Sincronia:
Near-Optimal Network Design for Coflows

Shijin Rajakrishnan

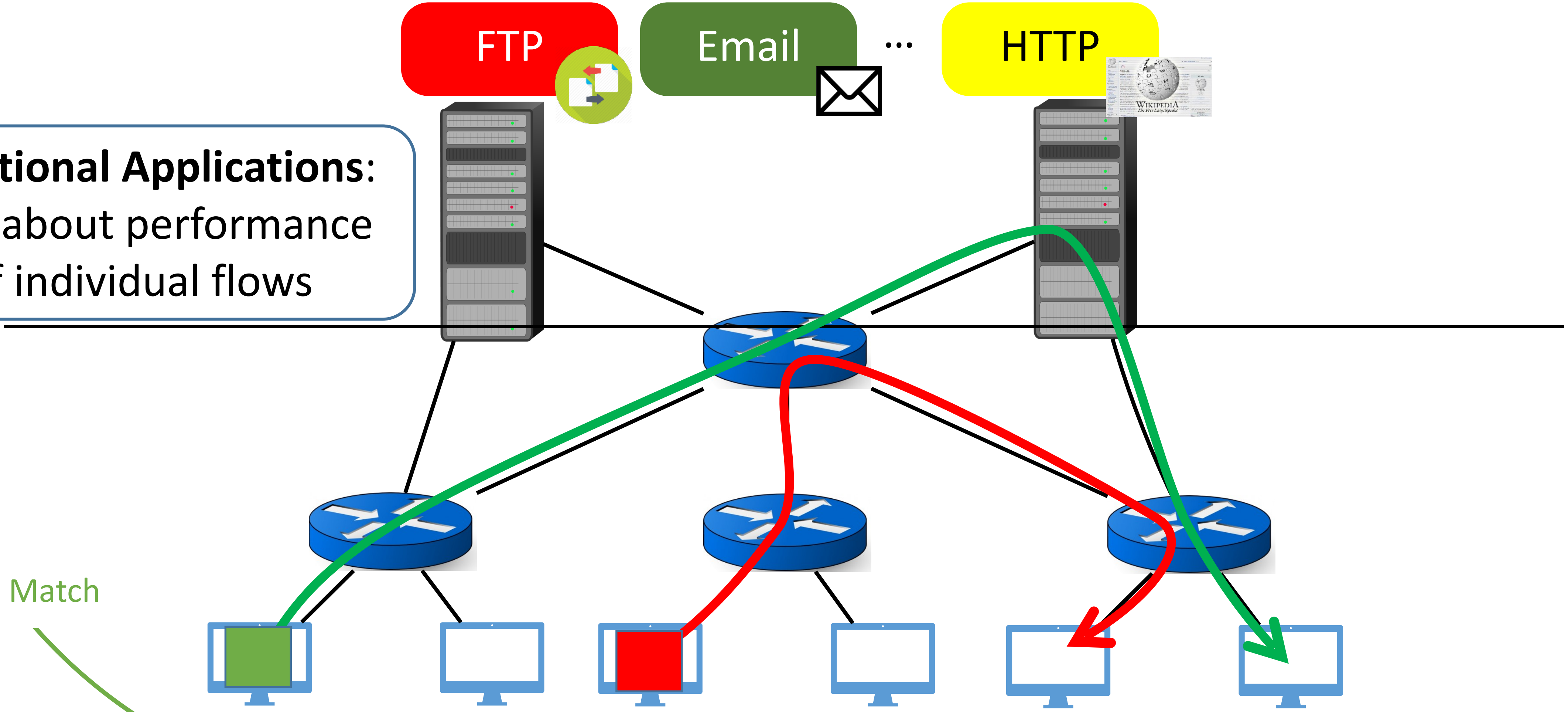
Joint work with

Saksham Agarwal | Akshay Narayan | Rachit Agarwal | David Shmoys | Amin Vahdat





The *Flow* Abstraction



Traditional Applications:
Care about performance of individual flows

Good Match

Optimized for **Flow-level** performance

Is Flow Still the Right Abstraction?

