UNIVERSITY OF CAMBRIDGE

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Edge Network opens the door of Heterogeneous Network Federation

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Self-introduction

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I'm the Director of Network and Software Communication Center, CS, BUPT.
I'm the Director of Academic Committee in Joint Laboratory of BUPT and Chuangcache.

B.S. degree (in CS) from Jilin University in 2012
Ph.D. degree (in CS) from Tsinghua University (Advisor: Prof.Ke Xu) in 2017
Postdoc in the Hong Kong University of Science and Technology in 2018 (with Prof. Kai Chen)
Visiting Researcher in Hong Kong Huawei 2012 Theory Lab in 2019.
Visiting Scholar in Cambridge University since Sept. 2021 (with Prof. Jon Crowcroft).

Outline

1. Cache on the edge

Exponentially growing data amount **VS.** Limited storage on the edge

2. Transmission among the edges

Large scale transmission **VS.** Real-time traffic requirements

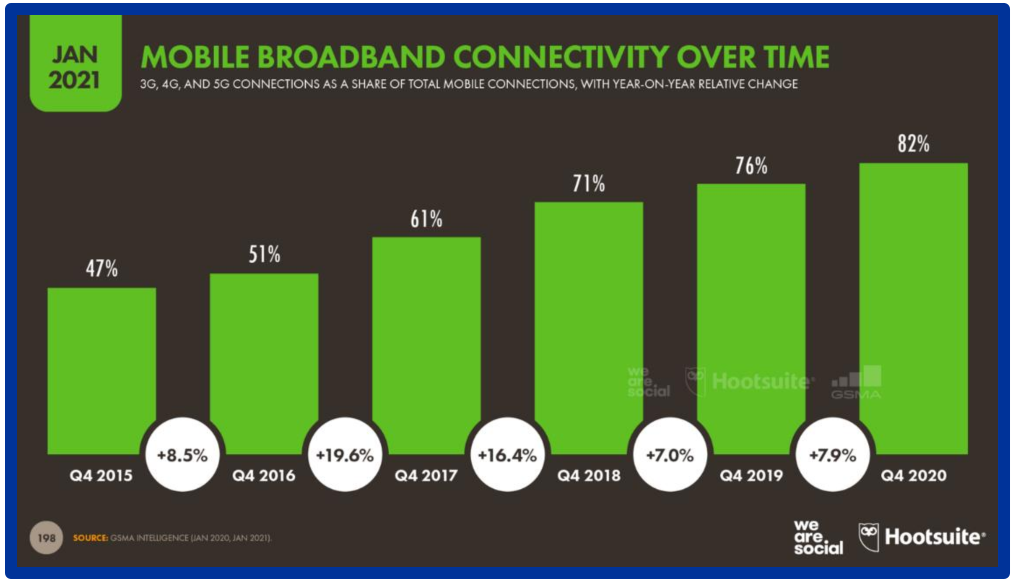
3. Federation of multiple edges

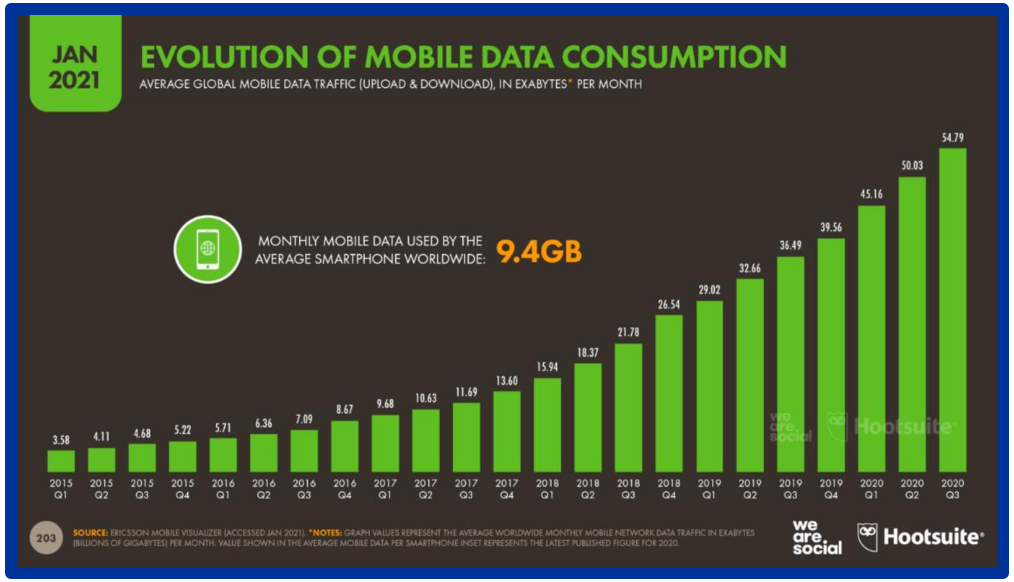
Strict data privacy **VS.** Multiple edge network collaboration

Short Videos

- Each user becomes a video producer

Data from edges are ever increasing





TIME

- **2015** **47%**
- **2020** **82%**
- **2015->2020** **+74.39%**
- **FUTURE** **?**

3G,4G, AND 5G CONNETCION AS SHARE OF TOTAL MOBILE CONNETIONS, YEAR-ON-YEAR RELATIVE CHANGE

DATA

- **2015 Q1** **3.58 EB**
- **2020 Q3** **54.79 EB**
- **2015->2020** **+51.21 EB**
- **FUTURE** **?**

AVERAGE GLPBAL MOBILE DATA TRAFFIC (UPLOAD&DOWNLOAD), IN EXABYTES*PER MONTH

We Are Social & Hootsuite, "DIGITAL 2021: GLOBAL OVERVIEW REPORT" [EB/OL]. https://datareportal.com/reports/digital-2021-global-overview-report, 2021.

1. Cache on the edge

CLOUD STORAGE

- Centralized Cloud DC
- capacity：EB–ZB
- edge distance：100-5000KM
- Advantage： **Store complete set**
- Disadvantage： **High latency**

STORAGE

EDGE STORAGE

- Edge DC
- capacity：GB–TB
- edge distance：200M-10KM
- Advantage： **Low latency**
- Disadvantage： **Store subset**

High latency

Low latency

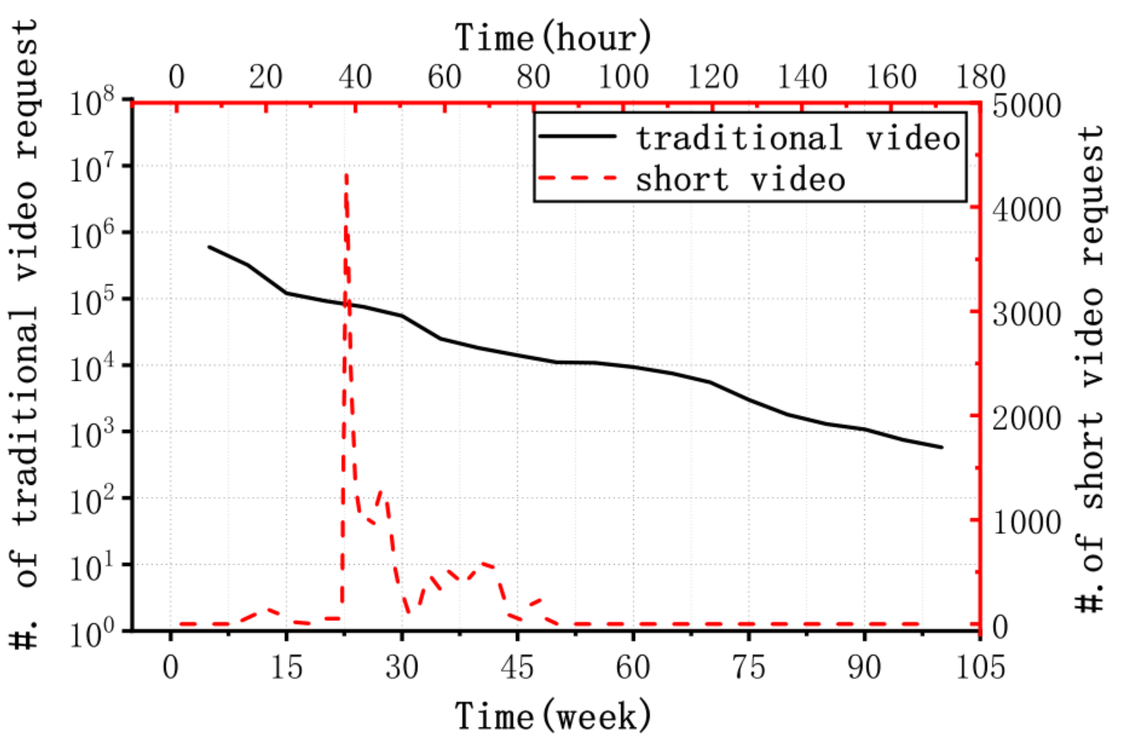
Characteristics

Comparison	All Online Video Platforms	One Short Video Platform	Times
#. of videos viewed per day Toutiao (2019); Ibzuo (2018)	46 million (from top 10 in China)	10 billion (only from Toutiao)	217
Length of video up-	0.1 million minutes (from all TV	340 million minutes	2850
Growth rate of use time QuestMobile (2019)	-12%	+521.8%	×

Daily active user

>400million

<100million



Explosive video and user quantity

- *It is difficult to guarantee the low latency under limited cost of server.*

Popularity changes quickly

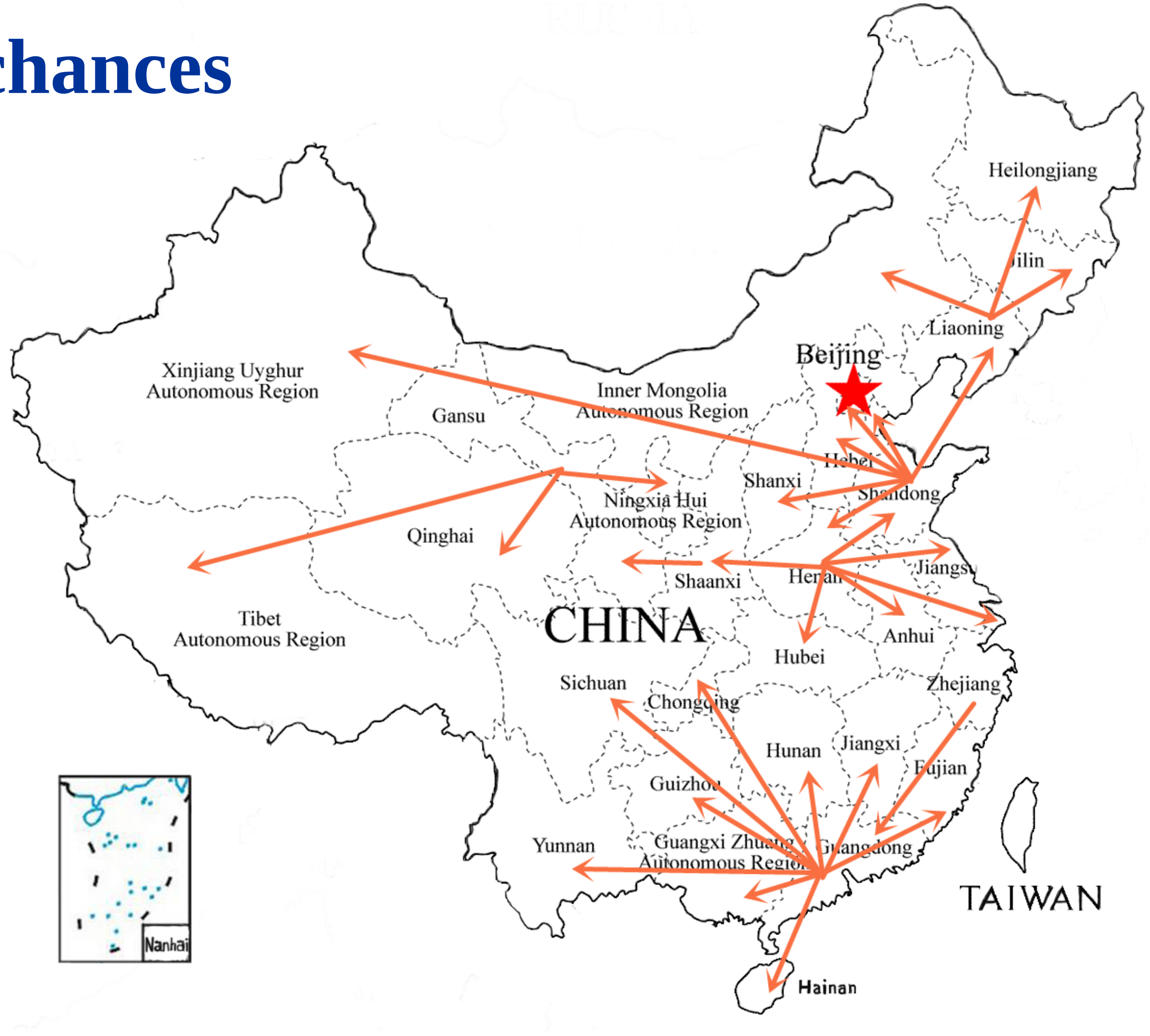
- *It is difficult to predict popular short videos*

