Master Course
Computer Networks
IN2097

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Outline

- Project feedback
- Internet Structure
- Network virtualisation

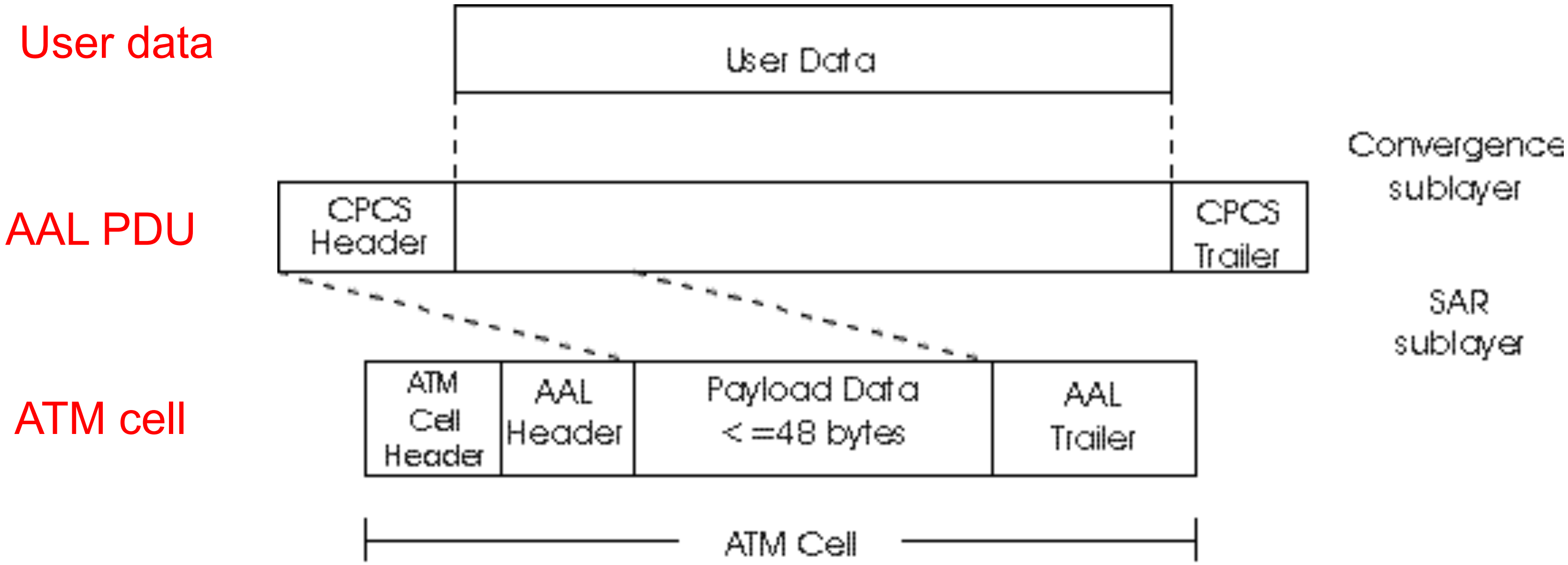
Network Architectures

Link virtualization: ATM, MPLS

ATM Adaptation Layer (AAL) [more]

Different versions of AAL layers, depending on ATM service class:

- AAL1: for CBR (Constant Bit Rate) services, e.g. circuit emulation
- AAL2: for VBR (Variable Bit Rate) services, e.g., MPEG video
- AAL5: for data (e.g., IP datagrams)



ATM Layer

Service: transport cells across ATM network

- analogous to IP network layer
- very different services than IP network layer
- possible Quality of Service (QoS) Guarantees

Network Architecture	Service Model	Guarantees ? Bandwidth	Loss	Order	Timing	Congestion feedback
Internet	best effort	none	no	no	no	no (inferred via loss)
ATM	CBR	constant rate	yes	yes	yes	no congestion
ATM	VBR	guaranteed rate	yes	yes	yes	no congestion
ATM	ABR	guaranteed minimum	no	yes	no	yes
ATM	UBR	none	no	yes	no	no

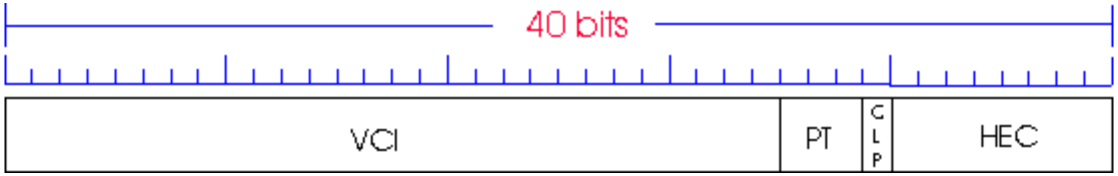
ATM VCs

- Advantages of ATM VC approach:
  - QoS performance guarantee for connection mapped to VC (bandwidth, delay, delay jitter)
- Drawbacks of ATM VC approach:
  - Inefficient support of datagram traffic
  - one PVC between each source/destination pair does not scale
  - SVC introduces call setup latency, processing overhead for short lived connections

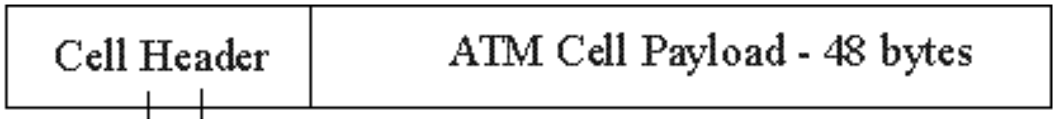
ATM Layer: ATM cell

- 5-byte ATM cell header
- 48-byte payload (Why?)
  - small payload ⇒ short cell-creation delay for digitized voice
  - halfway between 32 and 64 (compromise!)

