Towards an IPv6-only WLCG: more successes in reducing IPv4

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(on behalf of the HEPiX IPv6 Working Group)

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On behalf of all members of the HEPiX IPv6 working group - (many thanks all!)

M Babik (CERN), M Bly (RAL), N Buraglio (ESnet), T Chown (Jisc), D Christidis (CERN/ATLAS), J Chudoba (FZU Prague), P Demar (FNAL), J Flix (PIC), C Grigoras (CERN/ALICE), B Hoeft (KIT), H Ito (BNL), D P Kelsey (RAL), E Martelli (CERN), S McKee (U Michigan), C Misa Moreira (CERN), R Nandakumar (RAL/LHCb), K Ohrenberg (DESY), F Prelz (INFN), D Rand (Imperial), A Sciabà (CERN/CMS), T Skirvin (FNAL), C J Walker (Jisc)

- Special thanks to underlined co-authors for provision of some slides
- Many more in the past, and members join/leave from time to time
- ***many thanks** also to WLCG operations, WLCG sites, LHC experiments, networking teams, monitoring groups, storage developers…*

Outline

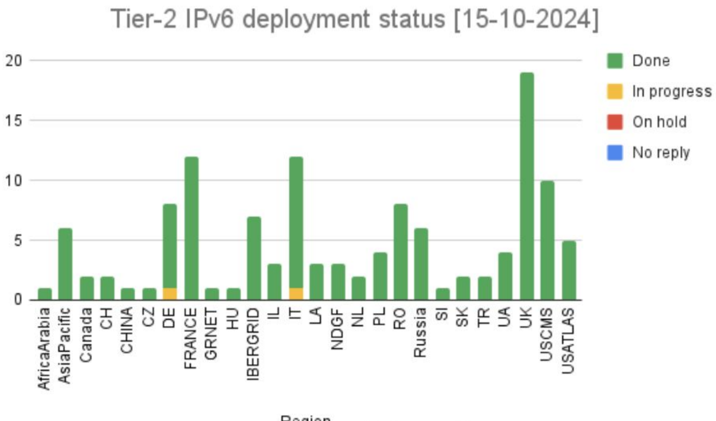
- The HEPiX IPv6 working group - reminder
  - Drivers for IPv6
  - IPv6/IPv4 dual-stack storage
- Dual-stack CPU & worker nodes campaign
- Observations during WLCG Data Challenge (DC24)
- Plans for IPv6-only WLCG
- Summary

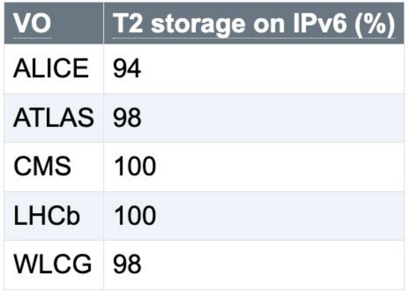
HEPiX IPv6 working group - History and drivers for use of IPv6

- Phase 1 - 2011-2016 - analysis, investigations, testbed, fix storage
- Phase 2 - 2017-2023 - deploy dual-stack storage on WLCG
- Phase 3 - 2019-onwards - plan for IPv6-only
- Sites running out of routable IPv4 addresses (avoid NAT)
  - Use IPv6 addresses for external public networking
- To be ready to support use of IPv6-only CPU clients
- There are other drivers for IPv6:
  - scitags.org – packet marking (in header of IPv6 packets)
    - Research Networking Technical Working Group (RNTWG)
  - USA Federal Government – directive on “IPv6-only” (Nov 2020)

Dual-stack WLCG Storage (Tier2s)

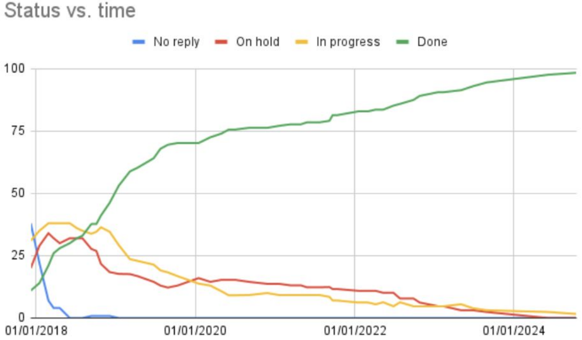
- Campaign “IPv6 on storage services” started in 2017
- Goal to allow IPv6-only WNs
- Main reason for delay - the institute networking
- Today, almost all WLCG sites have dual-stack IPv6/IPv4 Storage





VO	T2 storage on IPv6 (%)
ALICE	94
ATLAS	98
CMS	100
LHCb	100
WLCG	98

(checked on 15-10-2024)

