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Evaluating Dynamic Path Reconfiguration for Time-Sensitive Networks

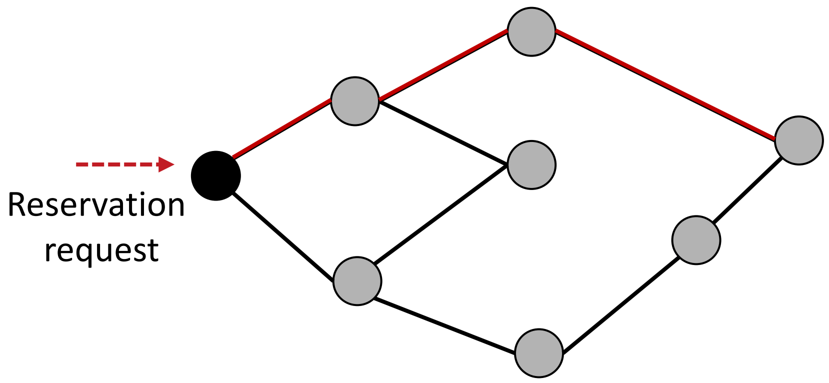
WueWoWAS '22

Time Sensitive Networking

- Safety and mission critical networks
  - IoT sensors, autonomous cars, industrial facilities
- “Low-latency and deterministic networking”
  - Bounded latency and a reliable delivery of data as a requirement
  - A violation of latency constraints
- IEEE Time-Sensitive Networking
  - Improves Ethernet with real-time capabilities
    - Enables use of ethernet in the mission critical environments
  - Mixed traffic scenarios
  - Guarantees proper transmission of (mission)-critical data

Motivation

- TSN flow reservation concept
  - Initial declaration of requirements
  - (Usually) established at start-up time of an application
  - Remain untouched until the flow ends



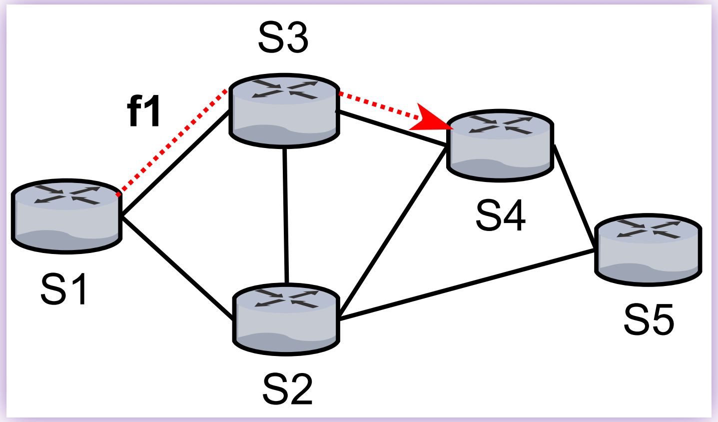
- Future network scenarios
  - Accommodating large number of flows
    - Degradation of resource utilization over time
    - Sub-optimal flow placement
      - Some flows cannot be embedded due to capacity limitations on certain links

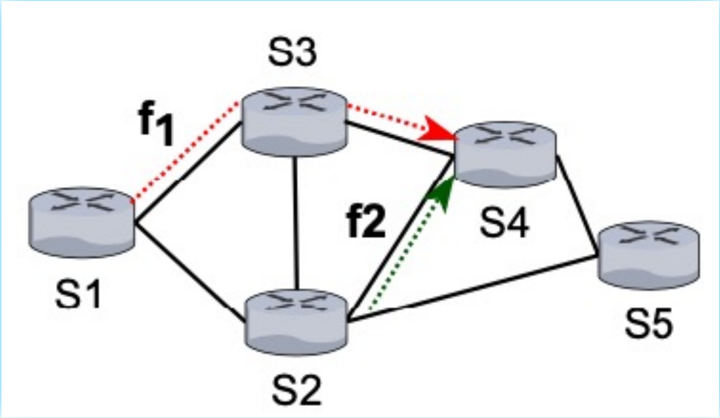
- Solution: Enabling the migration of existing flows
  - Without interrupting ongoing traffic
  - Preserving strict QoS constraints for critical traffic

Question:
Is it possible to seamlessly migrate time-sensitive flows for *better* flow placement ?

