# Analyzing scientific data sharing patterns for in-network data caching

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# Introduction

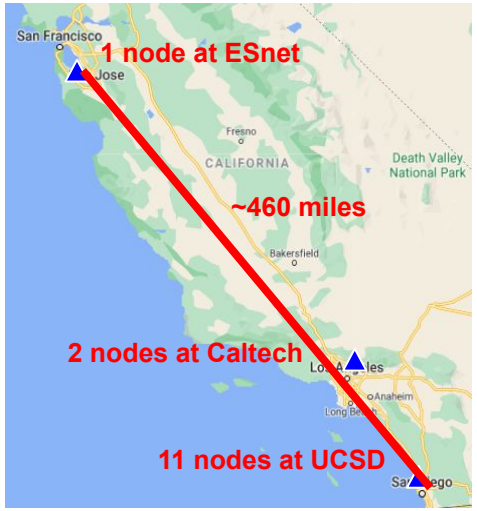
- Data generation in newer scientific experiments and simulations
  - Exponential data volume increase, particularly for geographically distributed large collaborations
    - E.g. Large Hadron Collider (LHC) and Large Synoptic Survey Telescope (LSST)
  - Network bandwidth requirement increase
- Observation
  - Significant portion of the popular dataset is transferred multiple times to different users as well as to the same user
  - Data sharing
    - Reduce the redundant data transfers
    - Save network traffic volume, consequently.
    - Lower data access latency
    - Overall application performance is expected to be improved

# In-network data caching

- In-network caching allows data sharing between users in same region
  - Reduces redundant transfers (costly, inefficient)
  - Reduce demand on transatlantic links
    - ESnet
    - HEP community
- Goals in this study
  - Analyze cache utilization and network utilization
    - Number of accesses, cache misses, cache hits, data transfer sizes, and shared data sizes
  - Identify and study the impact of node downtimes
  - Predict future resource loads and utilization to increase data availability
    - If users double, how will it affect accesses? cache hits? etc.
    - How many XCache nodes will maintain resource efficiency?

# Application use case with CMS

- Working with US CMS data analysis using MINIAOD/NANOAOD
- High-Luminosity Large Hadron Collider
  - HL-LHC aims to increase performance after 2025
    - Increase luminosity by factor of 10
    - Luminosity proportional to the number of collisions in a given time
- Southern California regional cache consists of 14 federated storage caches for US CMS
  - 11 at UCSD: each w/ 24 TB, 10 Gbps network connection
  - 2 at Caltech: each w/ 180 TB, 40 Gbps network connection
  - 1 at ESnet: 40 TB, 40 Gbps network connection
  - Spans 500 miles (socio-politically relevant distance)
- Measurement data
  - Regional data collected from XCache nodes from June - Aug 2020
  - ESnet node data collected from May - Dec 2020
  - Analysis on Cori at NERSC




Sunnyvale–San Diego
is the relevant distance scale

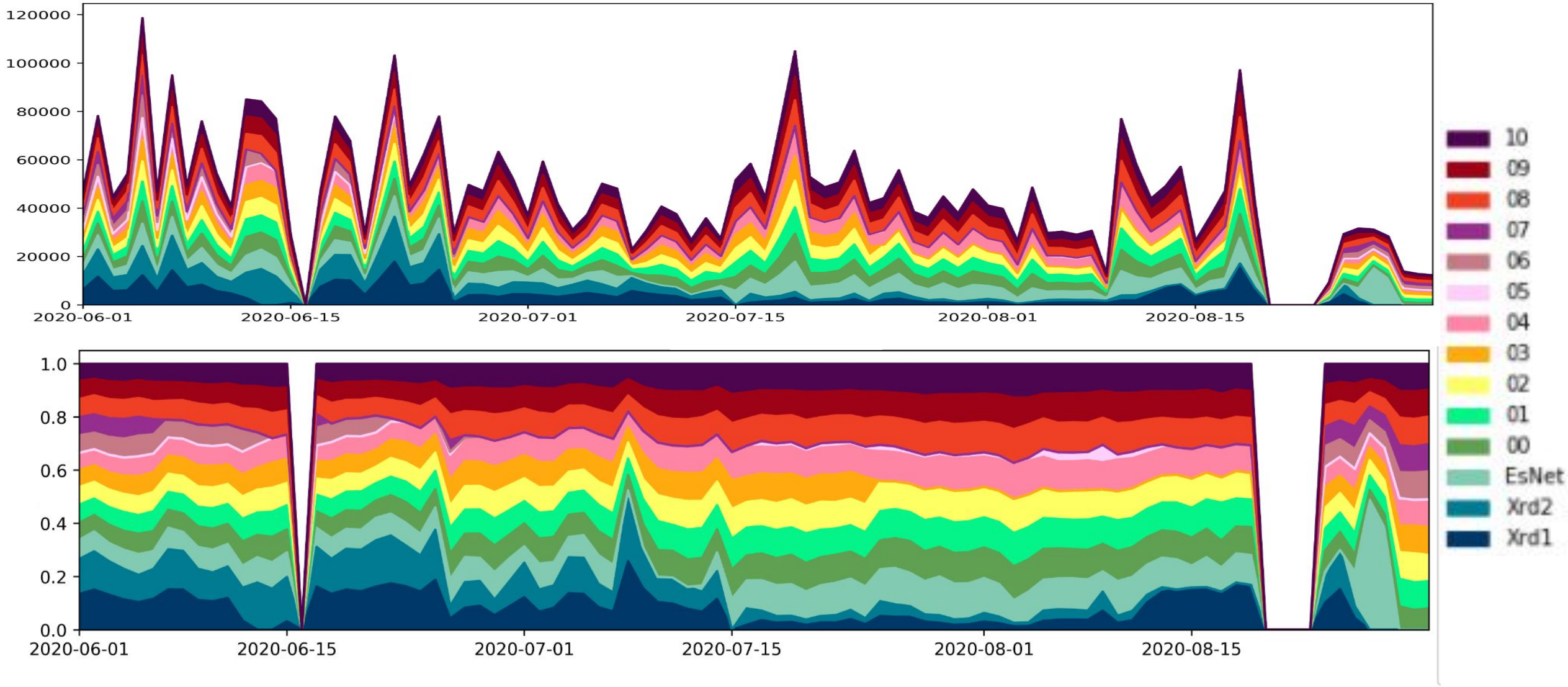
# Cache utilization

# Summary statistics for regional cache repo

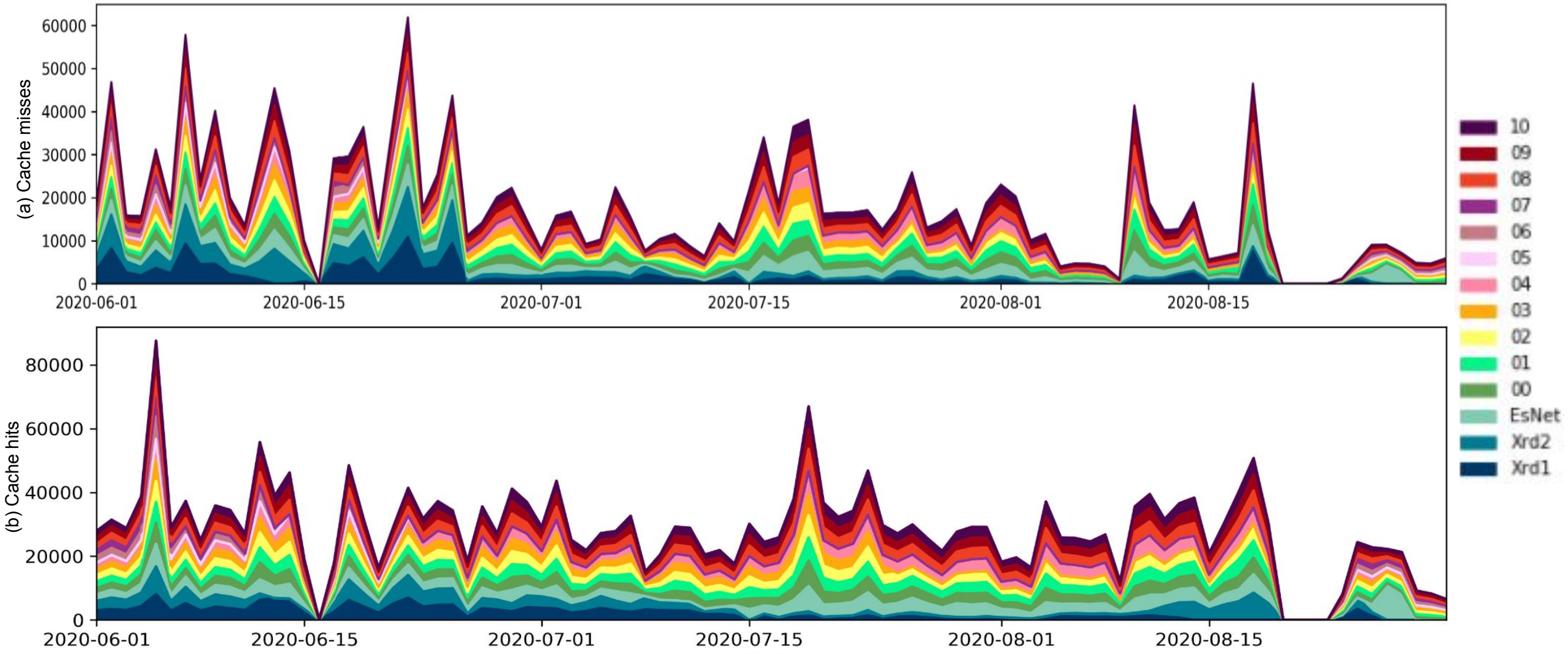
| | Number of accesses | Data transfer size (TB) | Shared data size (TB) | Percentage of shared data size |
|---|---|---|---|---|
| **June 2020** | 1,804,697 | 532.04 | 818.96 | 60.62% |
| **July 2020** | 1,426,585 | 354.45 | 764.35 | 68.32% |
| **Aug 2020** | 995,324 | 249.58 | 586.19 | 70.14% |
| **Total** | 4,226,606 | 1,136.07 | 2,169.49 | 65.63% |
| **Daily average** | 48,029.61 | 12.91 | 24.65 | |