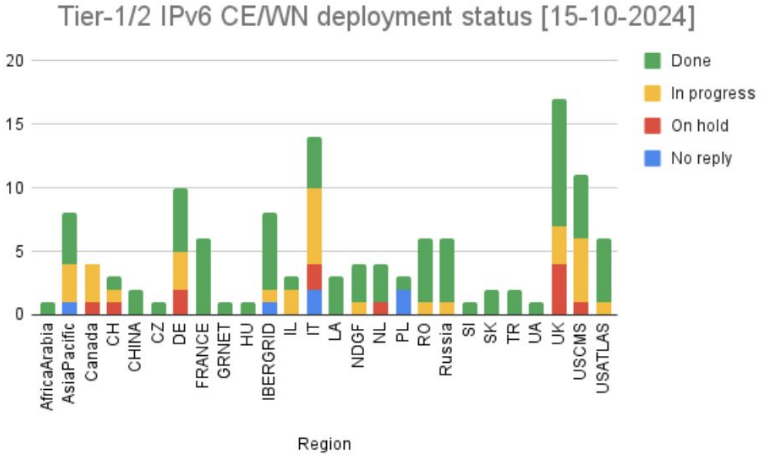


Dual-stack CPU and WN campaign

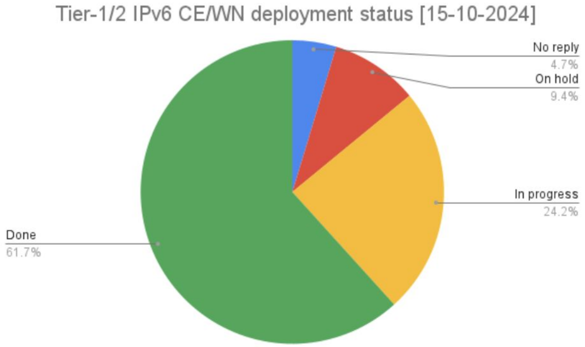
WLCG CPU - GGUS ticket campaign

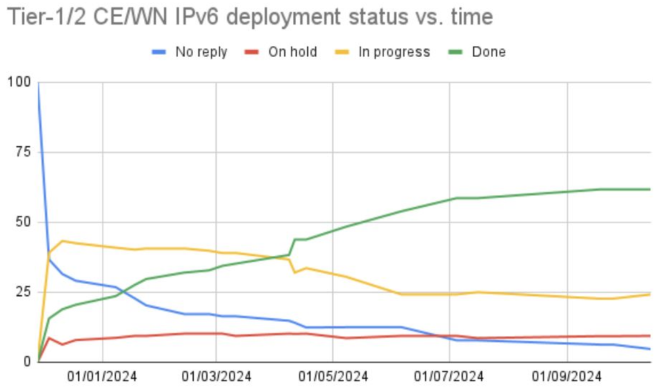
- Eliminate a large remaining source of IPv4 traffic
  - Data transfers between WNs and remote storage systems
- Approved by WLCG MB in October 2023
- Launched on 28 November 2023 on all WLCG sites
- **“Please deploy dual-stack connectivity (IPv4+IPv6) on your computing services (computing elements and worker nodes) as soon as possible and by 30 June 2024 at the latest”**
- Provide estimates for timescale and details on the necessary steps
- If cannot meet the deadline, then explain why

CPU Current status


Tier-1/2 IPv6 CE/WN deployment status [15-10-2024]

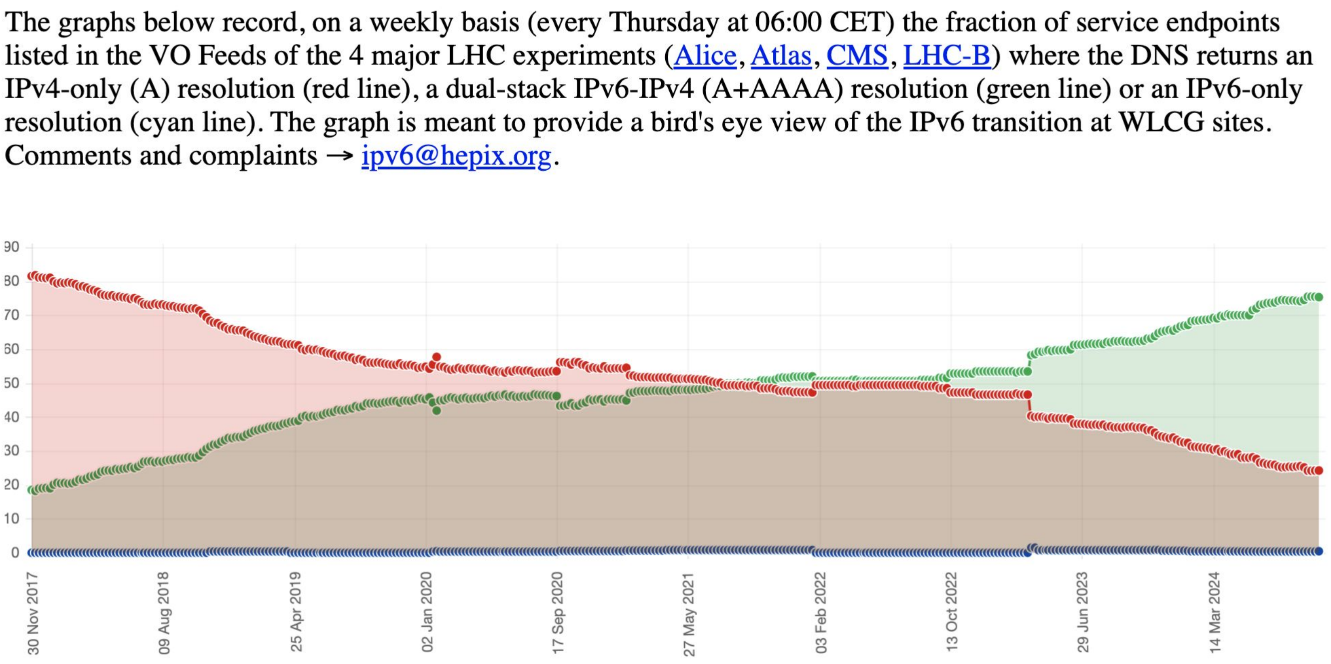
62% done - Status always visible from a twiki page


