Chair for Network Architectures and Services – Prof. Carle
Department for Computer Science
TU München

Master Course Computer Networks IN2097

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Technische Universität München

Outline

- Project
- Network virtualisation:
  Link virtualization: MPLS

Project

- Grades
  - are given in svn
    grades.txt
- Forum
  - you find the forum in https://www.moodle.tum.de/
  - 2 Forums online
    - *Announcements*
      administered by teachers and used for announcements.
    - *Projects*
      for use to exchange project related information by students

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Network Architectures

Link virtualization:
MPLS - Multi-Protocol Label Switching

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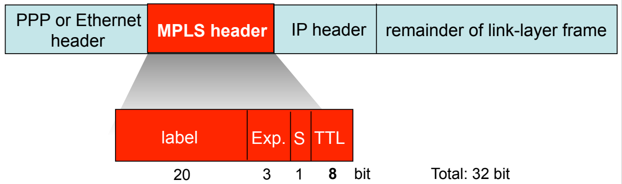
Multiprotocol label switching (MPLS)

- 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



Multiprotocol label switching (MPLS)

- RFC 3270: Le Faucheur, F., Wu, L., Davie, B., Davari, S., Vaananen, P., Krishnan, R., Cheval, P. and J. Heinanen, “Multi-Protocol Label Switching (MPLS) Support of Differentiated Services”, May 2002.
  - EXP: 3 bits - this field contains the value of the EXP field for the EXP<->PHB (Per-Hop-Behaviour) mapping
  - Mapping transported via signaling protocol
- RFC 3140: Black, D., Brim, S., Carpenter, B. and F. Le Faucheur, "Per Hop Behavior Identification Codes", June 2001.
    - Case 1: PHBs defined by standards action, as per [RFC 2474]. PHB is recommended 6-bit DSCP value for that PHB, left-justified in a 16 bit field, with bits 6 through 15 set to zero.
    - Case 2: PHBs not defined by standards action, i.e., experimental or local use PHBs In this case an arbitrary 12 bit PHB-ID is placed left-justified in the a bit field. Bit 15 is set to 1, Bits 12 and 13 are zero.

MPLS TTL Processing

c.f. RFC 3032 - MPLS Label Stack Encoding

- Protocol-independent rules
  - "outgoing TTL" of a labeled packet is either a) one less than the incoming TTL, or b) zero.
  - Packets with TTL=0 are discarded
- IP-dependent rules
  - When an IP packet is first labeled, the TTL field of the label stack is set to the value of the IP TTL field.
  - If the IP TTL field needs to be decremented, as part of the IP processing, it is assumed that this has already been done.
  - When a label is popped, and the resulting label stack is empty, then the value of the IP TTL field SHOULD BE replaced with the outgoing MPLS TTL value.
  - A network administration may prefer to decrement the IPv4 TTL by one as it traverses an MPLS domain.

ICMP

- When a router receives an IP datagram that it can’t forward, it sends an ICMP message to the datagram’s originator
- The ICMP message indicates why the datagram couldn’t be delivered
  - E.g., Time Expired, Destination Unreachable
- The ICMP message also contains the IP header and at least leading 8 octets of the original datagram
  - RFC 1812 - Requirements for IP Version 4 Routers extends this to “as many bytes as possible”
  - Historically, every ICMP error message has included the Internet header and at least
  - Including only the first 8 data bytes of the datagram that triggered the error is no longer adequate, due to use e.g. of IP-in-IP tunneling

ICMP in presence of MPLS

- When an LSR receives an MPLS encapsulated datagram that it can't deliver
  - It removes entire MPLS labels stack
  - It sends an ICMP message to datagram's originator
- The ICMP message indicates why the datagram couldn't be delivered (e.g., time expired, destination unreachable)
- The ICMP message also contains the IP header and leading 8 octets of the original datagram
  - RFC 1812 extends this to "as many bytes as possible"

ICMP in Presence of MPLS

Issue

- The ICMP message contains no information regarding the MPLS stack that encapsulated the datagram when it arrived at the LSR
- This is a significant omission because:
  - The LSR tried to forward the datagram based upon that label stack
  - Resulting ICMP message may be confusing

Why?