1.1 Potential opportunity

Predicting popular content -- chances

- **Hot Topic Propagation**
- **Quantity Number**
- **Time Sensitivity**

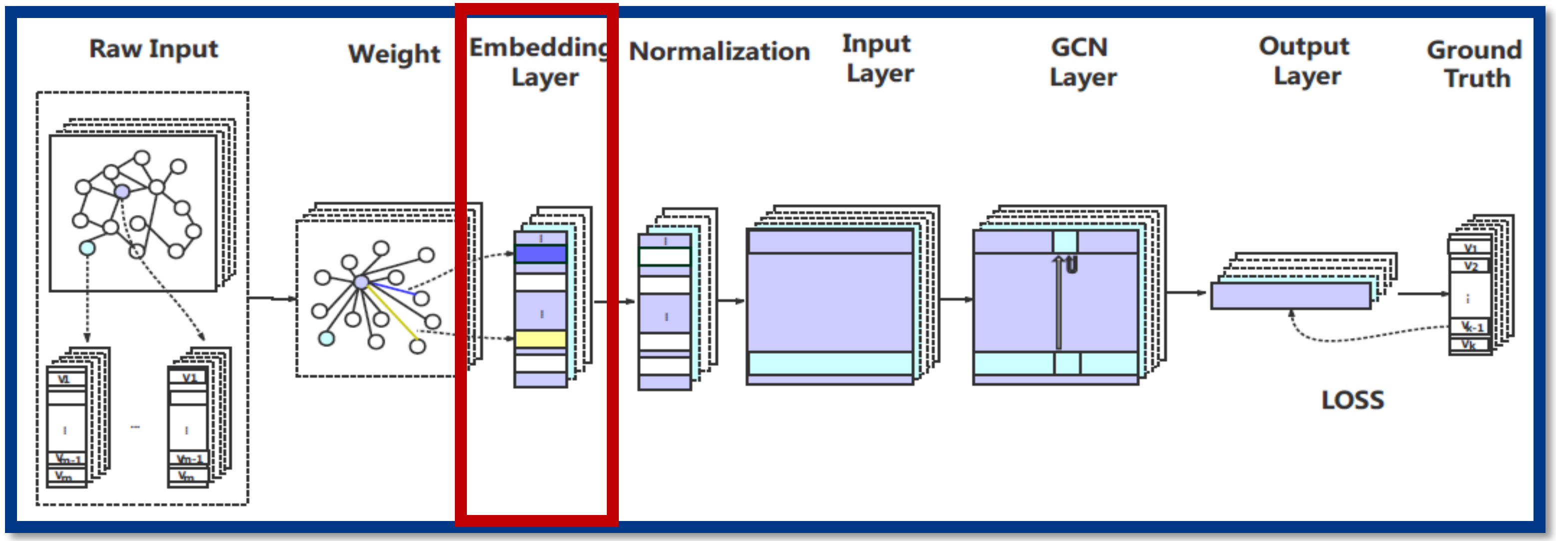
Dataset	Cache Size	Access #.	Server #.	Video #.
City 1	$3.96T$	$5,323,508$	30	$1,424,564$
City 2	$5.12T$	$9,202,618$	72	$1,813,058$
City 3	$2.51T$	$3,051,059$	10	$876,058$
City 4	$2.39T$	$2,765,419$	21	$843,219$
City 5	$2.48T$	$2,828,645$	6	$862,806$
...	...	...	...	...
Total	$78.75T$	$105,231,883$	488	$12,089,887$



1.1 GraphInf architecture

Predicting popular content -- GraphInf

We propose *GraphInf* based GCN network eight Layers, designing an embedding layer to capture the propagation relationship of popular videos.



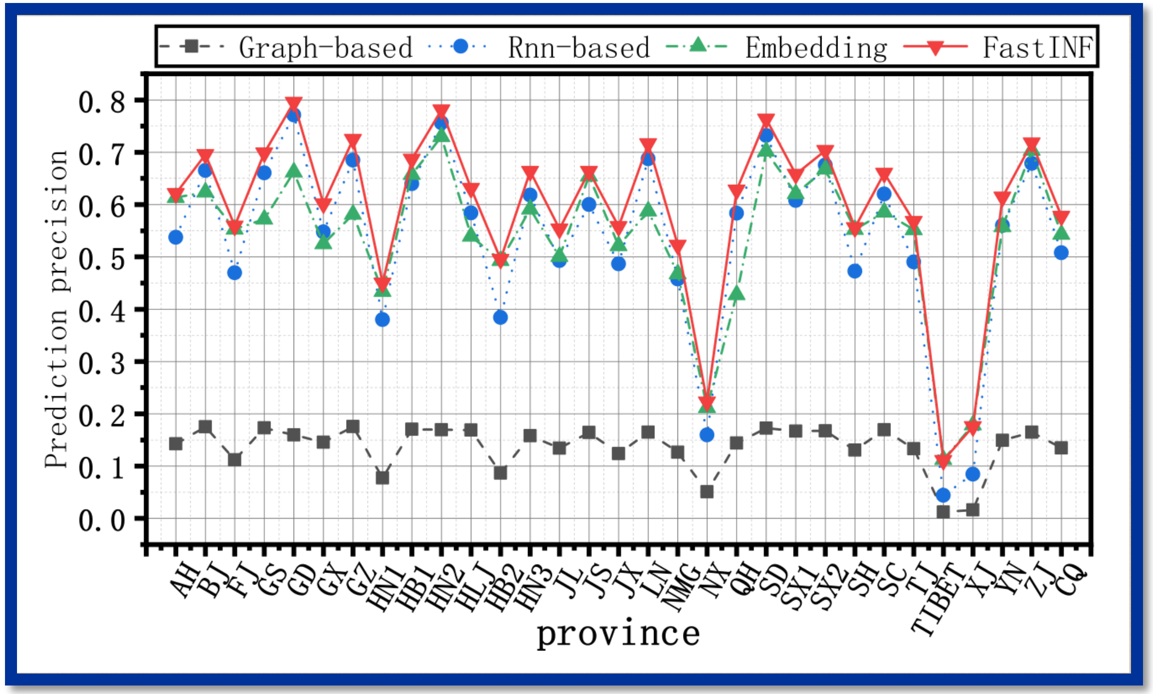
Input

- **Time slice**
- **Regions/provinces**
- **Hot items**

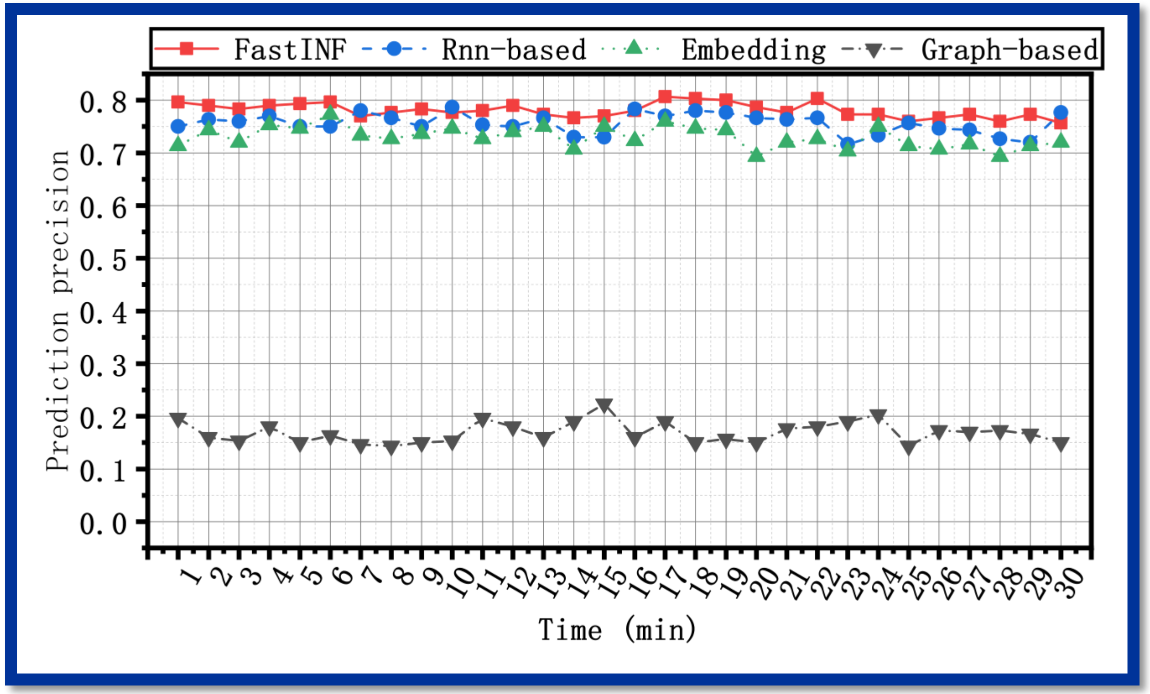
Output

- **Hot videos per region**

1.1 GraphInf evaluation



31 PROVINCES

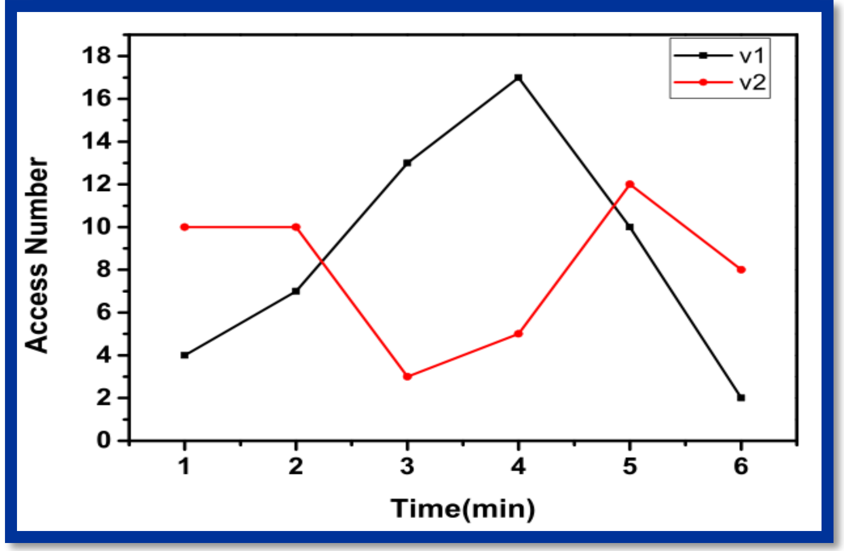


Henan

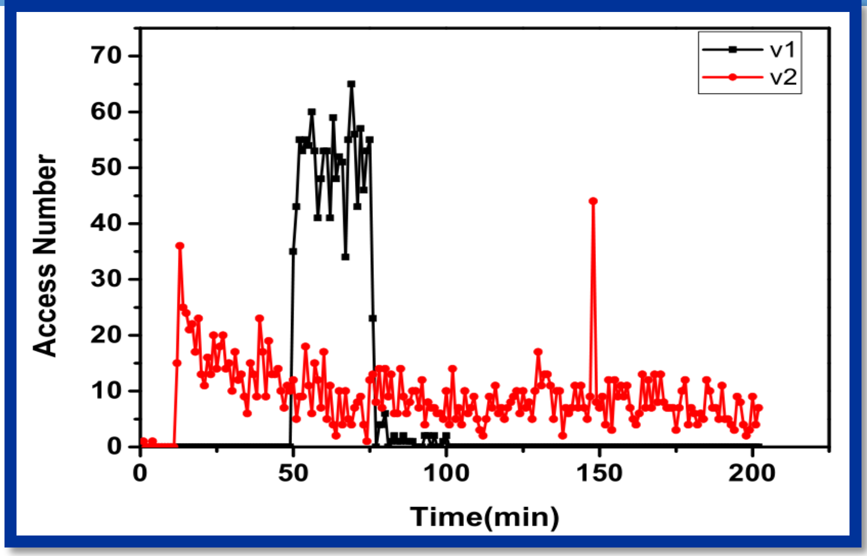
1.2 How to evict?

Prior solutions (such as LFU and DeepCache[1]) work well in traditional centralize-controlled CDNs, but become invalid in the emerging short video networks due to:

Non-stationary video access pattern.



