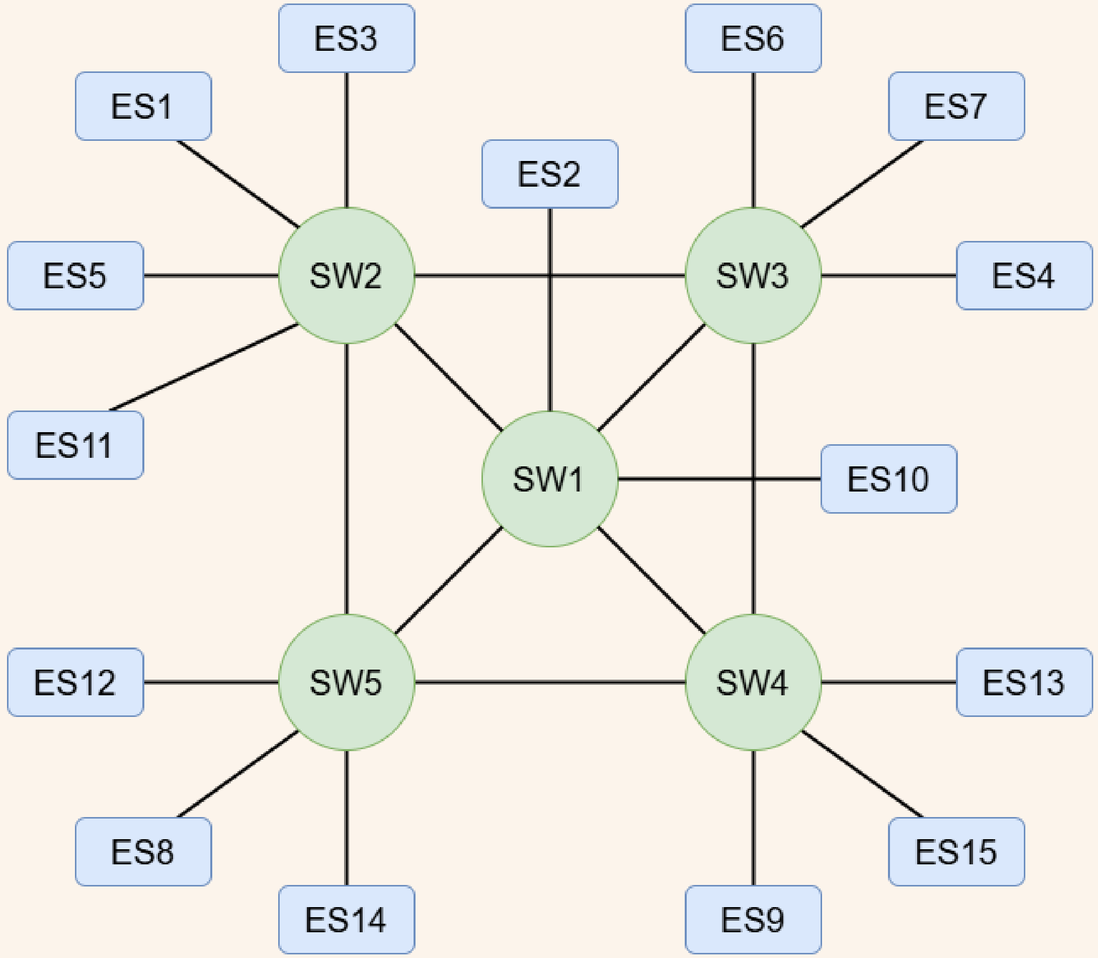
Online Reconfiguration for TSN in Avionics Using Backup Paths and Integrated Mapping, Scheduling, and Analysis Tools

Daniel Bujosa, Mohammad Ashjaei, Saad Mubeen

Mälardalen University

Industrial challenge: Embedded reconfiguration of TSN




```
TSN_Stream STR_ES1_ES2_A
STR_ES1_ES2_A.source = ES1
STR_ES1_ES2_A.period = 800000
STR_ES1_ES2_A.minFrameSize = 814
STR_ES1_ES2_A.maxFrameSize = 1273
STR_ES1_ES2_A.trafficClass = TC7
STR_ES1_ES2_A.utility = 7,2
STR_ES1_ES2_A.path = ES1 SW2 SW1 ES2
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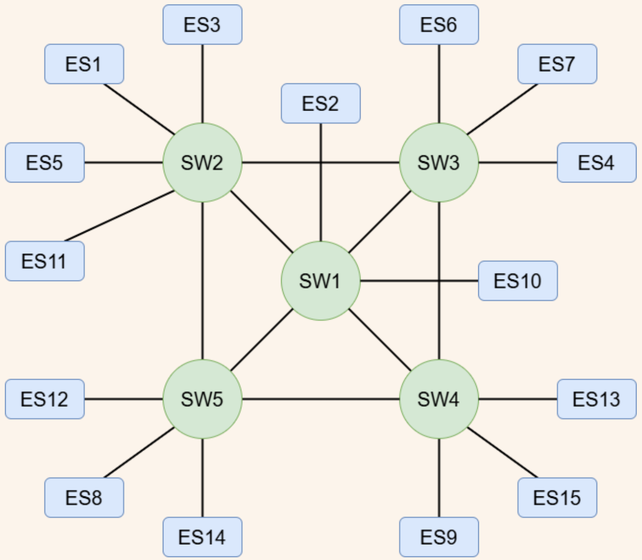


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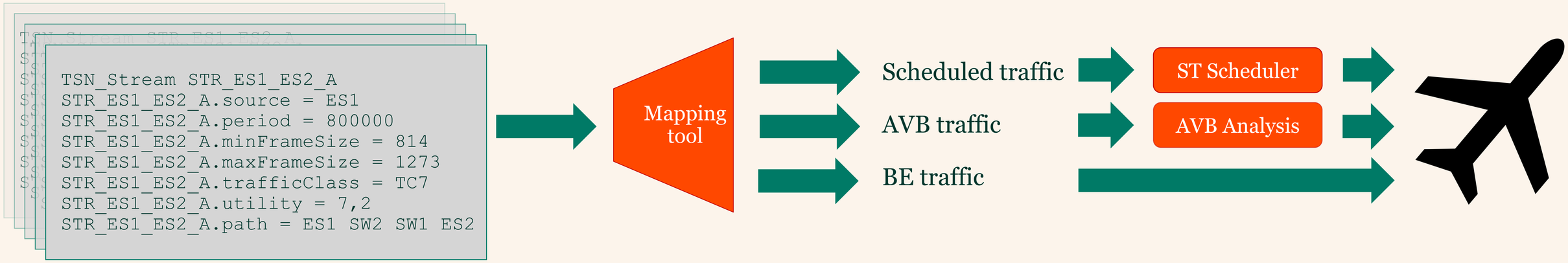