Cell header

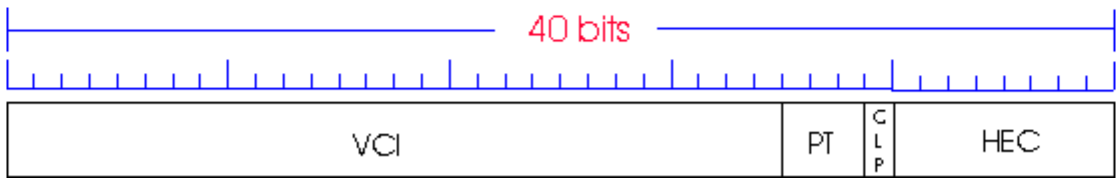


Cell format



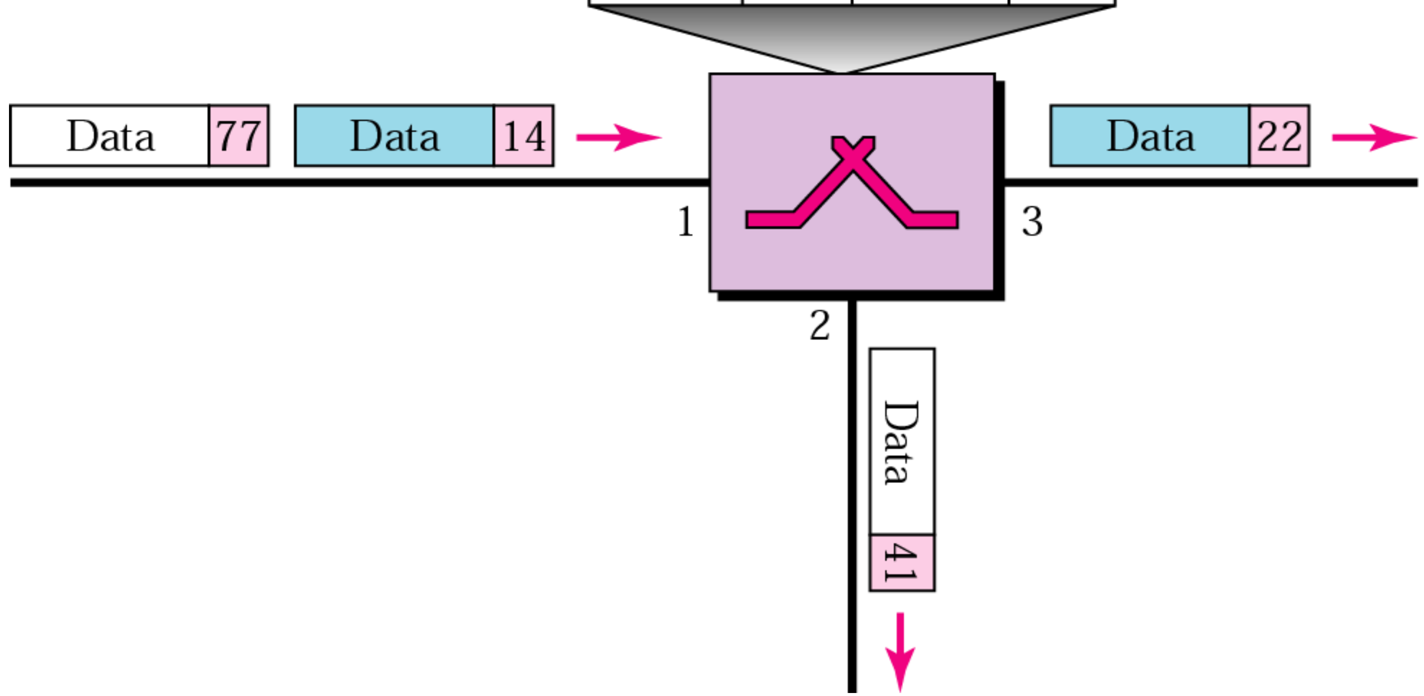
ATM cell header

- **VCI:** virtual channel ID
  - may *change* from link to link through network
- **PT:** Payload type: RM (resource management) vs. data cell
- **CLP:** Cell Loss Priority bit
  - CLP = 1 implies low priority cell, can be discarded if congestion
- **HEC:** Header Error Checksum
  - cyclic redundancy check



