

Update from the IPv6 Working Group

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RAL, STFC, UK Research and Innovation

(on behalf of the HEPiX IPv6 Working Group)

HEPiX Fall 2024, Oklahoma, November 2024

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

The logo for HEPiX, featuring the text "HEPiX" in white on a blue background, with an orange square to the right.

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)

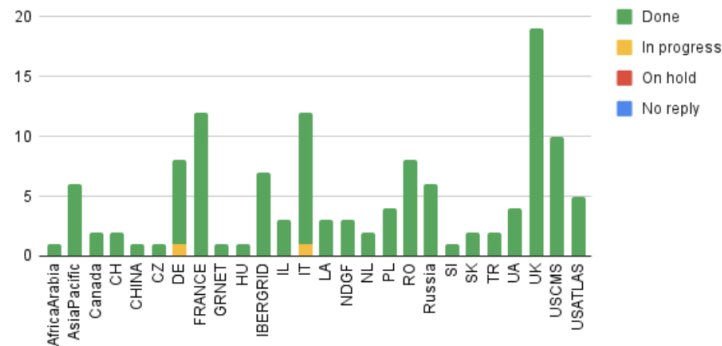
- Campaign “IPv6 on storage services” started in 2017
- Goal to allow IPv6-only WNs
- Main reason for delay - the institute networking
- Today, almost all WLCG sites have dual-stack IPv6/IPv4

Storage

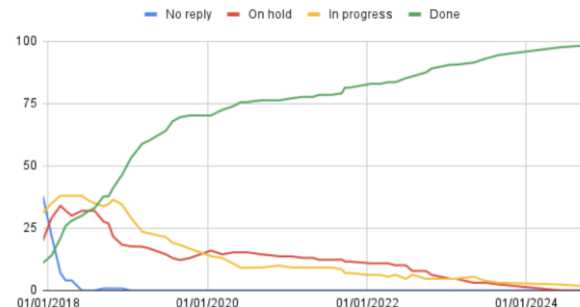
VO	T2 storage on IPv6 (%)
ALICE	94
ATLAS	98
CMS	100
LHCb	100
WLCG	98

(checked on 15-10-2024)

Tier-2 IPv6 deployment status [15-10-2024]



Region Status vs. time

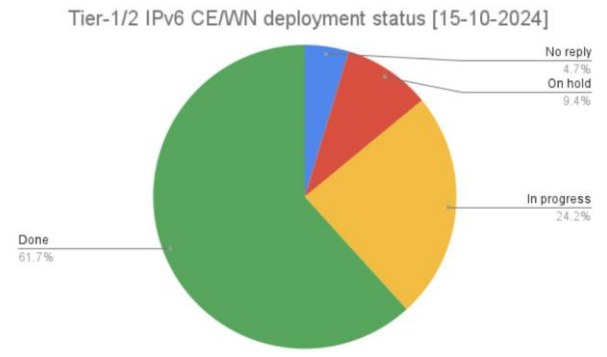
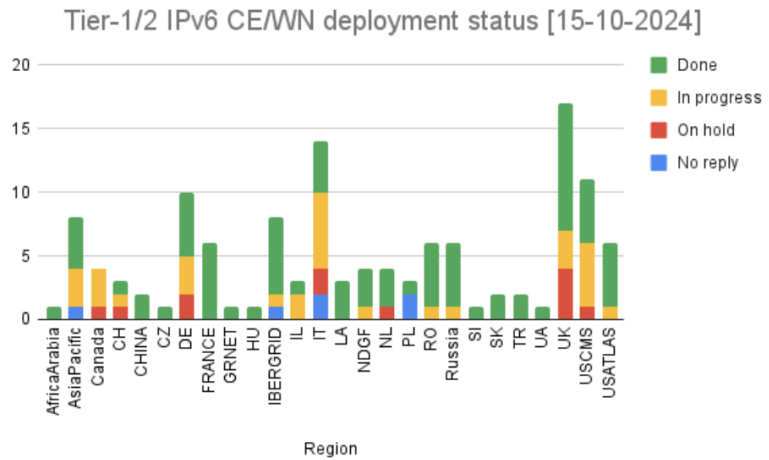


