ALBERT-LUDWIGS-UNIVERSITÄT FREIBURG

# Communication Systems

## IPv6

University of Freiburg
Computer Science
Computer Networks and Telematics
Prof. Christian Schindelhauer

CoNe Freiburg

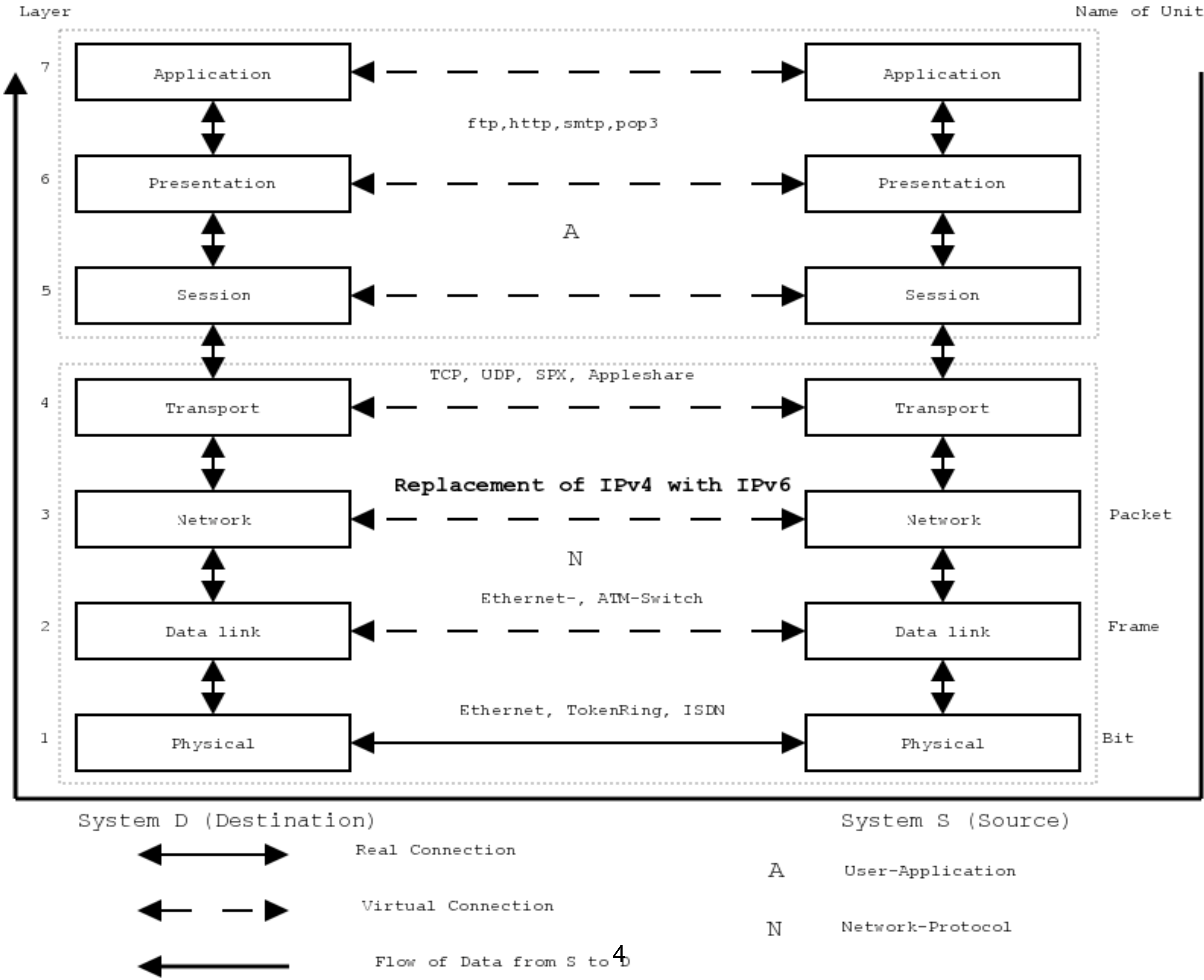
IIF
INSTITUT FÜR INFORMATIK FREIBURG

# Network Layer from IPv4 to IPv6

- Staying on the third layer but exchange the protocol
  - Introduction to future IP
  - The IP v6 address
  - IP v6 header and extension headers
  - IP v6 fragmentation
- Packet routing was one of the driving forces to switch

# Introduction to Future IP

- IP version 6 (IP v6 – around July 1994)
- Normally we start with the reasons to switch from a very successful implementation to a new one
  - rapid, exponential growth of networked computers
  - shortage (limit) of the addresses
  - new requirements towards the Internet infrastructure (streaming, real-time services like VoIP, video on demand)
- IP v6 is designed to be an evolutionary step from IP v4. It can be installed as a normal software upgrade in Internet devices and is interoperable with the current IP v4
- Next slide: OSI – IP v6 just replaces IP v4 on network layer ...


Layer
Name of Unit
7
Application
Application
ftp,http,smtp,pop3
6
Presentation
Presentation
A
5
Session
Session
TCP, UDP, SPX, Appleshare
4
Transport
Transport
Replacement of IPv4 with IPv6
3
Network
Network
Packet
N
Ethernet-, ATM-Switch
2
Data link
Data link
Frame
Ethernet, TokenRing, ISDN
1
Physical
Physical
Bit
System D (Destination)
System S (Source)
Real Connection
Virtual Connection
Flow of Data from S to D
A
User-Application
N
Network-Protocol

# Problems with IPv4

- Current version of IP - version 4 - is 25+ years old (rather old in the computer world)
  - 32 bits address range is too small (less max. number of addresses than inhabitants of earth, without counting the loss of addresses because of rather generous assignments)
  - routing is inefficient (long routing tables, problems with aggregation)
  - bad support for mobile (roaming) devices
  - security needs grew
- But some of the problems are of the late nineties and mostly solved or not as important any more ... thus postponed the switch over to the new scheme

# Capabilities of IP

- IP has accommodated dramatic changes since original design
  - Basic principles still appropriate today
  - Many new types of hardware
  - Scale of Internet and interconnected computers in private LAN
- Scaling
  - Size - from a few tens to a few tens of millions of computers
  - Speed - from 9,6Kbps over GSM mobile phone networks to 10Gbps over Ethernet or frame delay WAN connections
  - Increased frame size (MTU) in hardware