Reconfiguration constrains:

- Online computation
- Embedded computation
- Short reconfiguration time
- Continuous operation

Assumptions:

- Only port failure will be considered
- Fault detection out of the scope

Toolchain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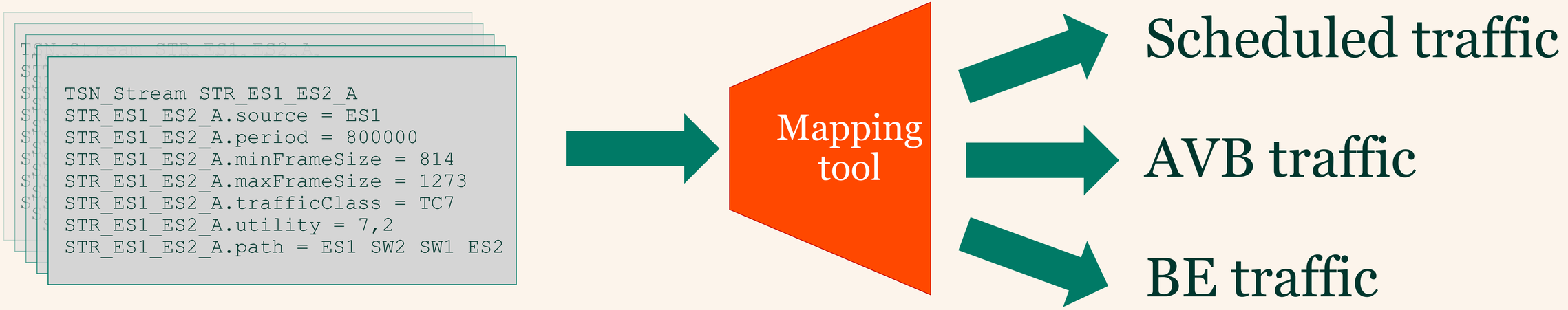
Mapping tool
Scheduled traffic
AVB traffic
BE traffic
ST Scheduler
AVB Analysis

Toolchain

Step 1: Mapping traffic into the three types of TSN traffic, including Scheduled, AVB, and BE traffic.



*Bujosa, Daniel, et al. "LETRA: Mapping legacy ethernet-based traffic into TSN traffic classes." *2021 26th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)*. IEEE, 2021.

