Communication Networks

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Online/COVID-19 Edition

Communication Networks
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Materials inspired from Scott Shenker and Jennifer Rexford

Last Monday on
Communication Networks

Web — http://www.google.ch

Video Streaming — HTTP-based

Web — http://www.google.ch

Video Streaming

HTTP performance goals vary depending on who you ask

	User	Network operators	Content provider
		⟷	NETFLIX
wish	fast downloads high availability	no overload	happy users cost-effective infrastructure
solution	Improve HTTP to compensate for TCP weakspots	Caching and Replication	

Considering the time to retrieve *n* small objects, pipelining wins

	# RTTS
one-at-a-time	~2*n*
M concurrent	~2*n*/M
persistent	~*n*+1
pipelined	2

Considering the time to retrieve *n* big objects, there is no clear winners as bandwidth matters more

\# RTTS

$$\frac{\sim n \text{ * avg. file size}}{\text{bandwidth}}$$

To limit staleness of cached objects, HTTP enables a client to validate cached objects

Server hints when an object expires (kind of TTL)
as well as the last modified date of an object

Client conditionally requests a ressources
using the "if-modified-since" header in the HTTP request

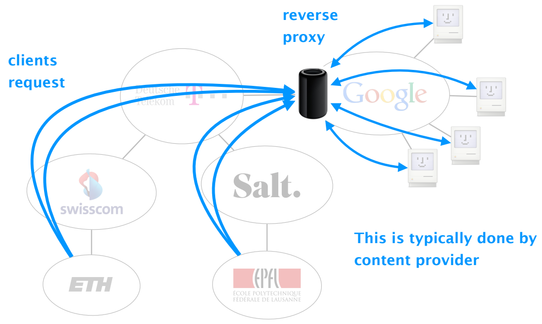
Server compares this against "last modified" time
of the resource and returns:

- Not Modified if the resource has not changed
- OK with the latest version

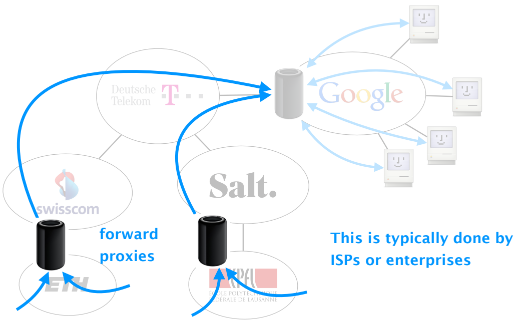
Caching can and is performed at different locations

client	browser cache
close to the client	forward proxy Content Distribution Network (CDN)
close to the destination	reverse proxy

Reverse proxies cache documents close to servers, decreasing their load



Forward proxies cache documents close to clients, decreasing network traffic, server load and latencies



Web

Video Streaming

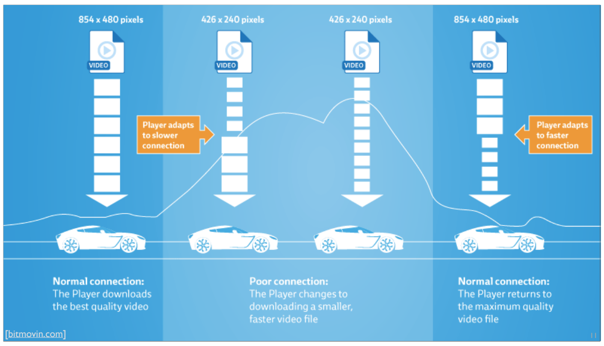
HTTP-based

The three steps behind most contemporary solutions

- Encode video in multiple bitrates
- Replicate using a content delivery network
- Video player picks bitrate adaptively
  - Estimate connection's available bandwidth
  - Pick a bitrate ≤ available bandwidth

Encoding | Replication | Adaptation

Encoding | Replication | Adaptation



Problem: this doesn't take into account the variability in the video content (slow moving vs. fast moving)

Bitrate (kbps)	Resolution
235	320x240
375	384x288
560	512x384
750	512x384
1050	640x480
1750	720x480
2350	1280x720
3000	1280x720
4300	1920x1080
5800	1920x1080

[netflix.com]


[netflix.com]


[bitmovin.com]

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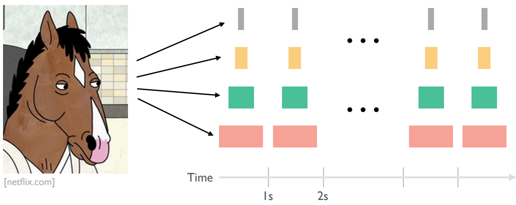
Your player download "chunks" of video at different bitrates



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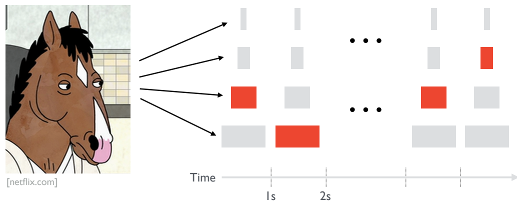
Depending on your network connectivity, your player fetches chunks of different qualities



