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IK1552 Internetworking/Internetteknik

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IK1552 Spring 2019, Period 4 2019.04.07

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Module 10: IPv6

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with James F. Kurose and Keith W. Ross, *Computer Networking: A Top-Down Approach*.

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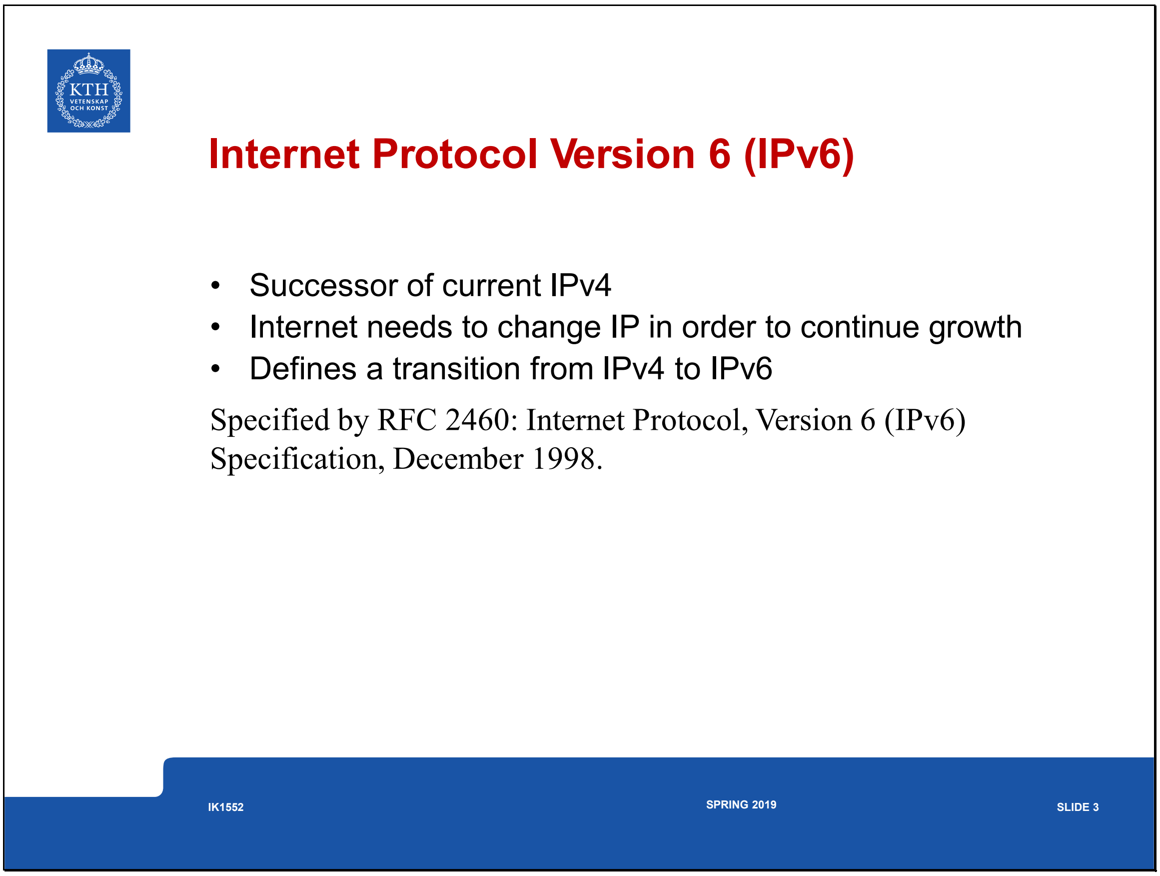

S. Deering and R. Hinden, ‘Internet Protocol, Version 6 (IPv6) Specification’, *Internet Request for Comments*, vol. RFC 1883 (Proposed Standard), December 1995, Available at http://www.rfc-editor.org/rfc/rfc1883.txt

S. Deering and R. Hinden, ‘Internet Protocol, Version 6 (IPv6) Specification’, *Internet Request for Comments*, vol. RFC 2460, December 1998, Available at http://www.rfc-editor.org/rfc/rfc2460.txt

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Growth

- IPv4 serves a market doubling every ~12 months
- In addition, new and very large markets are developing rapidly:
  - Nomadic Computing
  - Networked Entertainment
  - Device Control

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Nomadic Computing

Wireless computers
- supporting multimedia
- replacing pagers, cellular telephones, …

IPv6 includes support for mobility
- low overhead (?)
- auto configuration
- mobility

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Networked Entertainment

Your TV will be an Internet Host!
[consider the network attached Personal Video Recorders (PVR), such as TiVo's DVR, SONICblue's ReplayTV, Sony's SVR-2000, Philips' PTR, …)]

- 500 channels of television
- large scale routing and addressing
- auto-configuration
- requires support for real-time data

SonicBlues's ReplayTV 4000 a networked Digital Video Recorder (DVR) {i.e., coder/decoder + very big disk) that takes advantage of your broadband Internet connection - enables you to capture and transfer videos.

Providing "narrowcast" content via broadband ⇒ all the time is "primetime".

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Device Control

- Control everyday devices for
  - lightning, heating and cooling, motors, ...
  - new street light controllers already have IP addresses!
  - electrical outlets with addresses
  - networked vehicles (within the vehicle†, between vehicles, and vehicles to infrastructure)‡
- Market size is enormous
- Solution must be
  - simple, robust, easy to use
  - very low cost
  - potential power savings by (remote) network management based control may be quite large

There is already a networked: Toaster, a Coke machine, … .

† On-Board Diagnostic systems (OBD-II), see slide 8 [Murai 2005]
‡ See InternetCAR, slide 4 (showing a Yokohama City bus) [Murai 2005]

Jun Murai, "WIDE report", 5th CAIDA-WIDE Workshop, Information Sciences Institute, Marina del Rey, CA, 15 March 2005 http://www.caida.org/projects/wide/0503/slides/murai.pdf

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IPv6 features

- Expanded Addressing Capabilities
  - 128 bit address length
  - supports more levels of hierarchy
  - improved multicast routing by using a scope field
  - new cluster addresses to identify topological regions
- Header Format Simplification
  - some IPv4 fields have been dropped, some made optional
  - header is easier to compute
- Improved Support for Extensions and Options
  - more efficient for forwarding of packets
  - less stringent limits to length of options
  - greater flexibility for introduction of future options
- Flow Labeling Capability
  - labeling of packets belonging to a particular “flow”
  - allows special handling of, e.g., real-time, packets
- Authentication and Privacy Capabilities

  Extensions to support authentication, data integrity, and (optional) data confidentiality

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IPv6 header format

version 4 bits	Class 8 bits	flow label 20-bits
"payload" length (in octets) 16 bits	next header 8 bits	hop limit 8 bits
Source Address 128 bits		
Destination Address 128 bits		

IPv6 header (total length = 40 bytes)

IPv6: 6 fields + 2 addresses versus

IPv4: 10 fixed fields + 2 addresses + options

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Demultiplexing

Initially, it was assumed that by keeping the version field the same that IPv4 and IPv6 could be mixed over the same links with the same link drivers.

However, now IPv6 will be demultiplexed at the link layer: hence, IPv6 been assigned the Ethernet type 0x86DD (instead of IPv4's 0x8000)

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Simplifications

IPv6 builds on 20 years of internetworking experience - which lead to the following simplifications and benefits:

Simplification	Benefits
Use fixed format headers	Use extension headers instead, thus no need for a header length field, simpler to process
Eliminate header checksum	Eliminate need for recomputation of checksum at each hop (relies on link layer or higher layers to check the integrity of what is delivered)
Avoid hop-by-hop segmentation	No segmentation, thus you must do **Path MTU discovery** or only send small packets (1996: 536 octets, 1997: proposed 1500 octets) (for observed PMTUs see [Cho 2005]) • This is because we should have units of **control** based on the units of **transmitted** data.
Eliminate Type of Service (ToS) field	Instead use (labeled) flows

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Kenjiro Cho, “Measuting IPv6 Network Quality” (part 2), *Internet Iniative Japan (IIJ)* / WIDE, 5th CAIDA-WIDE Workshop, Information Sciences Institute, Marina del Rey, CA, 15 March 2005 http://www.caida.org/projects/wide/0503/slides/kenjiro-2.pdf

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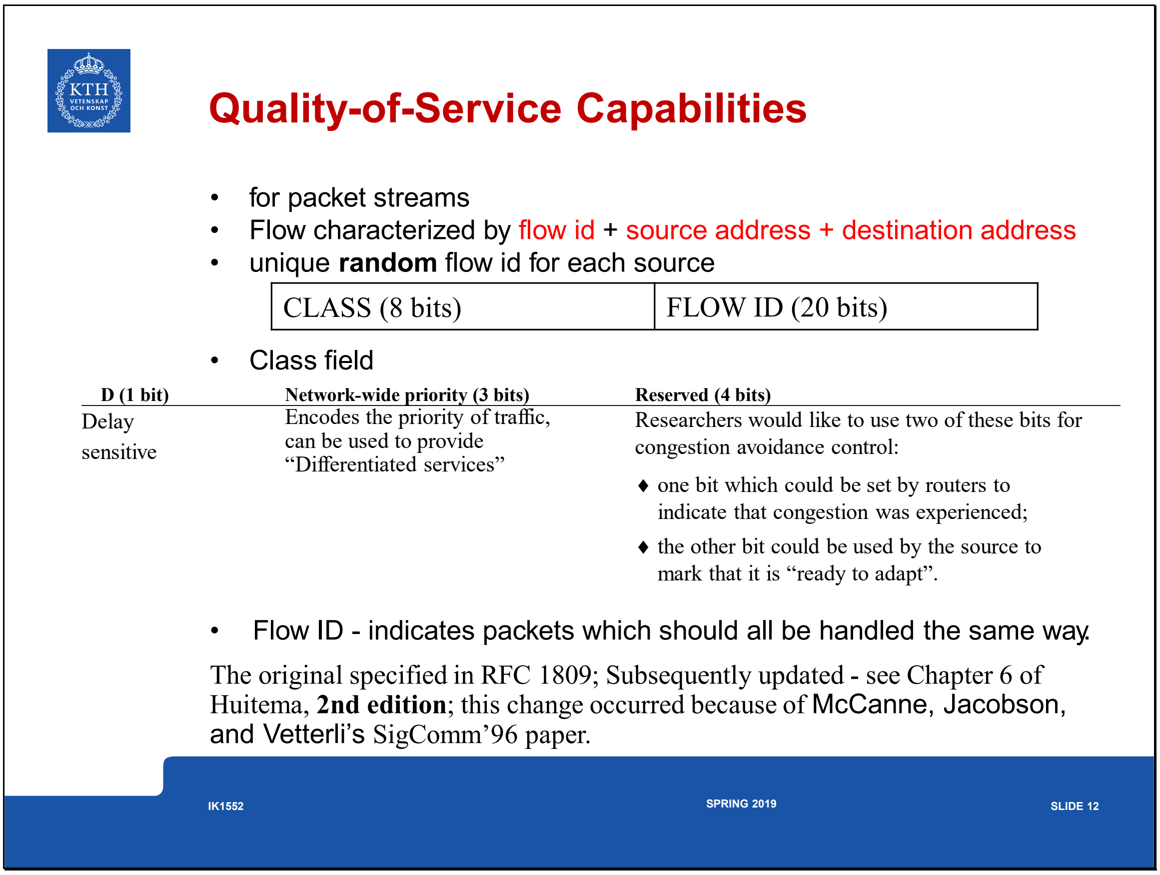

