IPv6 –
The New Internet Protocol

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Outline

- IPv4 Limitations
- IPv6
  - Features
  - Addresses
  - Autoconfiguration, Renumbering
  - Mobile IP
- 6bone, Vendor Support
- IPv6 @ DESY
- Summary
IPv4 Address Space

- 32-Bit Addresses => 4,294,967,296 Hosts
- Unusable areas have to be subtracted
  - Class D and E (Multicast and experimental), Null and Loopback Network, Private Addresses
- 3,706,650,624 usable Addresses
- H-Ratio (RFC 1715) predicts that only 200,000,000 Address will be usable due to insufficient address usage
  - DESY only uses 13,000 out of its 65,536 addresses
IPv4 Address Shortage

- Given the actual Internet growth, we will cross the 3.7 Billion Line in 2009, and we are currently crossing the 200 Million Line!
- It is already very hard to get IPv4 Addresses
  - China requested addresses to connect 60,000 schools and got **ONE** class B (same as DESY)
  - Countries late on the Internet have limited number of addresses (**ONE** class C!)
IPv4 Address Shortage

- Many ISPs are giving private addresses (192.168.x.x, 10.x.x.x) to their clients
  - These clients can communicate with the Internet via Network Address Translation (NAT)
  - Difficult to reach these computers directly
- Communication technologies need permanent connection to the Internet
  - Cellulare (UMTS will not work with IPv4)
  - VoIP, Videoconferencing, Radio/TV
  - Games, ...
IPv4 Address Shortage

- Network Address (NAT) and Port Translation (NAPT) can be seen as a solution, at least temporarily
  - Breaks the end-to-end model of IP
  - When a new application is not NAT-friendly, NAT devices requires an upgrade
  - Mandates that the network keeps the state of the connections
  - When there are many servers inside that need to be reachable for outside, NAT becomes difficult
IPv4 Problems

- We do have an IPv4 address shortage problem
- Current and future applications need globally scope reachable addresses
- Current and future applications need new functionalities not available by default in IPv4
- Need an enhanced version of the protocol but still want to keep IP => IPv6
  - IP Protocol #5 is already given to the Streaming Protocol (ST)
IPv6 Enhancements

- IPv4 was designed in the early 80s
  - Internet protocol needs are different now
- Many need “add-ons” to the protocol
  - Autoconfiguration
  - Renumbering
  - Mobile IP
  - Security
  - Quality of Service (QoS)
  - ...

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IPv6 History

- 1995: First specification: RFC 1883
- 1996: 6bone started
- 1999: Registries assign IPv6 prefixes
- 2000: Major vendors bundle IPv6 in their mainstream product line
- 2002: Provider start thinking about IPv6 production networks
IPv6 Features

- Larger address space
  - From 32 bits to 128 bits addresses enable
  - Global reachability
    - No hidden networks, hosts
    - All hosts can be reachable and be “servers”
- Auto configuration
  - Use of 64 bits for link-layer address encapsulation with warranty of uniqueness
- Efficient IP header and datagram
IPv6 Features

- Plug and play
  - By autoconfiguration
- Multihoming
  - Multiple prefixes for the same site enables multihoming
- Renumbering
  - By using autoconfiguration and multiple prefixes, renumbering becomes doable
IPv6 Features

- Less number of header fields enables
  - Routing efficiency
  - Performance
  - Forwarding rate scalability
- Extensibility of header
  - Better handling of options
  - No checksum (is done on layer 2 and 4, UDP!)
- 64 bits aligned (modern processors)
- Flow label
IPv6 Features

- Security
- Mobility
  - Much more optimized in IPv6 (Mobile IP)
- Multicast usage
  - No broadcast
  - Efficient use of the network
  - Scoped groups
IPv6 Addresses

- IPv4 = 32 bits (131.169.040.032)
- IPv6 = 128 bits
  - This is NOT 4 times the number of addresses
  - This is 4 times the number of bits
  - \( \sim 3.4 \times 10^{38} \) possible addressable nodes
  - \( \sim 10^{30} \) addresses per person on the planet
  - Well, as with any numbering scheme, we will be using only a portion of the full address space
IPv6 Addresses

  - Where x is a 16 bit hexadecimal field
    - 2001:0000:1234:0000:0000:C1C0:ABCD:0876

- Case insensitive
  - 2001:0000:1234:0000:0000:C1C0:abcd:0876

- Leading zeros in a field are optional
  - 2001:0:1234:0:0:C1C0:ABCD:876

- Successive fields of 0 are represented as ::
  - 2001:0:1234::C1C0:ABCD:876
  - Not 2001::1234::C1C0:ABCD:876
IPv6 Addresses

- Other examples
  - FF02:0:0:0:0:0:0:1 = FF02::1
  - 0:0:0:0:0:0:0:1 = ::1
  - 0:0:0:0:0:0:0:0 = ::

- In a URL it is enclosed in brackets

- Cumbersome for users
  - Mostly for diagnostic purposes
  - Should use fully qualified Domain Names
Address Types