# Introduction to Future IP – Why IPv6?

- IETF has proposed entirely new version to address some specific problems
- Address space
  - But...most are Class C and too small for many organizations
  - 214 Class B network addresses already almost exhausted (and exhaustion was first predicted to occur a couple of years ago)
  - Lot of waste within the address space (whole class A network for just the loopback device, no nets starting with 0 and 255)
  - No geographic orientation within IP number assignment
  - Next generation mobile phone networks may switch over their addressing scheme

# Introduction to Future IP – Address Exhaustion

- Address space exhaustion (main argument for IP v6)
  - Even with the excessive use of private networks, CIDR of the old Class-A networks, ...
  - Inefficient routing (very long routing tables)
  - Think of many households getting connected to the internet, new services and new devices with demand toward addressability over an Internet
  - Rise of continents beside Northern America and Europe with bigger population than the “new world” and “old europe”
  - Around 2010 to 2015 (according to forecasts) the address space is exhausted

# Introduction to Future IP – Further Reasons

- Type of service
  - Different applications have different requirements for delivery reliability and speed
  - Current IP has type of service that's not often implemented
  - Helper protocols for multimedia QoS seldom used
  - QoS routing only works hop-by-hop
  - More on QoS in later lectures
- Multicast
  - Experimental only within IP v4, not really used in production
  - Waste of IP numbers from 224.0.0.0 up to 254.255.255.255 for just experimental use

# Introduction to Future IP – Addresses

- $2^{128}$ is around 3.4 $10^{38}$ possible IP addresses
  - 6.4 $10^{28}$ for every human on earth
  - 6.6 $10^{14}$ for every square millimeter on earth (sea, continents and ice caps)
  - Opens lots of space for waste
- IP v6 16 byte long addresses
- So classical representation as we know it, e.g. 132.230.4.44 (4 byte IP v4 address) would not really be human readable

# Introduction to Future IP – Address Format

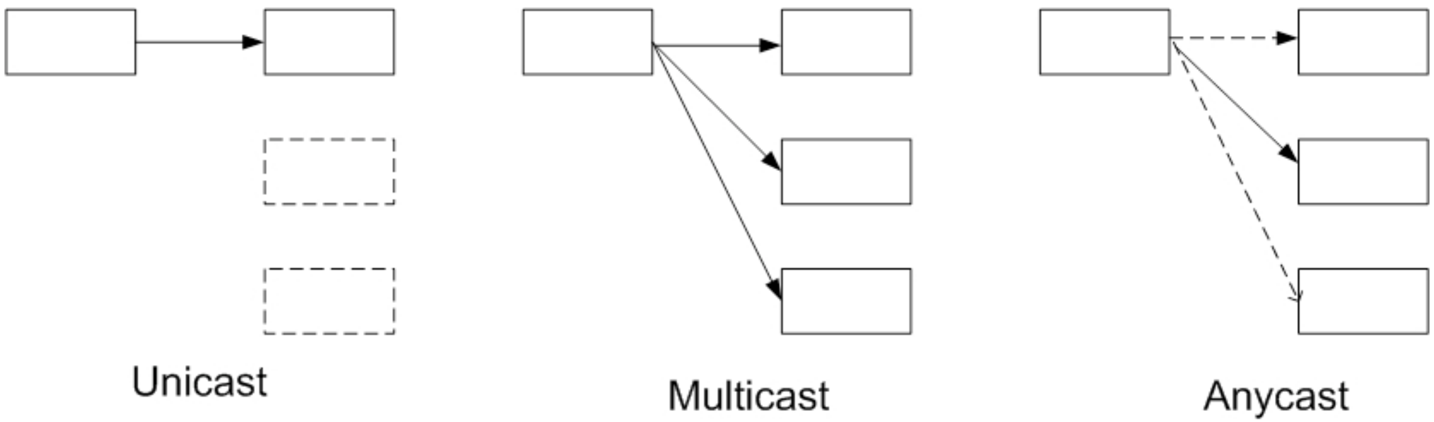
- IP v6 addresses are given in hexadecimal notation, with 2 bytes grouped together as known from ethernet MAC addresses
- Example:
  - 2822:0000:0000:0000:0000:0005:EBD2:7008
  - 2001:: (GEANT address prefix)
  - 2001:07C0:0100::/48 (BelWue address prefix)
  - 2001:07C0:0100::/64 (Freiburg university address prefix)
- Try to write that address in dotted quad notation, so ...
- Domain Name System becomes even more important
- For better handling compression is introduced

# Introduction to Future IP – Address Format

- Compression is achieved by
  - Replace groups of zeros by a second colon directly following the first
  - Delete leading zeros in each double byte
- The address
  - 0000:0000:0000:0000:00A5:B8C1:009C:0018 is reduced to
  - ::A5:B6C1:9C:18
  - 1000:0000:0000:0000:20A5:B8C1:0001:00A3 could be compressed
  - 1000:0:0:0:20A5:B8C1:1:A3 and finally 1000::20A5:B8C1:1:A3

# IP v6 – Address Types

- IP v6 knows three types of addresses
  - Classical unicast address
  - Multicast address
  - New type of address: anycast or cluster



# IP v6 – Address Composition

- Addresses are split into prefix and suffix as known from IPv4
- No address classes - prefix/suffix boundary can fall anywhere
- IPv4 broadcast flavors are subsets of multicast
- Unicast addresses are distinguishable by their format prefix
- The new aggregatable global address format splits address into
  - Global, public part
  - Location specific part
  - End system identificator