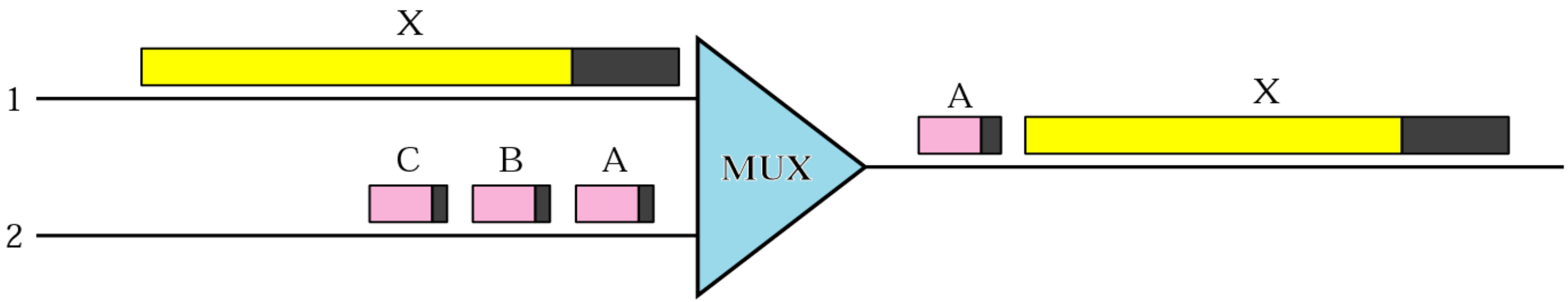
Virtual Circuit Switching

Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	22
1	77	2	41

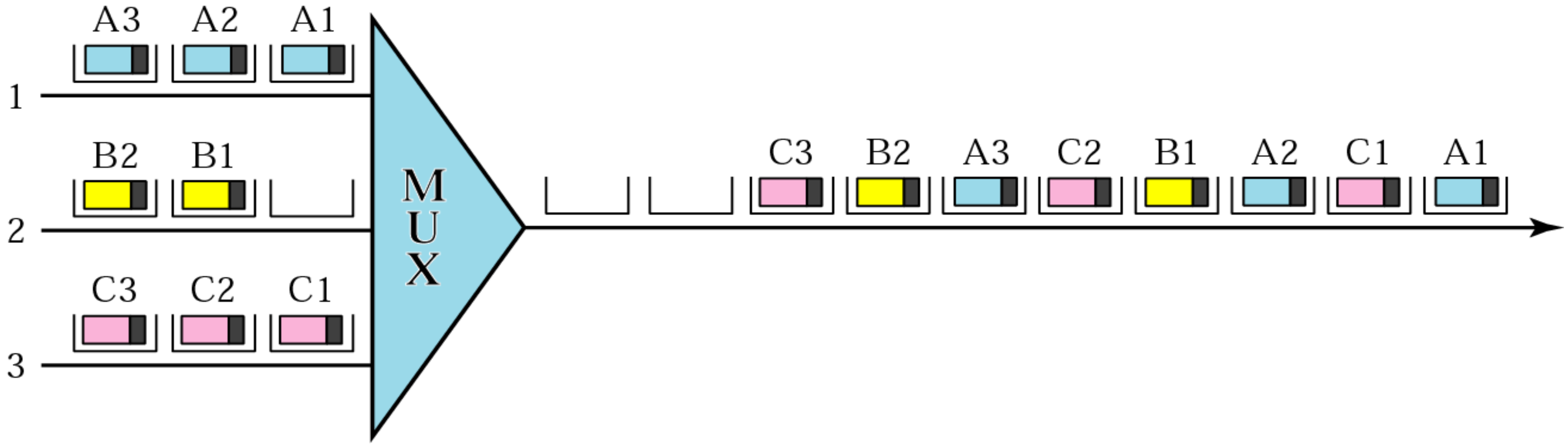


Multiplexing of Variable vs. Fixed Size Packets

- Multiplexing of variable size packets

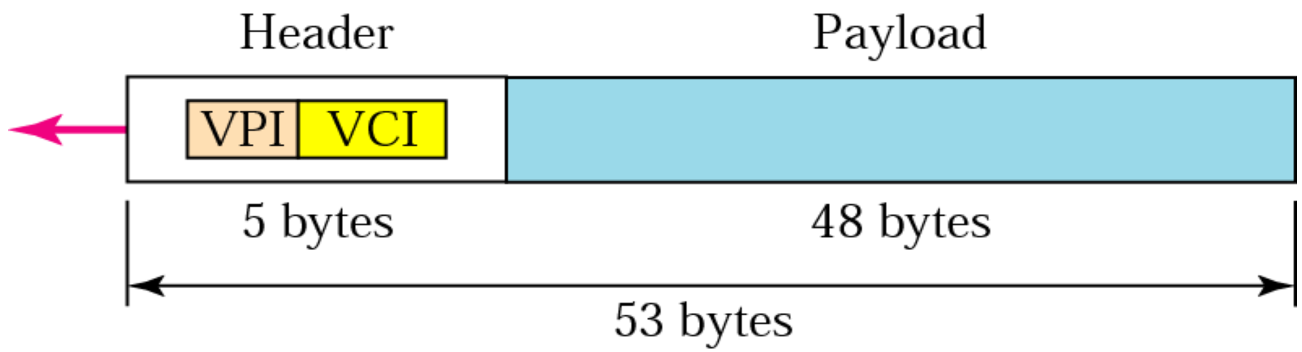


- ATM Multiplexing

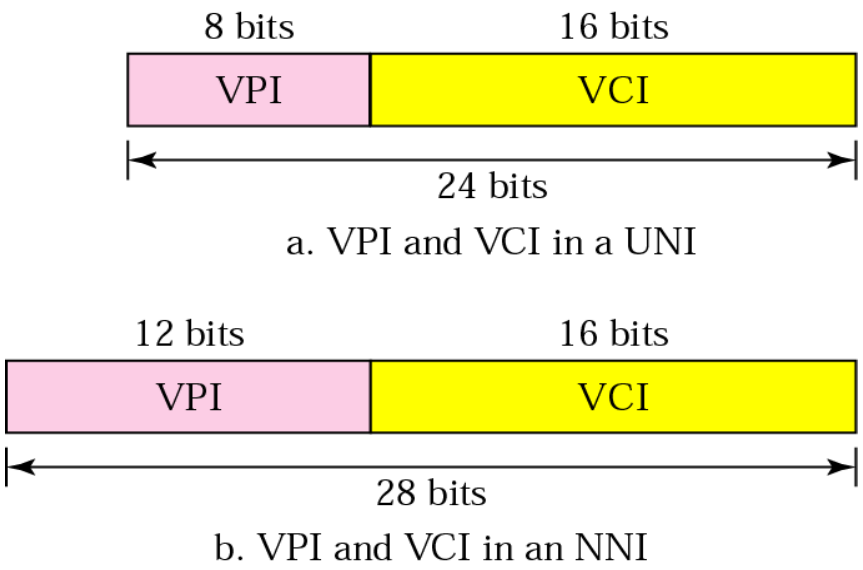


ATM Identifiers

- ATM Cell

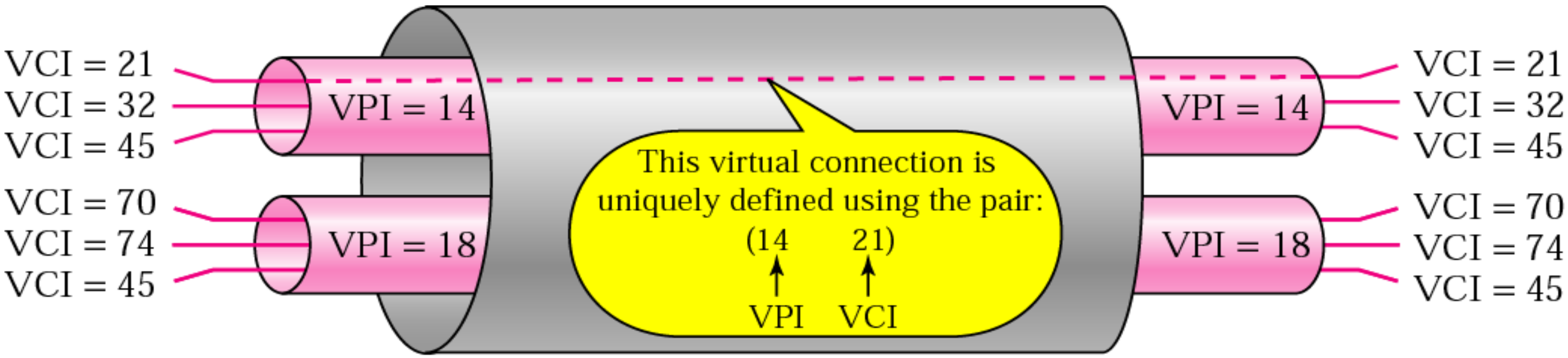


- Virtual Path Identifiers and Virtual Channel Identifiers



(UNI: User-to-Network-Interface
NNI: Network-to-Network-Interface)

ATM Virtual Connections



ATM Physical Layer

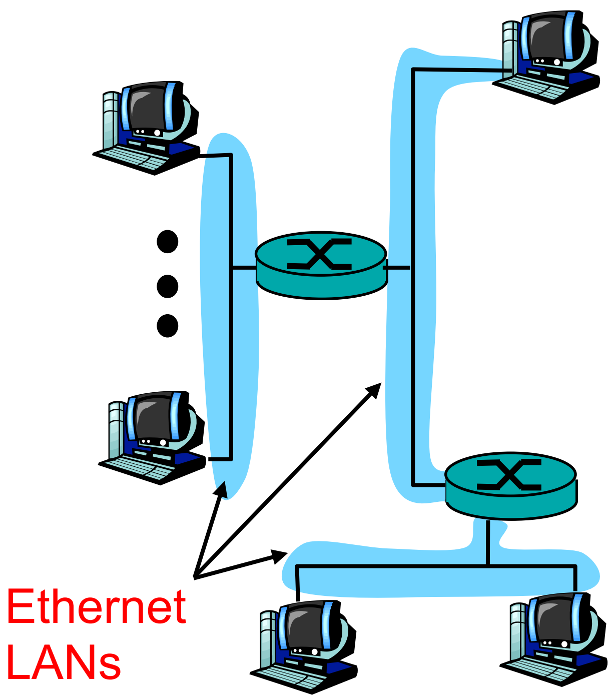
Physical Medium Dependent (PMD) sublayer

- **SONET/SDH**: transmission frame structure (like a container carrying bits);
  - bit synchronization;
  - bandwidth partitions (TDM);
  - several speeds:
  - OC3 = 155.52 Mbps
  - OC12 = 622.08 Mbps
  - OC48 = 2.45 Gbps
  - OC192 = 9.6 Gbps
- **TI/T3**: transmission frame structure (old telephone hierarchy): 1.5 Mbps/ 45 Mbps
- **unstructured**: just cells (busy/idle)
  - transmission of **idle cells** when no data cells to send

