Scalable Damper-based Deterministic Networking

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Related paper:
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CNSM HiPNet 2022. Thessaloniki, Greece. November 2022.

Plan

1. Introduction
2. Data plane mechanisms
3. Control plane problem
4. Performance evaluation
5. Conclusion and perspectives

1. INTRODUCTION

Context

Deterministic networking standards

- TSN [1];
- IETF DetNet [2];
- Our previous work DIP [3]: an implementation of IETF DetNet Large Deterministic Network (LDN).

Need time and frequency synchronization

Dampers

- Delay-jitter regulator to compensate the time between **a maximum queuing delay**, and the real queuing **delay** experienced at the **previous hop;**
- Can work even with **non ideal clocks** [4].

No need for synchronization

[1] Time-Sensitive Networking (TSN) Task Group. Accessed: Aug. 3, 2021. [Online]. Available: https://1.ieee802.org/tsn/
[2] Deterministic Networking (DETNET). Accessed: Aug. 3, 2021. [Online]. Available: https://datatracker.ietf.org/wg/detnet/about/
[3] B. Liu, S. Ren, C. Wang, V. Angilella, P. Medagliani, S. Martin, and J. Leguay, "Towards large-scale deterministic ip networks," in IFIP Networking, 2021
[4] MOHAMMADPOUR, Ehsan et LE BOUDEC, Jean-Yves. Analysis of Dampers in Time-Sensitive Networks With Non-Ideal Clocks. *IEEE/ACM Transactions on Networking*, 2022.

Contribution

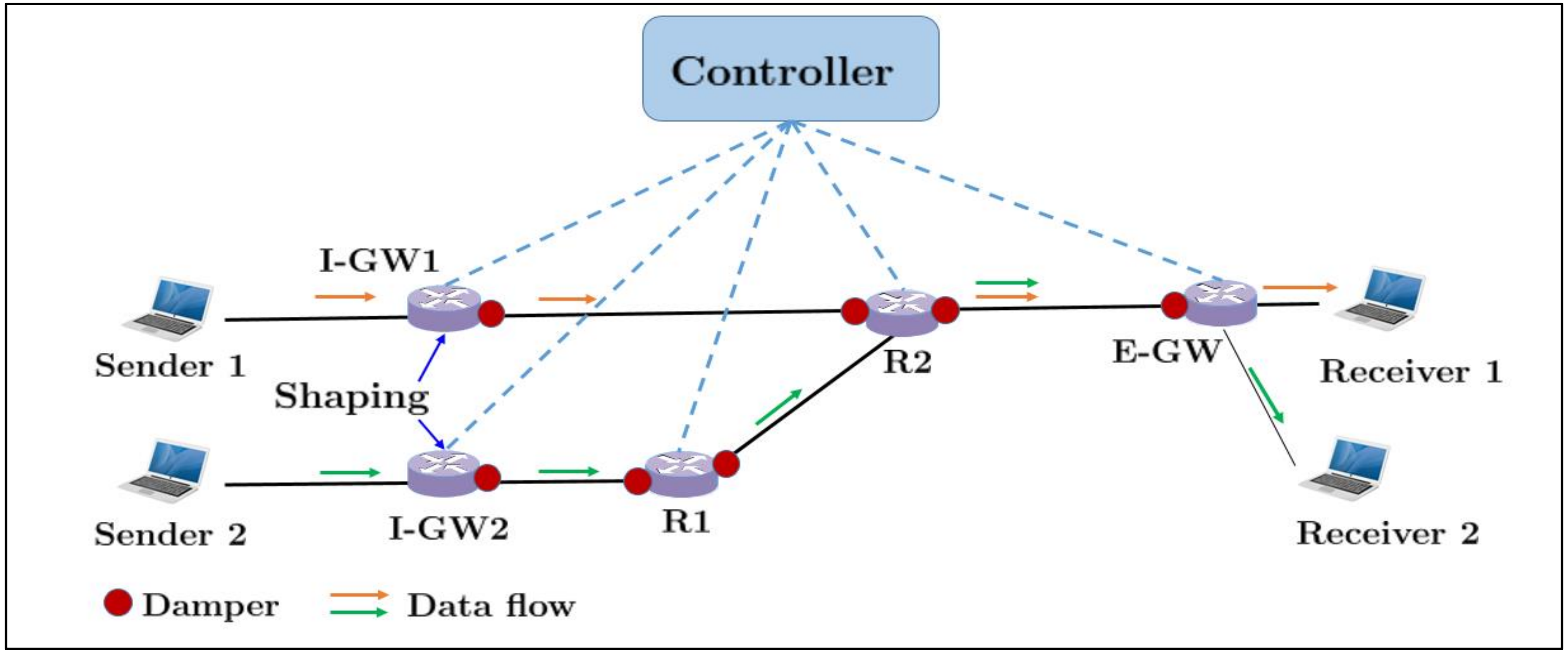
Data plane

- Implementation of dampers using gate-controlled queues;
- Jitter analysis;
- Analysis of traffic forwarding with dampers.

Control plane

- Study the optimization problem of admission control with dampers:
  - Model the problem via an Integer Linear Programming (ILP);
  - Design an advanced algorithm to optimize acceptance;
  - Performance evaluation.