- Data transfer size (= first time data access size, cache misses): From remote sites to the local node cache
- Shared data access size (= repeated data accesses, cache hits, network bandwidth savings): From the local node cache to the application, excluding the first time accesses (data transfers)

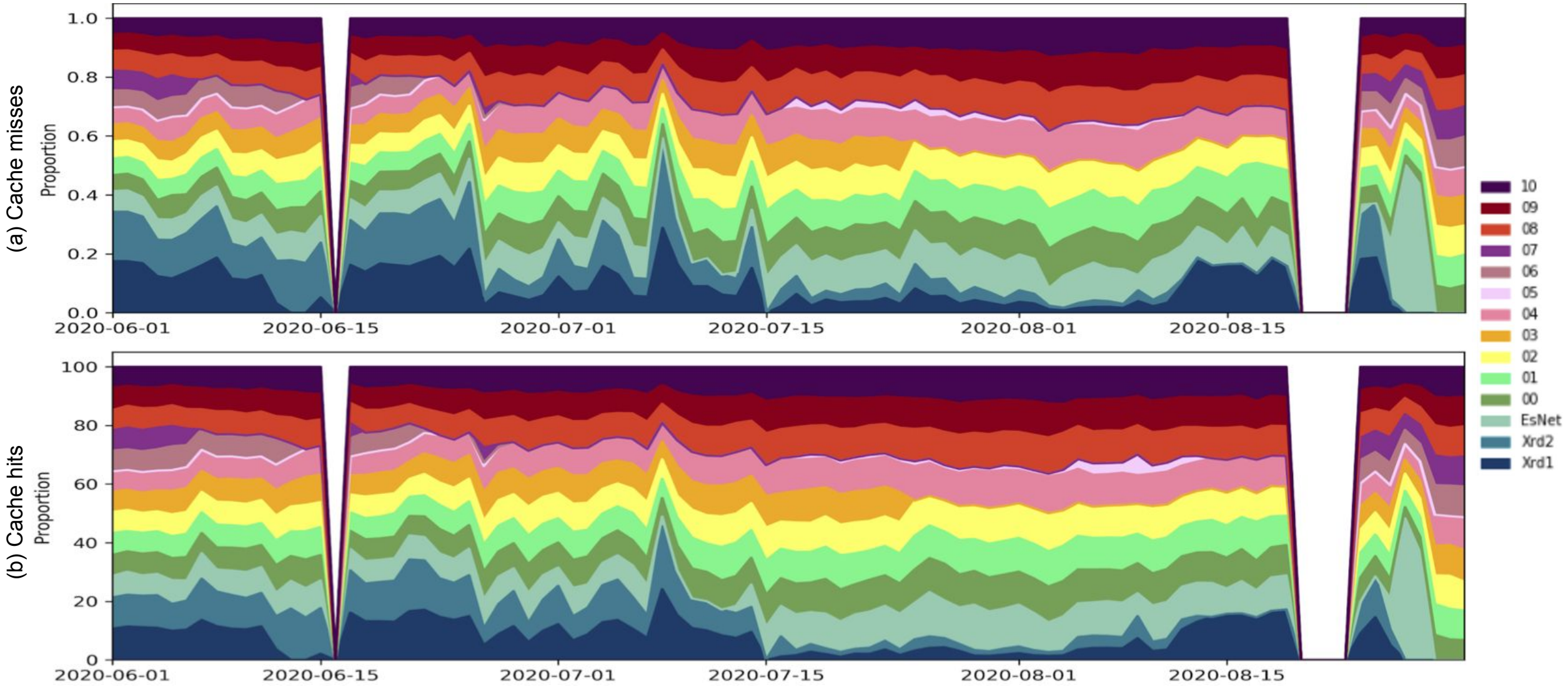
# Daily total number of data accesses



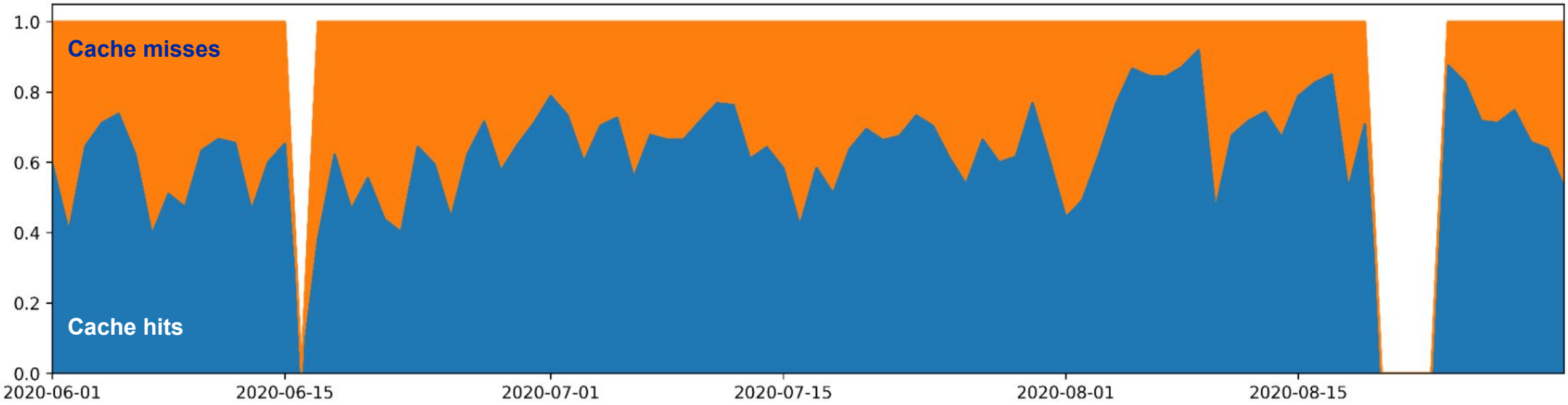