IP-Over-ATM

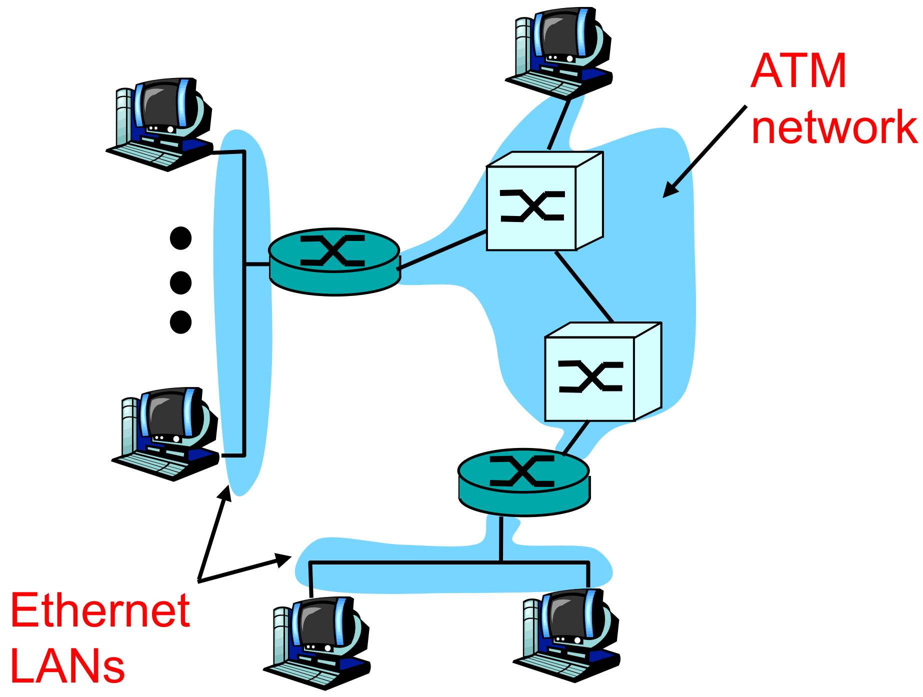
Classic IP only

- 3 "networks" (e.g., LAN segments)
- MAC (802.3) and IP addresses

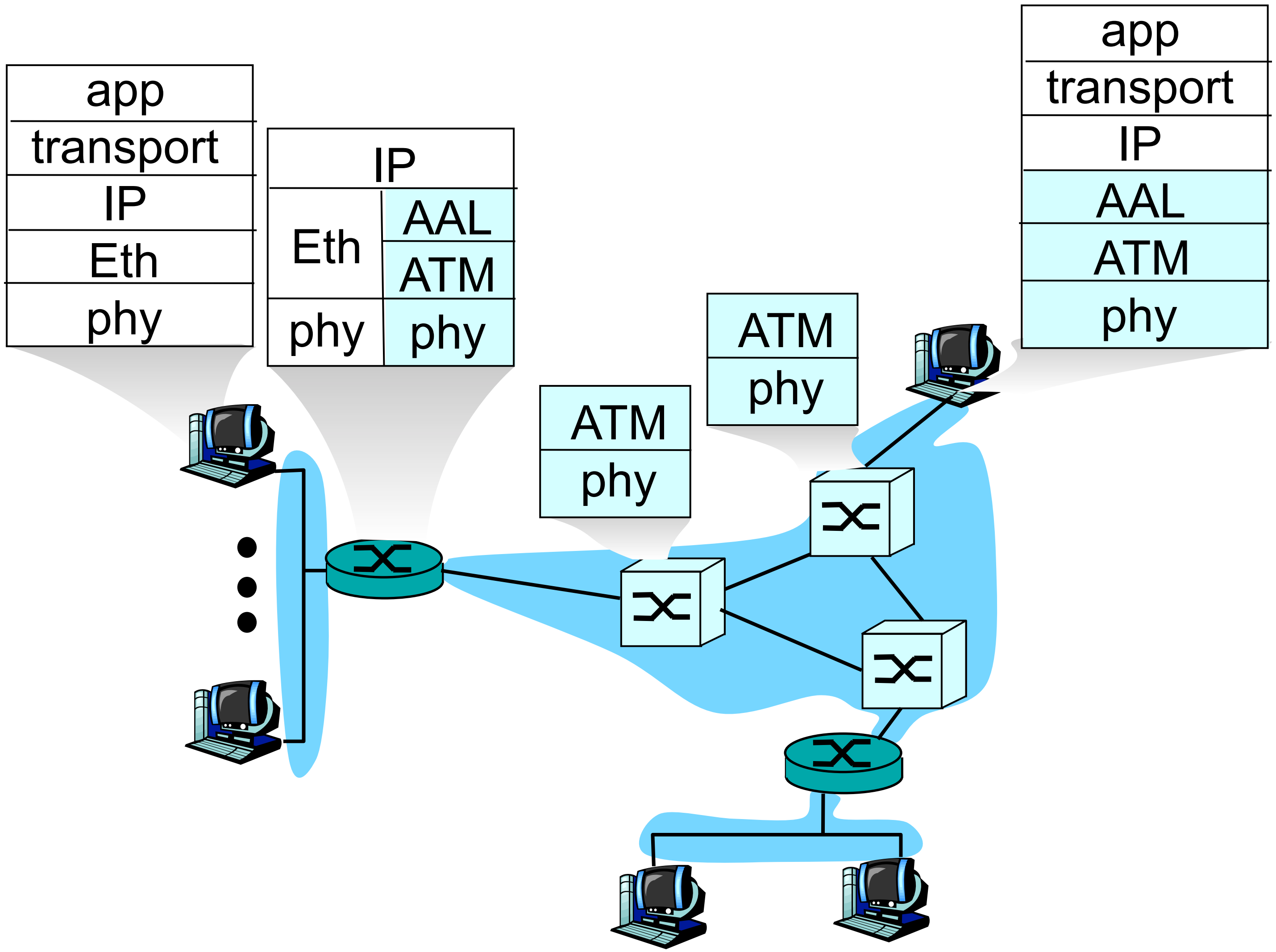


IP over ATM

- replace "network" (e.g., LAN segment) with ATM network
- ATM addresses, IP addresses



IP-Over-ATM


app
transport
IP
Eth
phy
IP
Eth
AAL
ATM
phy
phy
ATM
phy
ATM
phy
app
transport
IP
AAL
ATM
phy

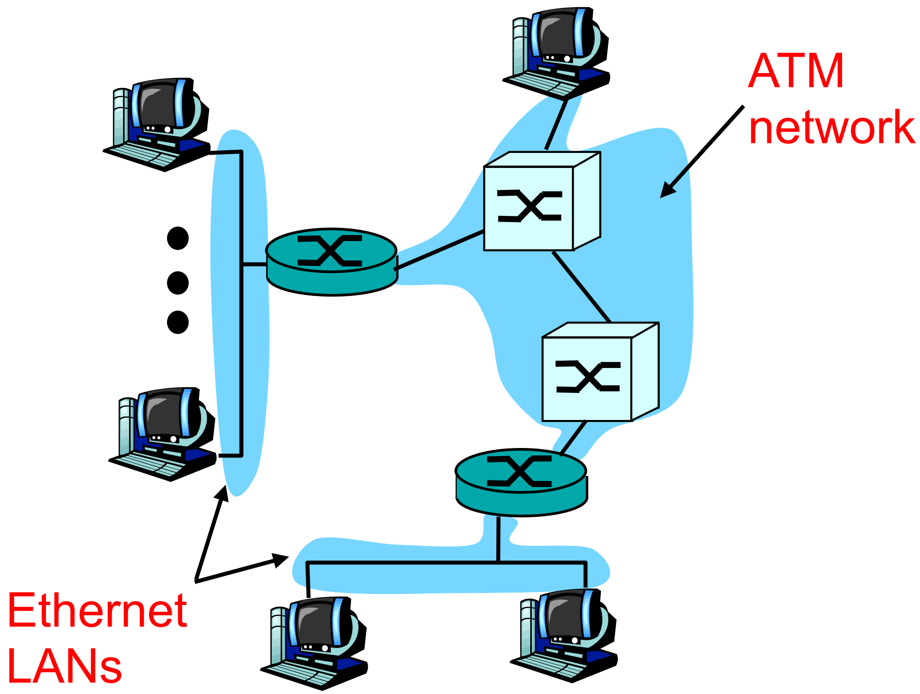
Datagram Journey in IP-over-ATM Network

- at Source Host:
  - IP layer maps between IP, ATM destination address (using ARP)
  - passes datagram to AAL5
  - AAL5 encapsulates data, segments cells, passes to ATM layer
- ATM network: moves cell along VC to destination
- at Destination Host:
  - AAL5 reassembles cells into original datagram
  - if CRC OK, datagram is passed to IP

IP-Over-ATM

Issues:

- IP datagrams into ATM AAL5 PDUs
- from IP addresses to ATM addresses
  - just like IP addresses to 802.3 MAC addresses!
  - ARP server



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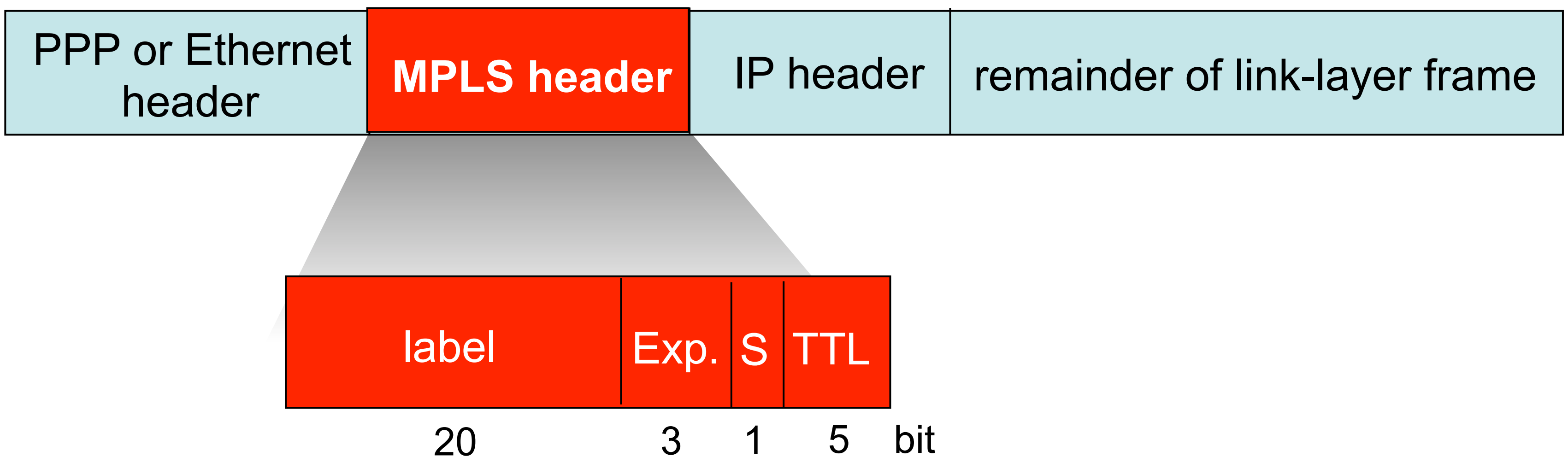
MPLS

Multi-Protocol Label Switching

Technische Universität München

Multiprotocol label switching (MPLS)