FTP Email HTTP …

Traditional Applications:
Care about performance of individual flows

M M … M

M: Mappers
R: Reducers

R R … R

Bulk Synchronous Model

Distributed Applications:
Care about performance for a group of flows

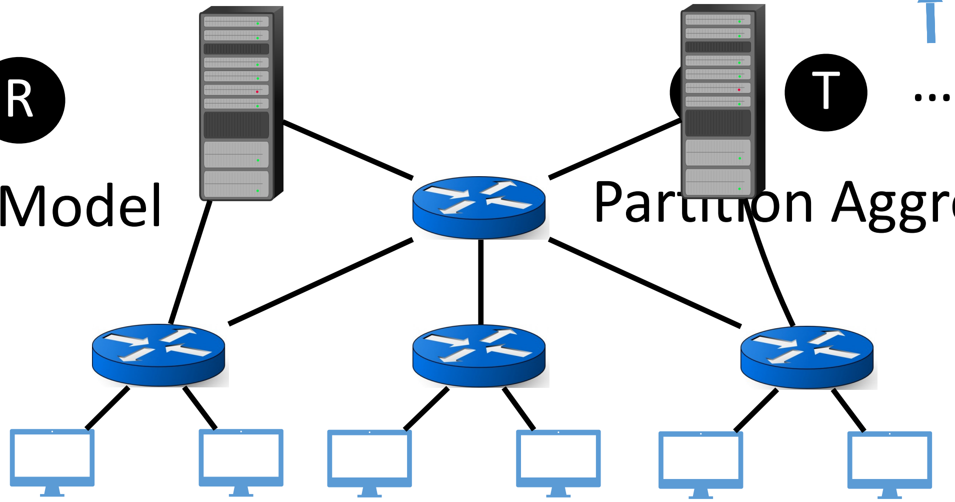
T

T … T

T … T T

T: Tasks

Partition Aggregate Model

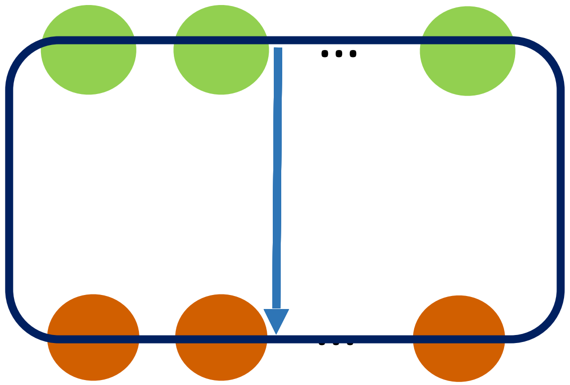


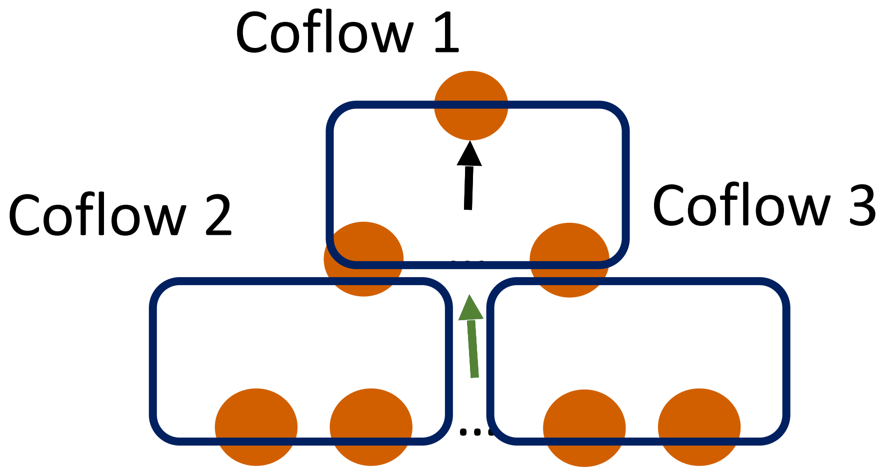
Mismatch

Optimized for **Flow-level** performance

The *Coflow* abstraction

Collection of semantically related **flows** [Chowdhury & Stoica, 2012]

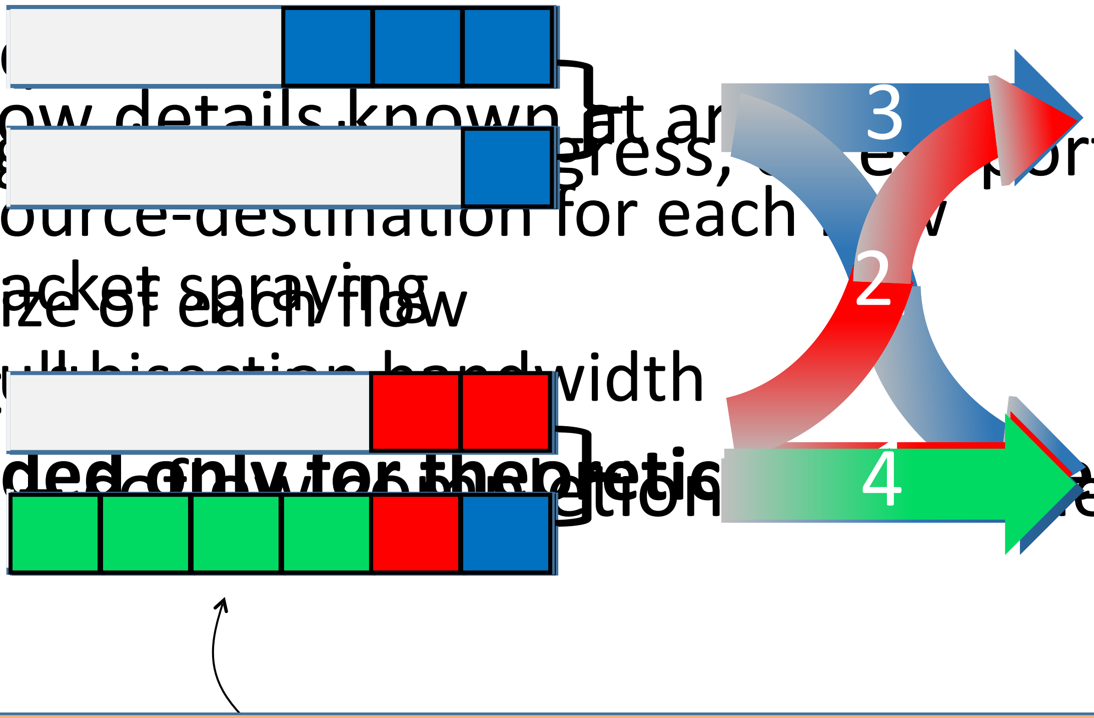


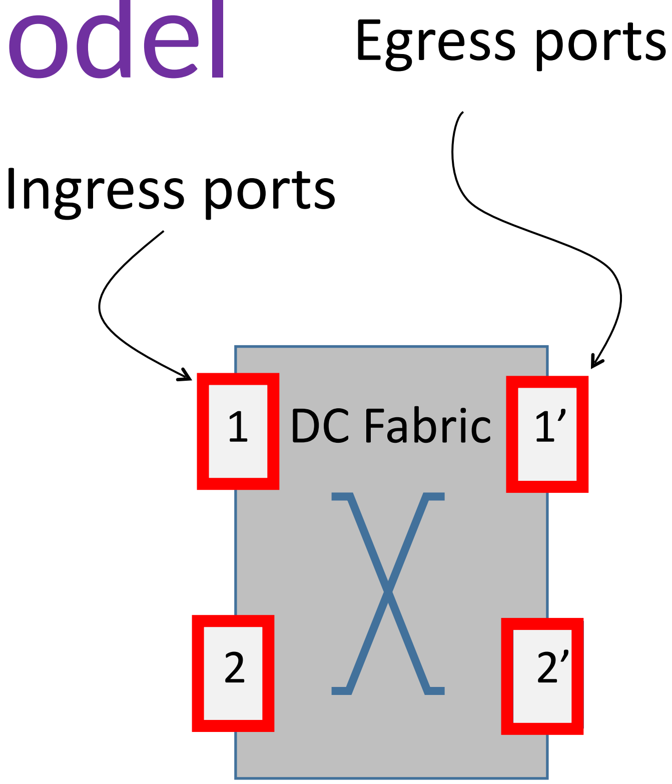


Allows applications to more precisely express their performance goals

Network and Coflow Model

- Big-switch model
- **Big-switch model**
  - Ingress and egress ports
    - Packet spraying
    - Full bisection bandwidth
  - **Needed only for theoretic**... **es**
- Clairvoyant scheduler
  - E...
  - Coflow details known at ar...
  - Con... ...gress, ...ports
    - Source-destination for each ... ...w
    - Size of each flow
    - C...
- Metr... ...gtion ... ...e when **all** flows complete