C. Partridge, 'Using the Flow Label Field in IPv6', *Internet Request for Comments*, vol. RFC 1809 (Informational), June 1995, Available at http://www.rfc-editor.org/rfc/rfc1809.txt

S. McCanne, V. Jacobson, M. and Vetterli, "Receiver-driven Layered Multicast", ACM SIGCOMM, August 1996, Stanford, CA, pp. 117-130. *ftp://ftp.ee.lbl.gov/papers/mccanne-sigcomm96.ps.gz*

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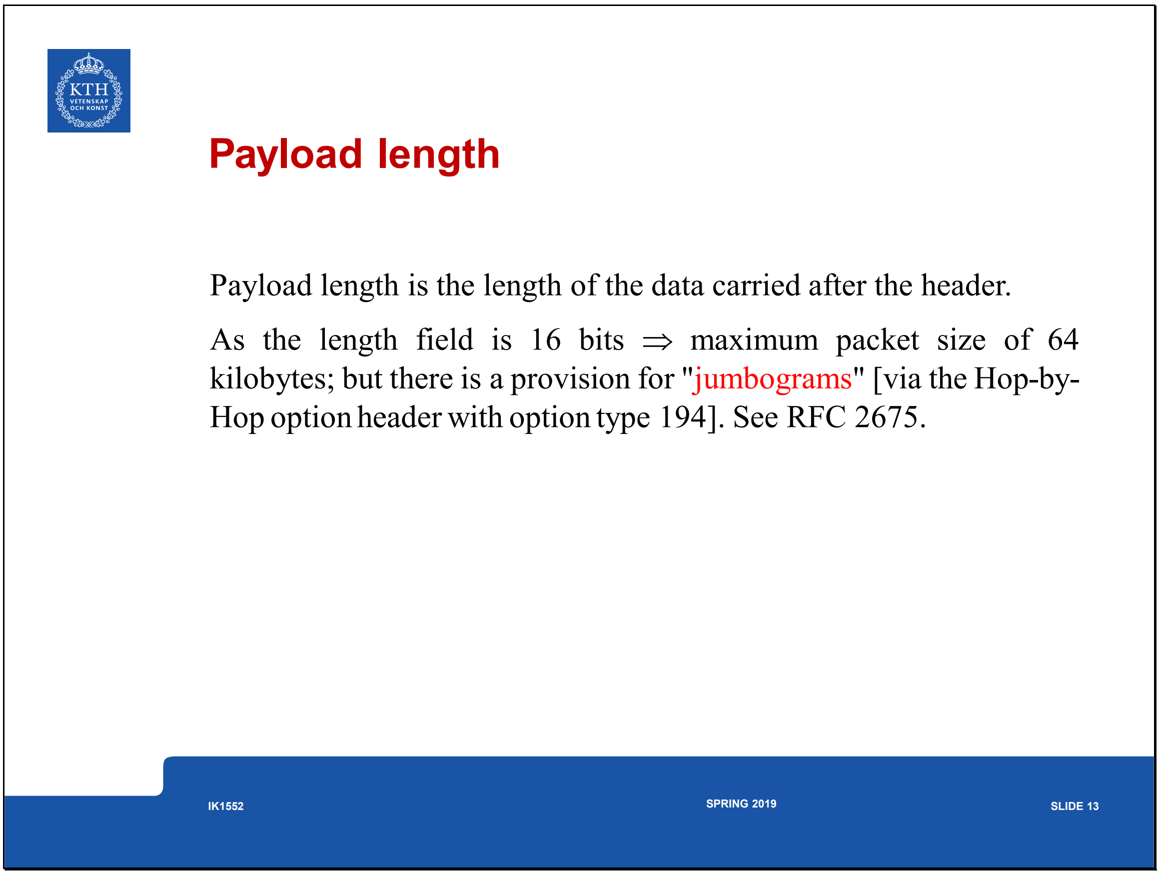

D. Borman, ‘TCP and UDP over IPv6 Jumbograms’, *Internet Request for Comments*, vol. RFC 2147 (Proposed Standard), May 1997, Available at http://www.rfc-editor.org/rfc/rfc2147.txt

D. Borman, S. Deering, and R. Hinden, ‘IPv6 Jumbograms’, *Internet Request for Comments*, vol. RFC 2675 (Proposed Standard), August 1999, Available at http://www.rfc-editor.org/rfc/rfc2675.txt

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IPv4 Protocol type ⇒ IPv6 Next Header type

Tells how to interpret the next header which follows, it is either the payload type or the type of the next header. [Payload types use the IPv4 protocol type values]

Decimal	Keyword	Header type
0	HBH	Hop-by-hop options
2	ICMP	IPv6 ICMP
3	GGP	Gateway-to-Gateway Protocol
5	ST	Stream
6	TCP	Transmission Control Protocol
17	UDP	User Datagram Protocol
43	RH	IPv6 Routing Header
44	FH	IPv6 Fragmentation Header
45	IDRP	Inter-domain Routing Protocol
51	AH	Authentication Header
52	ESP	Encrypted Security Payload
59	Null	No next Header (IPv6)
60		IPv6 Destination Options Header
88	IGRP	IGRP
89	OSPF	Open Shortest Path First
255		Reserved

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Extension headers

- Each header is a multiple of 8 octets long
- order (after IPv6 header):
  - Hop-by-hop option,
  - Destination options header (1)
  - Routing header,
  - Fragment header,
  - Authentication header,
  - Encapsulating security payload header,
  - Destination options header (2)
  - Followed by the upper layer header (e.g., TCP, UDP, …)

So a TCP packet looks like:

IPv6 header Next Header = **TCP**	TCP header + data

If we wanted to explicitly route the above packet, we simply add a routing header:

IPv6 header Next Header = **Routing**	Routing header Next Header = **TCP**	TCP header + data

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Addressing

- 128 bits long
- three types: unicast, multicast, anycast

Unicast	identifies exactly one interface
Multicast	identifies a group of interfaces; a packet sent to a multicast address will be delivered to all members of the group
Anycast	delivered to the nearest member of the group

- 2^{96} times more addresses than IPv4 are available !!!

IPv6 addresses per m^2

Earth: 511,263,971,197,990 m^2

$\Rightarrow$ 665,570,793,348,866,943,898,599 / m^2

- pessimistic estimate with hierarchies: ~1,564 addresses / m^2
- optimistic: 3,911,873,538,269,506,102 /m^2

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Writing an IPv6 address

The 128 bit IPv6 address is written as eight 16 bit integers using hexadecimal digits.

The integers are separated by colons, for example:
2001:0DB8:7654:3210:FEDC:BA98:7654:3210

A number of abbreviations are allowed:

- leading zeros in integers can be suppressed
- a single set of consecutive 16 bit integers with the value null, can be replaced by double colon, i.e., 2001:DB8:0:0:0:0:7654:3210 becomes 2001:DB8::7654:3210
- When an IPv4 address is turned into an IPv6 address we prepend 96 bits of zeros; but we can write it as:
  ::10.0.0.1 - hence combining dotted-decimal and IPv6 forms
- Prefixes can be denoted in the same manner as for IPv4, i.e., CIDR:
  2001:DB8::/32 - for a 32 bit long prefix

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Address Allocation [RFC 4291]

Binary prefix	Hex. prefix	Assignment
00...0 (128 bits)	::/128	Unspecified
00...1 (128 bits)	::1/128	Loopback
1111 1110 10	FE80::/10	Link-Local unicast
1111 1111	FF00::/8	Multicast

Everything else is Global Unicast

"Future specifications may redefine one or more sub-ranges of the Global Unicast space for other purposes, but unless and until that happens, implementations must treat all addresses that do not start with any of the above-listed prefixes as Global Unicast addresses." [RFC 4291, section 2.4]

http://www.iana.org/assignments/ipv6-address-space/ipv6-address-space.xhtml

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R. Hinden and B. Haberman, 'Unique Local IPv6 Unicast Addresses', *Internet Request for Comments*, vol. RFC 4193 (Proposed Standard), October 2005, Available at http://www.rfc-editor.org/rfc/rfc4193.txt

R. Hinden and S. Deering, 'IP Version 6 Addressing Architecture', *Internet Request for Comments*, vol. RFC 4291 (Draft Standard), Feb. 2006 [Online]. Available: http://www.rfc-editor.org/rfc/rfc4291.txt

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Global Unicast Addresses

RFC 2374 defined an IPv6 address allocation structure that which featured Top Level Aggregator (TLAs) and Next Level Aggregator (NLAs) - this has been replaced (see RFC 3587) by a coordinated allocation policy defined by the Regional Internet Registries (RIRs) [ripe-267]

The Subnet Local Aggregator (SLAs) of RFC 2374 ⇒ now called the “subnet ID”

001 (3 bits)	global routing prefix (45 bits)	Subnet ID (16 bits)	Interface ID (64 bits)

“IANA unicast address assignments are currently limited to the IPv6 unicast address range of 2000::/3.” - http://www.iana.org/assignments/ipv6-address-space/ipv6-address-space.xhtml

For a table of IPv6 unicast assignment see

http://www.iana.org/assignments/ipv6-unicast-address-assignments

R. Hinden, M. O’Dell, and S. Deering, ‘An IPv6 Aggregatable Global Unicast Address Format’, *Internet Request for Comments*, vol. RFC 2374 (Historic), July 1998, Available at http://www.rfc-editor.org/rfc/rfc2374.txt

