Next Generation Internet

IPv6 and Beyond

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Agenda

- Motivation
  - The Internet – Paradigm & Reality
  - The Limits of IPv4
  - Internet Service Problems
  - IPv6 Highlights
- Basic IPv6 Architecture
- Migration: Transition and Coexistence
- Lessons Learned & Future Trends: Beyond IPv6?

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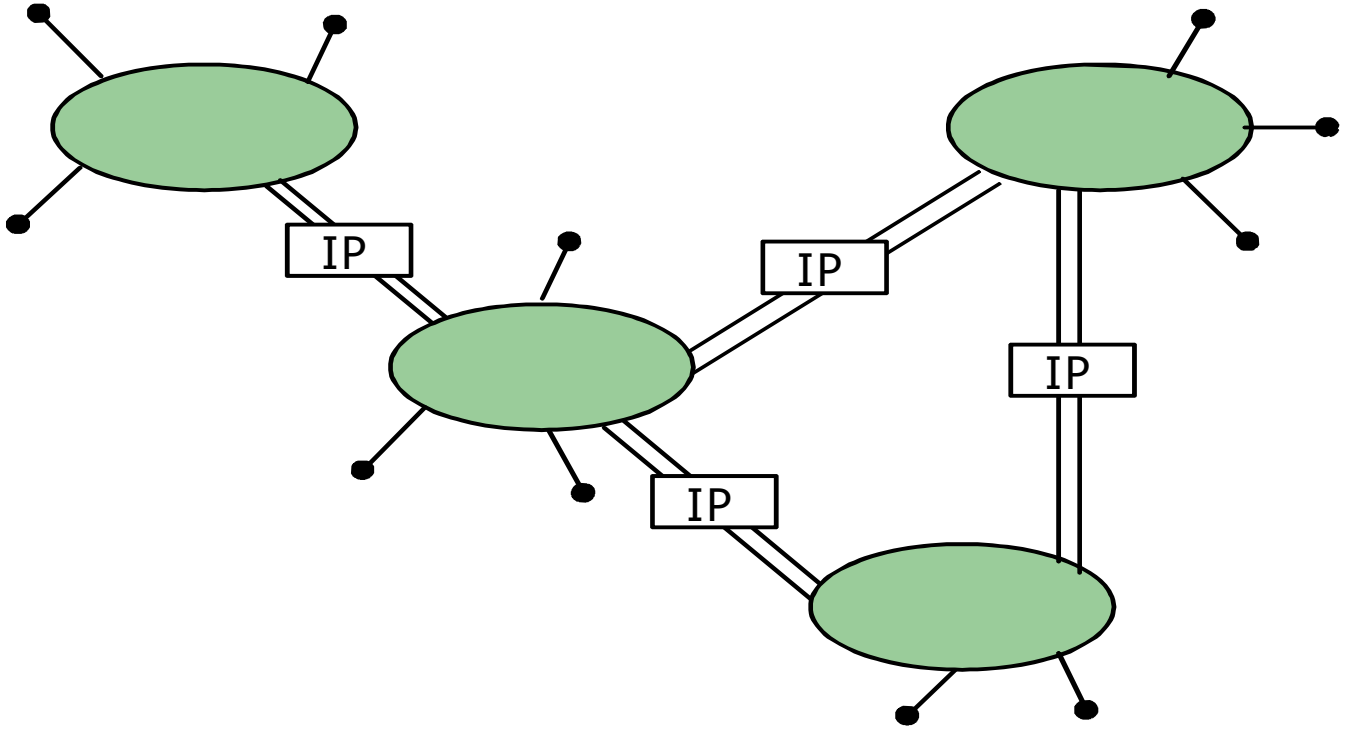
Hamburg University of Applied Sciences

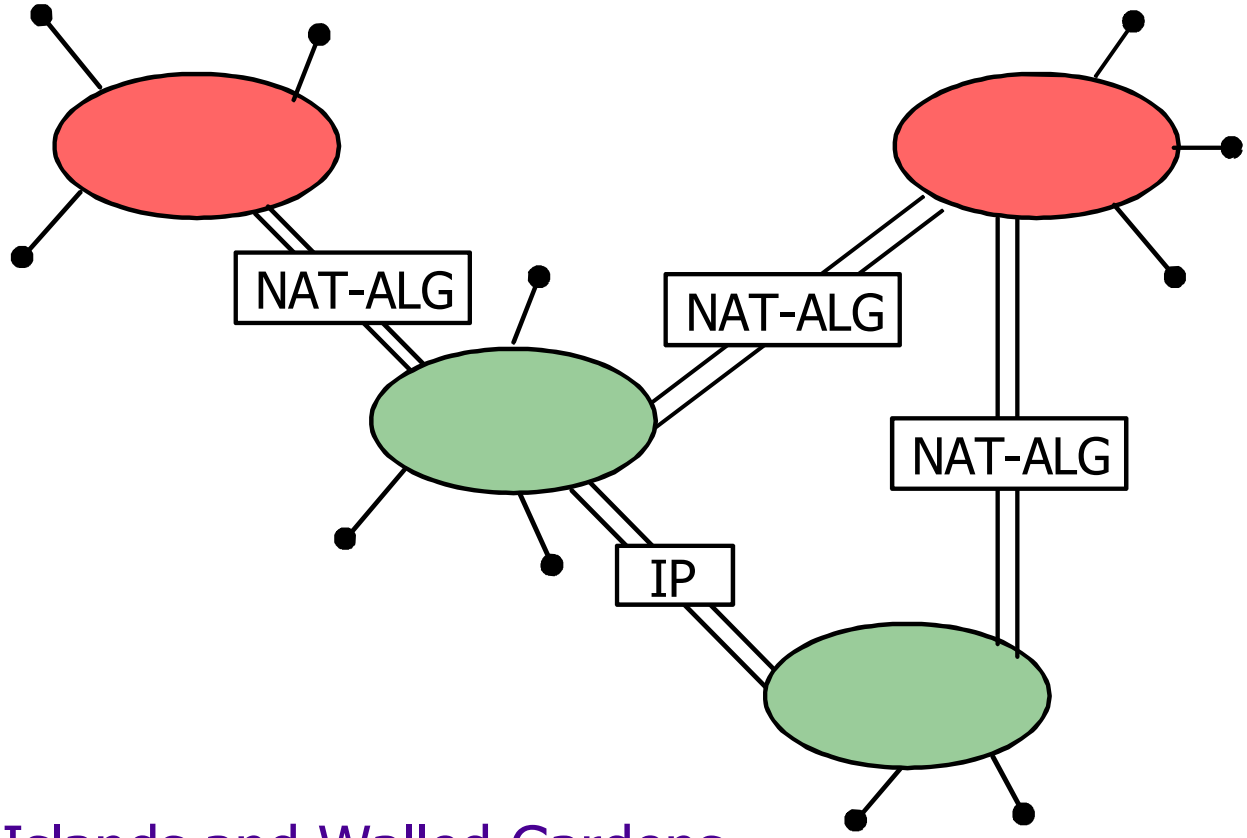
The Internet: Original Paradigm



One End-to-End Internet-Layer

- Global addressing
- Simple, application independent, transparent
- Stateless, application independent gateways