Direct Flow Embedding Scenario

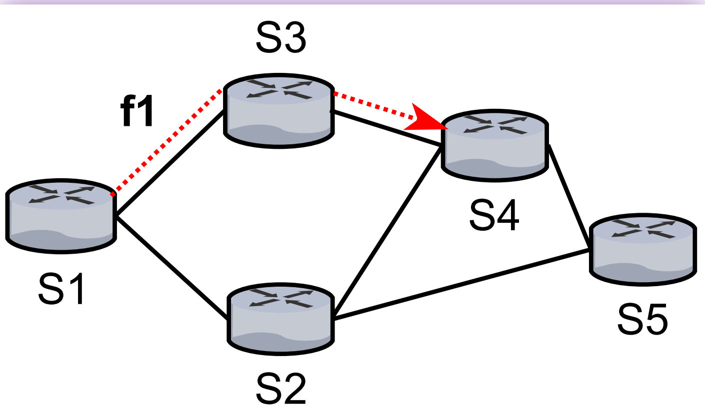
- When a new flow (f2:S2 to S4) can be directly put to its new path
  - No migration is needed



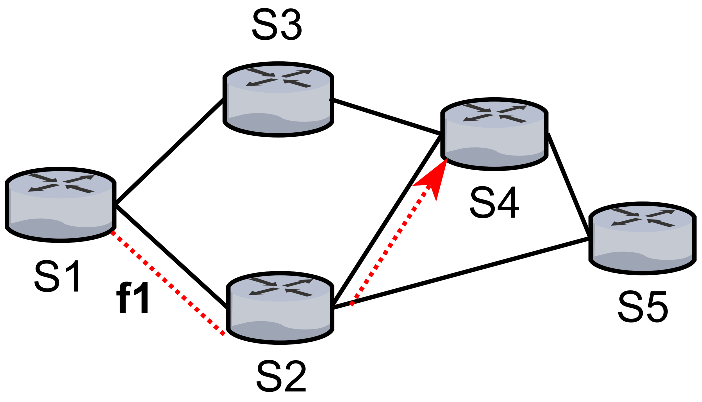


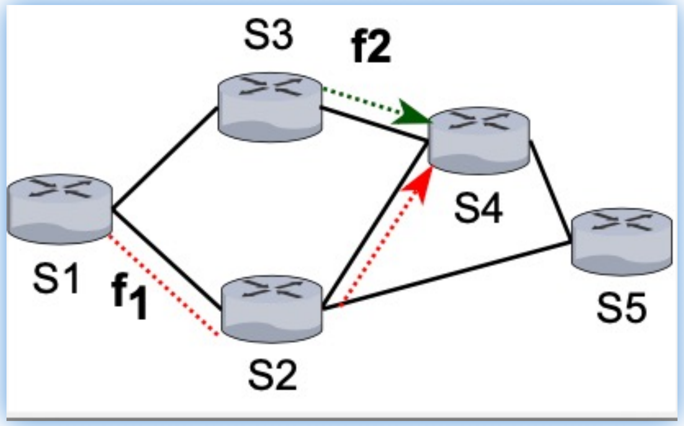
Flow Migration Scenario

- A new flow (f2:S3 to S4) cannot directly handled !
  - MUST wait until f1 migrated to its new path



"Flow migration"
Transfering m flows that could affect somehow each other to their new paths (sequentially)