Dual-stack CPU and WN campaign

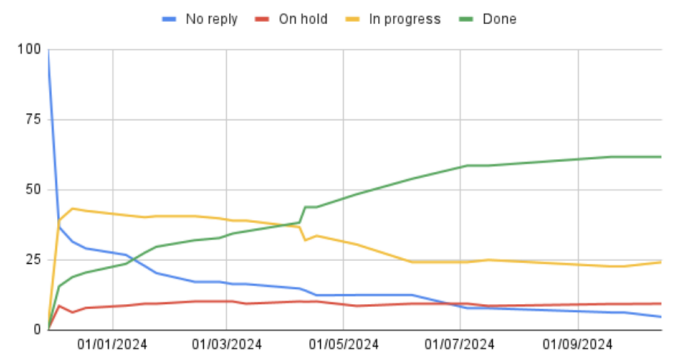
WLCG CPU - GGUS ticket campaign

- 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 CE/WN IPv6 deployment status vs. time

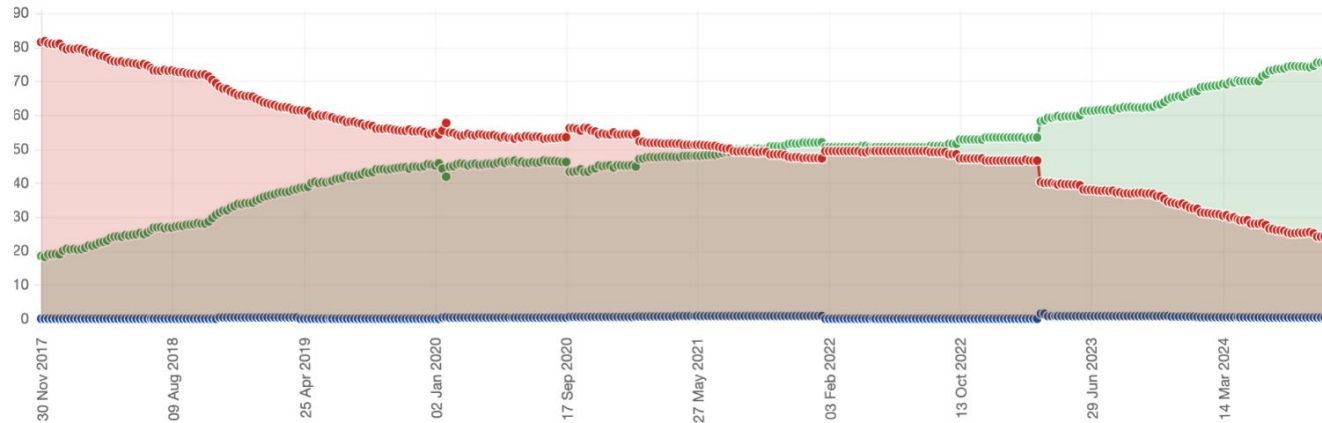


62% done - Status always visible from a [twiki page](#)

All WLCG services - “VOfeeds”

https://orsono.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@hepik.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

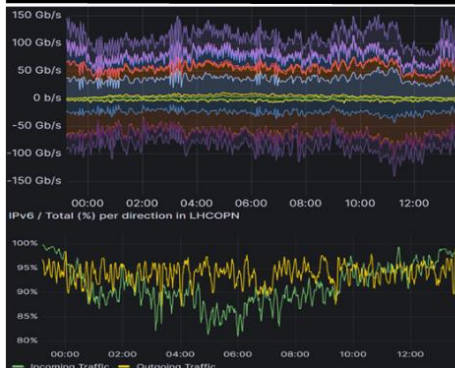
- cvmfs-sq4.gridka.de. dual-stack
- cvmfs-sq1.gridka.de. dual-stack
- cvmfs-sq3.gridka.de. dual-stack
- cvmfs-sq6.gridka.de. dual-stack
- cvmfs-sq2.gridka.de. dual-stack
- frontier-sq1.gridka.de. dual-stack
- fw-nat-inside-outside.gridka.de.