The Internet Today

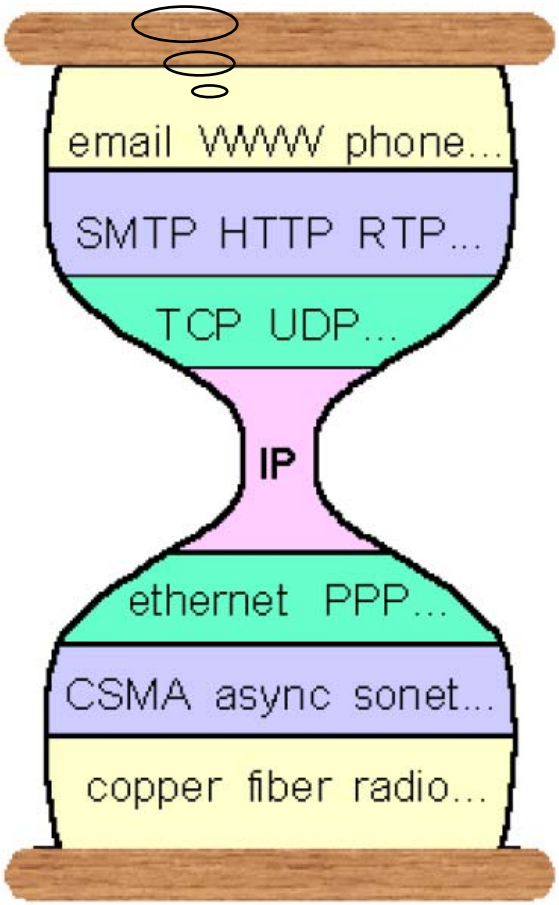


Private Islands and Walled Gardens

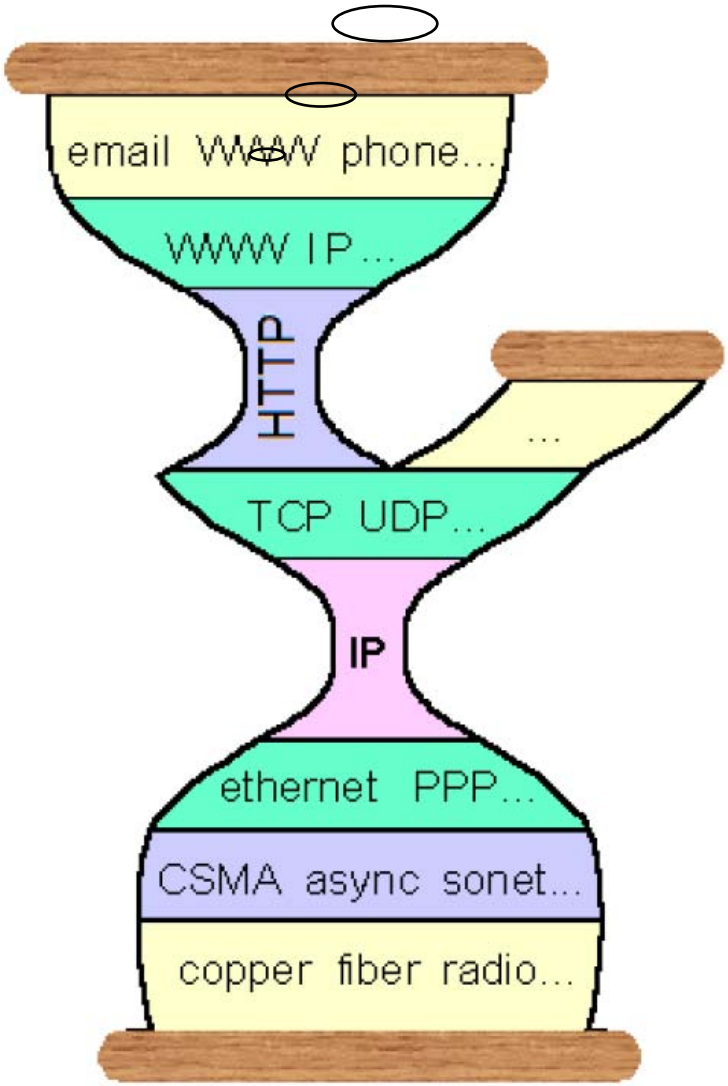
- No global addressing, NAT Application-Layer Gateways
- Statefull gateways for selected applications

Distortion of the IP Model (Deering/Rosenberg)

Deering 1990



Rosenberg 2008



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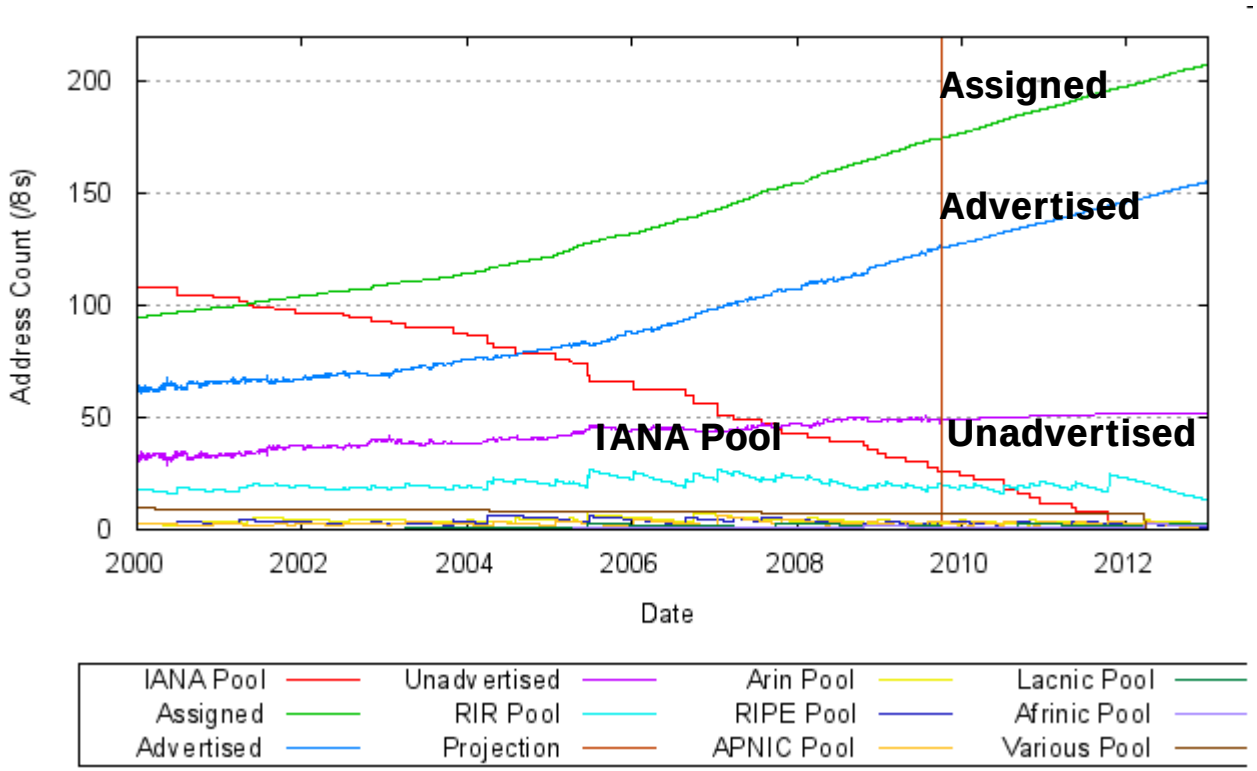
The Limits of IPv4

- Basic design about 30 years old
  - Packet format ... outdated
  - Hardware development of networks overran IP algorithms
- Address space exhausted
  - ‚Regular' Internet growth runs out of addresses
  - New kinds of Internet devices (mobile telephones, intelligent devices,...) need new quantities of addresses
  - Caused by address bottle-neck: NAT-ALGs
- Support of new services tedious to implement

IPv4 Address Exhaustion ?



- Projected IANA Unallocated Address Pool Exhaustion: 13-Oct-2011
- Projected RIR Unallocated Address Pool Exhaustion: 24-Dec-2012

Source: Geoff Huston, http://www.potaroo.net/tools/ipv4/ as of Oct 2009

IP Service Problems

- Address configuration: Static, not stateless
- Backbone Routing: Table explosion due to unstructured addresses
- Security: IP over IP tunnelling
- Multicasting: Routing too complex
- Anycasting: Application specific solutions
- QoS: No flow support
- Mobile: Identifier/locator problem - inefficient triangular tunnelling
- Multihoming: Provider abstraction missing

Why IPng: IPv6 + + + ?

- Tackle the Internet scaling problem: Addressing & Routing
- Return to openness for new services & future development
- Evolve the architecture of the Internet
- Meet new requirements of a 'business-critical' network
- Avoid tedious patchwork to keep the Internet going

IPv6 Innovations

- Addressing and routing
  - Elimination of address bottle-neck: 128 Bit addresses
  - Address hierarchy can (was intended to) simplify backbone routing
  - Several addresses per interface
- Simple administration
  - Autoconfiguration of interfaces without DHCPv6
  - Floating net masks, renumbering via prefix change
- Security: IPSec
  - Security header extension for authentication, integrity and encryption

IPv6 Innovations (2)

- Protocol architecture
  - Slim, fixed header for fast processing
  - Optional extension headers
  - Format framework for header classes
  - No header checksum
  - No fragmentation in routers
- Improved multicast, anycast, QoS and mobile services
- Support of Jumbograms (> 64 KB)
- Transition and coexistence concept IPv4 ↔ IPv6

IPv6 History

- o IETF WG IPng began to work in the early 90er
- o Winter 1992: 7 proposals for development of IP
  - CNAT, IP Encaps, Nimrod, Simple CLNP, PIP, SIP, TP/IX
- o Autumn 1993: several mergers lead to
  - 'Simple Internet Protocol Plus' (SIPP) and 'Common Architecture for the Internet' CATNIP
- o July 1994: IPng Area Director recommend roadmap (RFC 1752) on basis of SIPP (Steve Deering)
- o Dec. 1995: S. Deering, R. Hinden, „Internet Protocol, Version 6 (IPv6) Specification" (RFC 1883, now RFC 2460)
- o July 1999: End user addresses available (RIPE-NCC, APNIC, ARIN)
- o May 2007: ARIN advises Internet Community on Migration to IPv6

IPv6 Standardisation

- Key components in standard track:

  Specification (RFC2460) Neighbour Discovery (RFC2461)
  ICMPv6 (RFC2463) IPv6 Addresses (RFC1884 ++)
  RIP (RFC2080) BGP (RFC2545)
  IGMPv6 (RFC2710) OSPF (RFC2740)
  Router Alert (RFC2711) Jumbograms (RFC2675)
  Auto configuration (RFC2462) ….