Toolchain

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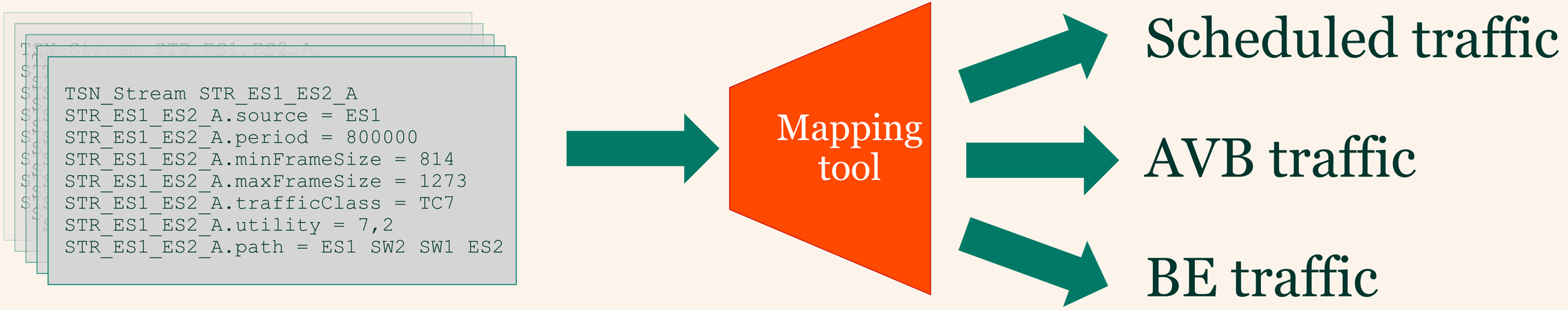

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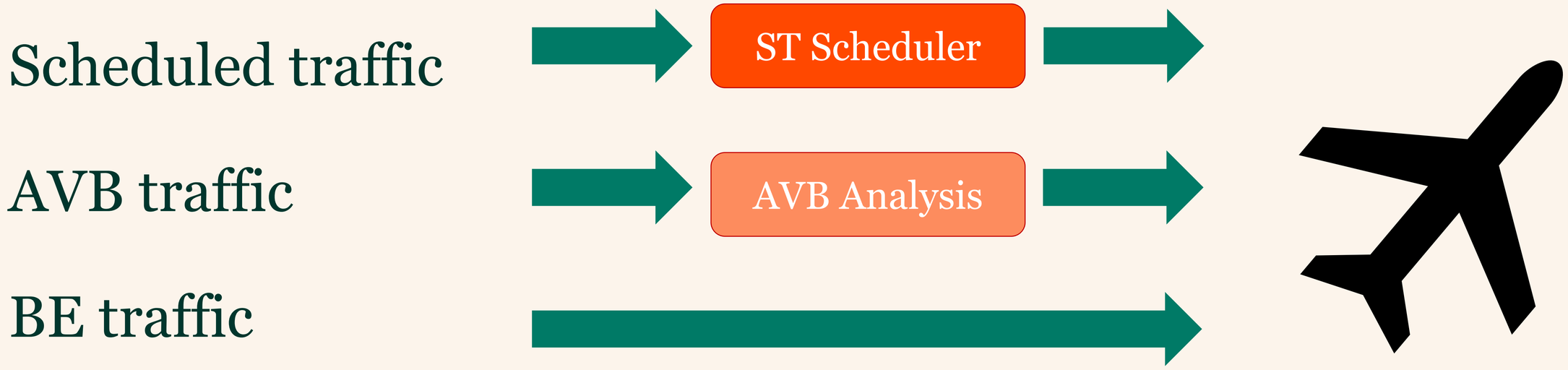
Toolchain

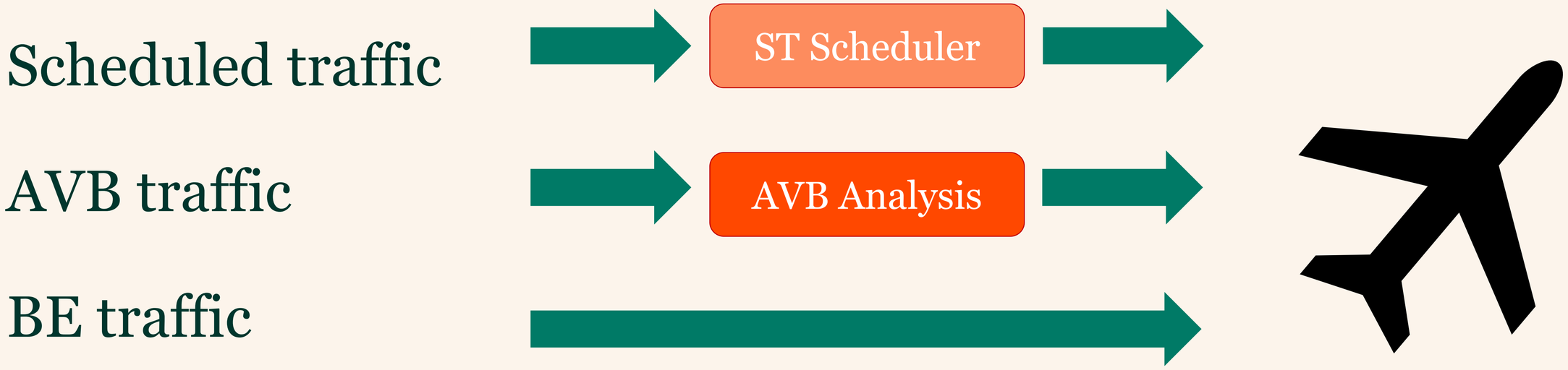
Step 2: Scheduling Scheduled traffic.



*Bujosa, Daniel, et al. "HERMES: Heuristic multi-queue scheduler for TSN time-triggered traffic with zero reception jitter capabilities." Proceedings of the 30th International Conference on Real-Time Networks and Systems. 2022.

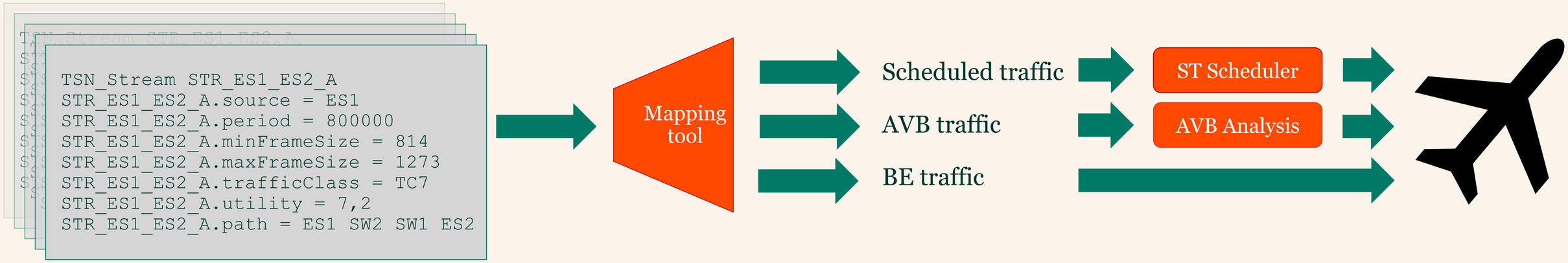
Toolchain

Step 3: Analyzing AVB traffic to guarantee it meets its time requirements.