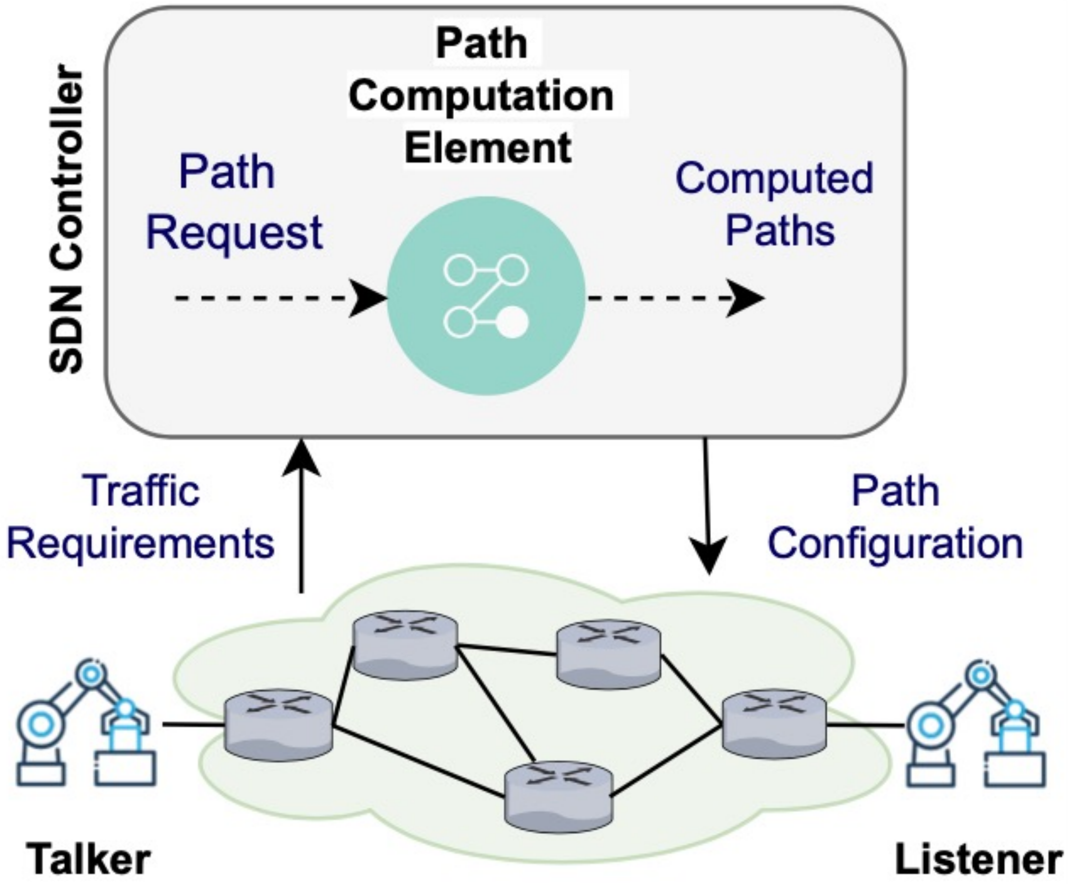




Dynamic path (re)configuration for TSN networks

- SDN-based framework
  - Global network view
    - Collection & inclusion of application requirements

- How to model our path computation problem ?
  - E2E paths for given demands under different QoS requirements
    - Including latencies derived from gate configuration per port
  - Objective: Minimizing the overall E2E communication latency



Time-sensitive optimal routing problem (TSOR)

- Objective: Minimizing the overall latency of the selected paths

$$min \ \sum_{d \in D} \sum_{p \in P_d} \sum_{e \in E} x_{dp} \alpha_{ep} \left[l_e^o + l_e^q (1 - g_{es}) \right]$$

assignment	$\sum_{p \in P_d} x_{dp} = 1$	$\forall d \ \in$
link capacity	$\sum_{d \in D} \sum_{p \in P_d} x_{dp} \alpha_{ep} h_d \ \leq c_e$	$\forall e \ \in E$
gate conf.	$\sum_{s \in S} g_{es} = 1$	$\forall e \ \in E$
additional gate conf.	$g_{es} - \sum_{d \in D} \sum_{p \in P_d} x_{dp} \alpha_{ep} \frac{h_d}{c_e} \geq 0$	$\forall e \ \in E, \ \forall s \ \in S$
demand latency	$\sum_{p \in P_d} \sum_{e \in E} x_{dp} \alpha_{ep} \left[l_e^o + l_e^q (1 - g_{es}) \right] \leq l_d$	$\forall d \ \in D$