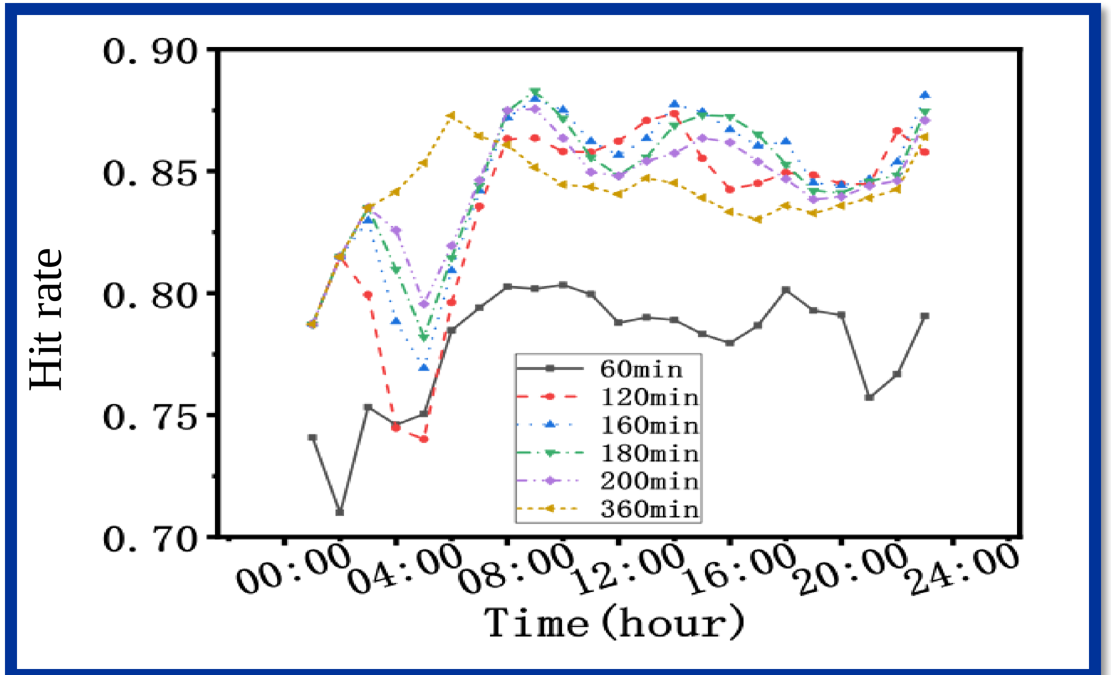
Temporal and spatial video popularity pattern.



1. J. Qiu, J. Tang, H. Ma, Y. Dong, K. Wang, and J. Tang, "Deepinf: Social influence prediction with deep learning," in Proceedings of the 24th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining. ACM, 2018, pp. 2110–2119.

1.2 How to evict?

Replacement



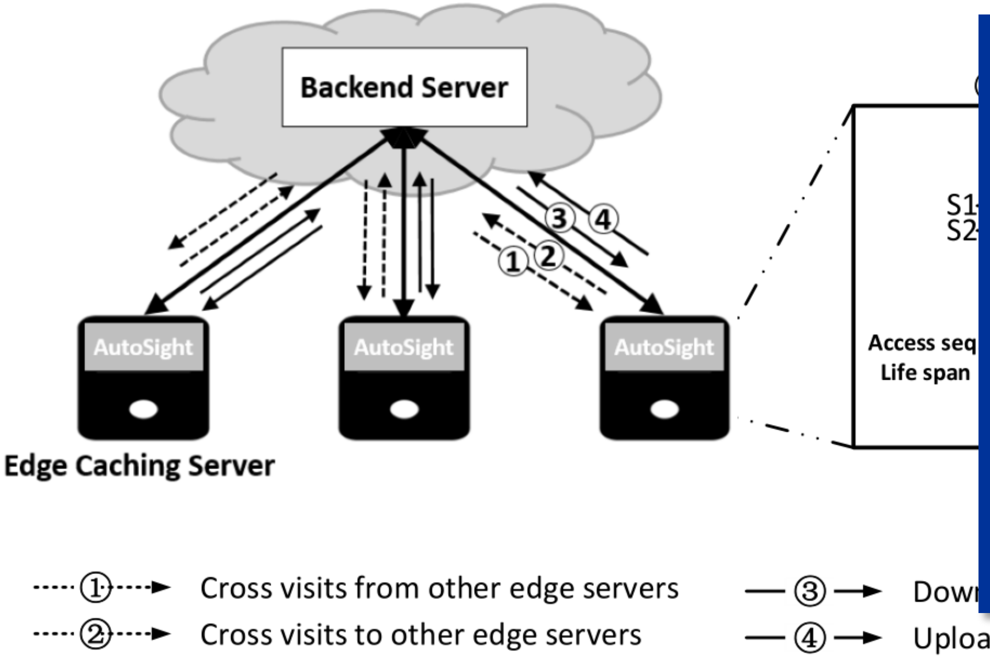
Different Future Horizon

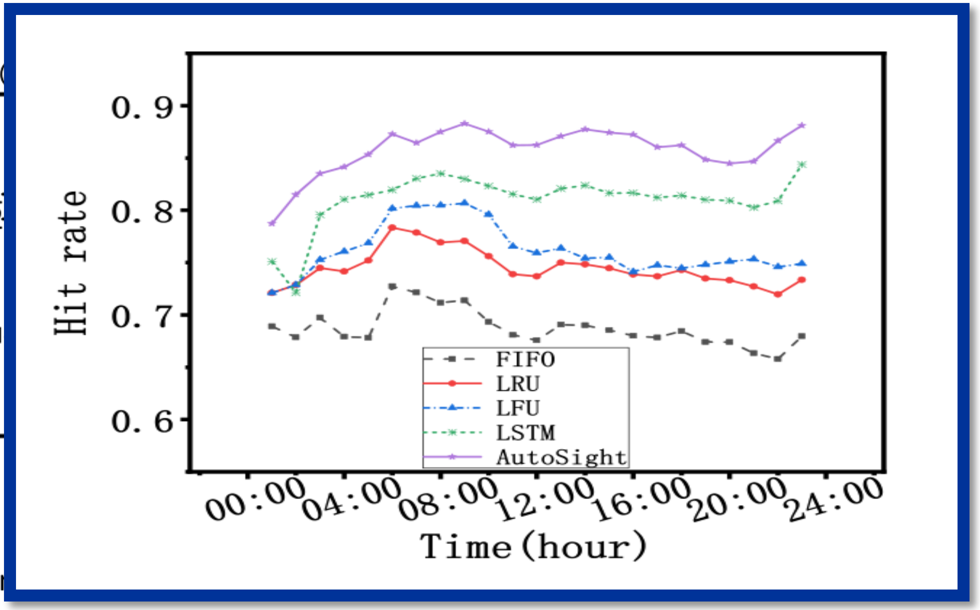
It is difficult to guarantee a constant high hit rate with static Future Horizon

1.2 How to evict?

AutoSight

AutoSight consists of a propagation-based predictor (CoStore) that predicts the number of times a video will be requested, and a caching engine (Viewfinder) with adaptive future horizon to make caching decisions.





AutoSight hit rate

1. Cache on the edge

PUBLICATION

[1] **Yuchao Zhang**, Pengmiao Li, Zhili Zhang, Bo Bai, Gong Zhang, Wendong Wang, Bo Lian. Challenges and Chances for the Emerging Short Video Network. IEEE International Conference on Computer Communications (Infocom'2019) Poster. 29 April - 2 May, Paris, France.

[2] **Yuchao Zhang**, Pengmiao Li, Zhili Zhang, Bo Bai, Gong Zhang, Wendong Wang, Bo Lian, Ke Xu. AutoSight: Distributed Edge Caching in Short Video Network. IEEE Network. 2020, 34(3), pp. 194-199. IF: 7.503, JCR Q1.

[3] **Yuchao Zhang**, Pengmiao Li, Zhili Zhang, Chaorui Zhang, Wendong Wang, Yishuang Ning, Bo Lian. GraphInf: A GCN-based Popularity Prediction System for Short Video Networks. 2020 International Conference on Web Services, Sept. 18-20, 2020, Honolulu, Hawaii, USA. (Virtual Conference)

[4] Pengmiao Li, **Yuchao Zhang#,** Huahai Zhang, Wendong Wang, Ke Xu, Zhili Zhang. CRATES: A Cache Replacement Algorithm for Low Access Frequency Period in Edge Servers. The 17th International Conference on Mobility, Sensing and Networking (MSN), December 13-15, 2021, **Exeter, UK**.

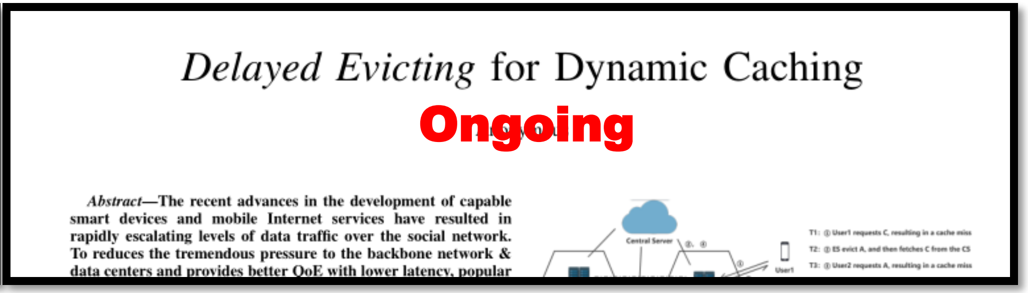
[5] Bo Yi, Fuliang Li, **Yuchao Zhang#,** Xingwei Wang. TPA based Content Popularity Prediction for Caching and Routing in Edge-Cloud Cooperation Network. 2021 IEEE Global Communications Conference (GlobeCom), December 7-11, 2021. Madrid, Spain. (Hybrid: In-Person and Virtual Conference)

ONGOING


Under submission

FastINF: Popularity Prediction in Short Video Network by a Fast Graph Convolutional Neural Network

Pengmiao Li, Yuchao Zhang, *Member, IEEE*, Zhili Zhang, *Fellow, IEEE*,


Delayed *Evicting* for Dynamic Caching

Ongoing

Abstract—The recent advances in the development of capable smart devices and mobile Internet services have resulted in rapidly escalating levels of data traffic over the social network. To reduces the tremendous pressure to the backbone network & data centers and provides better QoE with lower latency, popular

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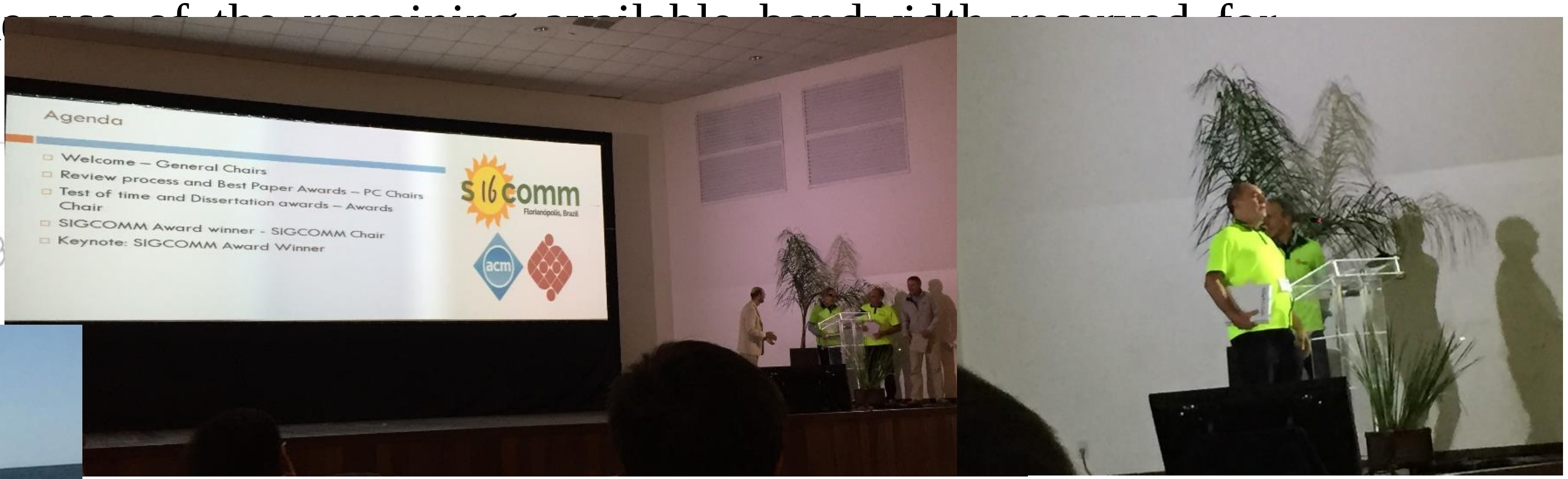
2. Transmission among the edges

- As described in the previous part, the demand for inter-domain transmission (cross multiple edge networks) is exploding.

2.1 Data Replication

- BDS+ is an application-level multicast overlay network with a fully centralized architecture, which fully utilizes the available overlay paths and leverages dynamic bandwidth separation to mak… …fic.