*Bujosa, Daniel, et al. "An Improved Worst-Case Response Time Analysis for AVB Traffic in Time-Sensitive Networks." 2024 IEEE Real-Time Systems Symposium (RTSS). IEEE, 2024.

Configuration



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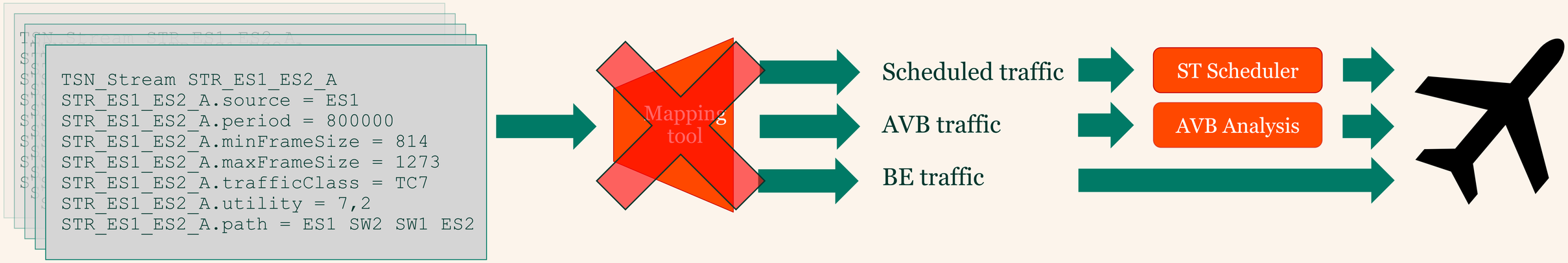