Tier-1/2 IPv6 CE/WN deployment status [15-10-2024]


Tier-1/2 CE/WN IPv6 deployment status vs. time

All WLCG services - “VOfeeds”

https://orsone.mi.infn.it/~prelz/ipv6_vofeed/



The graphs below record, on a weekly basis (every Thursday at 06:00 CET) the fraction of service endpoints listed in the VO Feeds of the 4 major LHC experiments (Alice, Atlas, CMS, LHC-B) where the DNS returns an IPv4-only (A) resolution (red line), a dual-stack IPv6-IPv4 (A+AAAA) resolution (green line) or an IPv6-only resolution (cyan line). The graph is meant to provide a bird's eye view of the IPv6 transition at WLCG sites. Comments and complaints → ipv6@hepix.org.

~75% dual stack

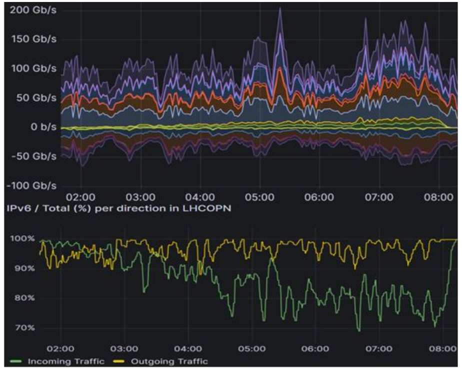
~25% IPv4

Observations during WLCG Data Challenge (DC24)

During WLCG DC24 - IPv6 sub-project

- Work to study the LHCOPN link between CERN and KIT
- Understand when and why IPv4 is being used
- Early on - large IPv4 transfer seen to ALICE at CERN
  - Failed transfers on IPv6 failing over to use of IPv4
- Later - some transfers from KIT to NL-T1
  - All end-points were dual-stack but NL-T1 preferred IPv4 to avoid some observed problems with many concurrent IPv6 streams
- Then see next slide
  - Plot of XRootD file transfers from CERN
  - Squid at KIT - all would work if IPv6-only but often fails back to IPv4
- Lots of detailed investigations - and STILL ongoing (see later slides)

XRootD file transfer from CERN



```
2024-02-20 06:50:17.012   22.500 TCP    128.142.56.61  59332   192.108.47.90  1094    2.7 M   4.1 G   1.5 G  1499    1
2024-02-20 06:02:38.012   16.000 TCP   128.142.57.111  40594   192.108.47.89  1094    2.7 M   4.1 G   2.1 G  1499    1
2024-01-31 09:33:31.833   11.653 TCP   128.142.63.105  43670   192.108.46.89  1094    2.8 M   4.2 G   2.9 G  1498    1
```

Summary: total flows: 597053, total bytes: 33.0 TeraByte

1625 Server at CERN

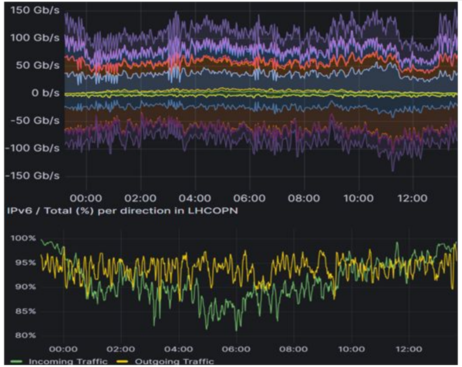
Only 16 Server at KIT

- cvmfs-sq4.gridka.de. dual-stack
- cvmfs-sq1.gridka.de. dual-stack
- cvmfs-sq3.gridka.de. dual-stack
- cvmfs-sq5.gridka.de. dual-stack
- cvmfs-sq6.gridka.de. dual-stack
- cvmfs-sq2.gridka.de. dual-stack
- frontier-sq1.gridka.de. dual-stack
- fw-nat-inside-outside.gridka.de.