R. Hinden, S. Deering, and E. Nordmark, ‘IPv6 Global Unicast Address Format’, *Internet Request for Comments*, vol. RFC 3587 (Informational), August 2003, Available at http://www.rfc-editor.org/rfc/rfc3587.txt

APNIC, ARIN, and RIPE NCC, "IPv6 Address Allocation and Assignment Policy", Document ID: ripe-267, January 22, 2003 *http://www.ripe.net/ripe/docs/ipv6policy.html*

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IPv6 unicast assignments (as of 2016-01-28)

Prefix	Designation	Date	Status	Note
2001:0000::/23	IANA	1999-07-01	ALLOCATED	2001:0000::/23 is reserved for IETF Protocol Assignments [RFC2928]. 2001:0000::/32 is reserved for TEREDO [RFC4380]. 2001:1::1/128 is reserved for Port Control Protocol Anycast [RFC7723]. 2001:2::/48 is reserved for Benchmarking [RFC5180]. 2001:3::/32 is reserved for AMT [RFC7450]. 2001:4:112::/48 is reserved for AS112-v6 [RFC7535]. 2001:5::/32 is reserved for EID Space for LISP [draft-ietf-lisp-eid-block]. 2001:10::/28 is deprecated (previously ORCHID) [RFC4843]. 2001:20::/28 is reserved for ORCHIDv2 [RFC7343]. 2001:db8::/32 is reserved for Documentation [RFC3849]. For complete registration details, see [IANA registry iana-ipv6-special-registry].
2001:0200::/23	APNIC	1999-07-01	ALLOCATED	
2001:0400::/23	ARIN	1999-07-01	ALLOCATED	
2001:0600::/23	RIPE NCC	1999-07-01	ALLOCATED	
2001:0800::/23	RIPE NCC	2002-05-02	ALLOCATED	
2001:0a00::/23	RIPE NCC	2002-11-02	ALLOCATED	
2001:0c00::/23	APNIC	2002-05-02	ALLOCATED	2001:db8::/32 reserved for Documentation [RFC3849]. For complete registration details, see [IANA registry iana-ipv6-special-registry].

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http://www.iana.org/assignments/ipv6-unicast-address-assignments

R. Hinden, S. Deering, R. Fink, and T. Hain, 'Initial IPv6 Sub-TLA ID Assignments', *Internet Request for Comments*, vol. RFC 2928 (Informational), September 2000, Available at http://www.rfc-editor.org/rfc/rfc2928.txt

C. Huitema, 'Teredo: Tunneling IPv6 over UDP through Network Address Translations (NATs)', *Internet Request for Comments*, vol. RFC 4380 (Proposed Standard), February 2006, Available at http://www.rfc-editor.org/rfc/rfc4380.txt

S. Kiesel and R. Penno, 'Port Control Protocol (PCP) Anycast Addresses', *Internet Request for Comments*, vol. RFC 7723 (Proposed Standard), Jan. 2016 [Online]. Available: http://www.rfc-editor.org/rfc/rfc7723.txt

C. Popoviciu, A. Hamza, G. V. de Velde, and D. Dugatkin, 'IPv6 Benchmarking Methodology for Network Interconnect Devices', *Internet Request for Comments*, vol. RFC 5180 (Informational), May 2008, Available at http://www.rfc-editor.org/rfc/rfc5180.txt

G. Bumgardner, 'Automatic Multicast Tunneling', *Internet Request for Comments*, vol. RFC 7450 (Proposed Standard), Feb. 2015 [Online]. Available: http://www.rfc-editor.org/rfc/rfc7450.txt

J. Abley, B. Dickson, W. Kumari, and G. Michaelson, ‘AS112 Redirection Using DNAME’, *Internet Request for Comments*, vol. RFC 7535 (Informational), May 2015 [Online]. Available: http://www.rfc-editor.org/rfc/rfc7535.txt

P. Nikander, J. Laganier, and F. Dupont, ‘An IPv6 Prefix for Overlay Routable Cryptographic Hash Identifiers (ORCHID)’, *Internet Request for Comments*, vol. RFC 4843 (Experimental), April 2007, Available at http://www.rfc-editor.org/rfc/rfc4843.txt

J. Laganier and F. Dupont, ‘An IPv6 Prefix for Overlay Routable Cryptographic Hash Identifiers Version 2 (ORCHIDv2)’, *Internet Request for Comments*, vol. RFC 7343 (Proposed Standard), Sep. 2014 [Online]. Available: http://www.rfc-editor.org/rfc/rfc7343.txt

G. Huston, A. Lord, and P. Smith, ‘IPv6 Address Prefix Reserved for Documentation’, *Internet Request for Comments*, vol. RFC 3849 (Informational), July 2004, Available at http://www.rfc-editor.org/rfc/rfc3849.txt

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IPv6 unicast assignments (as of 2016-01-28)

Prefix	Designation	Date	Status	Note
2001:0e00::/23	APNIC	2003-01-01	ALLOCATED	
2001:1200::/23	LACNIC	2002-11-01	ALLOCATED	
2001:1400::/23	RIPE NCC	2003-02-01	ALLOCATED	
2001:1600::/23	RIPE NCC	2003-07-01	ALLOCATED	
2001:1800::/23	ARIN	2003-04-01	ALLOCATED	
2001:1a00::/23	RIPE NCC	2004-01-01	ALLOCATED	
2001:1c00::/22	RIPE NCC	2004-05-04	ALLOCATED	
2001:2000::/20	RIPE NCC	2004-05-04	ALLOCATED	
2001:3000::/21	RIPE NCC	2004-05-04	ALLOCATED	
2001:3800::/22	RIPE NCC	2004-05-04	ALLOCATED	
2001:3c00::/22	IANA		RESERVED	2001:3c00::/22 is reserved for possible future allocation to the RIPE NCC.
2001:4000::/23	RIPE NCC	2004-06-11	ALLOCATED	
2001:4200::/23	AFRINIC	2004-06-01	ALLOCATED	
2001:4400::/23	APNIC	2004-06-11	ALLOCATED	
2001:4600::/23	RIPE NCC	2004-08-17	ALLOCATED	
2001:4800::/23	ARIN	2004-08-24	ALLOCATED	
2001:4a00::/23	RIPE NCC	2004-10-15	ALLOCATED	
2001:4c00::/23	RIPE NCC	2004-12-17	ALLOCATED	
2001:5000::/20	RIPE NCC	2004-09-10	ALLOCATED	
2001:8000::/19	APNIC	2004-11-30	ALLOCATED	
2001:a000::/20	APNIC	2004-11-30	ALLOCATED	
2001:b000::/20	APNIC	2006-03-08	ALLOCATED	

KTH has a /48 allocation from SUNET: 2001:6b0:1::/48
from this CoS has: 2001:6b0:1:10f0::/64

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http://www.lan.kth.se/ipv6/

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IPv6 unicast assignments (as of 2016-01-28)

Prefix	Designation	Date	Status	Note
2002:0000::/16	6to4	2001-02-01	ALLOCATED	2002::/16 is reserved for 6to4 [RFC3056]. For complete registration details, see [IANA registry iana-ipv6-special-registry].
2003:0000::/18	RIPE NCC	2005-01-12	ALLOCATED	
2400:0000::/12	APNIC	2006-10-03	ALLOCATED	2400:0000::/19 was allocated on 2005-05-20. 2400:2000::/19 was allocated on 2005-07-08. 2400:4000::/21 was allocated on 2005-08-08. 2404:0000::/23 was allocated on 2006-01-19. The more recent allocation (2006-10-03) incorporates all these previous allocations.
2600:0000::/12	ARIN	2006-10-03	ALLOCATED	2600:0000::/22, 2604:0000::/22, 2608:0000::/22 and 260c:0000::/22 were allocated on 2005-04-19. The more recent allocation (2006-10-03) incorporates all these previous allocations.
2610:0000::/23	ARIN	2005-11-17	ALLOCATED	
2620:0000::/23	ARIN	2006-09-12	ALLOCATED	

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IPv6 unicast assignments (as of 2016-01-28)

Prefix	Designation	Date	Status	Note
2800:0000::/12	LACNIC	2006-10-03	ALLOCATED	2800:0000::/23 was allocated on 2005-11-17. The more recent allocation (2006-10-03) incorporates the previous allocation.
2a00:0000::/12	RIPE NCC	2006-10-03	ALLOCATED	2a00:0000::/21 was originally allocated on 2005-04-19. 2a01:0000::/23 was allocated on 2005-07-14. 2a01:0000::/16 (incorporating the 2a01:0000::/23) was allocated on 2005-12-15. The more recent allocation (2006-10-03) incorporates these previous allocations.
2c00:0000::/12	AFRINIC	2006-10-03	ALLOCATED	
2d00:0000::/8	IANA	1999-07-01	RESERVED	
2e00:0000::/7	IANA	1999-07-01	RESERVED	
3000:0000::/4	IANA	1999-07-01	RESERVED	
3ffe::/16	IANA	2008-04	RESERVED	3ffe:831f::/32 was used for Teredo in some old but widely distributed networking stacks. This usage is deprecated in favor of 2001::/32, which was allocated for the purpose in [RFC4380]. 3ffe::/16 and 5f00::/8 were used for the 6bone but were returned. [RFC5156]
5f00::/8	IANA	2008-04	RESERVED	3ffe::/16 and 5f00::/8 were used for the 6bone but were returned. [RFC5156]

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Interface ID

Must be unique to the link, but there are some advantages of making it more globally unique.

Hence, most will be based on the IEEE EUI-64 format, but with the “u” (unique) bit inverted.

- The “u” bit is the 7th most significant bit of a 64 bit EUI.
- The inversion was necessary because 0:0:0:0 is a valid EUI, but this would collide with one of the IPv6 special addresses.
- u=1, when the address comes from a valid EUI, and is 0 otherwise.

To go from a 48 bit IEEE 802, you insert 0xFFFE in between the 3rd and 4th octets of an IEEE 802 address, i.e., 123456789abc becomes 123456FFFE789abc.