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Encoding

Replication

Adaptation

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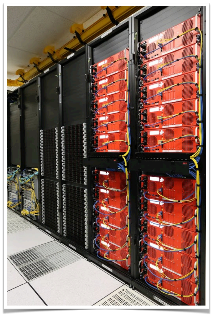
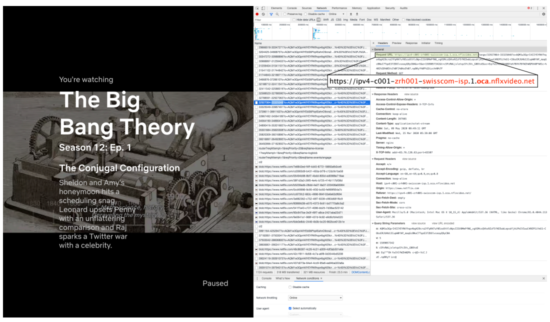


20



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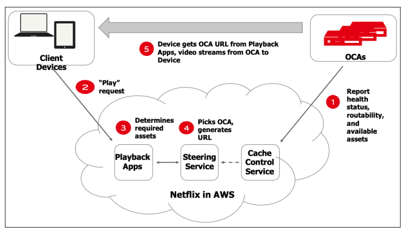
Complete Playback Workflow @Netflix



[more-ip-event.net]

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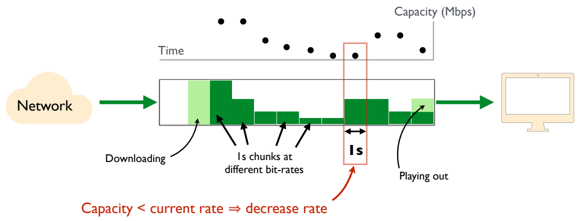
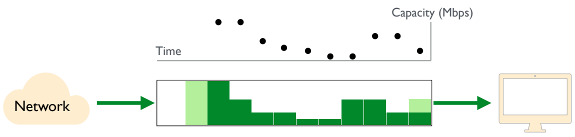
Encoding | Replication | Adaptation

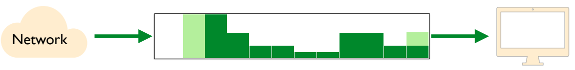


Capacity estimation



Decide based on the buffer alone?

Buffer-based adaptation



Nearly full buffer ⇒ large rate

Buffer-based adaptation

Nearly empty buffer ⇒ small rate

Today on
Communication Networks

E-mail
MX, SMTP, POP, IMAP

IPv6
128-bits IPv4 addresses?
(the beginning)

Today on
Communication Networks

E-mail
MX, SMTP, POP, IMAP

IPv6
128-bits IPv4 addresses?

We'll study e-mail from three different perspectives

Content	Infrastructure/ Transmission	Retrieval
Format: Header/Content Encoding: MIME	SMTP: Simple Mail Transfer Protocol Infrastructure mail servers	POP: Post Office Protocol IMAP: Internet Message Access Protocol

Content

Infrastructure/ Transmission

Retrieval

Format: Header/Content

Encoding: MIME

An e-mail is composed of two parts

E-mail

A header, in 7-bit U.S. ASCII text

Header

From: Laurent Vanbever <lvanbever@ethz.ch>
To: Tobias Buehler <buehlert@ethz.ch>
Subject: [comm-net] Exam questions

A body, also in 7-bit U.S. ASCII text

From: Laurent Vanbever <lvanbever@ethz.ch>
To: Tobias Buehler <buehlert@ethz.ch>
Subject: [comm-net] Exam questions

Body

Hi Tobias,

Here are some interesting questions…

Best,
Laurent

Type, followed by ":"

Value

Header

From: Laurent Vanbever <lvanbever@ethz.ch> CRLF
To: Tobias Buehler <buehlert@ethz.ch> CRLF
Subject: [comm-net] Exam questions CRLF

Series of lines ending with Carriage Return and Line Feed

Series of lines with no structure/meaning

Body

Hi Tobias,

Here are some interesting questions…

Best,
Laurent

Header

Body

A blank line separates the header from the body

Header

Body

A blank line separates the header from the body

.

A dot (".") on a new line ends the body

Email relies on 7-bit U.S. ASCII...
How do you send non-English text? Binary files?