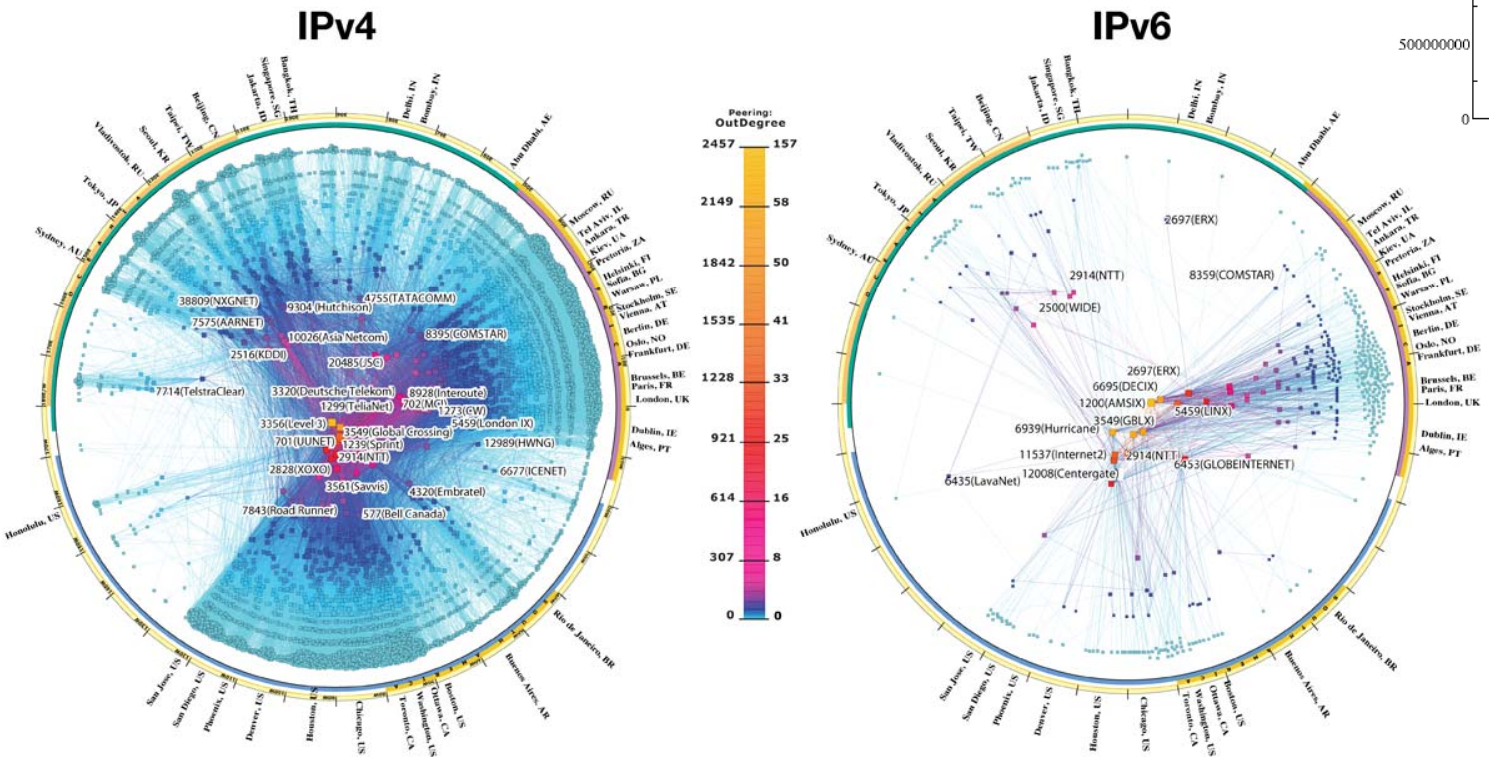
- IPv6 over: PPP (RFC2023) Ethernet (RFC2464)
  FDDI (RFC2467) Token Ring (RFC2470)
  NBMA(RFC2491) ATM (RFC2492)
  Frame Relay (RFC2590) ARCnet (RFC2549)

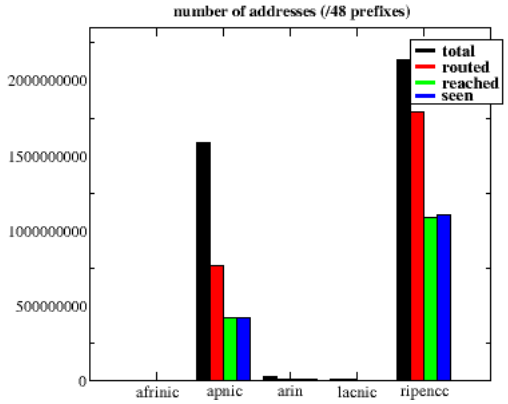
- Since then 100++ further standards: Flow labelling, MIPv6, 3GPP, Routing advertisement, ….

- Implemented basically in every Internetworking system platform

IPv4 & IPv6
INTERNET TOPOLOGY MAP
JANUARY 2009

AS-level INTERNET GRAPH





- Source: CAIDA (http://www.caida.org/research/topology/as_core_network/ipv6.xml)

Agenda

- Motivation
- Basic IPv6 Architecture
  - Addressing
  - Packet Format
  - ICMP, Neighbour Discovery, Autoconfiguration
  - Routing, Anycasting, QoS, Multihoming
- Migration: Transition and Coexistence
- Lessons Learned & Future Trends: Beyond IPv6?

Addressing

- IPv6 addresses are 128-bit long and variably built
- Address architecture: RFC 1884, now 4291 (Feb ´06, Hinden & Deering)
- Automatic address configuration
- Global address hierarchy from top level allocation to the interface-ID designated
- Aggregation-based allocation to simplify the global routing (target objective)
- Format prefix (FP) (3 Bit initially) used for identification of address type

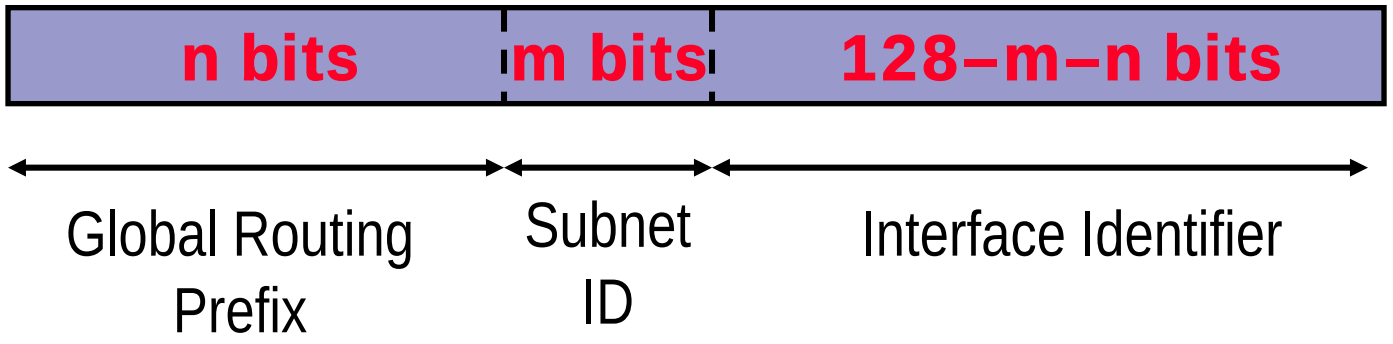
Notation of IPv6 Addresses

- Standard form: 8 x 16 bit hexadecimal
  Example: 1080:0:FF:0:8:800:200C:417A
- Short form: sequences of nulls replaced by ::
  Example: FF01:0:0:0:0:0:0:43 → FF01::43
- IPv4 compatible addresses:
  Example: 0:0:0:0:0:FFFF:13.1.68.3 → ::FFFF:13.1.68.3
- CIDR notation for prefixes:
  Example: 1080:645:FF::/48

Address Types

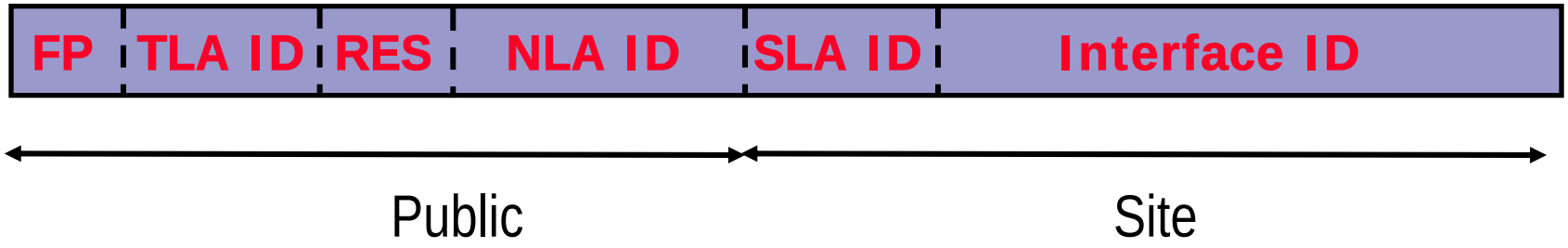
Type	Binary Prefix	
o Unicast (one-to-one)		
- global	all not specified elsewhere	
- site-local (deprecated)	1111 1110 11	(FEC0::/10)
- unique local (ULA)	1111 110	(FC00::/7)
- link-local	1111 1110 10	(FE80::/10)
- IPv4-mapped	000…0:FFFF	(::FFFF:xxx.xxx.xxx.xxx)
- loopback	0000…1	(::1/128)
- unspecified	0000…0	(::/128)
o Multicast (one-to-many)	1111 1111	(FF00::/8)
o Anycast (one-to-nearest)	of Unicast Prefixes	
o No broadcast addresses (only multicast)!		

Global Unicast Addresses - RFC 4291



- All fields have variable length and are not 'self-explanatory' (as of CIDR)
- All global unicast addresses, which do not begin with 000 (binary), carry a 64 bit interface ID, this means m + n = 64
- Mechanisms of automatic prefix exchange provided

Historic – RFC2374: Aggregatable Global Unicast Format



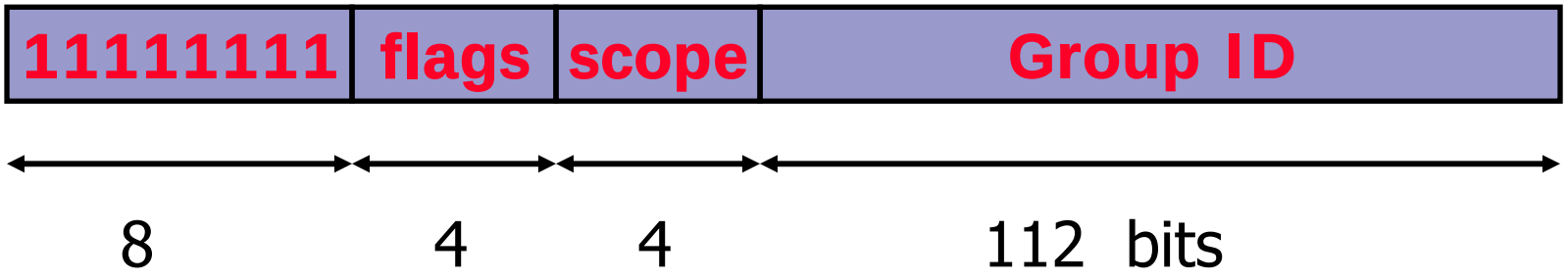
- Previous approach: Standardized prefix hierarchy as Top/Next/Side Level Aggregator
- Current approach:
  - IAB/IESG Recommendations on IPv6 Address Allocations to Sites, RFC 3177
  - Left to RIR policies cf. http://www.ripe.net/ripe/docs/ipv6policy.html