8 Storage Server at DE-KIT (XRootD Port – 1094):

- f01-032-114-e.gridka.de.
- f01-124-110-e.gridka.de. dual-stack
- f01-124-159-e.gridka.de. dual-stack
- f01-124-160-e.gridka.de. dual-stack
- f01-124-161-e.gridka.de. dual-stack
- f01-125-159-e.gridka.de. dual-stack
- f01-125-160-e.gridka.de. dual-stack
- f01-125-161-e.gridka.de. dual-stack

Green line - CERN to KIT %IPv6 70 to 80%



```
2024-02-20 23:26:09.012    0.500 TCP   128.142.249.74  38908  192.108.68.144  1094      12    2266   36256   188    1
2024-02-21 02:39:33.262    0.250 TCP   128.142.240.76  55700   192.108.46.89  1094      10     706   22592    70    1
```

Summary: total flows: 1460049, total bytes: 43.1 TeraByte

2426 Server at CERN

Only 25 Server at KIT

Squid service

Port 3401

cvmfs-sq4.gridka.de.
cvmfs-sq1.gridka.de.
cvmfs-sq3.gridka.de.
cvmfs-sq5.gridka.de.
cvmfs-sq6.gridka.de.
cvmfs-sq2.gridka.de.
frontier-sq1.gridka.de.
fw-nat-inside-outside.gridka.de.

XRootD Port 1094

f01-124-109-e.gridka.de.
f01-124-110-e.gridka.de.
f01-124-112-e.gridka.de.
f01-124-155-e.gridka.de.
f01-124-159-e.gridka.de.
f01-124-160-e.gridka.de.
f01-124-161-e.gridka.de.
f01-125-109-e.gridka.de.
f01-125-110-e.gridka.de.
f01-125-155-e.gridka.de.
f01-125-159-e.gridka.de.
f01-125-160-e.gridka.de.
f01-125-161-e.gridka.de.
f01-117-137-e.gridka.de.
f01-152-140-e.gridka.de.
f01-152-191-e.gridka.de.
f01-152-192-e.gridka.de.

Green line - and again

Plans for IPv6-only WLCG

IPv6-only on WLCG (CHEP2019)

https://doi.org/10.1051/epjconf/202024507045

- The end point of the transition from IPv4 is an IPv6-only WLCG core network - agreed by WLCG MB
- To simplify operations
  - Dual-stack infrastructure is the most complex
  - Reduced complexity reduces chance of making security errors
- Large infrastructures (e.g. Facebook, Microsoft,...) use IPv6-only internally
- The goal we are still working towards
  - “IPv6-only” for the majority of WLCG services and clients
- Timetable still to be defined - but aiming for “before LHC Run 4”

What do we mean by IPv6-only?

Choices (one or more of):

- WLCG site services are IPv6-only (CE, SE, …)
- WLCG Tier 2 is fully IPv6-only
- Other WLCG central services (e.g. Rucio, FTS etc.) are IPv6-only
- LHCOPN and/or LHCONE networks are IPv6-only
- All WAN WLCG traffic is IPv6-only

What does the IPv6 working group wish to achieve:

- All WLCG services (site and central) are IPv6-only
- Removes complexity of dual-stack
- No longer have to chase use of IPv4 by dual-stack endpoints
- All WLCG WAN traffic is IPv6-only

Plans for IPv6-only WLCG

First steps:

- Any site can today have IPv6-only clients and fully function in WLCG
- We are gradually moving all WLCG services to be fully dual-stack
- We need more sites to test “IPv6-only” clients, worker nodes etc.

Ongoing plan:

- By end of Run 3 *all* WLCG services to be fully dual-stack (today ~75%)
- Continue removing use of legacy IPv4 on LHCOPN (until end of Run 3)
- Turn-off IPv4 peering on LHCOPN when possible
- Remove all WAN traffic over IPv4

Working group observations/questions:

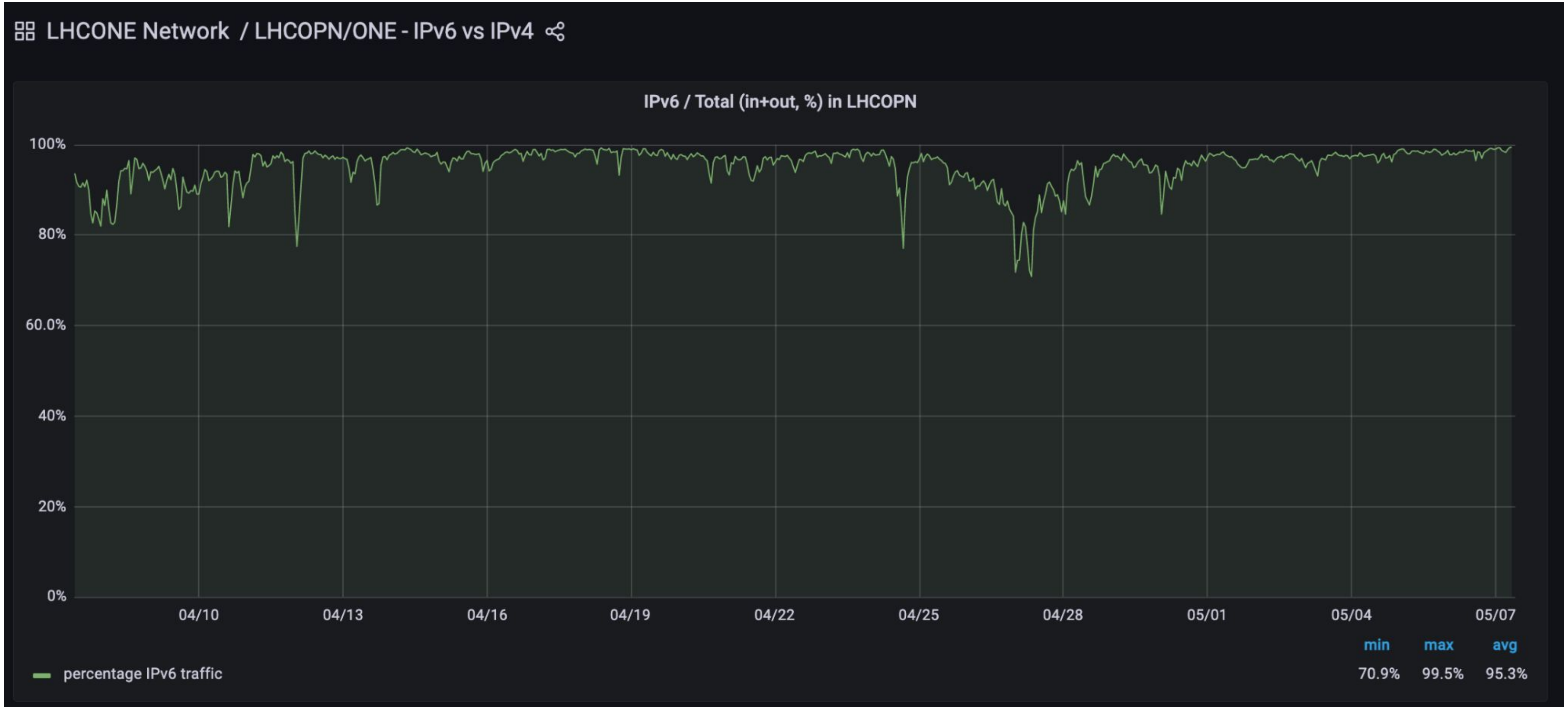
- When should perfSONAR stop performing IPv4 tests?
- Can we add “IPv4 versus IPv6” traffic split in the WLCG Site egress monitoring network I/O (for DC24) (every minute)?

Some plots: IPv6 and IPv4 traffic on LHCOPN (5 to 9 Oct 2024) (and compare with CHEP2023)

