Designing a Resilient Time-Aware Shaper Configuration for TSN

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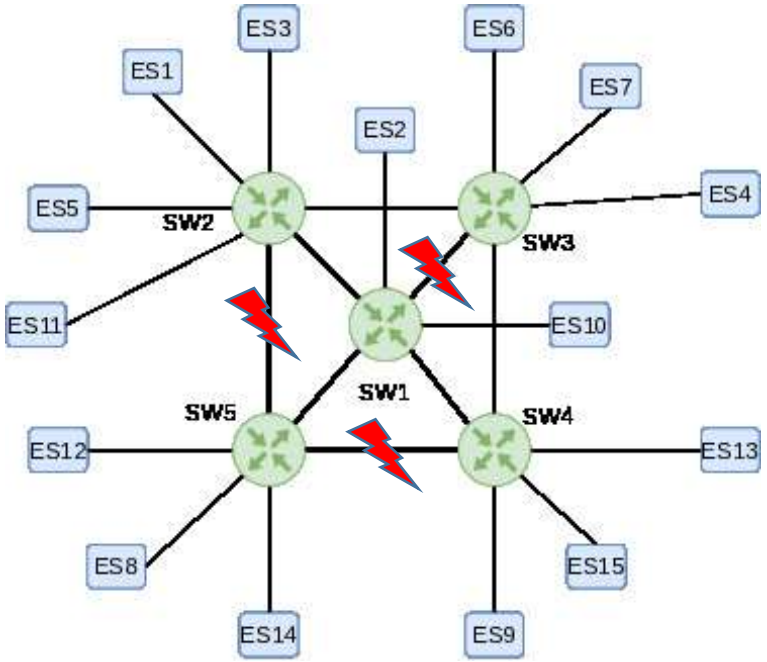
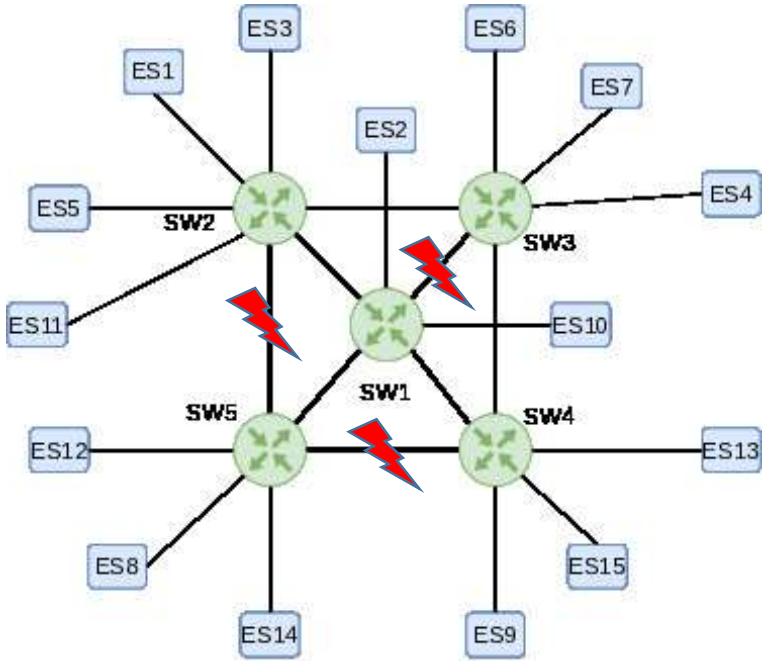
Context

- TSN: Time Sensitive Networking
  - IEEE real-time Ethernet
- A TSN network
- Set of real-time data flows (*streams)*
- Initial static configuration
- Possible faults



Challenge

- Reconfiguration in case of permanent link faults
- Challenges:
  - Finding routes: easy
  - Allocating resources for real-time: hard
    - Especially in short time
- Use case: presented as « Industrial Challenge » at ECRTS 2025 conference



