CERN

Intelligent Networks: using convolutional LSTM models to estimate network traffic

NOTED GRID'2021

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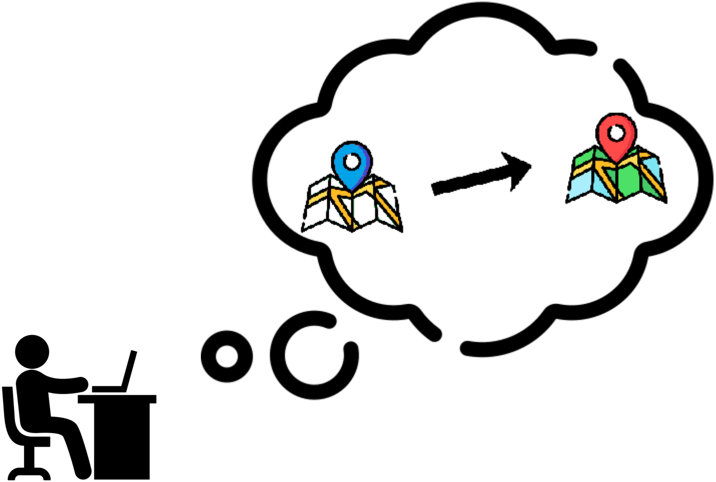
July 5, 2021

1. Introduction & Motivation
2. Traffic forecasting
   - Data and models
   - Results
3. Conclusion

Section 1

Introduction & Motivation



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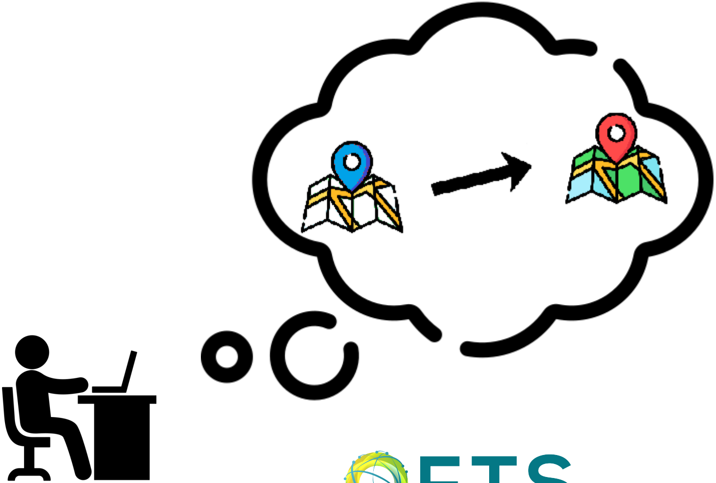

FTS

File Transfer Service

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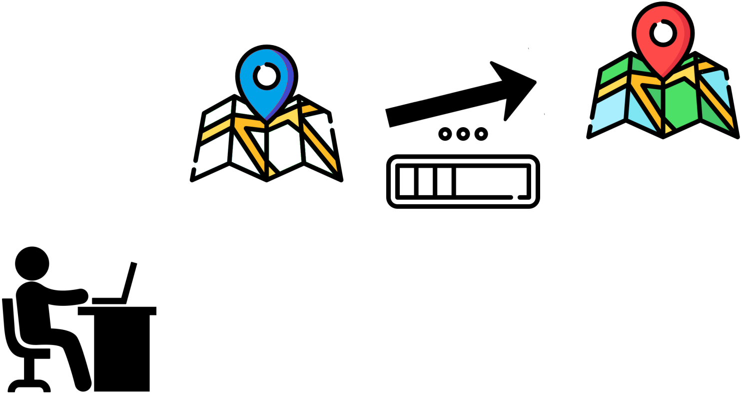

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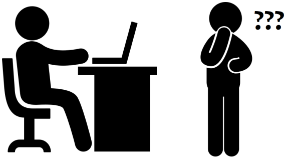

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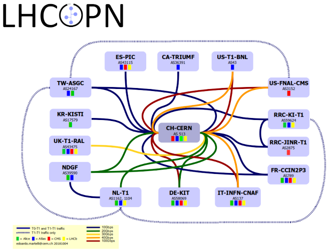


Figure: LHCOPN (Large Hadron Collider Optical Private Network) topology

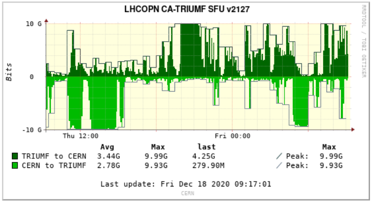
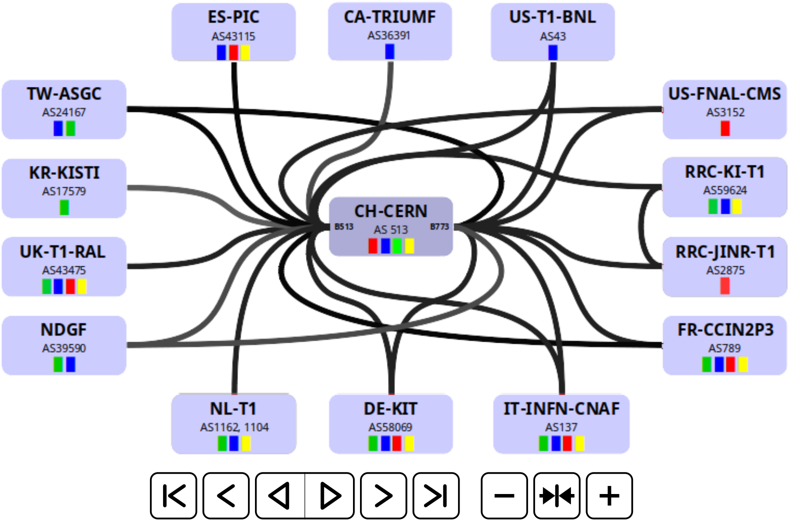