- Output:
  - end-to-end paths for given demands under different QoS requirements → x_{dp}
  - gate configurations for each switch → g_{es}

Decision variables: x_{dp}, g_{es}

Path Configuration Strategies

Different path configuration strategies with varying degrees of constraints

Restricted path reconfiguration: TSOR

→ Keeps the previous demands fixed

! Reduced flexibility

Reconfiguration at every path request: TSOR-U

→ Enables replanning all path configurations from scratch

! Increased (re)configuration overhead

Threshold-triggered reconfiguration: TSOR-T

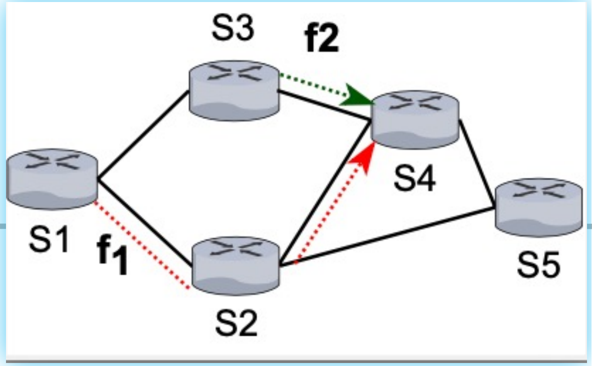
→ Reconfigure if the computed objective exceeds a threshold

Reconfiguration at every k-th path request: TSOR-P

→ Reconfiguration in dependence on the arrival rate of flows

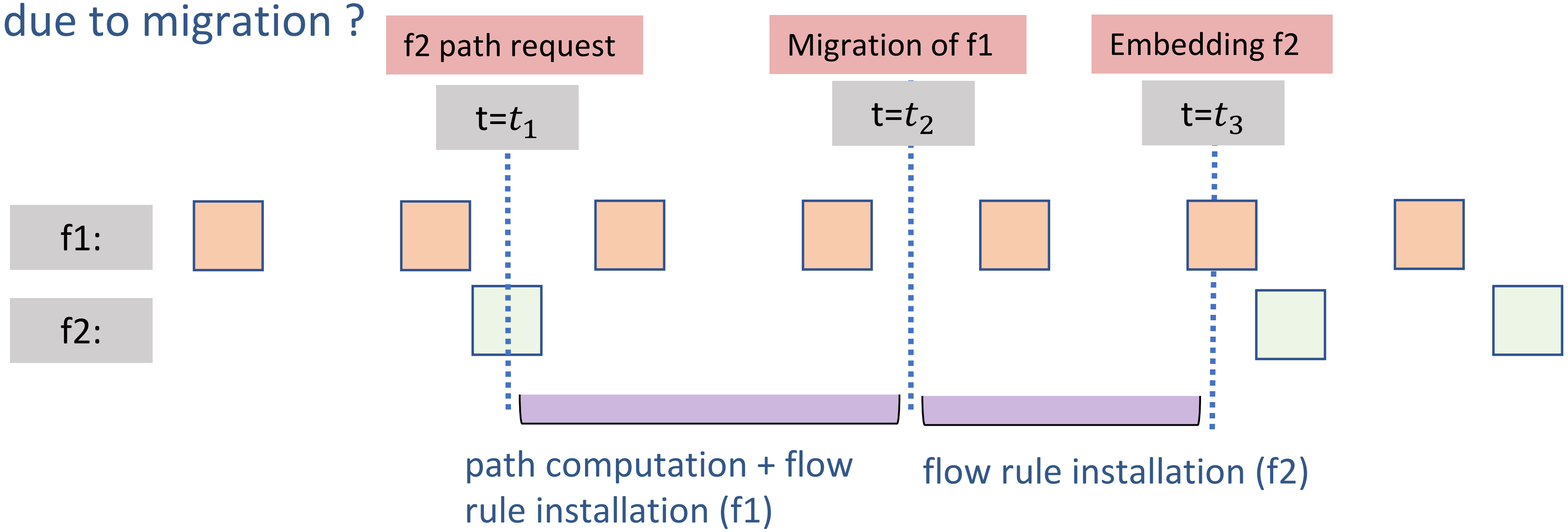
Idea: Keep some demands fixed & reconfigure remaining