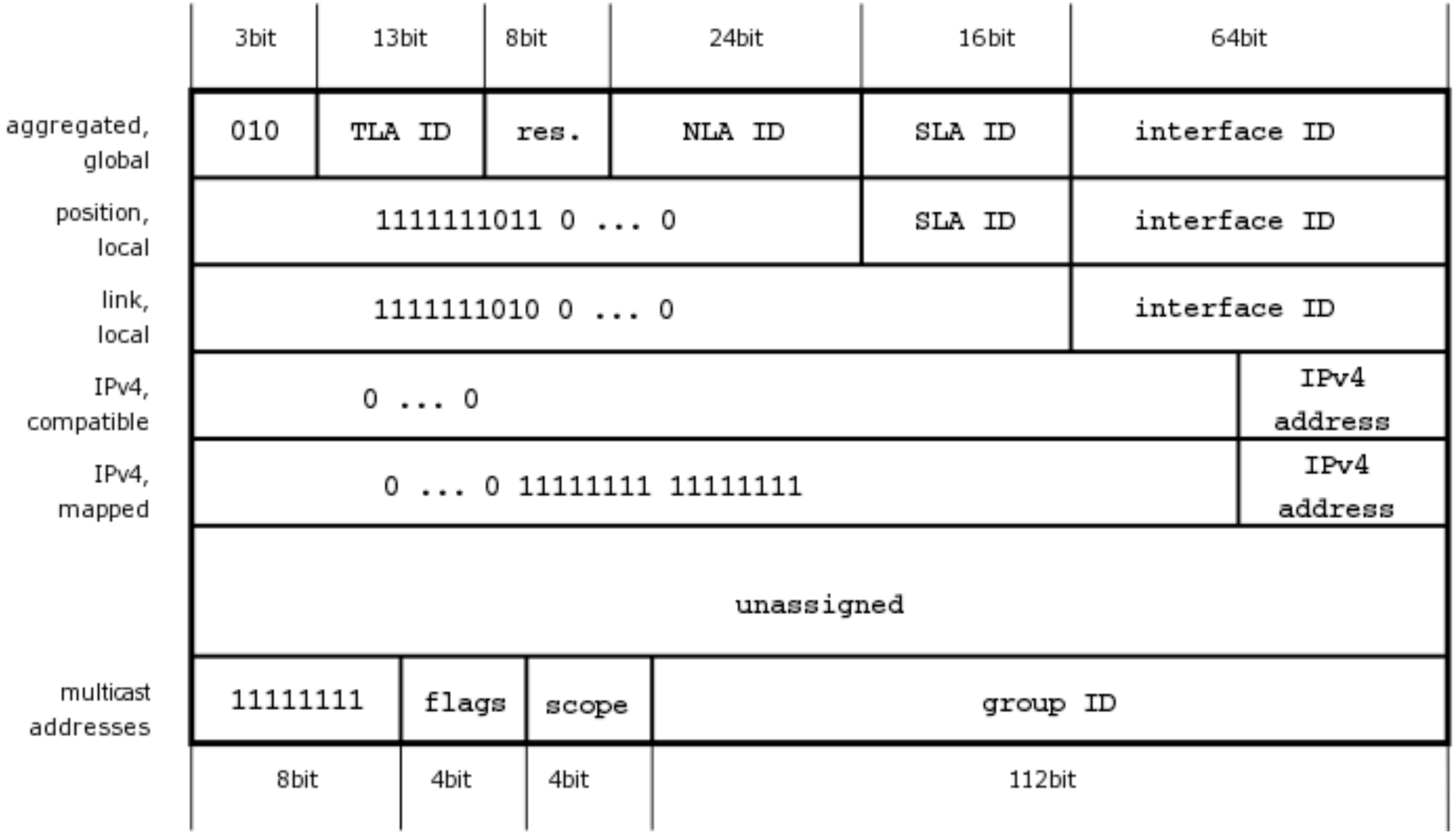
# IP v6 – Address Composition

- Addresses split into prefix and suffix as known from IP v4
- Unicast addresses are distinguishable by their format prefix
- The new aggregatable global address format splits address into
  - Global, public part
  - Location specific part
  - End system identificator
- Global part consists of prefix, Top Level Aggregator (TLA) and Next Level Aggregator (NLA)
- Describes a site (group of machines) within the global internet

# IP v6 – Address Composition

- TLA are only available for service providers who provide internet transit services, e.g. GEANT (2001::)
- NLAs for smaller service providers / organizations / firms which use a TLA provider, e.g. BelWue (2001:07C0:0100::)
- NLA could be split in several hierarchy layers
- Location specific part of the address the Site Level Aggregator (SLA) describes subnet structure of a site and the interface ID of connected hosts
- Interface ID consists of 64bit and can contain the MAC address of the interface card for global uniqueness

# IP v6 – Address Space Assignment



# IP v6 – Address Space Assignment

- Link local addresses – contain beside the prefix only the interface ID
- Used for automatic configuration or used in networks without router
- Position local addresses used for sites which are not connected to the IP v6 network (aka Internet) yet
- The prefix is interchanged with the provider addresses (TLA, NLA) in case of connection to the net
- Anycast – new type of address, introduced with IP v6

# IP v6 – Address Space Assignment

- Special addresses:
  - Loopback: 0:0:0:0:0:0:0:1 = ::1
  - for use in tunnels: 0::FFFF:a.b.c.d
    - 139.18.38.71 (IP v4)
      = ::FFFF:139.18.38.71 (IPv6)
      = ::FFFF:8b12:2647 (IP v6)
  - IP v4-compatible-addresses ::a.b.c.d
    = 0.0.0.0.0.0.139.18.38.71
  - Link local
    - Interface address auto assignment (like 169.254.X.Y)
    - Start with FE80:: local MAC is last part