ICMP in Presence of MPLS

Issue

- ICMP Destination Unreachable
  - Message contains IP header of original datagram
  - Router sending ICMP message has an IP route to the original datagram's destination
  - Original datagram couldn't be delivered because MPLS forwarding path was broken
- ICMP Time Expired
  - Message contains IP header of original datagram
  - TTL value in IP header is greater than 1
  - TTL expired on MPLS header. ICMP Message contains IP header of original datagram

ICMP with MPLS

c.f. RFC 4950 - ICMP Extensions for Multiprotocol Label Switching

- defines an ICMP extension object that permits an LSR to append MPLS information to ICMP messages.
- ICMP messages include the MPLS label stack, as it arrived at the router that is sending the ICMP message.
- equally applicable to ICMPv4 [RFC792] and ICMPv6 [RFC4443]
- sample output from an enhanced TRACEROUTE:

```
> traceroute 192.0.2.1
traceroute to 192.0.2.1 (192.0.2.1), 30 hops max, 40 byte packets
1 192.0.2.13 (192.0.2.13) 0.661 ms 0.618 ms 0.579 ms
2 192.0.2.9 (192.0.2.9) 0.861 ms 0.718 ms 0.679 ms
   MPLS Label=100048 Exp=0 TTL=1 S=1
3 192.0.2.5 (192.0.2.5) 0.822 ms 0.731 ms 0.708 ms
   MPLS Label=100016 Exp=0 TTL=1 S=1
4 192.0.2.1 (192.0.2.1) 0.961 ms 8.676 ms 0.875 ms
```

- MPLS Label Stack Object: can be appended to ICMP Time Exceeded and Destination Unreachable messages.

```
       0                   1                   2                   3
+-------------+-------------+-------------+-------------+
|                    Label               |EXP |S|      TTL     |
+-------------+-------------+-------------+-------------+
|                                                               |
|            // Remaining MPLS Label Stack Entries //           |
|                                                               |
+-------------+-------------+-------------+-------------+
```

- Must be preceded by an ICMP Extension Structure Header and an ICMP Object Header, defined in [RFC4884].

Multi-Part ICMP Messages - RFC 4884

- ICMP Extension Structure may be appended to ICMP v4 / v6 Destination Unreachable and Time Exceeded messages
- ICMP Extension Structure Header

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version|      (Reserved)           |           Checksum            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

ICMP extension version number: 2

- ICMP Object Header and Object Payload

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Length            |   Class-Num   |   C-Type      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   // (Object Payload) //                      |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```


MPLS for Linux

The work of James Leu:
https://sourceforge.net/projects/mpls-linux/
Discussions:
http://sourceforge.net/mailarchive/forum.php?forum_name=mpls-linux-devel
Bug fixes of Jorge Boncompte:
http://mpls-linux.git.sourceforge.net/git/gitweb.cgi?p=mpls-linux/net-next;a=shortlog;h=refs/heads/net-next-mpls
Additional bug fixes by Igor Maravić:
https://github.com/i-maravic/MPLS-Linux
https://github.com/i-maravic/iproute2

MPLS for Linux Labs
by Irina Dumitrascu and Adrian Popa: graduation project with purpose of teaching MPLS to university students, at Limburg Catholic University College
http://ontwerpen1.khlim.be/~lrutten/cursussen/comm2/mpls-linux-docs/
inlcudes e.g. Layer 2 VPN with MPLS, Layer 3 VPN with MPLS

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Virtual Private Networks

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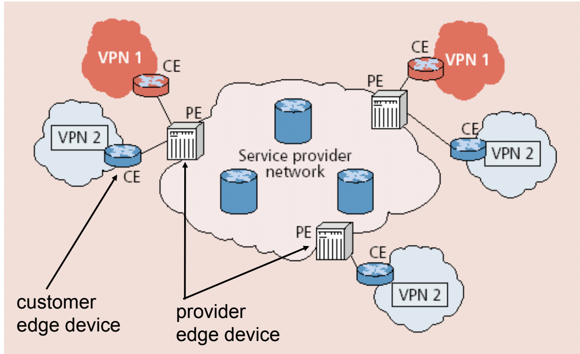
Virtual Private Networks (VPN)

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)