Figure: Focusing only on **one link** – network traffic observed on the LHCOPN path between CERN and TRIUMF. Link saturation occurs in both directions.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AS36391
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TW-ASGC
AS24167
US-FNAL-CMS
AS3152
KR-KISTI
AS17579
RRC-KI-T1
AS59624
CH-CERN
B513
AS 513
B773
UK-T1-RAL
AS43475
RRC-JINR-T1
AS2875
NDGF
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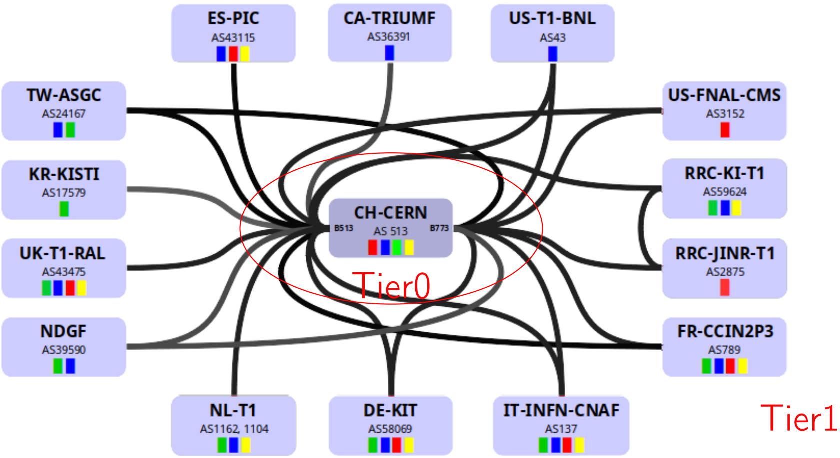
AS1162, 1104
DE-KIT
AS58069
IT-INFN-CNAF
AS137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AS17579
RRC-KI-T1
AS59624
CH-CERN
B513
AS 513
B773
UK-T1-RAL
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RRC-JINR-T1
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Tier0
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AS39590
FR-CCIN2P3
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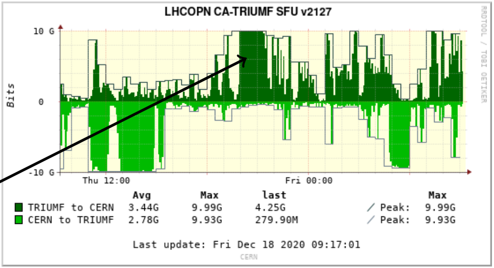
AS1162, 1104
DE-KIT
AS58069
IT-INFN-CNAF
AS137
Tier1

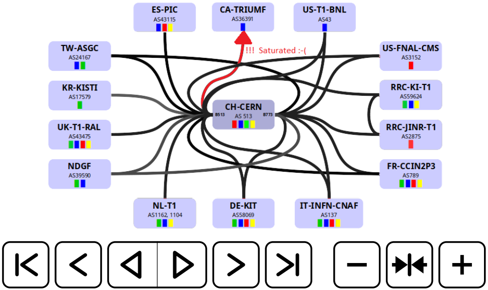
The goal of the project



We would like to **optimise transfers** of LHC data **eliminating network saturation** along the chosen path.

Solution - how to avoid saturation

Automatically recognise when the link will be saturated for a long period of time, and **automatically modify** the configuration of network devices (SDNC) (Add extra path/link to balancing traffic).

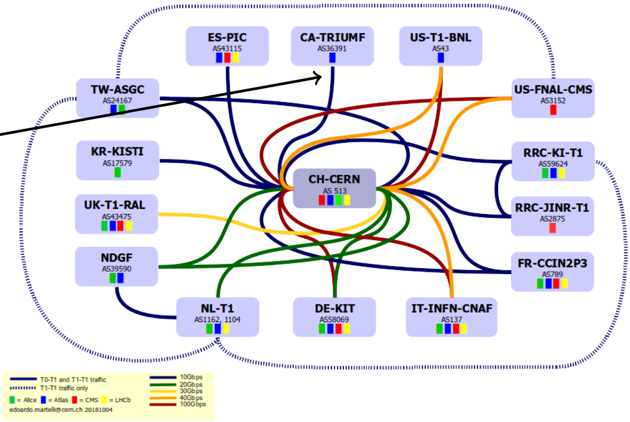


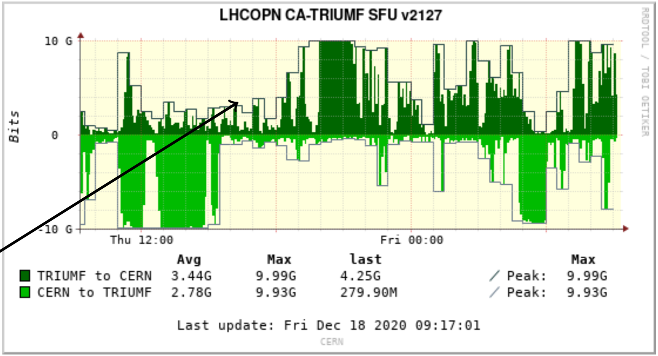
Ok, we know how, but when?

Let's assume that we have data representing aggregated information about all transfers between sites on long time in the network.

LHCOPN

X (input) - Aggregated information about all transfers from CA-Triumf to another sites (CH-CERN is the Tier0 and others in LHCOPN are the Tier1)