Cost of flow migration



- Latency of frames should not violate their latency requirements (aka deadlines)
  - Processing latency
  - Queuing latency
  - Transmission & propagation latency

- What about latency due to migration ?



- Migration affects frames come between t_1 and t_3

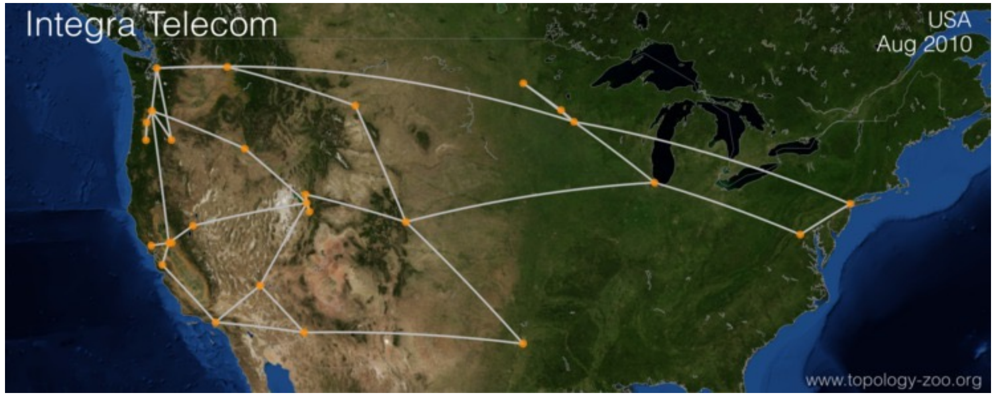
How does real time flow migration affects packet delivery under realistic TSN settings ?

Evaluation

- OMNeT++ simulations
  - Optimization problem is solved by CPLEX
- Traffic generation