- Unicast
  - Unspecified
  - Loopback
  - Scoped addresses (!)
    - Link-local
    - Site-local
  - Aggregatable Global
  - Multicast
  - Anycast (!)
Address Types, Unspecified ::

- Used as a placeholder when no address available
  - Initial DHCP request
  - Duplicate Address Detection
- Like 0.0.0.0 in IPv4
- 0:0:0:0:0:0:0:0 or ::
Address Types, Loopback ::1

- Identifies self
- Localhost
- Like 127.0.0.1 in IPv4
- 0:0:0:0:0:0:0:1 or ::1
- To find out if your IPv6 stack works:
  - Ping6 ::1
Address Types, Link Local

- Scoped address (new in IPv6)
- Scope = local link (i.e. VLAN, subnet)
  - Only to be used between nodes of the same link
  - Cannot be routed
- Automatically configured on each interface
  - Uses the interface identifier (based on MAC)
- Format:
  - FE80:0:0:0::<interface identifier>
- Gives an address to start communications
Address Types, Site-Local

- Scoped address
- Scope = site (a network of links)
  - Only to be used between nodes of the same site
  - Cannot be routed outside the site
  - Very similar to IPv4 private addresses
- Not configured by default
- Format:
  - FEC0:0:0:<subnet id>:<interface id>
  - Subnet id = 16 bits = 65K subnets
Address Types, Aggregatable Global

- Allocated by IANA
  - To Regional Registries
  - Then to Tier-1 Providers (i.e. DFN)
    - Called Top-level Aggregator (TLA)
  - Then to Intermediate Providers (i.e. DESY)
    - Called Next-Level Aggregator (NLA)
  - Then to sites
  - Then to subnets
Address Types, Aggregatable Global

- Structure: TLA, RES, NLA, SLA, Interface
- 128 bits total, 48 bits prefix to site, 16 bits for the subnets, 64 bits for host part
- Consists of the following
  - 3 bits 001 (10% of the total address space reserved)
  - 13 bits for the TLA ($2^{13}$ TLA ~8K TLAs)
  - 8 bits reserved
  - 24 bits for the NLAs ($2^{24}$ NLA per TLA, 16M NLAs
  - 16 bits for the site subnets (64K subnets)
  - 64 bits for the interface identifier ($2^{64}$ nodes/subnet)
IPv6 Address Allocation

- Address allocation
  - Only to providers
  - Started on July 1999
- IANA started with 2001::/16 and give /23 to registries
- Registries give /35 to ISPs
- ISPs give /48 to organisations
- If ISP exhausted its /35 it would go back to registry and receive a /29
Address Types, Multicast

- Multicast = one-to-many
- No broadcast in IPv6, Multicast is used instead, mostly on local links
- Scoped addresses:
  - Node, link, site, organization, global
- Format:
  - FF<flag><scope>::<multicast group>
- All nodes on local link: ping6 FF02::1
- All router on local link: ping6 FF02::2
Address Types, Anycast

- One-to-nearest: great for discovery functions
- A few examples:
  - Mobile IPv6 home-agent discovery
  - Discussions for DNS discovery
- Defines an anycast group
  - 7 bits
  - Targeted to a specific subnet
- Format: <prefix 64>:FFF...F<7bits>
Summary IPv6 Address Features

- IPv6
  - Has a much larger address space
  - Has specific formatting for addresses
  - Introduces new kind of addresses (scoped)
- IPv6 nodes have many addresses and need to select which one to use
- Addressing architecture has a lot of space available for future use
IPv6 over Ethernet

- Interface identifier for stateless autoconfiguration
  - EUI-64 interface identifier
    - Building a 64bit address from 48bit MAC-Address:
    - i.e. MAC = 00:90:27:17:fc:0f
    - Is split in two parts and ff:fe inserted
      => 00:90:27:ff:fe:17:fc:0f
    - Seconds bit of first byte is the “universal/local” (U/L) bit and is set to 1
    => 02:90:27:FF:FE:17:FC:0F
IPv6 Neighbor Solicitation

- Sent by a node to determine link-layer address of a neighbor
- =~ ARP request
- Packet description
  - Source Address = link-local address
  - Destination = solicited-node multicast address
  - Data contains link-layer address of source
  - Query is: give me your link-layer address?
IPv6 Neighbor Advertisement

- Response to a Neighbor Solicitation
- ~= ARP response
- Includes my MAC address so you can send me information
- Packet description
  - Source address = link-local address of source
  - Destination = destination address
  - Data contains link-layer address of me
IPv6 Router Advertisement

- Max. time between advertisements can be in the range from 4 and 1800 seconds
- The advertisement has a lifetime (=0 if not a default router)
- Advertisement contains on or more prefixes
- Specifies if stateful or stateless autoconfiguration is to be used
- Plays a key role in site renumbering
Autoconfiguration Process

- Host configured for autoconfiguration
- Host boots. Sends a Router Solicitation
- Host receives the Router Advertisement, specifying prefix, lifetimes, default router, ...
- Host generates its IP address by merging:
  - Received subnet prefix (64 bits)
  - Interface address modified for EUI-64 format
- Host verifies usability by doing the Duplicate Address Detection process
Renumbering

