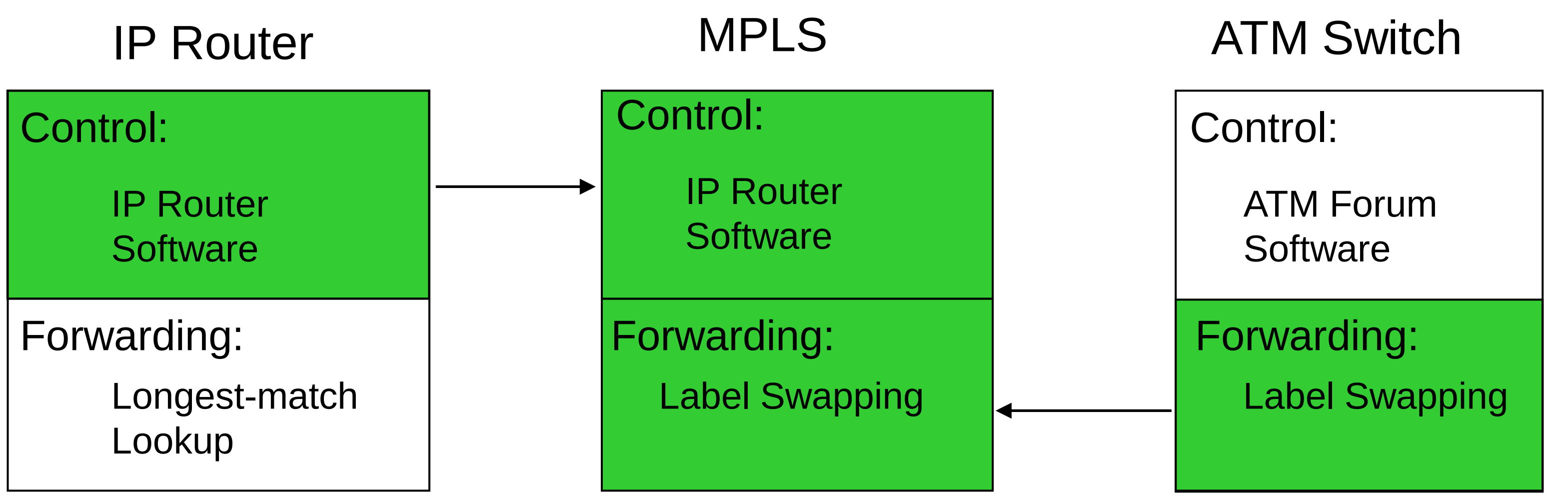
- Internet was designed for relatively easy applications: file transfer, remote login etc.
- To meet these needs a routing software and a hardware supporting T1/E1 or T3/E3 connections were sufficient.
- At present, layer-3 switching is widespread. This technology enables commutation between both layer-2 and layer-3 switching directly at hardware level. The bottleneck caused by traditional routers was therefore removed.
- Packets are routed searching always the best route, but without consideration of lags, jitter and network congestions.

Introduction

- MPLS is a technology that defines a specific route for every packet contituting a communication.
- This system lowers the amount of work a router has to perform: routers don’t need anymore to read routing tables in order to establish the route of a specific packet.
- MPLS allows most of the packets to be redirected before using the layer-3 information, this enhances considerably the performance and optimizes modern network routing and switching.
- MPLS is a versatile solution to solve modern network problems e.g.:
  - Speed
  - Scalability
  - Quality of Service management
  - Traffic engineering
- Modern internet technology applications demand more and more service classes that ensure their functionality, in this contest MPLS plays a key-role.

Origins of MPLS

- MPLS is a hybrid model adopted by IETF to incorporate best properties in both packet routing & circuit switching



What is MPLS

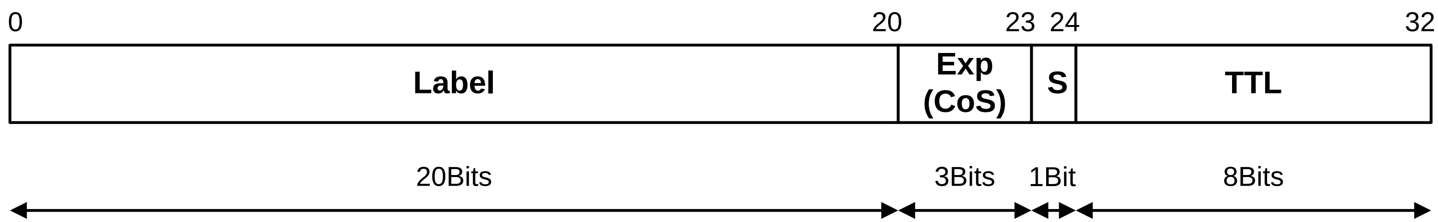
- MPLS is an IETF (Internet Engineering Task Force) speficied framework that foresees efficiency in the frame of routing, switching of traffic flows and through the network.
- Forwarding of user data traffic using fixed sized headers which contain a label value.
- Virtual Circuit for IP
  - Unidirectional path through the network
  - Tunnel through the network
- Traffic Engineering
  - Using paths other than the IGP shortest-path
- Mapping IP prefixes to LSPs
- Forwarding Equivalence Class (FEC)

What is MPLS

- MPLS implements the following features:
  - Specification of traffic flow procedures between differnet hardware and software.
  - Indipendent behaviour towards the existing layer-2 and layer-3 protocols.
  - Procedure to map IP addresses on “labels” of fixed length, this labels identify the route of a packet. The lables are used by different switching and routing technologies to route the packets.
  - Routing protocol interfacind and reservation of existing resources (RSVP).
  - Support of IP, ATM and frame-relay (therefore named multiprotocol).

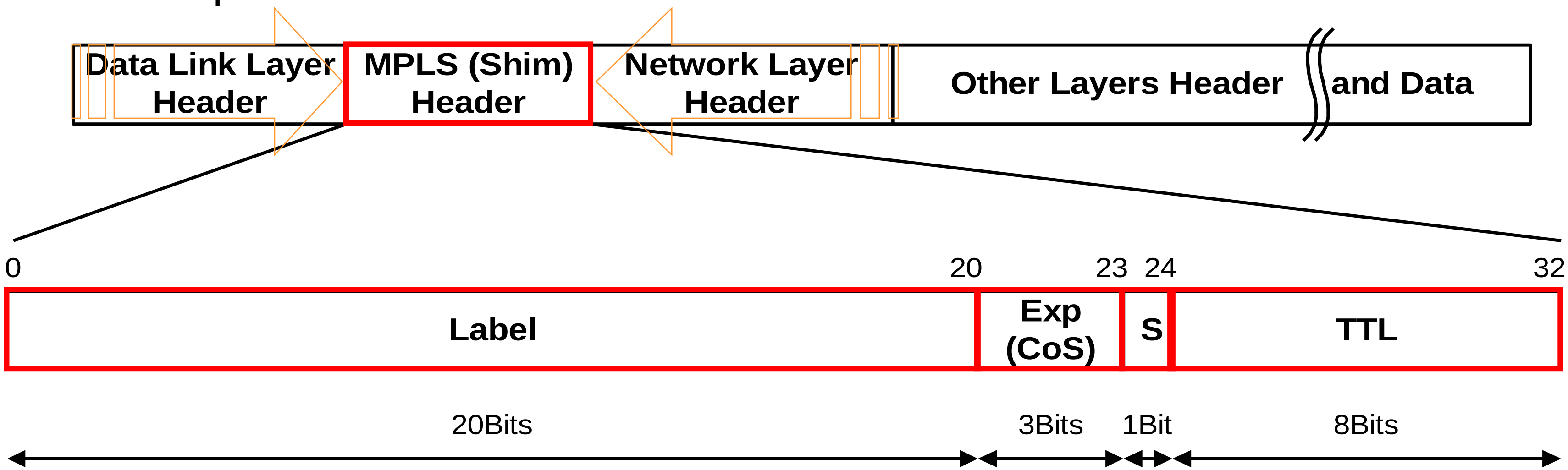
MPLS Labels

- Fixed Length
- Local Significance
- Labels usually change on each network segment
- Assigned upstream by signaling protocols
- Four defined fields
  - Label 20 bits (= 1,048,575 values)
  - Experimental
  - Stack Bit (0=additional labels 1=end of stack)
  - Time-to-Live

