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The end-to-end principle

Principles and looking ahead



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End-to-end principle - the basics

*The end-to-end (E2E) principle is a design principle in **computer networking** that requires **application-specific features** (such as reliability and security) to be implemented in the communicating **end nodes** of the network, instead of in the network itself.*

Emphasis added, Wikipedia, “End-to-end principle”

End-to-end principle - example

E2E-network

- Layered
- Function per layer
- Best effort
- Internet, etc

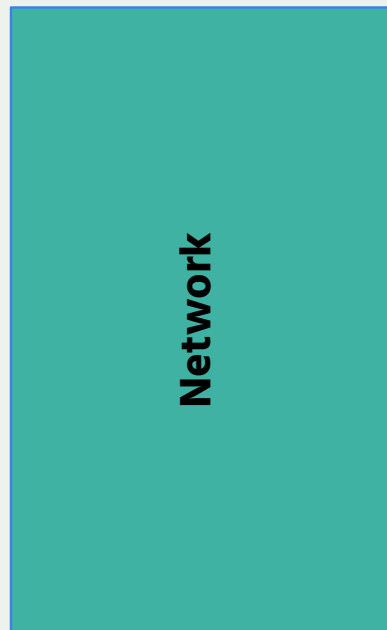
Vertical Networks

- Function per network
- SLA
- PTSN, New IP, FVCN, etc

E2E-network



Vertical Network



“Permissionless innovation at the **edge**”

Network operator revenue decoupled from the innovation capacity of the system, c.f. #FairShare debate, Draghi-, Letta-reports, and DNA-proposal

The end-to-end-principle is an engineering principle, not a regulatory target



Examples and discussion

From the perspective of the end-to-end-principle



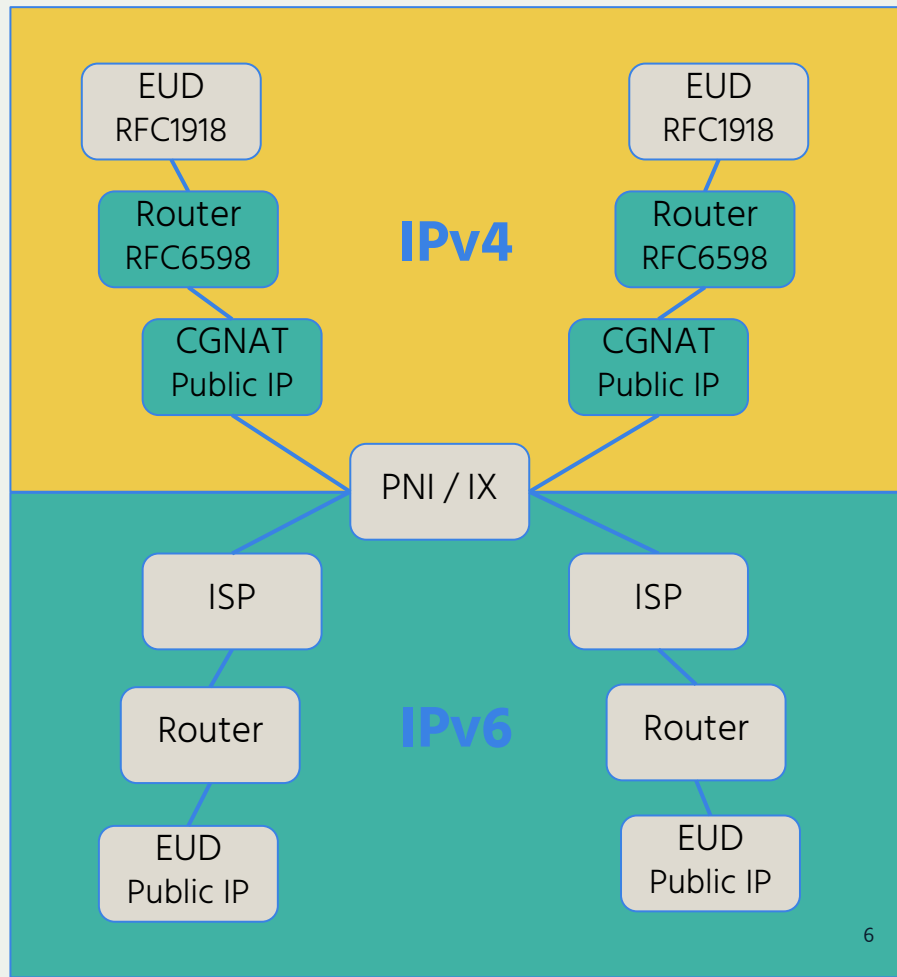
End-to-end in an IPv6-world

IPv4-connections are (usually)

- CGNAT:ed
 - Addresses seen in transit are not the same as the end-device-identifiers / addresses
 - NAT:ing looks at ports (usually)