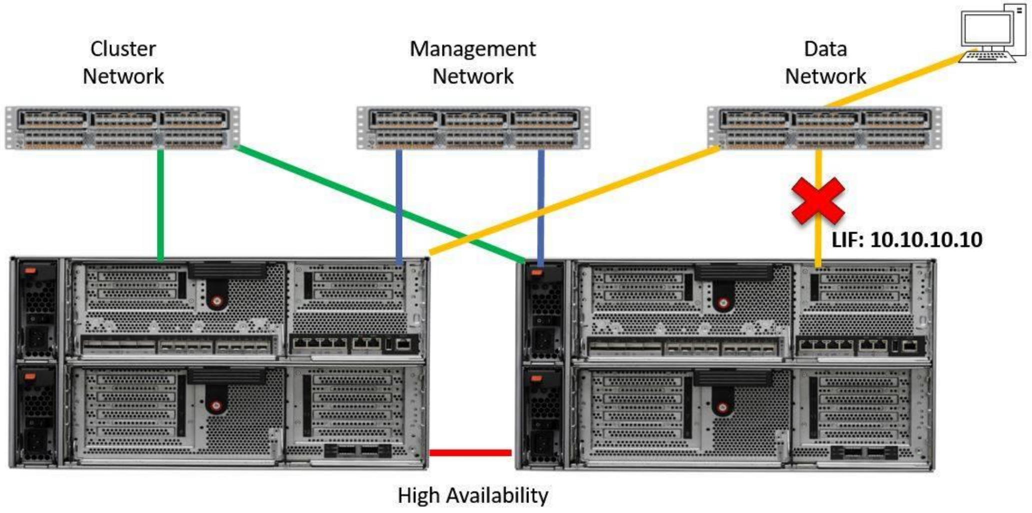
[1] **Yuchao Zhang**, Ke Xu, Guang Yao, Miao Zhang, Xiaohui Nie. "A Cross-DR scale Large Data Transmission Scheduling System" [C] *Proceedings of the 2016 conference on ACM SIGCOMM 2016 Poster*. ACM, 2016: 553-554. 22-26 August, Florianopolis, Brazil.

[2] **Yuchao Zhang**, Junchen Jiang, Ke Xu, Xiaohui Nie, Martin J. Reed, Haiyang Wang, Guang Yao, Miao Zhang, Kai Chen. BDS: A Near-Optimal Overlay Network for Inter-Datacenter Data Replication. In *Proceedings of the ACM Thirteenth Eurosys Conference, 2018*, pp.10-23. 23-26 April, Porto, Portugal.

[3] **Yuchao Zhang#,** Xiaohui Nie, Junchen Jiang, Wendong Wang, Ke Xu, Youjian Zhao, Reed Martin, Kai Chen, Haiyang Wang, Guang Yao. BDS+: An Inter-Datacenter Data Replication System with Dynamic Bandwidth Seperation. *IEEE/ACM Transaction on Networking* ***(ToN)***. 2021, 29(2): 918-934. DOI: 10.1109/TNET.2021.3054924.

2.2 When link fails?

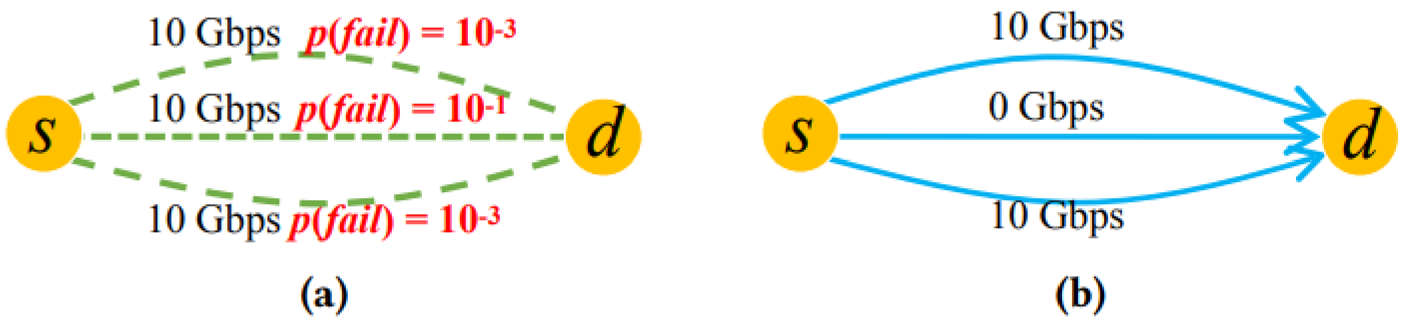
- With the scale of inter-DC networks growing exponentially, failures are quite common.
- In a production inter-DC wide area network with more than 200 routers and 6000 links, the link failure frequency is close to **25%** in every 5 minutes, and close to **40%** in every 10 minutes[2].



[2]. H. H. Liu, S. Kandula, R. Mahajan, M. Zhang, and D. Gelernter, “Traffic engineering with forward fault correction,” in Proceedings of the 2014 ACM Conference on SIGCOMM, 2014, pp. 527–538.

2.2 Existing Solutions & Drawbacks

- ***Availability***
  - TEAVaR[3] concentrates on striking the balance between availability and utilization, but it cost too much time for it takes the whole network into computation, while in inter-DC situations, fast failure recovery is needed.

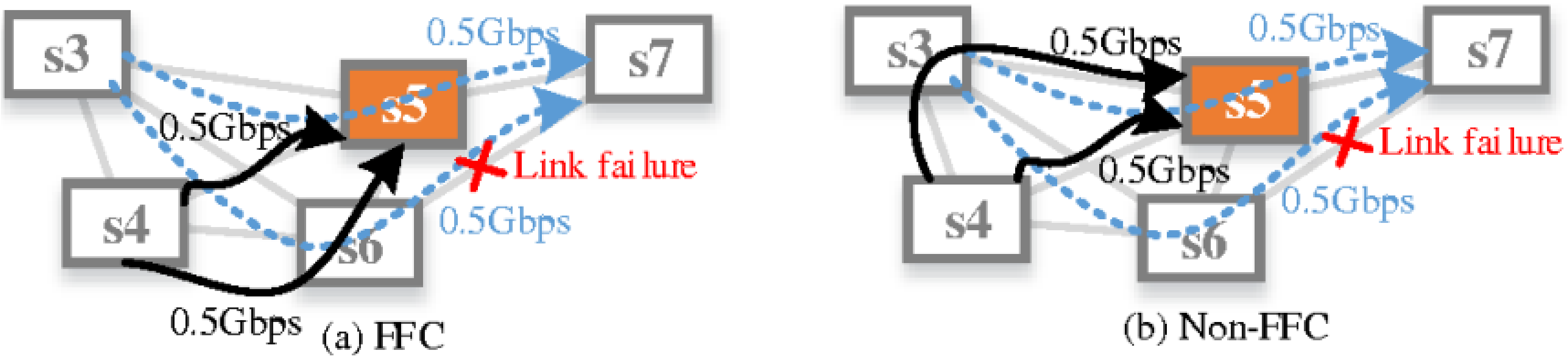


TEAVaR example

[3]. J. Bogle, N. Bhatia, M. Ghobadi, I. Menache, N. Bjørner, A. Valadarsky, and M. Schapira, “Teavar: striking the right utilization-availability balance in wan traffic engineering,” in Proceedings of the ACM Special Interest Group on Data Communication, 2019, pp. 29–43.

2.2 Existing Solutions & Drawbacks

- ***Efficiency***
  - FFC[2] achieves fast failure recovery, but sacrifices network throughput, and no guarantee on future availability/performance.



FFC for link failures(k=1)

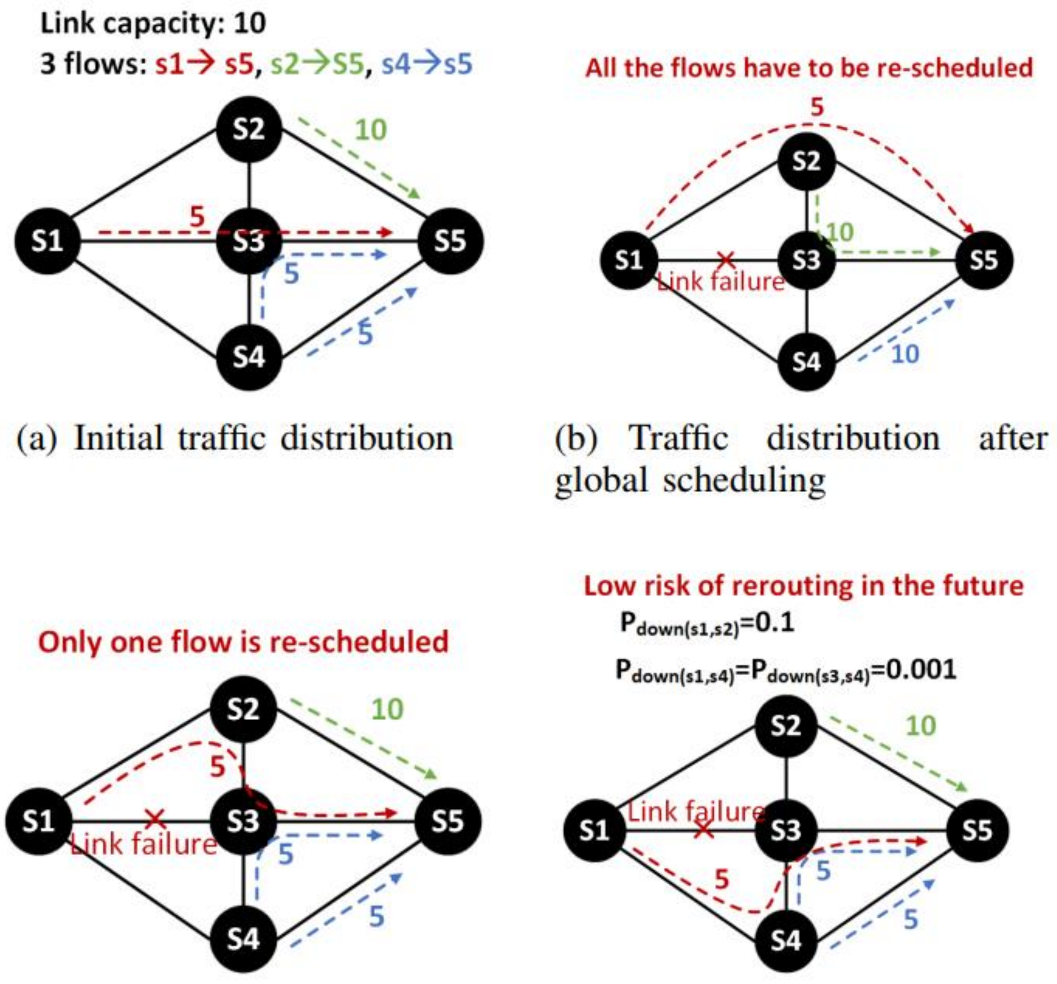
[2]. Liu H H, Kandula S, Mahajan R, et al. Traffic engineering with forward fault correction[C]//Proceedings of the 2014 ACM Conference on SIGCOMM. 2014: 527-538..

2.2 Motivation

- Challenges – we want both
  - ***Efficiency***: Fast recovery against frequent network failures
  - ***Availability***: Keep high throughput and avoid future failure

- Ideal
  - **Less shuffle**: The less traffic we reroute, the fast recovery we achieve.
  - **Lowest risk**: Reroute traffic in the way with lowest risk to encounter future failures.

2.2 A Motivating Example



(a) Initial traffic distribution

(b) Traffic distribution after global scheduling

(c) Incremental scheduling

(d) FRAVaR scheduling

- Potential solution
  - ***Incremental scheduling:***
    - Fast computation: reroute from the source of failure link. (See Fig(c)).
    - Reduce impact on other links: reconfiguration of the whole network brings unnecessary traffic reroute. (See Fig(b)).
  - ***Guarantee future performance***:
    - Risk: prefer to route to a lower failure probability route. (See Fig(d)).