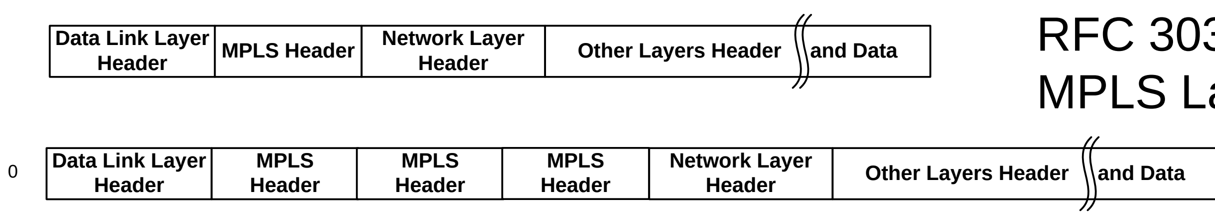


MPLS Header

- Labels are placed between L2 header and L3 data

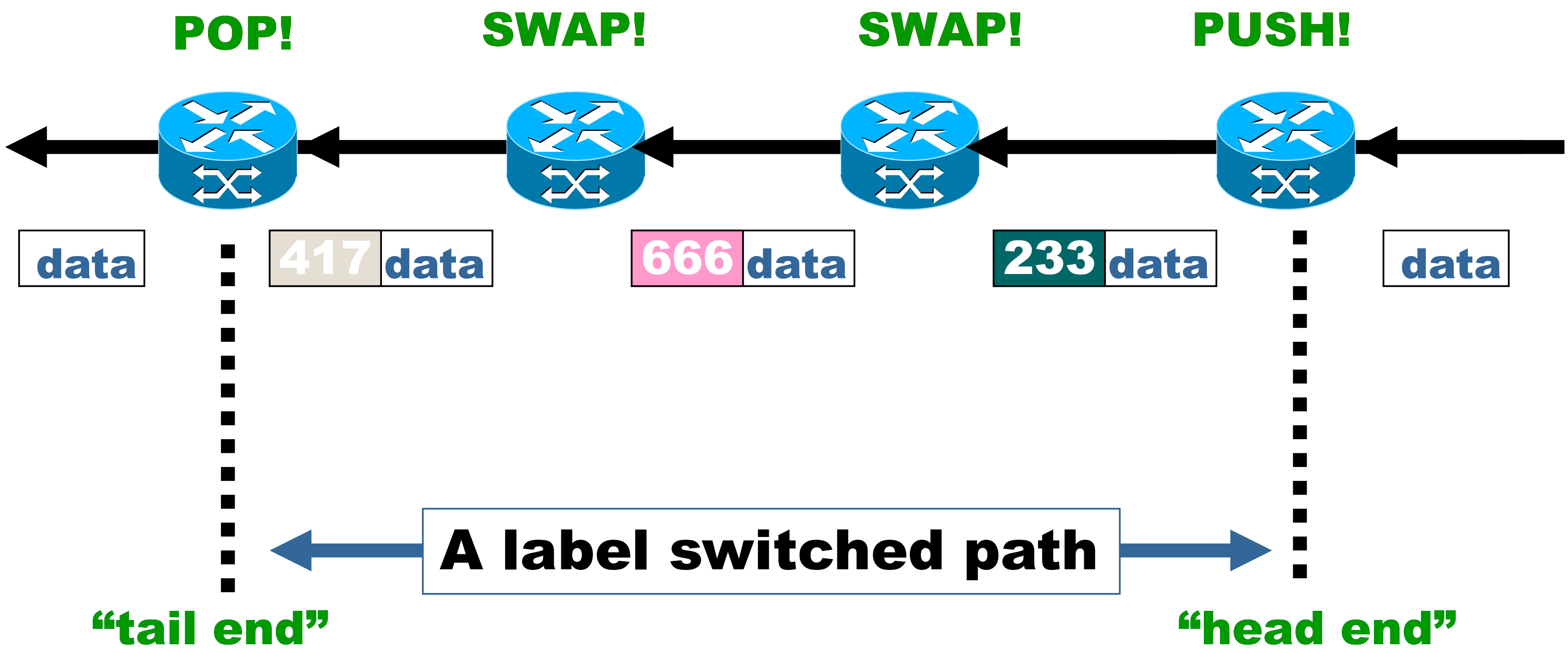


- Multiple labels may be stacked together

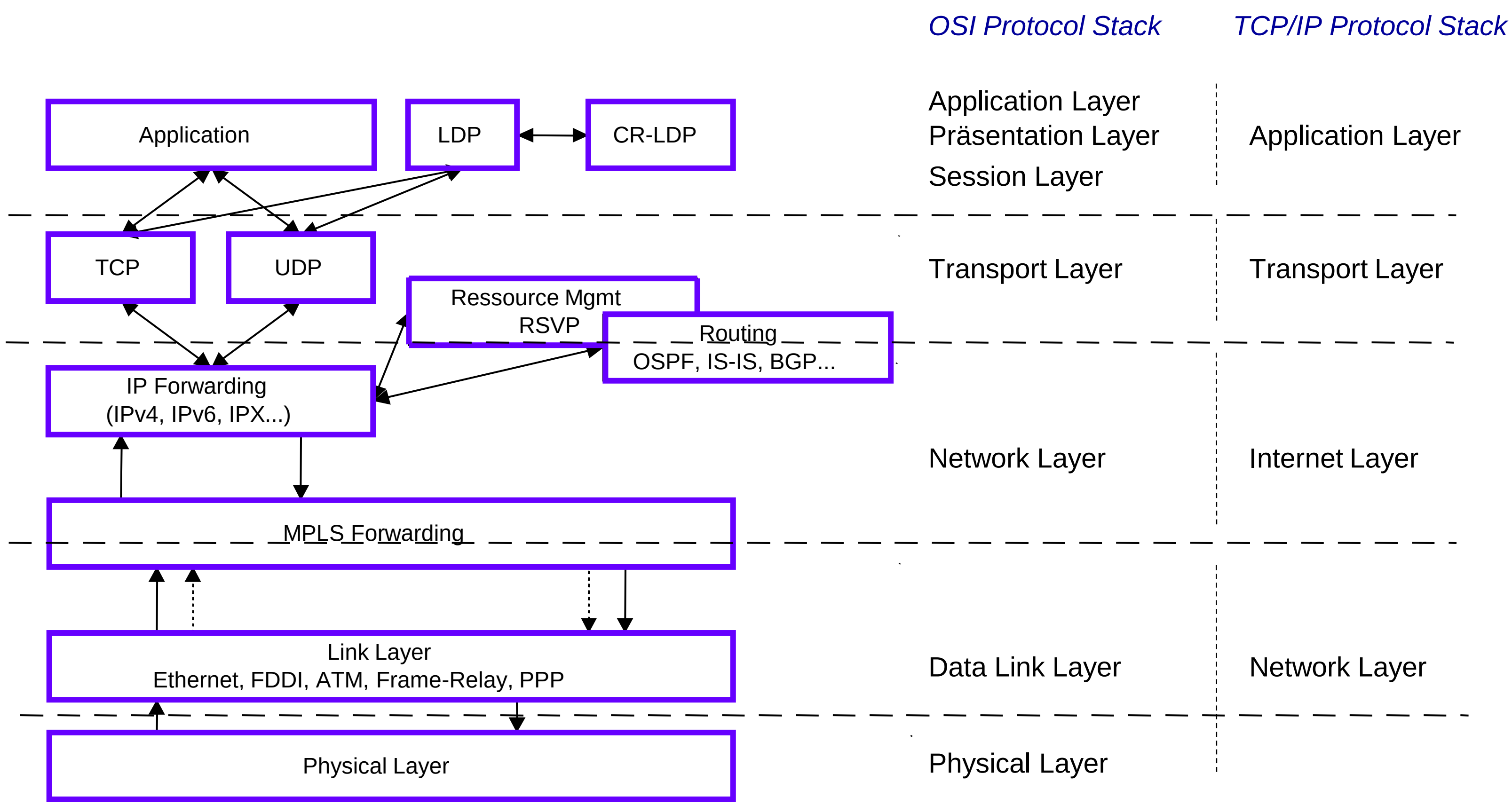


RFC 3032:
MPLS Label Stack Encoding

MPLS Label Switched Patch

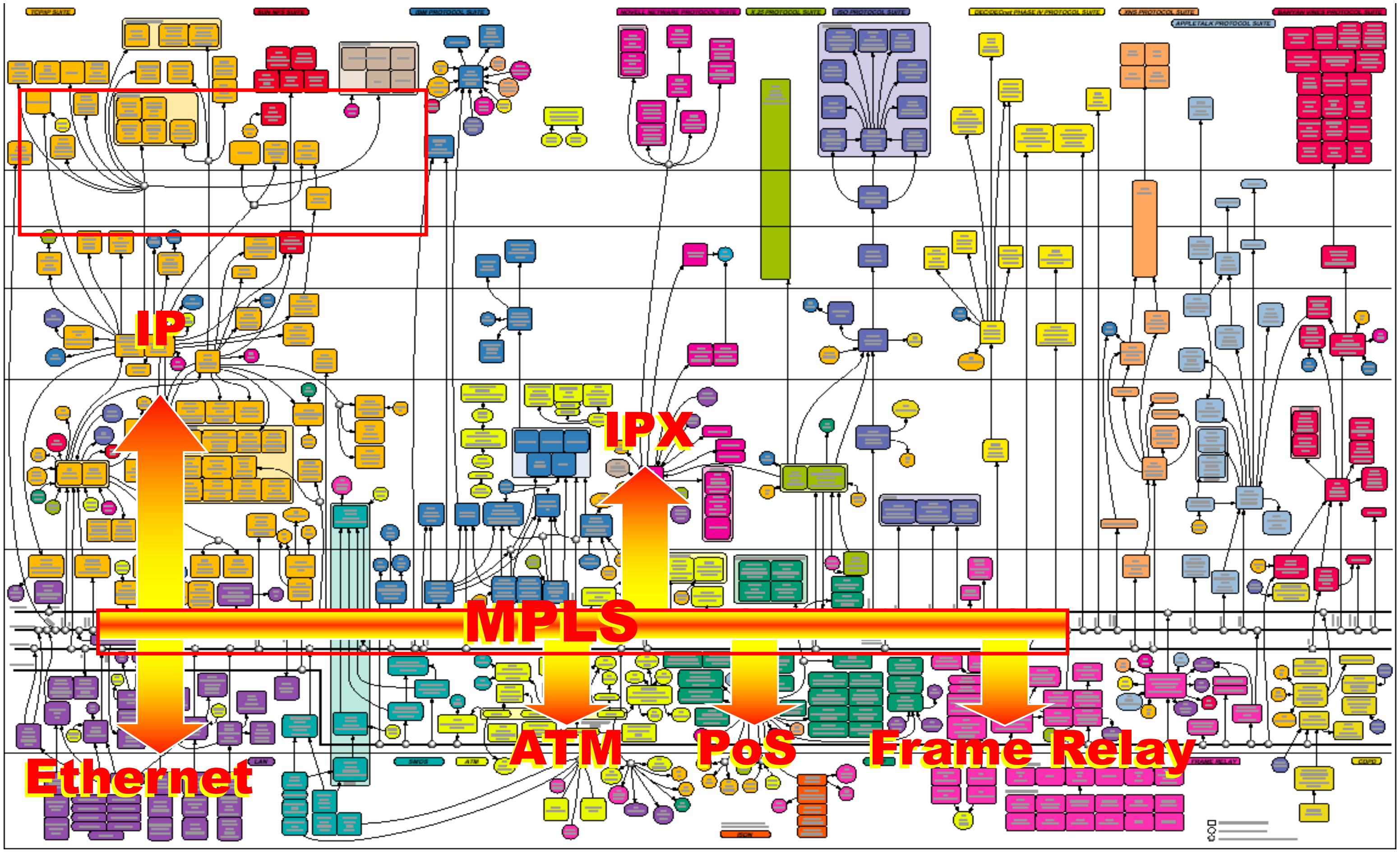


Protocol Stack

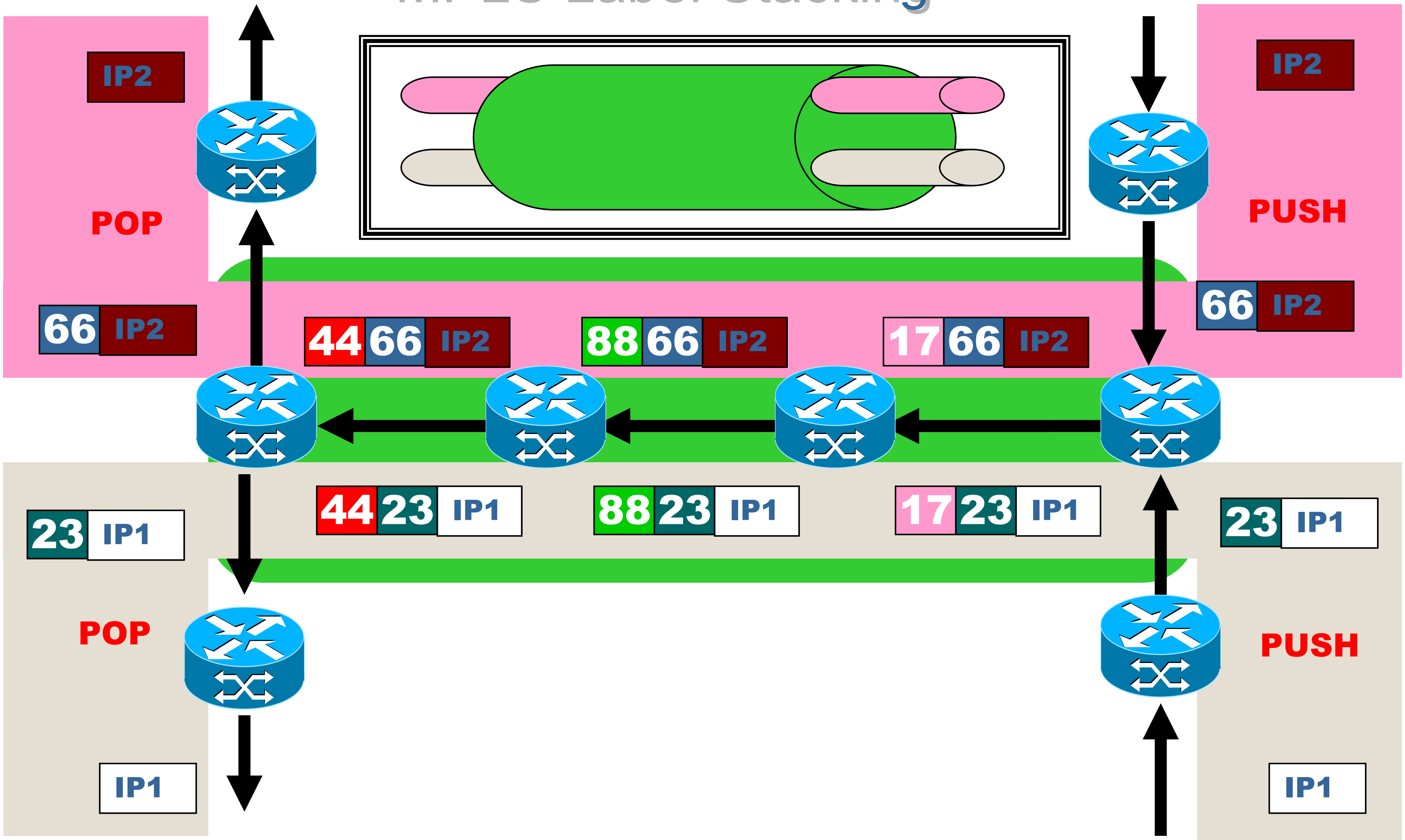


MPLS impacts on OSI Layer 2.5 - ...

MPLS Technology



MPLS Label Stacking



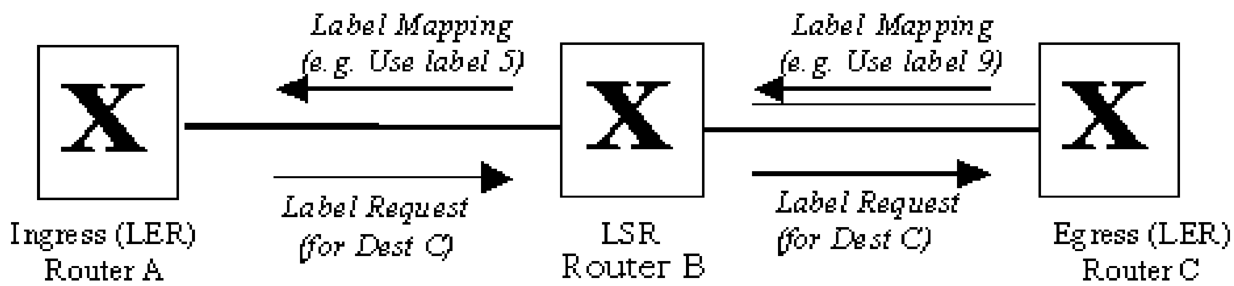
MPLS: how it works

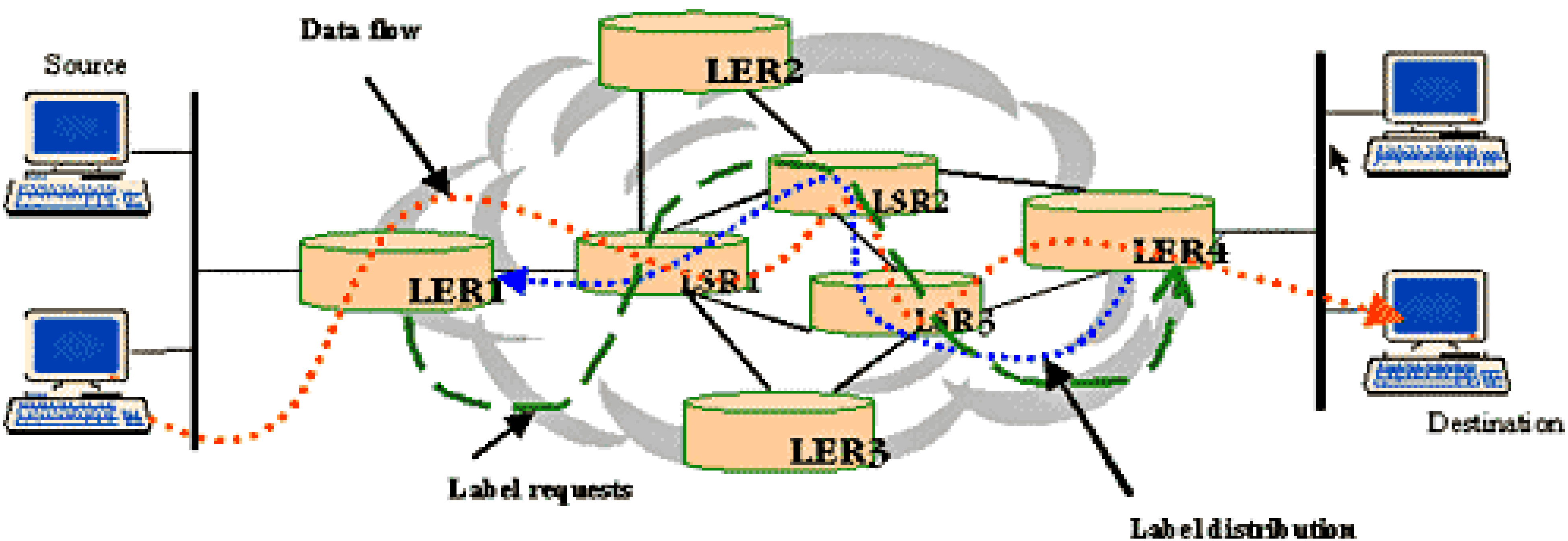
- **Step 1**
  - Network automatically builds the routing tables
  - Service provider infrastructures use the routing protocols like OSPF, EIGRP, or IS-IS.
  - “Label Distribution Protocol” (LDP) sets values to adiacent devices.
  - “Label Switched Paths” (LSPs) creates maps among destinations. VPIs/VCIs manually configured (only exception: “permanent virtual circuits” (PVC).
  - Labels always automatically configured.

MPLS: how it works

- **Step 2.**
  - Packet arrives at “Edge Label Switch Router” (Edge LSR).
  - Packet is progcessed to determine required Layer 3 service (QoS + bandwidth).
  - Routing decisions are taken by “Edge LSR”, who selects and labels the packet.
  - Packet is passed to next LSR.
- **Step 3.**
  - Core LSR read the label and substitutes it with new one as defined in table.
  - Packet is passed to next LSR.
  - Step3 is repeated for each LSR in the core.
- **Step 4.**
  - The Edge LSR at the exit removes the label
  - The Edge LSR reads header of the pacjket and passes it to its final destination.