# Daily number of cache misses and hits



# Number of cache misses and cache hits

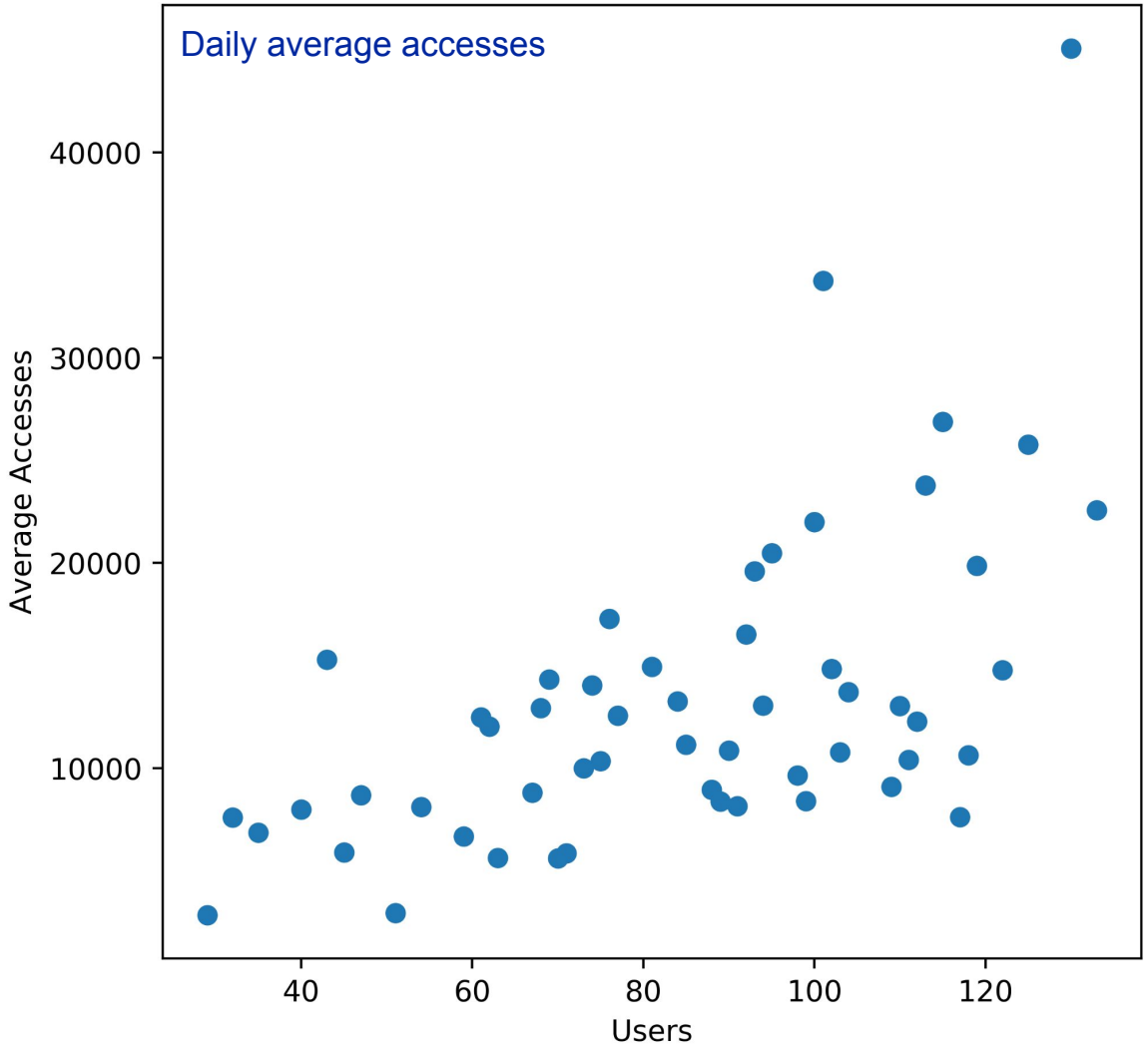


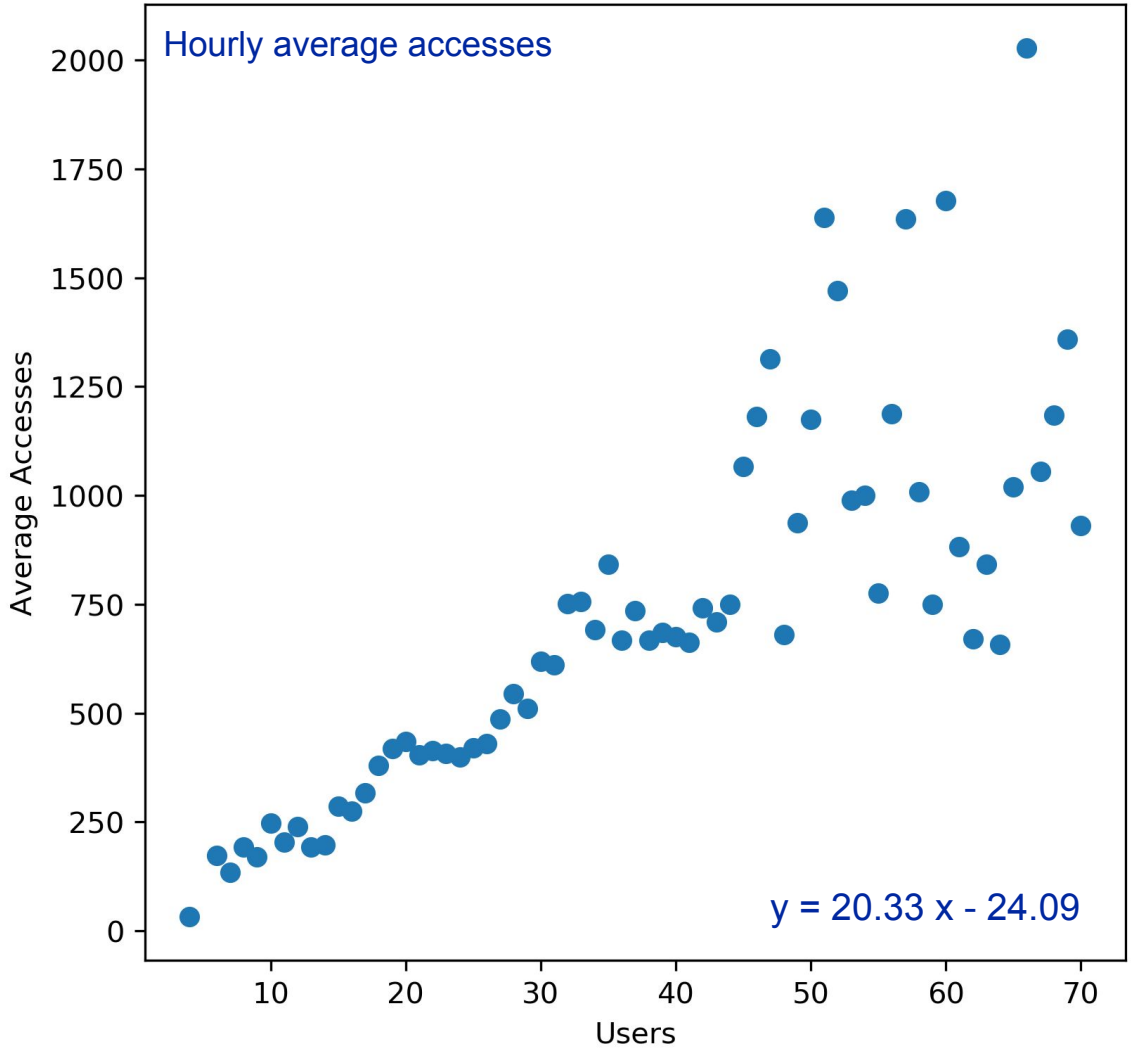
# Daily proportion of number of cache misses and cache hits



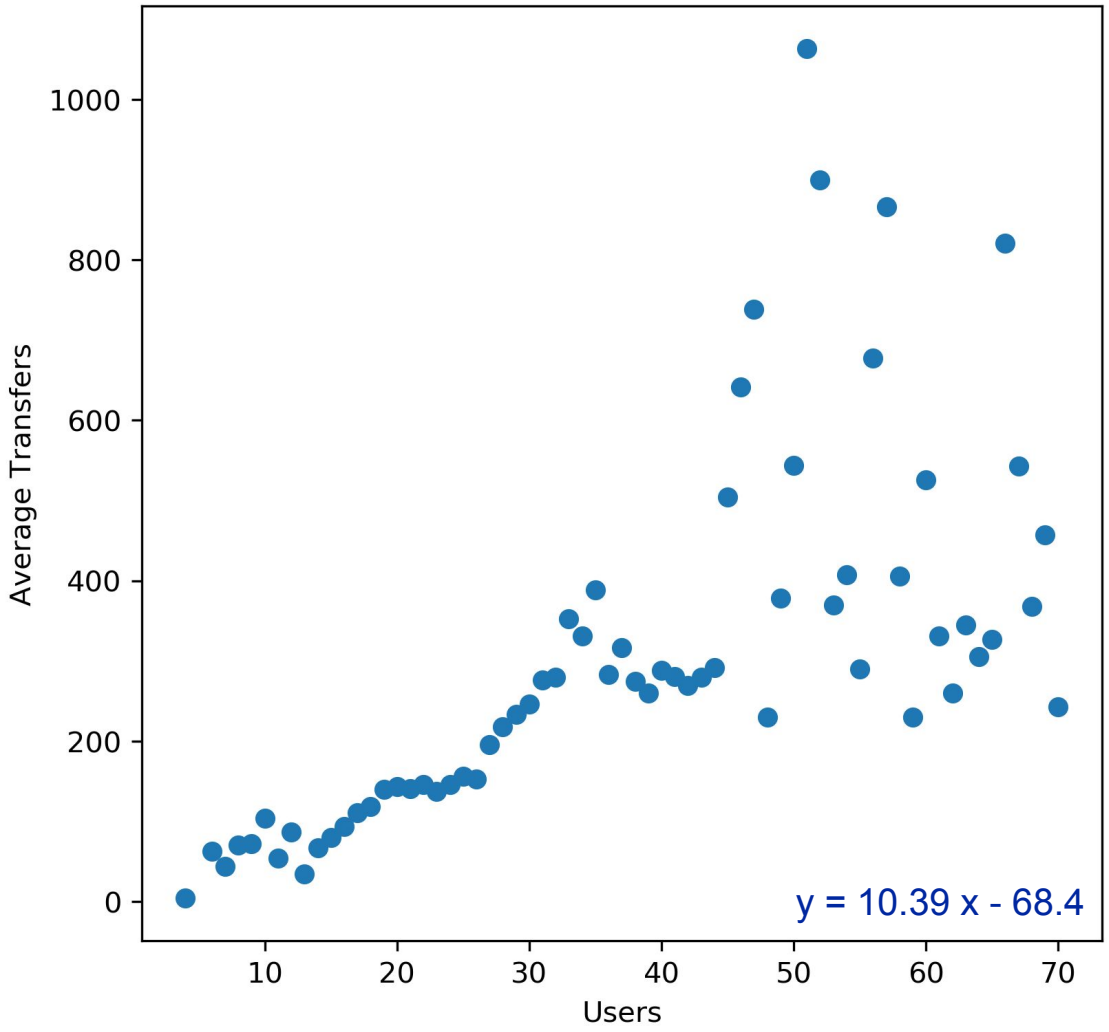

Network transfer savings = ~2.6 million transfers
Network demand frequency reduction rate = (Cache misses + Cache hits) / Cache misses = **2.617**