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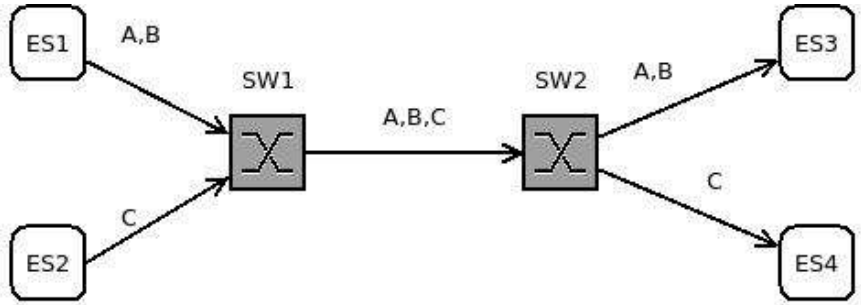
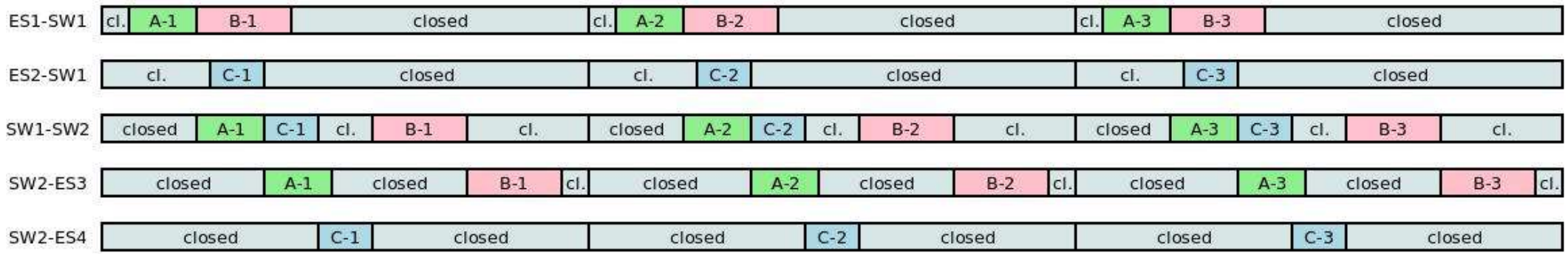
A one slide TAS presentation