# IP v6 – Anycast Addresses

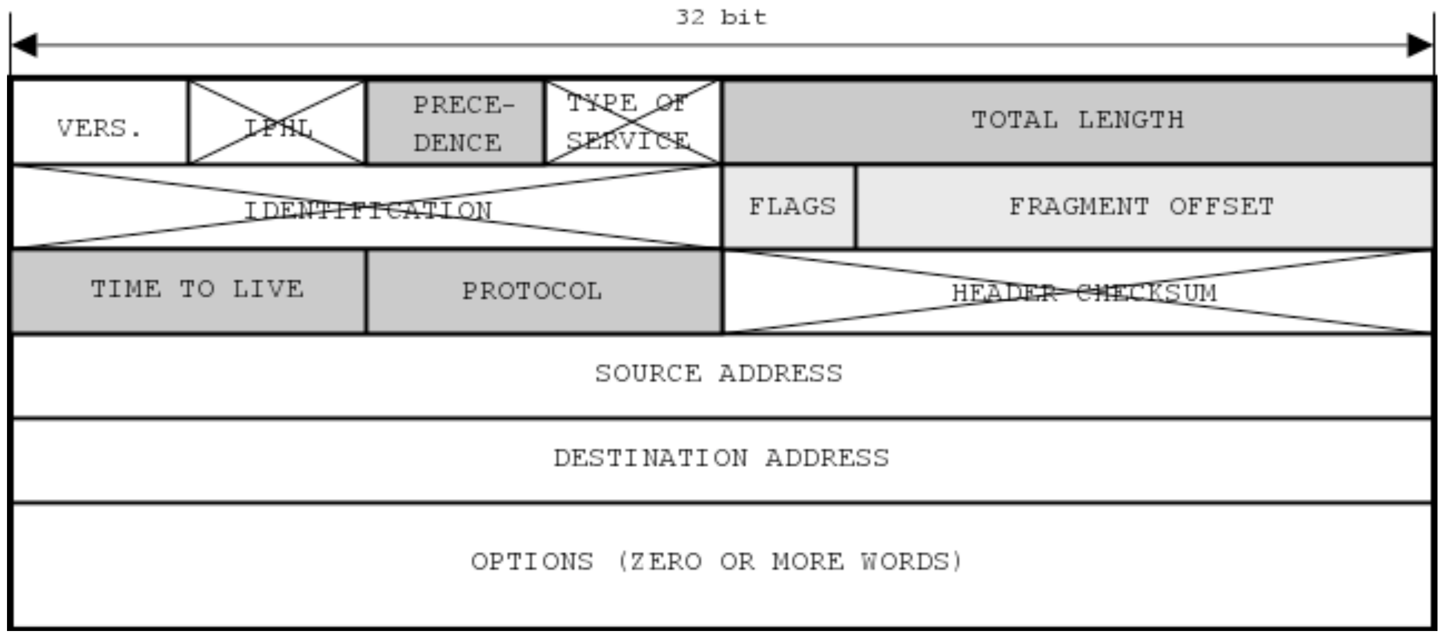
- Type of address used for number of interfaces connected to different end systems
- An anycast packet is routed to the next interface of that group
- Anycast addresses are allocated within unicast address space
- Idea: route packets over a subnet of a specific provider
- Cluster / anycast addressing allows for duplication of services
- Implementation: do not use them as source address and identify only routers with them

# IP v6 – Multicast Addresses

- Now fixed part of the specification
- One sender could generate packets which are routed to a number of hosts throughout the net
- Multicast addresses consists of a prefix (11111111), flag and scope field and group ID
- Flag for marking group as transient or permanent (registered with IANA)
- Scope defines the coverage of address (subnet, link, location or global)

# IP v6 – Header Format

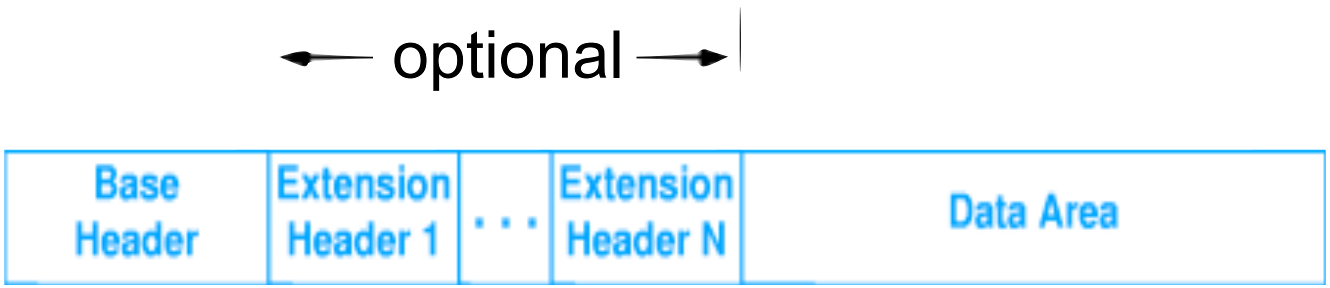
- Some important changes within header format – faster processing within routers
- Header length, type of service and header checksum were removed



# IP v6 – Header Format

- Other header parts moved to so called extension headers (light gray)
- IP v6 header contains less information than IP v4 header
- Less header information for routing speed up and avoiding of duplication of standard information

Other header parts moved to so called extension headers (light gray)
IP v6 header contains less information than IP v4 header
Less header information for routing speed up and avoiding of duplication of standard information