Will skip these if no time to show

LHCOPN - %IPv6 traffic - shown at CHEP2023

7 April to 7 May 2023 - shows drops in %IPv6



min	max	avg
70.9%	99.5%	95.3%

100%

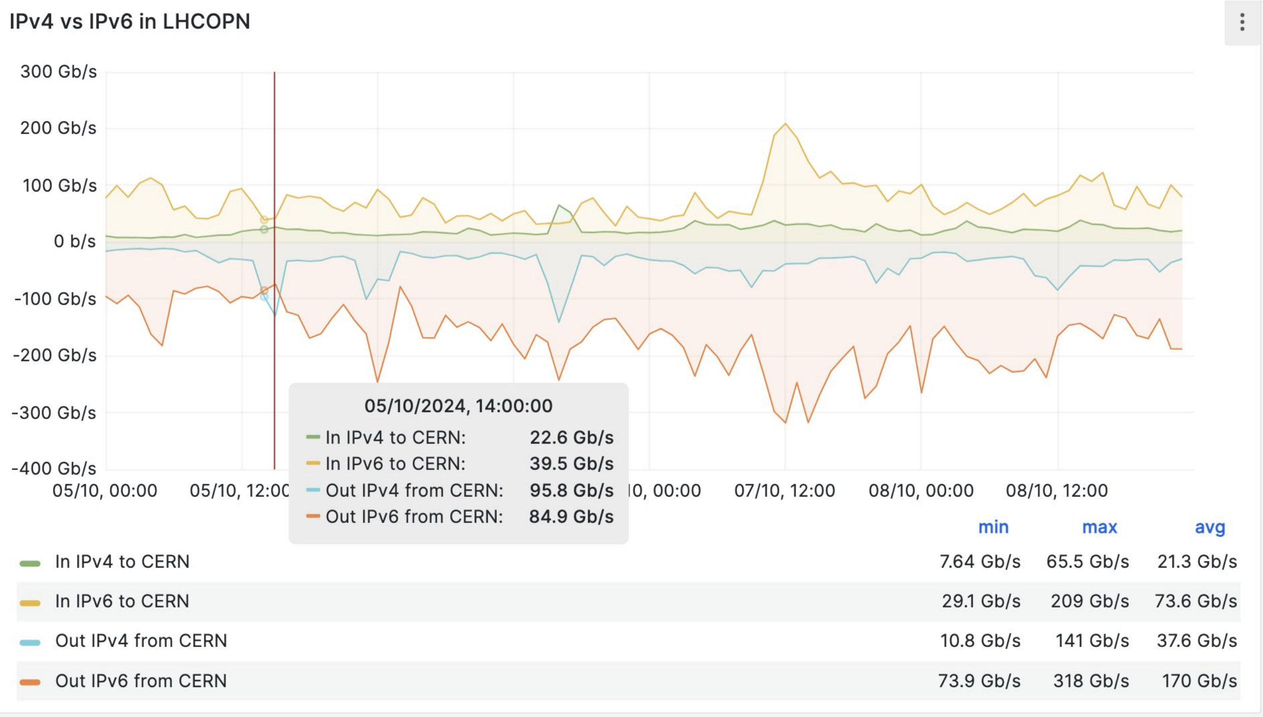
Max
99.5%

Avg
95.3%

Min
70.9%

LHCOPN total traffic, split IPv4 & IPv6 (as seen at CERN)

https://monit-grafana-open.cern.ch/d/cumEJJb4z/lhcopn-one-ipv6-vs-ipv4?orgId=16&from=1728079200000&to=1728424799000