Goal: Minimize Average Weighted Coflow Completion Time (CCT)

Prior Results

Impossibility Results

- NP-hard
- <2x approximation hard

Systems/ Theory	State-of-the-art	Performance Guarantees	Runs on Existing Transport	Work Conserving	Starvation Avoiding
Systems	**Varys** [SIGCOMM '14]	✗	✗	✓	✓
Theory	**On Scheduling Coflows** [IPCO '17]	✓ (4-apx)	✗	✗	✗

Practi

x

echanism

ws?

When all coflows arrive at time 0;
Can be extended to general setting

Sincronia:
Two key results

#1

Guarantees 4-approximation for (weighted) average CCT

#2

Given a set of coflows and a “right” ordering,
ANY per-flow rate allocation mechanism that is
work-conserving
produces average CCT within 4x of optimal

- Per-flow rate allocation **irrelevant**
- Transport layer agnostic

Sincronia – Near-Optimal Network Design

Systems/ Theory	Name	Performance Guarantees	Runs on Existing Transport	Work Conserving	Starvation Avoiding
Systems	**Varys**	✖	✖	✔	✔
Theory	**On Scheduling Coflows**	✔ (4-apx)	✖	✖	✖
Systems	**Sincronia**	✔ (4-apx)	✔	✔	✔

Also outperforms state-of-the-art across evaluated workloads

Sincronia Design

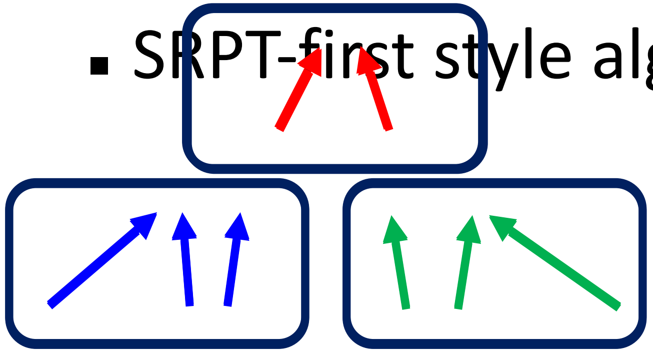
Set of coflows → Coflow Scheduling → Priorities on flows

Ordered set of coflows

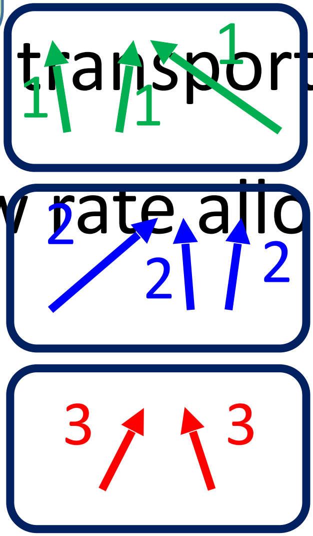
Coflow ordering

Flow Scheduling

- Algorithm – BS
  - Bottleneck, Select, Scale, Iterate
  - SRPT-first style algorithm

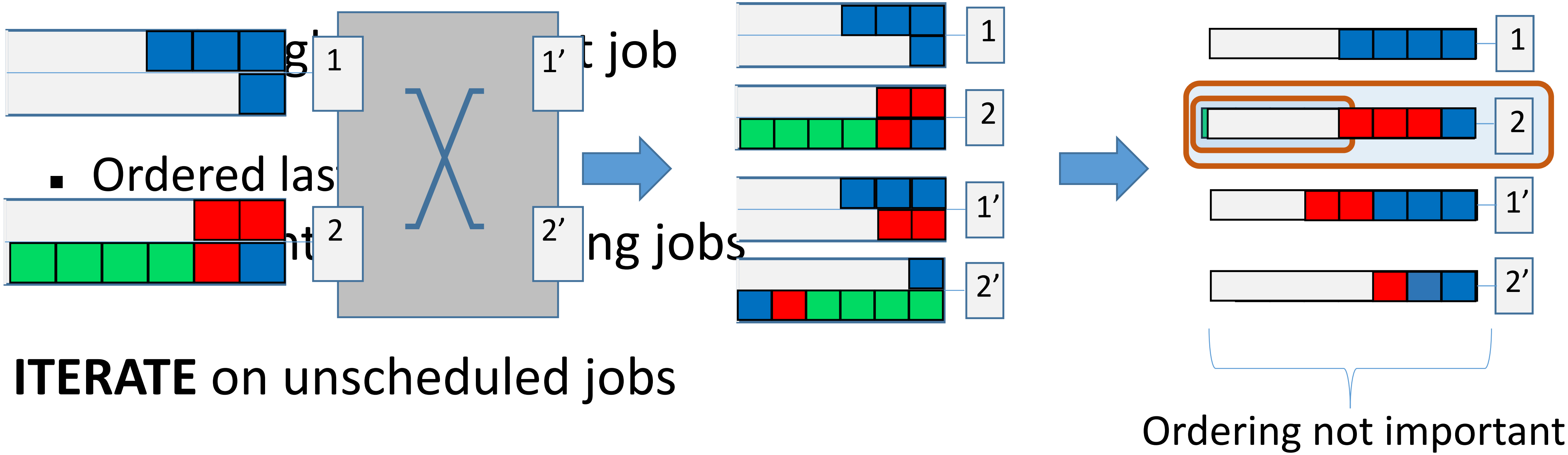


- Priori order
- Flows offloaded to transport layer
- No explicit per-flow rate allocation