We would like to predict Y *(output)*

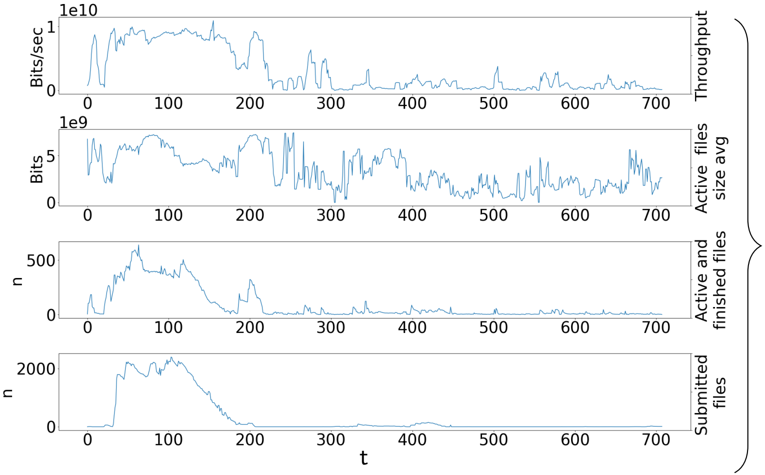
- Traffic from Netstat.cern.ch

Section 2

Traffic forecasting

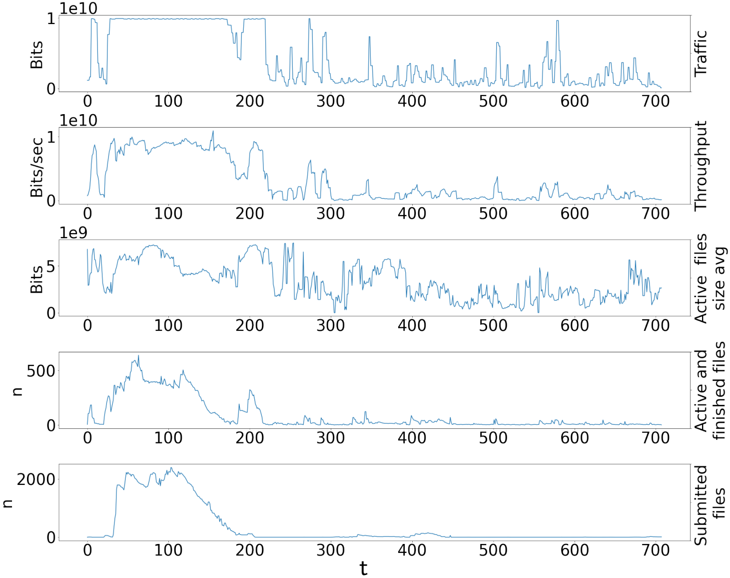
Subsection 1

Data and models

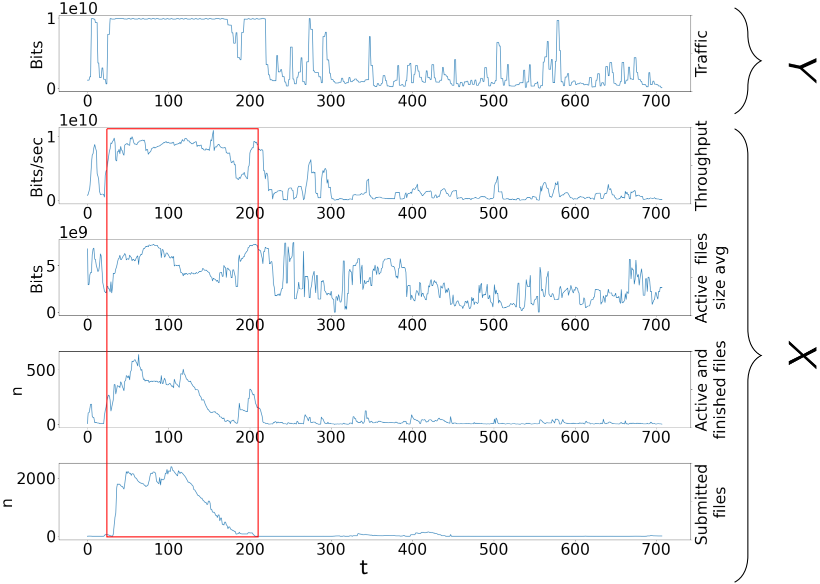


X – input data from FTS

*The figure shows data used as the test data set during modeling



Y (real) – data from NetStat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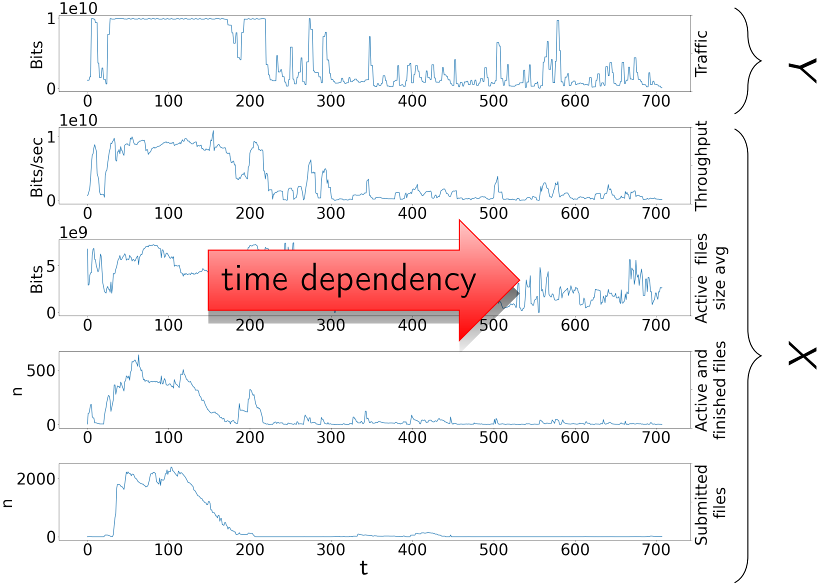
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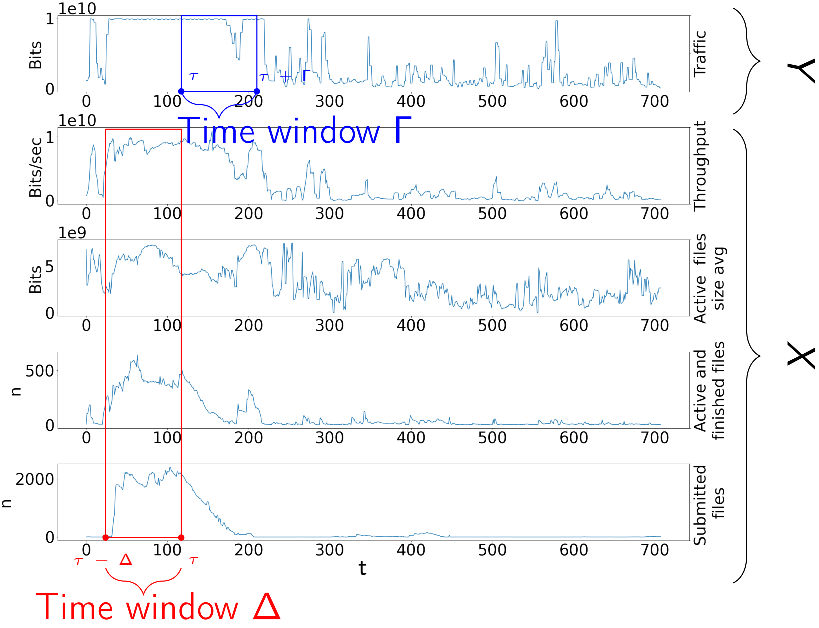
We can use time windows of length Δ and estimate next Γ traffic values



layer types

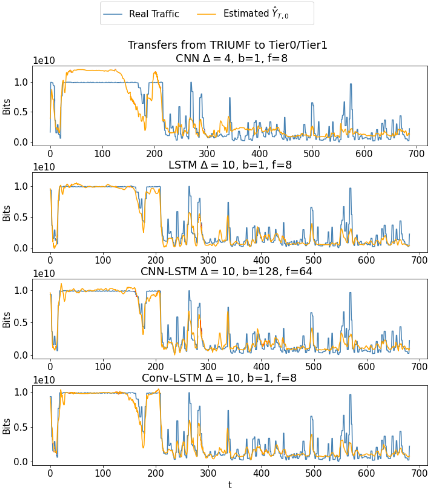
- convolution layer - Conv2d (model CNN)
- LSTM layer - LSTM (model LSTM)
- one convolution layer + one LSTM layer - Conv2d + LSTM (model CNN-LSTM)
- Convolutional LSTM layer - ConvLSTM2D (Conv-LSTM)

Hyperparameters:

- were chosen based on observation and discussion with those responsible for the FTS.