FRAVaR example

2.2 Quantify the Recovery Efficiency

- Global schemes:

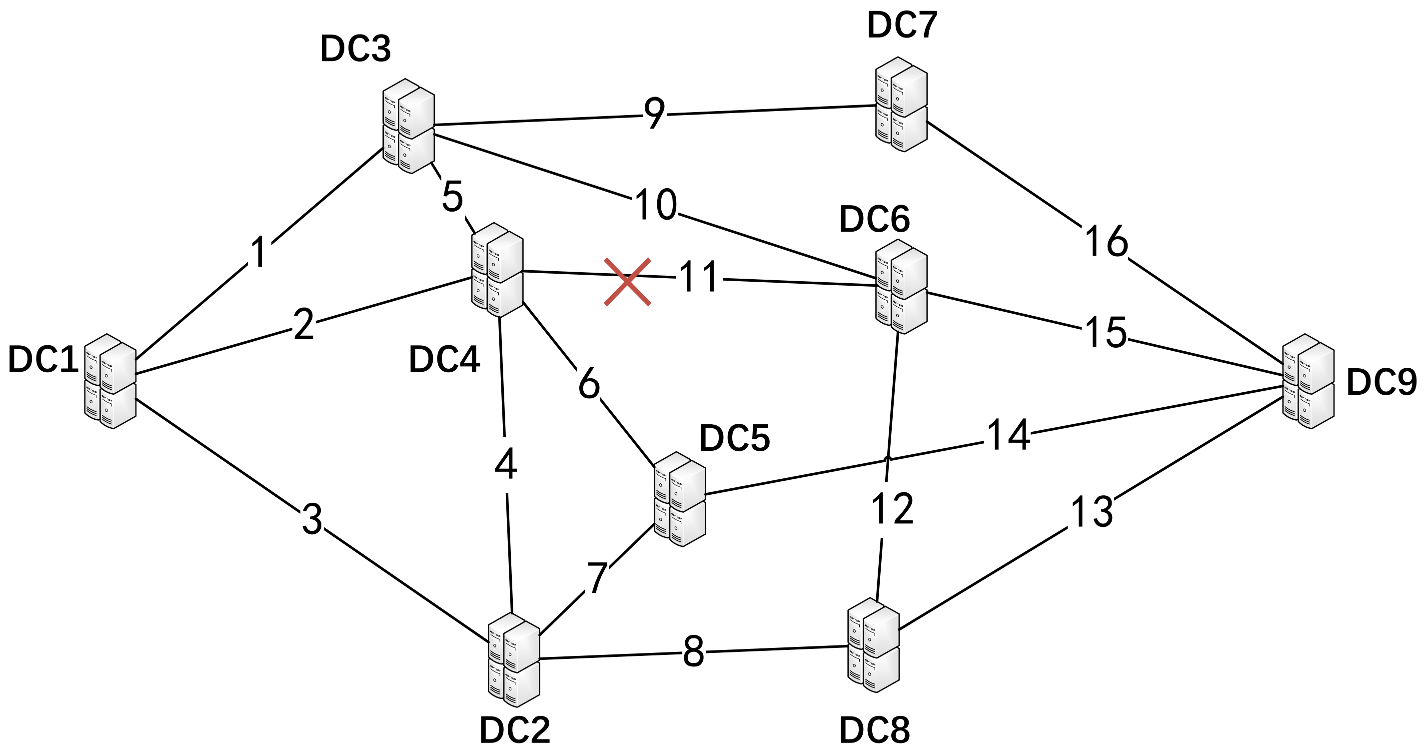
1. The controller has to calculate a global optimization scheme with high complexity.
2. The network has to reconfigure the routing rules on the shuffled paths.
3. A measure in [4] shows when a new routing rules inserting, up to 466 moves are required and each move consumes hundreds of milliseconds.

- Intuitively, a smaller scale of traffic shuffle requires shorter computation time.

[4]. P. He, W. Zhang, H. Guan, K. Salamatian, and G. Xie, “Partial order theory for fast tcam updates,” IEEE/ACM Transactions on Networking, vol. 26, no. 1, pp. 217–230, 2017.

2.2 Incremental-scheduling

- Present a non-backtrace algorithm to search paths for recovery from the source to the end of the failed link.

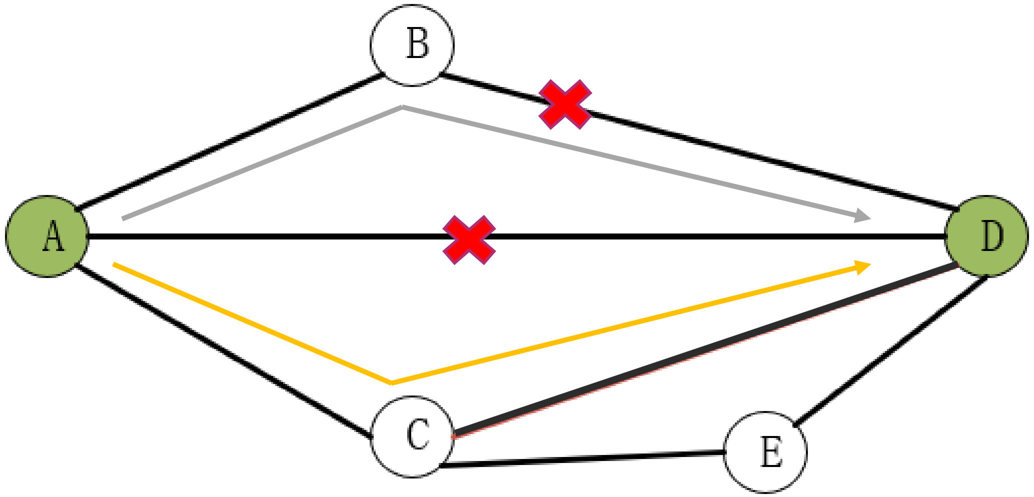


Link11 fails and traffic on it needs to be rerouted.
Search ends when we **get 3 paths.**

Queue	Results
{5,10},{DC3,DC6}	VALID, {5,10}
{4,8,12}, {DC2,DC8,DC6}	VALID, {4,8,12}
{4,8,13}, {DC2,DC8,DC9}	VISITED
{5,9,16}, {DC3,DC7,DC9}	VISITED
{6,14,15}, {DC5,DC9,DC6}	VALID, {6,14,15}
{5,1},{DC3,DC1}	VISITED
{5,10},{DC3,DC6}	VALID, {5,10}
{5,9}{DC3,DC7}	
{6,7}, {DC5,DC2}	VISITED
{6,14}, {DC5,DC9}	

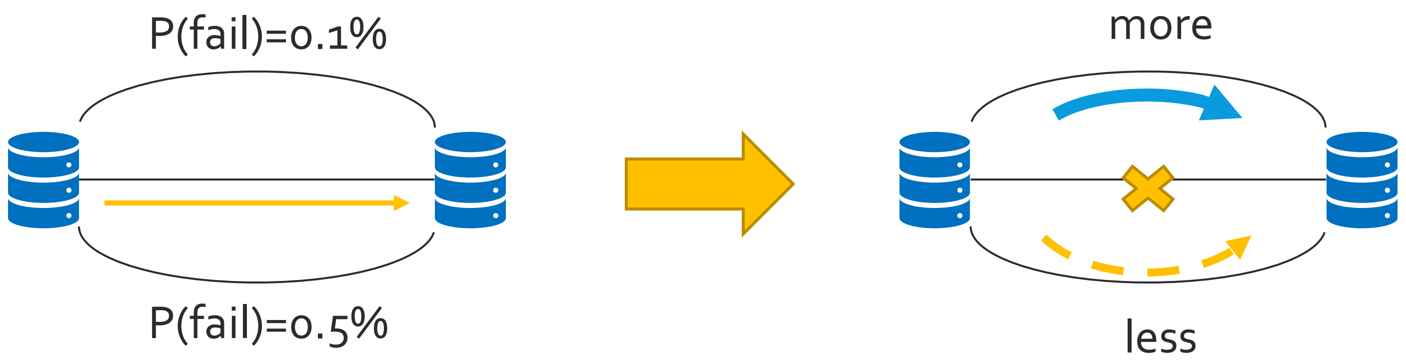
2.2 Overlapping Failure

- Guarantee future availability
  - After rerouted caused by one failure, the traffic encounters another failure later when transmitting. We call it the "***Overlapping Failure***" (OF).
  - An OF increases the scale of rerouted traffic while it should have been unnecessary.



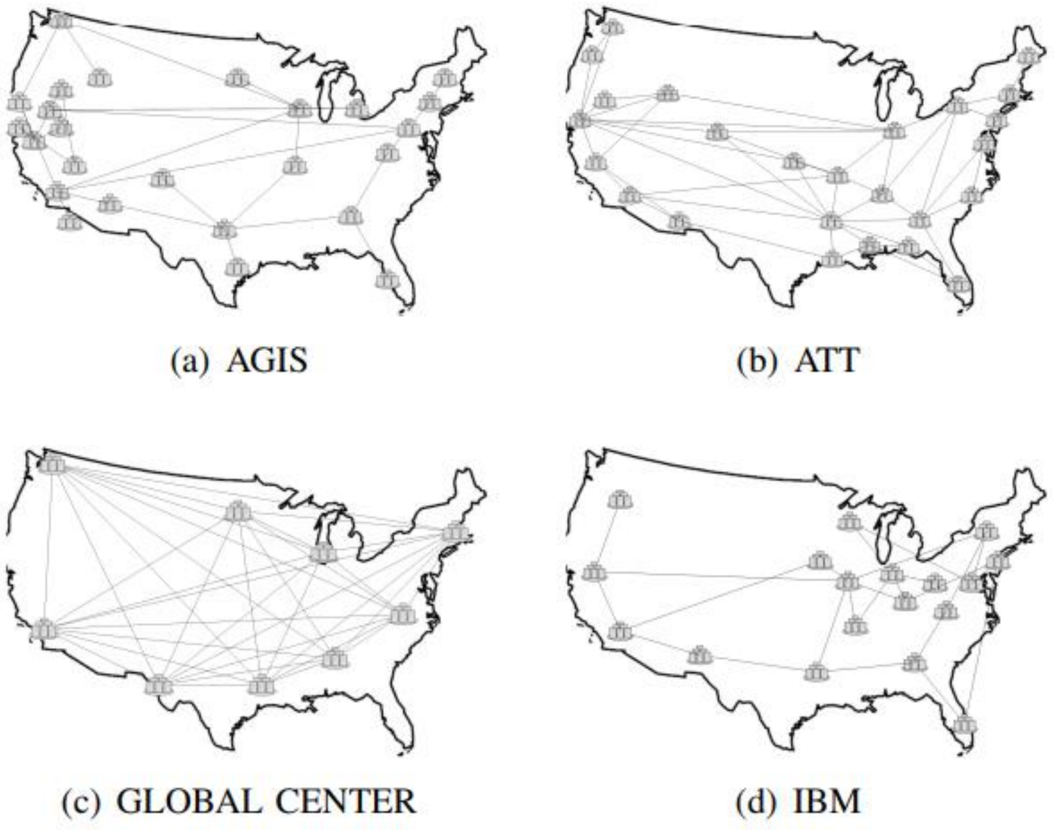
2.2 Overlapping Failure

- Avoid Overlapping Failures
  - Allocate less traffic to a high failure probability route to avoid OF.

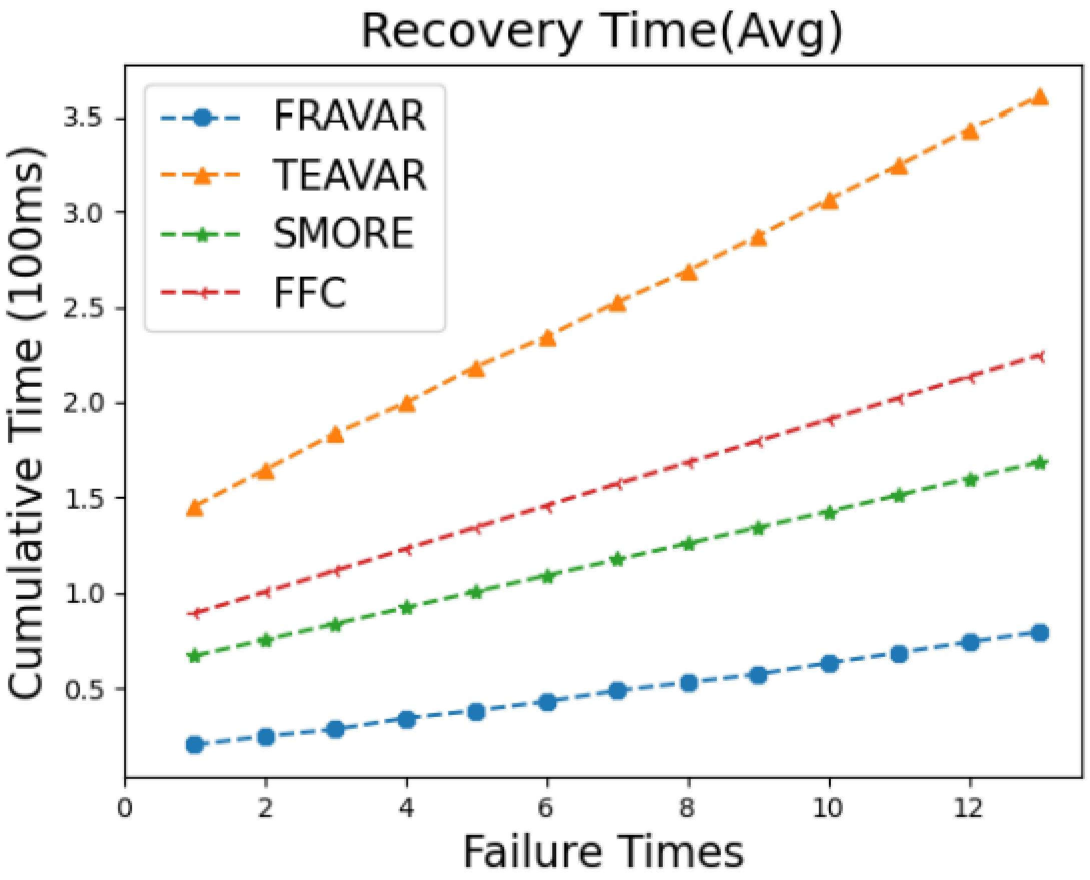


2.2 Evaluation

■ Average Recovery Time

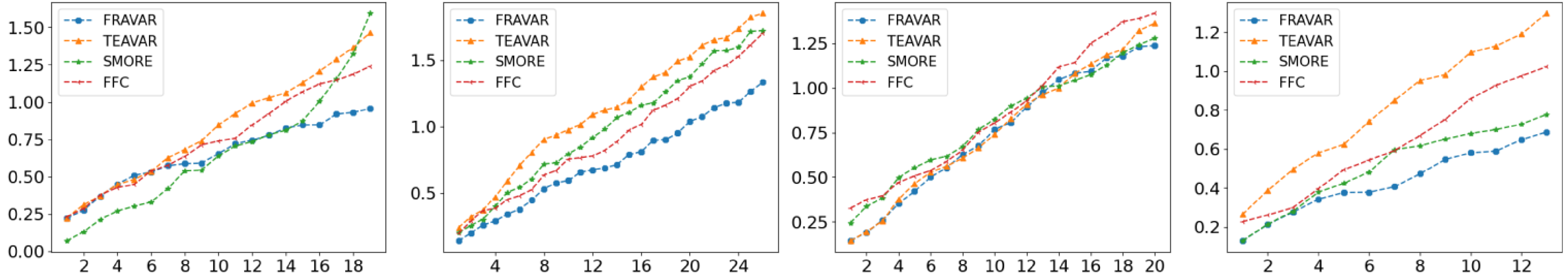


Network topologies applied in simulation.