An overview of the proposed Architecture



- The LDN network is composed by
  - ***Senders, Receivers***: user devices sending and receiving traffic;
  - Ingress gateways ***I-GWs:*** edge devices shaping;
  - ***E-GWs*** : edge devices routing the traffic to receivers;
  - Core routers ***R***: responsible for routing traffic and equipped with dampers;
  - ***Controller***: responsible for taking admission control decisions.

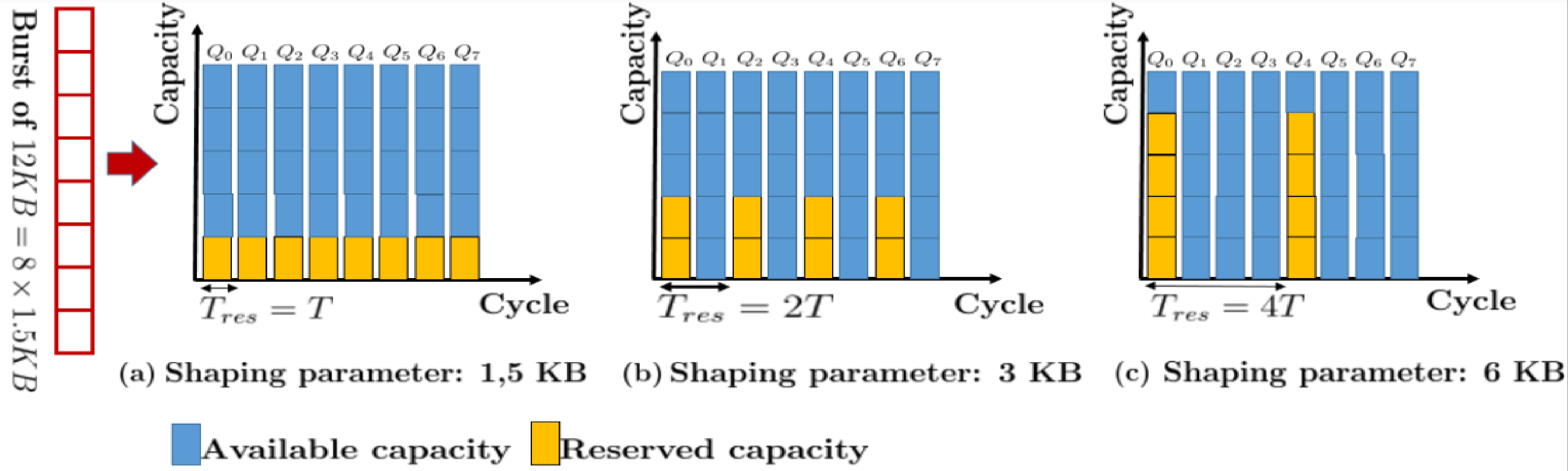
2. DATA PLANE MECHANISMS

Data plane mechanisms

Ingress shaping at I-GWs

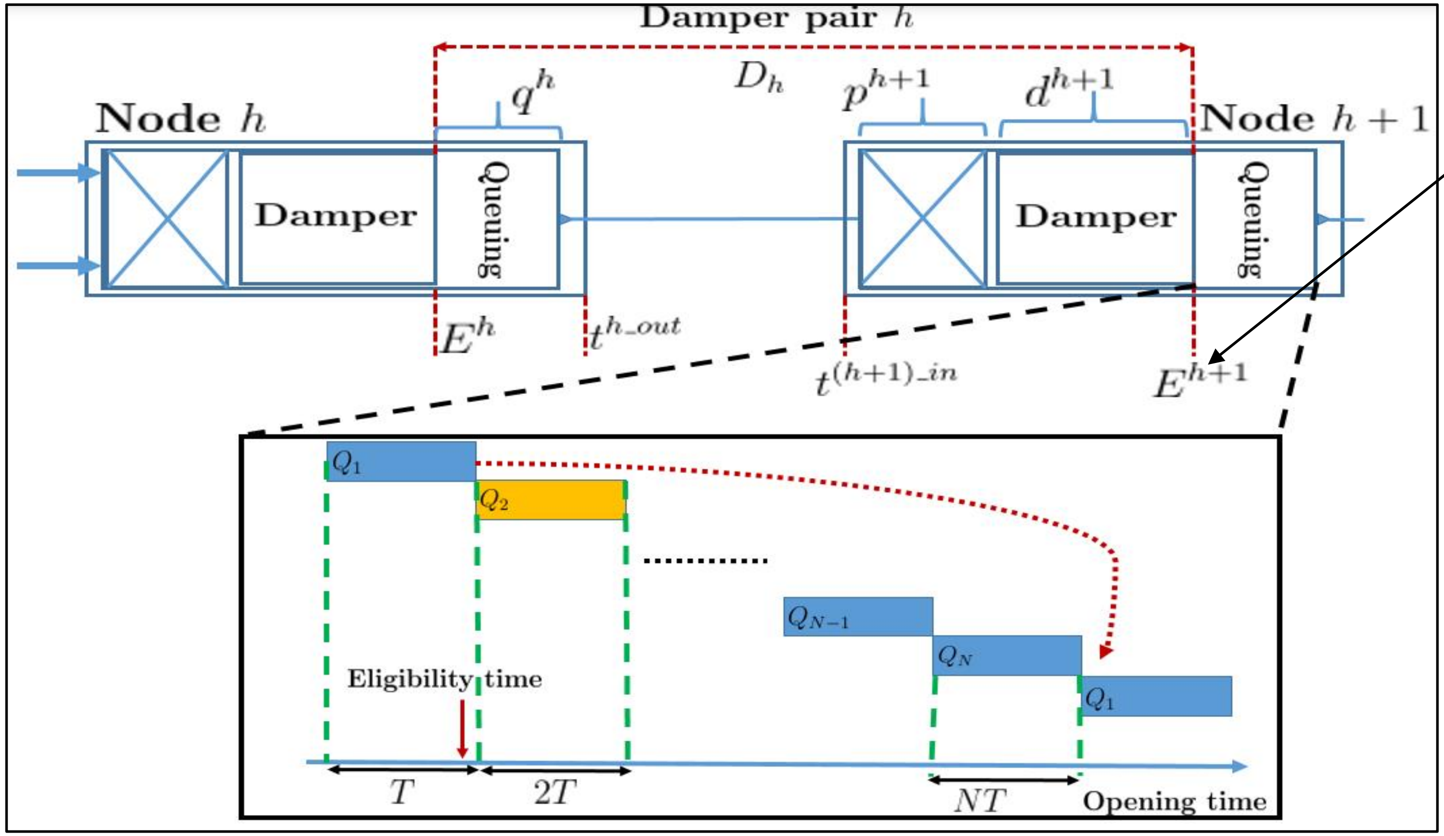
- Each flow f can be characterized by an *arrival curve* $A_f(t) = r_f\, t + b_f$
- Each I-GW shapes incoming flows into smaller bursts (*shaping parameter*);
- *Cyclic Opening of Gate Controlled Queues* (GCQs) mapping bursts into specific queues' reservations;
- *Regular patterns* reservations chosen by the Controller over a *hypercycle*.