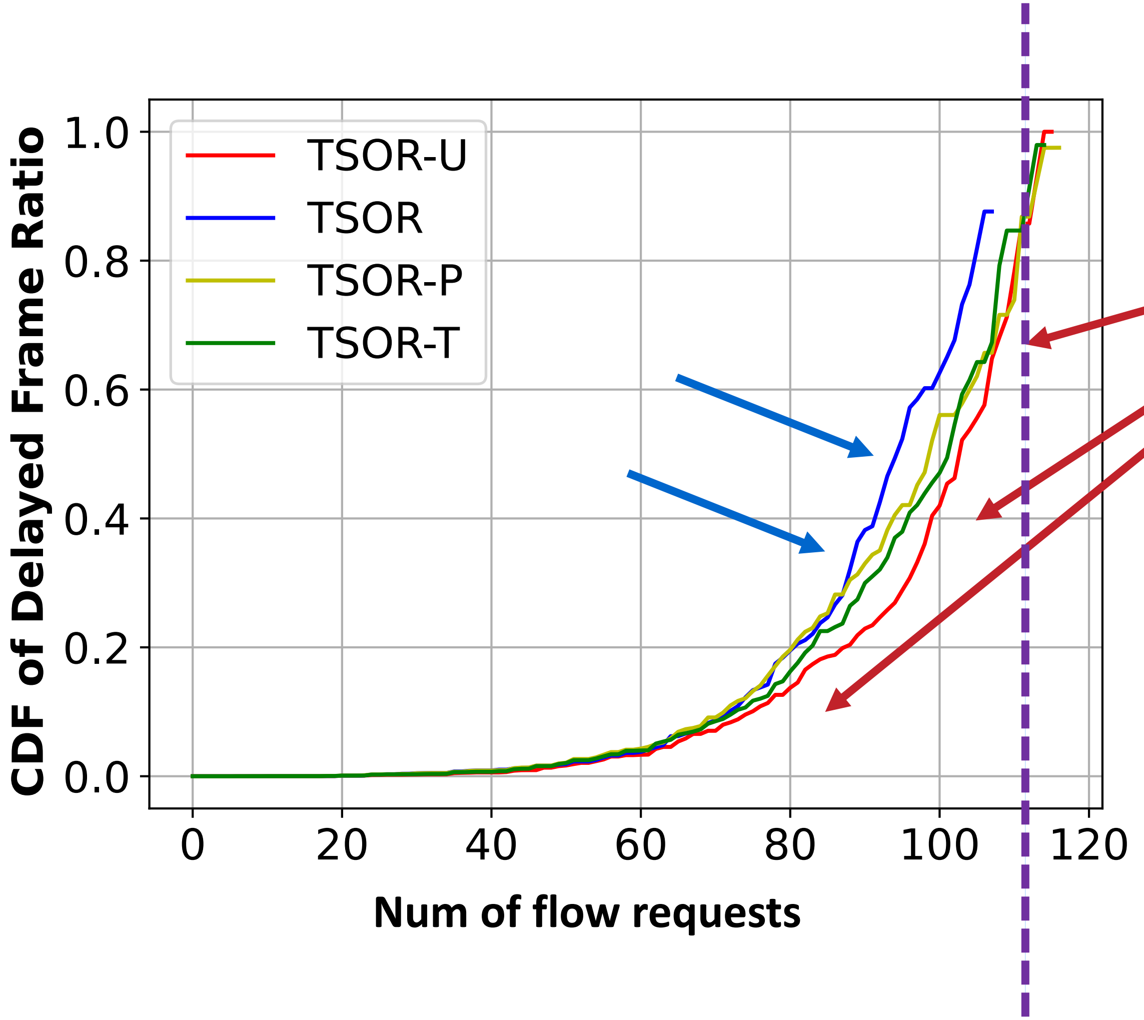
Category	Parameter	Value
Time-triggered traffic	Transmission period	Uniform(2,20) ms
	Frame size	50-1000 bytes
	Data-rate distribution	pareto, uniform, normal
Best-effort traffic	Transmission period	Exponentially distributed
	Frame size:	1500 bytes

- Real-world topologies from Topology Zoo dataset
- Evaluation metrics
  - Missing Deadline Ratio
  - Reconfiguration Overhead
    - Configuration Time



Experimental Results – I

How reconfigurations affect the TT traffic delivery?