- Initial goal: speed up IP forwarding by using fixed length label (instead of IP address) to do forwarding
  - borrowing ideas from Virtual Circuit (VC) approach
  - IP datagram still keeps IP address
  - RFC 3032 defines MPLS header
    - Label: has role of Virtual Circuit Identifier
    - Exp: experimental usage, may specify Class of Service (CoS)
    - S: Bottom of Stack - end of series of stacked headers
    - TTL: time to live



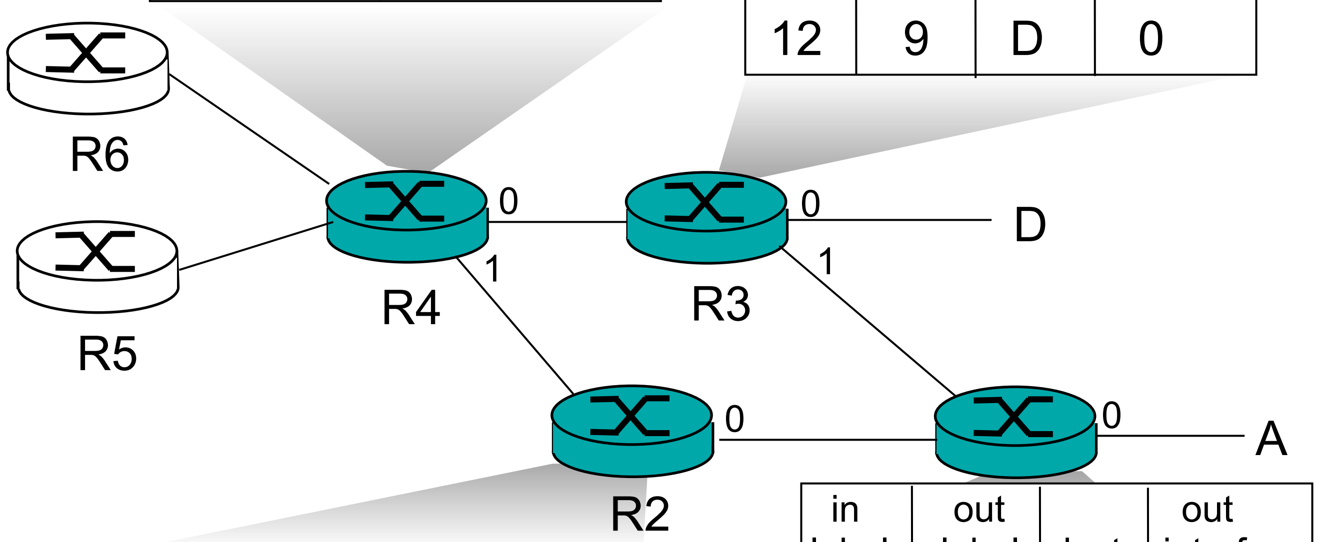
MPLS capable routers

- a.k.a. label-switched router
- forwards packets to outgoing interface based only on label value (don't inspect IP address)
  - MPLS forwarding table distinct from IP forwarding tables
- signaling protocol needed to set up forwarding
  - Label Distribution Protocol LDP
    (RFC 3036 → obsoleted by RFC 5036)
  - RSVP-TE (RFC 3209
    → updated by RFCs 3936, 4420, 4874, 5151, 5420, 5711)
- forwarding possible along paths that IP alone would not allow (e.g., source-specific routing)
- MPLS supports traffic engineering
- must co-exist with IP-only routers

MPLS forwarding tables

in label	out label	dest	out interface
	10	A	0
	12	D	0
	8	A	1

in label	out label	dest	out interface
10	6	A	1
12	9	D	0

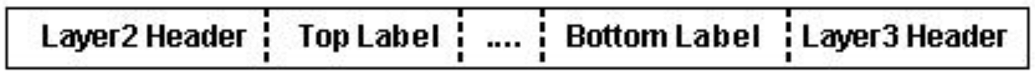


in label	out label	dest	out interface
8	6	A	0

in label	out label	dest	out interface
6	-	A	0

MPLS

- Label Switched Path (LSP)
  - set up by signalling protocol
  - has sequence of labels
- Forwarding Equivalence Class (FEC)
  - specification of packets treated the same way by a router
  - forwarded over same LSP
  - can be specified by destination prefix, e.g. FEC 10.1.1.0/24
- Label Switching Router
  - MPLS-capable IP router; may bind labels to FEC
- MPLS node
  - does not need IP stack
- stacked labels
  - label push; label pop

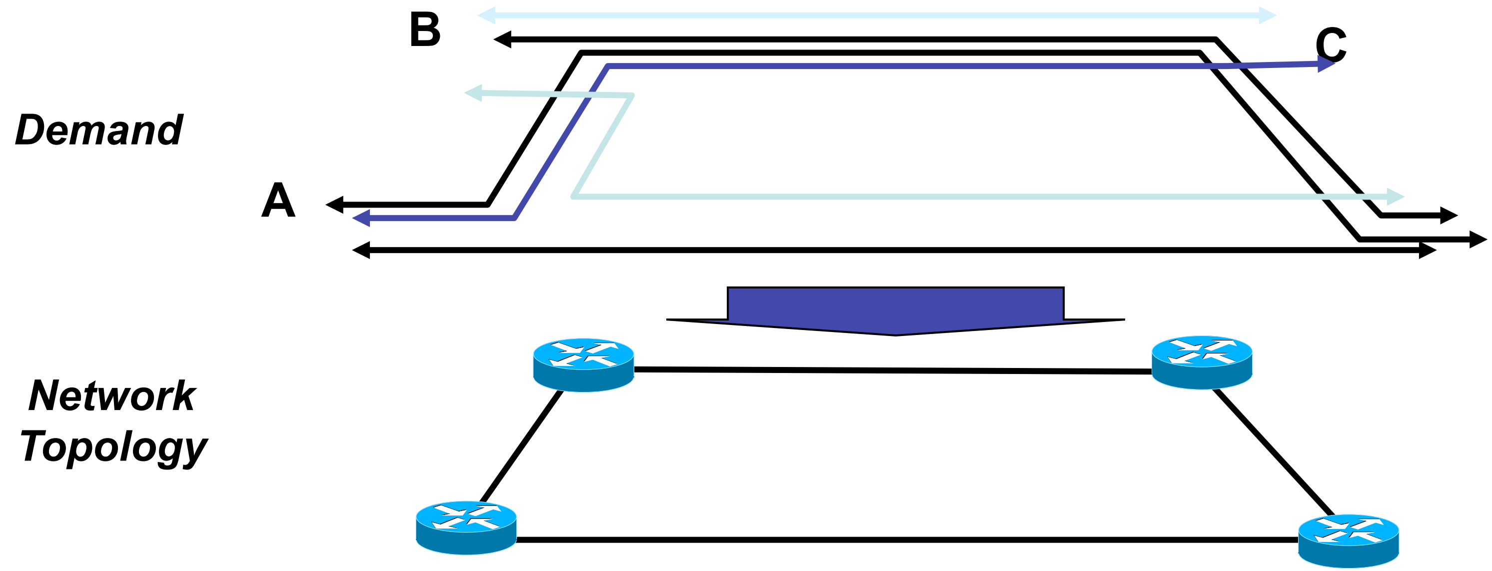


Benefits of MPLS

- High Speed Switching
  - facilitates construction of nodes with wire-line speed
- Simplifying packet forwarding
  - Routing decision can be limited to edge of AS
- Traffic Engineering
  - MPLS may control paths taken by different flows, e.g. to avoid congestion points for certain flows
- Quality of Service (QoS) support
  - resources may be specified for specific flows, isolation among flows
- Network scalability
  - label stacking allows to arrange MPLS domains in a hierarchy
- Supporting VPNs
  - tunneling of packets from an ingress point to an egress point

Traffic Engineering

- Traffic engineering: process of mapping traffic demand onto a network



- Purpose of traffic engineering:
  - Maximize utilization of links and nodes throughout the network
  - Engineer links to achieve required delay, grade-of-service
  - Spread network traffic across network links, reduce impact of failure
  - Ensure available spare link capacity for re-routing traffic on failure
  - Meet policy requirements imposed by the network operator