Examples of reservation patterns to shape an incoming flow



Data plane mechanisms

Scheduling and forwarding with dampers



Constant delay and bounded jitter

Eligibility time : time at which a packet is released by damper

Queuing delay= $Q^h = q^h + d^{h+1} = 2\,T.$

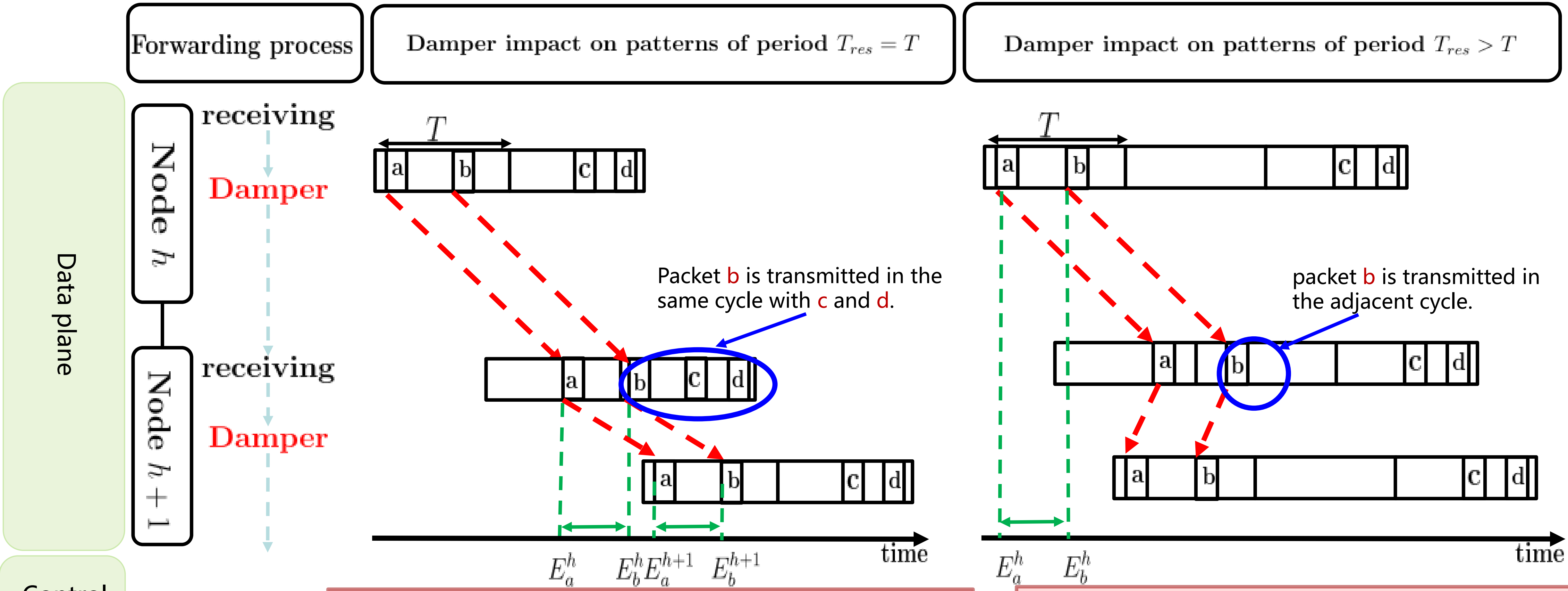
Damper pair delay = $D^h = Q^h + P^{h+1}.$