TSOR-U has the lowest delayed frame rate

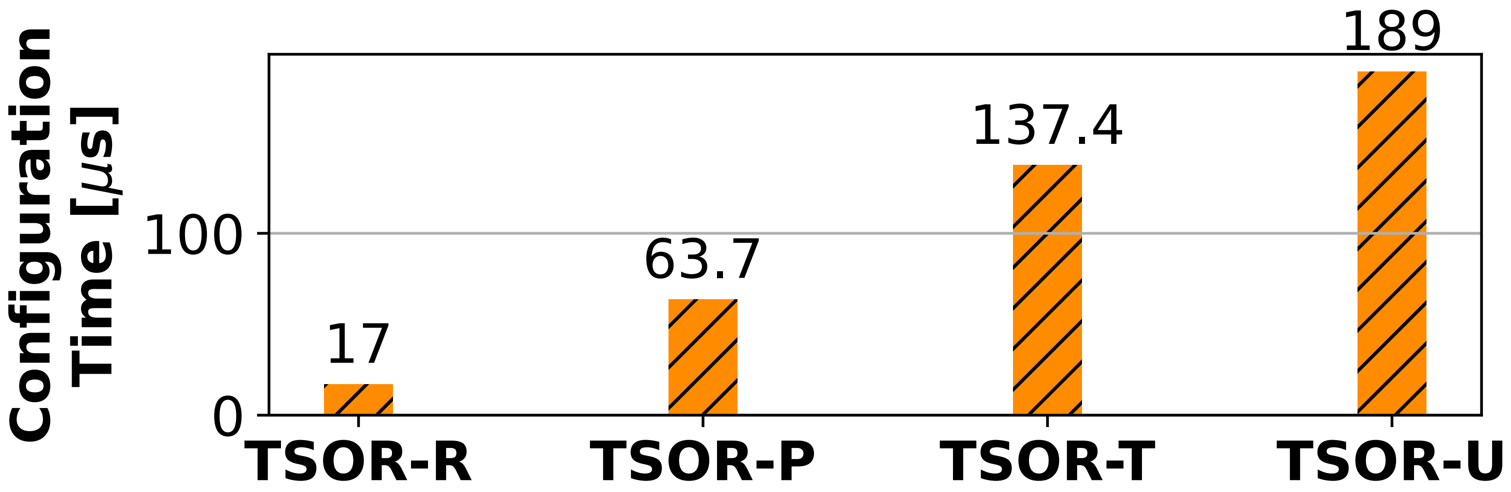
TSOR-P and *TSOR-T* perform better than *TSOR* and are close to *TSOR-U* *

After ≈110 flows, significant increase in TSOR-U due to higher number of accepted flows
e.g., TSOR-U (**52.81) vs** TSOR-P **(51.18**)

What is the reconfiguration overhead ?