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Special Address Formats

Unspecified address

"::" == "0:0:0:0:0:0:0:0 (::/128) - can only be used as a source address by a station which does not yet have an address

Loop-back address

0:0:0:0:0:0:0:1 (::1/128) - used to send an IPv6 datagram to yourself

IPv4-based address

prefix the 32 bit IPv4 address with 96 zero bits

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Link local addresses

Link local address are simply unique to a given link - they can be used by stations that have not yet been assigned a provider-based address.

1111 1110 10 (10 bits)	0 (54 bits)	Interface ID (64 bits)

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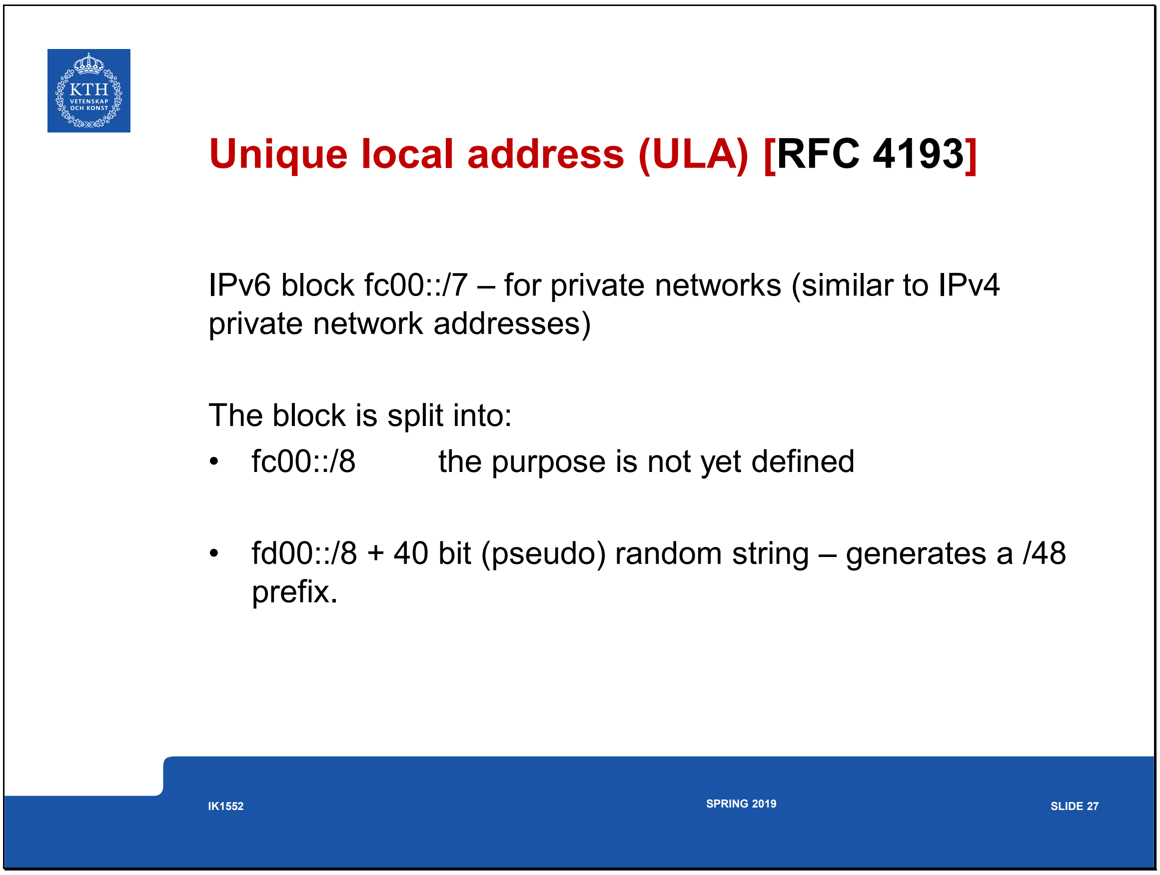

R. Hinden and B. Haberman, 'Unique Local IPv6 Unicast Addresses', *Internet Request for Comments*, vol. RFC 4193 (Proposed Standard), October 2005, Available at http://www.rfc-editor.org/rfc/rfc4193.txt

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Multicast Addresses

ff00::0/8

1111 1111	Flags 0RPT	Scope	112 bit - group id

T = 0 well-known permanent (assigned by the IANA)

T = 1 non-permanent

P: see RFC 3306

R: see RFC 3956

Scope	Purpose
0	reserved
1	Interface local scope
2	link local scope
3	unassigned
4	Admin-Local scope
5	site local scope
6, 7	unassigned
8	organization local scope
9, A, B, C, D	unassigned
E	global scope
F	reserved

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http://www.iana.org/assignments/ipv6-multicast-addresses/ipv6-multicast-addresses.xhtm

B. Haberman and D. Thaler, ‘Unicast-Prefix-based IPv6 Multicast Addresses’, *Internet Request for Comments*, vol. RFC 3306 (Proposed Standard), August 2002, Available at http://www.rfc-editor.org/rfc/rfc3306.txt

P. Savola and B. Haberman, ‘Embedding the Rendezvous Point (RP) Address in an IPv6 Multicast Address’, *Internet Request for Comments*, vol. RFC 3956 (Proposed Standard), November 2004, Available at http://www.rfc-editor.org/rfc/rfc3956.txt

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Permanently assigned groups

For example, group 0x43 has been assigned to the Network Time Protocol (NTP), hence:

FF01::43	represents all NTP servers on the same node as the sender
FF02::43	represents all NTP servers on the same link as the sender
FF05::43	represents all NTP servers on the same site as the sender
FF08::43	represents all NTP servers within the same organization as the sender
FF0E::43	represents all NTP servers in the Internet

IANA has assigned a whole series of group identifiers, including:

FF0X:0:0:0:0:0:0	Reserved multicast address - this can not be used within any scope
FF01:0:0:0:0:0:1	All Nodes on this node address
FF02:0:0:0:0:0:1	All Nodes on this link address
FF01:0:0:0:0:0:2	All Routers on this node address
FF02:0:0:0:0:0:2	All Router address on this link

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Multicast Multimedia conferences

FF0X:0:0:0:0:2:8000 .. FF0X:0:0:0:0:2:FFFF multimedia conferences

X=2 -- this link

X=5 -- this site

Use SAP to announce the conference - repeatedly until the end of the conference.

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Prefix for IPv6 documentation

The IPv6 unicast address prefix `2001:DB8::/32` is reserved for use in examples for books, RFCs, … [RFC 3849].

Note that this is a **non-routable** range - to help avoid problems!

G. Huston, A. Lord, and P. Smith, 'IPv6 Address Prefix Reserved for Documentation', *Internet Request for Comments*, vol. RFC 3849 (Informational), July 2004, Available at http://www.rfc-editor.org/rfc/rfc3849.txt

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Anycast

Sending a packet to a generic address to get a specific service from the “nearest” instance. This puts the burden of determining which instance to deliver it to on the routing system.

Requires defining a router entry for each anycast address.
Subnet Anycast Address:

Subnet prefix (n bits)	0 (128-n bits)

Thus the host ID of zero is treated as the subnet.

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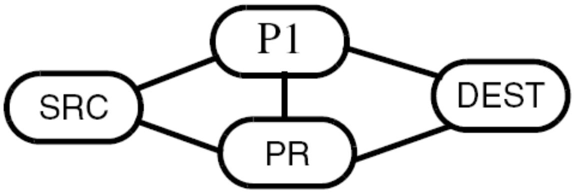
IPv6 Routing

- all standard routing protocols
- routing extensions
  - Provider Selection
  - Host Mobility (route to current location)
  - Auto-Readdressing (route to new address)



IPv6 Routing Option:
provider specifies: SRC, PR, P1, Dest
reply: Dest, PR, P1, SRC

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Routing header

Next Header (8 bits)	Header Ext Length (8 bits)	Routing Type=0 (8 bits)	Segments Left (8 bits)
reserved (32 bits)			
address[1] (128 bits)			
address[2]			
...			
address[n]			

Next Header identifies the next header in the chain of headers.

Header Ext. Length. - number of 64 bit words (not including the first 64 bits).

Routing type=0, is the generic routing header which all IPv6 implementations must support.

Number of Segments is the number of segments left in the list (between 0 and 23).

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Fragment header

Next Header (8 bits)	Reserved (8 bits)	Fragment offset (13 bits)	RESERVED (2 bits)	M (1 bit)
Identification				

Fragment offset - in units of 64 bit words, the field is the most significant 13 bits of a 16 bit words.

M == More fragment bit, set in all but the last fragment Identification - a 32 bit number

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Destination Options header

Next Header (8 bits)	Header Ext. Length (8 bits)	
Options		

Each options field is encoded as:

Option Type (8 bits)	Option Data Length (8 bits)	Option Data (n octets)

The option type:

Action (2 bits)	C (1 bit)	Number (6 bits)

Action tells what action must be taken if the processing nodes does **not** recognize the option.

Bits	Action
00	Skip over this option
01	Discard packet silently (i.e., without sending an ICMP report)
10	Discard packet and send an ICMP report - even if destination is multicast
11	Discard packet and send an ICMP report - only if destination is **not** multicast

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Destination Options header (continued)

C == change en route bit -- indicates that this option may be changed by intermediate relays on the way to the destination

Currently only two options are defined:

Pad1 == a null byte - for use in padding to a 64-bit boundary; note it does not have a null option length field after it - as it is the whole field

PadN - the length field says how many null bytes are needed to file to a 64-bit boundary.

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Hop-by-Hop Options header

Same basic format as Destination option header, but the hop-by-hop header will be processed at each hop along the way.

Next Header (8 bits)	Header Ext. Length (8 bits)	
Options		

Each options field is encoded as:

Option Type (8 bits)	Option Data Length (8 bits)	Option Data (n octets)

Currently three options are defined: Pad1, PadN, and

- Jumbo payload option (option type =194) - the option Data Length is 4 and is followed by a 32 bit Jumbo Payload Length value.

See RFC 2113: Router Alert Option and RFC 6398: IP Router Alert Considerations and Usage.

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D. Katz, 'IP Router Alert Option', *Internet Request for Comments*, vol. RFC 2113 (Proposed Standard), February 1997, Available at http://www.rfc-editor.org/rfc/rfc2113.txt

F. L. Faucheur, 'IP Router Alert Considerations and Usage', *Internet Request for Comments*, vol. RFC 6398 (Best Current Practice), October 2011, Available at http://www.rfc-editor.org/rfc/rfc6398.txt

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Security

- Header Authentication with signatures
  Must have support for Message Digest 5 (MD5) algorithm [RFC 1321]
- RFC 1810 examines MD5 performance
- Packet Encapsulation with e.g., DES

For more information see Chapter 5 of *IPv6*, 2nd edition, by Christian Huitema.