Neglecting transmission delay and assuming that processing delay is bounded

E2E Jitter bound= $Q^H = 2\,T.$

Data plane mechanisms

Impact of dampers on transmitted patterns



Control plane

- ➢ double the reservation per cycle with patterns of period $T_{res} = T$;
- ➢ provide same reservation per cycle with patterns of period $T_{res} > T$;

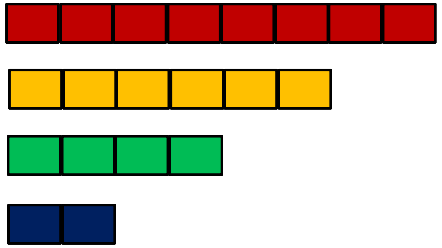
3. CONTROL PLANE PROBLEM

Control plane problem

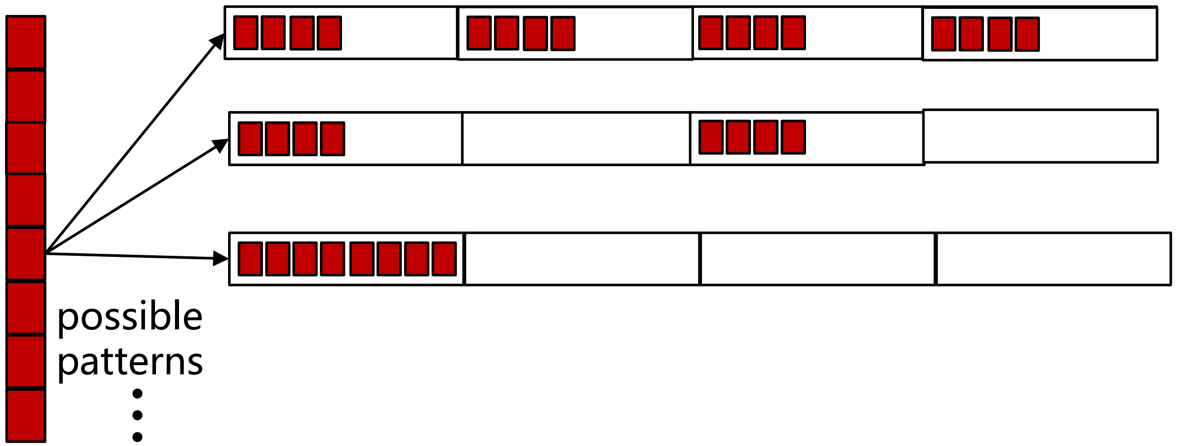
Input: an example of an instance

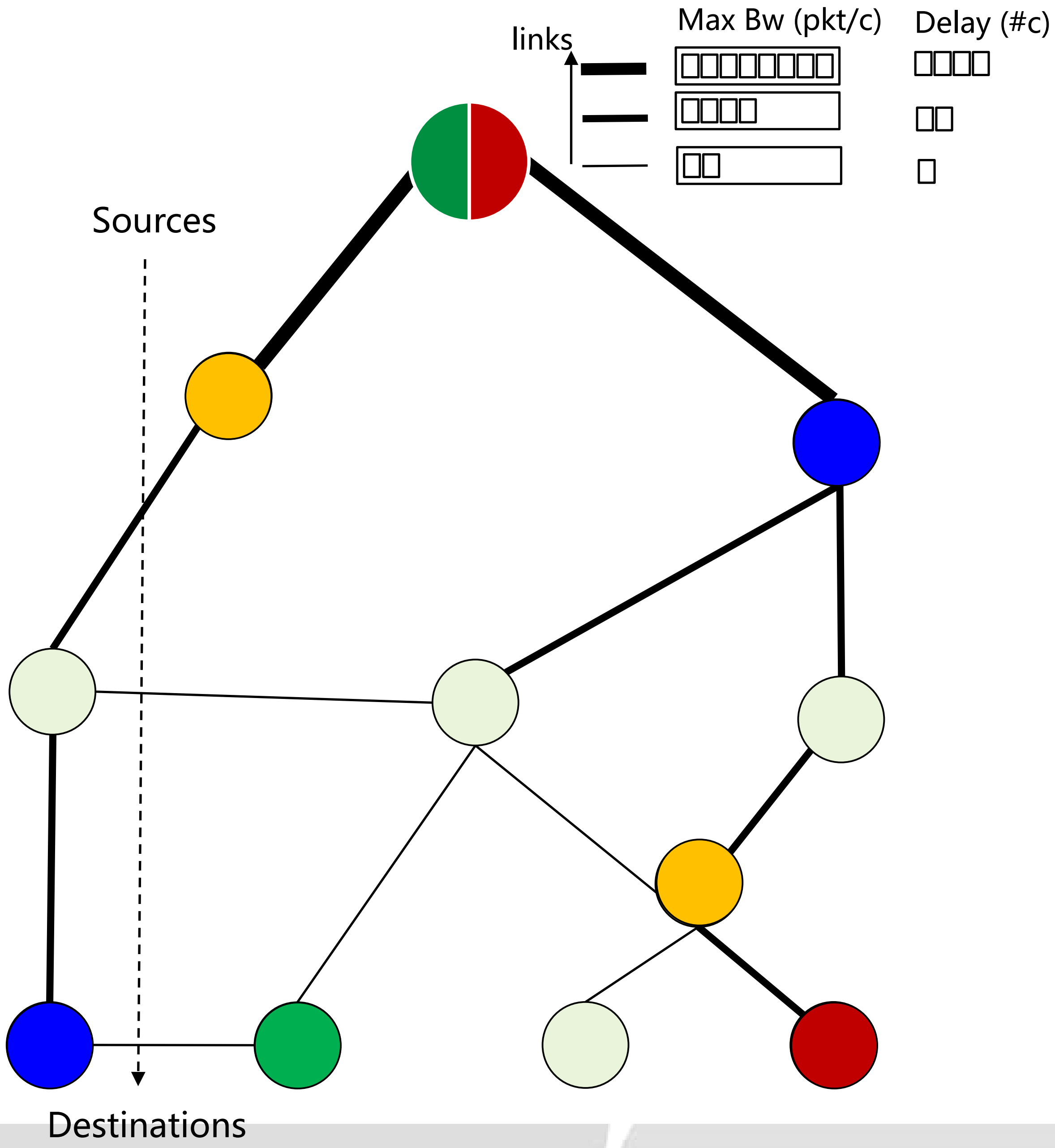
Packet (pkt)