IPv4 vs IPv6 in LHCOPN

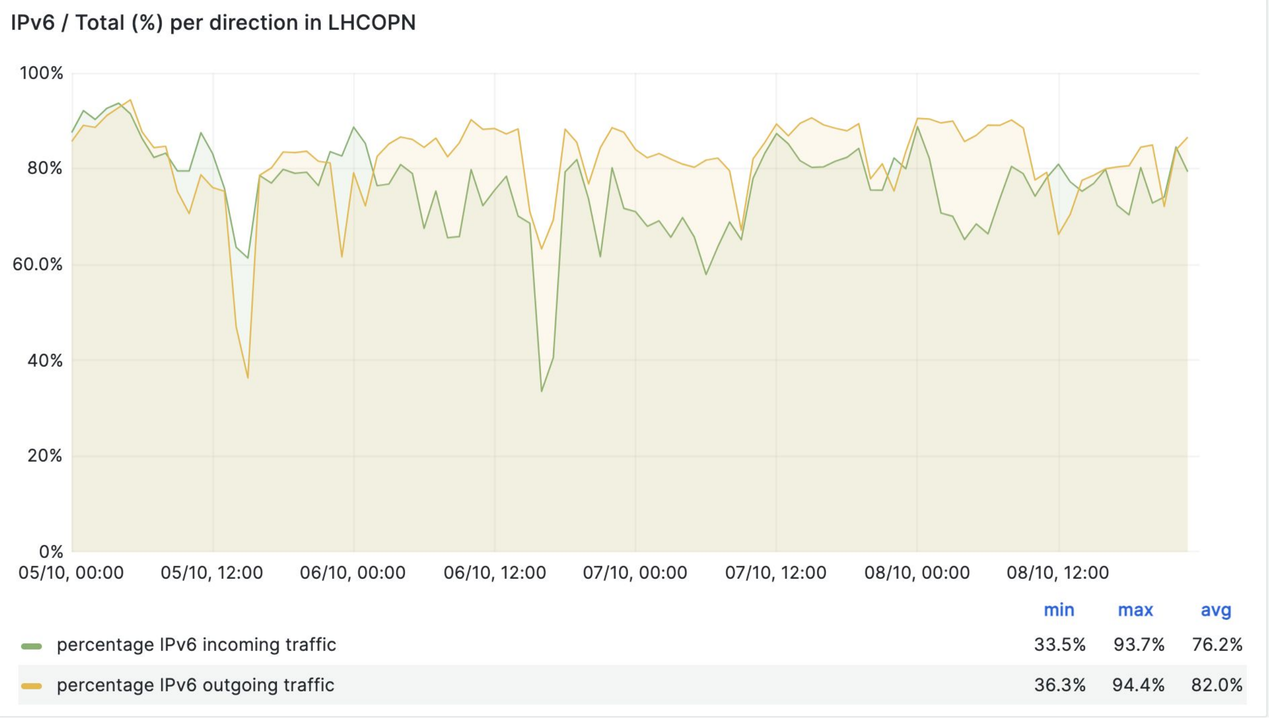
05/10/2024, 14:00:00

In IPv4 to CERN:	22.6 Gb/s
In IPv6 to CERN:	39.5 Gb/s
Out IPv4 from CERN:	95.8 Gb/s
Out IPv6 from CERN:	84.9 Gb/s

	min	max	avg
In IPv4 to CERN	7.64 Gb/s	65.5 Gb/s	21.3 Gb/s
In IPv6 to CERN	29.1 Gb/s	209 Gb/s	73.6 Gb/s
Out IPv4 from CERN	10.8 Gb/s	141 Gb/s	37.6 Gb/s
Out IPv6 from CERN	73.9 Gb/s	318 Gb/s	170 Gb/s

- 5 to 9 Oct 2024
- IPv6 Out of CERN
  - Avg 170 Gbps
- IPv4 Out of CERN
  - Avg 37.6 Gbps
- BUT
  - Large IPv4 peaks, e.g.
  - 5/10 @ 14:00
  - Out 95.8 Gbps

%IPv6 traffic - generally high - but large drops down to ~40%

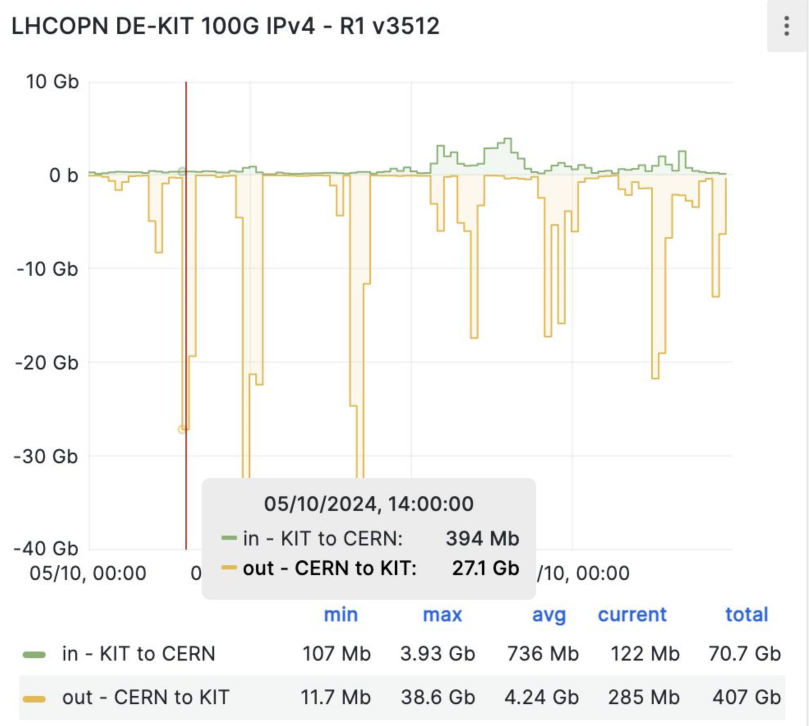

IPv6 / Total (%) per direction in LHCOPN

	min	max	avg
🟩 percentage IPv6 incoming traffic	33.5%	93.7%	76.2%
🟨 percentage IPv6 outgoing traffic	36.3%	94.4%	82.0%