Configuration

ST	AVB Class A	AVB Class B	AVB Class C	BE
ST streams	200000 ns			BE streams
	400000 ns			800000 ns
				1600000 ns
				3200000 ns
				6400000 ns
				12800000 ns

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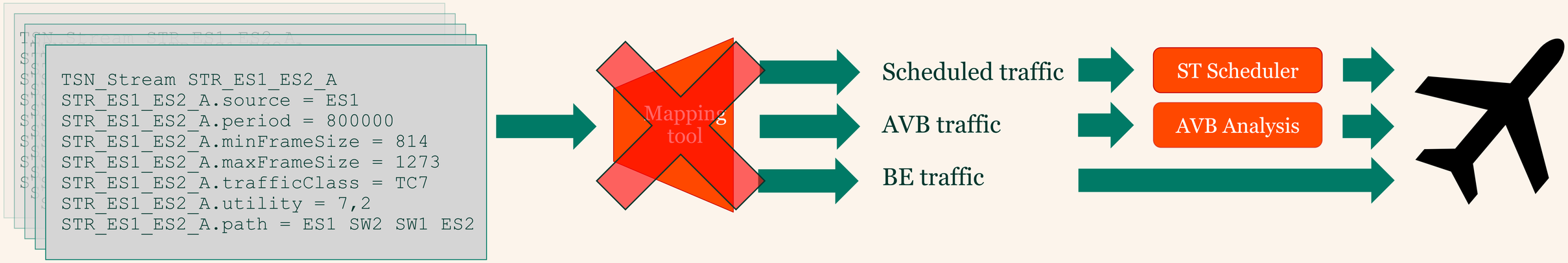
unschedulable

Configuration



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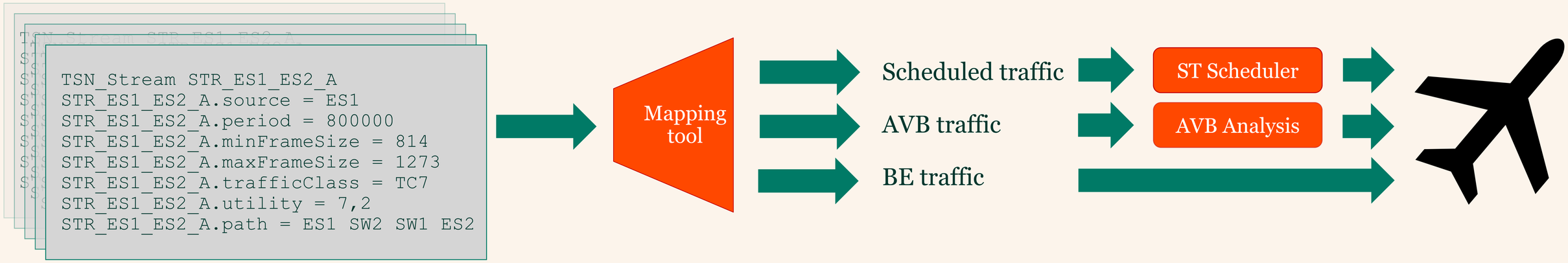

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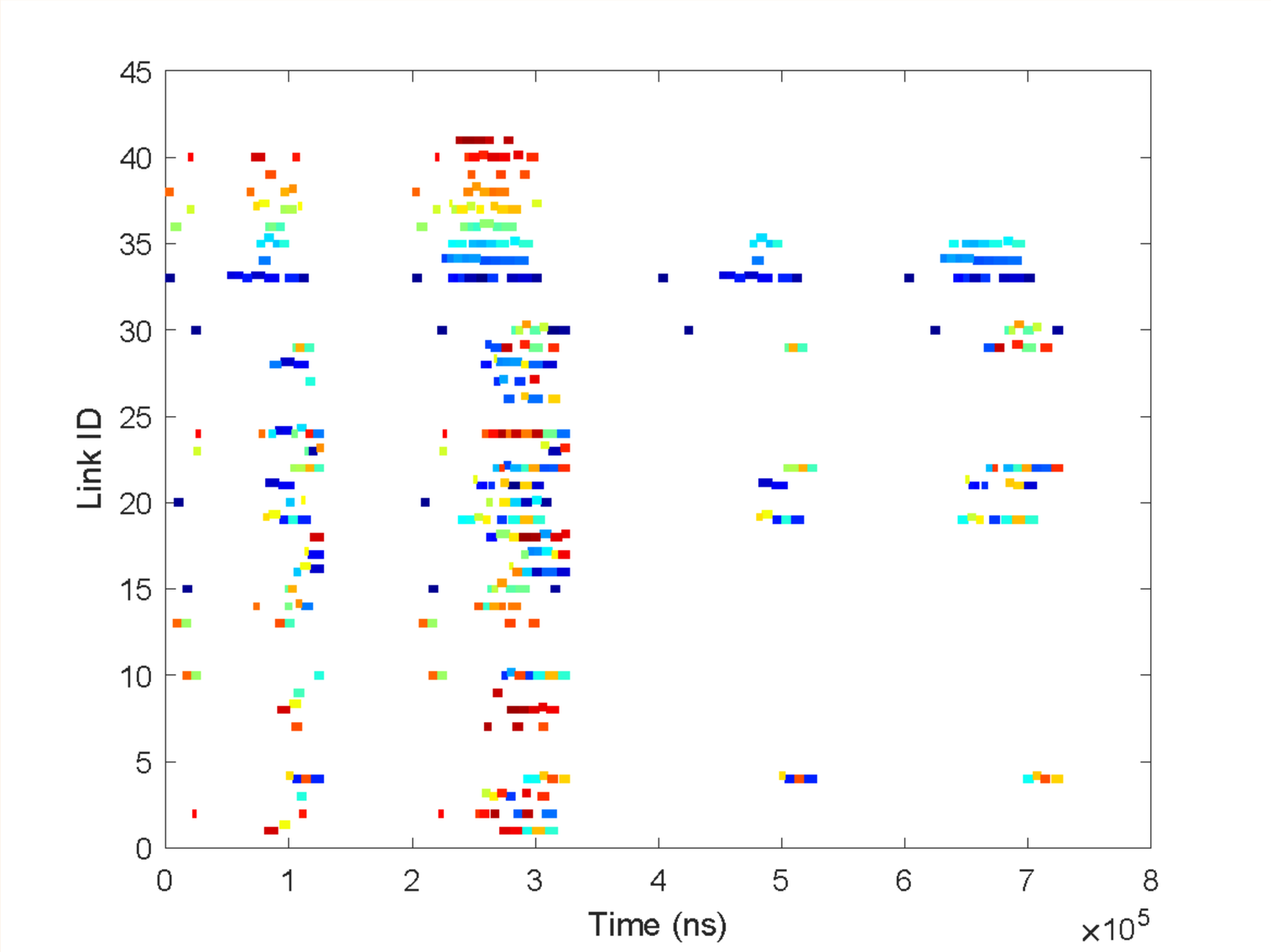