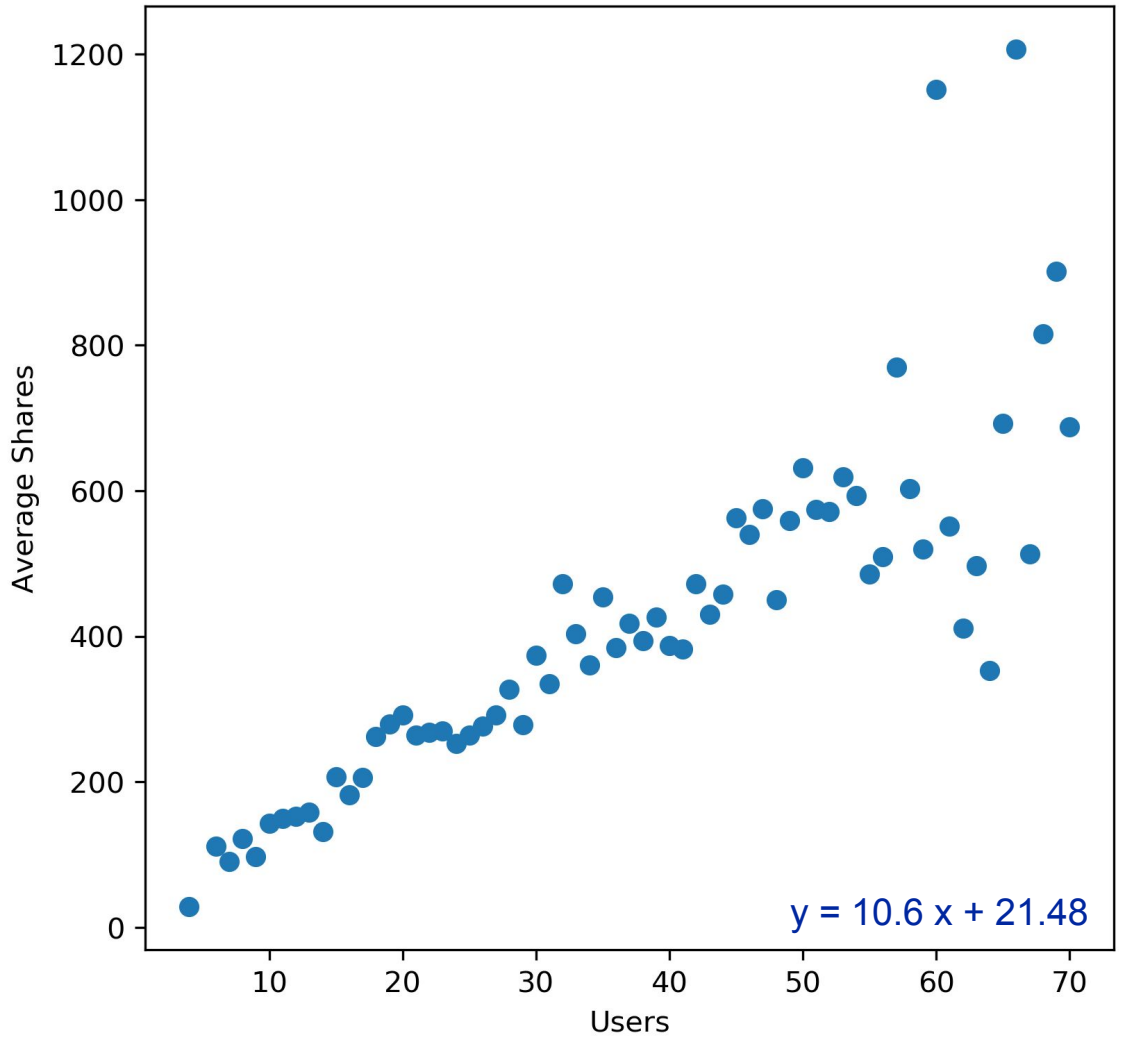
# Distribution of number of users and average data accesses



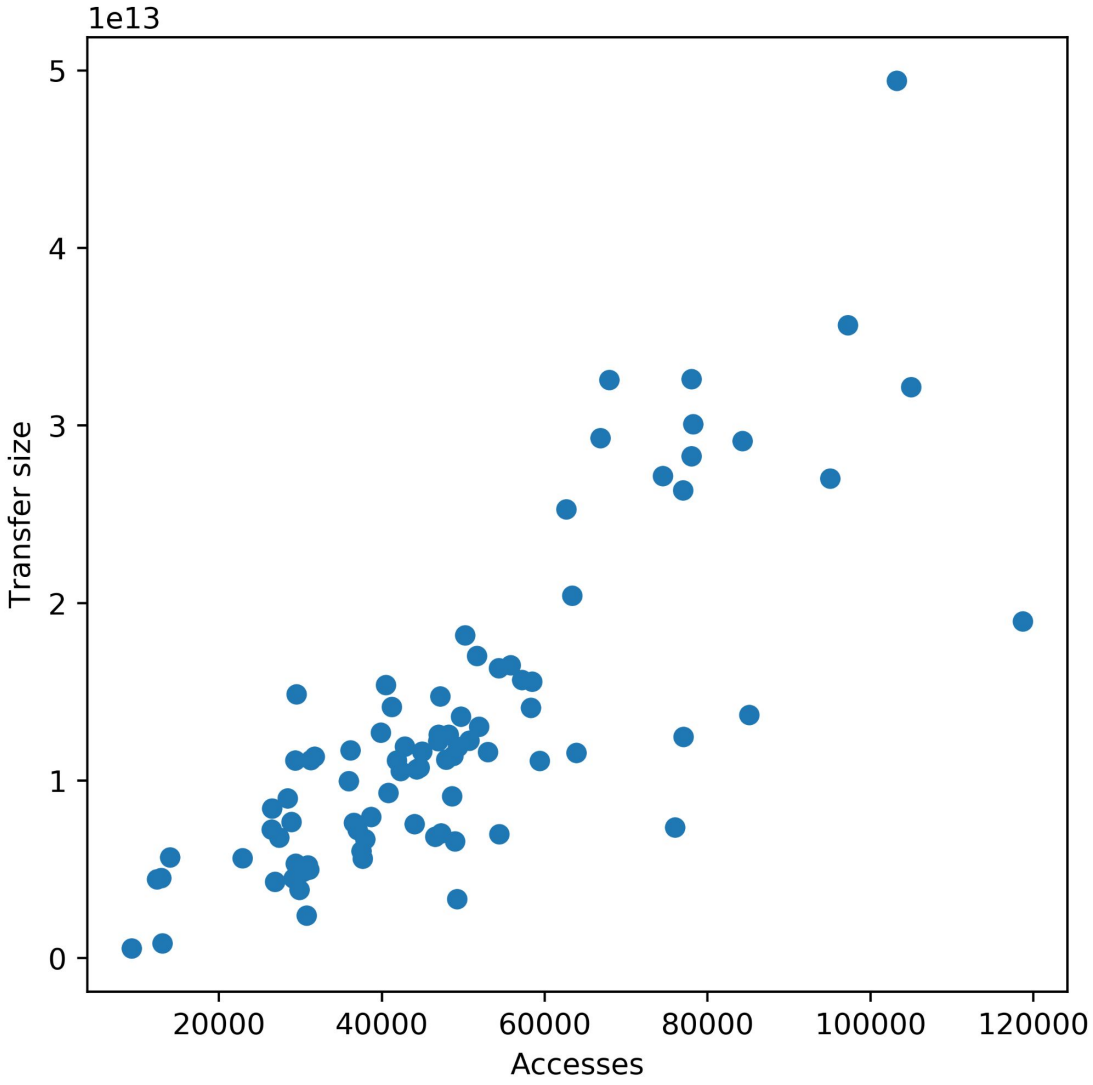



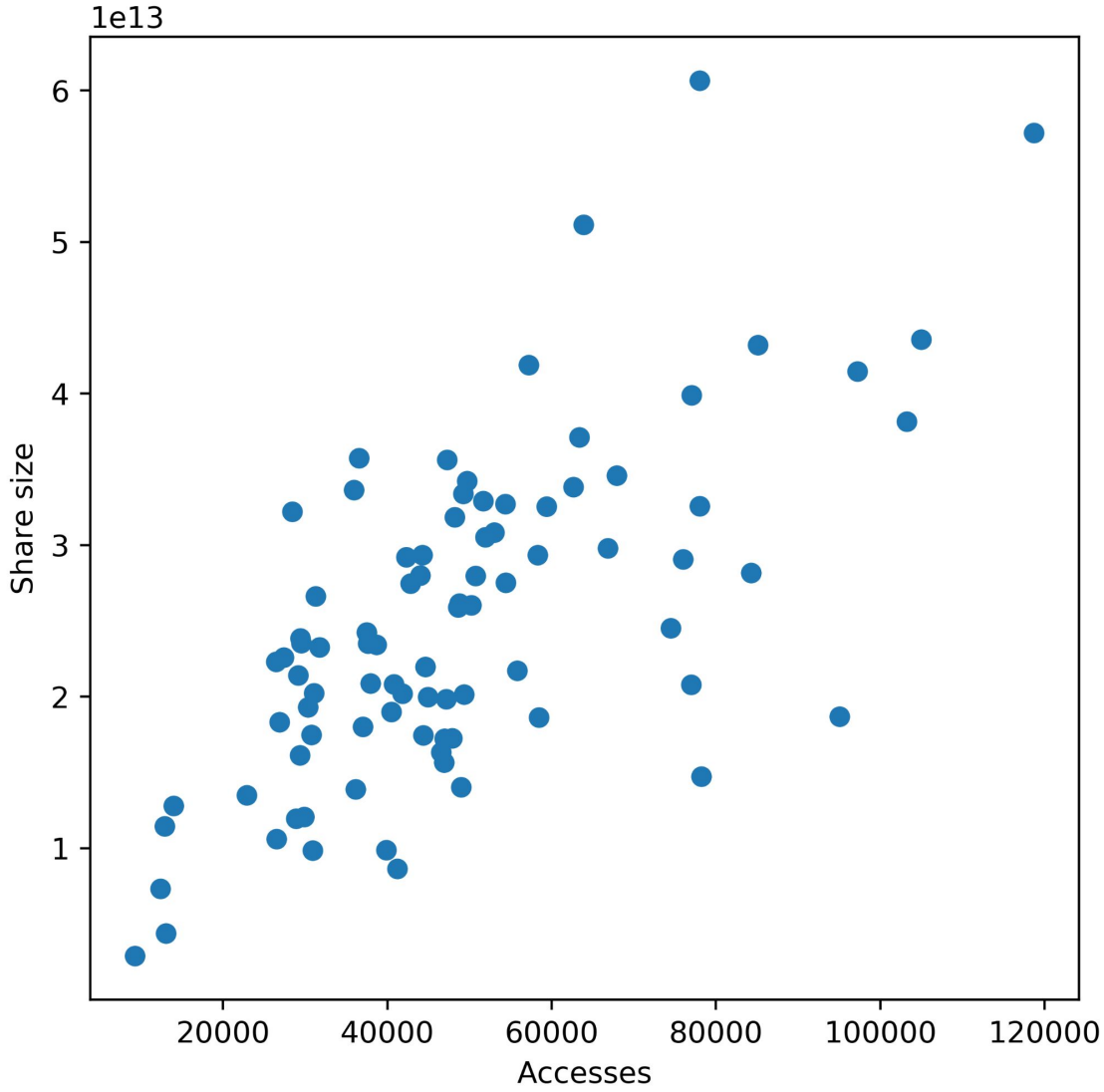
# Distribution of number of users and average transfer and shared data acceses