MPLS: how it works



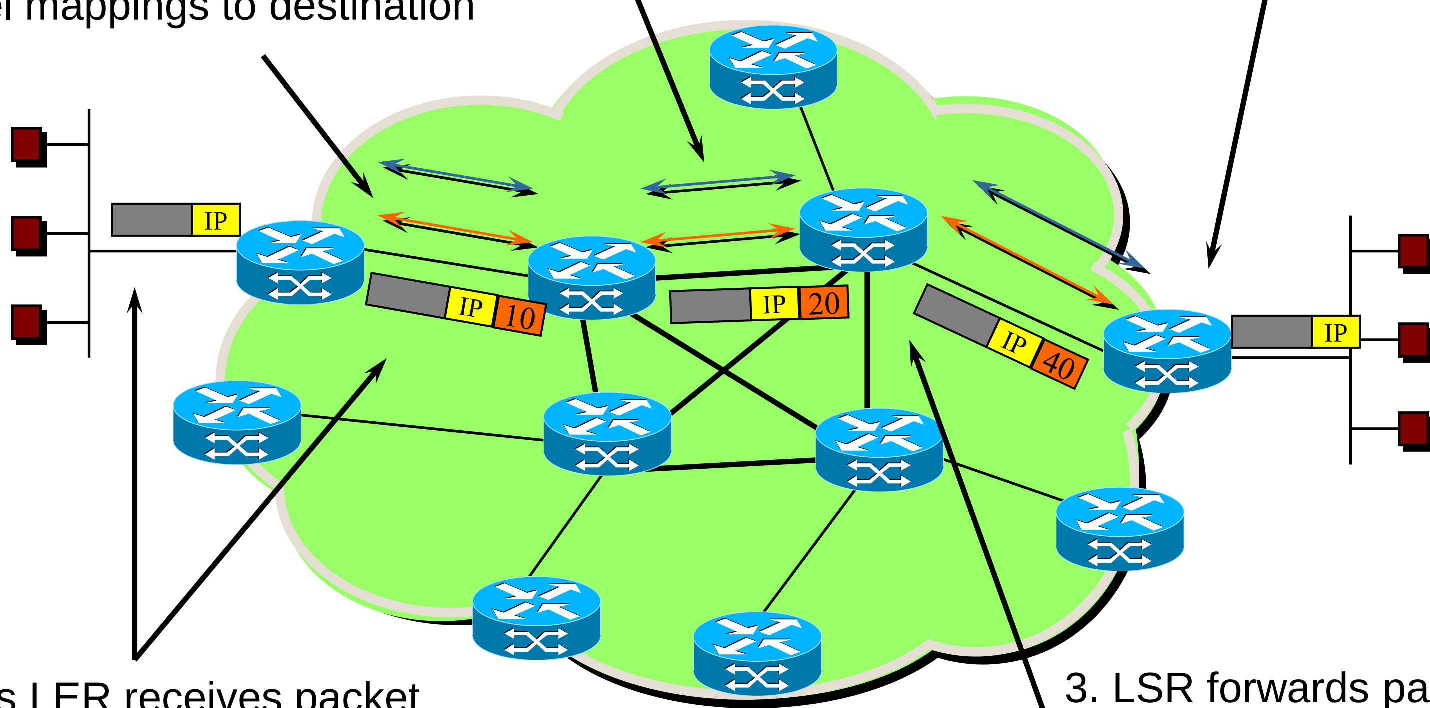


MPLS: how it works

1a. Routing protocols (e.g. OSPF-TE, IS-IS-TE) exchange reachability to destination networks

1b. Label Distribution Protocol (LDP) establishes label mappings to destination network

4. LER at egress removes label and delivers packet



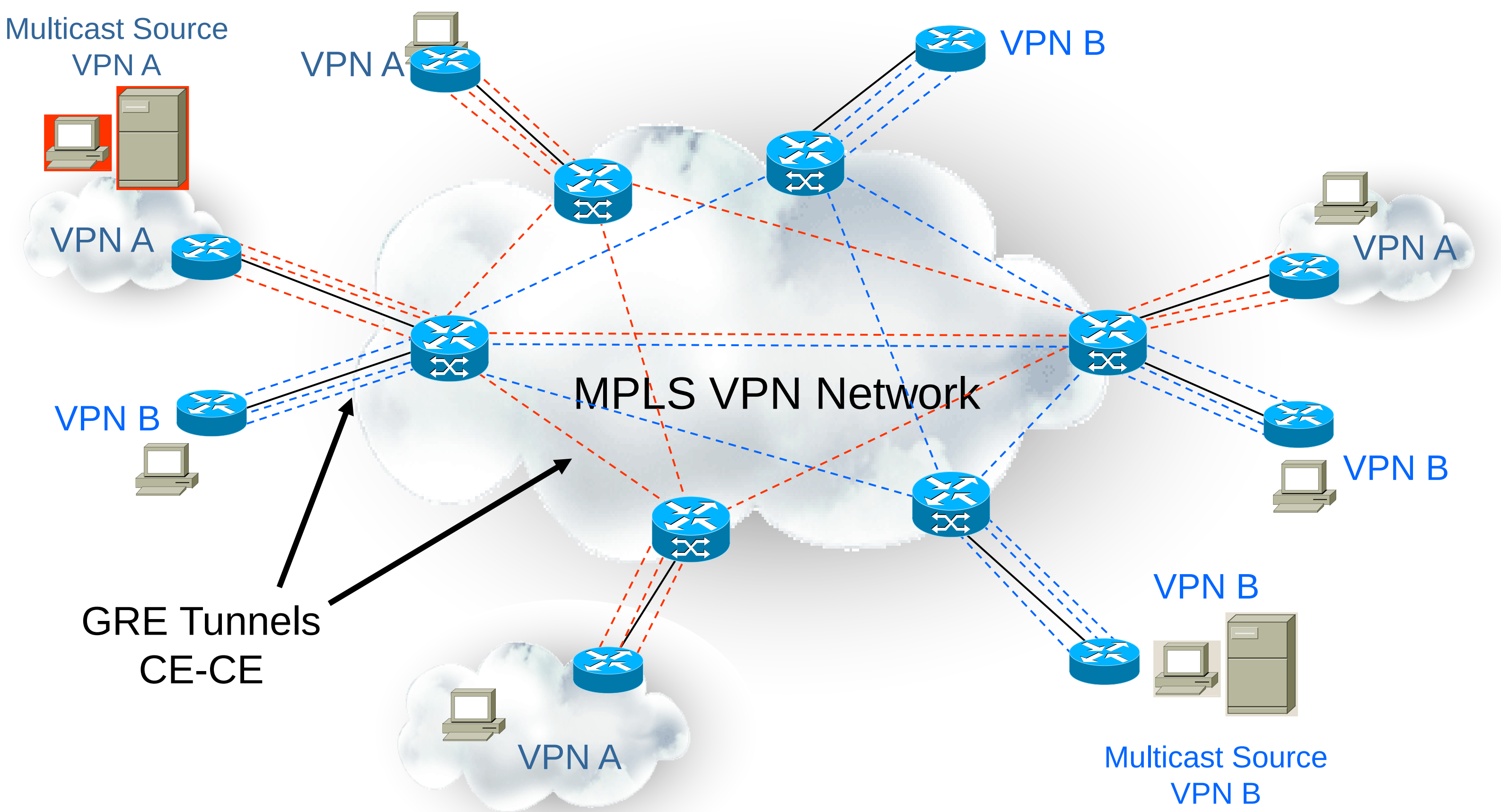
2. Ingress LER receives packet and “label”s packets

3. LSR forwards packets using label swapping

MPLS: IP+ATM

- MPLS permits ATM switches to virtually behave as IP routers. This property arises from the fact that the ‘forwarding’ paradigm used by MPLS (label swapping) is exactly the same implemented in hadrware by the ATM.
- The key difference between a conventional ATM switch and one that uses the ‘label switch’ is in the control software used to establish the ‘virtual channel identifier’ (VCI) in the tables of the switch. An ATM switch supporting ‘label switch’ uses routing protocols and the ‘label distribution protocol’ to establish such registrations.