Local Unicast Addresses

- Link-local addresses for use during auto-configuration and in nets without routers:

- Unique local addresses (RFC 4193), independent of TLA/NLA:
  - Globally unique for local communication, only (avoiding conflicts)
  - Not intended for global routing (but e.g., for dedicated site interconnects)

Multicast Addresses



- Flag field: lower bit indicates permanent (=0) respectively transient (=1) group, rest is reserved (==0)
- Scope field:
  - 1 - node local
  - 2 - link-local
  - 5 - site-local
  - 8 - organisation local
  - B - community-local
  - E - global (other values reserved)

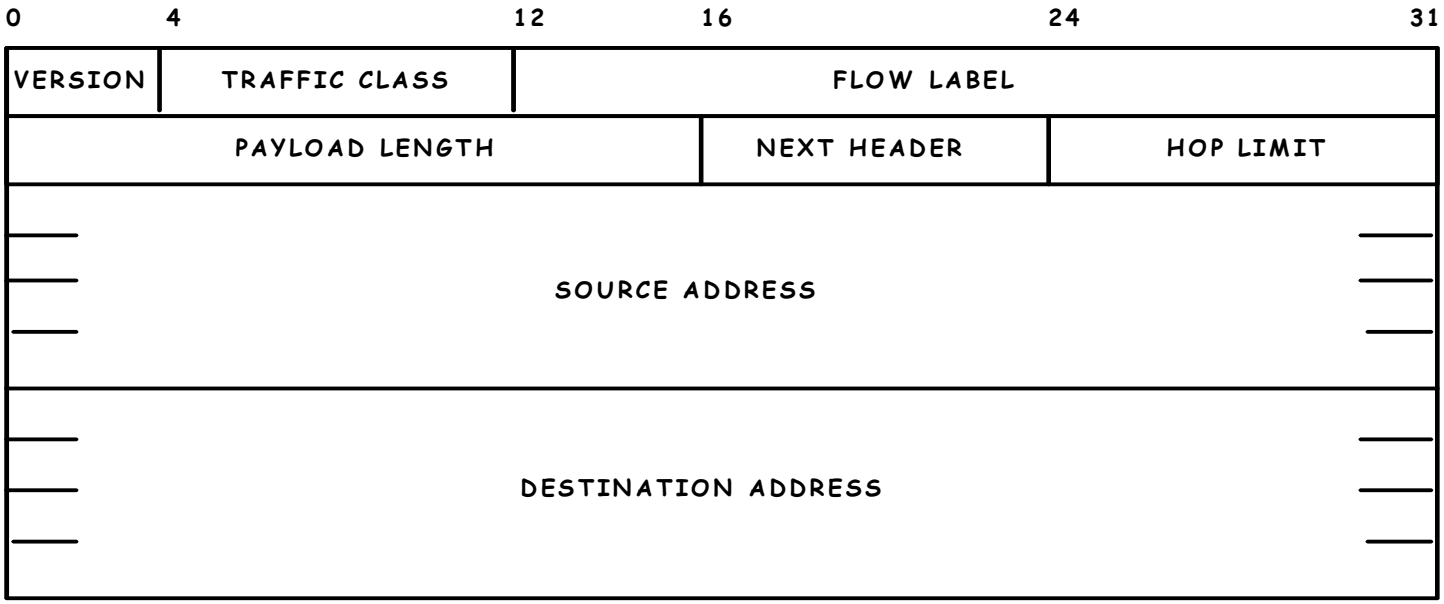
Example: FHTW IPv6 Net

- 2001:: /16 - Pre-set prefix
- 2001:**06**00:: /24 - Regional registry Europa (RIPE)
- 2001:06**38**:: /32 - DFN prefix
- 2001:0638:**0801**:: /48 - FHTW net address
- 2001:0638:0801:**0001**:: /64 - First FHTW subnet
- 2001:0638:0801:0001:**0000:0000:0000:0001** /128

  - First IPv6 computer address at FHTW in 2001 ☺

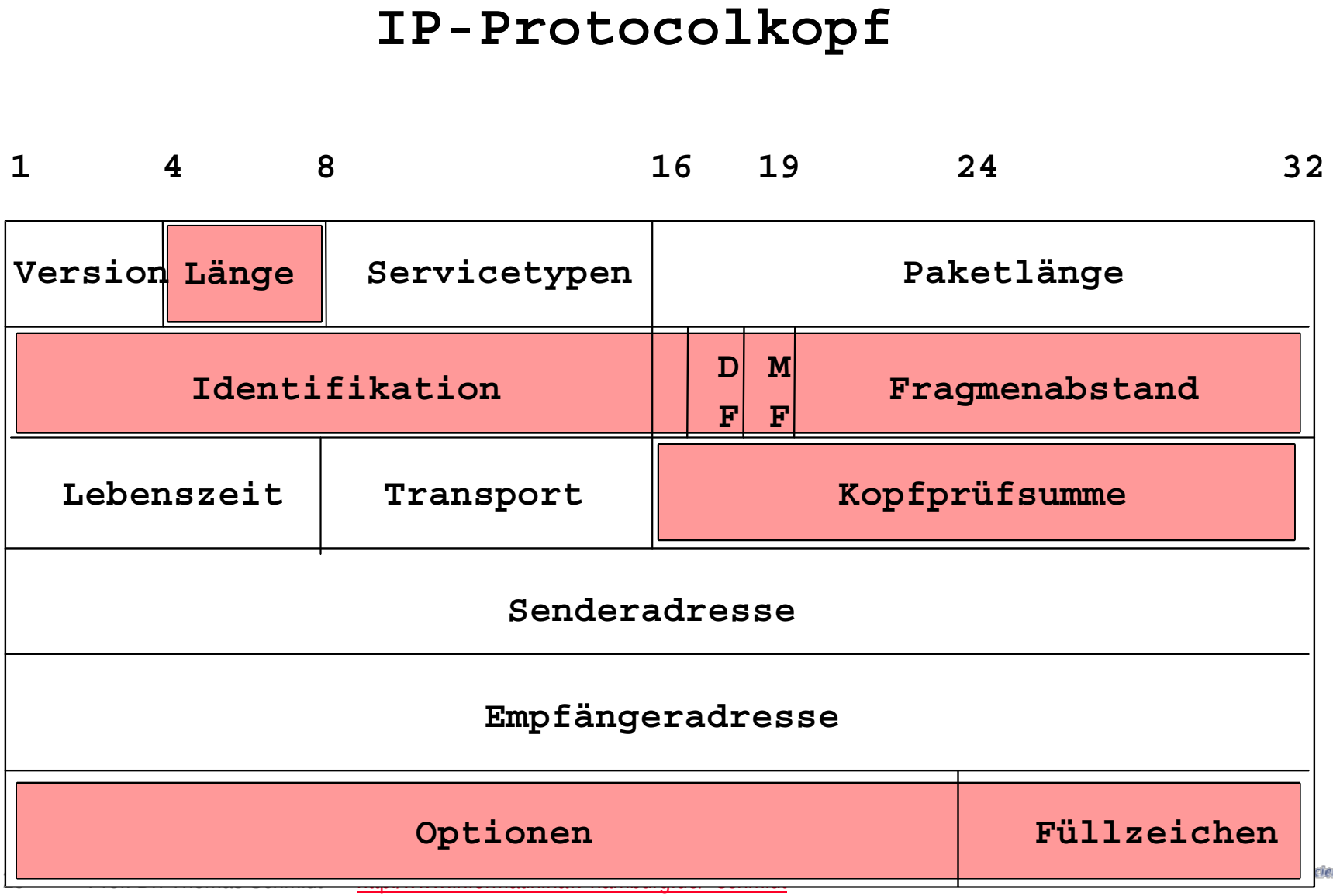
Addressing of Sub-TLAs (Ripe) according to RFC 2450

IPv6 Packet Format: Basic Header



VERSION	4 Bit	Internet Protocol Version Number = 6
TRAFFIC CLASS	8 Bit	Type of Services (QoS DiffServ field)
FLOW LABEL	20 Bit	Flow Identification at Routers (QoS)
PAYLOAD LENGHT	16 Bit	Octetts of Payload without IPv6-Header
NEXT HEADER	8 Bit	Type of Encapsulated Protocol
HOP LIMIT	8 Bit	TTL-Counter, Decremented per Router
SOURCE ADDRESS	128 Bit	Adress of Sender (128 Bits)
DESTINATION ADRESS	128 Bit	Adress of Receiver (128 Bits)

Compare: IPv4 Header

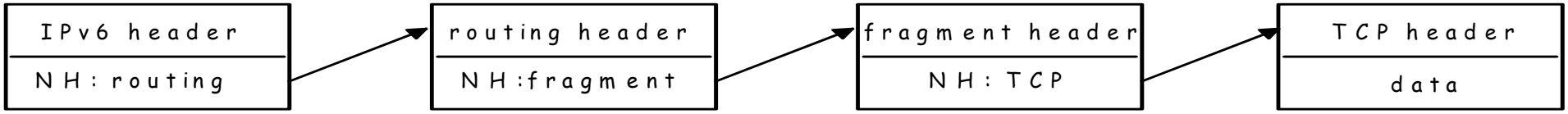


Header Changes of IPv4

- Addressing grows from 32 to 128 Bit
- Fragmenting will be deleted from basis header
- IP Options will be deleted from basis header → fixed length
- Header Checksum drop out
- Header length field drop out
- Flow Label newly included
- Time to Live → Hop Limit
- Protocol → Next Header
- Service types → Traffic Class
- Length field describes data without header
- Alignment increases from 32 to 64 Bit

IPv6 Packet Format: Option Headers

- Extended option mechanisms: Each header references a possible successive header or data, e.g.:



- Option headers have no length limit (IPv4: 40 Octets), Padding to 8 Octets
- Option headers will be processed only at destination host, not by routers. Exception: Hop-by-Hop Option Header