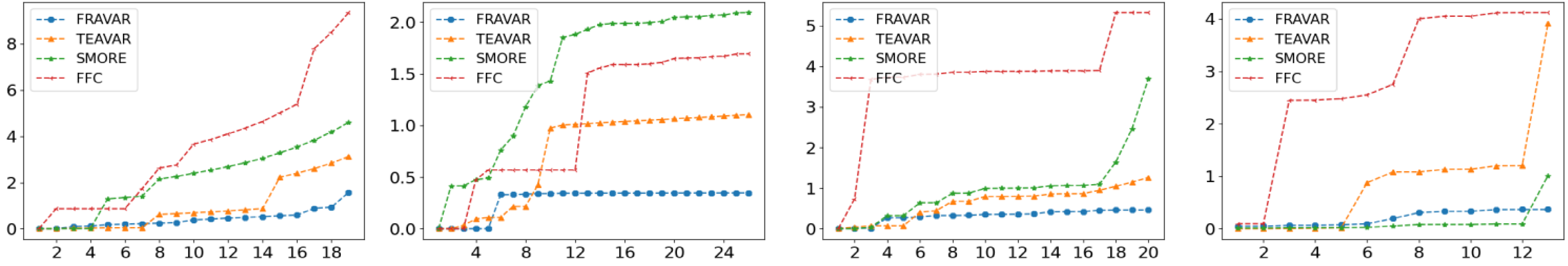
Average accumulated recovery time cost over 4 topologies.

2.2 Evaluation



(a) AGIS (b) ATT (c) Global Center (d) IBM

Fig1. Comparison of the scale of traffic rerouted by four failure recovery algorithms over four network topologies The x-axis is the failure times order by epoch and the y-axis is the cumulative scale of traffic rerouted/shuffled (metric:10GB).



(a) AGIS (b) ATT (c) Global Center (d) IBM

Fig2. Comparison of the scale of rescheduled traffic meeting overlapping failures in four failure recovery algorithms over four network topologies. The x-axis is the failure times order by epoch and the y-axis is the cumulative scale of traffic that meets overlapping failures (metric:10GB).

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3. Routing among multiple edge networks

Wrong config./status?

→Network Failures/Attack

No network status?

→Data island

Mark Zuckerberg

Facebook, Instagram, WhatsApp and Messenger are coming back online now. Sorry for the disruption today -- I know how much you rely on our services to stay connected with the people you care about.

1.9M 621K 449K

- **Facebook outage on 4th Oct.**
  - Our engineering teams have learned that configuration changes on the backbone routers that coordinate network traffic between our data centers caused issues that interrupted this communication. This disruption to network traffic had a cascading effect on the way our data centers communicate, bringing our services to a halt.

  -- Facebook

3. Existing Solutions and Drawbacks

- **How to use correct edge network inform./config. safely?**
  - Non-shared intra-domain state information cannot assist in cross-domain routing decisions, i.e., the data islands problem.
  - Intra-domain data sharing will lead to privacy data leakage issues.

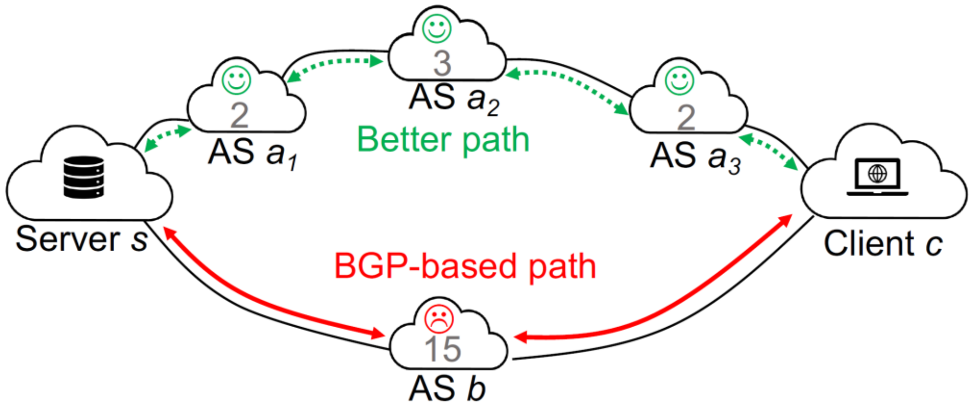


Figure 1. AS hop-based inter-domain routing policies may miss the optimal path

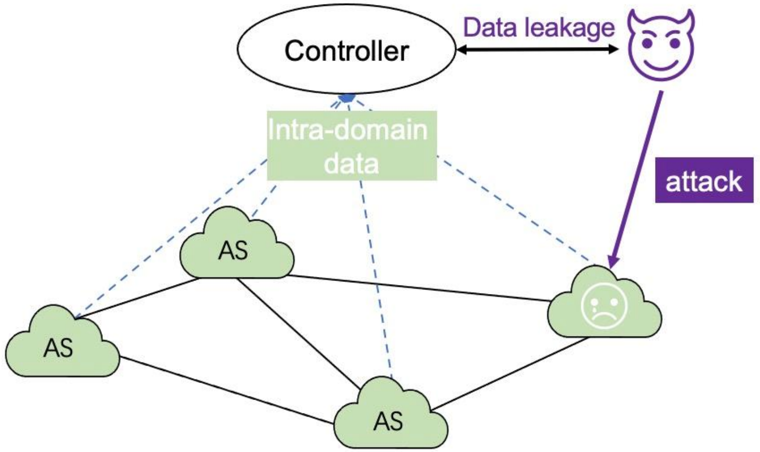


Figure 2. Naive data export will cause data privacy issues

Research Progress

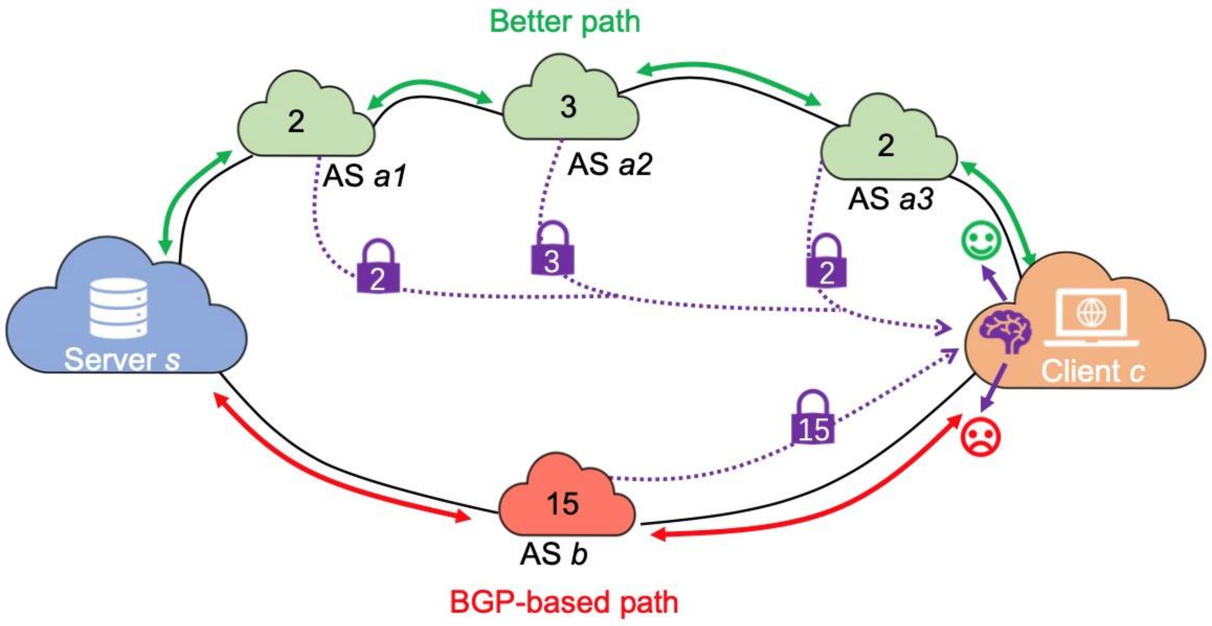
I²BGP (Intra-domain Information-aware Border Gateway Protocol)

■ Motivation

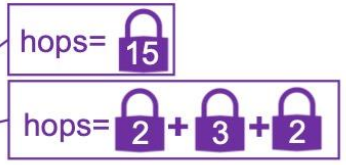
If the operations and comparisons are performed without knowing the specific values, then the contradictory problems in inter-domain routing can be solved to certain extent.

■ Overview

Homomorphic encryption has the characteristics that we need. Therefore, we propose I²BGP, an Intra-domain Information-aware Border Gateway Protocol, which can privately export intra-domain states.



Path	AS-path	Priority	State	Hops
[c, b, s]	2	high	selected	
[c, a3, a2, a1,s]	4	low	discarded	



I²BGP

I²BGP (Intra-domain Information-aware Border Gateway Protocol)

- Routing Diffusion Example

D (d.1)->B (b.2)				
Des	Next-hop	AS-path	MED	Des-AS
d.2	d.1	1	10	D

D (d.1)->C (c.2)				
Des	Next-hop	AS-path	MED	Des-AS
d.2	d.1	1	10	D

b.2->b.1				
Des	Next-hop	AS-path	MED	Des-AS
d.2	b.2	1	60	D

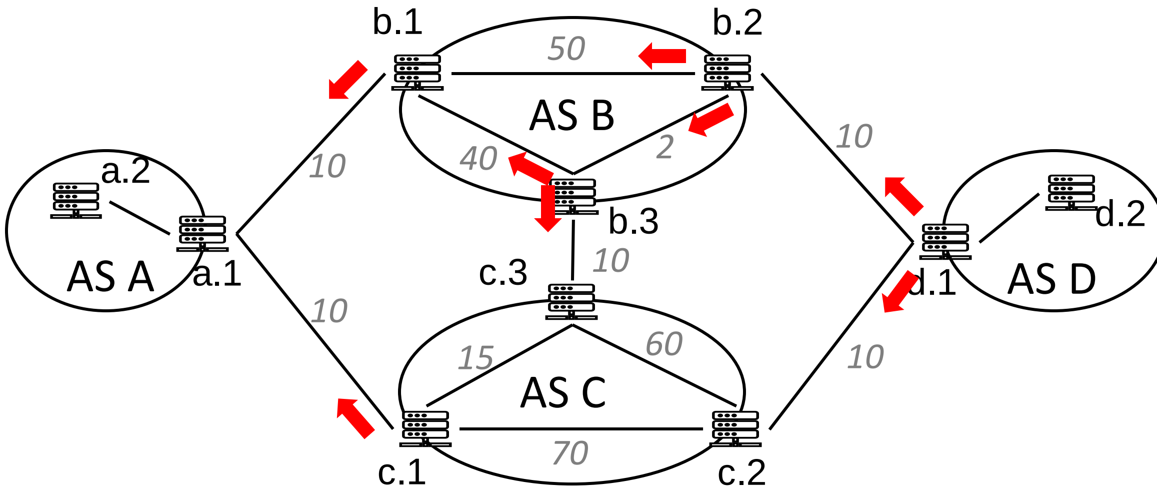
b.2->b.3				
Des	Next-hop	AS-path	MED	Des-AS
d.2	b.2	1	12	D