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R. Rivest, 'The MD5 Message-Digest Algorithm', *Internet Request for Comments*, vol. RFC 1321 (Informational), April 1992, Available at http://www.rfc-editor.org/rfc/rfc1321.txt

J. Touch, 'Report on MD5 Performance', *Internet Request for Comments*, vol. RFC 1810 (Informational), June 1995, Available at http://www.rfc-editor.org/rfc/rfc1810.txt

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IPSEC IPv6 implementation

The US Naval Research Lab (NRL) IPv6/IPsec Software Distribution

- a reference implementation of IPv6 and IP Security for the 4.4BSD-Lite networking software.
- Freely distributable (subject to U.S. export controls) and usable for commercial and non-commercial purposes (you must adhere to the NRL and UC Berkeley license terms) see also: *http://web.mit.edu/network/isakmp*

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IPv6 ICMP [RFC 2463]

Type (8 bits)	Code (8 bits)	Checksum (16 bits)
Message Body		

Currently defined ICMP Types

Type	Purpose
1	Destination Unreachable
2	Packet too big
3	Time exceeded
4	Parameter problem
128	Echo Request
129	Echo Reply

Type	Purpose
130	Group Membership Query
131	Group Membership Report
132	Group Membership Reduction
133	Router Solicitation
134	Router Advertisement
135	Neighbor Solicitation
136	Neighbor Advertisement
137	Redirect

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A. Conta and S. Deering, ‘Internet Control Message Protocol (ICMPv6) for the Internet Protocol Version 6 (IPv6) Specification’, *Internet Request for Comments*, vol. RFC 2463 (Draft Standard), December 1998, Available at http://www.rfc-editor.org/rfc/rfc2463.txt

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IPv6 ICMP Error Messages

Type: 1, 2, 3, or 4:

Type	Code	Checksum
Parameter		
As much of invoking packet as will fit - without the overall ICMP packet exceeding 576 octets		

For type 1 the code reveals the reason for discarding the datagram

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IPv6 ICMP Echo Request/Reply (PING)

Type: Echo Request = 128, Echo Reply = 129

Type	Code	Checksum	
Identifier		Sequence number	
Data			

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IPv6 ICMP and groups

Three group membership messages (type 130, 131, and 132):

Type	Code	Checksum
Maximum Response Delay		Unused
Multicast Address		

The Group Membership Reduction is used when a node leaves group. Reports are always sent to the same group address that is reported.

Maximum response delay is the time in milliseconds that the responding report messages can be delayed. Responding stations are supposed to spread their responses uniformly over this range of delays (to prevent everyone from responding at once).

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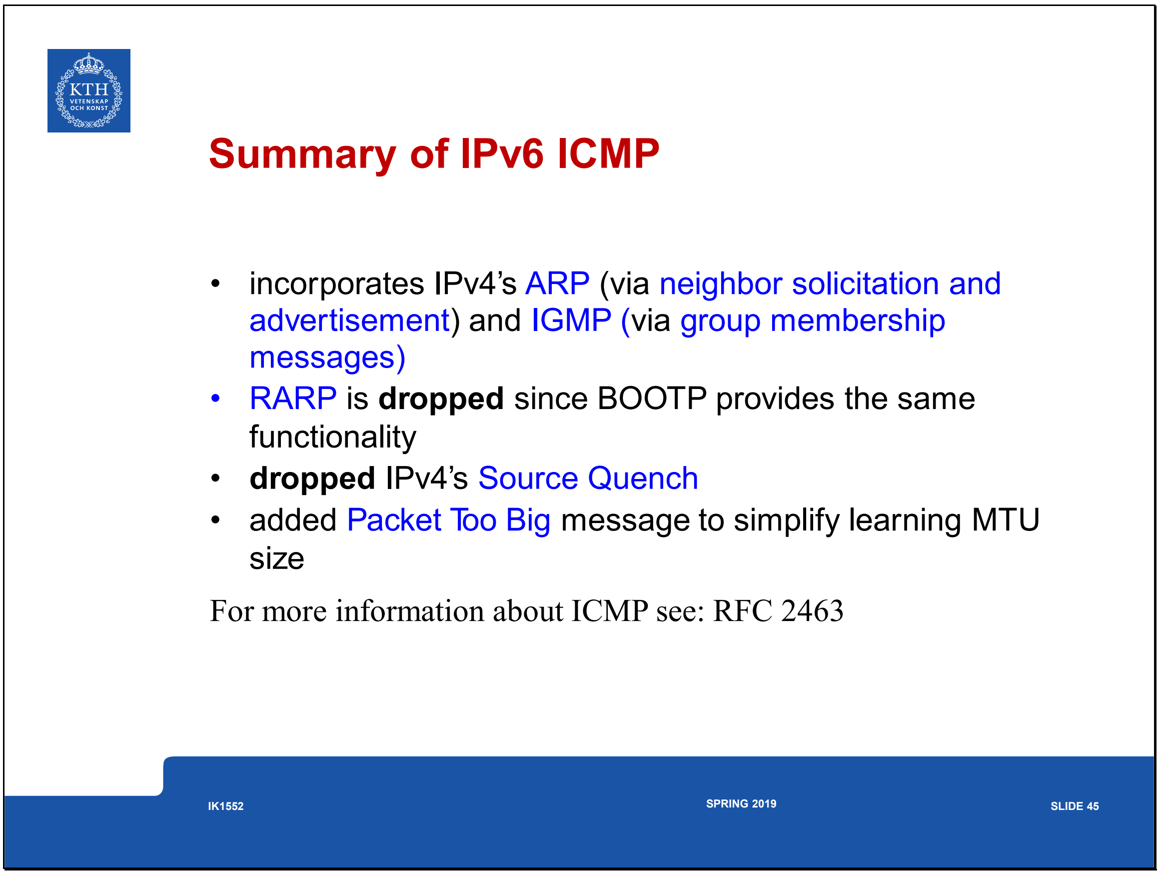

A. Conta and S. Deering, ‘Internet Control Message Protocol (ICMPv6) for the Internet Protocol Version 6 (IPv6)’, *Internet Request for Comments*, vol. RFC 1885 (Proposed Standard), December 1995, Available at http://www.rfc-editor.org/rfc/rfc1885.txt

A. Conta and S. Deering, ‘Internet Control Message Protocol (ICMPv6) for the Internet Protocol Version 6 (IPv6) Specification’, *Internet Request for Comments*, vol. RFC 2463 (Draft Standard), December 1998, Available at http://www.rfc-editor.org/rfc/rfc2463.txt

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DNS and IPv6

A new record type "AAAA" which contains a 128 bit address. Just as for the "in-addr.arpa" domain used for converting IPv4 addresses into names, IPv6 defines an "ipv6.int" domain: thus the address 2001:0DB8:1:2:3:4:567:89ab is represented as:
b.a.9.8.7.6.5.0.4.0.0.0.3.0.0.0.2.0.0.0.1.0.0.0.8.b.d.0.1.0.0.2.IP6.INT

For further information see RFC 3596.

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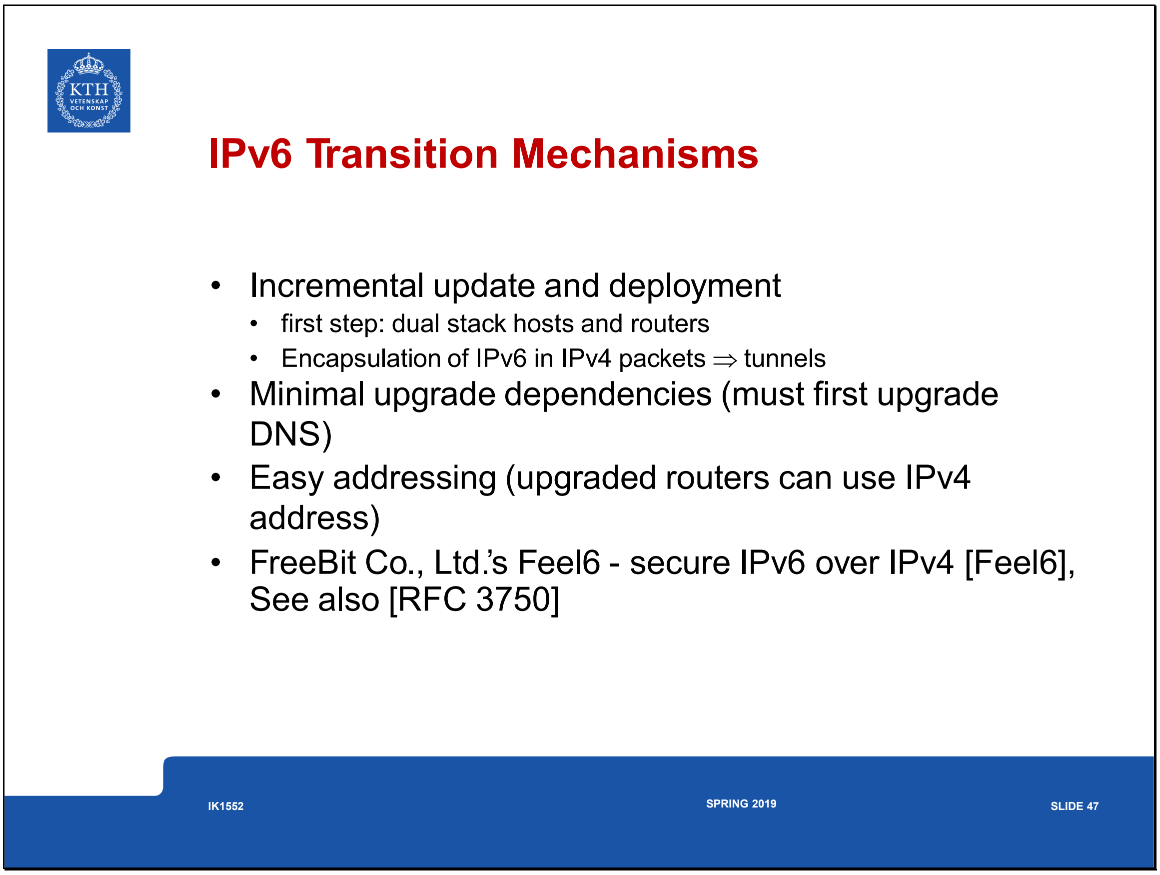
S. Thomson and C. Huitema, 'DNS Extensions to support IP version 6', *Internet Request for Comments*, vol. RFC 1886 (Proposed Standard), December 1995, Available at http://www.rfc-editor.org/rfc/rfc1886.txt

R. Bush, 'Delegation of IP6.ARPA', *Internet Request for Comments*, vol. RFC 3152 (Best Current Practice), August 2001, Available at http://www.rfc-editor.org/rfc/rfc3152.txt

S. Thomson, C. Huitema, V. Ksinant, and M. Souissi, 'DNS Extensions to Support IP Version 6', *Internet Request for Comments*, vol. RFC 3596 (Draft Standard), October 2003, Available at http://www.rfc-editor.org/rfc/rfc3596.txt

Slide 47



"Trying Out for Yourself: Smooth use of IPv6 from IPv4 by Feel6 Farm", IPv6Style, NTT Communications, 7 March 2003 (was at *http://www.ipv6style.jp/en/tryout/20030307/index.shtml*)

C. Huitema, R. Austein, S. Satapati, and R. van der Pol, 'Unmanaged Networks IPv6 Transition Scenarios', *Internet Request for Comments*, vol. RFC 3750 (Informational), April 2004, Available at http://www.rfc-editor.org/rfc/rfc3750.txt

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Why IPv6?