⇨ Traffic engineering key to optimizing cost/performance

Virtual Private Networks

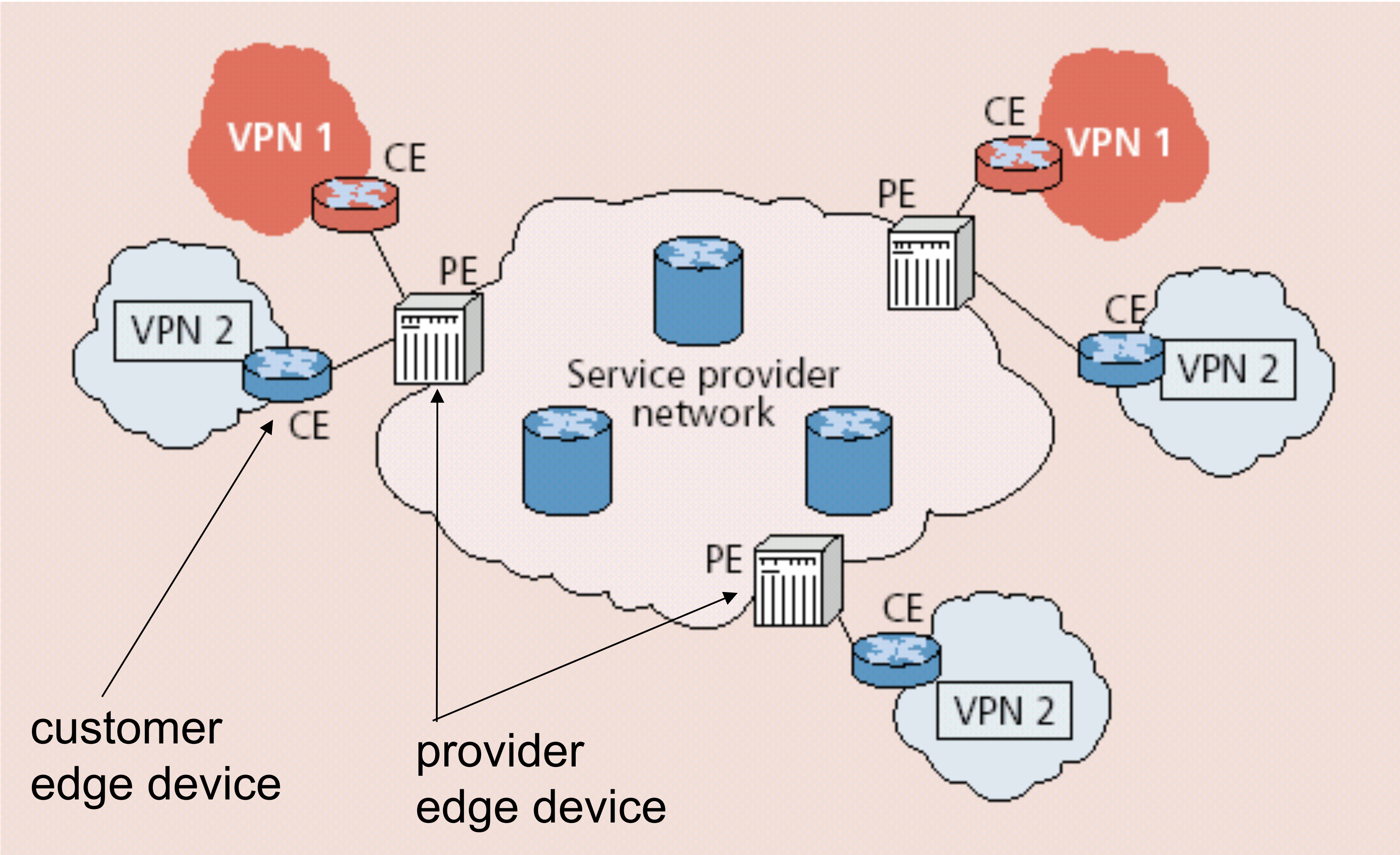
Virtual Private Networks (VPN)

VPNs

Networks perceived as being private networks by customers using them, but built over shared infrastructure owned by service provider (SP)

- Service provider infrastructure:
  - backbone
  - provider edge devices
- Customer:
  - customer edge devices
    (communicating over shared backbone)