Bottleneck-Select-Scale-Iterate (BSSI)

- Find **BOTTLENECK** port



- g... t job
  - Ordered las...
- ...nt... ng jobs
- **ITERATE** on unscheduled jobs

BSSI in Action

- Bottleneck
- Select
  - Ordered Last
- Scale
- Iterate

$$\frac{Size}{Weight} = 4$$

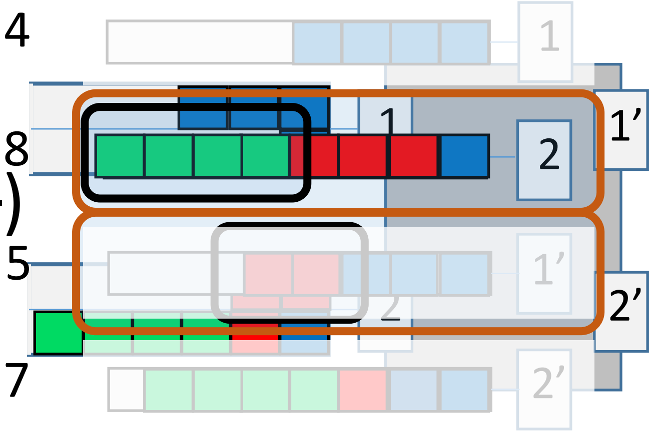
$$\frac{Size}{Weight} = 4$$

$$Weight \leftarrow Weight\left(1 - \frac{\frac{Size}{Weight}}{\frac{Size}{Weight}}\right)$$

$$\frac{Size}{Weight} = 1$$

$$Weight \leftarrow \frac{1}{8} \times \left(1 - \frac{3}{4}\right)$$

Scale weight of each flow (unscheduled coflows)

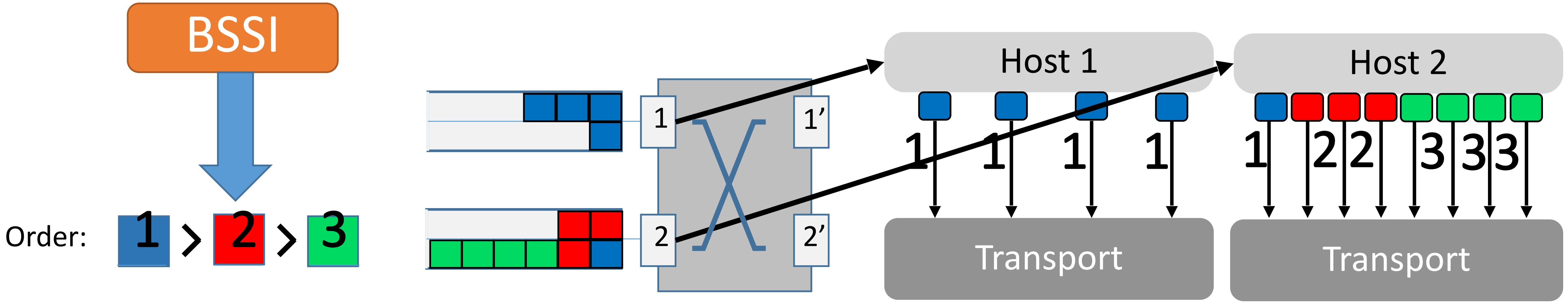


Weights:

~~1~~	~~1~~	~~1~~
~~¼~~	~~0~~	~~¾~~
0	0	⅜

Order: ■ > ■ > ■

End-to-End Design(Offline)

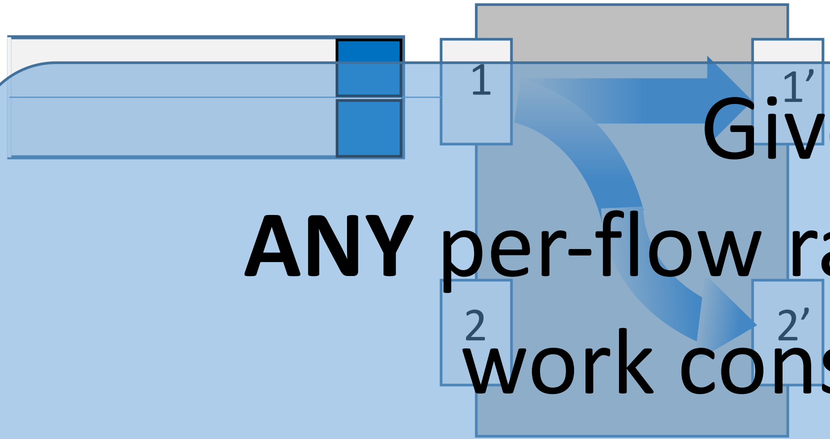


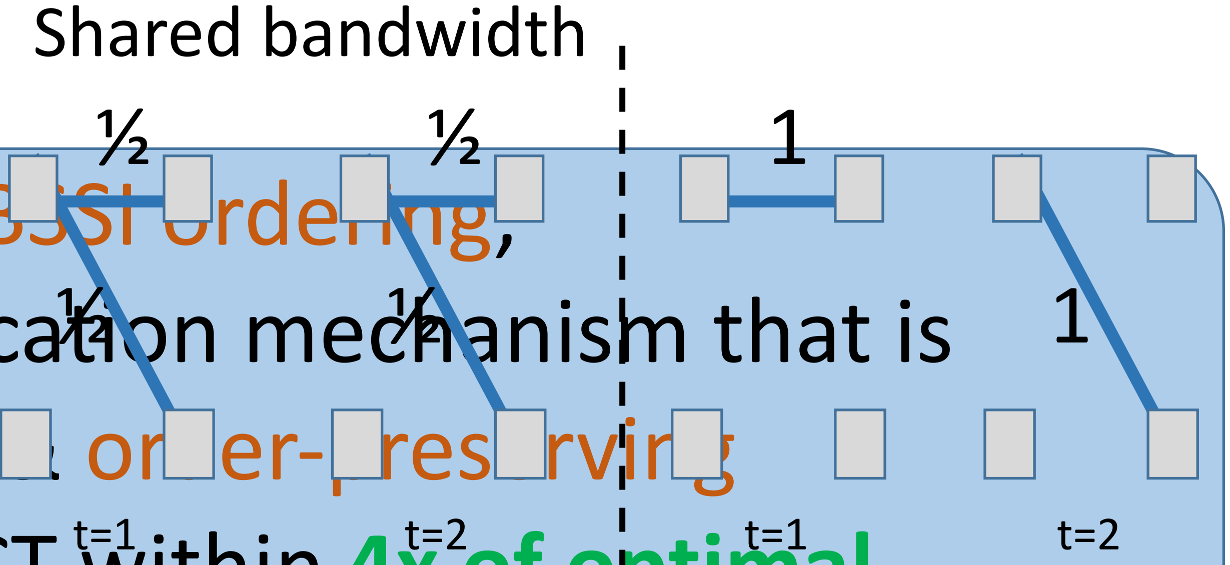
- Each host knows ordering
- Flows get priority of coflow
- Offloads to priority enabled transport layer