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

Only 16 Server at KIT

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

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.

Only 25 Server at KIT

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:

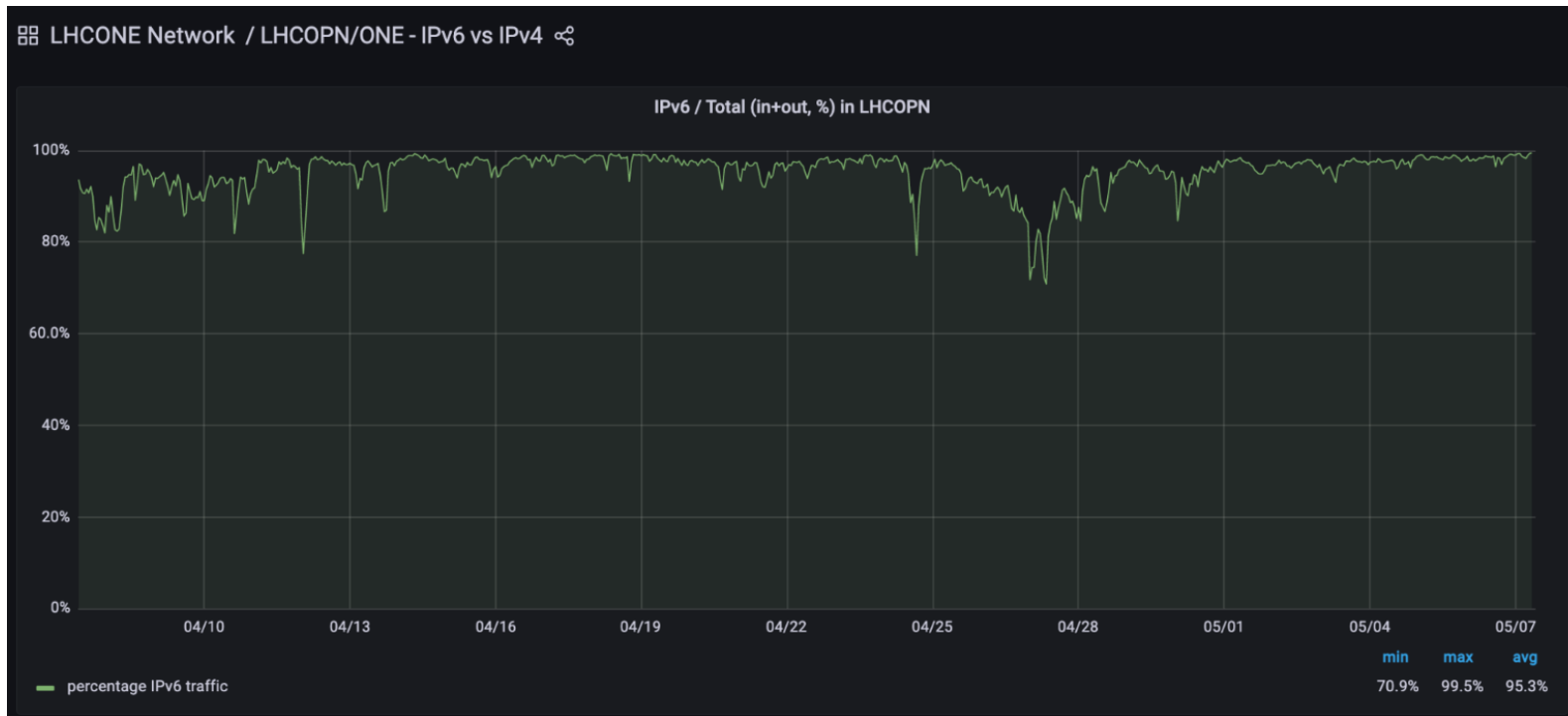
- By end of Run 3 **all** WLCG services to be fully dual-stack (today ~75%)
- Continue removing use of legacy IPv4 on LHCOPN (until end of Run 3)
- Turn-off IPv4 peering on LHCOPN when possible
- Remove all WAN traffic over IPv4