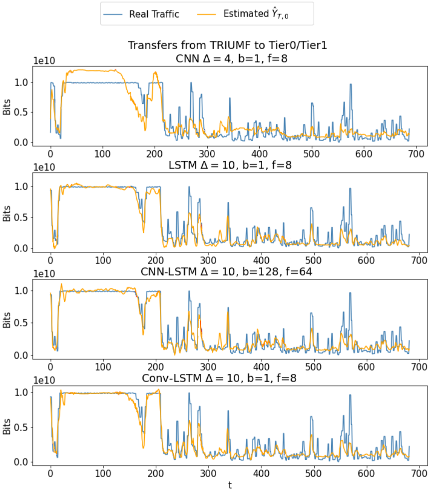
Subsection 2

Results



Prediction of instantaneous traffic

Figure: Effects of applying models with the best configuration on the test dataset. 1. We trained our model to predict traffic based on information about transfers from the FTS (from TRIUMF-SFU to Tier0/Tier1). Forecasting is based on aggregated information about transfers from last 2Δ minutes; b (batches); f(filters).



Prediction of instantaneous traffic

Table: Model comparison. Error = mean square error for Γ window.

Δ	Model	Batch - Filters\ Units	Error$_0$
4	CNN	1 - 8	0.206
10	LSTM	128 - 64	0.025
	CNN-LSTM	128 - 64	0.021
	CONV-LSTM	1 - 8	0.036

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Prediction of future traffic

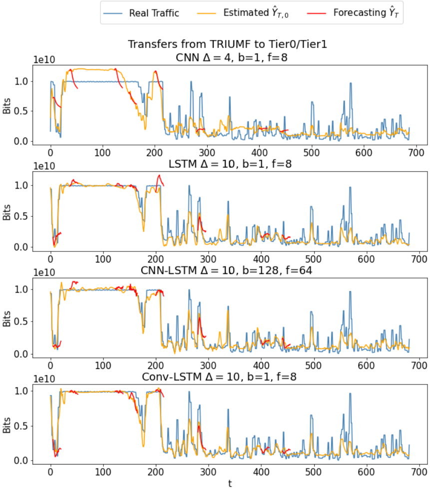
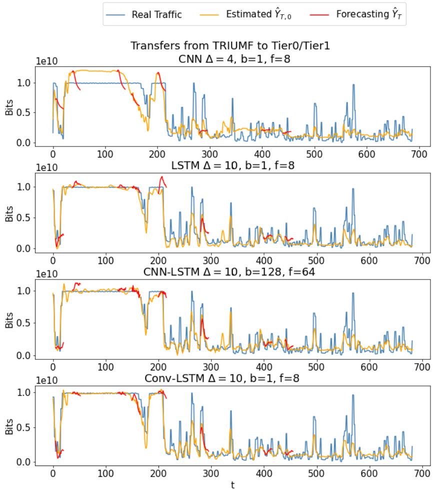


Figure: Effects of applying models with the best configuration on the test dataset. 1. We trained our model to predict traffic based on information about transfers from FTS (from TRIUMF-SFU to Tier0/Tier1). Forecasting is based on aggregated information about transfers from last 2Δ minutes; We predict the next Γ samples. b (batches); f(filters).



Prediction of future traffic

Table: Model comparison. Error = mean square error for Γ window.

Δ	Model	Batch - Filters\ Units	Error_{Γ}
4	CNN	1 - 8	0.206
10	LSTM	128 - 64	0.185
	CNN-LSTM	128 - 64	0.188
	CONV-LSTM	1 - 8	0.125

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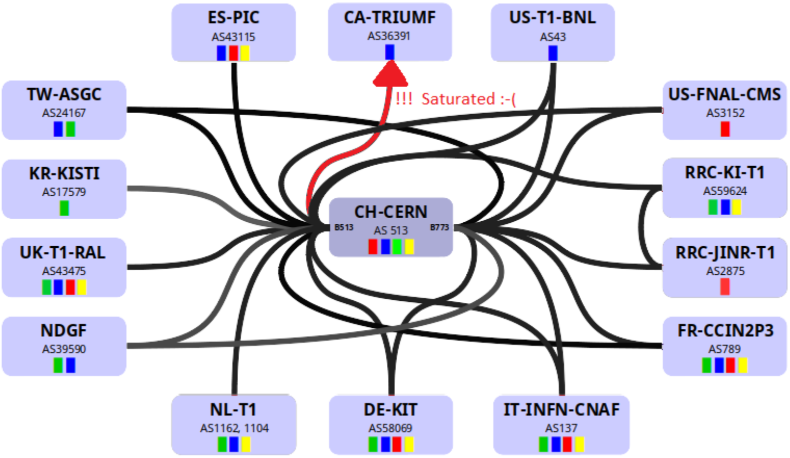
ES-PIC
AS43115
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AS36391
US-T1-BNL
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TW-ASGC
AS24167
!!! Saturated :-(
US-FNAL-CMS
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AS17579
RRC-KI-T1
AS59624
CH-CERN
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AS789
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Section 3

Conclusion

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Conclusion

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- We consider CNN-LSTM as the best prediction for instantaneous traffic prediction
- Conv-LSTM as the most suitable model to predict the end of saturation.

Conclusion

- Our work shows that **CNN-LSTM and Conv-LSTM architectures can indeed enable us to detect network saturation**
- They provide **great forecasting** accuracy even over long time periods **(up to 30 minutes)** based on short history (time window).
- We consider CNN-LSTM as the best prediction for instantaneous traffic prediction
- Conv-LSTM as the most suitable model to predict the end of saturation.
- **FTS analysis helps us optimise transfers and delivers better performance for users! :-)**

Thank you for your attention!