Solution — **Multipurpose Internet Mail Extensions**

commonly known as MIME, standardized in RFC 822

MIME defines

- additional headers for the email body
- a set of content types and subtypes
- base64 to encode binary data in ASCII

MIME defines

- additional headers for the email body

MIME-Version: the version of MIME being used
Content-Type: the type of data contained in the message
Content-Transfer-Encoding: how the data is encoded

MIME defines

- additional headers for the email body
- a set of content types and subtypes

e.g. image with subtypes gif or jpeg
text with subtypes plain, html, and rich text
application with subtypes postscript or msword
multipart with subtypes mixed or alternative

The two most common types/subtypes for MIME are: *multipart/mixed* and *multipart/alternative*

Content-Type	indicates that the message contains
multipart/mixed	multiple independent parts e.g. plain text *and* a binary file
multipart/alternative	multiple representation of the same content e.g. plain text *and* HTML

MIME defines

- additional headers for the email body
- a set of content types and subtypes
- base64 to encode binary data in ASCII

What kind of delimiter do we use?

multipart/mixed — **multiple** independent parts

multipart/alternative — **multiple** representation of the same content

---

Content-Type contains a parameter that specifies a string delimiter (chosen randomly by the client)

ensuring that the delimiter does *not* appear in the email itself

```
From: Laurent Vanbever <lvanbever@ethz.ch>
To: Tobias Buehler <buehlert@ethz.ch>
Subject: [comm-net] Final exam
MIME-Version: 1.0
Content-Type: multipart/related;
boundary="_004_cc163051808f425a9b67b778666b785eeeethzch_";
   type="multipart/alternative"

--_004_cc163051808f425a9b67b778666b785eeeethzch_
Content-Type: multipart/alternative;
   boundary="_000_cc163051808f425a9b67b778666b785eeeethzch_"

--_000_cc163051808f425a9b67b778666b785eeeethzch_
Content-Type: text/plain; charset=us-ascii
Content-Transfer-Encoding: 7bit

Let's start the exam with ...

--_000_cc163051808f425a9b67b778666b785eeeethzch_
Content-Type: text/html; charset="utf-8"
Content-Transfer-Encoding: base64

PGh0bWwgeG1sbnM6dj0idX ...
```

MIME relies on Base64 as binary-to-text encoding scheme

Relies on 64 characters out of the 128 ASCII characters
the most common *and* printable ones, i.e. A-Z, a-z, 0-9, +, /

Divides the bytes to be encoded into sequences of 3 bytes
each group of 3 bytes is then encoded using 4 characters

Uses padding if the last sequence is partially filled
i.e. if the |sequence| to be encoded is not a multiple of 3

Binary input	0x14fb9c03d97e
8-bits	00010100 11111011 10011100 00000011 11011001 01111110
6-bits	000101 001111 101110 011100 000000 111101 100101 111110
Decimal	5 15 46 28 0 61 37 62
base64	F P u c A 9 l +

Value	Char	Value	Char	Value	Char	Value	Char
0	A	16	Q	32	g	48	w
1	B	17	R	33	h	49	x
2	C	18	S	34	i	50	y
3	D	19	T	35	j	51	z
4	E	20	U	36	k	52	0
5	F	21	V	37	l	53	1
6	G	22	W	38	m	54	2
7	H	23	X	39	n	55	3
8	I	24	Y	40	o	56	4
9	J	25	Z	41	p	57	5
10	K	26	a	42	q	58	6
11	L	27	b	43	r	59	7
12	M	28	c	44	s	60	8
13	N	29	d	45	t	61	9
14	O	30	e	46	u	62	+
15	P	31	f	47	v	63	/

If the length of the input is not a multiple of three, Base64 uses "=" as padding character

Binary input	0x14
8-bits	00010100
6-bits	000101 000000
Decimal	5 0
base64	F A = =

```
From: Laurent Vanbever <lvanbever@ethz.ch>
To: Tobias Buehler <buehlert@ethz.ch>
Subject: [comm-net] Final exam
MIME-Version: 1.0
Content-Transfer-Encoding: base64
Content-Type: multipart/mixed;
        boundary="123boundary"

This is a multipart message in MIME format.

--123boundary
Content-Type: text/plain

Hi Tobias, Please find the exam enclosed. Laurent

--123boundary
Content-Type: application/pdf;
Content-Disposition: attachment;
        filename="exam_2020.pdf"

base64 encoded data .....
.........................
......base64 encoded data
```

Content | Infrastructure/ Transmission | Retrieval

SMTP: Simple Mail Transfer Protocol

Infrastructure
mail servers

An e-mail address is composed of two parts identifying the local mailbox and the domain

lvanbever @ ethz.ch

lvanbever → local mailbox

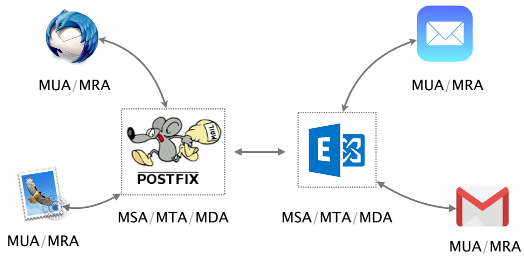
ethz.ch → domain name

actual **mail server** is identified using a DNS query asking for **MX records**

We can divide the e-mail infrastructure into five functions

Mail	User	Agent	Use to read/write emails (mail client)
Mail	Submission	Agent	Process email and forward to local MTA
Mail	Transmission	Agent	Queues, receives, sends mail to other MTAs
Mail	Delivery	Agent	Deliver email to user mailbox
Mail	Retrieval	Agent	Fetches email from user mailbox