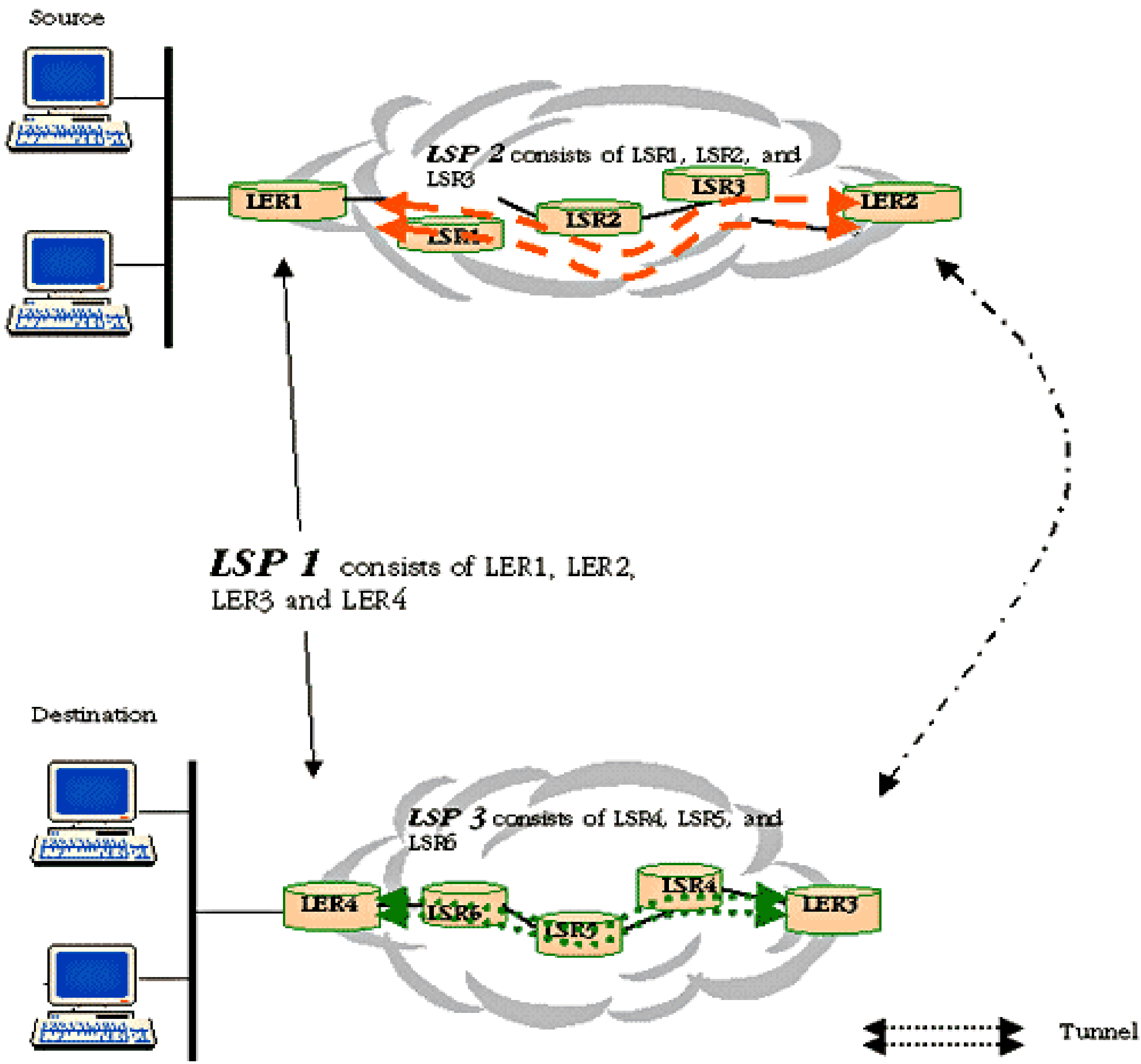
VPN based on MPLS



VPN basate su MPLS

- Si tratta di una peculiarità di MPLS
- E' possibile controllare il percorso di un pacchetto senza dichiarare esplicitamente tutti i routers che lo compongono
- Creazione di tunnel nel percorso dei routers

VPN basate su MPLS



Overhead of different Techniques

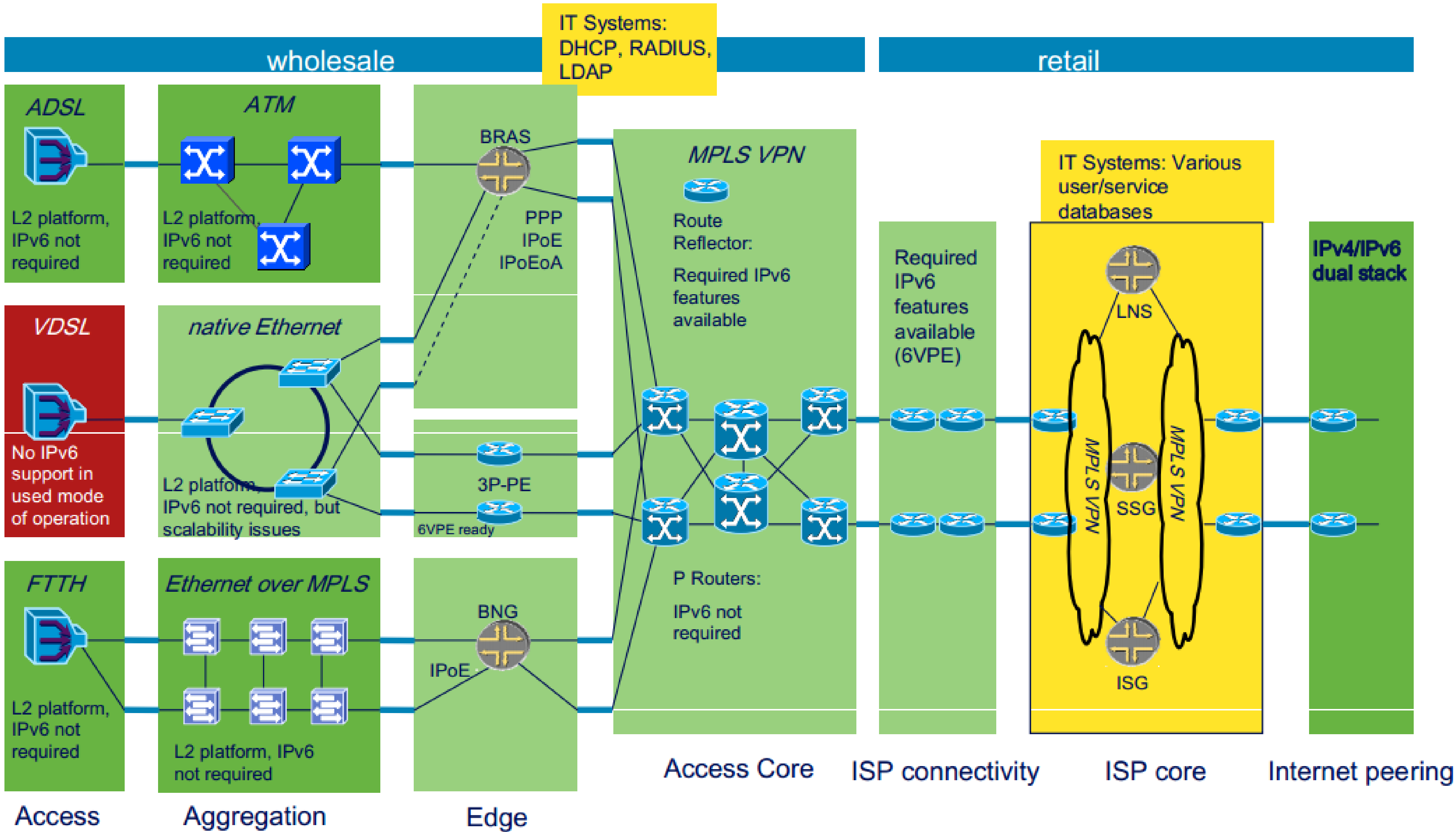
SDH	$100\% - \frac{100\% * 260 * 8 * 9 * 8000\,Bit/s}{270 * 8 * 9 * 8000\,Bit/s} = 3.7\%$	Rahmen = 270*9 Oktetts Payload = 260*9 Oktetts
TDM (2Mbit/s)	$100\% - \frac{100\% * 31 * 64000\,Bit/s}{32 * 64000\,Bit/s} = 3.1\%$	Nutzbare Timeslots = 31 Total Timeslots = 32
PPP/MPLS	$100\% - \frac{100\% * 490 * 8\,Bits}{(490+7+8) * 8\,Bits} = 3\%$	Payload inkl. TCP/IP Overhead von 40 Oktetts PPP = 7 Oktetts MPLS = 8 Oktetts (2*Shim-Header für VPN Unterstützung)
Frame Relay	$100\% - \frac{100\% * 490 * 8\,Bits}{(490 + 6) * 8\,Bits} = 1.2\%$	Payload inkl. TCP/IP Overhead von 40 Oktetts Frame-Relay Rahmen = 6 Oktetts (Theoretisch auch 5 Oktetts möglich)
ATM	$100\% - \frac{100\% * 48 * 8\,Bit}{53 * 8\,Bit} = 9.4\%$	Payload = 48 Oktetts Zellgrösse = 53 Oktetts
AAL-5	$100\% - \frac{100\% * 450 * 8\,Bit}{(450 + 8) * 8\,Bit} = 1.7\%$	AAL Trailer = 8 Oktetts
TCP/IP	$100\% - \frac{100\% * 450 * 8\,Bit}{(450 + 20 + 20) * 8\,Bit} = 8.2\%$	IP Overhead = 20 Oktetts TCP Overhead = 20 Oktetts