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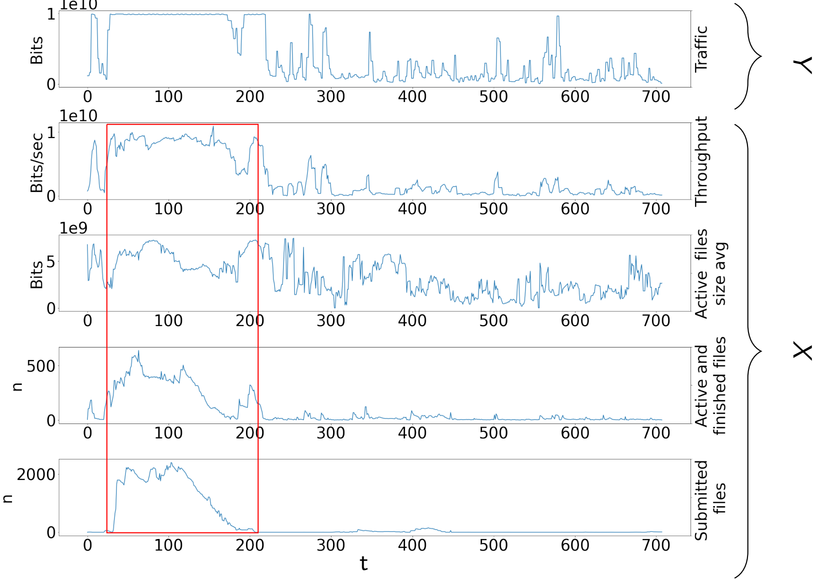
supplement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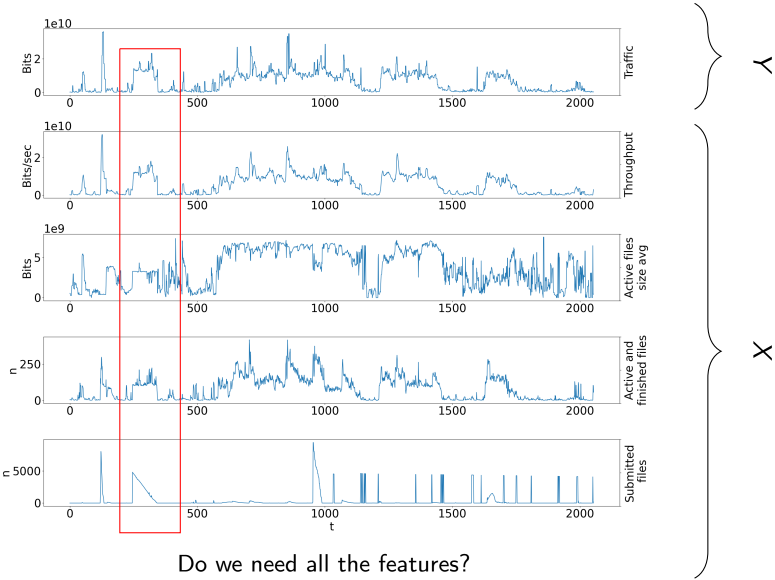
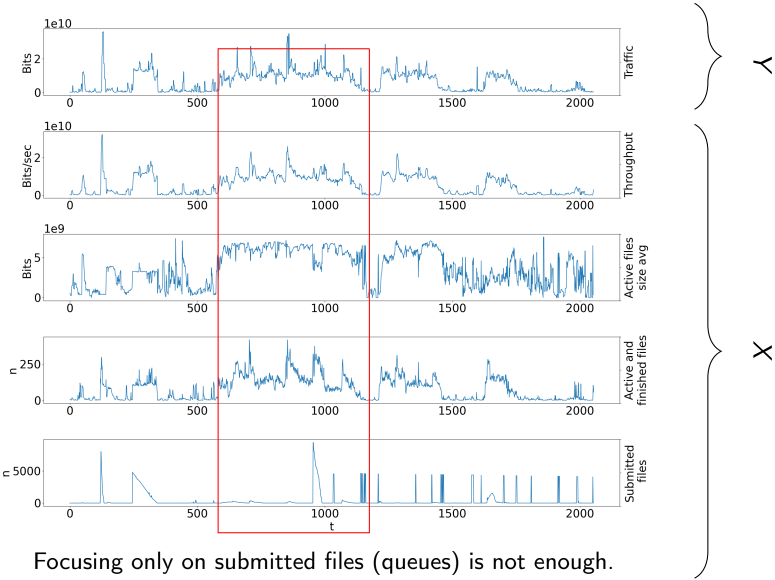


Do we need all the features?



Focusing only on submitted files (queues) is not enough.

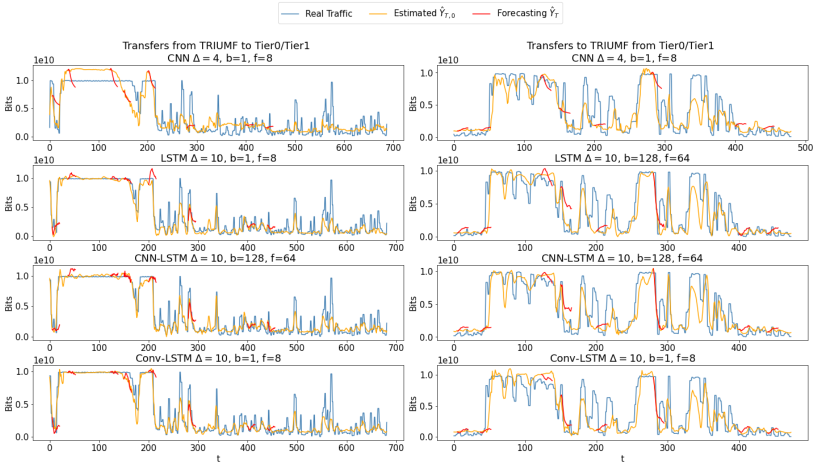


Figure: Effects of applying models with the best configuration on the test dataset. 1. We trained our model to predict traffic based on information about transfers from FTS (from TRIUMF-SFU to Tier0/Tier1). 2. Pictures present results on two data sets: from TRIUMF-SFU to Tier0/Tier1 and from Tier0/Tier1 to TRIUMF-SFU. Forecasting is based on aggregated information about transfers from last 2minutes; b (batches); f(filters). Forecasting $\hat{Y}_\Gamma$ is predicted Γ future values for chosen t. Here $\Gamma = 15$ (30 min).

