

A teal and black inflatable kayak is positioned on a sandy riverbank. The kayak has "TORTUGA" printed in large white letters on its side. The background shows a calm river reflecting the surrounding green foliage.

A Whirlwind Tour of IPv6

Differences and common features of IPv4 and IPv6

Agenda

- Reasons for IPv6
- Address schemas: IPv4 vs. IPv6
 - SLAAC: EUI-64 vs. Privacy Extension
- Link-local addresses
- Private addresses (ULA)
- Global addresses (GUA)
- Prefix Delegation
- Self-hosted Services for the Internet
 - „Dual Stack“ vs. „DS-Lite“
 - IPv4 \leftrightarrow IPv6 Gateway Technologies
- End-to-End Connectivity
 - No more NAT! / MTU discovery
 - Implications for Dynamic DNS / local firewalls

Reasons for IPv6

- **IPv4 address exhaustion**

- IPv4: 4 Bytes = $4 * 8 \text{ Bit} = 32 \text{ Bit}$
- example: 192.168.148.200

- **Larger address space**

- IPv6: 8 Words = $8 * 16 \text{ Bit} = 128 \text{ Bit}$
- example: 2001:16b8:2a60:6ef0:e922:304a:fec5:d131

- **Stateless address autoconfiguration (SLAAC)**

- automatic vs. static address assignments

- **Simplified processing by routers**

- fixed size headers (with optional extension headers)

- **Multicasting**

- instead of Broadcasting

- **Ipssec VPN protocol**

- also implemented for IPv4

Address schemas: IPv4 vs. IPv6

- IPv4 addresses (32 bits)
 - 4 decimal numbers: 0 – 255
 - separated by 3 dots: .
 - **network** + **host** part = 32 bits
 - Mostly only one address for each interface
 - CIDR notation:
 - 192.168.178.1/24
 - 24 bits for network: 192.168.178.0
 - 8 bits for host address: .1
 - 10.11.22.33/16
 - 16 bits for network: 10.11.0.0
 - 16 bits for host address: .22.33
 - 127.0.0.1/8
 - 8 bits for network: 127.0.0.0
 - 24 bits for host address: .0.0.1
- IPv6 addresses (128 bits)
 - 8 hexadecimal fields: 0 – ffff
 - separated by 7 colons: :
 - **network** part = 64 bits
 - **host** part = 64 bits
 - Usually more than one address for each interface
 - Special notations:
 - Leading zeros 0 may be dropped
 - Adjacent fields with all zeros can be written with double colons :: (allowed only one time)
 - CIDR notation is also possible:
 - 2001:16b8:2ab0:f000:f0ee:37ff:fe8c:5e73/64
 - network: 2001:16b8:2ab0:f000::/64
 - host: ::f0ee:37ff:fe8c:5e73/128

Host address: EUI-64 vs. Privacy Extension

- IPv4 addresses are either statically or dynamically assigned (via DHCP4).
- IPv6 addresses are either statically or self assigned (via router advertisements). DHCP6 is not often used.
- SLAAC addresses are either hardware derived (EUI-64) or deterministically generated.
- See “/etc/dhcpd.conf”:

```
# Generate SLAAC address using the  
Hardware Address of the interface  
#slaac hwaddr  
# OR generate Stable Private IPv6  
Addresses based from the DUID  
slaac private
```

- From MAC (48 bits) to EUI-64:

1. f2:ee:37:8c:5e:73
2. f2ee:3700:008c:5e73

xor

0200:00ff:fe00:0000

3. f0ee:37ff:fe8c:5e73

- From EUI-64 (64 bits) to MAC:

1. f0ee:37ff:fe8c:5e73

xor

0200:00ff:fe00:0000

2. f2ee:3700:008c:5e73
3. f2:ee:37:8c:5e:73

- Private host address:

- middle part is **not** ff:fe !
- e267:f3d3:f6cb:6611

Special addresses: IPv4 vs. IPv6

- IPv4 localhost / loopback addr.
 - 127.0.0.1/8
- IPv4 default route
 - 0.0.0.0/0
- IPv4 link-local addresses
Avahi / APIPA / Bonjour / zeroconf:
 - network: 169.254.0.0/16
- IPv4 documentation networks
 - 192.0.2.0/24
 - 198.51.100.0/24
 - 203.0.113.0/24
 - 233.252.0.0/24
- IPv6 localhost / loopback addr.
 - ::1/128
- IPv6 default route
 - ::/0
- IPv6 link-local addresses
 - network: fe80::/10
 - fe80::f0ee:37ff:fe8c:5e73/64
- IPv6 documentation network
 - 2001:db8::/32