Hyper cycle — Cycle (c)



Flow bursts	throughput	E2E max delay
	4	10
	3	16
	2	10
	1	10





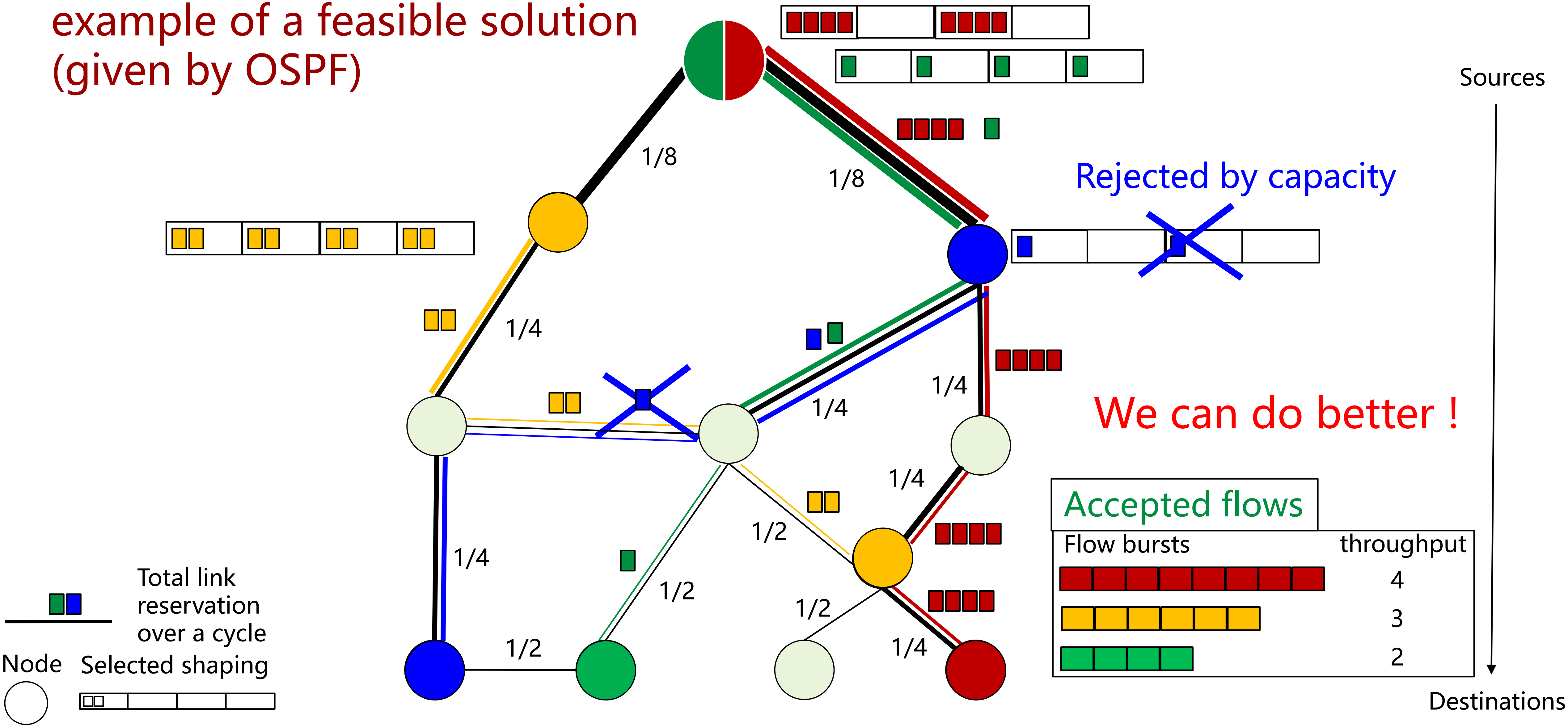
Control plane problem
Output

Maximizing the total throughput of accepted flows

- Deciding the shaping of flows;
- Deciding the routing of flows;
- Respecting the limits of nodes and links capacities;
- Respecting E2E delay constraints.