b.3->b.1				
Des	Next-hop	AS-path	MED	Des-AS
d.2	b.3	1	52	D

B (b.3)->C (c.3)				
Des	Next-hop	AS-path	MED	Des-AS
d.2	b.3	2	22	D

B (b.1)->A (a.1)				
Des	Next-hop	AS-path	MED	Des-AS
d.2	b.1	2	62	D

C (c.1)->A (a.1)				
Des	Next-hop	AS-path	MED	Des-AS
d.2	c.1	3	47	D



I²BGP workflow

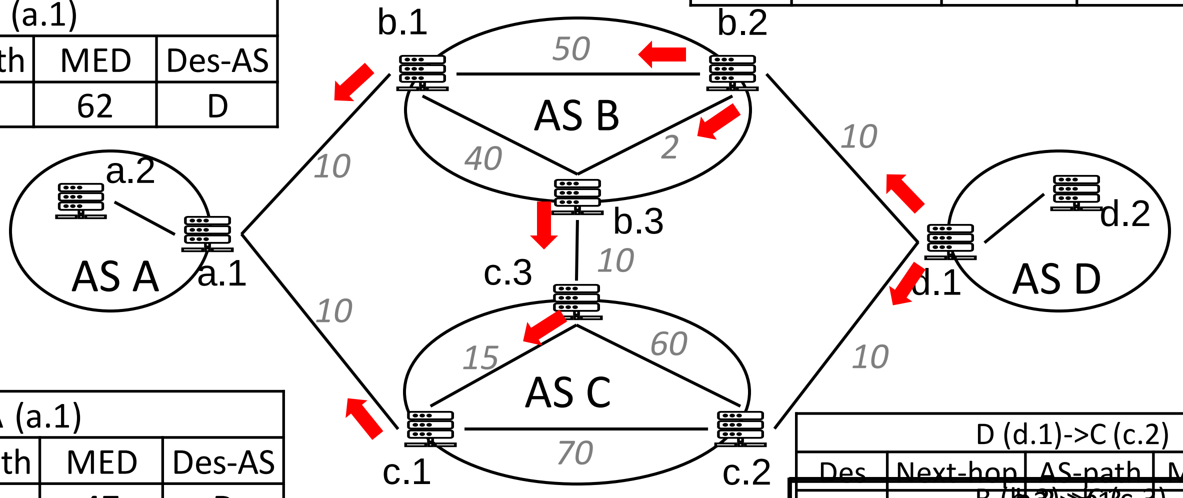
I²BGP (Intra-domain Information-aware Border Gateway Protocol)

- Example of a local RIB update.

B (b.1)->A (a.1)				
Des	Next-hop	AS-path	MED	Des-AS
d.2	b.1	2	62	D

D (d.1)->B (b.2)				
Des	Next-hop	AS-path	MED	Des-AS
d.2	d.1	1	10	D

[illegible]				
Des	Next-hop	AS-path	MED	Des-AS
d.2	b.2	1	60	D



C (c.1)->A (a.1)				
Des	Next-hop	AS-path	MED	Des-AS
d.2	c.1	3	47	D

D (d.1)->C (c.2)				
Des	Next-hop	AS-path	MED	Des-AS
d.2	d.1	1	10	D

B (b.3)->C (c.3)				
Des	Next-hop	AS-path	MED	Des-AS
d.2	b.3	2	22	D

BGP table of a.1				
Des	Next-hop	AS-path	MED	Des-AS
d.2	c.1	3	47 (update)	D
	b.1	2	62	D

BGP table of b.1				
Des	Next-hop	AS-path	MED	Des-AS
d.2	b.2	2	60 (update)	D
	b.3	2	52	D

BGP table of b.2				
Des	Next-hop	AS-path	MED	Des-AS
d.2	d.1	1	update	D
	b.3	2	80	D

BGP table of b.3				
Des	Next-hop	AS-path	MED	Des-AS
d.2	b.2	1	12 (update)	D
	c.3	2	70	D

BGP table of c.1				
Des	Next-hop	AS-path	MED	Des-AS
d.2	c.3	2	47 (update)	D
	c.2	1	80	D

BGP table of c.2				
Des	Next-hop	AS-path	MED	Des-AS
d.2	c.3	3	82	D
	d.1	1	consistent	D

BGP table of c.3				
Des	Next-hop	AS-path	MED	Des-AS
d.2	b.3	2	22 (update)	D
	c.2	1	70	D

Research Progress

I²BGP (Intra-domain Information-aware Border Gateway Protocol)

■ Privacy Protection

- ***Topology Abstraction***: abstracting each domain into a characteristic topology graph with its border routers *(Figure 1)*, so as to mask specific intra-domain states.

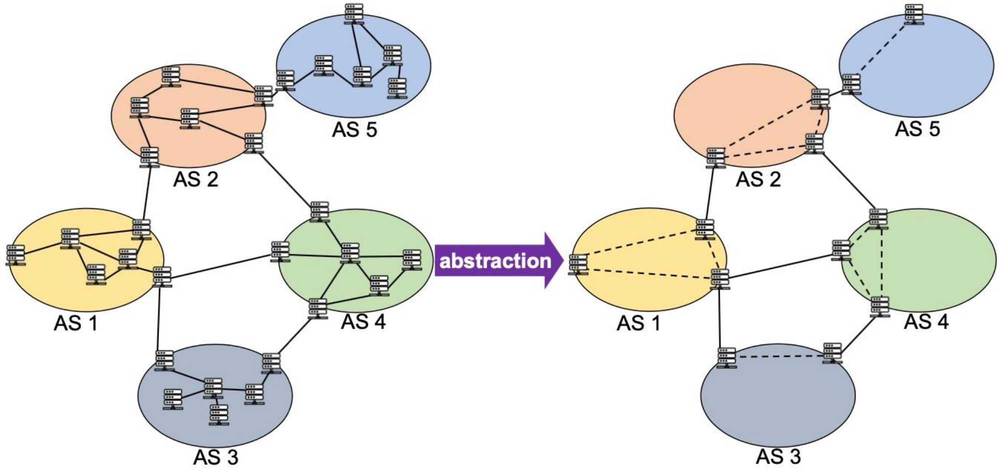


Figure 1. Topology Abstraction

- ***Random Number Confusion:*** for the directly connected case as shown in Figure 2(a), we confuse the source properties with random numbers to protect its privacy. It allows us get the hops/latency accumulated on the **whole path**.

$$d^{Exported} = d^{Authentic} + \delta_d$$

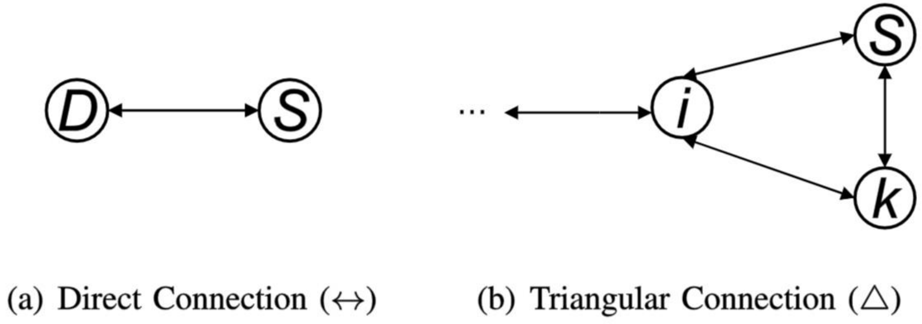


Figure 2. Connection Description

Research Progress

I^2BGP (Intra-domain Information-aware Border Gateway Protocol)

- ***Random Number Confusion:*** for the triangular connected case as shown in Figure 1(b), we use a homomorphic encryption-based privacy number comparison approach to constrain the route diffusion to protect the relevant data.

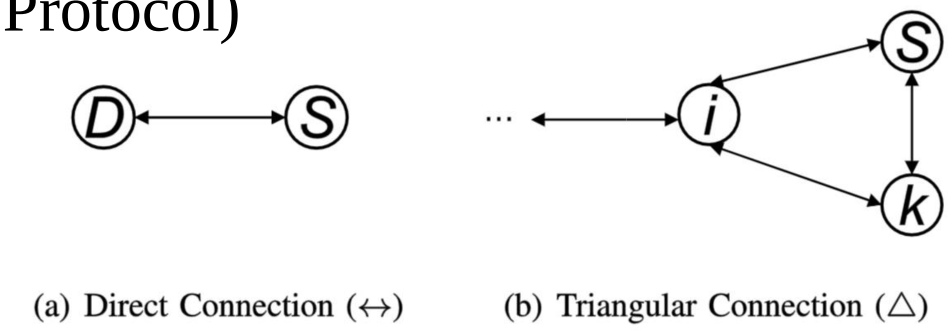


Figure 1. Connection Description

- ***Comparing Paths:***

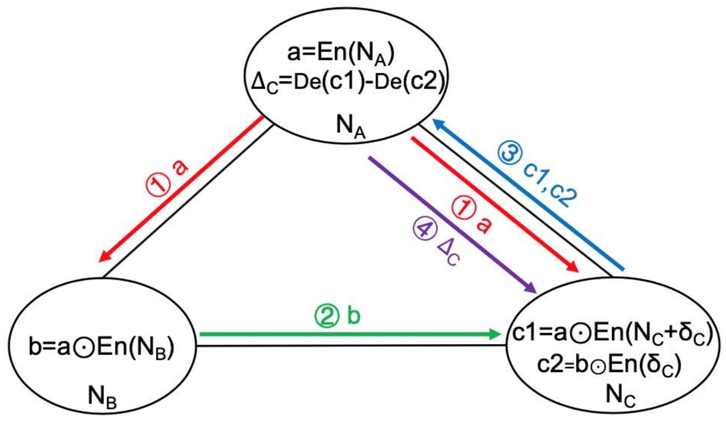


Figure 2. Comparison Example

- ***Constraining Diffusion:***

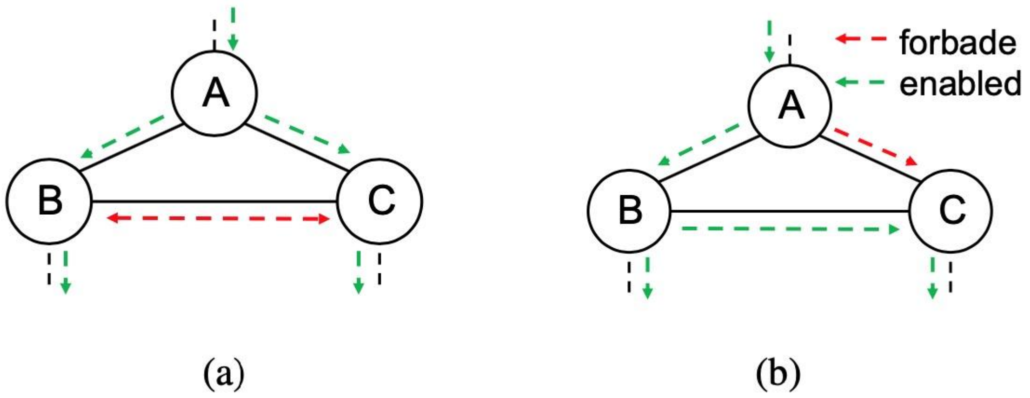
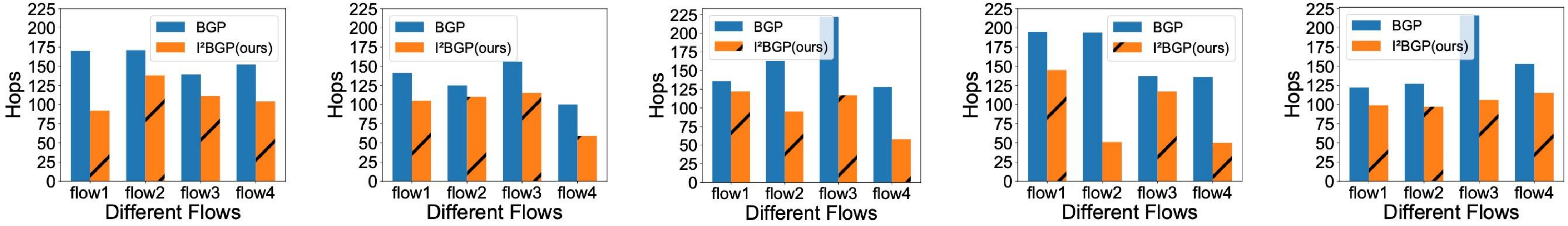