Basic Option Headers

- Routing
  Advanced routing information (source routing)
- Fragmentation
  Fragmentation / defragmentation information
- Authentication
  Security information: authentication and integrity
- Encapsulation
  ‚Tunnelling', i.g. for confidential data
- Hop-by-Hop Option
  Dedicated options to be processed by every router
- Destination Option
  Information for the destination host (header extension)

Order of Headers

The processing order of the headers will be arranged by the sender according to the following recommendation (RFC 2460):

1. IPv6
2. Hop-by-Hop Option
3. Destination Option (1)
4. Routing / Encapsulation
5. Fragmentation
6. Authentication
7. Destination Option (2)
8. Upper Layer

Internet Control Message Protocol (ICMPv6)

- RFC 2463 (Conta, Deering), now RFC 4443 + 4884
- Extension header protocol class (following base IP header)
- Defines two (expandable) message classes:

Informational Messages

- Echo Request (128)
- Echo Reply (129)

Error Messages

- Destination Unreachable (1)
- Packet Too Big (2)
- Time Exceeded (3)
- Parameter Problem (4)

IPv6 Neighbour Discovery

- RFC 2461, now RFC 4861
- Protocol over ICMPv6
  - Combination of IPv4 Protocols (ARP, ICMP,…)
- Autonomous interaction between hosts and routers
  - Defines 5 ICMPv6 packet types:
    - Router Solicitation / Router Advertisement
    - Neighbour Solicitation / Neighbour Advertisement
    - Redirect

IPv6 Neighbour Discovery (2)

- Defines communication mechanisms for nodes on the same link:
  - Router discovery
  - Prefix discovery
  - Parameter discovery, i.e.: link MTU, hop limit,…
  - Address auto-configuration
  - Address resolution (same function as ARP)
  - Next-hop determination
  - Neighbour unreachable detection (useful for default routers)
  - Duplicate address detection
  - Redirect
  - Network load balancing

Stateless Auto-Configuration

1. Interface assigns a link-local address on activation (default: EUI-64 built from a hardware address).
2. Interface sends *router solicitation,* to omit waiting for router advertisements.
3. Router sends *router advertisement* (prefix, default gateway, …).
4. The interface creates its global address from prefix and link-local address.
5. For verification of uniqueness a ICMP *neighbour solicitation* will be issued on own address (Duplicate Address Detection).

Secure Neighbour Discovery - SEND

- RFC 3971 (Arkko et al.)
- Employs Cryptographically Generated Addresses (CGAs – RFC 3972) to authenticate NDP ("prevent ARP spoofing")
- SEND ND messages can self-consistently authenticate its IP sender address (without PKI)
- Router/prefix advertisements require certificates (X.509v3) from a PKI to assure routing responsibility

Auto-Reconfiguration

- New address-prefixes can be distributed and retreated:
  - Coexistence periods between old and new prefixes
  - Hosts learn prefix-lifecycle and priorities via router advertisements
  - Old TCP-connections survive within coexistence periods, new TCP-connections survive prefix change
- Prefix-distribution via router renumbering protocol
- DNS-Structure (AAAA) does not follow this flexibility.

IPv6 DNS

Two approaches:

o AAAA ("Quad A") Res. Rec. – RFC 1886, 3596

- A record type of 128 bit length
- Reverse lookup domain IP6.ARPA

o A6 RR – RFC 2874

- Idea to support renumbering by prefix delegation
- A6 record contains a domain name pointer:

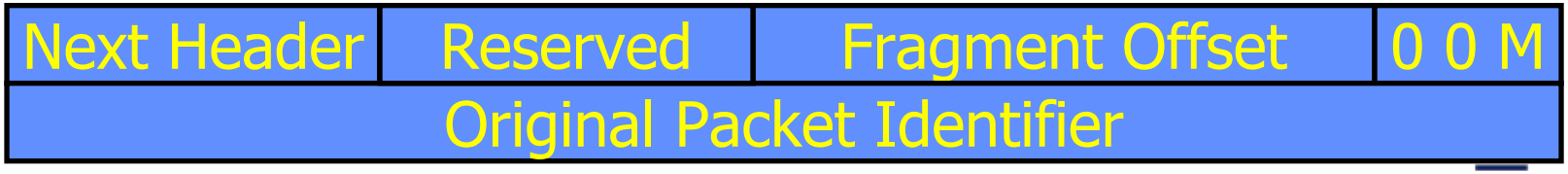
o IETF decided for AAAA – RFC 3363

MTU Handling

- The minimal Link-MTU for IPv6 is 1280 Bytes (versus 68 Bytes for IPv4).
- Path-MTU discovery:
  - Repeatedly send packets with known path-MTU size until no more ICMP 'Packet-too-big' is received
  - necessary only for packets > 1280 Bytes
- Minimal IP implementation can live without path-MTU discovery and without fragmentation (Packets ≤ 1280 Bytes).
- Upper Layer (TCP): MSS ≤ MTU – 60.
- A Hop-by-Hop Option supports the execution of Jumbograms with sizes up to 2^{32} Octets Payload.

Fragmentation

- IPv6 avoids the expensive fragmentation process on routers. The sender hast to fragment, if necessary.
- Sender should execute path-MTU discovery.
- Routers answer with ICMP „Packet too big".
- IPv6 Fragmentation Header can be used to support upper layers without dynamically executing MTU-Discovery.



Generic Packet Tunnelling of IPv6

- RFC 2473 (Conta, Deering)
- Mainly used for explicit routing path control
- Defines (statefull) end points:
  - Tunnel Entry-Point
  - Tunnel Exit-Point (at Unicast, Anycast or Multicast address)
- State variables contain MTU, Traffic Class, Flow Label
- Fragmentation may be necessary at tunnel entry point

IPv6 Routing

- Uses CIDR „longest prefix match"/ largest mask to go for.
- Hierarchical addressing is key issue for a scalable routing
  - VLSM route aggregation
  - Relies on provider-bound prefixes
- Dynamical routing protocols from IPv4 updated:

  Unicast: OSPF, RIP-II, BGP4+,...

  Multicast: MLD, MOSPF, PIM, BIDIR-PIM ...
- Can send packets through predefined regions by
  - routing headers (source routing) – type 0 deprecated (RFC 5095)
  - Anycast

Anycast

- Service to 'one out of many' , RFCs 4291, 4786
- Addressing from unicast
  - Prefix must cover all group members (least common)
  - Reg. Global Unicast, but some reserved:
    - Subnet (RFC 2526): subnet router, MIPv6 home agent
    - RFC 3068: 6to4 relays anycast address
    - RFC 4610: anycast rendezvous point in PIM
- Anycast Routing
  - Within IGP: Host routes (dynamic/static)
  - Globally: According to covering prefix

Anycast (2)

- There are transport issues with Anycast:
  - Subsequent packets may not always reach the same peer
  - Source address may never be anycast, so a unicast address must be used in a response
  - → TCP and IPSec cause conflicts, UDP deployable
- Today's deployment:
  - Use for routers only
  - Local / regional configuration
  - DNS root servers
  - 6-to-4 transition: Tunnel relay prefix 192.88.99.0/24
  - Multicast: PIM rendezvous point anycast addressing + AMT

IPv6 & QoS

Priority: Traffic Class Field (8 Bit) break down in two classes:

o Flow controlled traffic (0 - 7) – IPv4 compatible

0	Not specified	4	Bulk (i.g. ftp, http)
1	‚Feeder' (i.g. netnews)	5	(Reserved)
2	Unnoticed (i.g. email)	6	Interactive (i.g. telnet, X11)
3	(Reserved)	7	Internet control (i.g. rip)

o Traffic without flow control (Realtime, Constant Bitrate, ...)
Priority from 8 to 15 (ascending)

o Remaining priorisation according to DiffServ code points

Flow Labels

24-bit Flow Labels can be used by senders to mark associated packets.

- o RFC 3697
- o Goal: accelerated, uniform handling of packet streams through routers
- o Flow label assignment: Random per Flow
- o Header information consistent per flow (router caching)
- o Defines router states: 120 s lifecycle