Per-flow Rate Allocation is Irrelevant

- Intuition: Sharing bandwidth does not help CCT
- **Order-preserving schedule**:

Flow blocked **iff** ingress or egress port serving higher-ordered flow





Given the BSSI ordering,

ANY per-flow rate allocation mechanism that is

work conserving & order-preserving

produces average CCT within **4x of optimal**

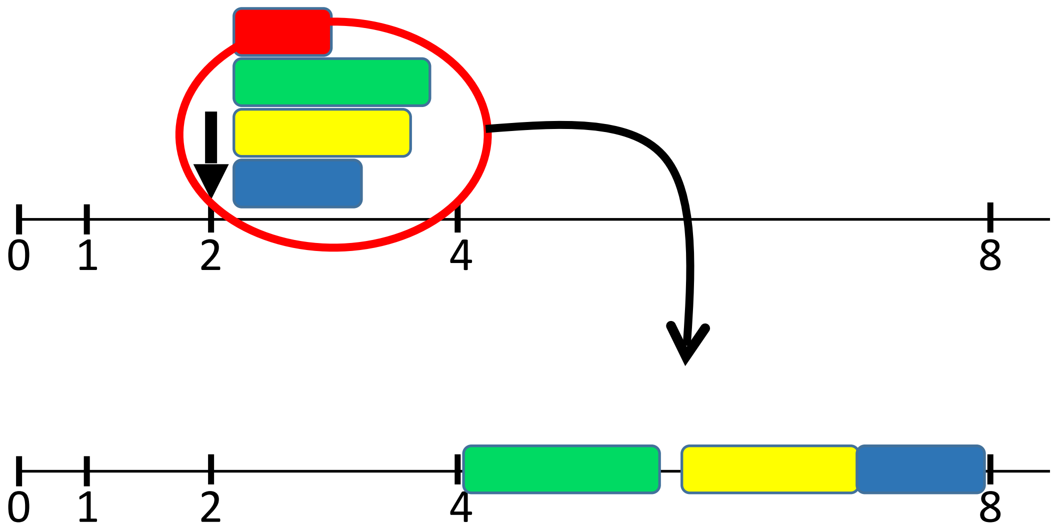
Avoiding per-flow rate allocation: Implications

- Implement on top of any transport layer
  - E.g. pFabric, pHost, TCP
- Design and implementation independent of
  - Network Topology
  - Location of Congestion
  - Paths of Coflows
- More scalable
  - No reallocations upon coflow arrivals/departures

Details in paper

Handling Arbitrary Arrival Times

- Framework: Khuller, Li, Sturmfels, Sun, Venkat, ‘18
- Time divided into epochs
- In each epoch
  - Choose subset of unscheduled jobs
  - Schedule in next epoch using offline alg.



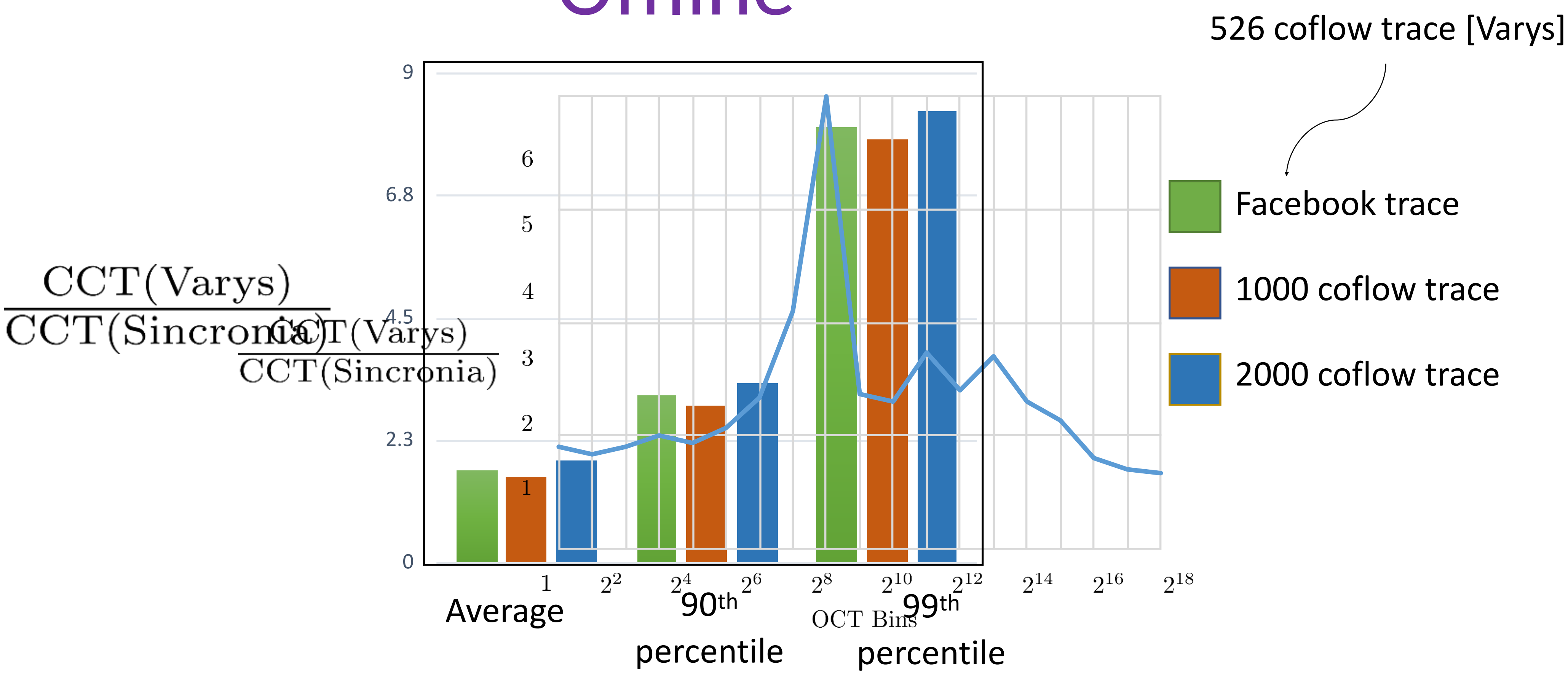
Provides 12-competitive performance
(details in paper)