- %IPv6
- In - avg 76.2%
  - Min 33.5%
- Out - avg 82.0%
  - Min 36.3%

LHCOPN traffic (CERN- KIT) German Tier1 - large IPv4 peaks

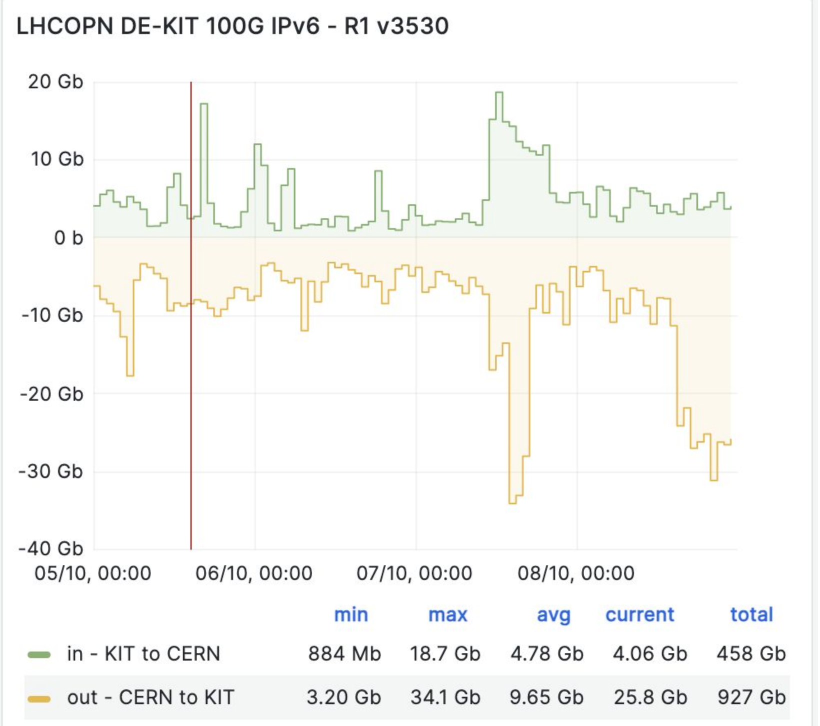
IPv4 plot



LHCOPN DE-KIT 100G IPv4 - R1 v3512

	min	max	avg	current	total
in - KIT to CERN	107 Mb	3.93 Gb	736 Mb	122 Mb	70.7 Gb
out - CERN to KIT	11.7 Mb	38.6 Gb	4.24 Gb	285 Mb	407 Gb

IPv6 plot



LHCOPN DE-KIT 100G IPv6 - R1 v3530

	min	max	avg	current	total
in - KIT to CERN	884 Mb	18.7 Gb	4.78 Gb	4.06 Gb	458 Gb
out - CERN to KIT	3.20 Gb	34.1 Gb	9.65 Gb	25.8 Gb	927 Gb

What are these large peaks of IPv4?

- Not easy
- Need access to Netflow data
- Study IP addresses and Port numbers
    - Aim to identify LHC Experiment
    - Source and Destination address
    - Type of data transfer
- Work in progress
    - But some evidence of Frontier/CVMFS/Squid, etc….

Summary

- WLCG already supports use of IPv6-only clients
- Dual-stack Storage campaign finished
  - Most WLCG data transfers use IPv6
- Campaign for dual-stack CPU and WN’s - well underway
- Observed use of legacy IPv4 during DC24 and afterwards
- We continue to chase use of legacy IPv4 and try to fix
- Aim to complete move to IPv6-only before start of HL-LHC Run 4

- ***Message to WLCG sites and LHC experiments:***
  - ***Deploy dual-stack on all services & clients and prefer use of IPv6***

HEPiX

Questions, Discussion?

Backup slides

The HEPiX IPv6 Working Group

- In 2010-11
  - some HEPiX sites running out of IPv4 addresses
  - IANA projecting imminent IPv4 address exhaustion
  - Moving to support IPv6 would not be fast - better start now!
- Phase 1 - 2011-2016 - full analysis, investigations, ran a testbed
  - lots of work by storage developers to be IPv6-capable
- Phase 2 - 2017-2023 - deploy dual-stack storage on WLCG
- Phase 3 - 2019-onwards - plan for IPv6-only
  - investigate and fix reasons for obstacles to deployment of IPv6
  - Deploy dual-stack CPU and worker nodes (2023-onwards)

https://www.hepix.org/e10227/e10327/e10326/

https://indico.cern.ch/category/3538/ (meetings)

“Obstacles” to IPv6

There are many reasons stopping the full use of IPv6/IPv4

- Dual stack is an essential step on the journey to IPv6-only

The Obstacles that we have been addressing:

1. **WLCG Sites not yet deployed IPv6 networking** ~done
2. **Sites have IPv6 but Tier-2 has no dual-stack storage** ~done
3. **IPv6 monitoring not available or broken**
    - Monitoring is essential
4. **Service is dual-stack but IPv4 still being used**
    - We continue to chase these problems

Obstacles to IPv6 - being addressed

5. **Non-storage services not yet dual-stack**
   a. ~75% of all WLCG services are dual-stack today, we need 100%
6. **WLCG client CPU (worker nodes, VMs, containers) some IPv4-only**
   a. GGUS ticket campaign well underway
7. **Services/clients outside of WLCG Tier-1/Tier-2 not yet addressed**
   a. Tier-3, Public/Commercial Clouds, Analysis facilities, Experiment portals…
8. **Use of new or evolving technologies** not yet tested or tracked
   a. New CPU architectures (GPU, non-x86, …), container orchestration, …
9. **Staffing issues can be an obstacle**
   a. Lack of effort, lack of IPv6 training/knowledge, pressure of other work