Multihoming

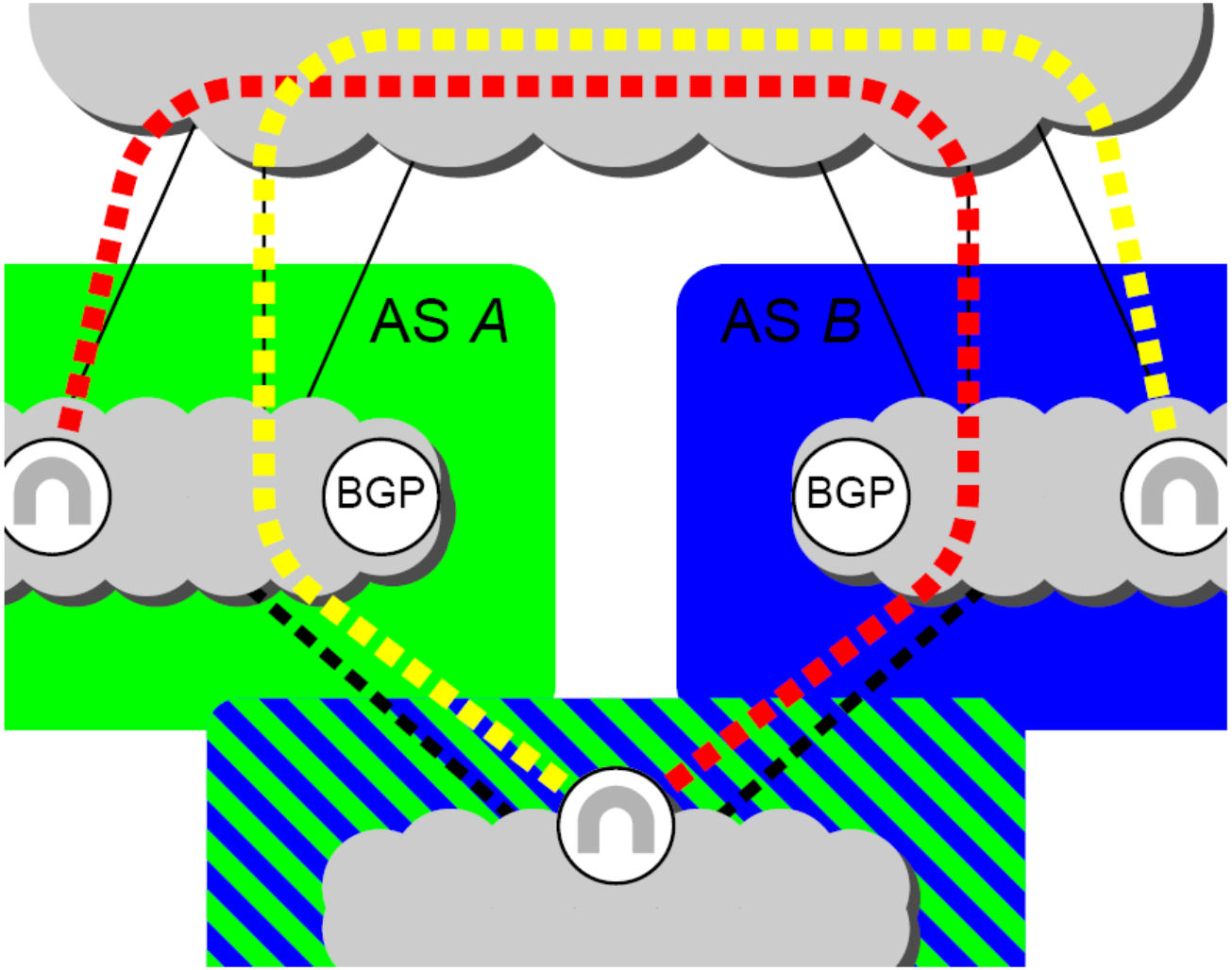
- Goal: Redundant ISP connectivity
- Problem space: Addressing & Routing
  - Using provider independent (PI) addresses prevents route aggregation
  - Using provider-bound addresses leaves administration to the end system domain
- Originally: No PIs in IPv6, but concept is broken

⇒ Threat of routing table explosion returned to IPv6

Multihoming without PI

- Two prefixes in end system domains
- Solution at node level:
  - Multiple DNS entries
  - End systems must chose preferred/correct address
  - SHIM6 protocol: draft-ietf-shim6-proto
- Solution at network level
  - Need failover implementation in network
  - Typically: Own AS, BGP announcements
- Continuous disturbing issue within the IETF

Multihoming: Cooperative Redundant Connectivity



Source: Benedict Stockebrand, European Conference on Applied IPv6, Sept. 2007

Agenda

- Motivation
- Basic IPv6 Architecture
- Migration: Transition and Coexistence
  - ➦ Programming: IPv6 API
  - ➦ Dual Stack
  - ➦ Tunnelling
- Lessons Learned & Future Trends: Beyond IPv6?

IPv4 → IPv6 Porting

- Source and binary code compatibility for existent application: 'all goes on', provided IPv4 is around
- Indirection for address data structure, new for IPv6: `addrinfo` is linked list of interface address structs
- Name-to-address translation:
  New functions to support IPv6 and IPv4
- Address conversion functions:
  New functions to support IPv6 and IPv4
- DNS resolver:
  Returns IPv6 or IPv4 address, or both
- Almost all standard (open source) applications ported

IPv4 → IPv6 Porting: API Changes

	IPv4	IPv6	
Data structures	AF_INET	AF_INET6	
	in_addr sockaddr_in	in6_addr sockaddr_in6	
Address conversion functions	inet_aton() inet_addr()	inet_pton()	IPv4 and IPv6 functions
	inet_ntoa()	inet_ntop()	
Name-to-address functions	gethostbyname() gethostbyaddr()	getipnodebyname() getipnodebyaddr getnameinfo() * getaddrinfo() *	

*** POSIX protocol independant functions**

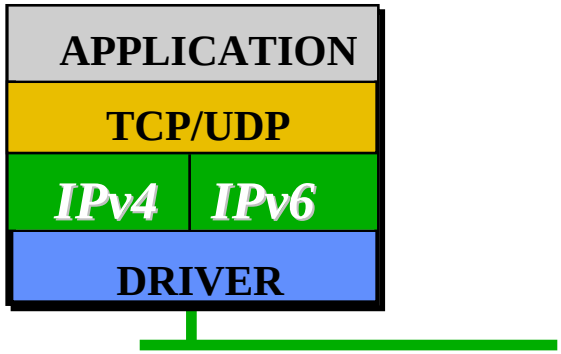
IPv4 → IPv6 Migration

Many migration techniques have been designed and implemented according to the following approach:

- Dual-Stack techniques, which allow the coexistence of IPv4 and IPv6 at the same device and subnet
- Tunnel, which connects IPv6 regions over IPv4 regions
- Protocol translator, which let IPv6 devices with IPv4 devices speak

During migration, the combined use of all these methods is likely.

Dual Stack

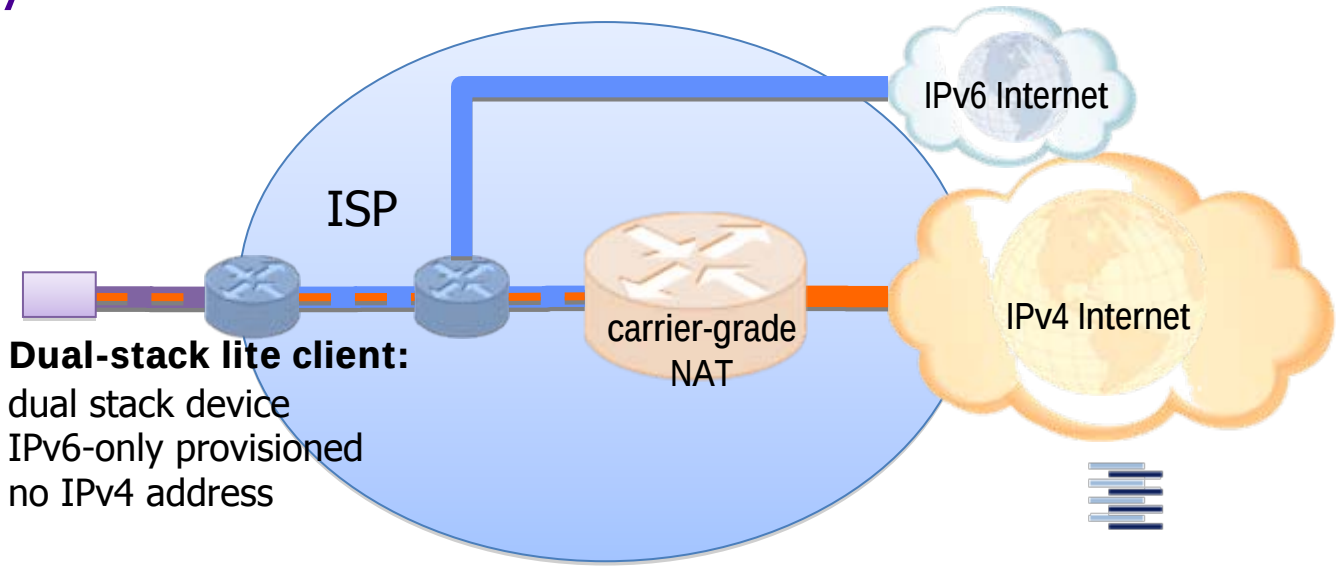


- On activation of IPv6, the IPv4 can continuously be used (multi protocol approach)
- Devices can keep their addresses (IPv4 in IPv6)
- Application / libraries choose the IP version:
  - in dependence of DNS answer with IPv6 preference
  - in dependence of received packets
- The Dual stack operation can continue without limits, allowing the step by step porting of applications
  - But requires an increasing use of IPv4-NATTING (recursive)
- Problems result from inconsistencies of Network / DNS configurations

Dual Stack Lite

- draft-ietf-softwire-dual-stack-lite -

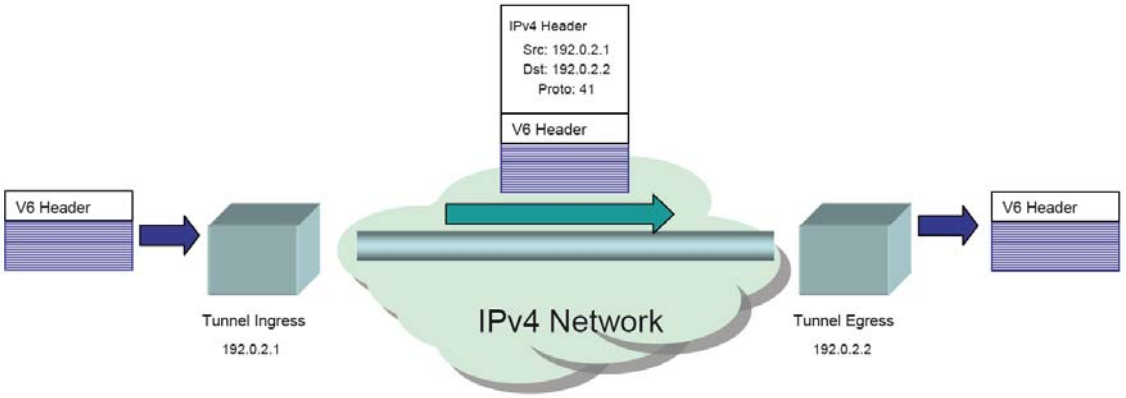
- IPv6-only at customer – but dual stack at system
- IPv4 over IPv6 tunnel to Carrier-grade IPv4-IPv4 NAT
- IPv4 access via globally unique IPv4 address shared among many customers