Evaluation Overview

- **Testbed implementation on top of TCP**
  - Evaluate impact of in-network congestion, and hardware constraints
- **Simulations**
  - **Coflows arrive at time 0**
  - **Coflows arrive at arbitrary times**
  - Sensitivity analysis
    - ➢Coflow sizes, structure, # of coflows
    - ➢Network topologies, Oversubscription ratios, Network load

All simulations, workloads, and implementations are open-sourced on Sincronia website

Simulation Results
Offline



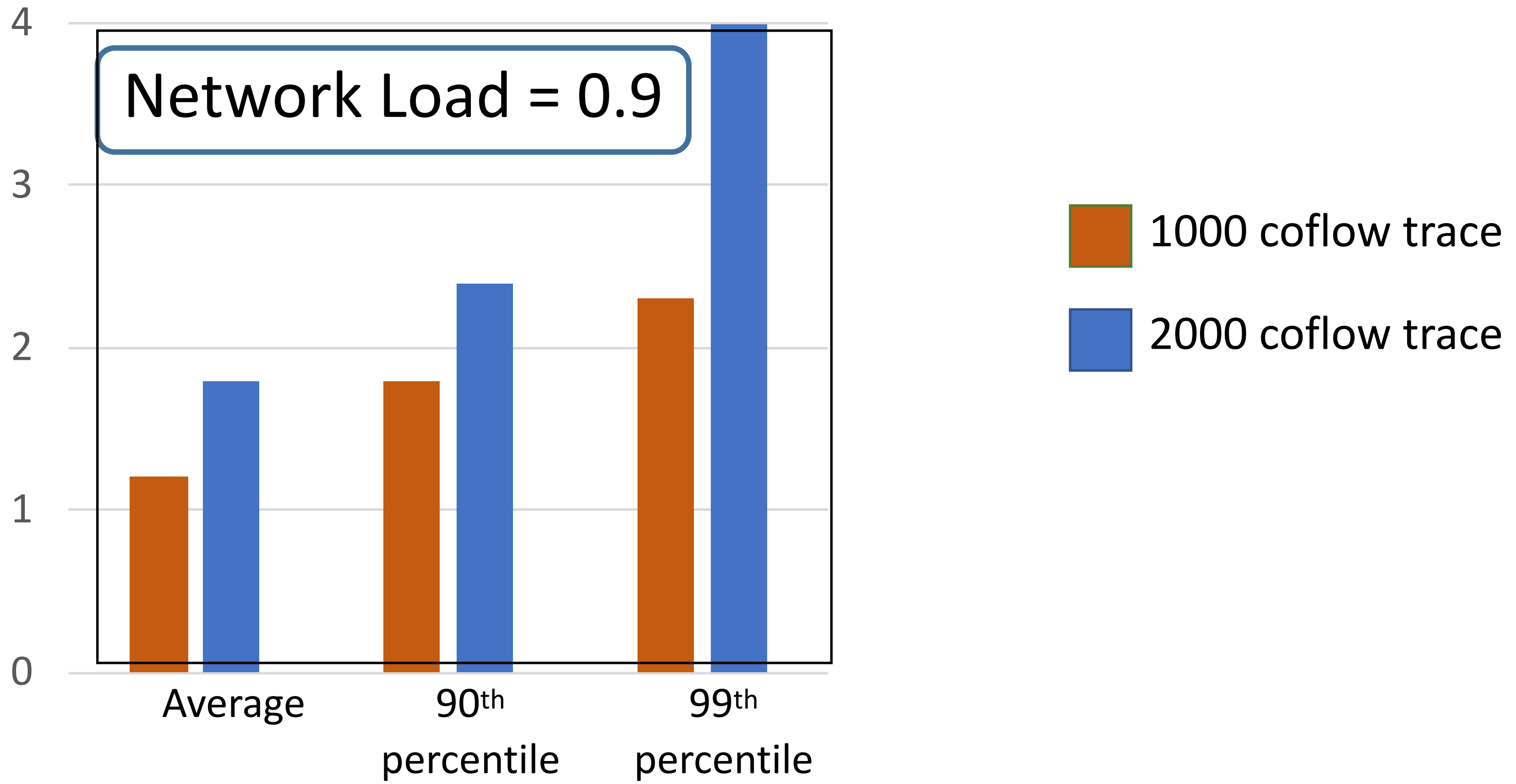
OCT: Completion time of a coflow in an unloaded network

Sincronia not only provides near-optimal guarantees, but also improves upon state-of-the-art design in practice