Table: Comparison of model parameters on the test data set representing transfers from TRIUMF to Tier0/Tier1. $\Gamma = 15$ (30 minutes). S is the standard deviation over 10 training repetitions.

Δ	Model	Batch - Filters\ Units	Error_{Ψ}	$S(\text{Error}_{\Psi})$	$\text{Error}_{\Psi,\mathbf{0}}$	$S(\text{Error}_{\Psi,\mathbf{0}})$
4	CNN	1 - 8	0.206	0.007	0.206	0.009
	LSTM	128 - 64	0.224	0.008	0.042	0.005
	CNN-LSTM	128 - 64	0.233	0.015	0.060	0.007
	CONV-LSTM	1 - 8	0.159	0.012	0.048	0.007
10	CNN	1 - 8	0.223	0.095	0.223	0.010
	LSTM	128 - 64	0.185	0.012	0.025	0.006
	CNN-LSTM	128 - 64	0.188	0.011	0.021	0.006
	CONV-LSTM	1 - 8	0.125	0.008	0.036	0.008

- $\text{Error}_{\Psi,\mathbf{0}}$ – $\text{MSE}_{\Psi,\mathbf{0}}(\Delta,\Gamma)$ for input window time Δ and output window time Γ. We calculate the mean square error only for estimation traffic $y_{\tau,\mathbf{0}}$ on time τ, where $\tau \in \Psi$
- Error_{Ψ} – $\text{MSE}_{\Psi}(\Delta,\Gamma)$ We calculate the mean square error for all estimation traffic $y_{\tau,\gamma}$ on time τ, where $\tau \in \Psi$, and $\gamma \in [0,\ldots,\Gamma]$
- Ψ period when observed link (TRIUMF -> CERN) was overloaded.

Model schemes

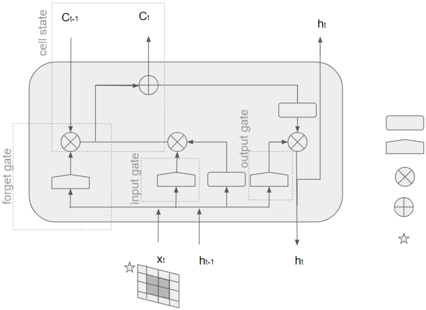


Figure: CNN-LSTM

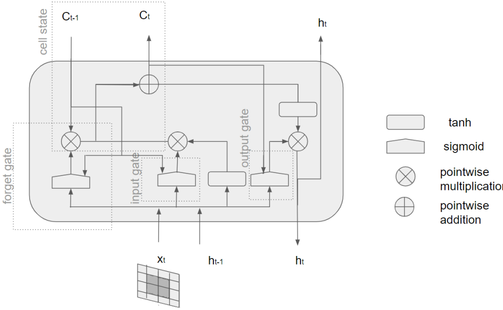


Figure: Conv-LSTM

MSE – Mean Square Error

We consider the one-step MSE and calculate an average MSE for the Γ-steps forecasting during $\mathcal{N}$ period when N samples were observed:

$$\mathrm{MSE} = \mathrm{MSE}_{\mathcal{N}}(\Delta, \Gamma) = \sum_{i=0}^{\Gamma} \mathrm{MSE}_i, \tag{1}$$

where $\mathrm{MSE}_i = \frac{1}{N-\Gamma-\Delta} \sum_{t=\Delta}^{N-\Gamma} (y_{t,i} - \hat{y}_{t,i})^2$, for $i \in \{0, \ldots, \Gamma\}$.

$\mathrm{MSE}_{\Psi,0}(\Delta, \Gamma)$ means MSE calculating during Ψ period for hyperparameters Δ and Γ. 0 index means result is calculate only for $\hat{y}_{\tau,0}$, where $\tau \in \{\Delta, \cdots, N - \Gamma\}$.

How have we chosen hyperparameters?

- Time window Γ
- Time window Δ

Forecasting

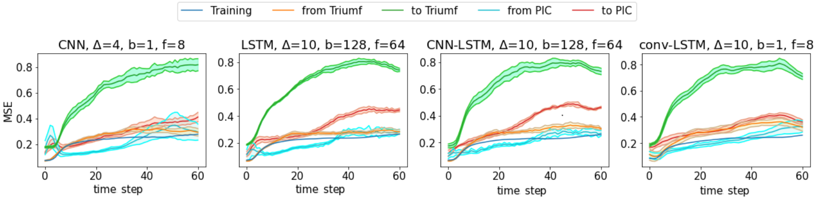
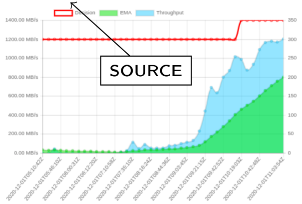
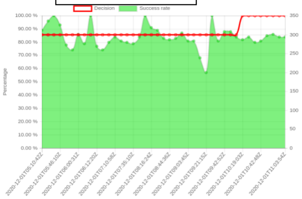


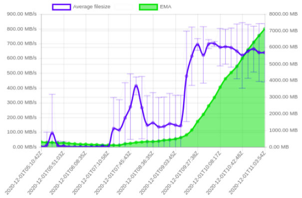
Figure: Average MSE and its variance with respect to the forecasting steps (here: $\Gamma = 60$).