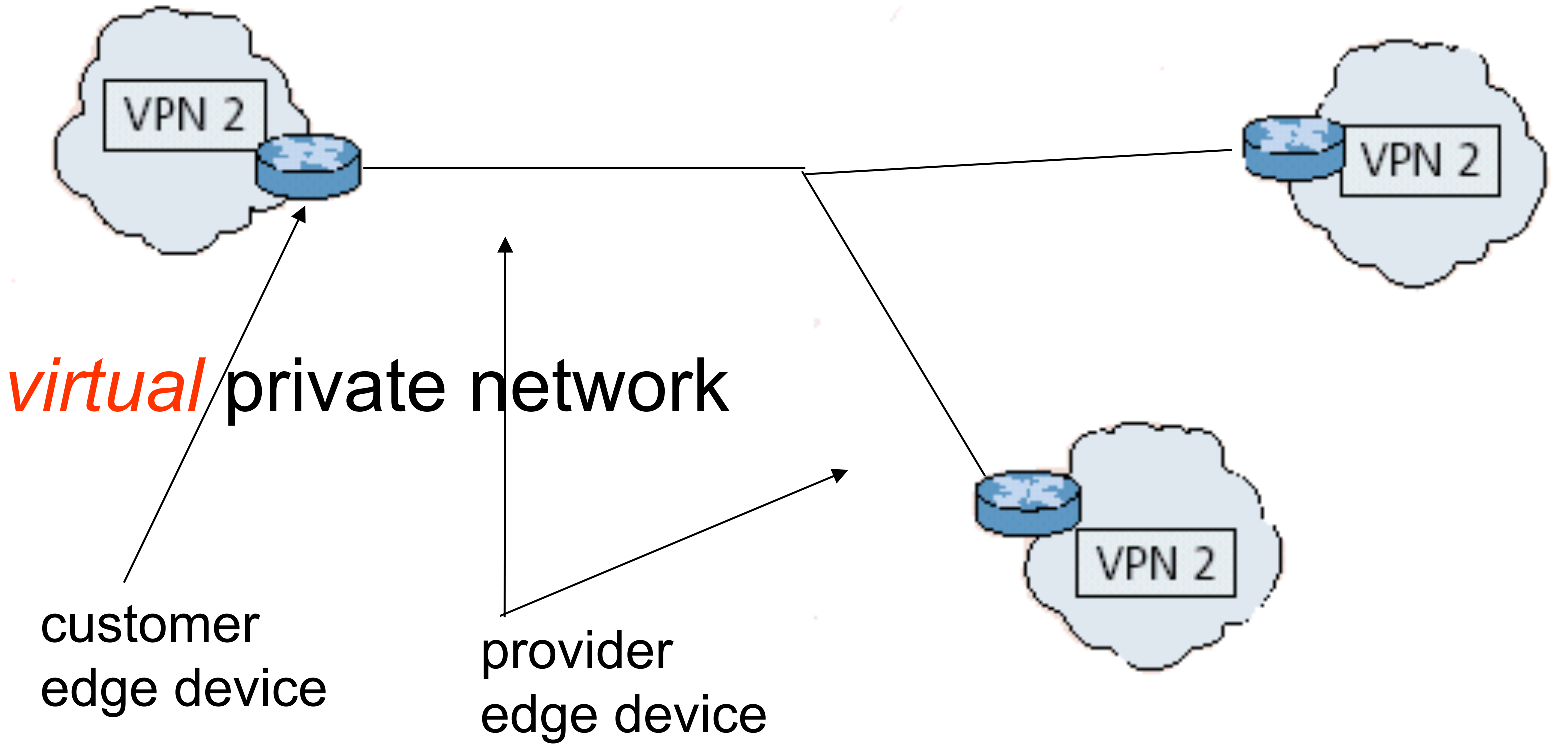
VPN Reference Architecture



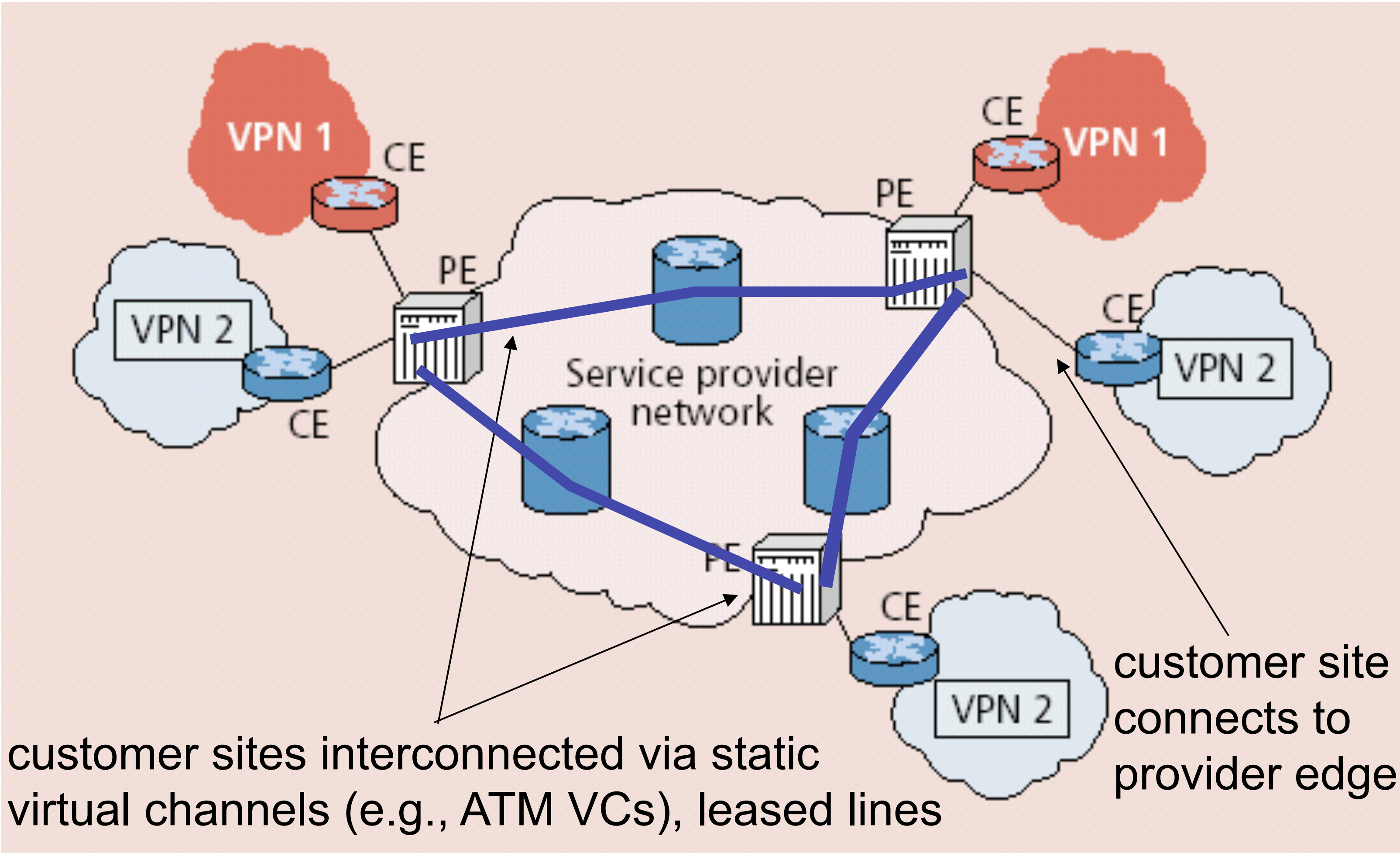
VPNs: Why?

- Privacy
- Security
- Works well with mobility (looks like you are always at home)
- Cost
  - many forms of newer VPNs are cheaper than leased line VPNs
  - ability to share at lower layers even though logically separate means lower cost
  - exploit multiple paths, redundancy, fault-recovery in lower layers
  - need isolation mechanisms to ensure resources shared appropriately
- Abstraction and manageability
  - all machines with addresses that are "in" are trusted no matter where they are