Key to performance gains: medium-sized coflows

Simulation Results
Online

$$\frac{\text{CCT}}{\text{OCT}} = \text{Slowdown}$$

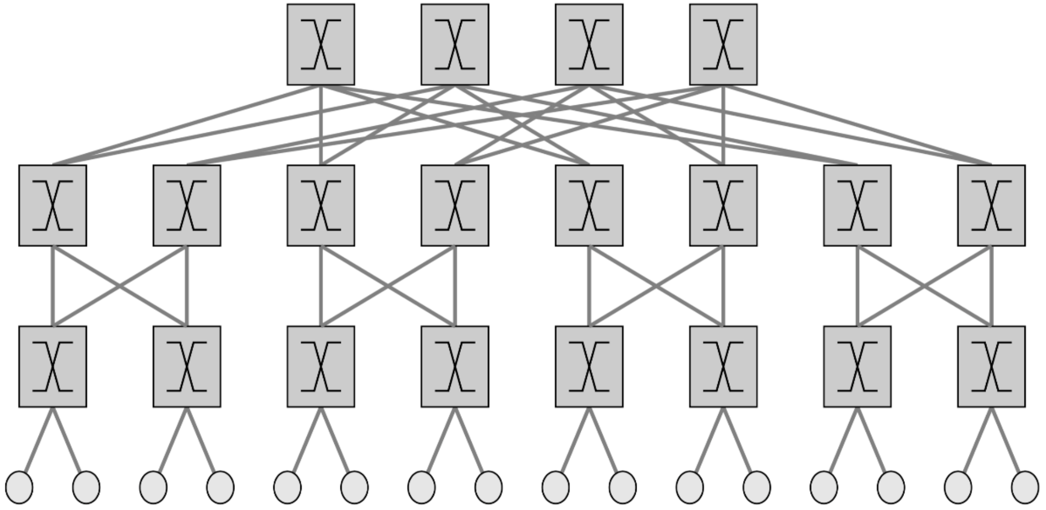


Even at such high network loads,
Sincronia achieves CCT close to that of an unloaded network

Implementation Results

Implemented on top of TCP

- 16-server Fat tree topology
  - Full bisection bandwidth
  - 20 PICA8 switches
    - Supports 8 priority levels
- DiffServ for priority scheduling



Implementation Results

- Unfair Evaluation

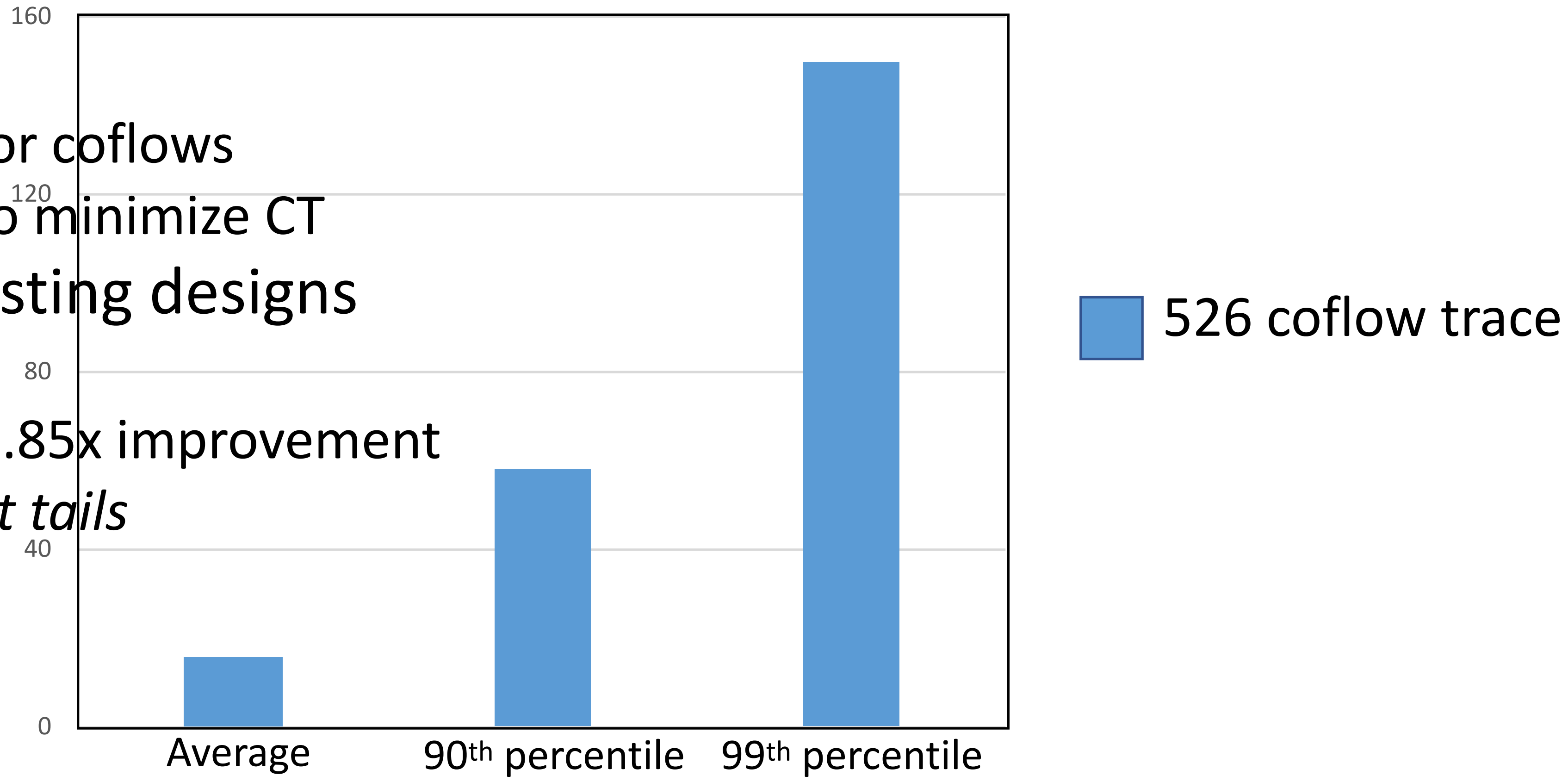
- TCP not designed for coflows
- TCP not designed to minimize CT

+ Compare against existing designs

$$\frac{\mathrm{CCT(TCP)}}{\mathrm{CCT(Sincronia)}}$$

- E.g. Varys reports 1.85x improvement

at mean and at tails



Sincronia achieves significant improvements over existing network designs even with a small number of priority levels

Summary

- Sincronia – a network design for coflows
  - 4x within optimal
  - No per-flow rate allocation

Name	Performance Guarantees	Run on existing Transport	Work Conserving	Starvation Avoiding
Varys	✗	✗	✓	✓
On Scheduling Coflows	✓ (4-apx)	✗	✗	✗
Sincronia	✓ (4-apx)	✓	✓	✓

- Paper discusses number of open problems

Thanks!