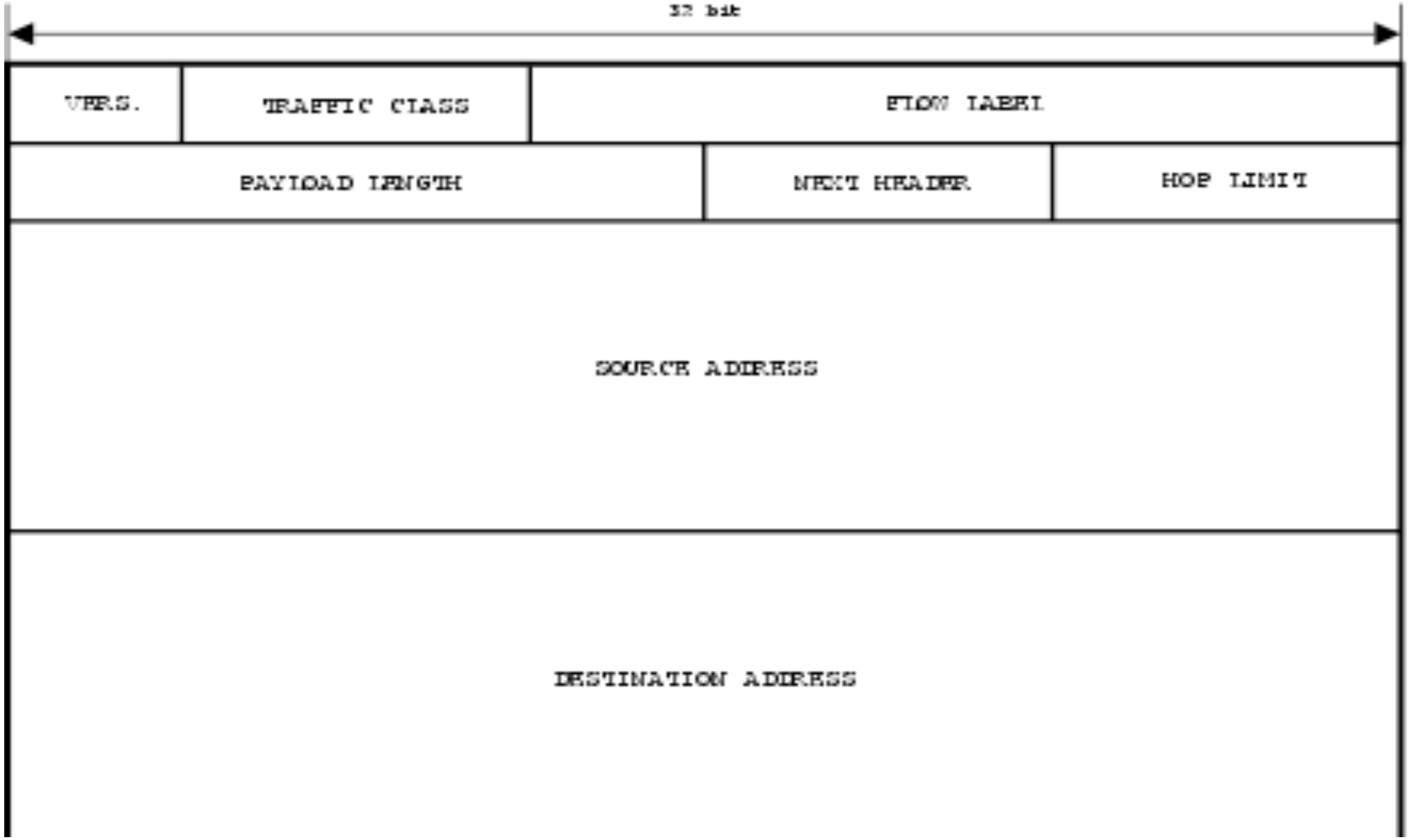


# IP v6 – Header Format

- Concept of on-the-way packet fragmentation dropped
  - Slow down of routers
  - Reassembly was possible at destination only
- Fragmentation is done by source and destination only (explained later this lecture)
- If packet is too big for transit intermediate routers send special “packet too big” ICMP message
  - Minimum MTU in IPv4 was 576 for IPv6 1280 Byte
  - Host has to do MTU path discovery
- No header checksum – left to UDP/TCP or layer 2 protocols, like Ethernet

# IP v6 – Header Fields

- Precedence, total length, time to live and protocol are replaced with traffic class, payload length, hop limit and next header (type)



# IP v6 – Header Fields

- NEXT HEADER points to first extension header
- FLOW LABEL used to associate datagrams belonging to a flow or communication between two applications
  - Traffic class for Quality of Service routing
  - Specific path
  - Routers use FLOW LABEL to forward datagrams along prearranged path
- Base header is fixed size (other than IP v4) - 40 octets
- NEXT HEADER field in base header defines type of header

# IP v6 – Header Fields – Traffic Classes

- 000-111 = time insensitive (could be discarded)
- 1000-1111 = priority (should not be discarded)
- 0 = uncharacterized
- 1 = filler (net news)
- 2 = unattended transfer (mail)
- 4 = bulk (ftp)
- 6 = interactive (telnet)
- 7 = Internet control
- 8 = video
- 15 = low quality audio

# IP v6 – Extension Headers

- All optional information moved to extension headers
- Put in between IP v6 header and payload header (e.g. TCP header)
- Extension headers (mostly) not interpreted by routers
- Each header is tagged with special mark
  - Hop-by-hop options
  - Destination options header
  - Routing header
  - Fragment header
  - Authentication header

# IP v6 – Extension Headers

  - Encapsulated security payload header
  - Destination options header
  - Next header: transportation (TCP, UDP, ...)
- Extension headers have task specific format
- Each header is of multiple of 8 byte
- Some extensions headers are variable sized
  - NEXT HEADER field in extension header defines type
  - HEADER LEN field gives size of extension header

# IP v6 – Extension Headers

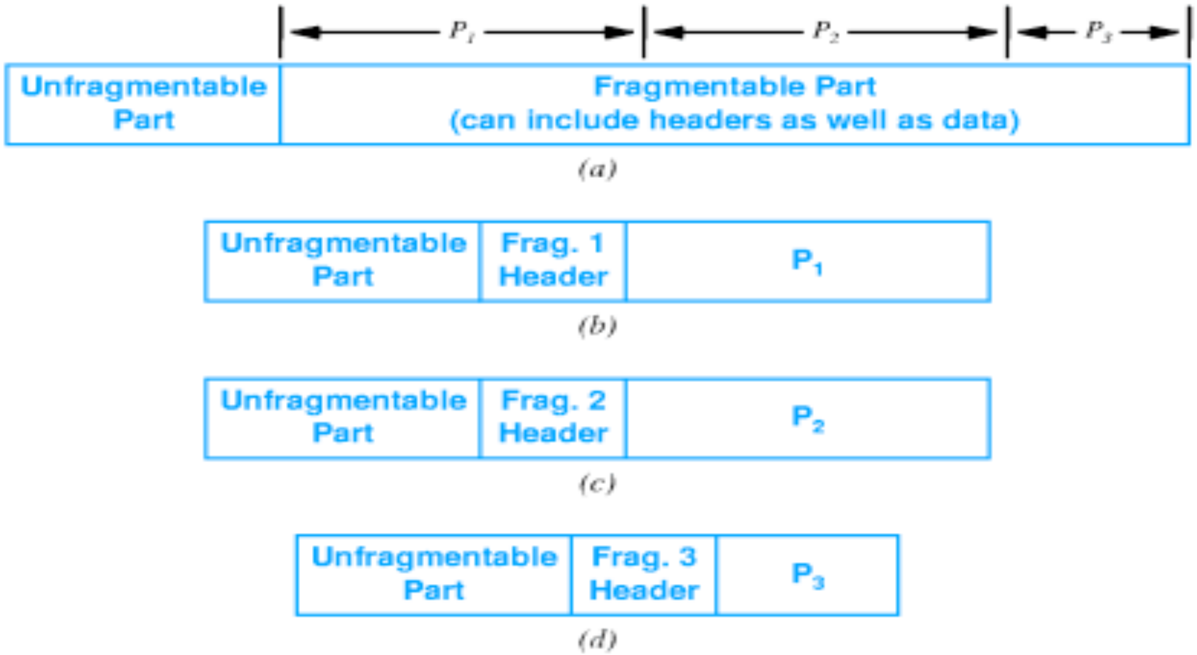
- Special hop-by-hop option is header for so called jumbograms
- Normal packet length is 65535 byte - but can be extended with jumbo payload length of a 4 byte length indicator
- But problems with UDP and TCP specification
  - UDP contains 16bit packet length field
  - TCP contains MSS (max. segment size) field set with the start of every TCP connection, could be omitted but then problems with urgent pointer