VPN: logical view

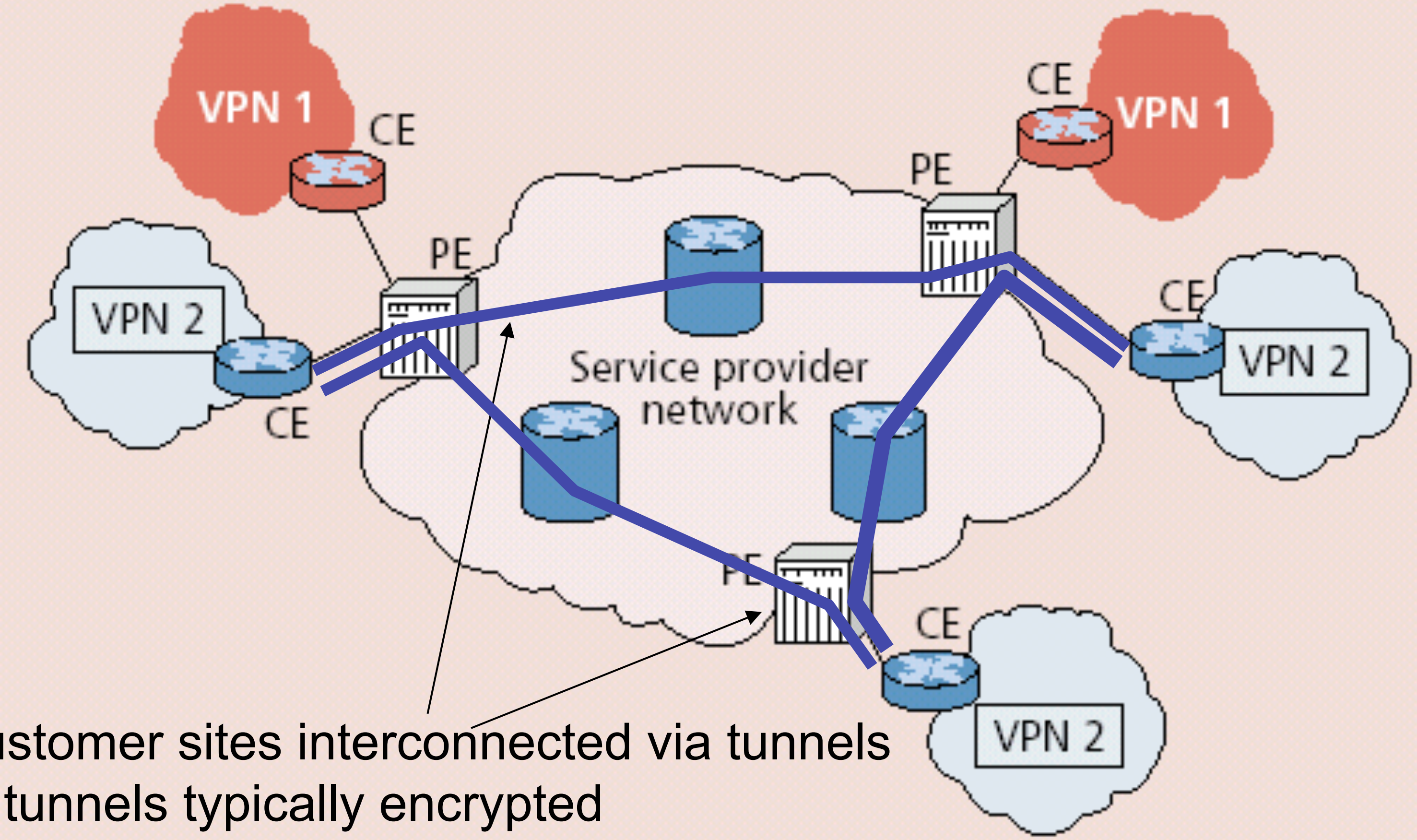


Leased-Line VPN



Customer Premise VPN

- all VPN functions implemented by customer



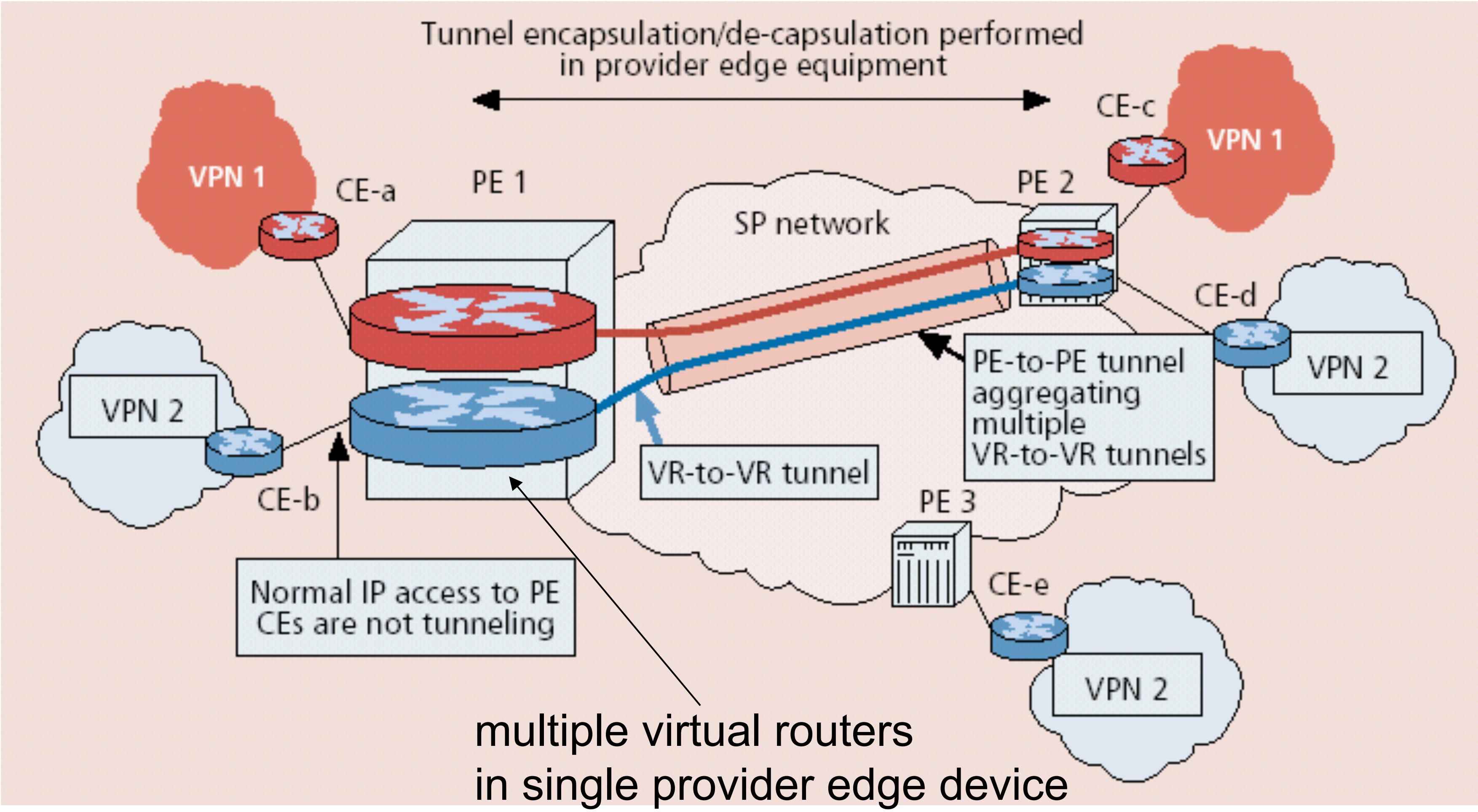
customer sites interconnected via tunnels

- tunnels typically encrypted
- Service provider treats VPN packets like all other packets

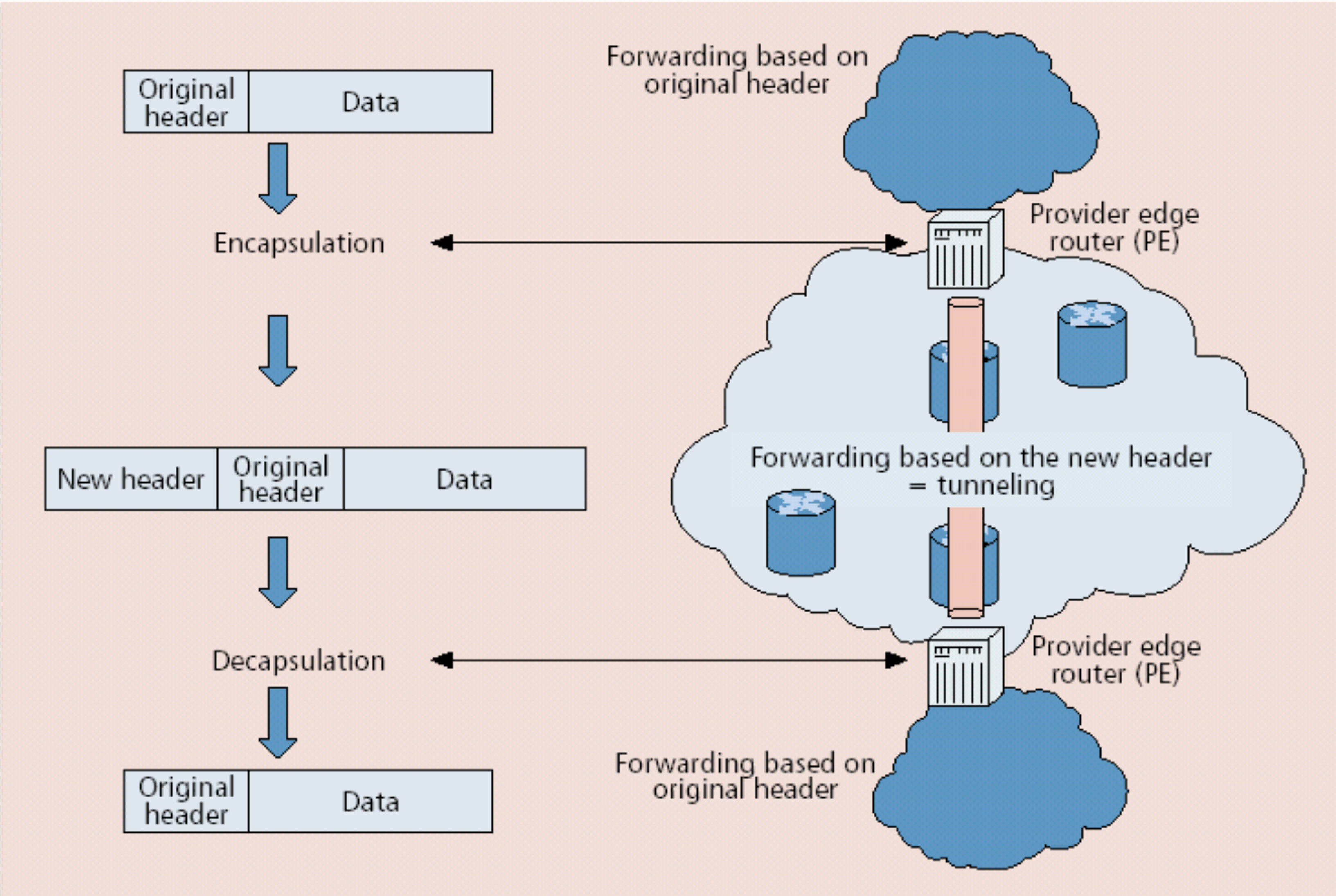
Variants of VPNs

- Leased-line VPN
  - configuration costs and maintenance by service provider: long time to set up, manpower
- CPE-based VPN
  - expertise by customer to acquire, configure, manage VPN
- Network-based VPN
  - Customer routers connect to service provider routers
  - Service provider routers maintain separate (independent) IP contexts for each VPN
    - sites can use private addressing
    - traffic from one VPN cannot be injected into another

Network-based Layer 3 VPNs



Tunneling



Original header
Data
Encapsulation
New header
Original header
Data
Decapsulation
Original header
Data
Forwarding based on original header
Provider edge router (PE)
Forwarding based on the new header = tunneling
Provider edge router (PE)
Forwarding based on original header

MPLS-based VPN