Overhead einzelner Techniken

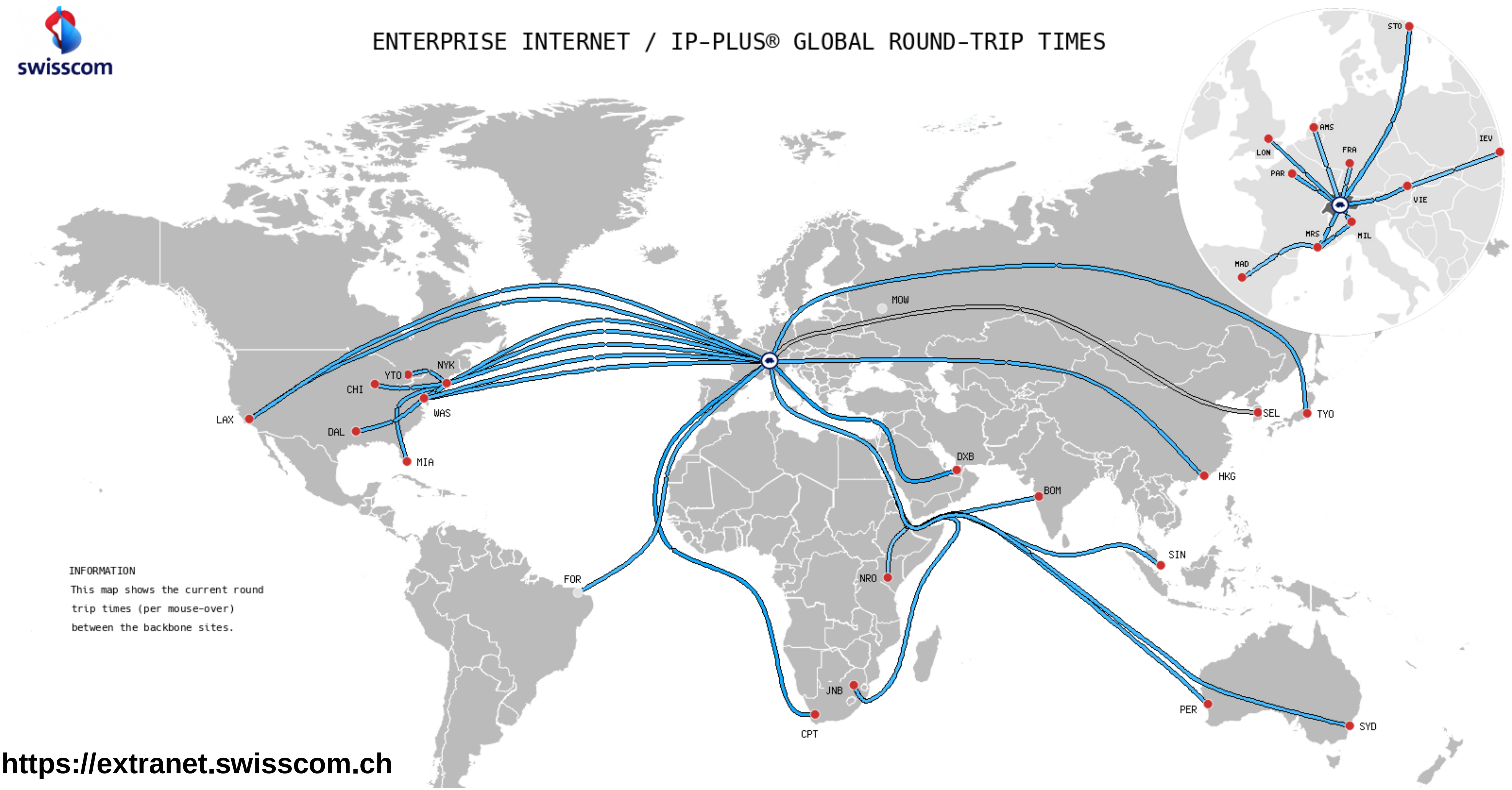
Overhead Network Architectures

PoS, MPLS, TCP/IP	3,7% + 3% + 8,2% = 14,9%
TDM, Frame-Relay, TCP/IP	3.1% +1,2% + 8,2% = 12,5%
SDH, ATM, AAL	3,7% + 9,4% +1,7% = 14,8%
ATM, AAL	9,4% +1,7% = 11,1%
SDH, ATM, AAL, TCP/IP	3,7% + 9,4% +1,7% + 8,2% = 23%

Overhead verschiedener Technikkombinationen


wholesale
IT Systems: DHCP, RADIUS, LDAP
retail
ADSL
L2 platform, IPv6 not required
ATM
L2 platform, IPv6 not required
BRAS
PPP
IPoE
IPoEoA
MPLS VPN
Route Reflector:
Required IPv6 features available
IT Systems: Various user/service databases
Required IPv6 features available (6VPE)
LNS
IPv4/IPv6 dual stack
VDSL
No IPv6 support in used mode of operation
native Ethernet
L2 platform, IPv6 not required, but scalability issues
3P-PE
6VPE ready
MPLS VPN
SSG
MPLS VPN
FTTH
L2 platform, IPv6 not required
Ethernet over MPLS
L2 platform, IPv6 not required
BNG
IPoE
P Routers:
IPv6 not required
ISG
Access Core
ISP connectivity
ISP core
Internet peering
Access
Aggregation
Edge

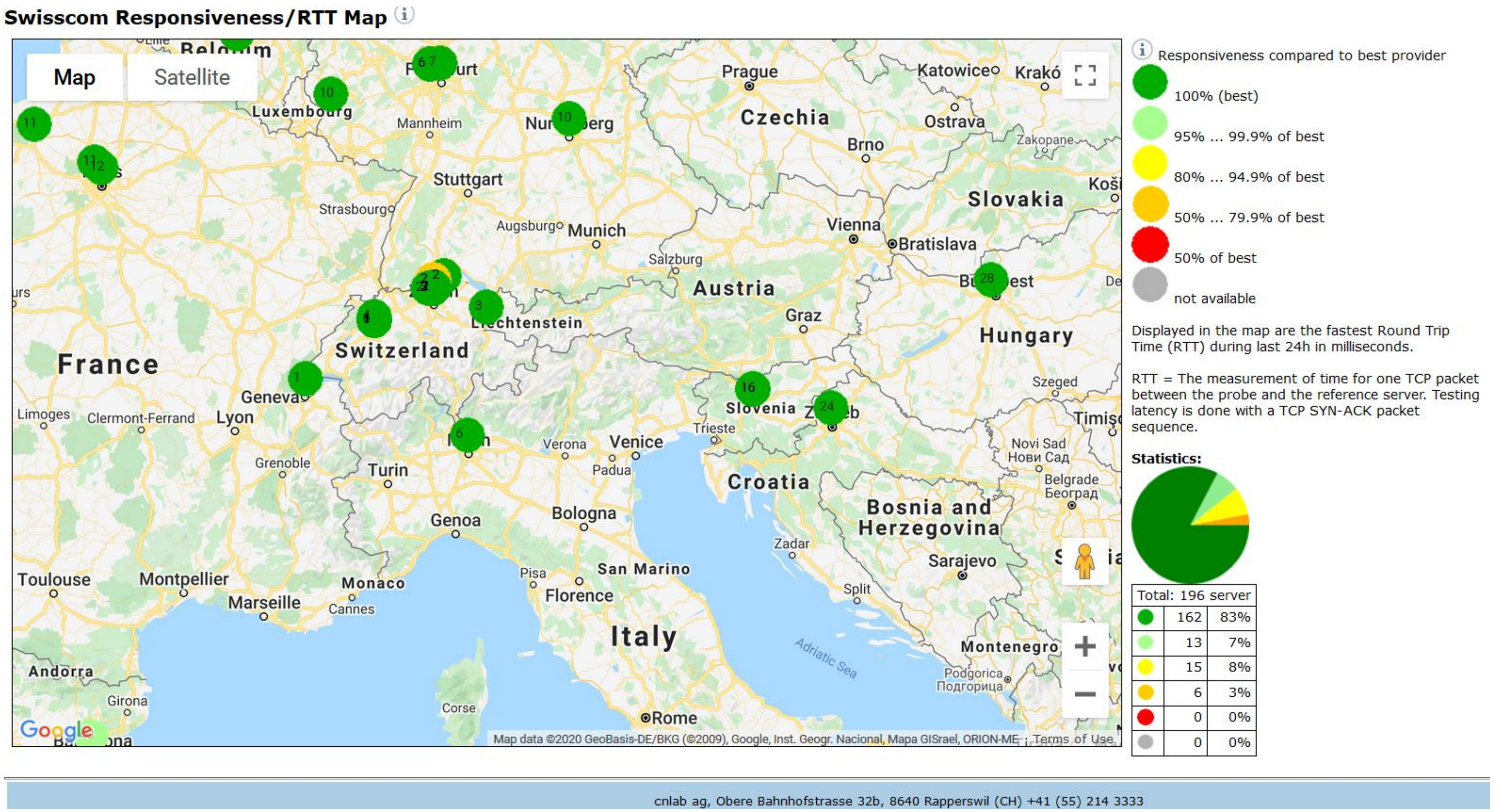
Sample of a global connectivity strategy



https://extranet.swisscom.ch

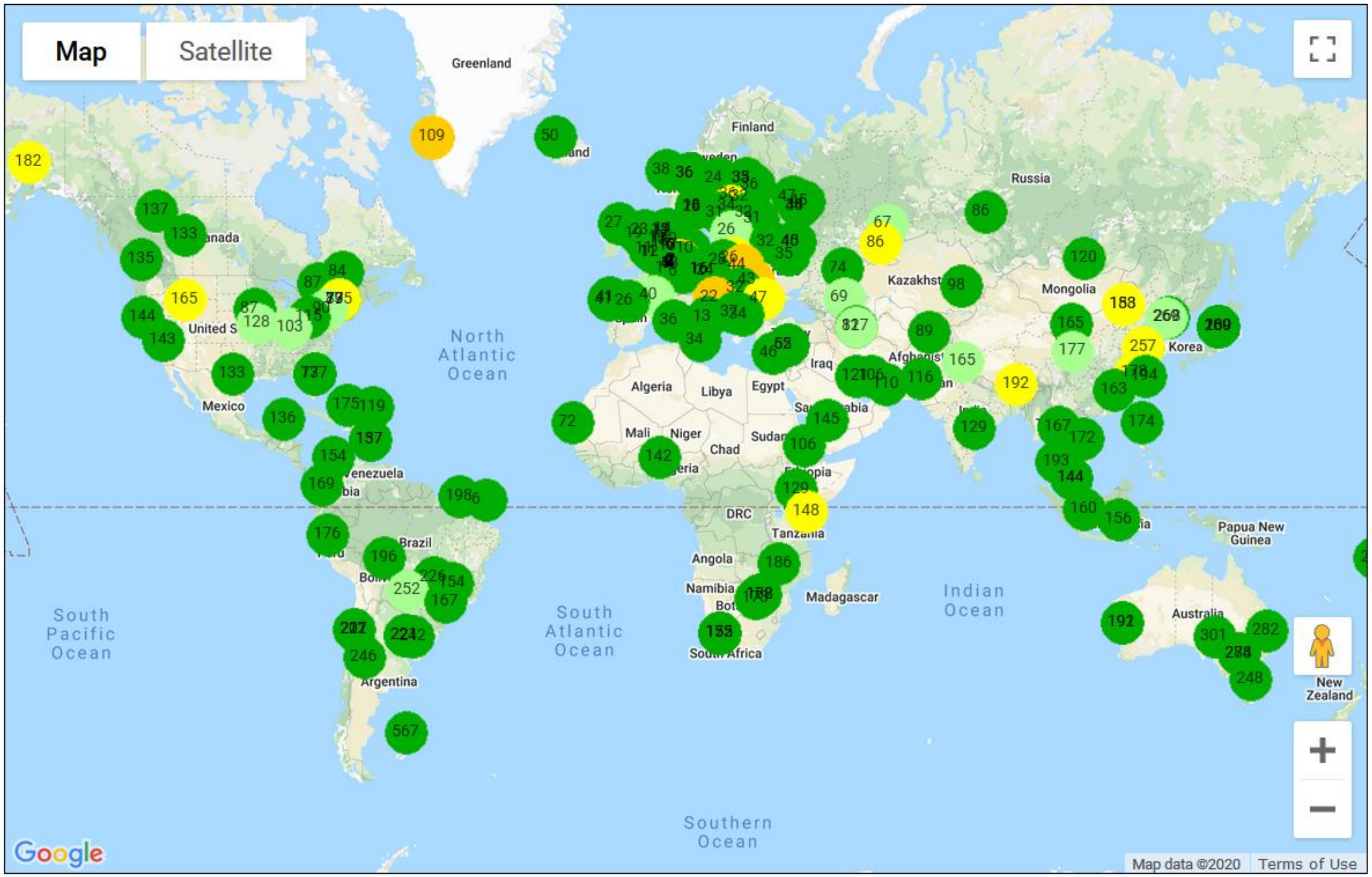
IP Network performance measurements

Network responsiveness and performance:
https://ux.cnlab.ch/performance/map_statistic/map.jsp?language=en?language=it