# IP v6 – Extension Headers

- Use of multiple headers:
- Efficiency - header only as large as necessary
- Flexibility - can add new headers for new features
- Incremental development - can add processing for new features to testbed; other routers will skip those headers
- Conclusion: streamlined 40 byte IP header
  - Size is fixed
  - Information is reduced and mostly fixed
  - Allows much faster processing

# IP v6 – New Concept of Fragmentation

- Fragmentation information kept in separate extension header
- Each fragment has base header and (inserted) fragmentation header



# IP v6 – New Concept of Fragmentation

- Entire datagram, including original header may be fragmented
- IPv6 source (not intermediate routers) responsible for fragmentation
  - Routers simply drop datagrams larger than network MTU
  - Source must fragment datagram to reach destination
- Source determines path MTU
  - Smallest MTU on any network between source and destination
  - Fragments datagram to fit within that MTU

# IP v6 – New Concept of Fragmentation

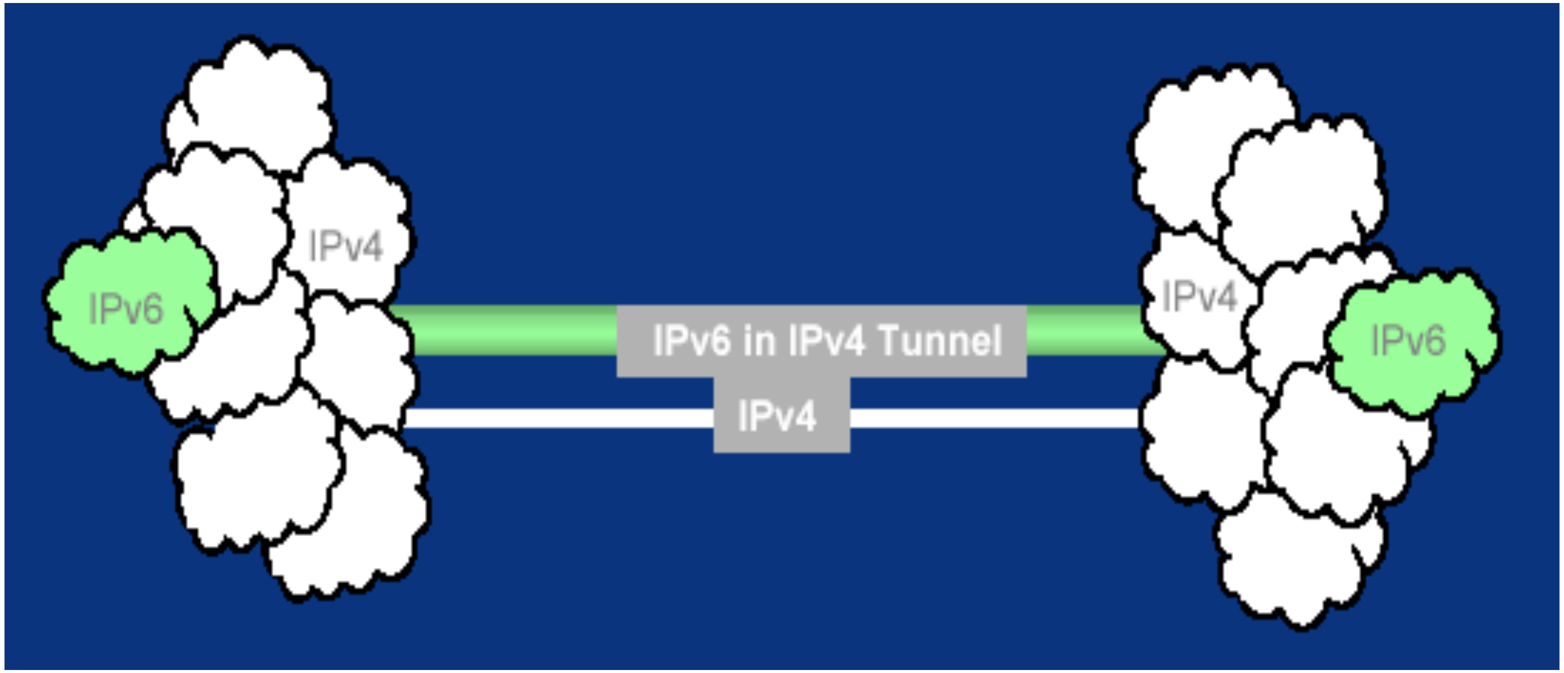
- Uses path MTU discovery (as discussed with IP v4 / ICMP)
  - Source sends probe message of various sizes until destination reached
  - Must be dynamic - path may change during transmission of datagrams
- Standard MTU is about 1300 octets (ethernet MTU minus special headers like PPPoE, tunnels, ...)
- New ICMP for IP v6 introduced

# IP v4 to IP v6 Transition

- Typical problem – who should start with it?
- IP v6 implemented in some backbones (e.g. German Telekom)
- DFN is talking about testbeds, university of Münster is conducting test installations and networks
- IP v6 address space assigned for GEANT(2), BelWue, Uni FR
  - But nobody really using it at the moment (connectivity often worse than for IPv4)
- End user systems are capable of IP v6?
  - Linux, BSD works with it for quite a while
  - WinXP was incompatible to itself with different patch levels, but working implementation since SP2
  - Vista has IPv6 fully integrated