# Distribution of the data transfer and shared data sizes



# Summary statistics for ESnet node

| | Number of accesses | Data transfer size (GB) | Shared data access size (GB) |
|---|---|---|---|
| May 4-31, 2020 | 189,984 | 30,150.50 | 47,986.56 |
| June 2020 | 215,452 | 40,835.23 | 55,929.47 |
| July 2020 | 205,478 | 33,399.81 | 66,457.35 |
| Aug 2020 | 203,806 | 30,819.80 | 68,723.19 |
| Sep 2020 | 165,910 | 10,153.97 | 38,036.19 |
| Oct 2020 | 306,118 | 22,723.93 | 45,614.91 |
| Nov 2020 | 276 | 3.33 | 47 |
| Dec 2020 | 8514 | 1236.81 | 4523 |
| Total (May-Oct) | 1,286,748 | 168,083.27 | 322,747.67 |
| Daily average | 9,674.79 | 1,263.8 | 2,426.67 |

- Total number of active days until the end of Oct 2020: 133
- Monitoring issues from later Sep to Dec that measurements were not collected properly

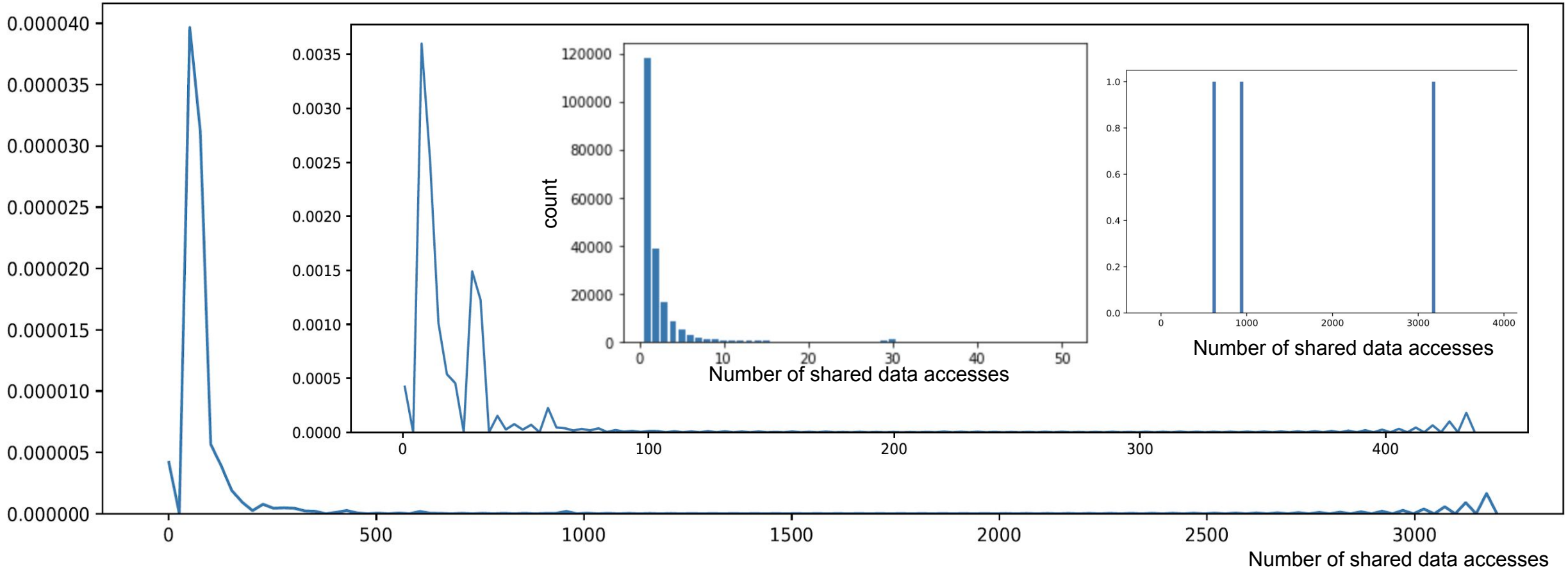
# Number of data accesses over time on ESnet node

# Notes on data transfer spike on ESnet node in 10/2020

| | data_user | data_transfer | data_zero_operation_time | metadata__id | data_file_lfn | | data_read_bytes | | | data_file_size | data_operation_time |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | count | nunique | count | max | sum | max | sum | mean |
| 0 | User 1 | False | False | 1 | 1 | 1 | 775856549 | 775856549 | 775856549 | 775856549 | 325.000000 |
| 1 | User 1 | True | False | 1 | 1 | 1 | 0 | 0 | 729145901 | 729145901 | 621.000000 |
| 2 | User 2 | True | False | 8 | 8 | 8 | 0 | 0 | 10921350 | 20772110 | 83.500000 |
| 3 | User 2 | True | True | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0.000000 |
| 4 | User 3 | True | False | 14 | 14 | 14 | 0 | 0 | 459441739 | 726622941 | 270.285714 |
| 5 | User 3 | True | True | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0.000000 |
| 6 | User 4 | False | False | 45 | 45 | 45 | 13723775 | 433735867 | 13723775 | 433735867 | 12.444444 |
| 7 | User 4 | True | False | 11763 | 6547 | 11763 | 0 | 0 | 14537889 | 19644221225 | 6.160928 |
| 8 | User 4 | True | True | 3295 | 2757 | 3295 | 0 | 0 | 0 | 0 | 0.000000 |
| 9 | User 5 | True | False | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1152.000000 |

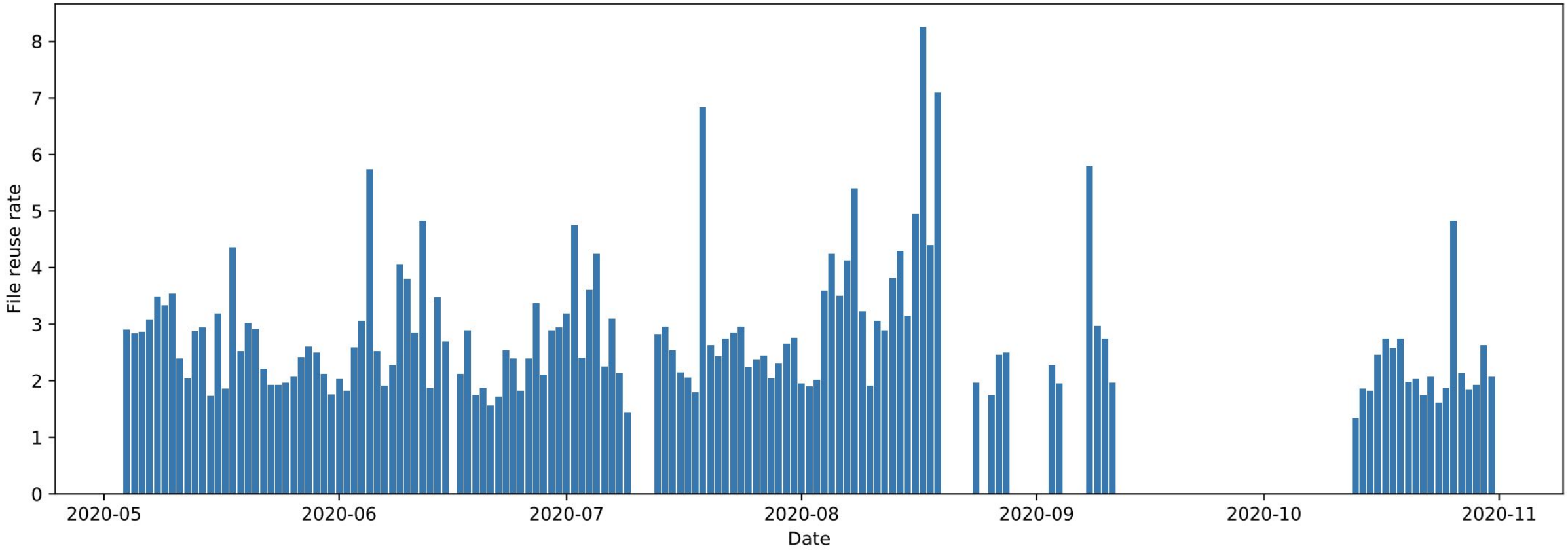
- 12pm-1pm, October 26, 2020, 15058 transfer operations for one user
- 3295 records has 0 file transfer size and 0 transfer time.
- For the other 11,763 transfer records, 6547 unique files are requested.