MSA/MTA/MDA and MRA/MUA are often packaged together leading to simpler workflows



Simple Mail Transfer Protocol (SMTP) is the current standard for transmitting e-mails

SMTP is a text-based, client-server protocol

client sends the e-mail, server receives it

SMTP uses reliable data transfer

built on top of TCP (port 25 and 465 for SSL/TLS)

SMTP is a push-based protocol

sender pushes the file to the receiving server

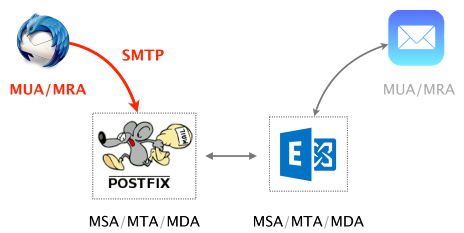
	SMTP 3 digit response code			comment
Status	2XX	success	220	Service ready
			250	Requested mail action completed
	3XX	input needed	354	Start mail input
	4XX	transient error	421	Service not available
			450	Mailbox unavailable
			452	Insufficient space
	5XX	permanent error	500	Syntax error
			502	Unknown command
			503	Bad sequence

server — 220 hamburger.edu

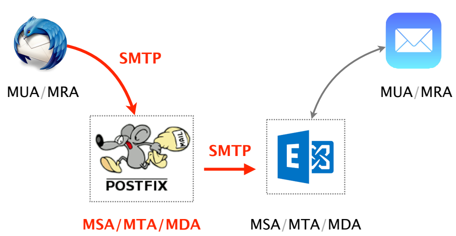
client — MAIL FROM: <alice@crepes.fr>

```
220 hamburger.edu
EHLO crepes.fr
250  Hello crepes.fr, pleased to meet you
MAIL FROM: <alice@crepes.fr>
250 alice@crepes.fr... Sender ok
RCPT TO: <bob@hamburger.edu>
250 bob@hamburger.edu ... Recipient ok
DATA
354 Enter mail, end with "." on a line by
itself
Do you like ketchup?
How about pickles?
.
250 Message accepted for delivery
QUIT
221 hamburger.edu closing connection
```

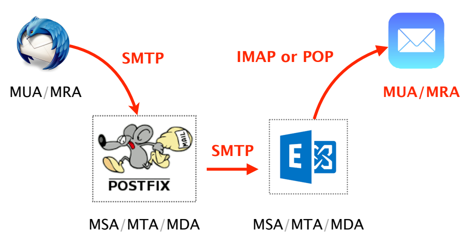
The sender MUA uses SMTP to transmit the e-mail to a local MTA (e.g. mail.ethz.ch, gmail.com, hotmail.com)



The local MTA then looks up the MTA of the recipient domain (DNS MX) and transmits the e-mail further



Once the e-mail is stored at the recipient domain, IMAP or POP is used to retrieve it by the recipient MUA



E-mails typically go through at least 2 SMTP servers,
but often way more

sending and receiving sides

Each SMTP server/MTA hop adds its identity to
the e-mail header by prepending a "Received" entry

8 **Received**: from edge20.ethz.ch (82.130.99.26) by CAS10.d.ethz.ch (172.31.38.210) with Microsoft SMTP Server (TLS) id 14.3.361.1; Fri, 23 Feb 2018 01:48:56 +0100

7 **Received**: from phil4.ethz.ch (129.132.183.133) by edge20.ethz.ch (82.130.99.26) with Microsoft SMTP Server id 14.3.361.1; Fri, 23 Feb 2018 01:48:57 +0100

6 **Received**: from outprodmail02.cc.columbia.edu ([128.59.72.51]) by phil4.ethz.ch with esmtps (TLSv1:AES256-SHA:256) (Exim 4.69) (envelope-from <ethan@ee.columbia.edu>) id 1ep1Xg-0002s3-FH for lvanbever@ethz.ch; Fri, 23 Feb 2018 01:48:55 +0100

5 **Received**: from hazelnut (hazelnut.cc.columbia.edu [128.59.213.250]) by outprodmail02.cc.columbia.edu (8.14.4/8.14.4) with ESMTP id w1N0iAu4026008 for <lvanbever@ethz.ch>; Thu, 22 Feb 2018 19:48:51 -0500

4 **Received**: from hazelnut (localhost.localdomain [127.0.0.1]) by hazelnut (Postfix) with ESMTP id 421126D for <lvanbever@ethz.ch>; Thu, 22 Feb 2018 19:48:52 -0500 (EST)

3 **Received**: from sendprodmail01.cc.columbia.edu (sendprodmail01.cc.columbia.edu [128.59.72.13]) by hazelnut (Postfix) with ESMTP id 211526D for <lvanbever@ethz.ch>; Thu, 22 Feb 2018 19:48:52 -0500 (EST)