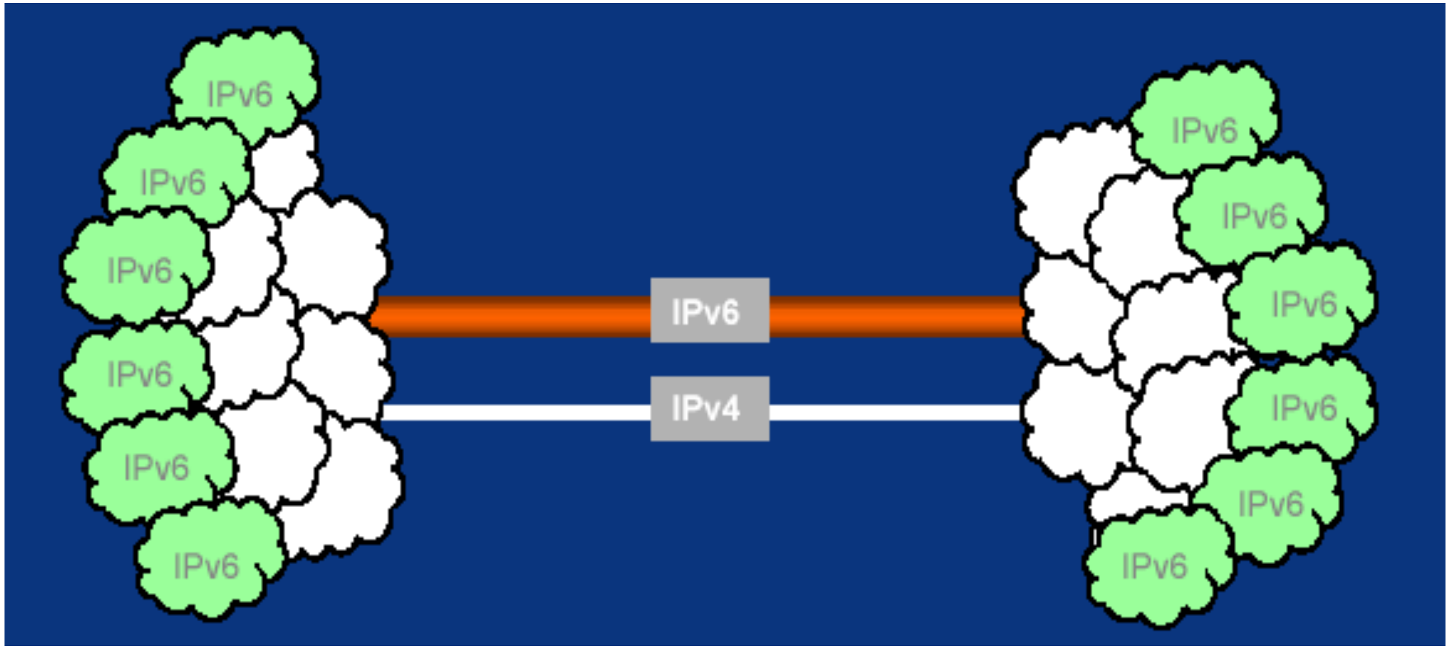
# IP v4 to IP v6 Transition

- Step 1: Add IPv6 capable nodes into the current IP v4 infrastructure
- IPv6 traffic is tunnelled in IPv4 traffic



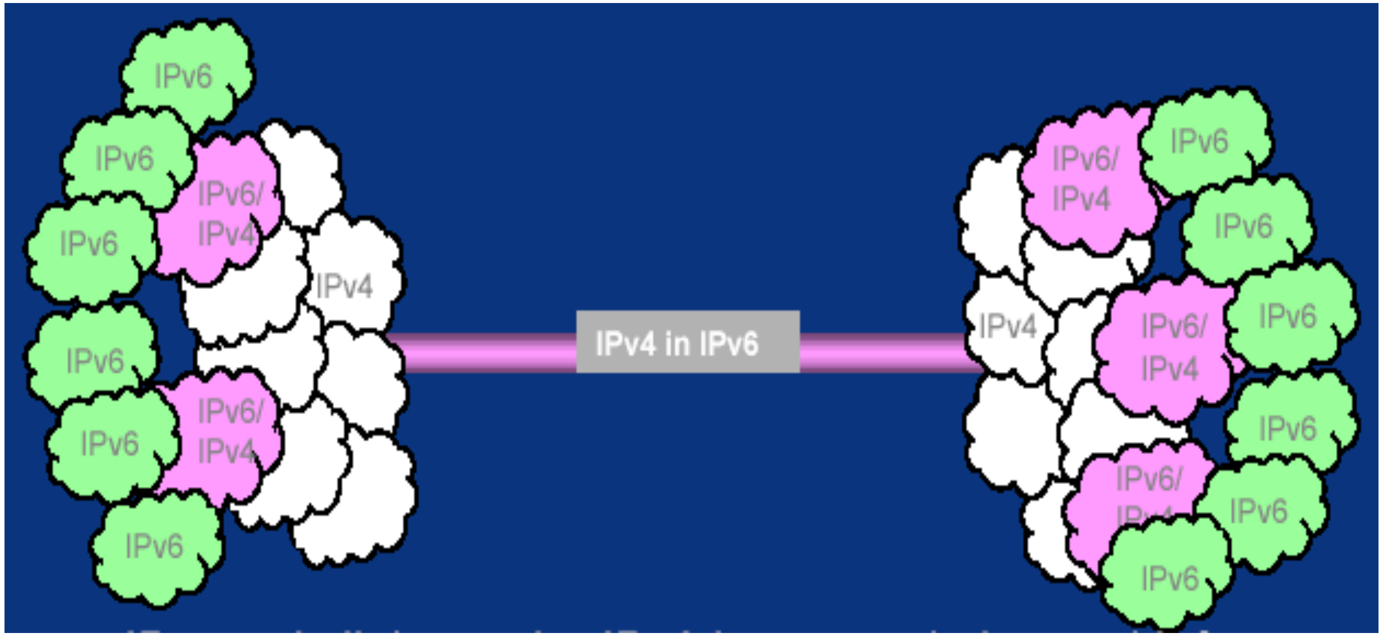
# IP v4 to IP v6 Transition

- Step 2: Add more IPv6 capable nodes
- Add separate IPv6 infrastructure



# IP v4 to IP v6 Transition

- Step 3: IPv6 dominates. Remove IPv4 infrastructure and tunnel IPv4 traffic in IPv6 traffic.
- Transition finishes