# Distribution of the shared data accesses on ESnet node




- Distribution of the shared data access count during 05/2020-10/2020
  total shared access count=490,944, unique file count=198,940
- Distribution of the shared data access count (<= 500), total shared access count=486,182, unique file count=198,937
- Density plot of shared data access count (> 500), total shared access count=4,762, unique file count=3

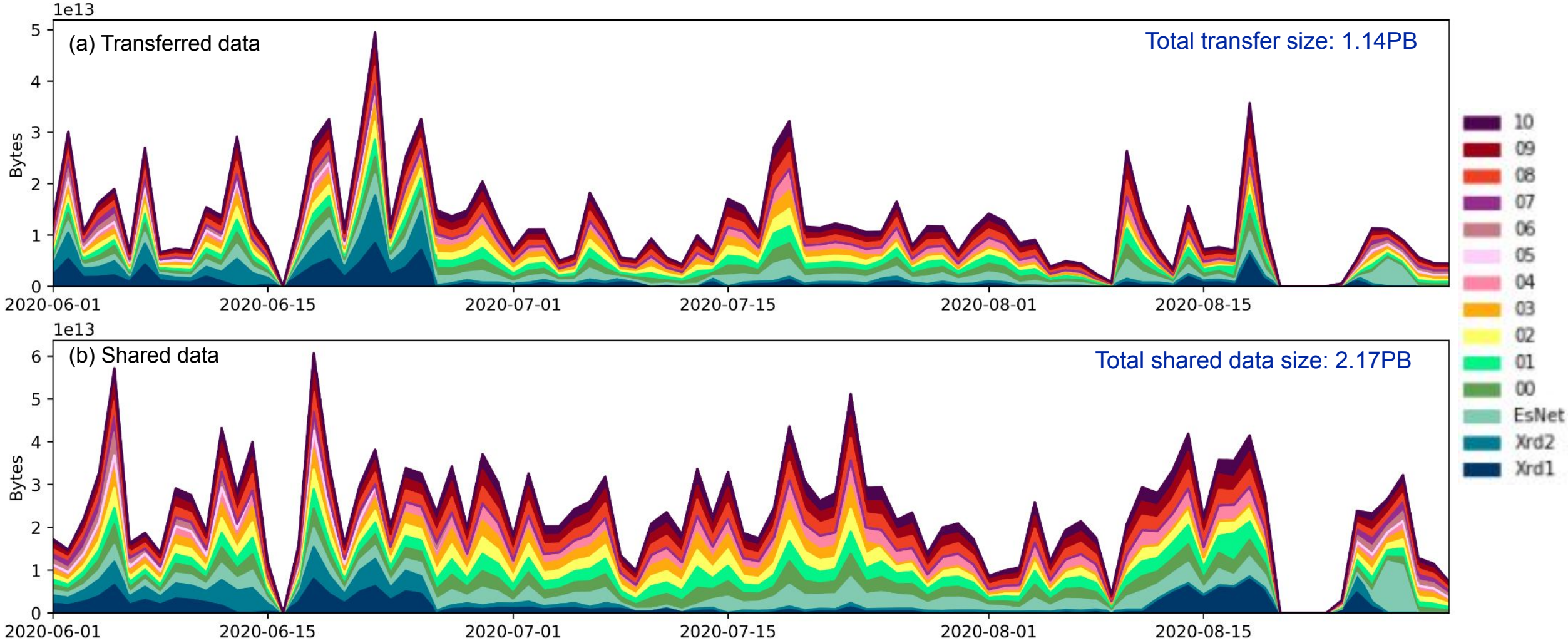
# Daily data file reuse rates for ESnet node



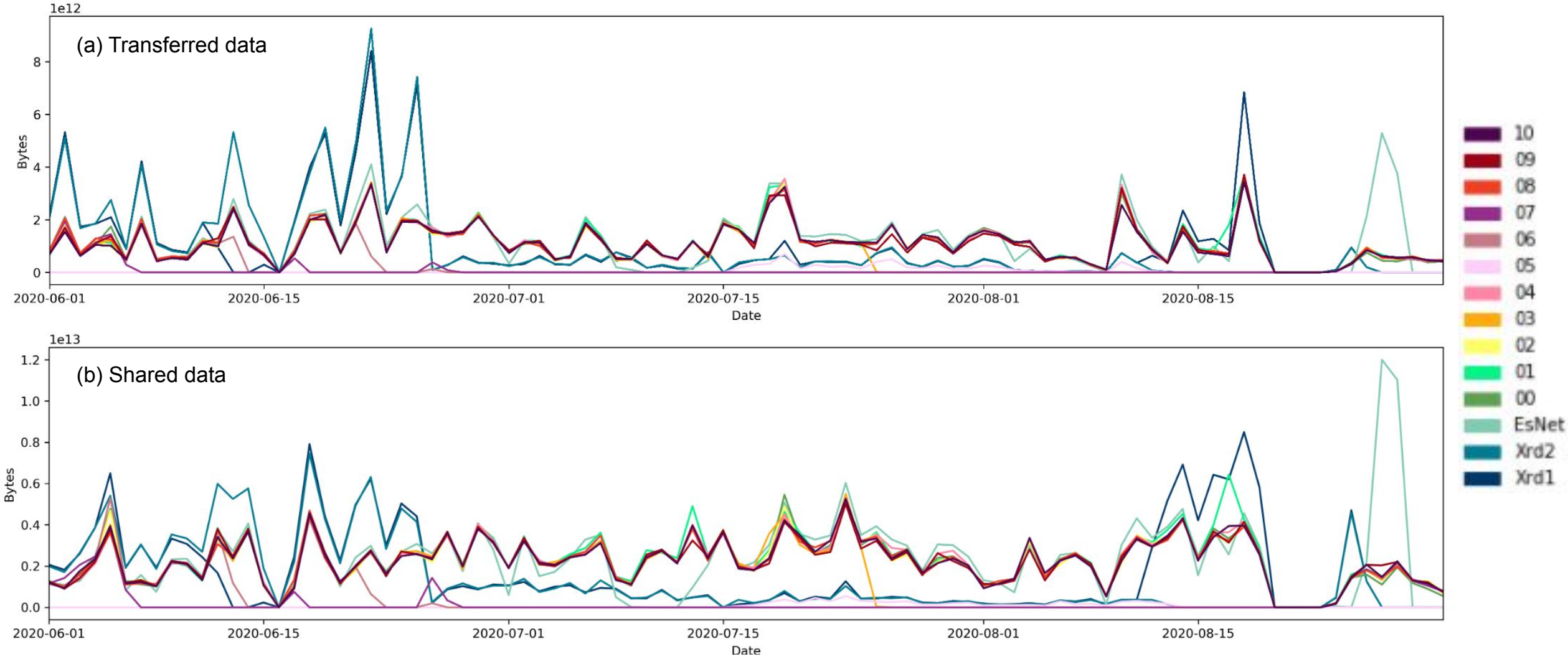

- Data file reuse rate = (sum of accesses) / (total number of unique files)
  - Sum of accesses = all accesses for the day
  - Total number of unique files = number of unique files for the day