- solves Internet scaling problem
  - “eliminates” the problem of running out of addresses
  - allows route aggregation - which allows the size of the routing tables in the backbone routers to decrease
- flexible transition (interworks with IPv4)
- meets the needs of new markets
- new functionality
- real-time flows
- provider selection
- host mobility
- end-to-end security

auto-configuration - chapter 4, “Plug and Play” in *IPv6*, 2nd edition, by Christian Huitema - this a **very major** advantage of IPv6. See also [RFC 2462]

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S. Thomson and T. Narten, ‘IPv6 Stateless Address Autoconfiguration’, *Internet Request for Comments*, vol. RFC 2462 (Draft Standard), December 1998, Available at http://www.rfc-editor.org/rfc/rfc2462.txt

N. Moore, ‘Optimistic Duplicate Address Detection (DAD) for IPv6’, *Internet Request for Comments*, vol. RFC 4429 (Proposed Standard), April 2006, Available at http://www.rfc-editor.org/rfc/rfc4429.txt

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IPv6 networks

6Bone - http://www.gogo6.com/page/6bone a testbed for deployment of IPv6

- Note the phase out of the 3FFE::/16 prefix

  prefix returned to the unassigned address pool on 6 June 2006 [RFC 3701].

6NET http://www.6net.org/ - project co-funded by European Commission (concluded 30 June 2005), followed by http://www.6diss.org/

Internet Society Deploy 360 programme: http://www.internetsociety.org/deploy360/ipv6/

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R. Fink and R. Hinden, '6bone (IPv6 Testing Address Allocation) Phaseout', *Internet Request for Comments*, vol. RFC 3701 (Informational), March 2004, Available at http://www.rfc-editor.org/rfc/rfc3701.txt

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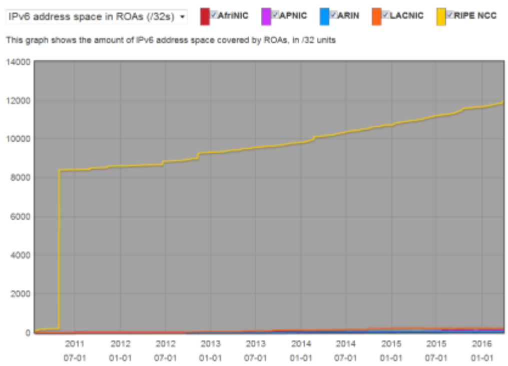
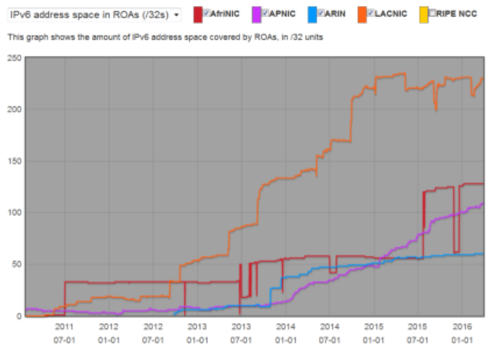
RIR assignments of IPv6 addresses





For the latest statistics see: https://labs.ripe.net/statistics?tags=ipv6
http://certification-stats.ripe.net/?type=roa-v6u

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RIPE, "Total number of allocated IPv6 prefixes per RIR on 13/05/2005", web page accessed 2005.05.14 *http://www.ripe.net/rs/ipv6/stats/index.html*

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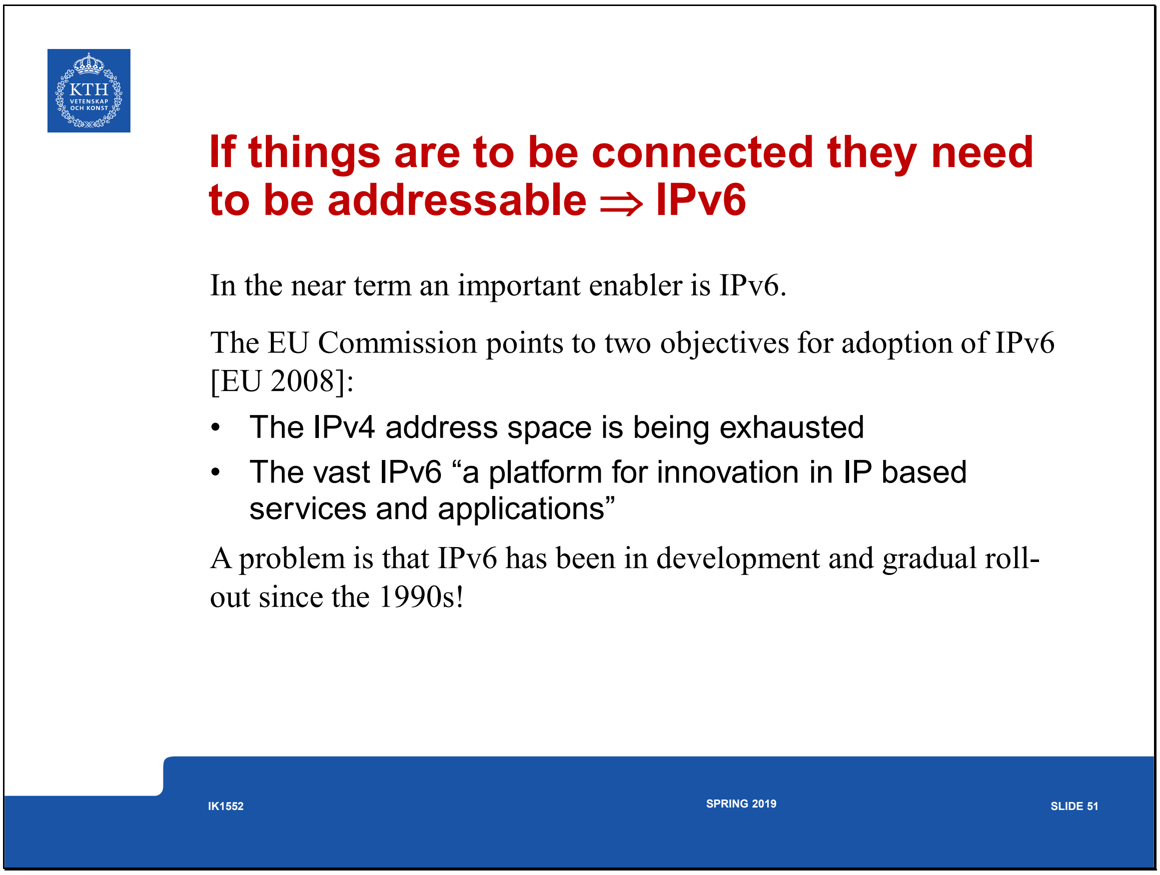

[EU 2008]: Advancing the Internet, Action Plan for the Deployment of Internet Protocol version 6 (Ipv6) In Europe, Communication from the Commission to the European Parliament, The Council, the European Economic and Social Committee and the Committee of the Regions, Brussels, 27 May 2008 http://ec.europa.eu/information_society/policy/ipv6/docs/european_day/communication_final_27052008_en.pdf

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Migration to IPv6

A set of priorities for the “migrating to the new Internet protocol IPv6” were published by the EU Commission in 2002 [EC 2002]:

1 “An increased support towards IPv6 in public networks and services,
2 The establishment and launch educational programmes on IPv6,
3 The adoption of IPv6 through awareness raising campaigns,
4 The continued stimulation of the Internet take-up across the European Union,
5 An increased support to IPv6 activities in the 6th Framework Programme,
6 The strengthening of the support towards the IPv6 enabling of national and European Research Networks,
7 An active contribution towards the promotion of IPv6 standards work,
8 The integration of IPv6 in all strategic plans concerning the use of new Internet services.”

[EC 2002]: European Commission, Next Generation Internet priorities for action in migrating to the new Internet protocol IPv6, Communication from the Commission to the Council and the European Parliament, 21 February 2002

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Where are ISPs?