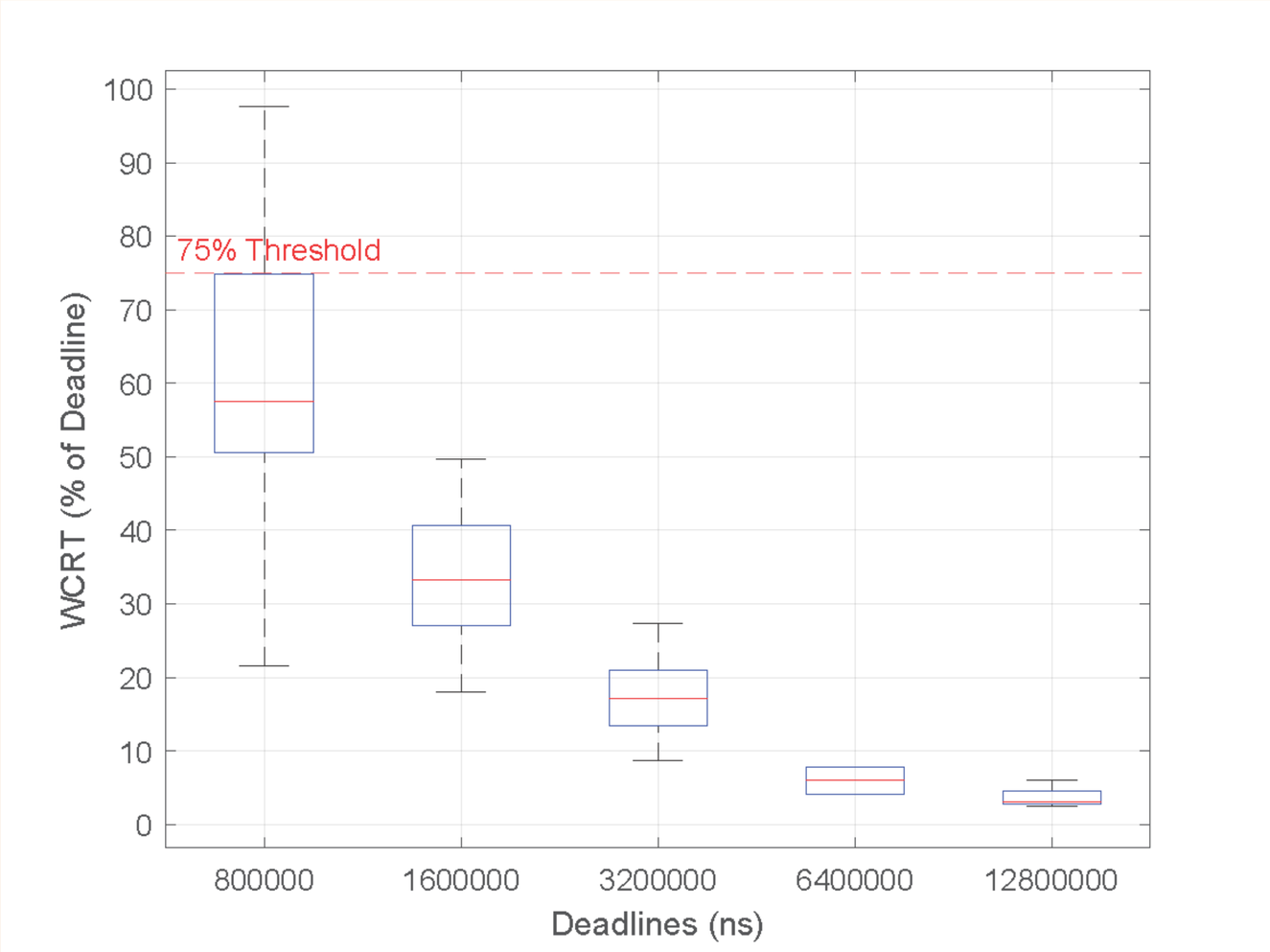
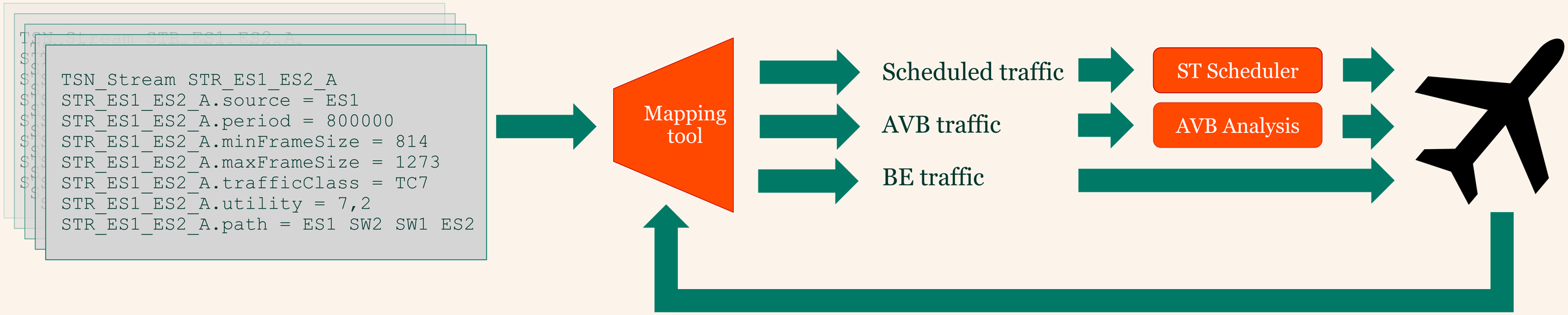


Configuration

1st iteration



Configuration



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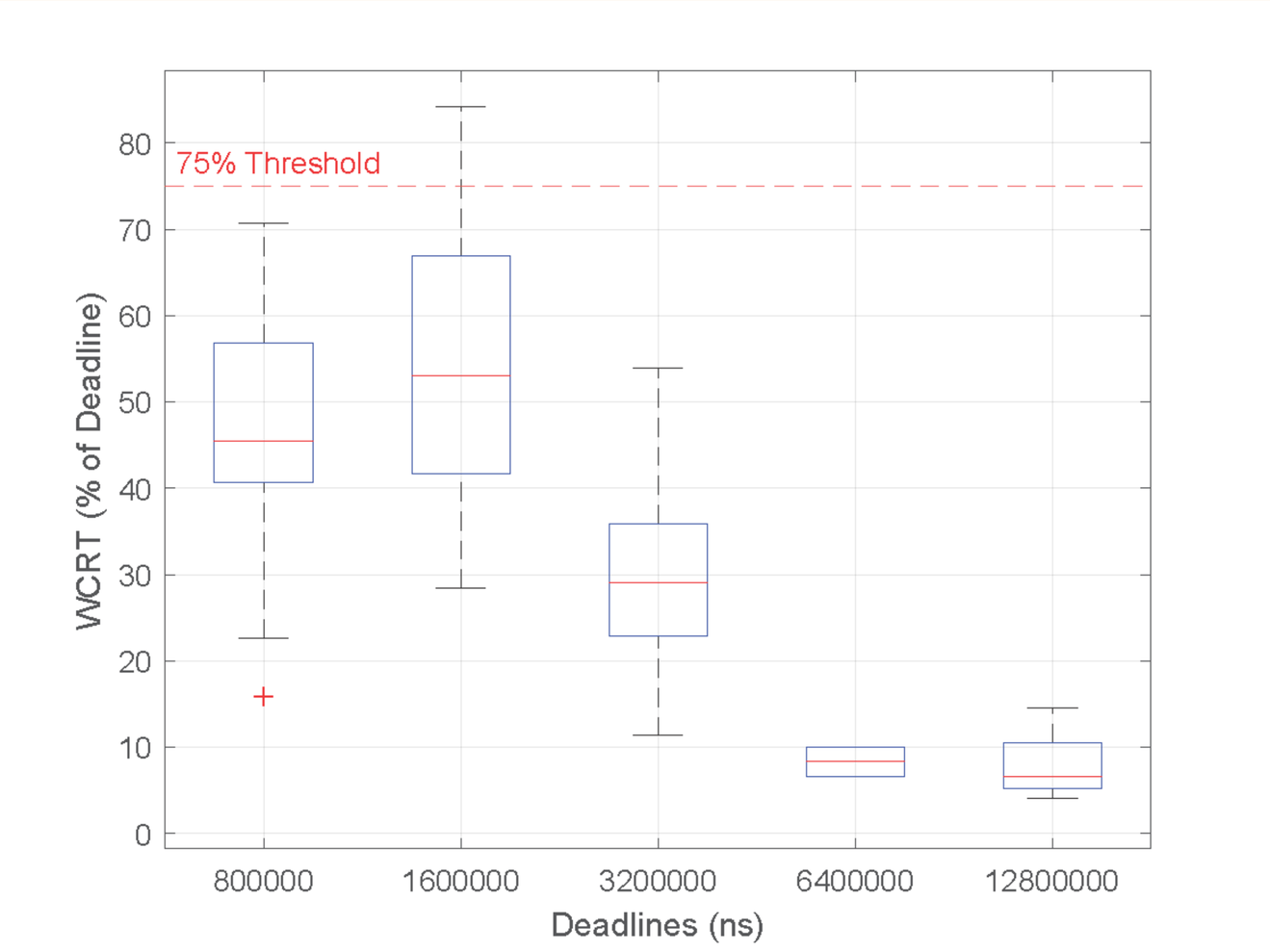
Configuration