Transition by Tunnels

- Embedding of IPv6 packets in IPv4 packets
- Diverse methods to build a tunnel:
  - Manuel
  - Tunnel Broker (web based application to build a tunnel)
  - 6-over-4 (intradomain)
  - 6-to-4 (interdomain, IPv4 address as IPv6 site prefix)
- View:
  - IPv6 use IPv4 as a virtual link layer
  - IPv6 VPN over IPv4

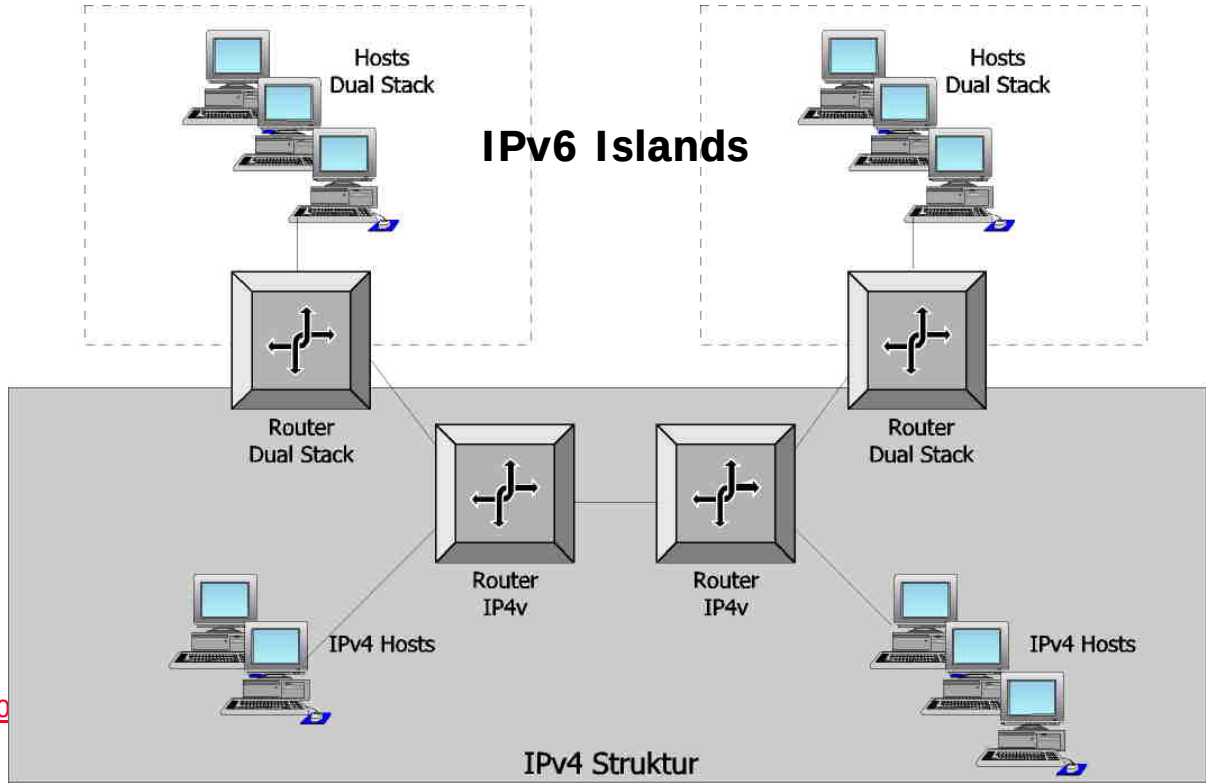
6-over-4 Tunnels



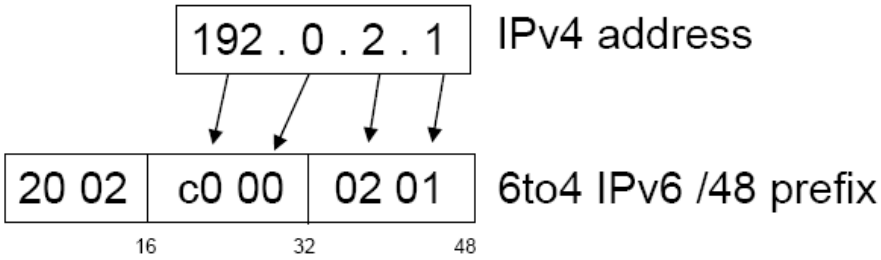
Isolated IPv6 islands in an IPv4 world

IPv6 ↔ IPv4 inter-connects: Embedding

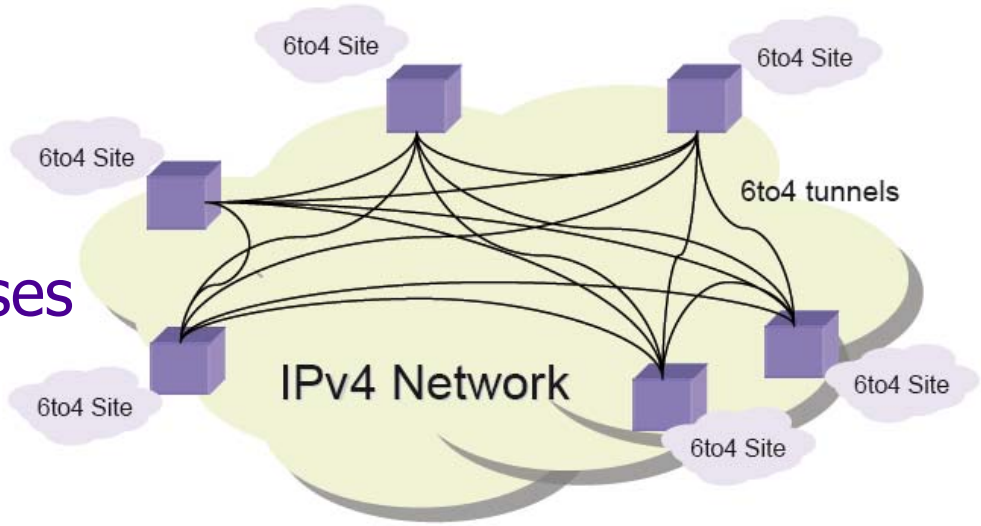
IPv6 ↔ IPv6 inter-connects: Following tunnel configurations



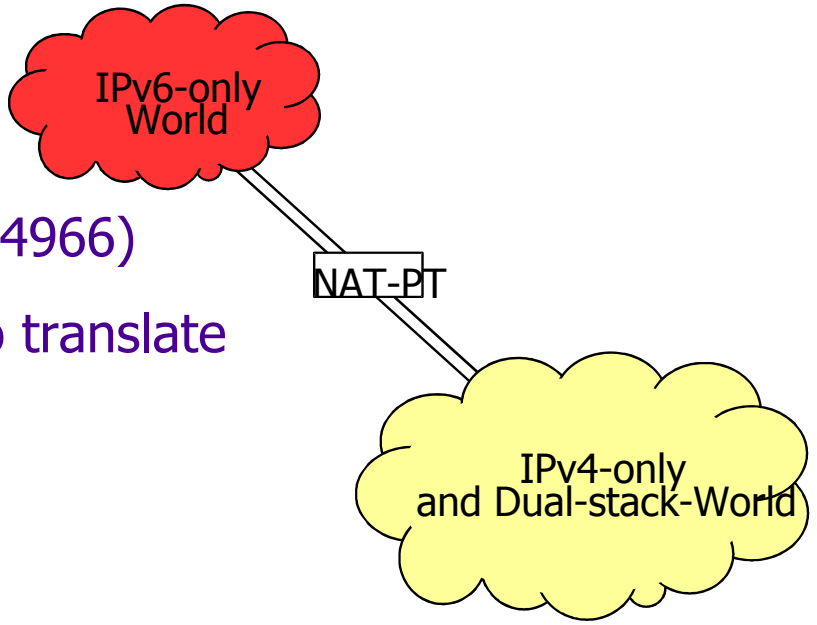
6-to-4



- Defines automated point-to-multipoint tunnels, RFC 3056 ff.
- Assigns an IPv6 network to each IPv4 address (taken as prefix)
- Allows IPv6 islands to automatically interconnect, using IPv4 as a non-broadcast multi-access network
- Automatic tunnel access via well-known Anycast addresses
- TEREDO: Extension to NAT traversal



Protocol Translation



- RFCs 3142, 2766 (deprecated by RFC 4966)
- NAT-PT: stateless extension of NAT to translate header formats and addresses
  - IPv6 nodes behind translator attain full IPv6 functionality
  - Stateless protocol translation by SIIT (RFC 2765)
- NAPT-PT: Statefull address + port translation (RFC 2766)
- Scenario:
  - New ‚domains' from Internet devices (telephones, cars, ...)
  - When a pure IPv6 configuration should/must be used

Agenda

- Motivation
- Basic IPv6 Architecture
- Migration: Transition and Coexistence
- Lessons Learned & Future Trends: Beyond IPv6?