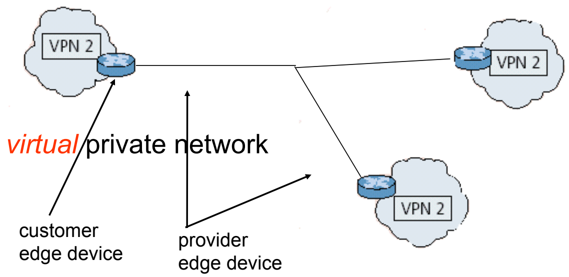
VPN Reference Architecture



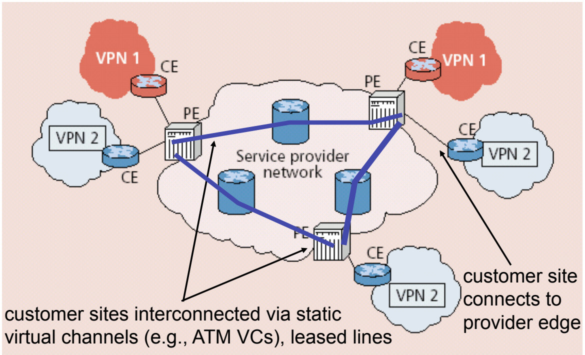
VPNs: Why?

- 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

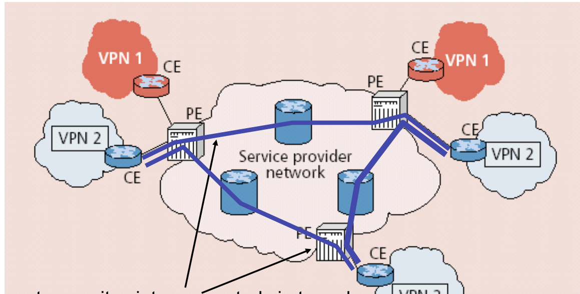


Leased-Line VPN



Customer Premise VPN

- all VPN functions implemented by customer

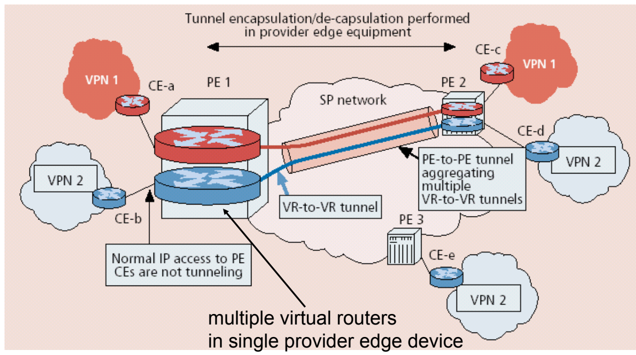


customer sites interconnected via tunnels
- tunnels typically encrypted
- Service provider treats VPN packets like all other packets

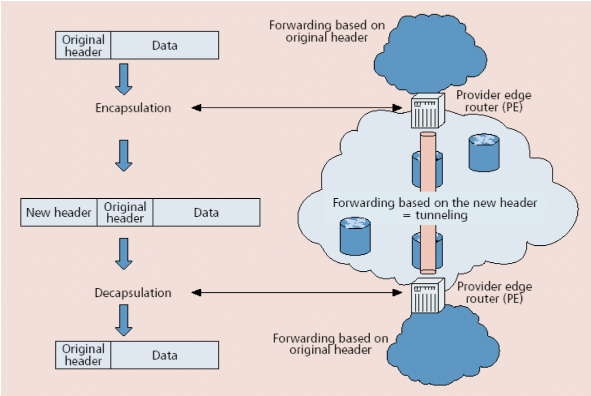
Variants of VPNs

- 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

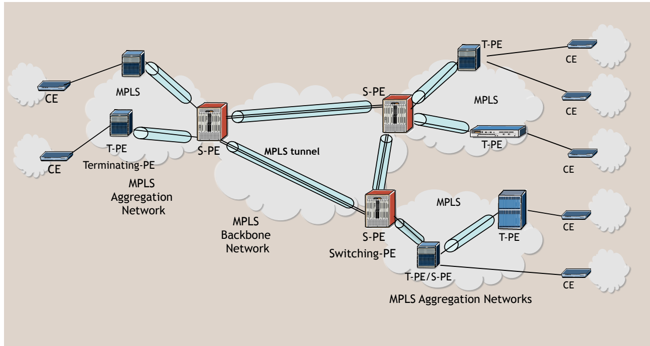
Network-based Layer 3 VPNs



Tunneling



MPLS-based VPN



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Thank you

for your attention!

Your Questions?