FTS details - how transfer report format look like

Details for davs://eosatlas.cern.ch → davs://webdav-at1.pic.es ← DESTINATION



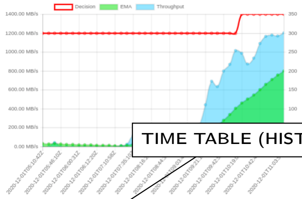


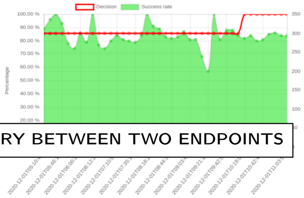


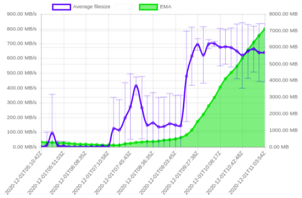
First | Previous | 1 | Next | Last

Timestamp	Decision	Running	Queue	Success rate (last 1min)	Throughput	EMA	Diff	Explanation
2020-12-01T11:03:54Z	350	183	2137	84.00%	1.18 GiB/s	800.38 MiB/s	0	Range fixed
2020-12-01T10:59:35Z	350	183	2174	84.00%	1.14 GiB/s	755.59 MiB/s	0	Range fixed
2020-12-01T10:54:59Z	350	184	2250	86.00%	1.15 GiB/s	709.42 MiB/s	0	Range fixed
2020-12-01T10:49:15Z	350	185	2312	85.00%	1.14 GiB/s	657.39 MiB/s	0	Range fixed
2020-12-01T10:42:48Z	350	186	2367	81.00%	1.07 GiB/s	600.82 MiB/s	0	Range fixed
2020-12-01T10:35:21Z	350	183	2443	80.00%	933.49 MiB/s	546.35 MiB/s	0	Range fixed
2020-12-01T10:27:34Z	350	127	2556	84.00%	871.47 MiB/s	503.33 MiB/s	0	Range fixed
2020-12-01T10:19:03Z	350	125	2611	82.00%	985.44 MiB/s	462.42 MiB/s	0	Range fixed
2020-12-01T10:08:17Z	300	133	2694	84.00%	1014.78 MiB/s	404.31 MiB/s	0	Range fixed
2020-12-01T09:55:39Z	300	118	2798	88.00%	870.12 MiB/s	336.48 MiB/s	0	Range fixed
2020-12-01T09:42:52Z	300	133	2884	88.00%	799.20 MiB/s	277.19 MiB/s	0	Range fixed
2020-12-01T09:35:03Z	300	132	2909	81.00%	631.83 MiB/s	219.19 MiB/s	0	Range fixed
2020-12-01T09:27:38Z	300	192	2947	100.00%	689.37 MiB/s	173.34 MiB/s	0	Range fixed
2020-12-01T09:21:15Z	300	194	2929	57.00%	440.40 MiB/s	116.00 MiB/s	0	Range fixed
2020-12-01T09:15:34Z	300	195	2896	68.00%	228.99 MiB/s	79.96 MiB/s	0	Range fixed
2020-12-01T09:09:51Z	300	17	26	81.00%	133.48 MiB/s	63.40 MiB/s	0	Range fixed
2020-12-01T09:03:45Z	300	26	24	81.00%	110.26 MiB/s	55.61 MiB/s	0	Range fixed

Details for davs://eosatlas.cern.ch → davs://webdav-at1.pic.es







TIME TABLE (HISTORY BETWEEN TWO ENDPOINTS

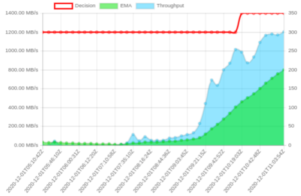
First Previous 1 Next Last

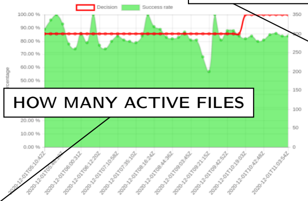
Timestamp	Decision	Running	Queue	Success rate (last 1min)	Throughput	EMA	Diff	Explanation
2020-12-01T11:03:54Z	350	183	2137	84.00%	1.18 GiB/s	800.38 MiB/s	0	Range fixed
2020-12-01T10:59:35Z	350	183	2174	84.00%	1.14 GiB/s	755.59 MiB/s	0	Range fixed
2020-12-01T10:54:59Z	350	184	2250	86.00%	1.15 GiB/s	709.42 MiB/s	0	Range fixed
2020-12-01T10:49:15Z	350	185	2312	85.00%	1.14 GiB/s	657.39 MiB/s	0	Range fixed
2020-12-01T10:42:48Z	350	186	2367	81.00%	1.07 GiB/s	600.82 MiB/s	0	Range fixed
2020-12-01T10:35:21Z	350	183	2443	80.00%	933.49 MiB/s	546.35 MiB/s	0	Range fixed
2020-12-01T10:27:34Z	350	127	2556	84.00%	871.47 MiB/s	503.33 MiB/s	0	Range fixed
2020-12-01T10:19:03Z	350	125	2611	82.00%	985.44 MiB/s	462.42 MiB/s	0	Range fixed
2020-12-01T10:08:17Z	300	133	2694	84.00%	1014.78 MiB/s	404.31 MiB/s	0	Range fixed
2020-12-01T09:55:39Z	300	118	2798	88.00%	870.12 MiB/s	336.48 MiB/s	0	Range fixed
2020-12-01T09:42:52Z	300	133	2884	88.00%	799.20 MiB/s	277.19 MiB/s	0	Range fixed
2020-12-01T09:35:03Z	300	132	2909	81.00%	631.83 MiB/s	219.19 MiB/s	0	Range fixed
2020-12-01T09:27:38Z	300	192	2947	100.00%	689.37 MiB/s	173.34 MiB/s	0	Range fixed
2020-12-01T09:21:15Z	300	194	2929	57.00%	440.40 MiB/s	116.00 MiB/s	0	Range fixed
2020-12-01T09:15:34Z	300	195	2896	68.00%	228.99 MiB/s	79.96 MiB/s	0	Range fixed
2020-12-01T09:09:51Z	300	17	26	81.00%	133.48 MiB/s	63.40 MiB/s	0	Range fixed
2020-12-01T09:03:45Z	300	26	24	81.00%	110.26 MiB/s	55.61 MiB/s	0	Range fixed

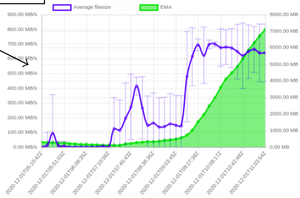
Details for davs://eosatlas.cern.ch → davs://webdav-at1.pic.es

AVERAGE FILESIZE

HOW MANY ACTIVE FILES







First | Previous | 1 | Next | Last

Timestamp	Decision	Running	Queue	Success rate (last 1min)	Throughput	EMA	Diff	Explanation
2020-12-01T11:03:54Z	350	183	2137	84.00%	1.18 GiB/s	800.38 MiB/s	0	Range fixed
2020-12-01T10:59:35Z	350	183	2174	84.00%	1.14 GiB/s	755.59 MiB/s	0	Range fixed
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2020-12-01T10:35:21Z	350	183	2443	80.00%	933.49 MiB/s	546.35 MiB/s	0	Range fixed
2020-12-01T10:27:34Z	350	127	2556	84.00%	871.47 MiB/s	503.33 MiB/s	0	Range fixed
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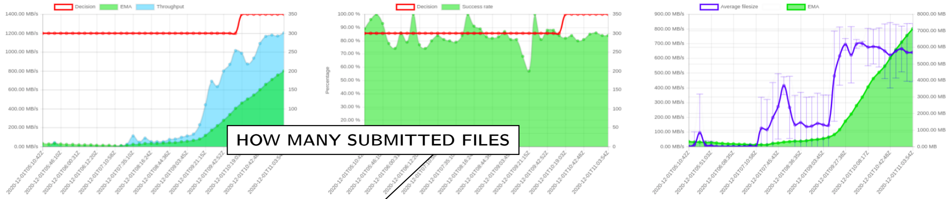