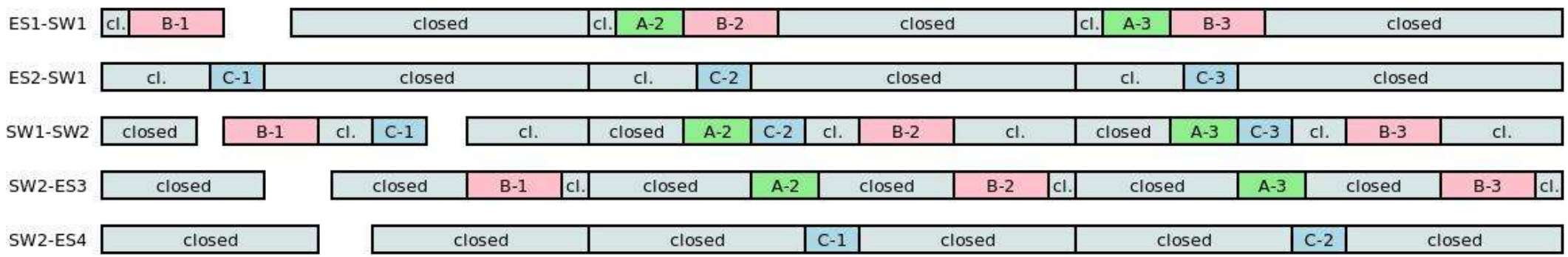
TAS = Time Aware Shaper



Nominal TAS behavior



Loss impact



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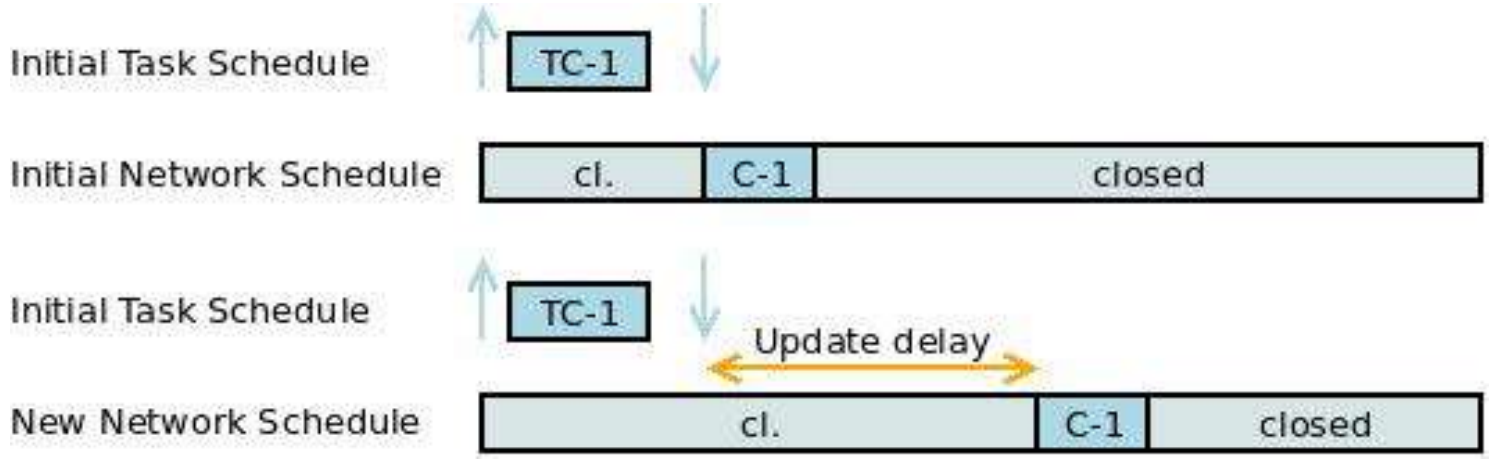
Contribution

TAS incremental reconfiguration

- A Time-Aware Shaper *reconfiguration*
  - Incremental: offsets/windows of existing flows are not modified
  - Fast (in seconds or minutes)
  - Without update of Gate Control List
    - => fast deployment
    - => no coherency problem
  - Immune to TAS losses problem
    - Not using flow isolation

Why incremental update ?

- Def: Do not change time windows of existing flows
  - Why does it matter ?
- Network <-> application synchronisation
  - Data are produced by tasks
  - Tasks and network schedule must (should) be synchronized



=> Try to maintain the network schedule for flows not impacted by the fault

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WPEx

Windows Precedence Exclusion

+

Window enlargment

+

Protective gating

WPEx principle

Main idea: use a basic idea

- Build a schedule with some « slack »
  - Reserve time windows larger than required
- Use the slack to host new data flow

Challenges

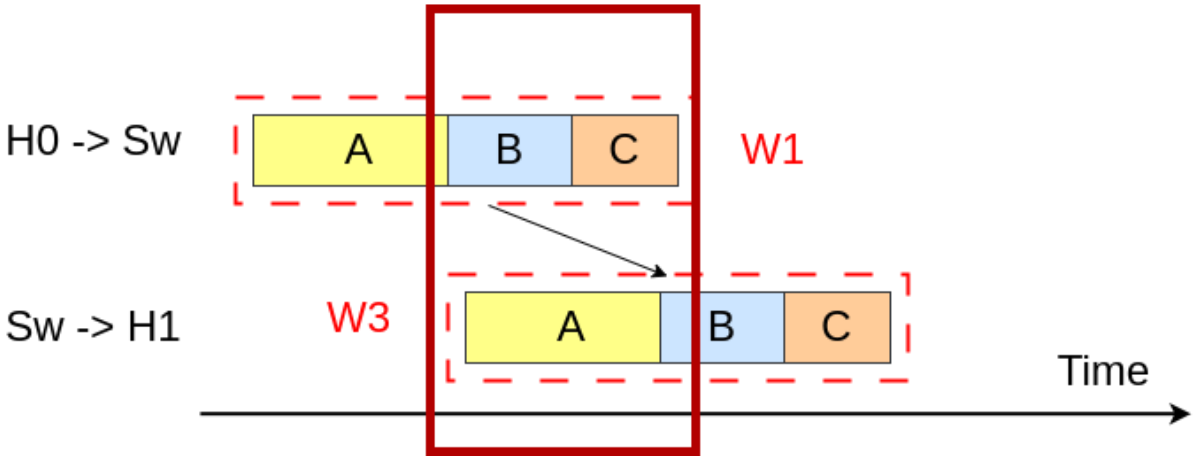
- Slack is wasting bandwidth
- Share windows between several flows