IP Network performance measurements

Swisscom Responsiveness/RTT Map



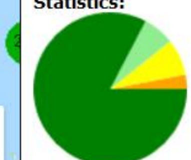
Responsiveness compared to best provider

- 100% (best)
- 95% ... 99.9% of best
- 80% ... 94.9% of best
- 50% ... 79.9% of best
- 50% of best
- not available

Displayed in the map are the fastest Round Trip Time (RTT) during last 24h in milliseconds.

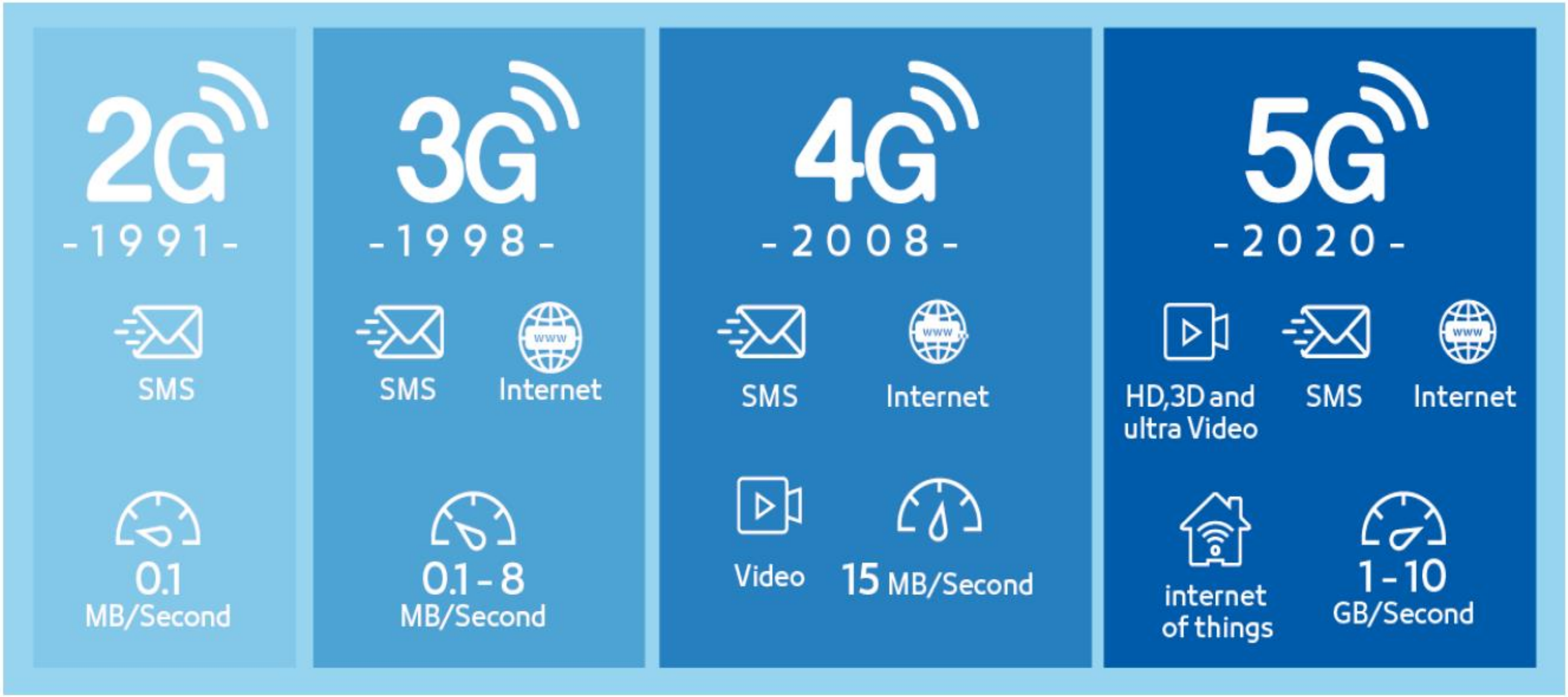
RTT = The measurement of time for one TCP packet between the probe and the reference server. Testing latency is done with a TCP SYN-ACK packet sequence.

Statistics:

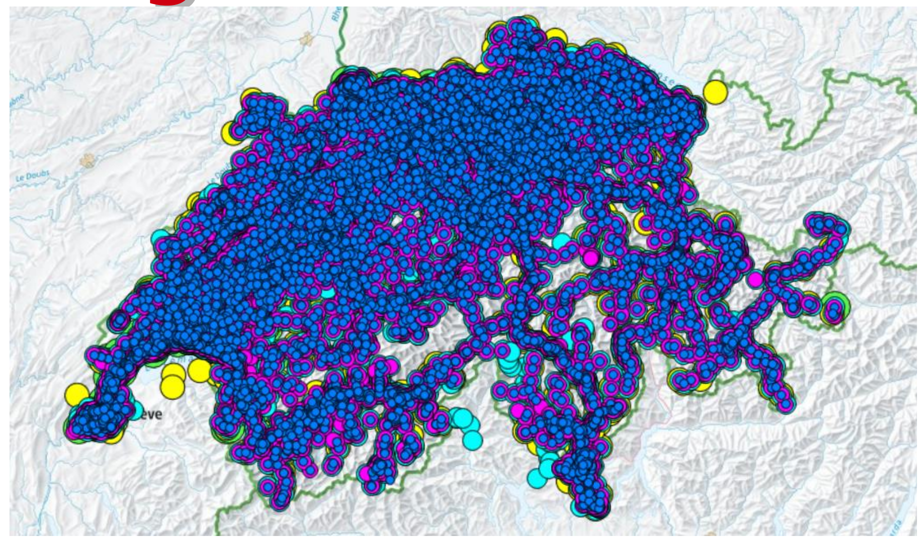


Total: 196 server		
	162	83%
	13	7%
	15	8%
	6	3%
	0	0%
	0	0%

Mobile network deployment / coverage

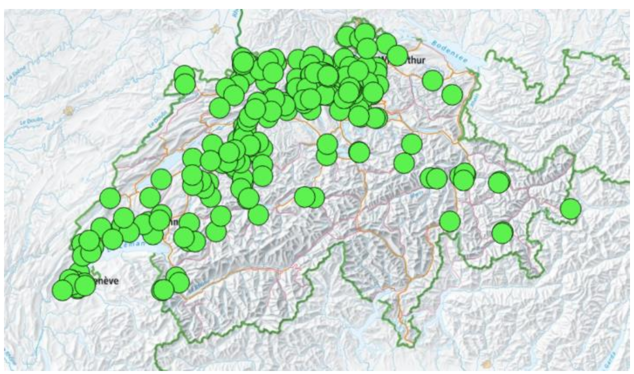


Mobile network deployment / coverage

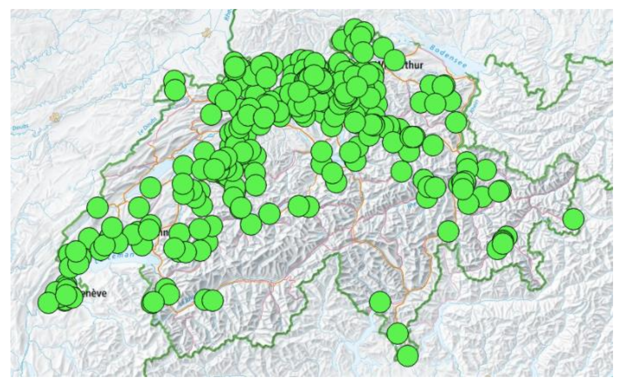


2G, 3G, 4G access points in CH – Mai 2019

http://map.funksender.admin.ch

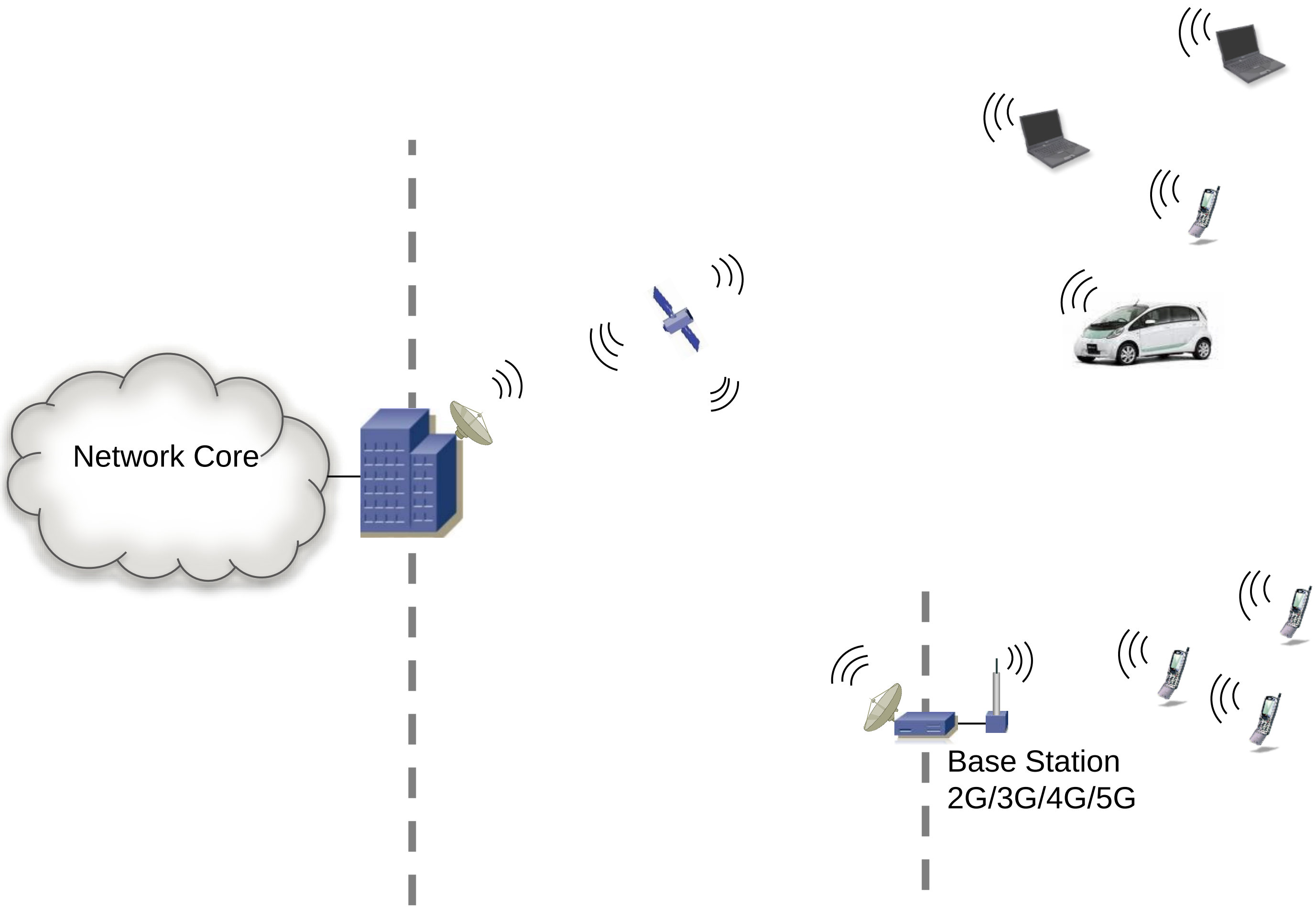


5G deployment in CH – Mai 2019



5G deployment in CH – August 2019

Satellite Network Access



Satellite Network Access

- **Intelsat:** 58 geostationary satellites; covers the entire globe.
  Revenue of $542.0 million USD (2016).
  As of 2018, Intelsat provides service to over 600 Earth
  stations in more than 149 countries, territories and dependencies.
  Coverage
  map: http://www.intelsat.com/fleetmaps/

Source: https://en.wikipedia.org/wiki/Intelsat

- **Eutelsat:** 27 geostationary satellites concentrated between 15 ° west and 75 ° east; they have just launched the KA-SAT, with a capacity of 70 Gbit/s.
  European satellite operator with Headquarters in Paris, France.
  In September 2018, Eutelsat launched Eutelsat CIRRUS.

- **Inmarsat:** 13 geostationary satellites; that operated using the Ka band.
  British satellite telecommunications company.
  18 February 2020 Inmarsat launched connectivity services in Saudi Arabia.
  Revenue of $1,465.2 million USD (2018).

Satellite Network Access

- **Interspoutnik:** 12 satellites in geostationary orbit.

- **Iridium:** 66 satellites in low orbit (780 km); mainly used by journalists, navigators and the military.
  Revenue of $523.0 million USD (2018).

- **Globalstar:** 48 + 4 satellites in low orbit (1'450 km).
  Coverage map: https://www.globalstar.com/en-us/products/coverage-maps

- **Thuraya:** 3 satellites covering Middle East, North and Central Africa, Western Europe, Asia and Australia.

- Others: **ASTRA Digital Radio, 1worldspace, Echostar, SIRIUS Satellite Radio, Dish Network Corporation, Direct TV, AfriStar, Sky Television plc, Viasat, etc. These companies do not all have their own satellites.**

Satellite Network Access

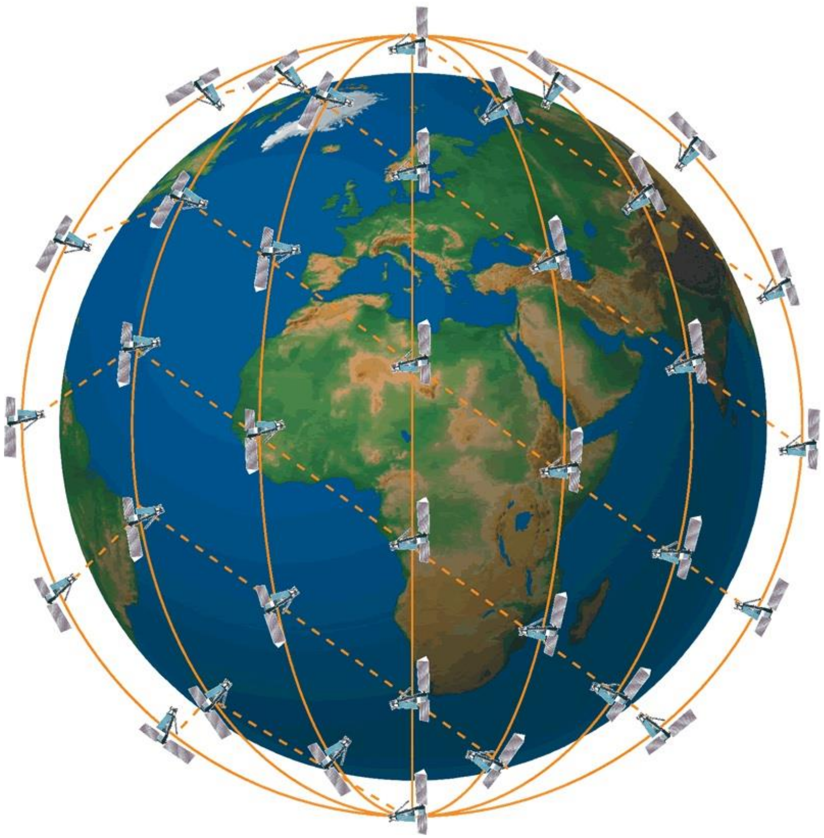
- **Skylink: >1600 micro-satellites: SpaceX satellite constellation to provide Global broadband Internet access.** The constellation will consist of up to 12000 mass-produced small satellites.
  The total cost of the decade-long project is estimated to be about US$10 billion.
  https://en.wikipedia.org/wiki/SpaceX_Starlink
  https://www.starlink.com/
  https://www.theverge.com/2018/11/15/18096943/spacex-fcc-starlink-satellites-approval-constellation-internet-from-space

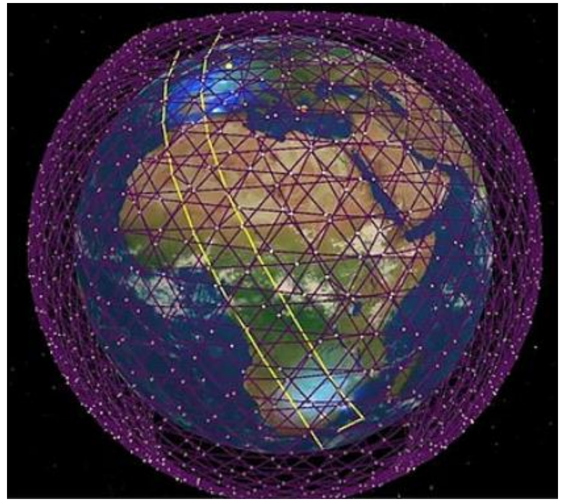
- **OneWeb: 650 satellites: manufacturer: Google**
  https://oneweb.world/
  https://www.theverge.com/2019/2/27/18242120/oneweb-650-satellite-constellation-arianespace-soyuz-launch

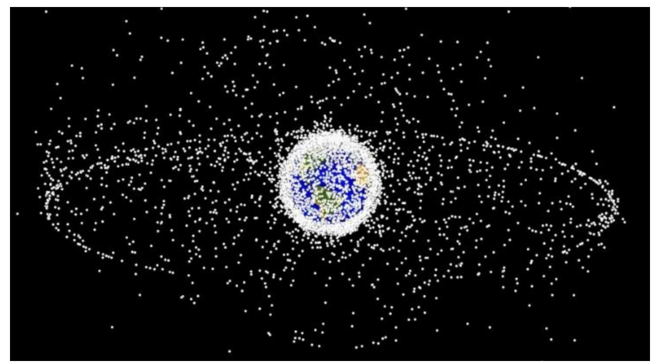
- **Kuiper project: 3236 satellites: Amazon**
  https://www.theverge.com/2019/4/4/18295310/amazon-project-kuiper-satellite-internet-low-earth-orbit-facebook-spacex-starlink
  https://techcrunch.com/2019/12/18/amazon-will-establish-a-new-headquarters-for-its-kuiper-satellite-broadband-project/

Geostationary orbit satellite constellations

Low orbit satellite constellations







Interesting animation: https://www.youtube.com/watch?v=xj-8ic77hDE