Experimental Results - II

- Configuration time is highly dependent on the number of reconfigurations



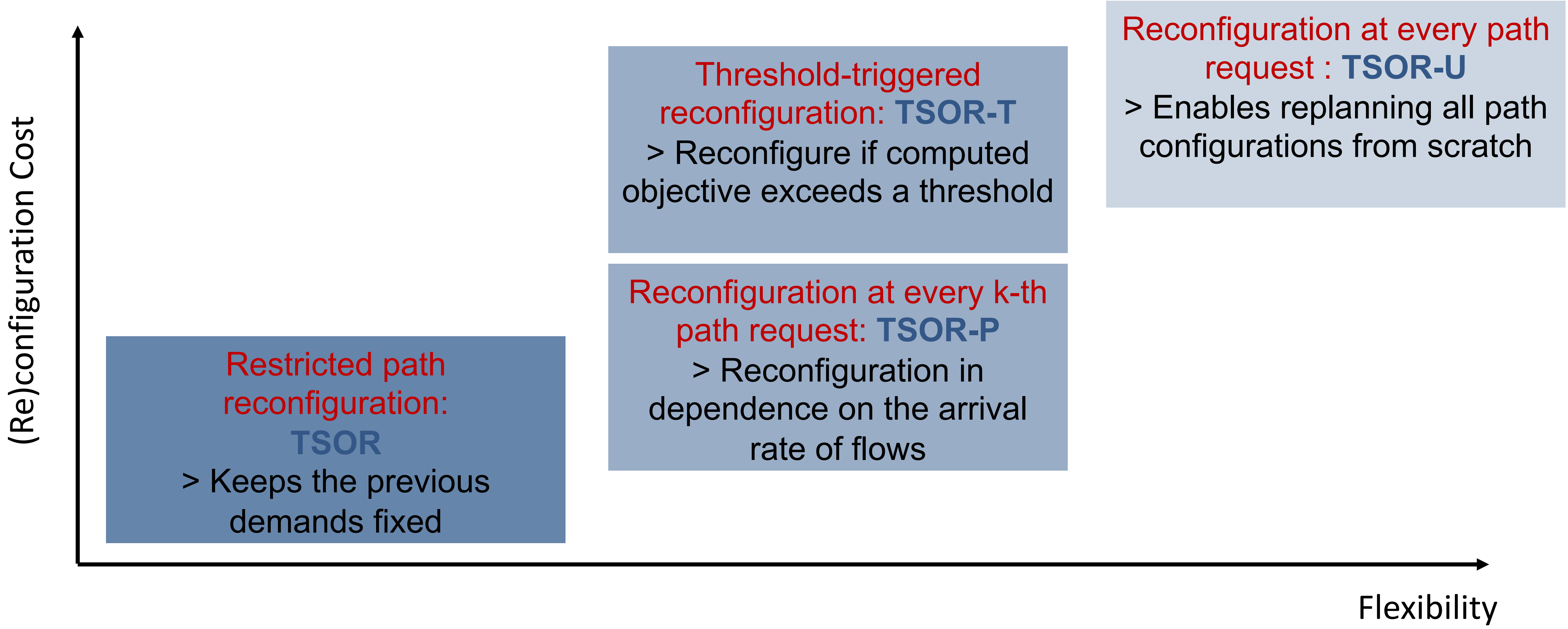
TSOR-R has zero *reconfigurations*

TSOR-U has the highest *reconfiguration ratio* due to frequent reconfigurations

Performance of *TSOR-P* and *TSOR-T* is highly related to the chosen parameters

Summary

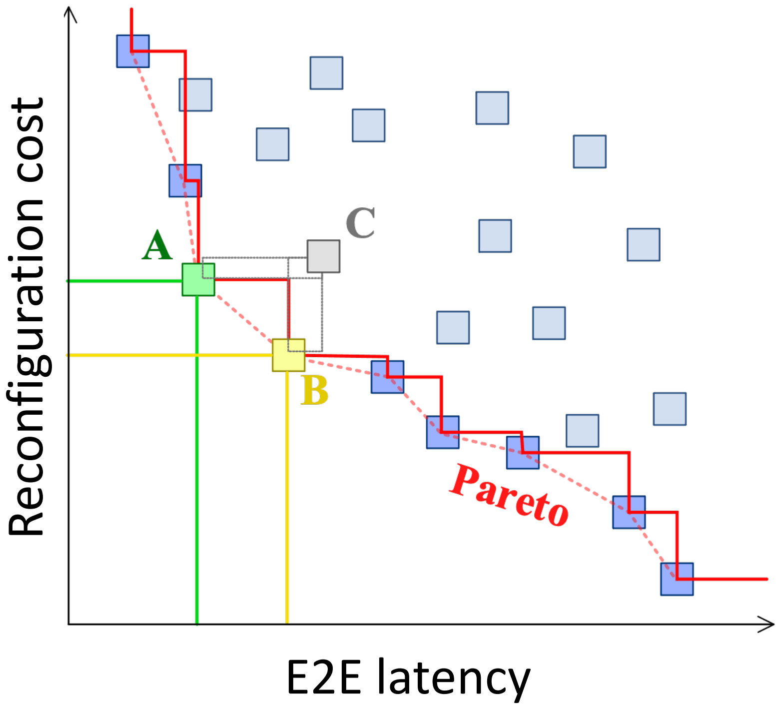
- (Re)configuration strategy can be selected depending on the requirements of the environment
  - Highly dynamic small/medium scale environments



Future work

- Future use cases requires more frequent flow migrations
  - Rerouting due to failures
  - Dynamic traffic patterns

- Performance as a significant design criteria
  - Estimate the reconfiguration cost and related benefits (reduced E2E latency) *before* taking a decision
  - Dual objectives with the aim to
    - (i) minimize the overall latency of the selected paths
    - (ii) minimize the reconfiguration cost



Thank you for your attention!

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