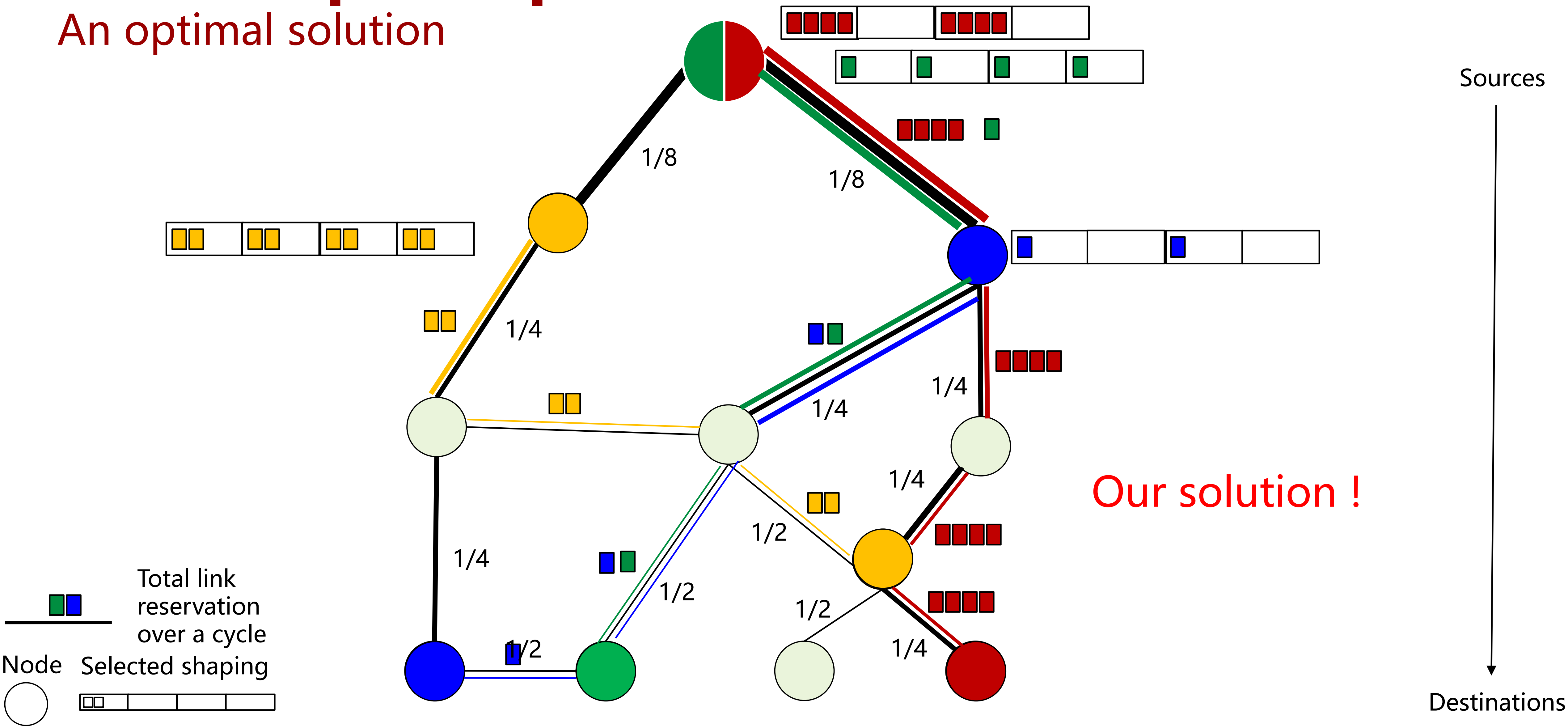
Control plane problem

example of a feasible solution
(given by OSPF)



Control plane problem

An optimal solution



Control plane problem
Complexity

The admission control problem is NP-Complete

- The problem reduces to a classical Multi-Commodity Flow (MCF) problem, with the same pattern for each flow and infinite E2E delay;

Control plane problem

Notations

Sets:	
V	set of nodes
A	set of arcs
$\mathcal{F}$	set of flows
Π^f	set of path-pattern pairs of flow $f \in \mathcal{F}$ such that the end-to-end delay constraint is respected.
Indices:	
v	node $(v \in V)$
a	arc $(a = (i, j) \in A)$
s^f	source of flow f
t^f	destination of flow f
π	path-pattern couple $(\pi \in \Pi^f)$
Parameters:	
c_v	buffer capacity of node v
c_a	capacity of link a
R_f	throughput of flow f
$\beta(f, \pi)$	maximum per cycle reservation of pattern π and flow f
Decision variables:	
$x_f^{p,\pi} \in \{0, 1\}$	indicates if path-pattern (p, π) is selected for flow f