Private addresses (ULA): IPv4 vs. IPv6

- IPv4 private network A
 - 10.0.0.0/8
- IPv4 private network B
 - 172.16.0.0/12 → 16 networks
 - from 172.16.0.0/16
 - thru 172.31.0.0/16
- IPv4 private network C
 - 192.168.0.0/16 → 256 networks
 - from 192.168.0.0/24
 - thru 192.168.255.0/24
- IPv4 benchmark tests
 - 198.18.0.0/15
- IPv4 IETF protocols
 - 192.0.0.0/24 → RFC-6333
- IPv4 shared address space for carrier-grade NAT (CGNAT)
 - 100.64.0.0/10
- IPv6 network range reserved for **Unique Local Addresses** within networks of private organizations
 - fc00::/7
- Usage in private IPv6 networks
 - fd00::/8 → 2⁵⁶ networks
 - from fd00:0000:0000:0000::/64
 - thru fdff:ffff:ffff:ffff::/64
- The 40 **green** bits are a global ID and should be chosen randomly:
 - fd00:dead:beef:cafe::/64
- The remaining 16 **purple** bits are a subnet ID and can be used to address 2¹⁶ (= 65.536) subnets within an organization:
 - fd00:dead:beef:cafe::/64

Global Unicast Addresses (GUA)

- IPv6 network range reserved for **Global Unicast Addresses**
 - `2000::/3` → 2^{61} networks
 - from `2000:0000:0000:0000::/64`
 - thru `3fff:ffff:ffff:ffff::/64`
- Equivalent to **public IPv4** addresses
- Some subnet ranges have been reserved for special purposes
 - Teredo tunneling
 - `2001::/32` → `2001:0000::/32`
 - Documentation
 - `2001:db8::/32` → `2001:0db8::/32`
 - 6to4 tunneling
 - `2002::/16`
 - Benchmark tests
 - `2001:0002::/48` → `2001:0002:0000::/48`

Global Unicast Addresses (GUA)

- Real IPv6 addresses of German ISPs assigned to Fritz!Box CPEs
 - Telekom (1+1)
 - Dues-V3: 2003:00e5:57ff:063f:cece:1eff:fe:fe:c367
 - Versatel (1+1)
 - Lu-F2: 2001:16b8:2102:cc22:0a96:d7ff:feea:f30c
 - Lu-F48: 2001:16b8:2103:30ea:3631:c4ff:fe:fc:3337
 - Kabel Deutschland (Vodafone)
 - Lu-E12: 2a02:810c:0000:0011:89d2:f887:71ac:7a5f

Prefix Delegation

- Besides an IPv6 address, the CPE device also gets an IPv6 subnet range assigned, that can be further sub netted and delegated to internal devices of the customer's network.
- Prefix `2001:16b8:2aee:e000::/56` can be sub netted into `256 x /64` networks or `16 x /60` networks or anything in between.



Der Online-Monitor stellt Informationen zu Ihrer Internetverbindung und zu aktivierten Zusatzfunktionen zur Verfügung.

DSL	● verbunden, ↓ 116,8 Mbit/s ↑ 32,0 Mbit/s
Internet, IPv4	● FRITZ!Box verwendet einen DS-Lite-Tunnel , 1&1 Internet, reale Bandbreite: ↓ 55,0 Mbit/s ↑ 11,1 Mbit/s AFTR-Gateway:2001:1438:fff:a::1
Internet, IPv6	● verbunden seit 15.05.2021, 05:55 Uhr, 1&1 Internet, reale Bandbreite: ↓ 55,0 Mbit/s ↑ 11,1 Mbit/s, IPv6-Adresse: 2001:16b8:2103:30ea:3631:c4ff:fefc:3337, Gültigkeit: 258871/172471s, IPv6-Präfix: 2001:16b8:2aee:e000::/56, Gültigkeit: 215859/129459s
Genutzte DNS-Server	2001:1438:2:4::8 (aktuell genutzt für Standardanfragen) 2001:1438:2:3::8

Prefix-Delegation (ISP to CPE)