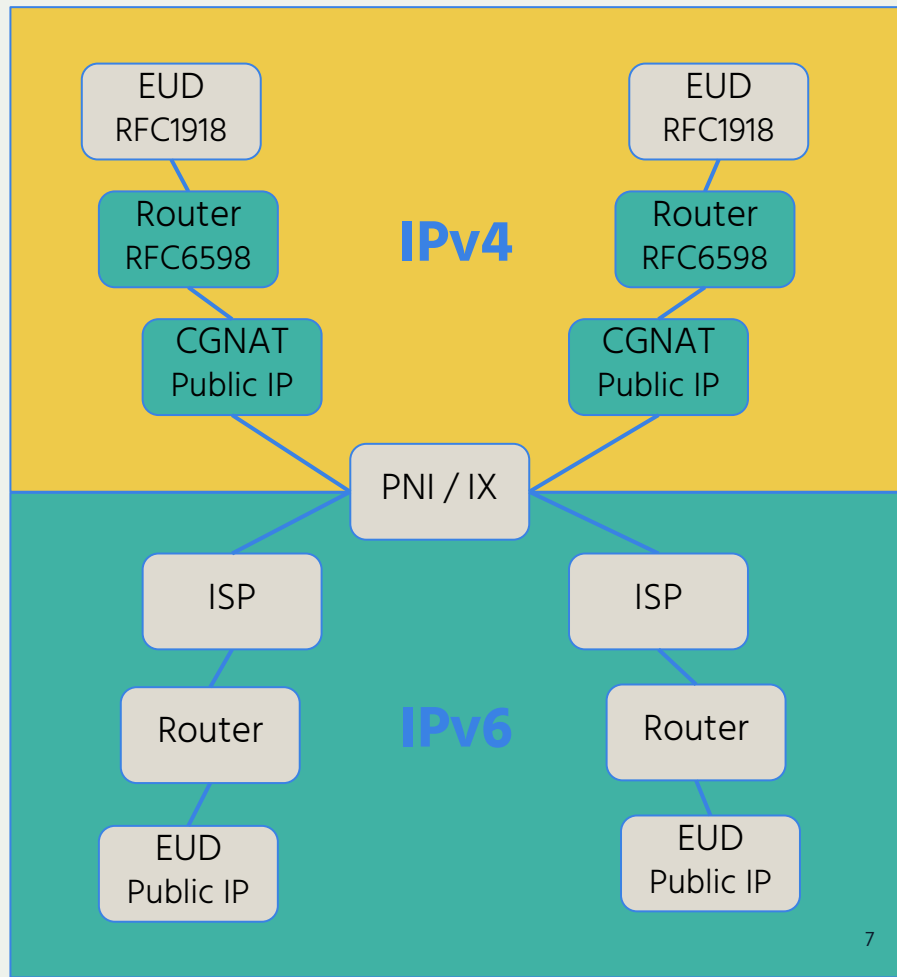
IPv6-connection are (usually)

- Not (CG)NAT:ed
 - Addresses represent end-to-end addressing schemas
- End-to-end-addressing (usually) preserved



End-to-end and ossification

- “**Protocol ossification** is the loss of flexibility, extensibility and evolvability of network protocols”
 - Wikipedia
- If routers / FWs / devices along the route looks “above” IP-layer, the layer above (usually TCP / UDP) is also ossified by the network
- In an Internet-context, only IP-level required protocols (such as IPv4 / v6, ICMPv4 / v6, etc) should be ossified by the devices of the networks themselves
 - E.g. **not** edge devices
- QUIC...



End-to-end principle from a crime prevention perspective

Goal: metadata pertaining to end-users

Addresses which are NAT:ed multiples times, proxied, etc are costly to log and a privacy nightmare from a retention perspective

In IPv6 / end-to-end-networks the addresses used at packet level are representative of that connection / layer

- E.g. ends of encapsulation / tunnels / sessions
- France and the Netherlands have pushed IPv6 with crime fighting rationale as addresses then are assumed to better target individuals rather than groups of individuals / organisations

End-to-end principle at a higher level

End-to-end-encryption adaptation provisions are harmonising number independent communication services with telephony rules. E.g. comparing E2E-communications with PTSN.

- iMessage (Apple), Facetime (Apple), Discord, Snapchat, Google Messages, Google Meet, Kik Messenger, Line, Messenger (Meta), Skype, Slack, Telegram, Viber and Whatsapp are explicitly targeted
- Gmail, Outlook and Apple Mail also explicitly targeted
- Adaptability requirements for end-to-end-encrypted communication service
 - Clear text communication needs to be available to law enforcement upon request
- Breaks *end-to-end-principle* between application content and application provider

Recap - End-to-end-principle

Architecturally necessary (according to ISOC-SE)

- Innovation at the edges
 - Applications, AI, etc
- Current (CG)NAT:ing partially breaks E2E
- Full IPv6 adoption and use <-> E2E
- Applications and use decoupled from place and operator

Threatened by

- Large operators by value capture
 - C.f. #FairShare-discussion
- Political initiatives
 - Smart network over stupid network
 - Digital sovereignty, new IP, FVCN, etc

“Permissionless innovation at the **edge”**

“Stupid networks, dumb pipes and neutrality”



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