Control plane problem

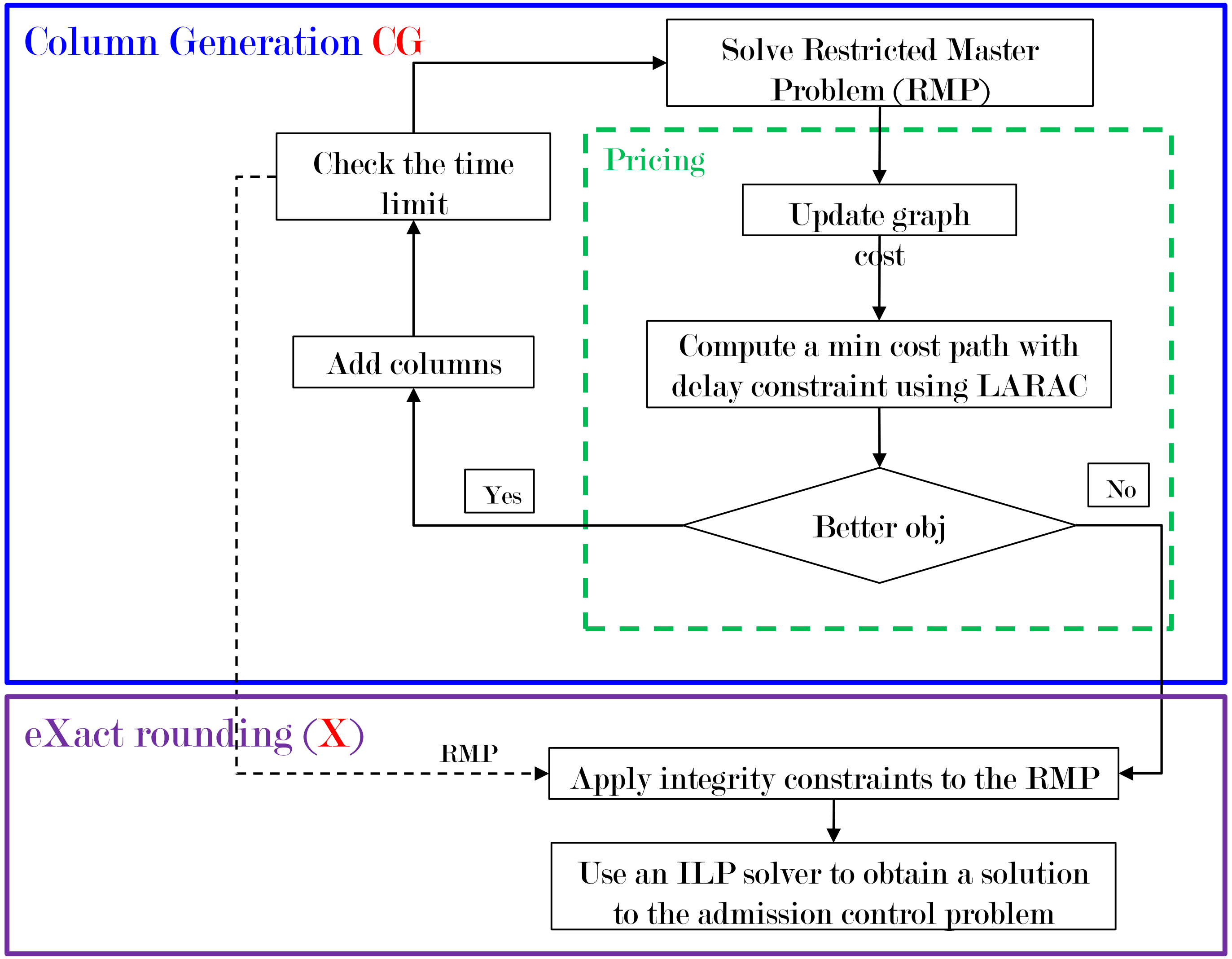
ILP path formulation

$\max \sum_{f\in\mathcal{F}} \sum_{(p,\pi)\in\Pi_f} R_f x_f^{p,\pi}$	**total throughput of accepted flows**

$\sum_{(p,\pi)\in\Pi_f} x_f^{p,\pi} \leq 1 \quad f\in\mathcal{F}, \quad \text{(1. routing and shaping)}$	
$\sum_{f\in\mathcal{F}} \sum_{(p,\pi)\in\Pi_f : a\in p} \beta(f,\pi) x_f^{p,\pi} \leq c_a \quad a\in A, \quad \text{(2. arc capacity)}$	**apacity**
$\sum_{f\in\mathcal{F}} \sum_{(p,\pi)\in\Pi_f : v\in p} \beta(f,\pi) x_f^{p,\pi} \leq c_v \quad v\in V, \quad \text{(3. buffer capacity)}$	**capacity**
$x_f^{p,\pi} \in \{0,1\} \quad f\in\mathcal{F}, (p,\pi)\in\Pi_f \quad \text{(4. integrality)}$	

Control plane problem

CGX algorithm



4. PERFORMANCE EVALUATION

Performance evaluation

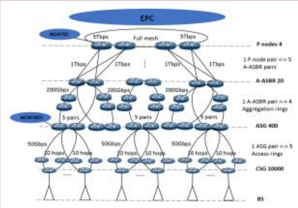
Numerical settings

Instances

- Shaping: $H\ C = 8$ cycles; $T = 10\ \mu s$.