Figure 3. Two types of diffusion constraint

Research Progress

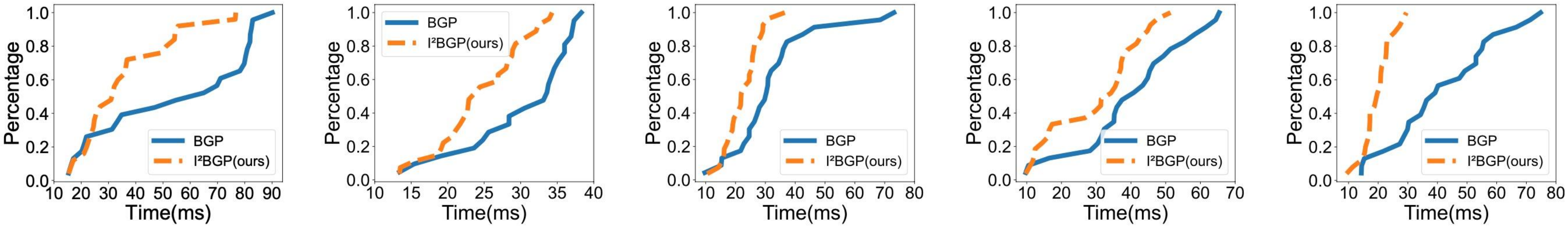
I²BGP (Intra-domain Information-aware Border Gateway Protocol)

- Performance



(a) ATMnet (b) Claranet (c) Compuserve (d) NSFnet (e) Peer1

Figure 1. Hops improvements under 5 topologies



(a) ATMnet (b) Claranet (c) Compuserve (d) NSFnet (e) Peer1

Figure 2. Latency improvements under 5 topologies

- This work, I2BGP, has been submitted to INFOCOM2022

Recall the challenges

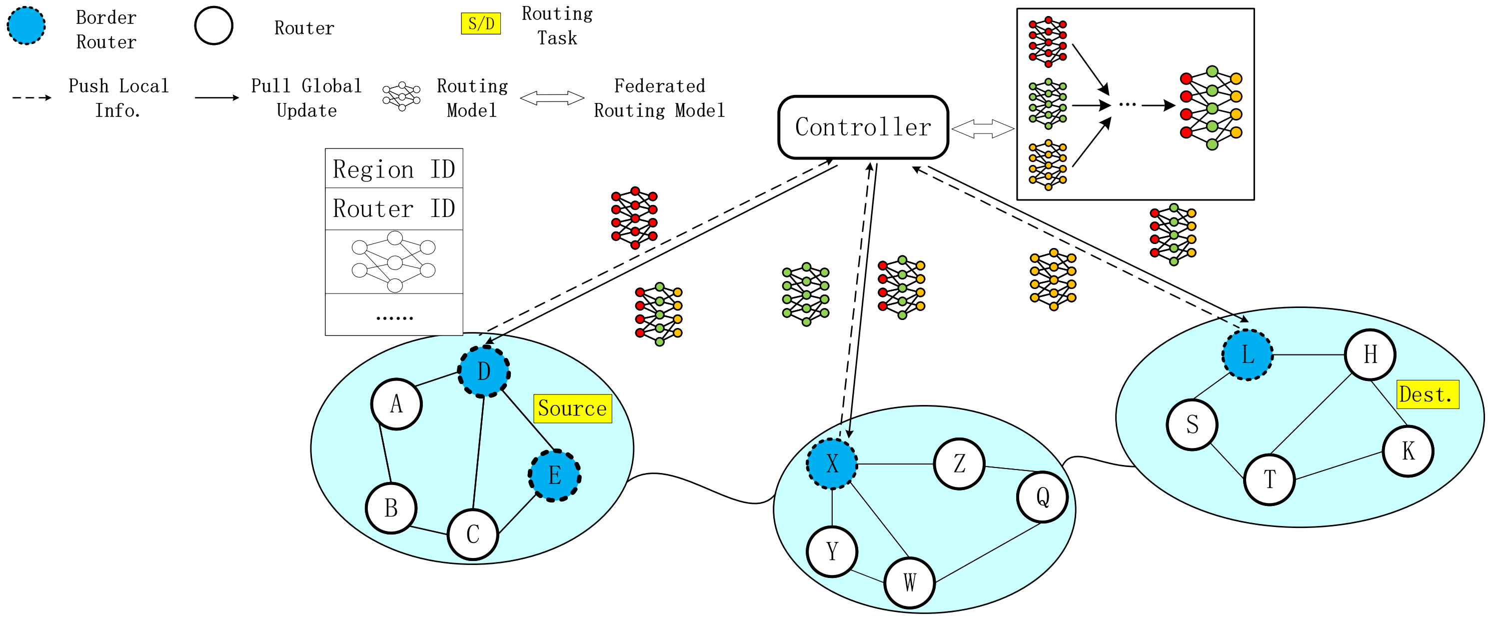
- **Core challenge**
  - Information from multiple network **VS.** Safety & privacy

- **Opportunity**
  - *Federated Learning*, a machine learning framework, which can effectively assist multiple organizations in data usage while meeting user privacy protection and data security requirements.

Potential Solutions

■ Federated Routing

- a federated learning-based inter-domain routing mechanism
- uses the model parameters from each AS
- to co-construct a federated routing model
- achieve optimal inter-domain routing decisions with intra-domain state
- without disclosing private data.



Research Progress

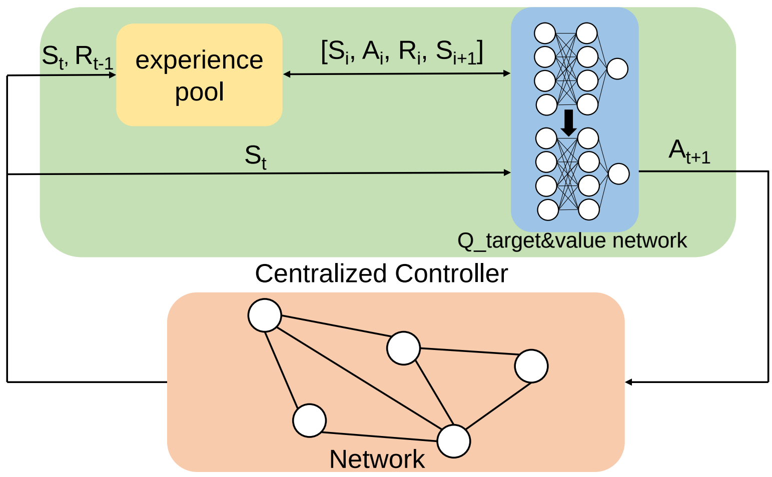
- A centralized DQN-based intra-domain control strategy:

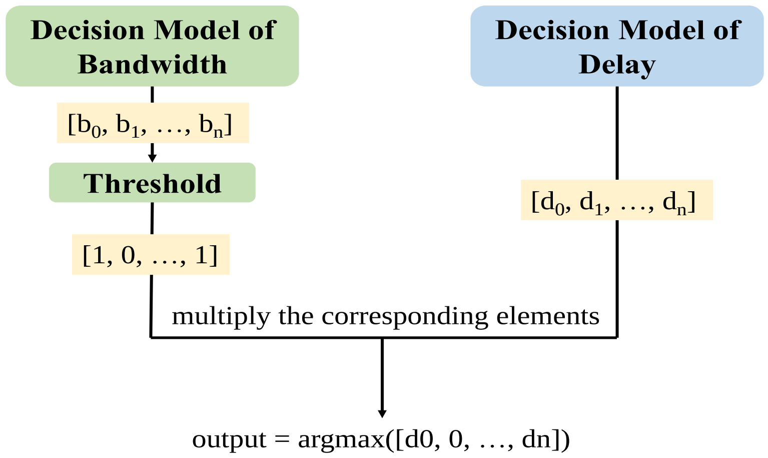
  1.Getting network *status* and action *rewards*

  2.Q_value network outputs strategies and sends them out for execution

  3.Q_target network trains the network and updates the value network

  4.Iterating the above process





- Model fusion-based multi-constraint routing strategy:

  1. Defining link priority rules
  2. Calculating the best path by model policy fusion

Research Progress

- This solution enables sharing link attributes flexibly with significant performance improvement.

With the help of intra-domain information, to co-build inter-domain federated routing model.

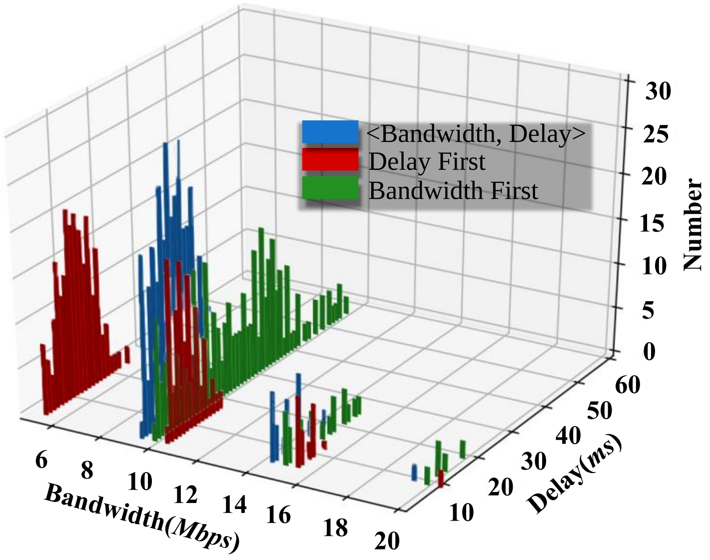


Figure 1. Routing decision performance.

Published Papers：

- Cong P, **Zhang Y,** Wang W, et al. A Deep Reinforcement Learning-based Routing Scheme with Two Modes for Dynamic Networks[C]//ICC 2021-IEEE International Conference on Communications. IEEE, 2021: 1-6.
- Cong P, **Zhang Y,** Liu Z, et al. A deep reinforcement learning-based multi-optimality routing scheme for dynamic IoT networks[J]. Computer Networks, 2021, 192: 108057.

2. Transmission among edges

PUBLICATION

[1] **Yuchao Zhang,** Ye Tian, Wendong Wang, Peizhuang Cong, Chao Chen, Dan Li, Ke Xu. Federated Routing Scheme for Large-scale Domain Network. IEEE International Conference on Computer Communications (Infocom'2020) Poster. 6-9 July, 2020, Toronto, Canada. (Virtual Conference)

[2] Peizhuang Cong, **Yuchao Zhang#,** Wendong Wang, Ke Xu, Ruidong Li, Fuliang Li. A Deep Reinforcement Learning-based Routing Scheme with Two Modes for Dynamic Networks. 2021 IEEE International Conference on Communications (ICC). 14-23 June 2021, Montreal. (Virtual Conference)

[3] Peizhuang Cong, **Yuchao Zhang#,** Zheli Liu, Thar Baker, Hissam Tawfik, Wendong Wang ,Ke Xu, Ruidong Li, Fuliang Li. A Deep Reinforcement Learning-based Multi-Optimality Routing Scheme for Dynamic IoT Networks. Computer Networks (CN), 2021, 192: 108057.

ONGOING

2021 IEEE infocom submission

Straightforward? Why Not! A Desensitization-based Inter-domain Routing Protocol

Anonymous

Abstract—**With the rapid development of Internet technology and the diverse requirements of services, the inter-domain transmission scenario becomes more and more common, which accompanied with ever increasing amount of data. The de facto inter-domain routing protocol, BGP, cannot perceive the intra-domain information, which takes each domain as indiscriminate blackbox. On this basis, the inter-domain routing path that only considers the number of AS is not optimal, which will lead to unbalanced link utilization, unsatisfied transmission perfor-**

[6]. The strategy of treating all domains as *indiscriminate blackbox* exists pitfalls, which completely ignores valuable intra-domains states. For example, when an AS provides poor performance of transmission services, e.g., link congestion, high packet loss rate, etc., then performance of all paths that contains this AS will be greatly impaired. Or, it will introduce a large amount of traffic to a popular AS in shortest paths,

Outline

1. Cache on the edge

Exponentially growing data amount **VS.** Limited storage on the edge

2. Transmission among the edges

Large scale transmission **VS.** Real-time traffic requirements

More…

3. Federation of multiple edges

Strict data privacy **VS.** Multiple edge network collaboration

Some other ongoing work

- ***When the model on the federated nodes are heterogeneous?***
  - Network structure
  - Data characteristics
  - Non-IID (Independent and Identical Distribution)
  - ……
- ***How to make the complex federated model lightweight?***
  - Knowledge distillation
  - Identify the difficulty of samples
  - Adaptive training sequence
  - ……

Project of National Natural Science Foundation of China (PI) 2021.08 - 2025.07

Some other ongoing work

- ***Blockchain: Nested-chain Architecture between Massive Off-chain and On-chain Data***
  - Problem: it is difficult to upload the data of application networks to the blockchain system, due to:
    - the massive scale
    - high real-time performance
  - This project:
    - 1) Design of interoperable architecture based on nested chain;
    - 2) Sub-chain construction for massive real-time data;
    - 3) Collaborative consensus based on distributed hash.

Key Project of Beijing Natural Science Foundation (PI) 2021.01 - 2023.12

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You are more than welcome to discuss and work together!