Questions

- Why is circuit switching expensive?
- Why is packet switching cheap?
- Is best effort packet switching able to carry voice communication?
- What happens if we introduce "better than best effort" service?
- How can we charge fairly for Internet services: by time, by volume, or flat?
- Who owns the Internet?
- You've invented a new protocol. What do you do?
- How does the Internet grow? Exponentially? What is the growth perspective?

Tunneling and Overlay

Benefits

- Allows bootstrapping and incremental deployment of innovative protocols and mechanisms
- Many new networks have begun as overlay networks
- Innovations do not have to be deployed at every node

Costs

- Overhead
  - Additional layer: additional header + processing
- Complexity
  - possible unintended interactions between layers

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Packet Switch Architectures

An overview of router architectures

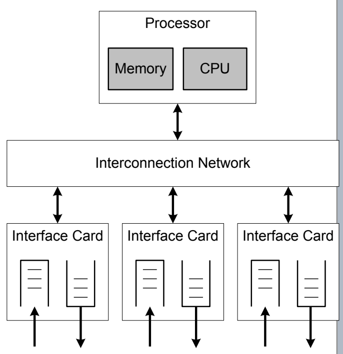
Introduction

What is a Packet Switch?

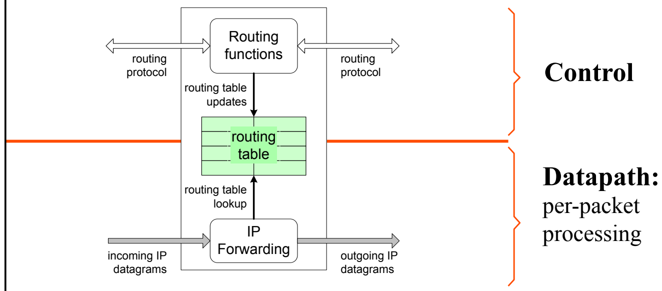
- Basic Architectural Components of an IP Router
- Example Packet Switches

Router Components

- Hardware components of a router:
  - Network interfaces
  - Interconnection network
  - Processor with a memory and CPU
- **PC router:**
  - interconnection network is the (PCI) bus and interface cards are NICs
  - All forwarding and routing is done on central processor
- **Commercial routers:**
  - Interconnection network and interface cards are sophisticated
  - Processor is only responsible for control functions **(route processor)**
  - Almost all forwarding is done on interface cards



Functional Components



Routing and Forwarding

Routing functions include:

- route calculation
- maintenance of the routing table
- execution of routing protocols

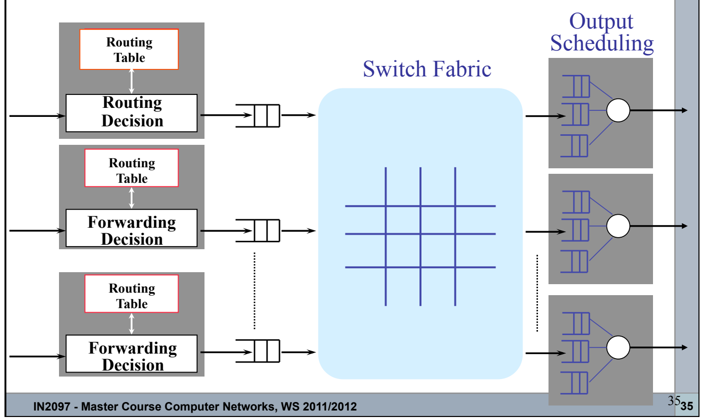
- On commercial routers handled by a single general purpose processor, called *route processor*

IP forwarding is per-packet processing

- On high-end commercial routers, IP forwarding is distributed
- Most work is done on the interface cards

Basic Architectural Components

Per-packet processing



IP Router

- Lookup packet destination address in forwarding table.
  - If known, forward to correct port.
  - If unknown, drop packet.
- Decrement TTL, update header checksum.
- Forward packet to outgoing interface.
- Transmit packet onto link.

ATM Switch

- Look up VCI/VPI of cell in VC table.
- Replace old VCI/VPI with new.
- Forward cell to outgoing interface.
- Transmit cell onto link.

Ethernet Switch

- Lookup frame destination address in forwarding table.
  - If known, forward to correct port.
  - If unknown, broadcast to all ports.
- Learn source address of incoming frame.
- Forward frame to outgoing interface.
- Transmit frame onto link.

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