Window Precedence Exclusion

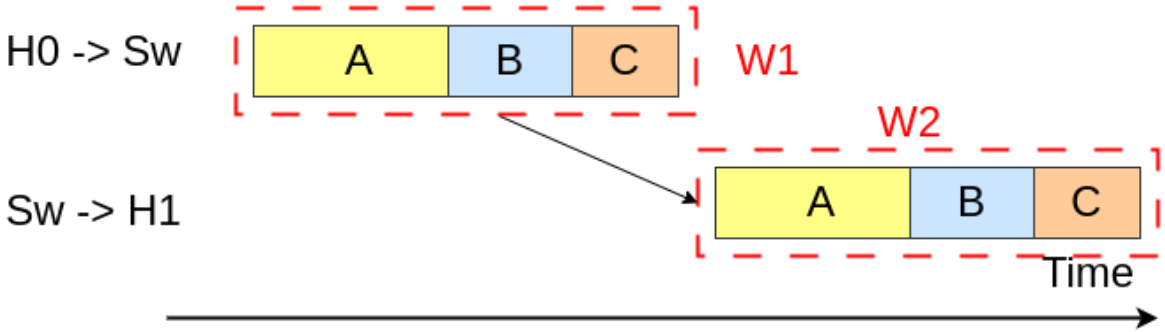
No overlap between sending and receiving windows

Property 1: Immune to losses

Property 2: all frames are enqueued before window start (keep in mind)