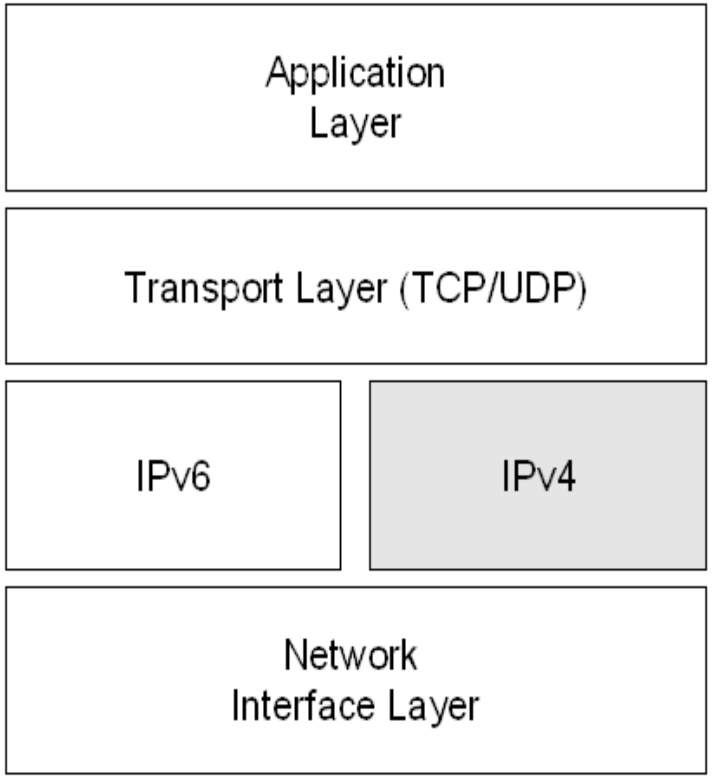


# IP v4 to IP v6 Transition

- Several transition mechanisms proposed
- IETF ngtrans working group has proposed many transition mechanisms:
  - Dual Stack
  - Tunnelling
  - Translation
- Every mechanism has pros and cons
  - choose one or more of them, depending on specific transition scenarios
  - no one suits for all

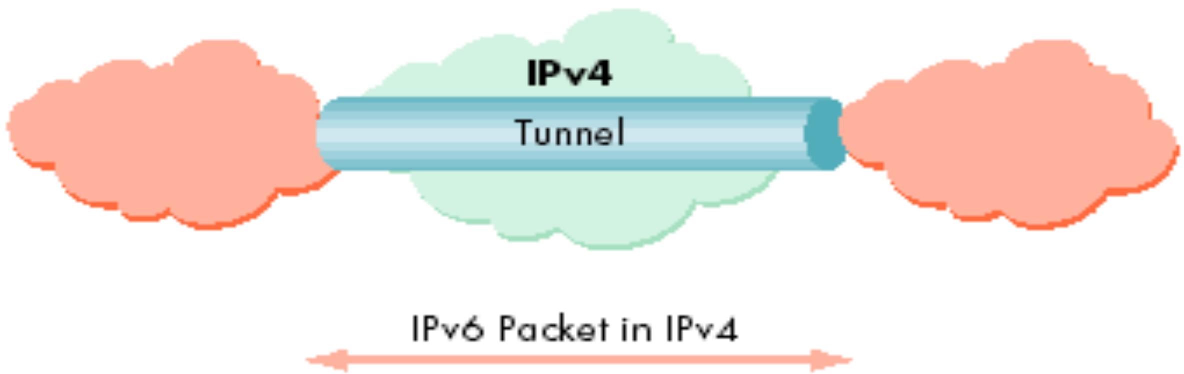
# IP v4 to IP v6 Transition

- Dual Stack
- Both of IPv4 and IPv6 are implemented;
- IPv4 address and IPv6 address;
- DNS must be upgraded to deal with the IPv4 A records as well as the IPv6 AAAA records



# IP v4 to IP v6 Transition

- Tunnelling is a process whereby one type of packet
  - in this case IP v6 - is encapsulated inside another type of packet - in this case IP v4
- This enables IPv4 infrastructure to carry IPv6 traffic
- Most tunnelling techniques cannot work if an IPv4 address translation (NAT) happens between the two end-points of the tunnel.
- When firewalls are used, IP protocol 4 must be allowed to go through

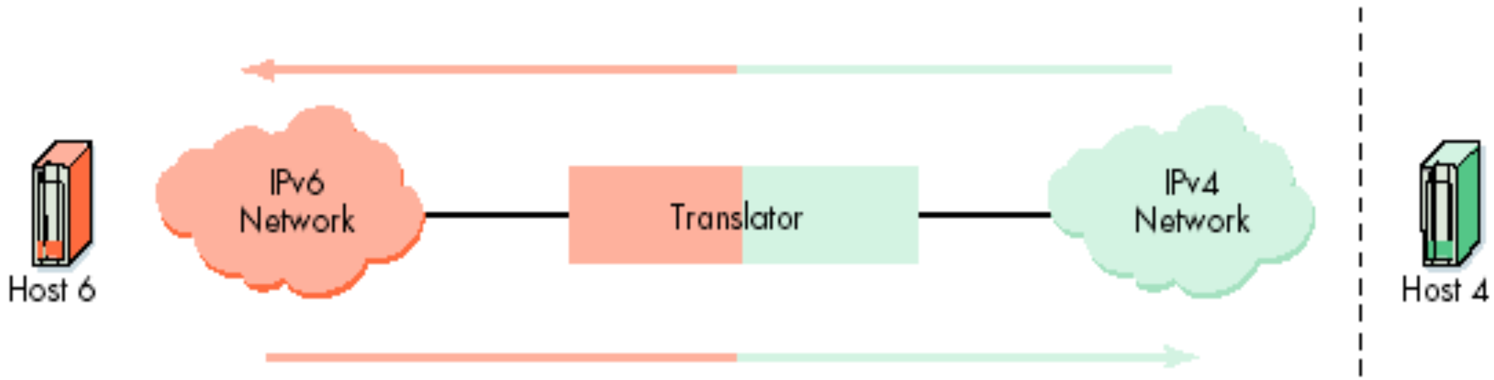


# IP v4 to IP v6 Transition

- Several tunneling mechanisms (and services)
  - Configured tunnels
    - 6to4
    - Tunnel broker
    - TSP
    - ISATAP
    - DSTM
  - Automatic tunnels
    - 6over4
    - Teredo
    - BGP-tunnel

# IP v4 to IP v6 Transition

- Translation
  - With tunnelling, communication between IP v6 nodes is established
  - How about communication between IP v4-only node and IP v6-only node?
  - We need translation mechanisms



# IP v4 to IP v6 Transition

- Several mechanisms too, just names here
  - SIIT
  - NAT-PT
  - ALG
  - TRT
  - Socks64
  - BIS
  - BIA

ALBERT-LUDWIGS-
UNIVERSITÄT FREIBURG

# Communication Systems

## IPv6

University of Freiburg
Computer Science
Computer Networks and Telematics
Prof. Christian Schindelhauer

CoNe Freiburg

IIF INSTITUT FÜR INFORMATIK FREIBURG