- IPRAN topology with 505 nodes and 1061 links
  - buffer capacity of $50Mb$;
  - link capacity of $100Gb/s$;
  - random link propagation delay between $10\ \mu s$ and $40\ \mu s$.

- Demands
- same maximum burst size of $1500\ Bytes$;
- a random rate in $1, \ldots, 10\ Gb/s$.



- Generate instances by varying
- Number of demands in $100, 500, 1000, \ldots, 5000$;
- E2E delay in 100, 200, .., 1000 μs.

Performance evaluation settings

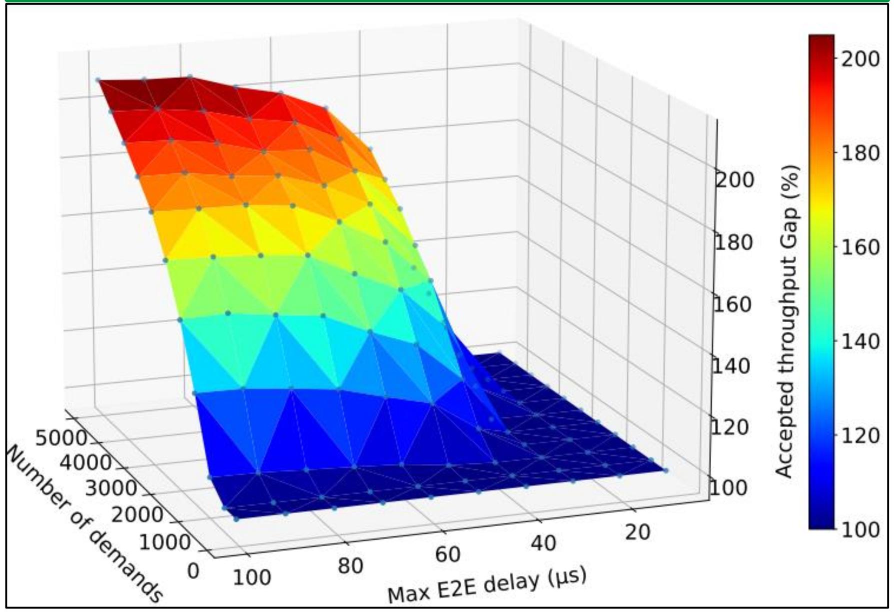
- Total time limited to 5 mins for CGX;
- Compare the performance of CGX to the OSPF routing protocol.

Performance evaluation

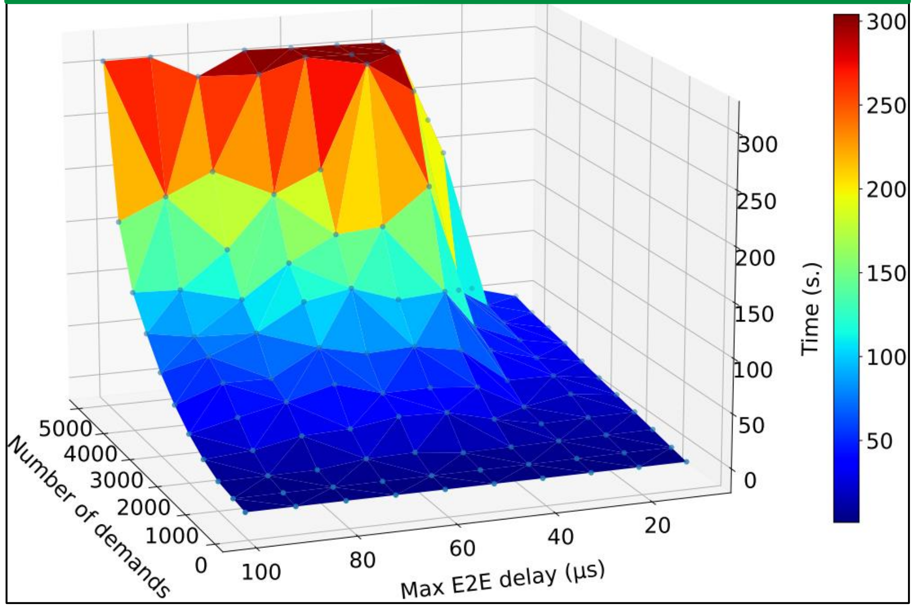
Sensitivity to E2E delay

Average optimality gap of 0.35%;

Throughput gap



CGX computational time



Good performance of CGX algorithm

- The time limit of 5 mins is reached only for some cases with 4000 and 5000 demands;
- CGX is better than OSPF routing protocol
  - it can accept up to 2 times more traffic.

5. CONCLUSION AND PERSPECTIVES

Conclusion and perspectives

Conclusion

- Implementation of the D-LDN
- Data plane:
  - Jitter and traffic analysis;
- Control plane:
  - An ILP model for the admission control problem
  - CGX algorithm for an efficient resolution
- Performance evaluation

Perspectives

- Further methods for the offline algorithm:
  - Column Generation and Randomized Rounding algorithm (CGRR)
    → very good solutions in shorter time compared to CGX;
- The online version of the problem with a convenient load balancing metrics.

Thank you

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