- Versatel (1+1)

- CPE address: 2001:16b8:2103:30ea:3631:c4ff:fefc:3337
- deleg. Prefix: 2001:16b8:2aee:e000::/56
- AFTR Gw: 2001:1438:fff:a::1

- CPE address: 2001:16b8:2102:cc22:0a96:d7ff:feea:f30c
- deleg. Prefix: 2001:16b8:2ad1:af00::/56
- AFTR Gw: 2001:1438:fff:a::1

- Telekom (1+1)

- CPE address: 2003:00e5:57ff:063f:cece:1eff:fefe:c367
- deleg. Prefix: 2003:00e5:5705:de00::/56

- Kabel Deutschland (Vodafone)

- CPE address: 2a02:810c:0000:0011:89d2:f887:71ac:7a5f
- deleg. Prefix: 2a02:810c:0880:7ac0::/62
- AFTR Gw: 2a02:8100:c0:407::b:1:af72

Prefix-Delegation (Fritz!Box to OPNsense)

- Telekom (1+1)

- CPE address: 2003:e5:57ff:063f:cece:1eff:fefe:c367

- ISP Prefix: 2003:e5:5705:de00::/56

- OPNsense1:

- WAN: 2003:e5:5705:de00:5054:ff:fe36:0810

- Prefix: 2003:e5:5705:de00::/60

- LAN: 2003:e5:5705:de01:5054:ff:fe08:1036

- OPNsense2:

- WAN: 2003:e5:5705:de00:e45f:13ff:fe97:34c3

- Prefix: 2003:e5:5705:de00::/60

- LAN: 2003:e5:5705:de00:445e:24ff:feae:d18b

- Versatel (1+1)

- CPE address: 2001:16b8:2103:30ea:3631:c4ff:fe9c:3337

- ISP Prefix: 2001:16b8:2aee:e000::/56

- OPNsense3:

- WAN: 2001:16b8:2aee:e000:0c0a:84ff:fe47:e4c7

- Prefix: 2001:16b8:2aee:e000::/60

- LAN: 2001:16b8:2aee:e000:a80d:f9ff:febc:21f7

Self-hosted Services for the Classic Internet

- Classic service hosting:
 - An application listens on a port of a server for incoming requests.
 - The server has a (fixed) publicly reachable **IPv4** address.
 - This **IPv4** address is usually assigned a permanent DNS **A**-record.
 - Other ports on the server are protected by a local firewall.
- Self-hosted services:
 - An application listens on a port of a server for incoming requests.
 - The server has a private **IPv4** address and **cannot** be reached from the Internet.
 - The CPE device has a public **IPv4** addresses that is often changing.
 - A Dynamic-DNS service can be used to announce this public address.
 - The CPE is doing masquerading (NAT and PAT), that is translation of addresses and ports from the internal ranges to the public address.
 - The CPE is acting as a firewall and can be used to forward requests from external ports to internal ports of the application server.
 - Other ports on the server are protected by the CPE and a local firewall.