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



100% ←

Max
99.5%

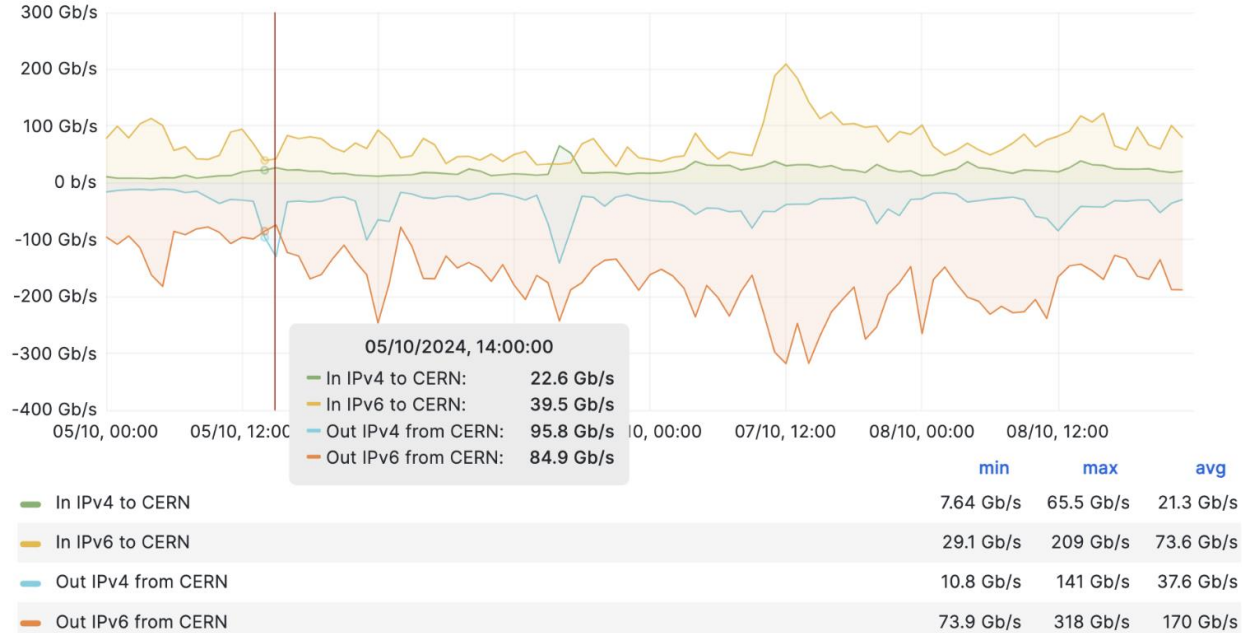
Avg
95.3%

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>

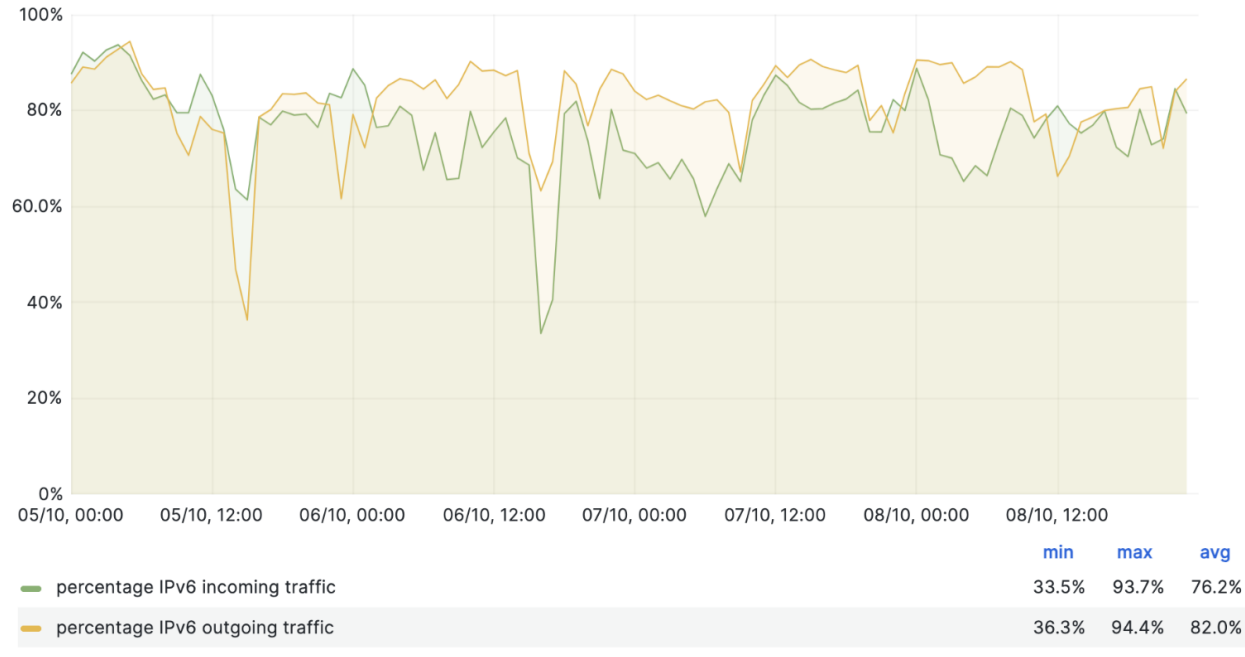
IPv4 vs IPv6 in LHCOPN



- 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

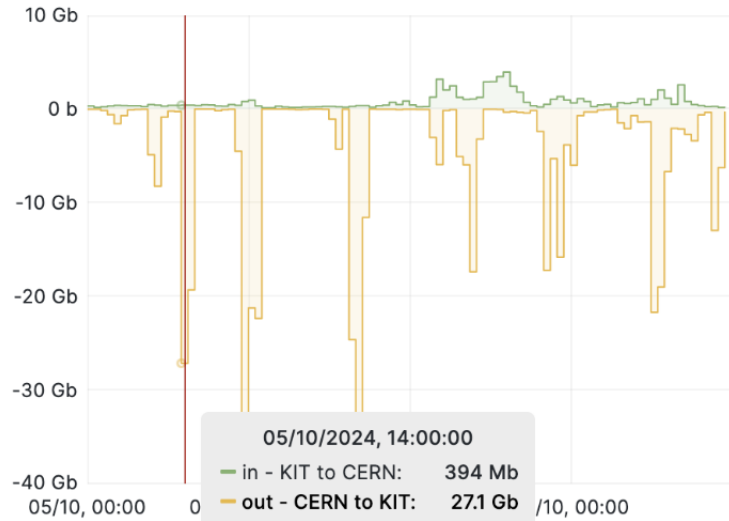


- %IPv6
- In - avg 76.2%