2 **Received**: from mail-pl0-f43.google.com (mail-pl0-f43.google.com [209.85.160.43]) (user=ebk2141 mech=PLAIN bits=0) by sendprodmail01.cc.columbia.edu (8.14.4/8.14.4) with ESMTP id w1N0mnlx052337 (version=TLSv1/SSLv3 cipher=AES128-GCM-SHA256 bits=128 verify=NOT) for <lvanbever@ethz.ch>; Thu, 22 Feb 2018 19:48:50 -0500

1 **Received**: by mail-pl0-f43.google.com with SMTP id u13so3927207plq.1 for <lvanbever@ethz.ch>; Thu, 22 Feb 2018 16:48:50 -0800 (PST)

E-mails typically go through at least 2 SMTP servers,
but often way more

Separate SMTP servers for separate functions

SPAM filtering, virus scanning, data leak prevention, etc.

Separate SMTP servers that redirect messages

e.g. from lvanbever@tik.ee.ethz.ch to lvanbever@ethz.ch

Separate SMTP servers to handle mailing-list

mail is delivered to the list server and then expanded

Try it out yourself!

SMTP-MTA	plaintext (!), hard to find	`telnet server_name 25`
SMTP-MSA	rely on TLS encryption	`openssl s_client -starttls smtp -connect mail.ethz.ch:587 -crlf -ign_eof (*)`
	authentication required	`perl -MMIME::Base64 -e 'print encode_base64("username");'` `perl -MMIME::Base64 -e 'print encode_base64("password");'`

(*) https://www.ndchost.com/wiki/mail/test-smtp-auth-telnet

As with most of the key Internet protocols,
security is an afterthought

SMTP Headers

MAIL FROM: no checks are done to verify that the sending MTA is authorized to send e-mails on behalf of that address

Email content (DATA)

From: no checks are done to verify that the sending system is authorized to send e-mail on behalf of that address

Reply-to: ditto

In short, *none* of the addresses in an email are typically reliable

Let's spoof some e-mails!
(don't try this at home)

And, as usual, multiple countermeasures have been proposed with various level of deployment success

Example* Sender Policy Framework (SPF)

Enables a domain to explicitly authorize
a set of hosts that are allowed to send emails
using their domain names in "MAIL FROM".

How? using a DNS TXT resource record

look for "v=spf1" in the results of "dig TXT google.com"

* if you are interested, also check out Sender ID, DKIM, and DMARC

Content | Infrastructure/ Transmission | Retrieval

POP: Post Office Protocol

IMAP: Internet Message Access Protocol

Content | Infrastructure/ Transmission | Retrieval

POP: Post Office Protocol

IMAP: Internet Message Access Protocol

POP is a simple protocol which was designed to support users with intermittent network connectivity

POP enables e-mail users to

- retrieve e-mails locally — when connected
- view/manipulate e-mails — when disconnected

and that's pretty much it...

Example

POP server —— client

```
+OK POP3 server ready
user bob
+OK
pass hungry
+OK user successfully logged on

list
1 498
2 912
.
retr 1
<message 1 contents>
.
dele 1
retr 2
<message 1 contents>
.
dele 2
quit
+OK POP3 server signing off
```

Authorization phase

Clients declares username password

Server answers +OK/-ERR

```
+OK POP3 server ready
user bob
+OK
pass hungry
+OK user successfully logged on

list
1 498
2 912
.
retr 1
<message 1 contents>
.
dele 1
retr 2
<message 1 contents>
.
dele 2
quit
+OK POP3 server signing off
```

Transaction phase

- `list` get message numbers
- `retr` retrieve message X
- `dele` delete message X
- `quit` exit session

```
+OK POP3 server ready
user bob
+OK
pass hungry
+OK user successfully logged on

list
1 498
2 912
.
retr 1
<message 1 contents>
.
dele 1
retr 2
<message 1 contents>
.
dele 2
quit
+OK POP3 server signing off
```

POP is heavily limited. Among others, it does not go well with multiple clients or always-on connectivity

Cannot deal with multiple mailboxes

designed to put incoming emails in one folder

Not designed to keep messages on the server

designed to download messages to the client

Poor handling of multiple-client access

while many (most?) users have now multiple devices

Content | Infrastructure/ Transmission | Retrieval

POP: Post Office Protocol

IMAP: Internet Message Access Protocol

Unlike POP, Internet Message Access Protocol (IMAP) was designed with multiple clients in mind

Support multiple mailboxes and searches on the server
client can create, rename, move mailboxes & search on server

Access to individual MIME parts and partial fetch
client can download only the text content of an e-mail

Support multiple clients connected to one mailbox
server keep state about each message (e.g. read, replied to)

Today on Communication Networks

E-mail
MX, SMTP, POP, IMAP

IPv6
128-bits IPv4 addresses?