Lessons Learned

- IPng deployment
  - Internet is inert "victim" of IPv4 success
  - Internet is "victim" of its uniqueness constraint
- Development – deployment of Internet innovations
  - Clear trend: broadening of the range of applications
  - Unclear: "who steers the IP layer" – Pipe owners pushing packets versus user-driven, intelligent layer 3 services
- Internet design – Quo Vadis?
- Routing – *the* scaling issue
- DNS – inflexible, updates too slow

Issue: Economic Models for Internet Operation

- Several players:
  - Infrastructure providers (pipes, routers, hosting)
  - Top-level ISPs (international transit providers)
  - Customer-oriented / regional ISPs
  - Edge domain operators (companies, consumer-ISPs)
- Problem: Grouping according to regions, not services
  - Little room for service innovation / dedication
- Approach: Virtualization of infrastructure
  - Allows for slicing of cables (λs), routers and servers
  - Offers playground for specialized service provisioning

Issue: Naming & Addressing

- IP addresses carry a dual meaning of Identifier (who) and locator (where)
  - Initially ID=name, Loc=address [Cohen, D., "On Names, Addresses and Routings", IEN 23, 1978]
  - TCP used addresses as identifiers
- Mobility re-raises the problem
  - MIPv6 creates an ID/Locator split on network layer
- Host Identity Protocol (HIP, RFC 5201) introduces abstraction layer between network and transport

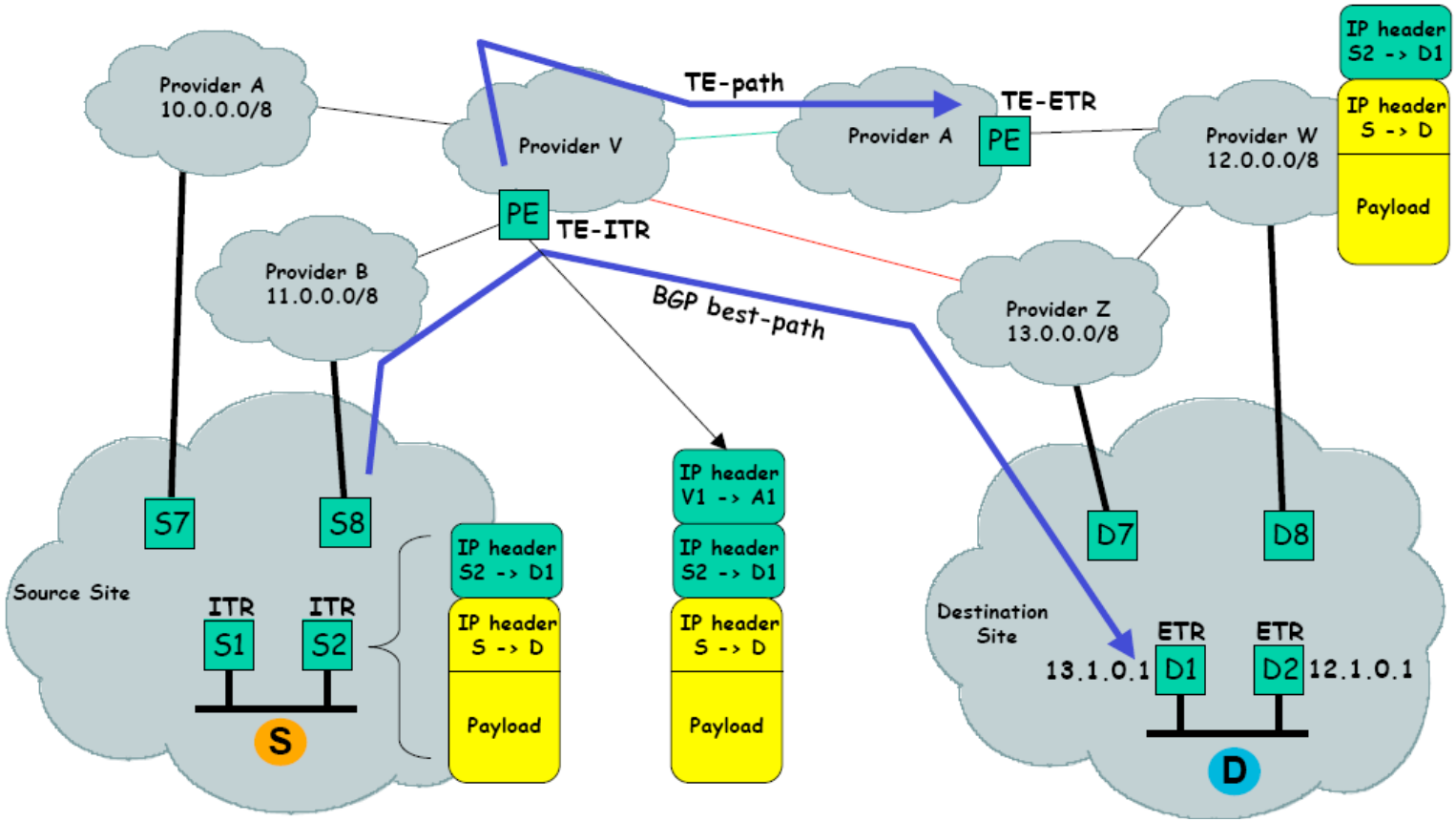
Issue: Route Scalability

- Routing table size and dynamics in the core increases due to growing numbers and heterogeneity at edge domains
- Two counter measures:
  - Aggregation – PA addressing as proposed by IPv6
  - Separation – decoupling of edges from core by a Map-Encapsulate mechanism
- Ongoing debate
  - Map/Encap opens freedom of design at edge domains

Locator ID Separation Protocol (LISP)

- *draft-farinacci-lisp*
- Sites / nodes have addresses (as in DNS): provider independent IDs
- Routers maintain a database of "Routing Locators (RLOCs)": provider-bound IP addresses of routers in a destination site
- Packets are tunnelled from egress to ingress router using RLOCs
- Problem: Router databases … to be learned from ICMP advertisements in LISP
- Result: Removes load from core routers

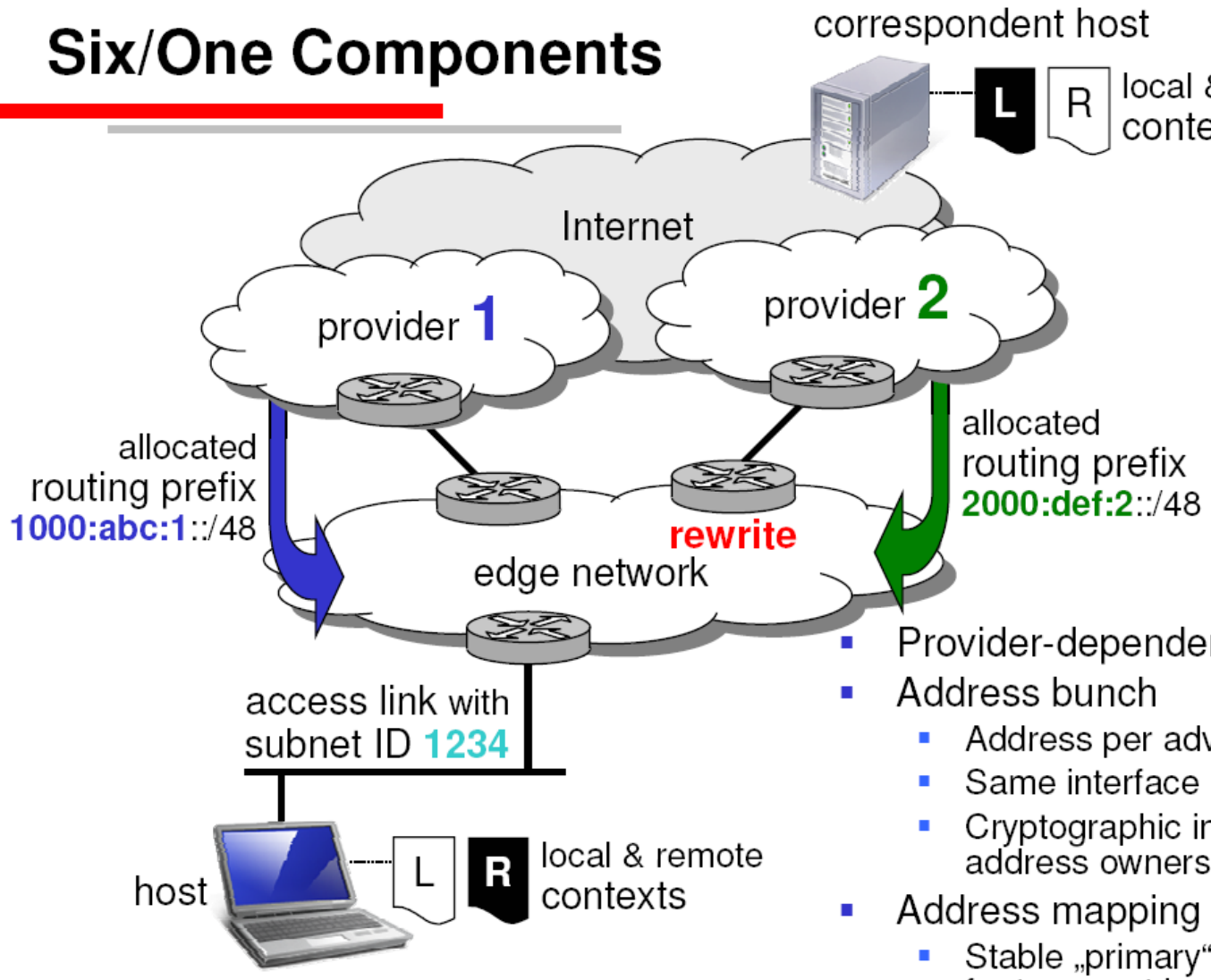
LISP Scenario



Six/One

- *draft-vogt-rrg-six-one*
- Nodes use bunches of provider-bound addresses per interface (different prefixes)
- Correspondent partners establish end-to-end context on which addresses to use in dialog
- Network can enforce prefix (provider) selection by address rewriting
- Bunches can be (partly) stored in DNS – initial reachability required

Six/One Components



- Provider-dependent addressing
- Address bunch
  - Address per advertised subnet prefix
  - Same interface ID across bunch
  - Cryptographic interface ID for address ownership proof
- Address mapping on host
  - Stable „primary“ address in bunch for transport layer and applications
  - Variable „active“ address on the wire
- Address rewriting in edge network
- Context pair for each host pair

Clean Slate Internet Initiatives

- Outside IETF/IRTF
- Focus scaling: overall logarithmic … as of DHTs (i^3)
- Focus virtualisation:
  Programmable virtual infrastructures for dedicated purposes
- Focus pluralisation/federation:
  Break with the paradigm of a universal network layer
- Major US initiative: GENI
  - Programmable routers & radios
  - Virtualised network (VINI) & wireless infrastructure
  - Monitoring & measurement
  - Federations
- EU: Future Internet Research and Experimentation – FIRE initiative
- Germany: German LAB (G-LAB)

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