 - Min 33.5%
- Out - avg 82.0%
 - Min 36.3%

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

IPv4 plot

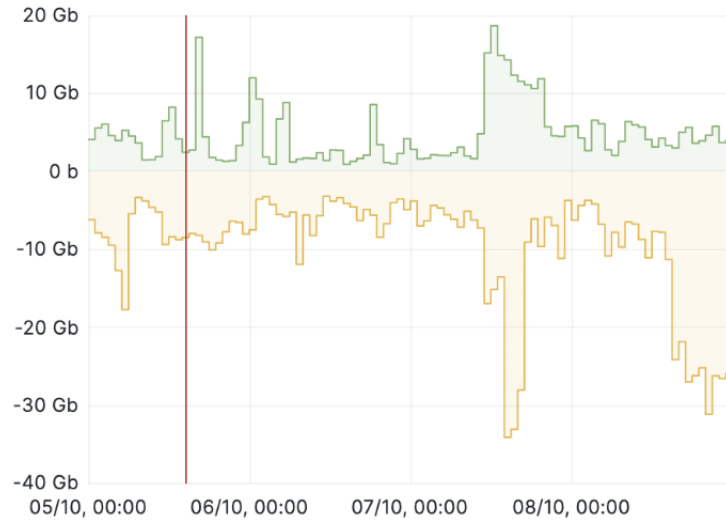
LHCOPN DE-KIT 100G IPv4 - R1 v3512



	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 WNs - 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***

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