(the beginning)

The long way from…

World population: 7.8 billion

~0.6 IPv4 addresses per person

…to…

Average # of atoms in a human: 6.10^{27}

~7.5 IPv6 addresses per "human" atom

Let's look at some history first

late 1980s	Exponential growth of the Internet
1992	Most class B networks have been assigned experts warn that IPv4 addresses might run out
1993	Introduction of classless IPv4 addresses
1994	"Address Allocation for Private Internets" 3 reserved IPv4 blocks for private networks Hosts in private IP space are unreachable from Internet

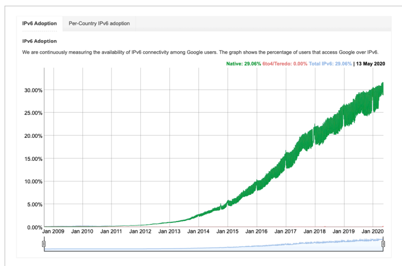
IPv6 originally appeared in 1998, more than 20 years ago

1994 (cont'd)	"IP Network Address Translator (NAT)" A public address is mapped to an entire private IP space
1998	IETF standardization of the IPv6 draft
2005	Estimated timeframe for massive adaption of IPv6 Did not happen…
2008	It is possible to resolve domain names using IPv6 only

IPv6 and is *finally* picking up steam

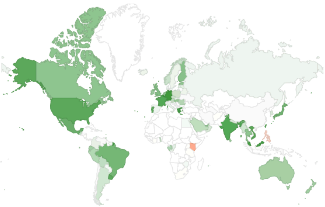
2011	Last unassigned top-level IPv4 block is distributed All major operating systems have stable IPv6 support Support for mobile devices varies
2012	World IPv6 Launch day A large number of content and ISPs permanently enable IPv6
2020	~30% of Google traffic is on IPv6 with wide differences across countries

Today, ~30% of the Google users access it using IPv6



https://www.google.com/intl/en/ipv6/statistics.html#tab=ipv6-adoption

Yet, there still exists wide discrepancy across countries



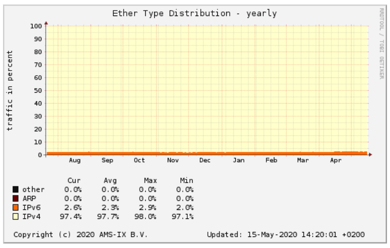
The darker the green,
the larger the deployment

Belgium
(56.59% adoption, leader)

Switzerland
(40.74% adoption)

https://www.google.com/intl/en/ipv6/statistics.html#tab=per-country-ipv6-adoption

Looking at AMS-IX traffic statistics, we see that less than 3% of it is v6



https://stats.ams-ix.net/sflow/ether_type.html

IPv4 has been very persistent, and for good reasons

Deploying IPv6 require every device to support it

All routers, middleboxes, end hosts, applications, …

Most of IPv6 new features were back-ported to IPv4

No obvious advantage in using IPv6

Network Address Translation is working well

The pain of address depletion is not obvious

Network Address Translation (NAT)

Sharing a single (public) address between hosts

Port numbers (transport layer) used to multiplex

One of the main reasons why we can still use IPv4

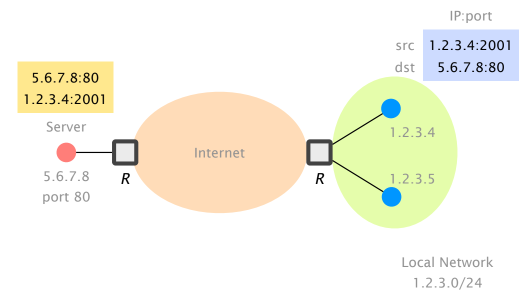
Saved us from address depletion

Violates the general end-to-end principle of the Internet

A NAT box adds a layer of indirection

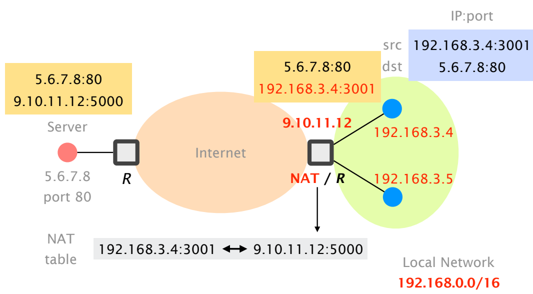
The Internet before NAT

Every machine connected to the Internet had a unique IP



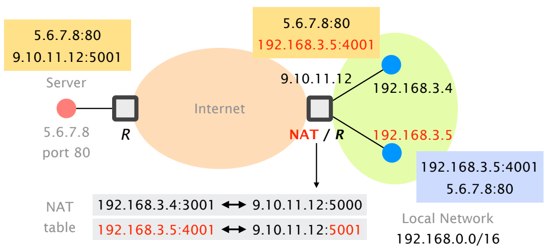
The Internet with NAT

Hosts behind NAT get a private address



The Internet with NAT

The port numbers are used to multiplex single addresses



NAT also provides other (dis-)advantages

Better privacy

All hosts in one network get the same public IP

But, cookies, browser version, … still identify hosts

Better security

From the outside you cannot directly reach the hosts

Problematic e.g., for online gaming

Reduced scalability (size of the mapping table)