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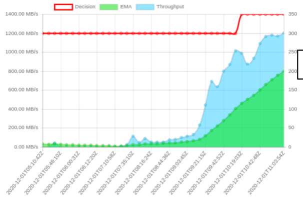
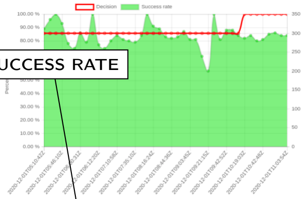
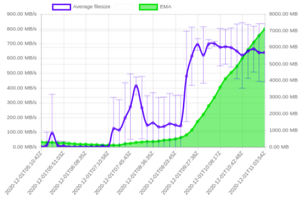
2020-12-01T09:03:45Z	300	26	24	81.00%	110.26 MiB/s	55.61 MiB/s	0	Range fixed

Details for davs://eosatlas.cern.ch → davs://webdav-at1.pic.es







First | Previous | 1 | Next | Last

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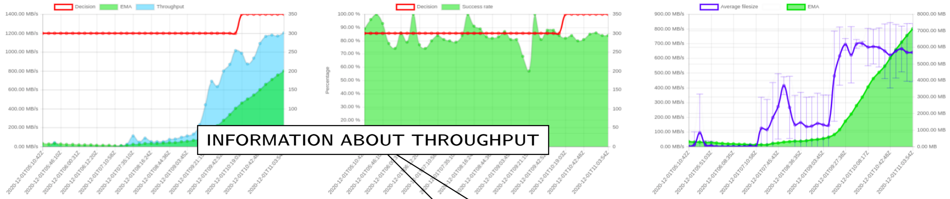

First | Previous | 1 | Next | Last

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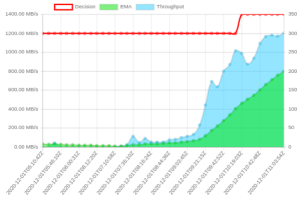
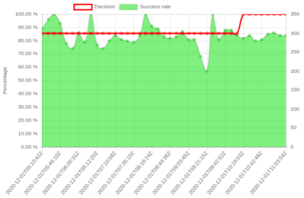
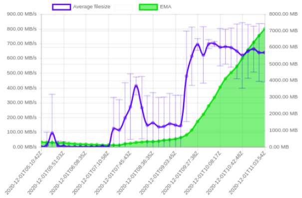
Details for davs://eosatlas.cern.ch → davs://webdav-at1.pic.es







First Previous 1 Next Last

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2020-12-01T10:59:35Z	350	183	2174	84.00%	1.14 GiB/s	755.59 MiB/s	0	Range fixed
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2020-12-01T09:42:52Z	30[illegible]	[illegible]	2884	88.00%	799.20 MiB/s	277.19 MiB/s	0	Range fixed
2020-12-01T09:35:03Z	30[illegible]	[illegible]	2909	81.00%	631.83 MiB/s	219.19 MiB/s	0	Range fixed
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NEW BULK

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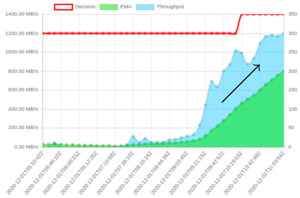

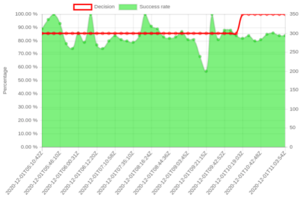

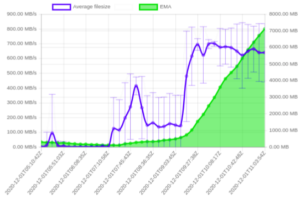

First | Previous | 1 | Next | Last

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NEW BULK

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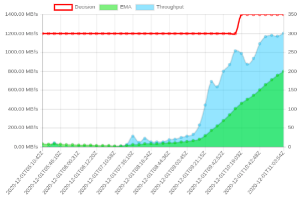

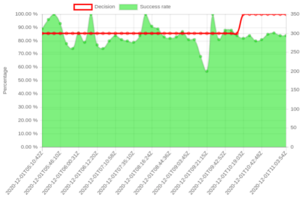

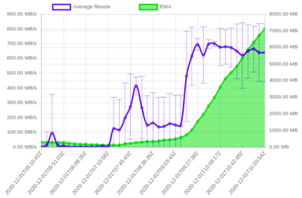

First | Previous | 1 | Next | Last

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2020-12-01T10:35:21Z	350	183	2443	80.00%	933.49 MiB/s	546.35 MiB/s	0	Range fixed
2020-12-01T10:27:34Z	350	127	2556	84.00%	871.47 MiB/s	503.33 MiB/s	0	Range fixed
2020-12-01T10:19:03Z	350	125	2611	82.00%	985.44 MiB/s	462.42 MiB/s	0	Range fixed
2020-12-01T10:08:17Z	300	133	2694	84.00%	1014.78 MiB/s	404.31 MiB/s	0	Range fixed
2020-12-01T09:55:39Z	300	118	2798	88.00%	870.12 MiB/s	336.48 MiB/s	0	Range fixed
2020-12-01T09:42:52Z	300	133	2884	88.00%	799.20 MiB/s	277.19 MiB/s	0	Range fixed
2020-12-01T09:35:03Z	300	132	2909	81.00%	631.83 MiB/s	219.19 MiB/s	0	Range fixed
2020-12-01T09:27:38Z	300	192	2947	100.00%	689.37 MiB/s	173.34 MiB/s	0	Range fixed
2020-12-01T09:21:15Z	300	194	2929	57.00%	440.40 MiB/s	116.00 MiB/s	0	Range fixed
2020-12-01T09:15:34Z	300	195	2896	68.00%	228.99 MiB/s	79.96 MiB/s	0	Range fixed
2020-12-01T09:09:51Z	300	17	26	81.00%	133.48 MiB/s	63.40 MiB/s	0	Range fixed
2020-12-01T09:03:45Z	300	26	24	81.00%	110.26 MiB/s	55.61 MiB/s	0	Range fixed

LINK WASN'T EMPTY

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