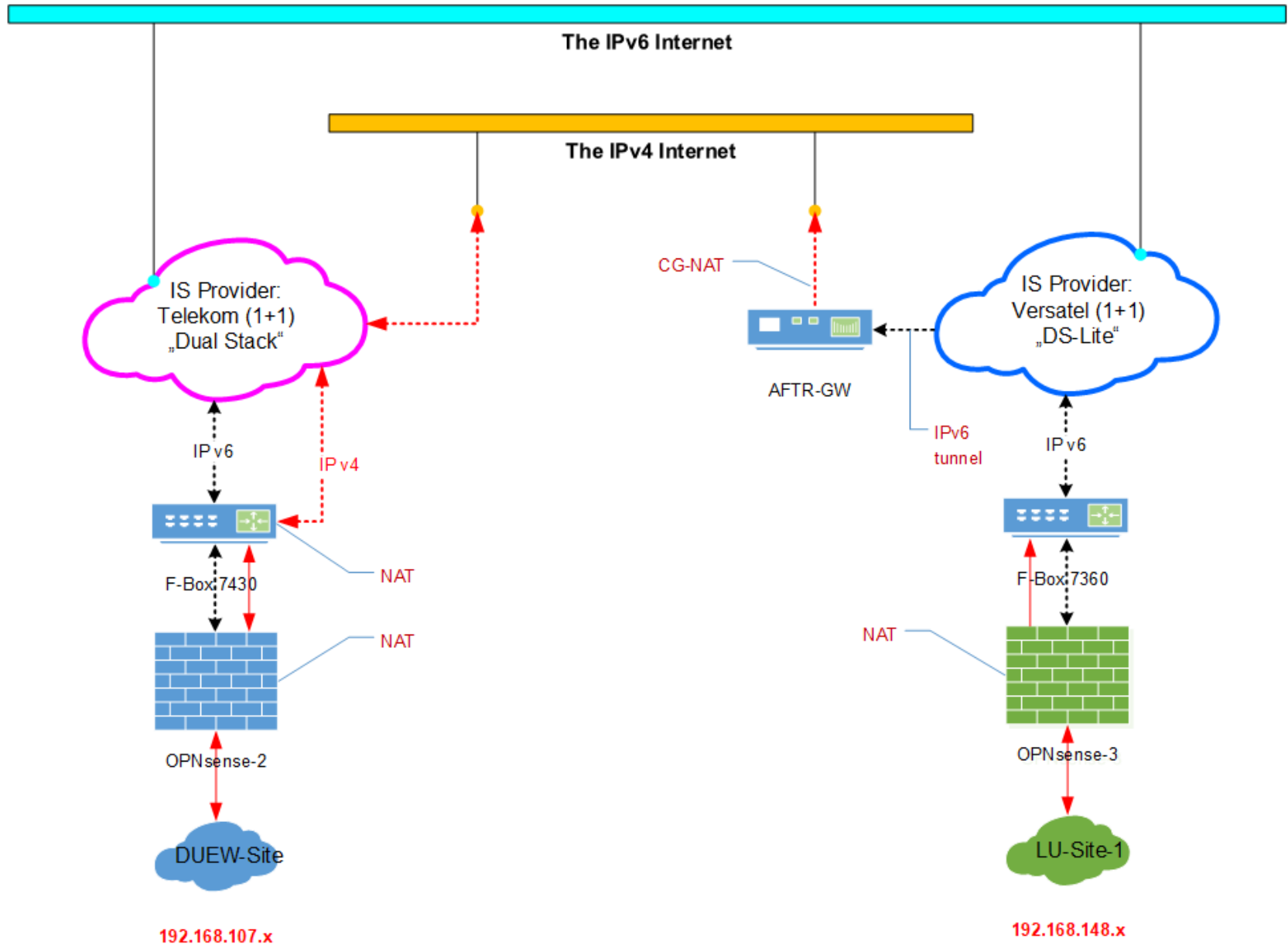
Self-hosted Services for the New Internet

- “Classic” service hosting:
 - An application listens on a port of a server for incoming requests.
 - The server has a (fixed) publicly reachable **IPv6** address.
 - This **IPv6** address is usually assigned a permanent DNS **AAAA**-record.
 - Other ports on the server are protected by a local firewall.
- Self-hosted services:
 - An application listens on a port of a server for incoming requests.
 - The CPE device has been delegated a public **IPv6** address range that is often changing.
 - The CPE assigns a public **IPv6** address from this range to the server.
 - The server **can** be reached via the **IPv6** gateway from the Internet.
 - A DynDNS service can be used to announce the server’s **IPv6** address.
 - The CPE is not doing any masquerading (neither NAT nor PAT).
 - The CPE is acting as a firewall and can be used to forward requests from external ports to internal ports of the application server.
 - Other ports on the server are protected by the CPE and a local firewall.