# Network utilization

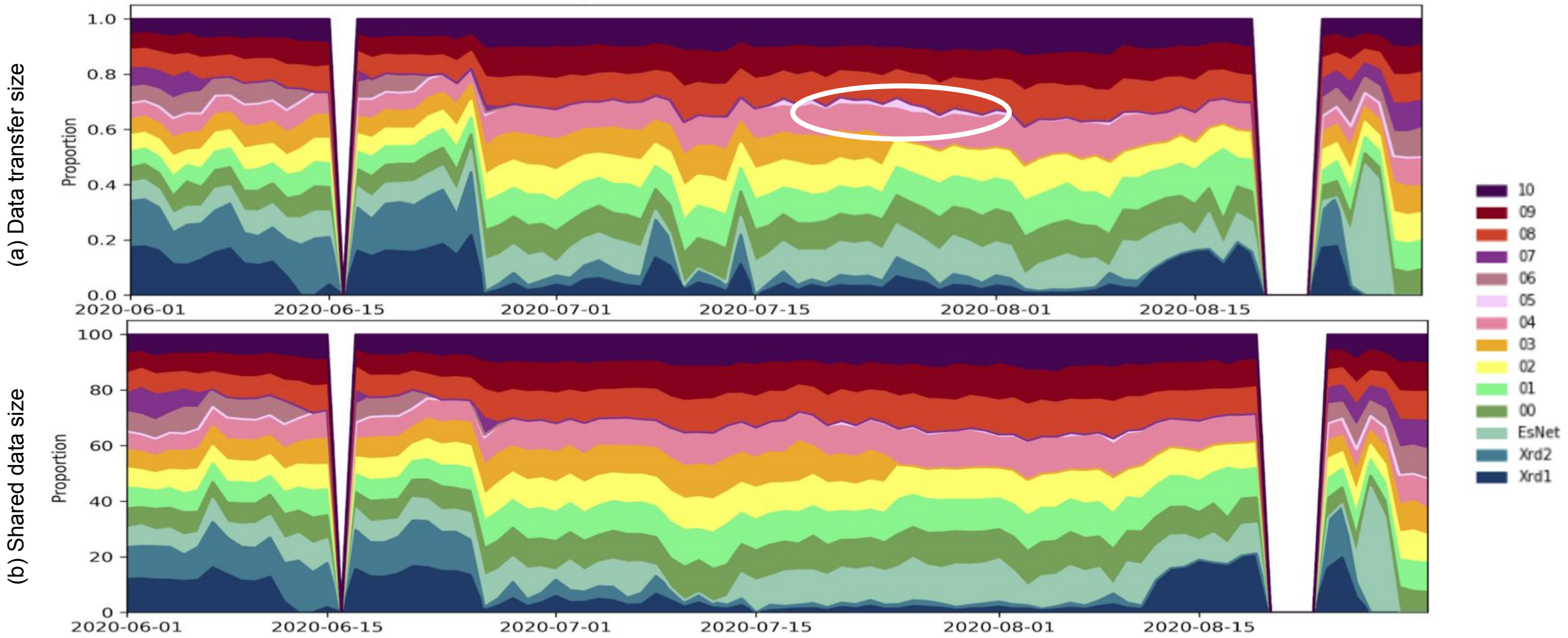
# Daily data access sizes



# Daily data access sizes

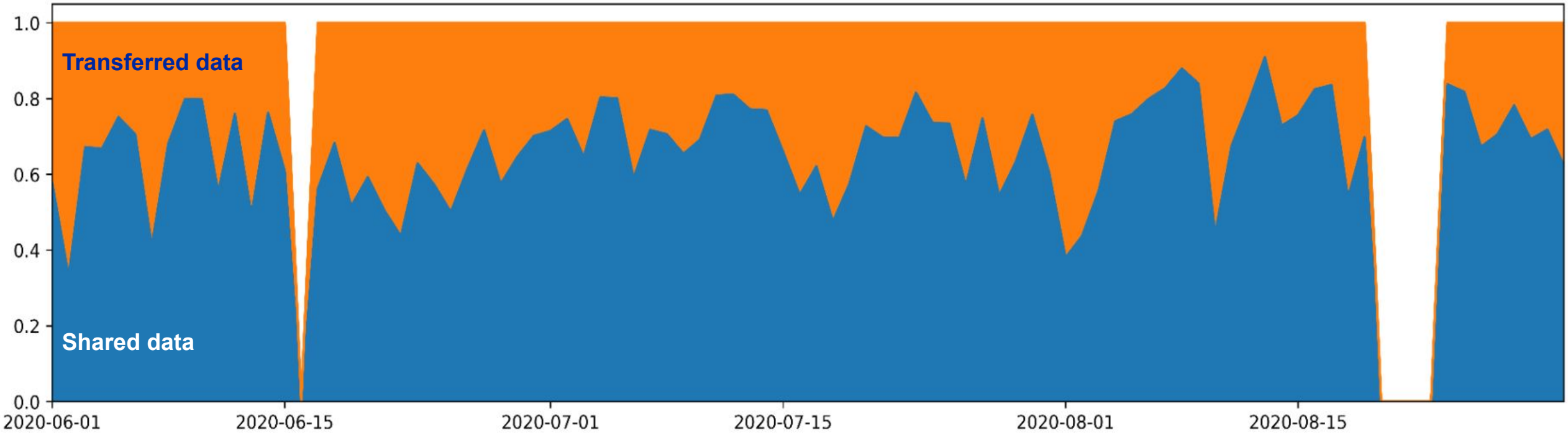


# Data transfer size and shared data size



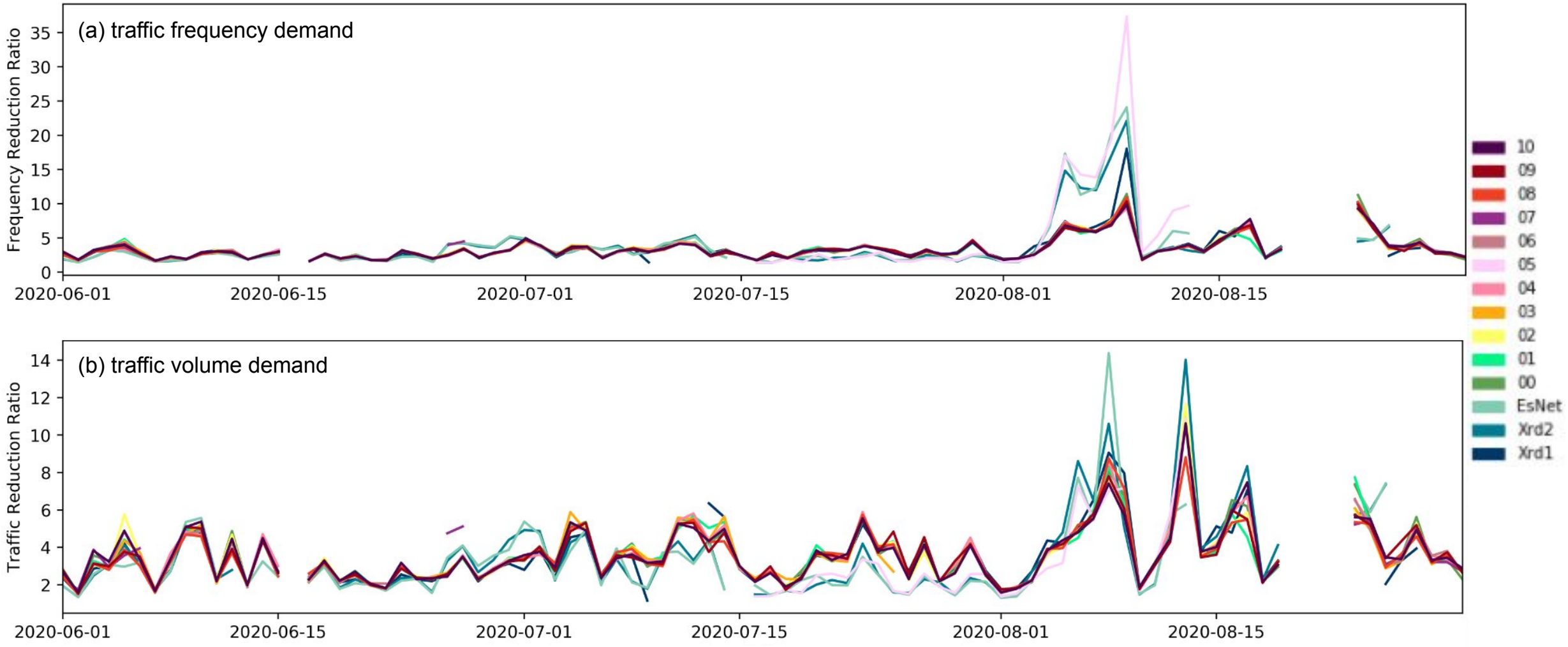

Two larger nodes have higher transfer proportion than share proportion, may be due to redirector policy

# Daily proportion of data transfer sizes and shared data sizes

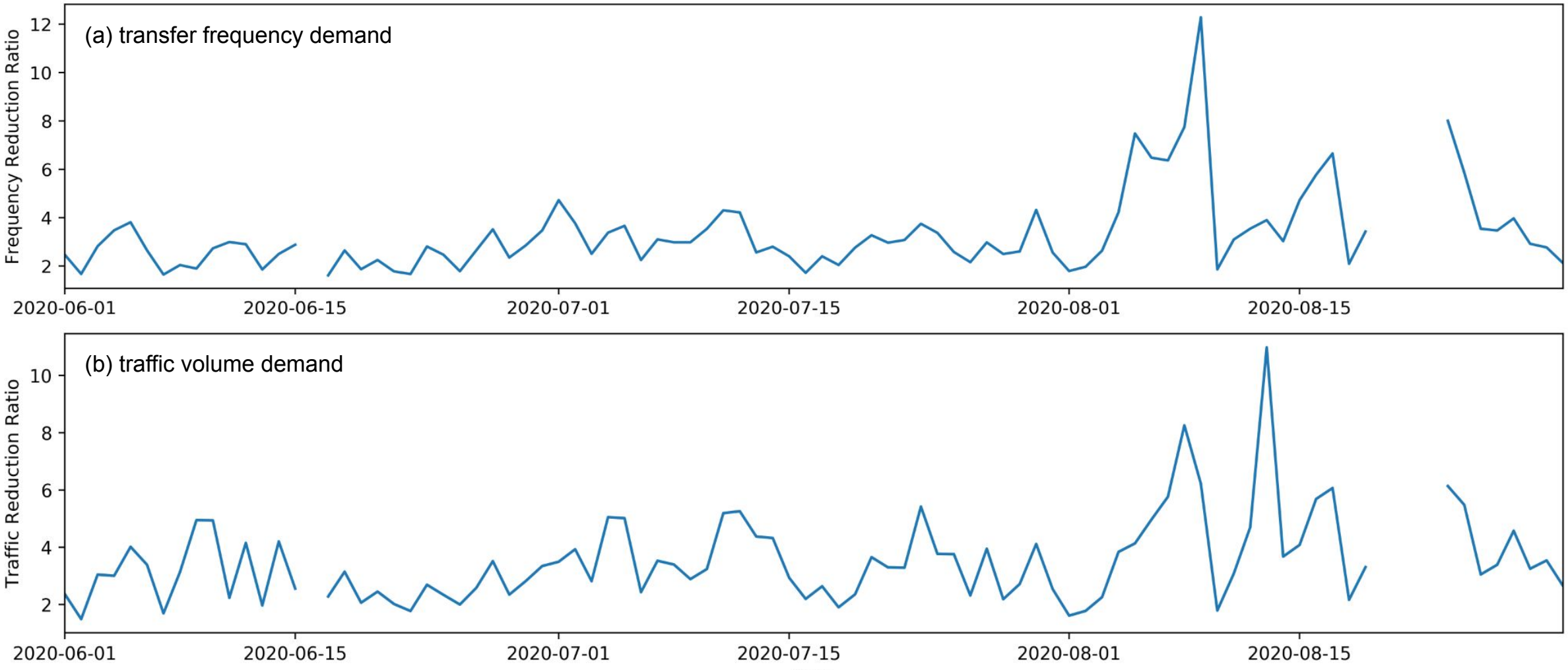



Network traffic volume savings during the study period = 2.17 PB
Network demand traffic reduction rate = (sum of total shared data + sum of total transfer data) / (sum of total transfer data)
Network demand traffic reduction rate = **2.9096**