Future Work

- Strengthen theoretical guarantees
    - Other metrics?
        - Flow time, stretch,…
    - More general topologies?
    - Bridge gap between upper and lower bounds for approximation

Sincronia + pFabric

Main Challenge: Coflow ordering → Flow priorities

pFabric

End hosts put flow priorities in packet headers

priority = remaining bytes in flow

+ Sincronia

priority = coflow ordering

Sincronia + pHost

Main Challenge: Coflow ordering → Flow priorities

pHost

Receiver assigns tokens, sources send one packet per token

priority = decided by receiver

\+ Sincronia

priority = receiver sends tokens in coflow order

sender uses received tokens for flows in the coflow order

Sincronia + TCP

Main Challenge: Coflow ordering → Flow priorities

TCP

priority = set using bits in DiffServ

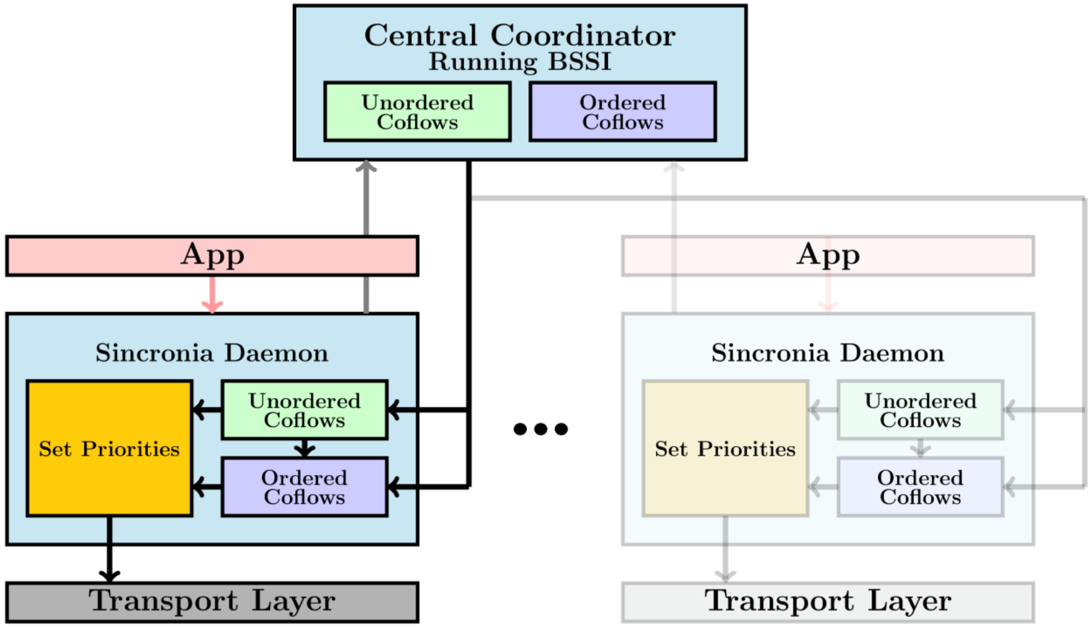
Fixed priority levels (hardware limitation, p=8)

+ Sincronia

priority = coflow order entered in DiffServ

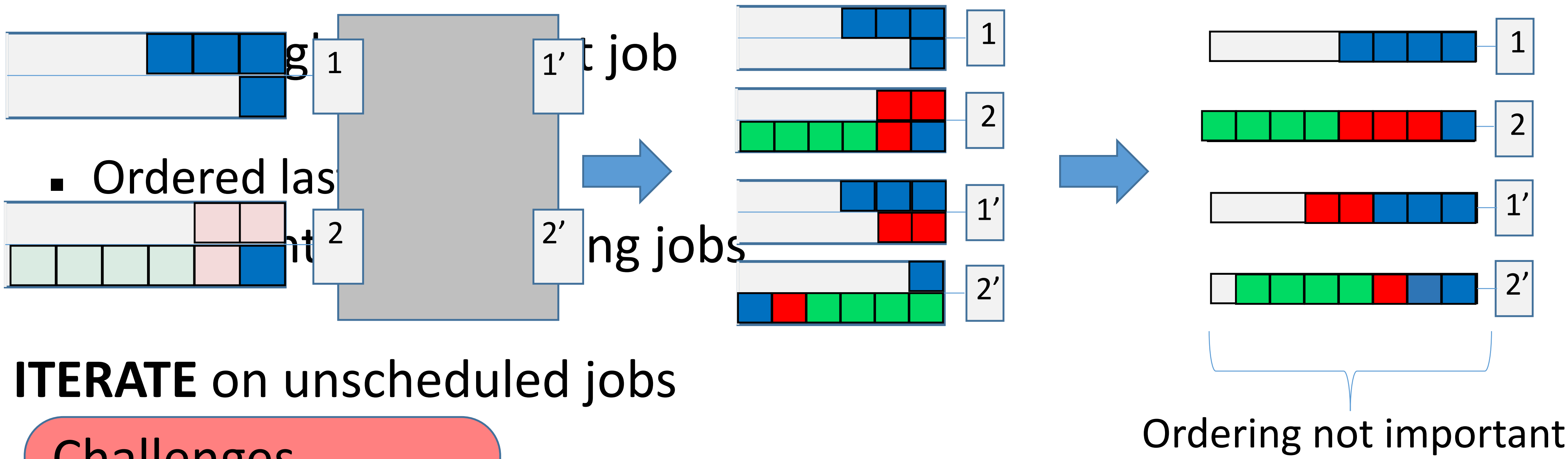
First p priorities = coflow order, Remaining priorities = p

Sincronia: End to End Design



Bottleneck-Select-Scale-Iterate (BSSI)

- Find **BOTTLENECK** port



- **ITERATE** on unscheduled jobs

Challenges
- “Size” of coflow
- Port Interactions

Coflow sizes: now at a per-port granularity