„Dual Stack“ vs. „DS-Lite“

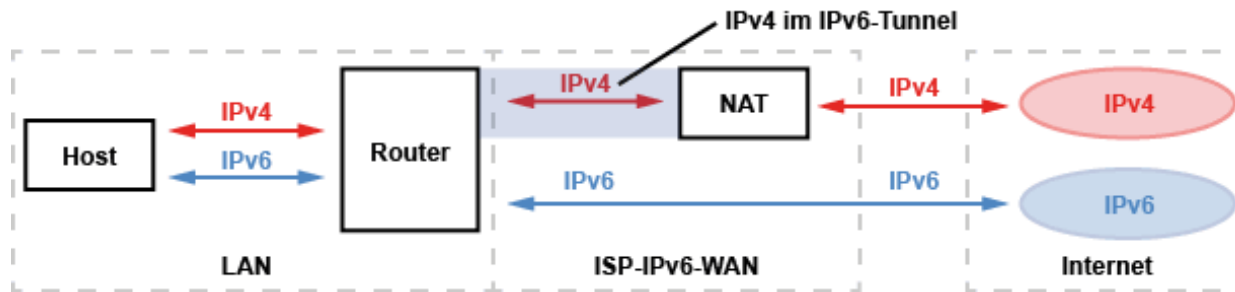
- Technically, the IPv4 and IPv6 Internets are disjoint networks, that are not compatible with each other.
- Thus, a network client that wants to access services in both worlds needs addresses and network connectivity to both IPv4 **and** IPv6.
- This can be accomplished by connecting to an ISP, that delivers a “**dual stack**” of public IPv4 **and** IPv6 addresses.
- But today, many ISPs are unable to give a public IPv4 address to the CPE device.
- See [RFC-6333](#) for “[DS-Lite](#)”.
- So many of these ISPs are delivering only a *light* version of “**dual stack**” to the customer.
- With “**DS-Lite**”, the ISP creates an IPv6 tunnel between the CPE device and an AFTR gateway in it’s IPv6 network.
- The **AFTR** (Address Family Transition Router) is essentially a NAT device, that translates the tunneled IPv4 packets.
- Thus, the ISP needs a lot less public IPv4 addresses to service many customers.
- However, it is *impossible* for the customer to run any IPv4 based services in a “**DS-Lite**” network.

„Dual Stack“ vs. „DS-Lite“

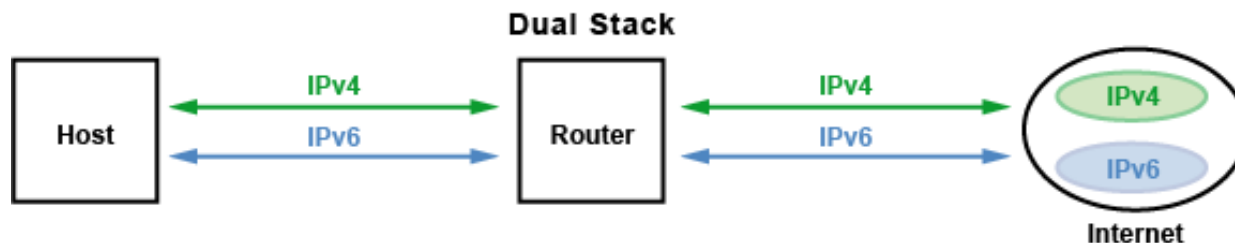


IPv4 ↔ IPv6 Transition Technologies

- Tunneling protocols (e.g. Teredo, 6in4, 6to4, 6over4, [DS-Lite](#), [AYIYA](#) = Anything in Anything)



- Parallel operation (e.g. [Dual-Stack](#), [CG-NAT](#))



- Protokoll translation (e.g. NAT64 and DNS64)
 - See "[IPv6-Workshop](#)" (by Dan Lüdtkke) – chapter 6.4 – pages 158 ff.

End-to-End Connectivity

- With IPv6, all communication partners (e.g. clients and servers) are having end-to-end (E2E) connectivity.
 - There are usually no address translations (NAT or PAT) involved. Neither by gateways, nor by firewalls.
- During connection setup, the **Maximum Transfer Unit** on the path between client and server is determined.
 - For PMTU discovery the ICMP6 protocol is used and required. Thus, ICMP6 **must** not be blocked by any firewalls.
 - The MTU size for IPv6 must be at least 1280 bytes.
- Due to the use of RA (**R**outer **A**dvertisement) and SLAAC (**S**tateless **A**ddress **A**utoconfiguration) in customer networks the DHCP6 protocol is rarely used.
- In contrast to IPv4, the CPE does not do masquerading of IPv6 communication end points.
 - Thus, Dynamic DNS providers for IPv6 **must** learn the server's GUA.
 - Free DynDNS provider: "dynv6.com"
 - Host-based, local firewalls **should** be deployed on all servers.

Testing IPv4 and IPv6 connectivity

ipv6-test.com

The screenshot shows the website ipv6-test.com with the following content:

ipv6 test
General Speed Ping Website Stats API

IPv6-test.com is a free service that checks your IPv6 and IPv4 connectivity and speed. Diagnose connection problems, discover which address(es) you are currently using to browse the Internet, and what is your browser's protocol of choice when both v6 and v4 are available.