Overlap

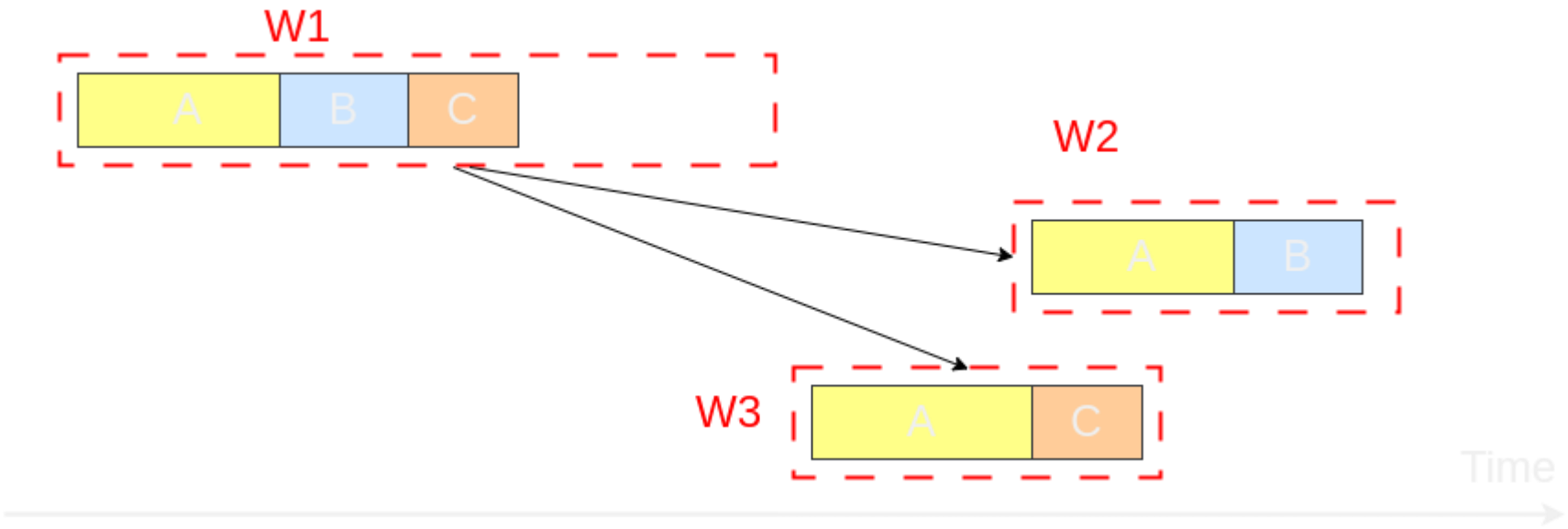


Precedence Exclusion

Window enlargment

Enlarge windows as much as possible

Keep space/time for future frames

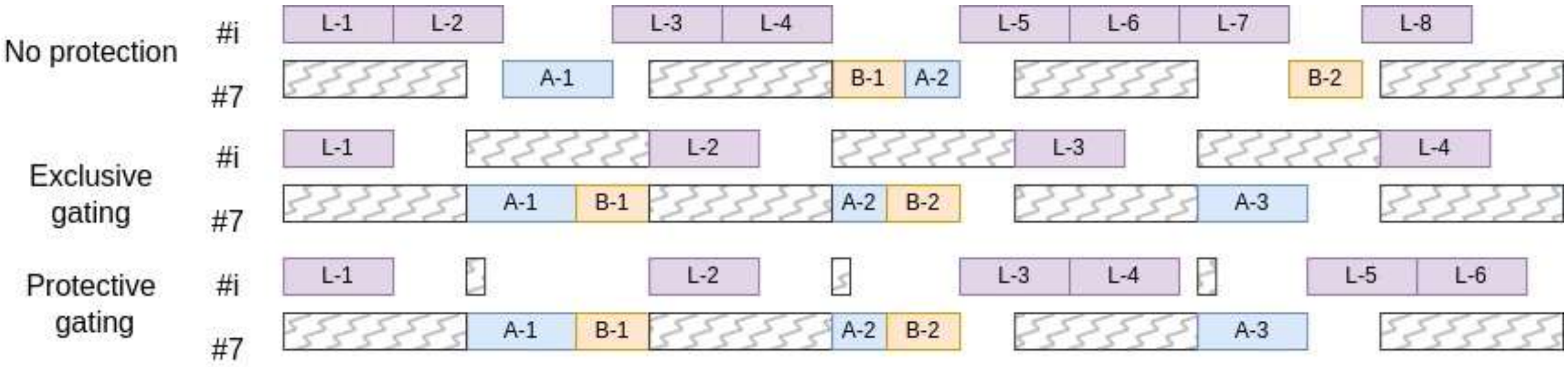


Protective gating

Protect only start of windows

Close gate of lower priority flows only at windows start

With property 2 (from WPEx): unused time is left for lower priority flows



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Implementation

Two phases implementation

- Build the initial schedule
  1. IBM CPLEX constraint solver: find a schedule WPEx-compatible
  2. Post-processing
     1. Spread windows along the hyper-period
     2. Enlarge window
     3. Add empty windows on low load links
- Fault handling
  1. Identify the set *B* of flows with broken link along their path
  2. Free resources of flows in *B* (ie remove allocation from windows)
  3. For each flow in *B*
     1. Try to find new paths (ie rescue paths)
     2. For each path, just « drop » a frame in each window and look if its reaches destination
        1. In case of success, allocate the resources (rescue schedule)
     - Computation < 1s

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Results

Results

- Removing one or two links
- How many flows of class #6 or #7 with a rescue path get a rescue schedule ?

Algorithm	Single link fault		Double link fault	
	Class #6	Class #7	Class #6	Class #7
CPLEX only	0.00 %	0.00 %	0.00 %	0.00 %
Enlarge (ECRTS Post processing)	12.20 %	9.09 %	25.68 %	9.17 %
Add windows (new)	19.51 %	9.09 %	22.04 %	8.97 %
Enlarge and Add	31.71 %	33.33 %	43.38 %	30.48 %
Add and Enlarge	43.90 %	24.24 %	48.15 %	23.94 %

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Conclusion

Conclusion

- TSN reconfiguration is a challenge
- Contribution:
  - reconfiguration of TSN subset: TAS
- A novel TAS schedule scheme: WPEx
- Good properties
  - Incremental
  - Immune to frame losses
  - No coherency problem
- Performances still under evaluations
- Several possible improvements