# Daily network demand reduction rate (each node)



# Daily network demand reduction rate (all nodes)

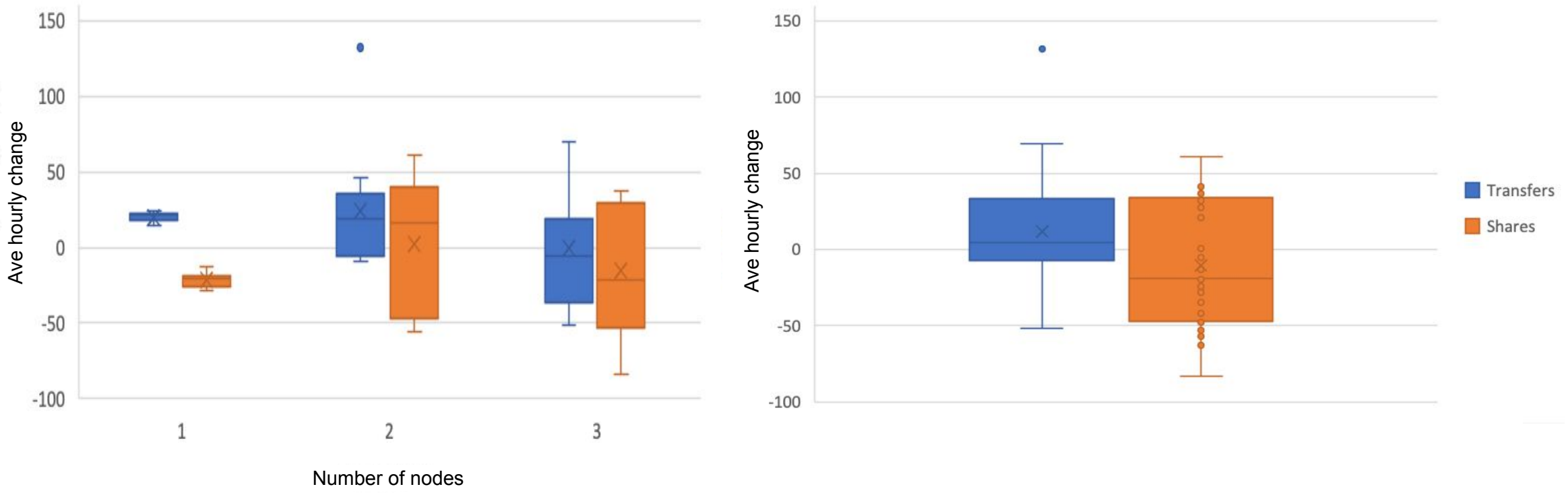


# Impact of a cache node

# Downtime of cache nodes

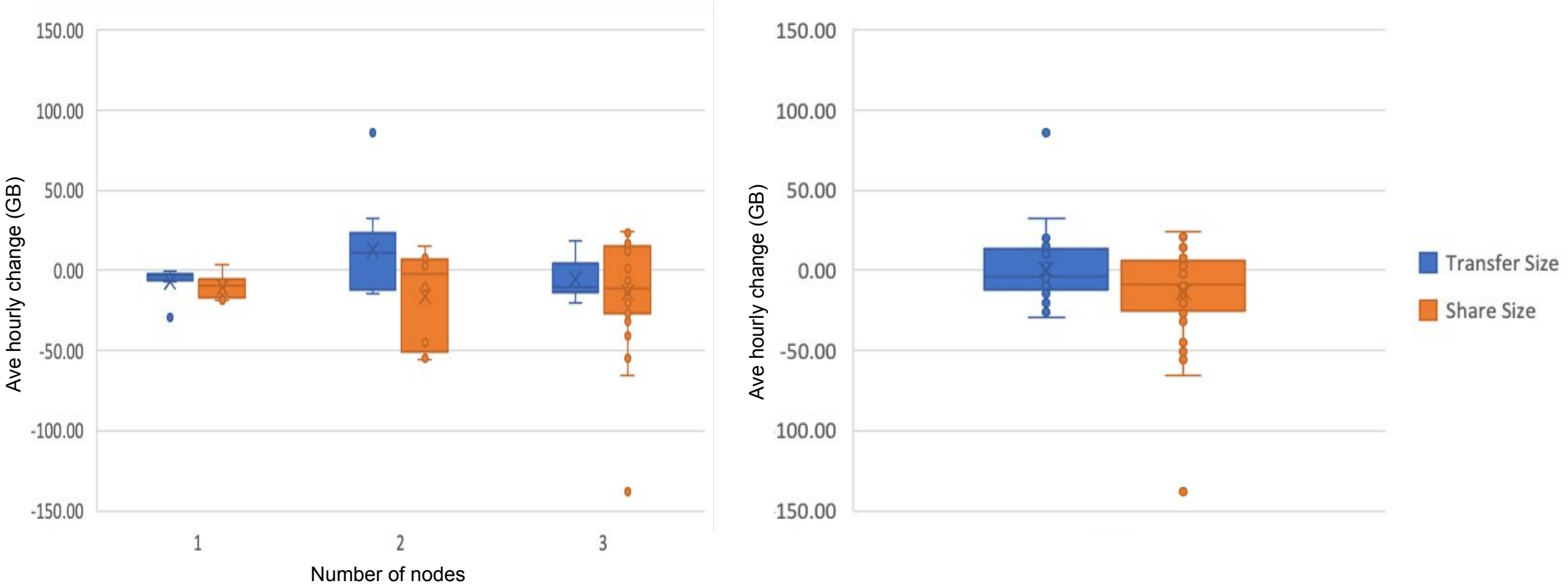
- XCache nodes went down occasionally throughout the summer
  - Identified all times that a node had 0 accesses over a full hour or longer
  - Grouped downtimes based on how many nodes were already down
- Downtime effectively reduces number of nodes
  - Allows to study the effects of adding/subtracting nodes from the network
    - How proportional data accesses changed
    - Number of cache misses and cache hits
    - Data transfer sizes and shared data sizes
- Observations
  - Proportional loads
    - Remaining nodes tend to split proportional load of the downed node
      - Particularly for access proportions
    - ESnet node proportion increases more
  - Larger nodes
    - Downtimes of larger nodes (Xrd1 and Xrd2) did not act as expected compared to other downtimes

# Change of effects of node down in data accesses




Avg hourly change over **all** downtimes studied: Shares: -58.64, Transfers: +105.67
Avg hourly change **without** data from two larger nodes: Shares: -264.59, Transfers: +67.81

# Change of effects of node down in data access sizes




Avg hourly change over all downtimes studied: Share size: +21.4GB, Transfer size: +77.3GB
Avg hourly change without downtimes of two larger nodes: Shares:  Share size: -149GB, Transfer size: +6.76GB

# Load estimation

- What would happen when the number of users double to the regional cache?
  - Number of data accesses would double
  - Number of data transfers & data shares would roughly double
    - Number of data shares likely to increase more as more files are cached
  - Data transfer size slightly less than doubles
  - Shared data size slightly more than doubles
- Effects of adding a node
  - Evenly takes loads off of other nodes
    - Evidence that further research will indicate a higher proportion of data being shared as the number of accesses/nodes increase
    - Will reduce time needed to access data files on average
  - Larger nodes do not necessarily take proportionally larger loads
    - Able to hold data files in cache for longer
    - Consequently increasing the network demand reduction rate as time goes on

# Summary

- Shared data caching mechanism
  - Reduced the redundant data transfers, saved network traffic volume
    - Network transfer savings: ~2.6 million transfers
    - Network traffic volume savings during the study period: 2.17 PB
  - Network traffic demand reduced by a factor of ~3
    - Increases as time goes on and more files are cached
    - Data transfer frequency reduction rate: ~2.62
  - Proportion of shared data increases as more files are cached
    - Decreases average applications wait time
    - Decreases network loads
- Additional nodes allow more data files to be cached
  - Increase cache hits
  - Reduces data access latency and increases overall application performance
- Further studies
  - How are the repeated cache misses affecting the application performance?
  - Anomaly detection and prevention
  - How many XCache installations are needed for certain data access loads?
  - What size of each disk cache would be appropriate?

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