"… There is evidence that less than half of the ISPs offer some kind of IPv6 interconnectivity. Only a few ISPs have a standard offer for IPv6 customer access service (mainly for business users) and provide IPv6 addresses.[1] The percentage of Autonomous Systems (typically ISPs and large end-users) that operate IPv6 is estimated at 2.5%.[2]
Accordingly, IPv6 traffic seems to be relatively low. Typically the IPv6/v4 ratio is less than 0.1% at Internet Exchange Points (of which about one in five supports IPv6).[3] However, this omits direct ISP to ISP traffic and IPv6 which is tunnelled and so appears at first glance to be still IPv4. Recent measurements suggest that this kind of traffic IPv6 which is "tunnelled" is growing."[EC 2002]

1 http://www.sixxs.net/faq/connectivity/?faq=ipv6transit
http://www.sixxs.net/faq/connectivity/?faq=native
2. http://bgp.he.net/ipv6-progress-report.cgi
3. "Traffic analysis at Amsterdam Internet Exchange reveals for the first 10 months 2007 average daily IP traffic of 177 Gbs; of which IPv6 traffic is 47 Mbs, i.e. 0.03%." http://www.ripe.net/ripe/meetings/ripe-55/presentations/steenman-ipv6.pdf

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http://www.sixxs.net/faq/connectivity/?faq=ipv6transit

http://www.sixxs.net/faq/connectivity/?faq=native

European Commission, Next Generation Internet priorities for action in migrating to the new Internet protocol IPv6, Communication from the Commission to the Council and the European Parliament, 21 February 2002

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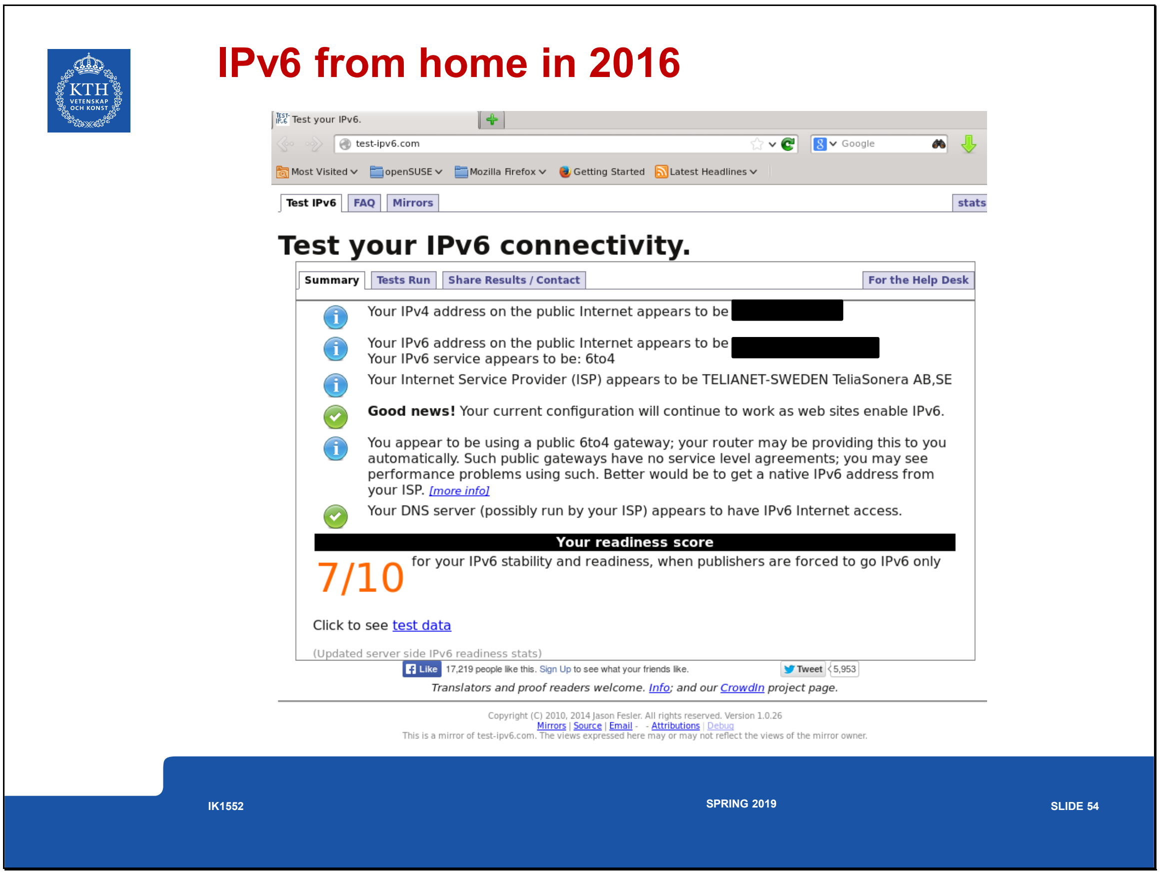
IPv6 from home in 2016
Test your IPv6.
test-ipv6.com
Most Visited openSUSE Mozilla Firefox Getting Started Latest Headlines
Test IPv6 FAQ Mirrors stats
Test your IPv6 connectivity.
Summary Tests Run Share Results / Contact For the Help Desk
Your IPv4 address on the public Internet appears to be [redacted]
Your IPv6 address on the public Internet appears to be [redacted]
Your IPv6 service appears to be: 6to4
Your Internet Service Provider (ISP) appears to be TELIANET-SWEDEN TeliaSonera AB,SE
Good news! Your current configuration will continue to work as web sites enable IPv6.
You appear to be using a public 6to4 gateway; your router may be providing this to you automatically. Such public gateways have no service level agreements; you may see performance problems using such. Better would be to get a native IPv6 address from your ISP. [more info]
Your DNS server (possibly run by your ISP) appears to have IPv6 Internet access.
Your readiness score
7/10 for your IPv6 stability and readiness, when publishers are forced to go IPv6 only
Click to see test data
(Updated server side IPv6 readiness stats)
Like 17,219 people like this. Sign Up to see what your friends like.
Tweet 5,953
Translators and proof readers welcome. Info; and our Crowdin project page.
Copyright (C) 2010, 2014 Jason Fesler. All rights reserved. Version 1.0.26
Mirrors | Source | Email - Attributions | Debug
This is a mirror of test-ipv6.com. The views expressed here may or may not reflect the views of the mirror owner.
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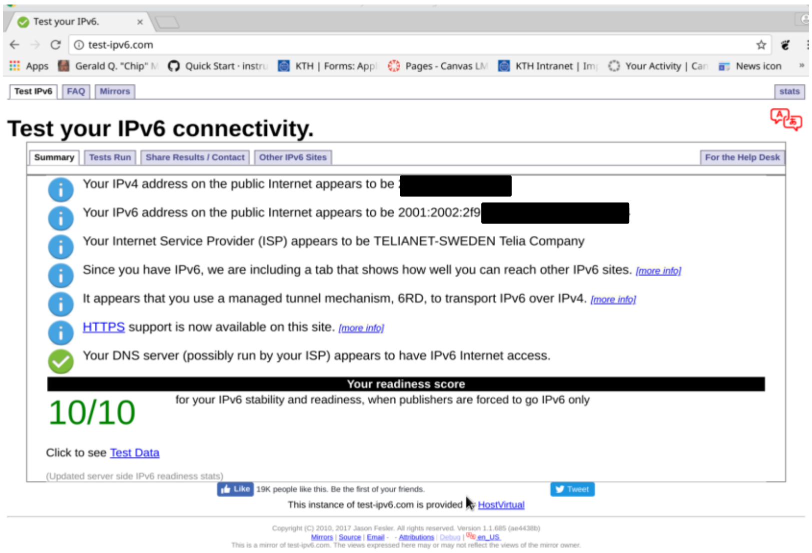
IPv6 from home in 2017