IPv4 connectivity (Supported)

IPv4	Supported
Address	208.127.99.74
Hostname	netblock-208-127-99-74.dslextrame.com
ISP	Google LLC

IPv6 connectivity (Not supported)

IPv6	Not supported
Address	
Type	
SLAAC	
ICMP	
Hostname	
ISP	

Score: 4 / 20

Browser

Default	IPv4
Fallback	No

DNS

DNS4 + IP6	Unreachable
DNS6 + IP4	Reachable
DNS6 + IP6	Unreachable

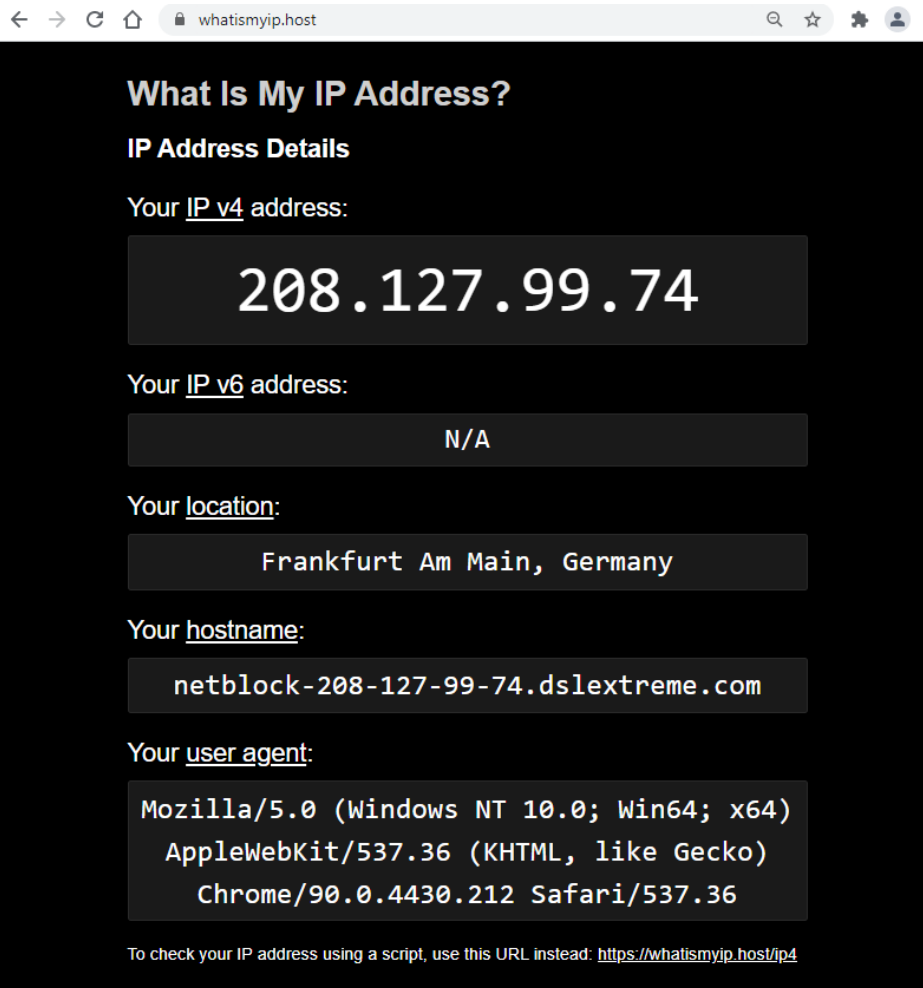
More

[Speed test »](#) [Ping test »](#)

Testing IPv4 and IPv6 connectivity

whatismyip.host

test-ipv6.com



What Is My IP Address?

IP Address Details

Your IP v4 address:

208.127.99.74

Your IP v6 address:

N/A

Your location:

Frankfurt Am Main, Germany

Your hostname:

netblock-208-127-99-74.dslextrême.com

Your user agent:







Mozilla/5.0 (Windows NT 10.0; Win64; x64)
AppleWebKit/537.36 (KHTML, like Gecko)
Chrome/90.0.4430.212 Safari/537.36

To check your IP address using a script, use this URL instead: <https://whatismyip.host/ip4>



Testen Sie Ihre IPv6-Konnektivität.