- Hosts renumbering
  - On the router, decrease the lifetime of the prefix in the router advertisement
  - Start advertising the new prefix
  - Host configure the new address and start using it
- Connections will continue without interruption
- Host must always listen to router advertisements, even after autoconfiguration
Summary IPv6 ICMP

- ICMPv6 is similar to IPv4, but is enhanced for Neighbor Discovery functions
- Neighbor discovery enables ARP like functions and autoconfiguration
- Renumbering is achieved by modifying the advertisements of prefixes
- Duplicate address detection is used to ensure uniqueness of addresses on link
IPv6 and DNS

- New Records
  -AAAA
    - Equivalent to IPv4 A record
    - Supported in Bind since 4.9.5
  -A6
    - Same function as AAAA record
    - Helps renumbering by cutting the request in subrequests
    - Supported in Bind 9
IPv6 and DNS

- PTR record
  - Defines the mapping from an IPv6 address to a name
  - Same record as for IPv4
  - New top level for the IPv6 space is used: was ip6.int, is moving to ip6.arpa (IPv4 in-addr.arpa)
  - May use the new records: DNAME
Renumbering and DNS

- When renumbering a site, the 64 rightmost bits do not change but the leftmost do
- DNS Name-to-address mapping must be updated to reflect the new leftmost bits
- A6 divide the Name-to-address query into subqueries
  - Give me the rightmost 64 bits and the other entry that points to to leftmost 64 bits
  - The entry for the leftmost 64 bits will be the only place in the DNS tree to change
Mobile IP

- Mobility gets more important, we expect our network communication to reconnect automatically when we change our point of attachment to the network
  - Like Roaming in the mobile telephone world
- Basically only the network prefix is changing
  - Autoconfiguration gives network connectivity
  - Home Agent redirects packets to Mobile Nodes new “care-of” address
  - Packets are send to the Mobile Nodes new address with home address in Destination Options header
IPSec and IPv6

- IPSec has AH and ESP functions
  - IPSec Authentication Header (AH)
    - Integrity
    - Authentication of the source
  - Ipsec Encapsulating Security Payload (ESP)
    - Confidentiality
    - Integrity of the inner packet
    - Authentication of the source
  - Implemented via Header ExtensionAddress scan takes longer ...

- Easier to deploy because no NAT involved
IPv6 Transition

- Many new technologies didn't succeed because of lack of transition scenarios/tools
- IPv6 was designed at the beginning with transition in mind: no D day
- For end-systems, there is:
  - Dual Stack approach
- For network integration, there is:
  - Tunnels
  - IPv6-only to IPv4-only: some sort of translation
Tunneling IPv6 in IPv4

- IPv6 encapsulated in IPv4
  - IP protocol 41
- Many topologies possible
  - Router to router
  - Host to router
  - Host to host
- The tunnel node endpoints take care of the encapsulation. This process is “transparent” to the other nodes.
6bone

- IPv6 networks interconnected through tunnels and some native links
- Started in 1996
- As of yesterday: 60 countries, 1279 sites
- Volunteer-based, production IPv6 is managed by service providers
- 6bone nodes have test address
- Native IPv6 is coming (Abilene)
6bone
IPv6 OS Support: Sun

- Has an implementation since 1995
- Many Sun engineers involved in the specifications and IETF work
- Bundled and supported since Feb. 2000 in Solaris 8
- Most networking applications converted
- Third parties?
IPv6 OS Support: Microsoft

- Has an implementation since 1998, done by Microsoft Research
  - IPv6 Research Stack available for NT and 2000
- XP includes IPv6 Stack
  - More developed than Research Stack, still prerelease code (activate with “ipv6 install”)
  - Production code with SP1
- Most basic networking applications converted: IE, RPC-based apps, Microsoft Networks, ...
IPv6 OS Support: Linux

- **Kernel:**
  - 2.2.x: basic support
  - 2.4.x: Improved and usable in production

- **Libc:**
  - 2.0 compliant with RFC 2553

- **Lots of application on modern distributions are IPv6 ready**
  - Ping, dig, bind, apache, mozilla, ...
IPv6 OS Support: Cisco

- Has an implementation since 1995
- Principal inventor of IPv6 is a Cisco engineer (Steve Deering)
- Bundled and supported starting in 12.2(1)T, March 2001
  - Most platforms supported (except router blades in switches and GSR hardware support)
- Clear commitment and roadmap
IPv6 Applications

- Web:
  - Apache 2.0
  - Patch for Apache 1.3
  - Mozilla has native support
- DNS: Bind 9 or > 8.3.1
- Mail: Sendmail 8.12.2
- Openssh 3.1
- And already many more
IPv6 @ DESY

- Address is registered
  - 2001:0638:0700::/48

- Infrastructure is being set up:
  - 1 IPv6 Router
  - Currently working on DNS server
  - Currently working on 6bone connectivity
  - Test environment available in 2 weeks?

- Only basic experience, no applications tested yet
Summary

- Clear need for IPv6
  - Mobile Devices (Mobile IP)
  - Address Shortage
  - Videoconferencing
- Basic Support from all Vendors available
- The question in not will IPv6 come, the question is when