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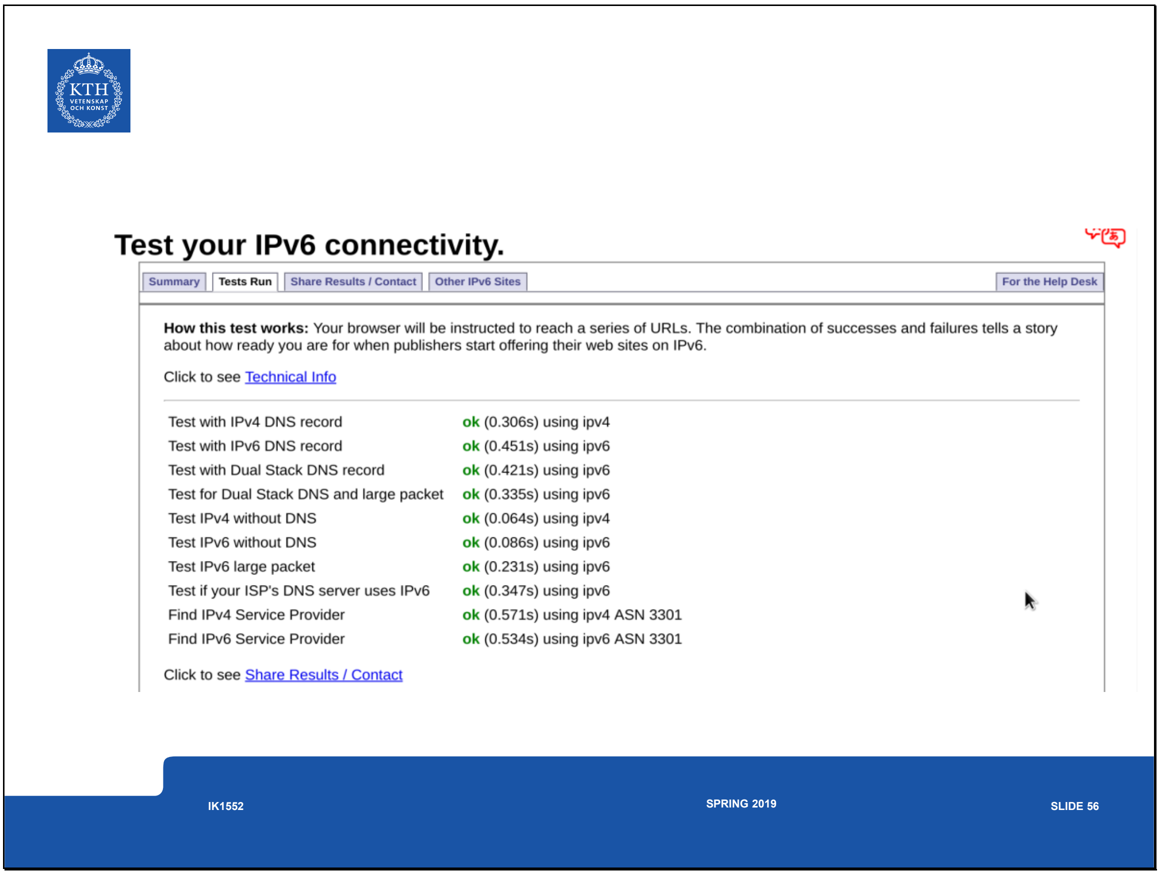
Test your IPv6 connectivity.
Summary
Tests Run
Share Results / Contact
Other IPv6 Sites
For the Help Desk
How this test works: Your browser will be instructed to reach a series of URLs. The combination of successes and failures tells a story about how ready you are for when publishers start offering their web sites on IPv6.
Click to see Technical Info
Test with IPv4 DNS record ok (0.306s) using ipv4
Test with IPv6 DNS record ok (0.451s) using ipv6
Test with Dual Stack DNS record ok (0.421s) using ipv6
Test for Dual Stack DNS and large packet ok (0.335s) using ipv6
Test IPv4 without DNS ok (0.064s) using ipv4
Test IPv6 without DNS ok (0.086s) using ipv6
Test IPv6 large packet ok (0.231s) using ipv6
Test if your ISP's DNS server uses IPv6 ok (0.347s) using ipv6
Find IPv4 Service Provider ok (0.571s) using ipv4 ASN 3301
Find IPv6 Service Provider ok (0.534s) using ipv6 ASN 3301
Click to see Share Results / Contact
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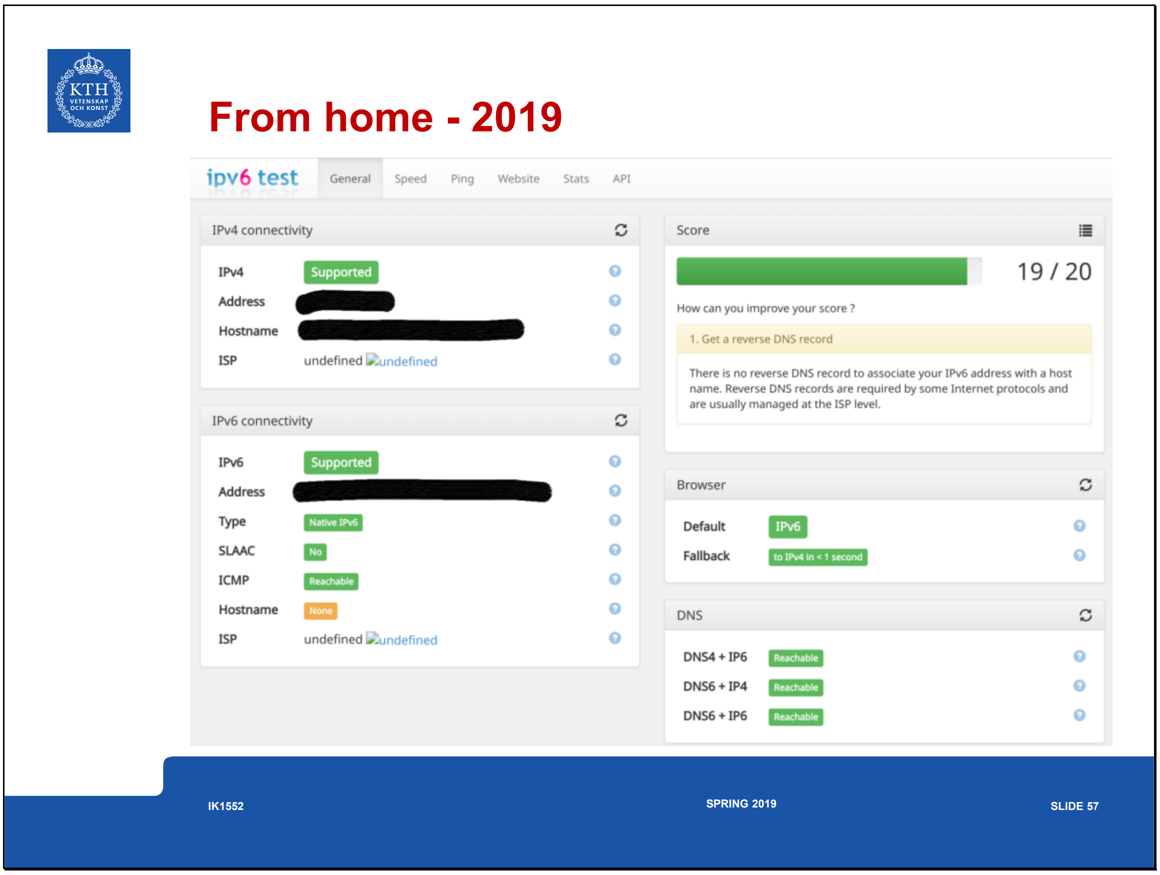
From home - 2019
ipv6 test
General
Speed
Ping
Website
Stats
API
IPv4 connectivity
IPv4 Supported
Address [redacted]
Hostname [redacted]
ISP undefined undefined
IPv6 connectivity
IPv6 Supported
Address [redacted]
Type Native IPv6
SLAAC No
ICMP Reachable
Hostname None
ISP undefined undefined
Score
19 / 20
How can you improve your score ?
1. Get a reverse DNS record
There is no reverse DNS record to associate your IPv6 address with a host name. Reverse DNS records are required by some Internet protocols and are usually managed at the ISP level.
Browser
Default IPv6
Fallback to IPv4 in < 1 second
DNS
DNS4 + IP6 Reachable
DNS6 + IP4 Reachable
DNS6 + IP6 Reachable
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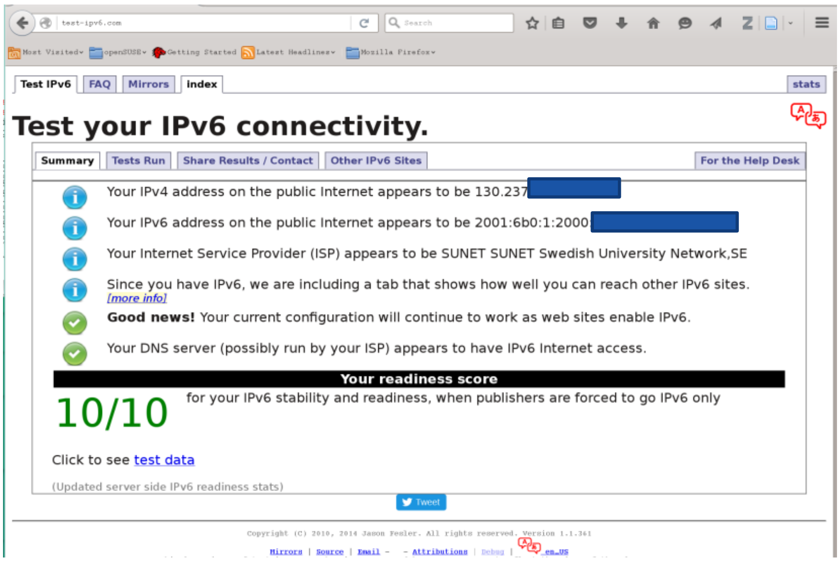
IPv6 from my office in 2016



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More tests from my office

Test IPv6 | FAQ | Mirrors | index

Test your IPv6 connectivity.

Summary | Tests Run | Share Results / Contact | Other IPv6 Sites

How this test works: Your browser will be instructed to reach a series of URLs. successes and failures tells a story about how ready you are for when publishers sites on IPv6.

Click to see Technical Info

Test with IPv4 DNS record	**ok** (0.179s) using ipv4
Test with IPv6 DNS record	**ok** (0.191s) using ipv6
Test with Dual Stack DNS record	**ok** (0.342s) using ipv6
Test for Dual Stack DNS and large packet	**ok** (0.183s) using ipv6
Test IPv4 without DNS	**ok** (0.360s) using ipv4
Test IPv6 without DNS	**ok** (0.347s) using ipv6
Test IPv6 large packet	**ok** (0.354s) using ipv6
Test if your ISP's DNS server uses IPv6	**ok** (0.340s) using ipv6
Find IPv4 Service Provider	**ok** (0.369s) using ipv4 ASN 1653
Find IPv6 Service Provider	**ok** (0.354s) using ipv6 ASN 1653

test-ipv6.com

See also http://test-ipv6.se/

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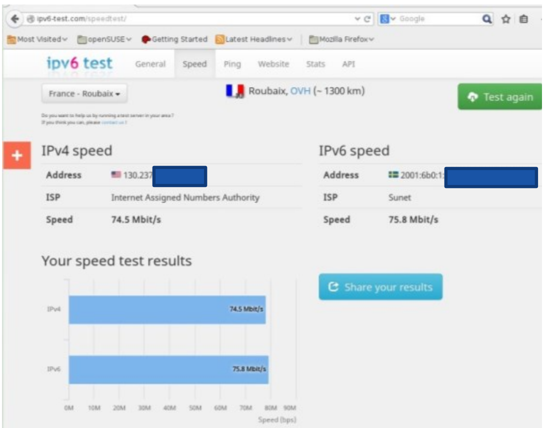
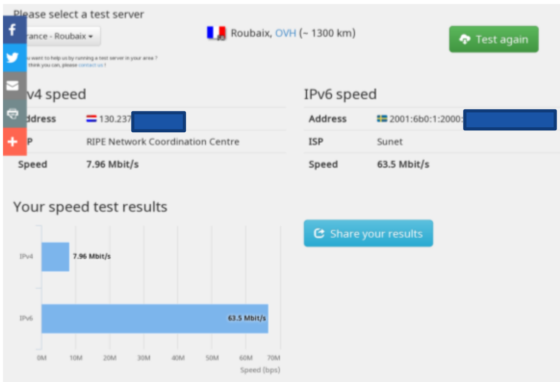
IPv4 versus IPv6 data rates



2015.04.19



2016.03.29

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Further information

See:

- http://www.ipv6.org/
- http://www.ipv6forum.com/
- Measurements of dual stack IPv6 implementations: http://mawi.wide.ad.jp/mawi/dualstack/ (old data – you might consider a new set of measurements in a course project)

See also: [Cho 2005 parts 1 and 2].

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Kenjiro Cho, "Measuting IPv6 Network Quality" (part 2), *Internet Iniative Japan (IIJ)* / WIDE, 5th CAIDA-WIDE Workshop, Information Sciences Institute, Marina del Rey, CA, 15 March 2005 http://www.caida.org/projects/wide/0503/slides/kenjiro-2.pdf

Kenjiro Cho, "Measuting IPv6 Network Quality" (part 1), 5th CAIDA-WIDE Workshop, Information Sciences Institute, Marina del Rey, CA, 15 March 2005 *http://www.caida.org/projects/wide/0503/slides/kenjiro-1.pdf*

Kenjiro Cho, "Measuting IPv6 Network Quality" (part 2), *Internet Iniative Japan (IIJ)* / WIDE, 5th CAIDA-WIDE Workshop, Information Sciences Institute, Marina del Rey, CA, 15 March 2005 *http://www.caida.org/projects/wide/0503/slides/kenjiro-2.pdf*

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Summary

In this module we have discussed: IPv6

- Adoption is increasing
- Try it from your home or office!

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¿Questions?