Example: Wi-Fi access problems in public places

(e.g., lecture hall) often due to a full NAT table

Enters IPv6

The easy way to think of IPv6 is to consider it as equivalent to IPv4 but with 128 bits addresses

Notation	8 groups of 16 bits each separated by colons (:) Each group is written as four hexadecimal digits
Simplification	Leading zeros in any group are removed Max 1 section of zeros can be replaced by a double colon (::) Normally, the longest section
Examples	1080:0:0:0:8:800:200C:417A → 1080::8:800:200C:417A FF01:0:0:0:0:0:0:0101 → FF01::101 0:0:0:0:0:0:0:1 → ::1

There are three types of IPv6 addresses: unicast, anycast, and multicast

Unicast	Identifies a single interface Packets are delivered to this specific interface
Anycast	Identifies a set of interfaces Packets are delivered to the *nearest* interface
Multicast	Identifies a set of interfaces Packets are delivered to *all* interfaces

Unicast	Identifies a single interface Packets are delivered to this specific interface

Global unicast addresses are hierarchically allocated

similar to global IPv4 addresses

128 bits

N bits	M bits	128-N-M bits
global routing prefix	subnet ID	Interface ID

Identifies the ISP responsible for the address

A subnet in this ISP or a customer of the ISP

Usually 64 bits
Based on the MAC address

Allocation of IPv6 (global unicast) addresses

iana
Internet Assigned Numbers Authority

The Internet Assigned Numbers Authority (IANA) assigns blocks to Regional IP address Registries (RIR)

For example RIPE, ARIN, APNIC, ...

Currently, only 2000::/3 is used for global unicast

All addresses are in the range of 2000 to 3FFF

Link-local addresses are unique to a single link (subnet)

same as private IPv4 addresses

128 bits

10 bits	54 bits	64 bits
FE80	0000...0000	Interface ID

Each host/router **must** generate a link-local address for **each** of its interfaces

An interface therefore can have multiple IPv6 addresses

ETH's IPv6 prefix 2001:67c:10ec::/48

```
inet6num:       2001:67c:10ec::/48
netname:        ETHZ-NET-IPv6
descr:          ETHZ
descr:          Zurich, Switzerland
country:        CH
org:            ORG-ETHZ1-RIPE
admin-c:        AW1297-RIPE
tech-c:         HE688-RIPE
status:         ASSIGNED PI
mnt-by:         RIPE-NCC-END-MNT
mnt-by:         SWITCH-MNT
mnt-routes:     SWITCH-MNT
mnt-domains:    SWITCH-MNT
created:        2012-09-18T11:49:33Z
last-modified:  2016-04-14T08:45:10Z
source:         RIPE # Filtered
sponsoring-org: ORG-SG2-RIPE
```

In addition to global and link-local addresses, some IPv6 unicast addresses have a special meaning

Unspecified address	0:0:0:0:0:0:0:0 Used as src address if no IPv6 address available
Loopback address	0:0:0:0:0:0:0:1 ⟶ ::1 127.0.0.1 for IPv4 addresses
IPv4 embedded	The lowest 32 bits contains an IPv4 address useful when deploying IPv6
Important	There are no IPv6 broadcast addresses

Anycast	Identifies a set of interfaces Packets are delivered to the „nearest" interface

IPv6 anycast addresses

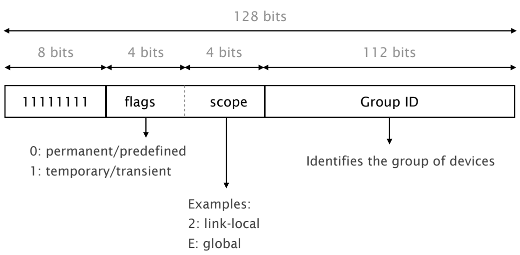
Multiple interfaces with the same address
Packets are sent to the nearest interface

Anycast use the global unicast address range
E.g. for DNS or HTTP services

IPv6 anycast is rarely used (as of now)

Multicast	Identifies a set of interfaces Packets are delivered to **all** interfaces

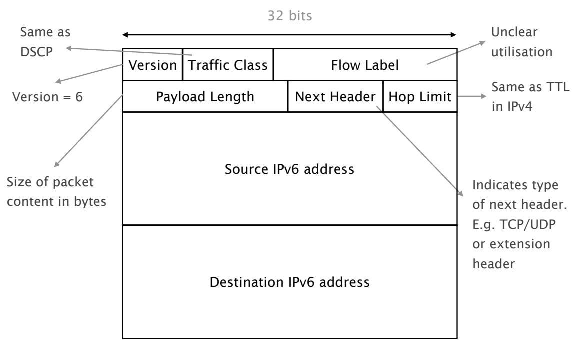
Multicast addresses identify a group of receivers/interfaces



Some multicast addresses are well-known and used for auto-discovery, bootstrapping, etc.