Zusammenfassung | Durchgeführte Tests | Ergebnisse einschicken / Kontakt | Für den Helpdesk

-  Ihre IPv4 Internet-Adresse ist höchstwahrscheinlich 208.127.99.74, 208.127.99.74
-  Keine IPv6-Adresse erkannt [\[mehr Infos\]](#)
-  Wenn Inhalte sowohl via IPv4 als auch via IPv6 verfügbar sind, benutzt Ihr Webbrowser IPv4 ohne Einschränkungen in der Qualität.
-  Verbindungen zu Inhalten, welche nur via IPv6 erreichbar sind, resultieren in einer Zeitüberschreitung. Alle Webseiten, welche nur via IPv6 erreichbar sind, werden daher nicht funktionieren.
-  Um die beste Internet-Leistung und Konnektivität sicherzustellen, fragen Sie bei Ihrem ISP nach nativem IPv6. [\[mehr Infos\]](#)
-  Wir sind manchmal nicht in der Lage, Teredo und 6to4 zu erkennen, wenn Sie HTTPS verwenden. [\[mehr Infos\]](#)
-  Die HTTPS Unterstützung auf dieser Website ist in der **Beta-Phase**. [\[mehr Infos\]](#)
-  Ihr DNS Server (wahrscheinlich von Ihrem ISP betrieben) scheint über IPv6-Internetzugriff zu verfügen.

Ihr Bereitschafts-Ergebnis

0/10 für Ihre IPv6-Stabilität und -Bereitschaft, wenn Inhalte nur via IPv6 verfügbar sind

Hier klicken für [Testdaten](#)

(Serverseitige IPv6 Bereitschafts-Statistik aktualisiert)

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[Spiegel](#) | [Quellcode](#) | [E-Mail](#) - [Beteiligung](#) | [Debug](#) | [90.de_DE](#) 99.46% | Teilen auf: [Facebook](#) [Twitter](#)
Dies ist eine Kopie von test-ipv6.com. Die hier geäußerten Ansichten können müssen aber nicht der des Mirrorbetreibers entsprechen.

Testing IPv4 and IPv6 connectivity

heise.de

kame.net

← → ↻ 🏠 heise.de/netze/tools/meine-ip-adresse/

heise online > Tools > Meine IP-Adresse

Meine IP-Adresse

Ihre Anfrage kommt von der IP-Adresse: **208.127.99.74**

Ihre Anfrage wurde von einem Proxy bearbeitet. Wahrscheinlich erscheint daher oben dessen Adresse. Der Proxy gibt als IP-Adresse Ihres PC **208.127.99.74** an.

← → ↻ 🏠 ⚠ Nicht sicher | kame.net ☆ ⚙ 👤 ⋮

The KAME project

1998.4 - 2006.3



Use IPv6 HTTP and you will watch [the dancing kame](#)

The KAME project was a joint effort of six companies in Japan to provide a free stack of IPv6, IPsec, and Mobile IPv6 for BSD variants.

Our products are available in:

- [FreeBSD](#) 4.0 and beyond
- [OpenBSD](#) 2.7 and beyond
- [NetBSD](#) 1.5 and beyond
- BSD/OS 4.2 and beyond

The project officially concluded in March 2006 (see [press release](#) from the WIDE project). Almost all of our implemented code has been merged to FreeBSD and NetBSD. The historical archive of the KAME repository is available at [github](#).

[\[Top\]](#) [\[Old info\]](#)

Ressources

- Wikipedia
 - [IPv4](#)
 - [CG-NAT](#)
 - [Reserved IP addresses](#)
 - [IPv6](#)
 - [Link-local addresses](#)
 - [ULA](#)
 - [Private networks](#)
- [RFC](#) documents of the IETF
- [IPv6](#) docs for the [pfSense](#) firewall
- Free DynDNS service at “[dynv6.com](#)”

Ressources in German

- Excellent book by Dan Lüdtkke: “[IPv6 Workshop](#)”
- “[Elektronik-Kompendium.de](#)” has lots of good content
- German Wikipedia
 - [IPv4](#)
 - [IPv6](#)
- [AVM](#)’s explanation of [DS-Lite](#)
- [Heise](#)’s network tools
 - What is [my IP](#)?
 - [IPv4](#)
 - [IPv6](#)