FF02::1	All IPv6 end-systems E.g. hosts, servers, routers, mobile devices, …
FF02::2	All IPv6 routers All routers automatically belong to this group

The IPv6 packet header format



Compared to IPv4, IPv6 does…

not include checksums in the packet header
link, transport or application layer provide checksums

not support fragmentation
End host is required to send small enough packets

provide more flexibility
flow labels and extension headers

Extension header example: ICMPv6

Similar functions than IPv4 ICMP

Version	Traffic Class	Flow Label	
Payload Length		58 - ICMPv6	Hop Limit
Source IPv6 address			
Source IPv6 address			
Type	Code	Checksum	
Message Body			

The next header field indicates the type of the extension header

Extension header

ICMPv6 can be used for neighbor discovery

replacement for IPv4's ARP

First step: neighbor solicitation

Type:135	Code:0	Checksum
Reserved		
Target IPv6 address		

IPv6 address for which we need the link-layer address

ICMPv6 can be used for neighbor discovery

Second step: neighbor advertisement

Type:136			Code:0	Checksum
R	S	O	Reserved	
Target IPv6 address				
Target link layer address				

Is a router?

Answer to neighbor solicitation?

Requested link-layer address

How can a node obtain its IPv6 address(es)?

Manual configuration
As in the project, e.g. with ifconfig

From a server by using DHCPv6
Similar to the IPv4 version

Automatically
Using its link-local address and neighbor discovery

IPv6 autoconfiguration to find link-local address

Consider an end-system which has just started,
it needs an IPv6 address to send ICMPv6 messages

Ethernet (MAC): 0800:200C:417A
Link-local: FE80::M_{64}(800:200C:417A)
M_{64}: 64-bit representation of the MAC address

Neighbor solicitation for FE80::M_{64}(800:200C:417A)
If **no** answer, the created link-local address is valid

IPv6 autoconfiguration to obtain the IPv6 prefix of subnet

Routers periodically advertise the prefix
Sent to all end-systems: FF02::1

The advertisements can contain:
IPv6 prefix and length
Network MTU to use
Maximum hop limit to use
Lifetime of the default router
How long generated addresses are preferred

IPv6 autoconfiguration to build global unicast address

Ethernet (MAC): 0800:200C:417A

Prefix: 2001:6a8:3080:1::/64

Global unicast:
2001:6a8:3080:1:M_{64}(800:200C:417A)

contains MAC address of host

To port your IPv4-based application to IPv6, you need to…

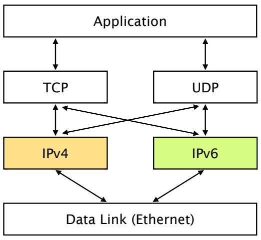
change the used socket functions

adjust all logging functions

adapt all data structures to support IPv6 addresses

adjust user interface elements to display IPv6

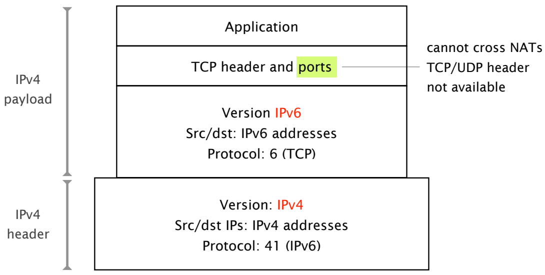
Today, a lot of applications and OSes
use a dual stack approach



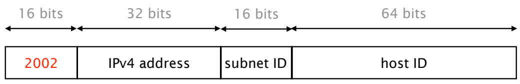
Over the years, a lot of
transition mechanisms were developed

- 6in4
- 6to4
- Teredo
- SIIT
- 6rd
- GRE
- AYiYA
- …

Tunnel IPv6 packets over static IPv4 links (6in4)



6to4 uses special IPv6 addresses

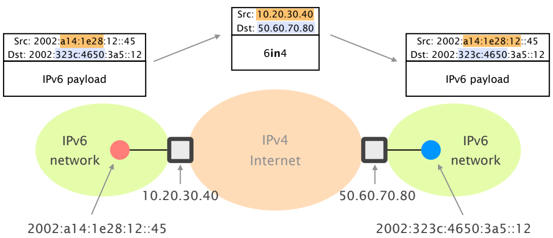


IPv4: 192.15.3.73

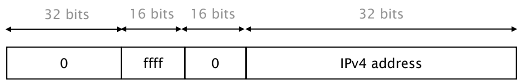
c0.0f.03.49

6to4: 2002:c00f:0349::/48

6to4 transmits IPv6 packets
over IPv4 networks without explicit tunnels



Stateless IP/ICMP Translation (SIIT)
uses IPv4-embedded IPv6 addresses



Example: ::ffff:0:c00f:0349

Other notation: ::ffff:0:192.15.3.73

Similar to 6to4, a router translates addresses

/96 prefix is such that checksums stay the same
when going from IPv6 to IPv4

If you don't have IPv6 @home already,
look at your set-top box configuration to activate it

(Swisscom set-top box's Configuration)

Head to www.kame.net to check
if you see the dancing turtle 😃