2nd iteration



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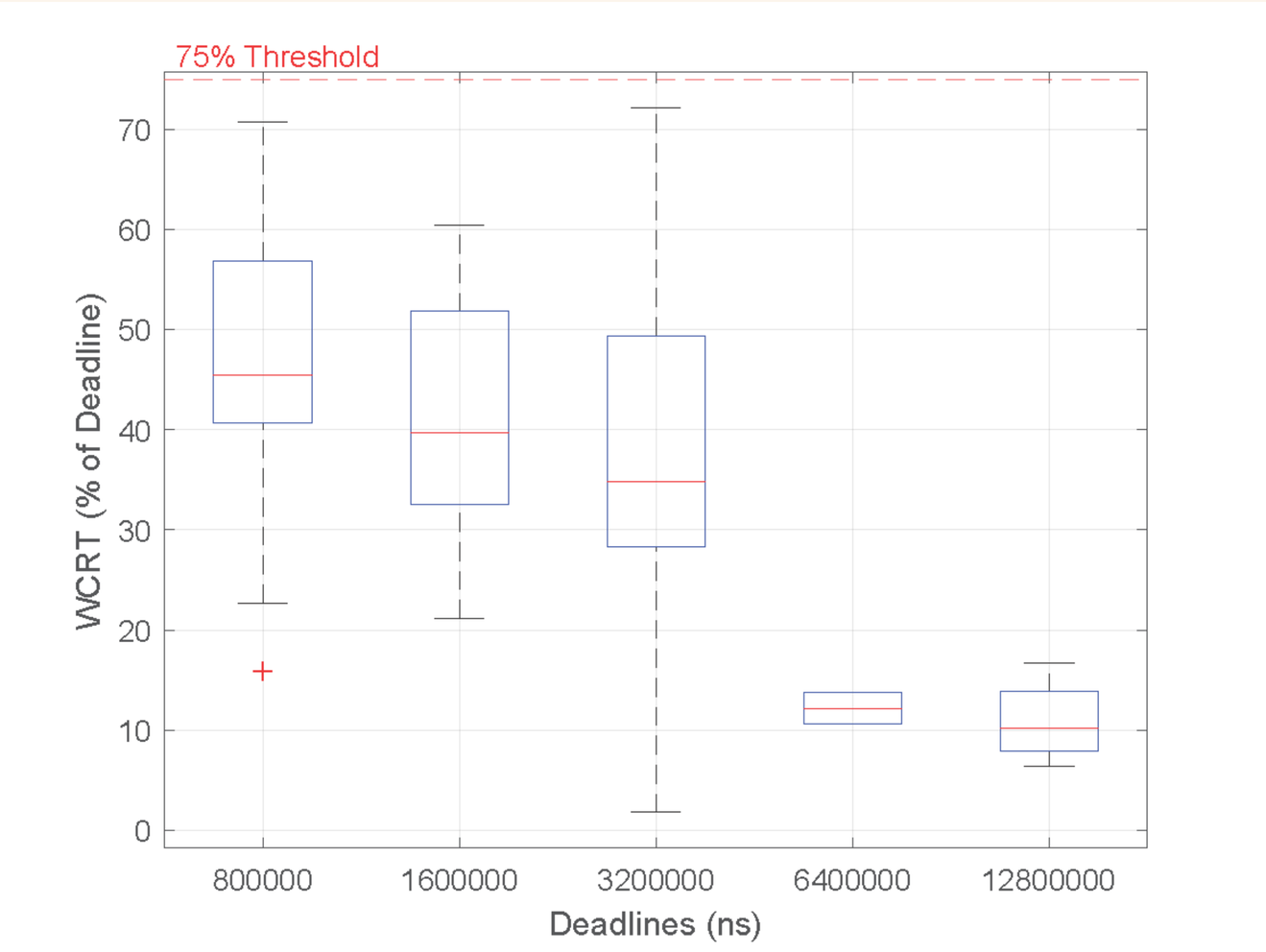
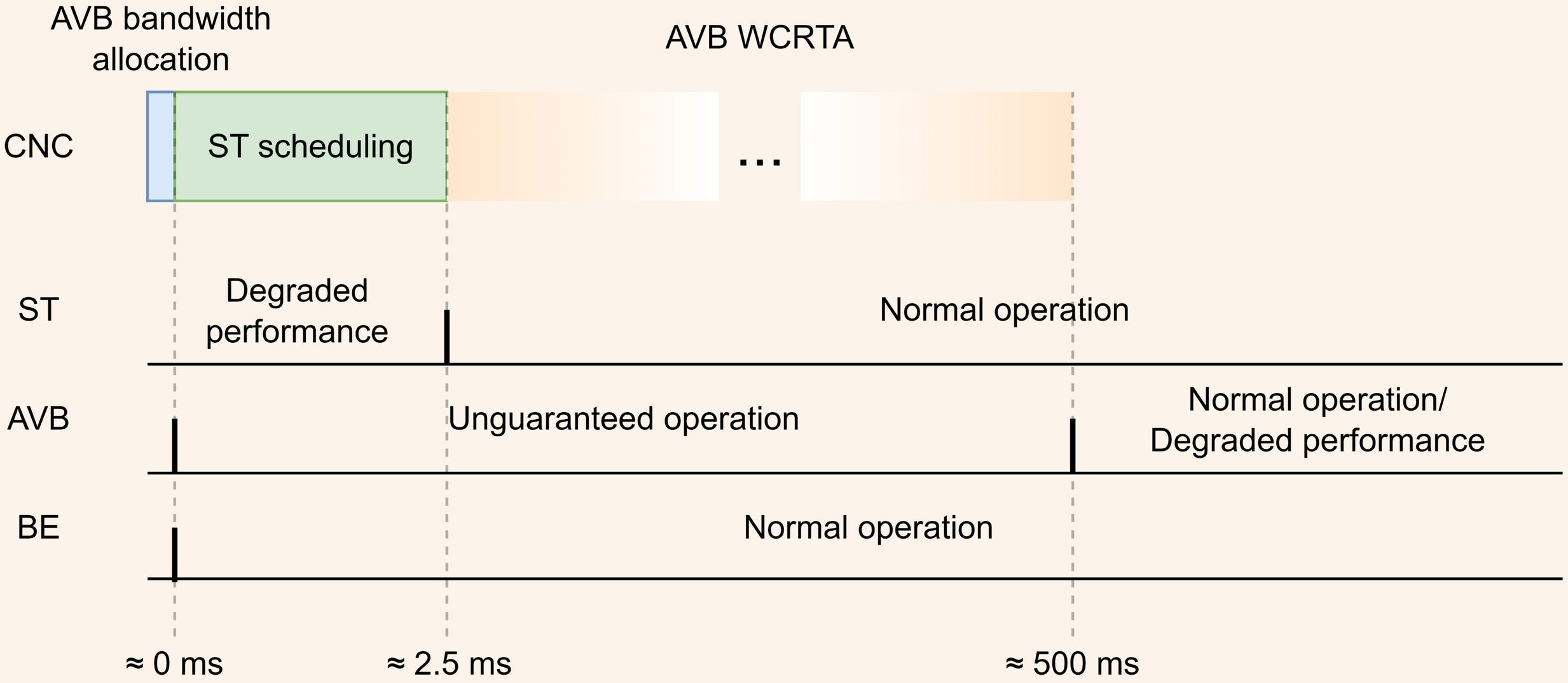
Configuration

3rd iteration



Reconfiguration



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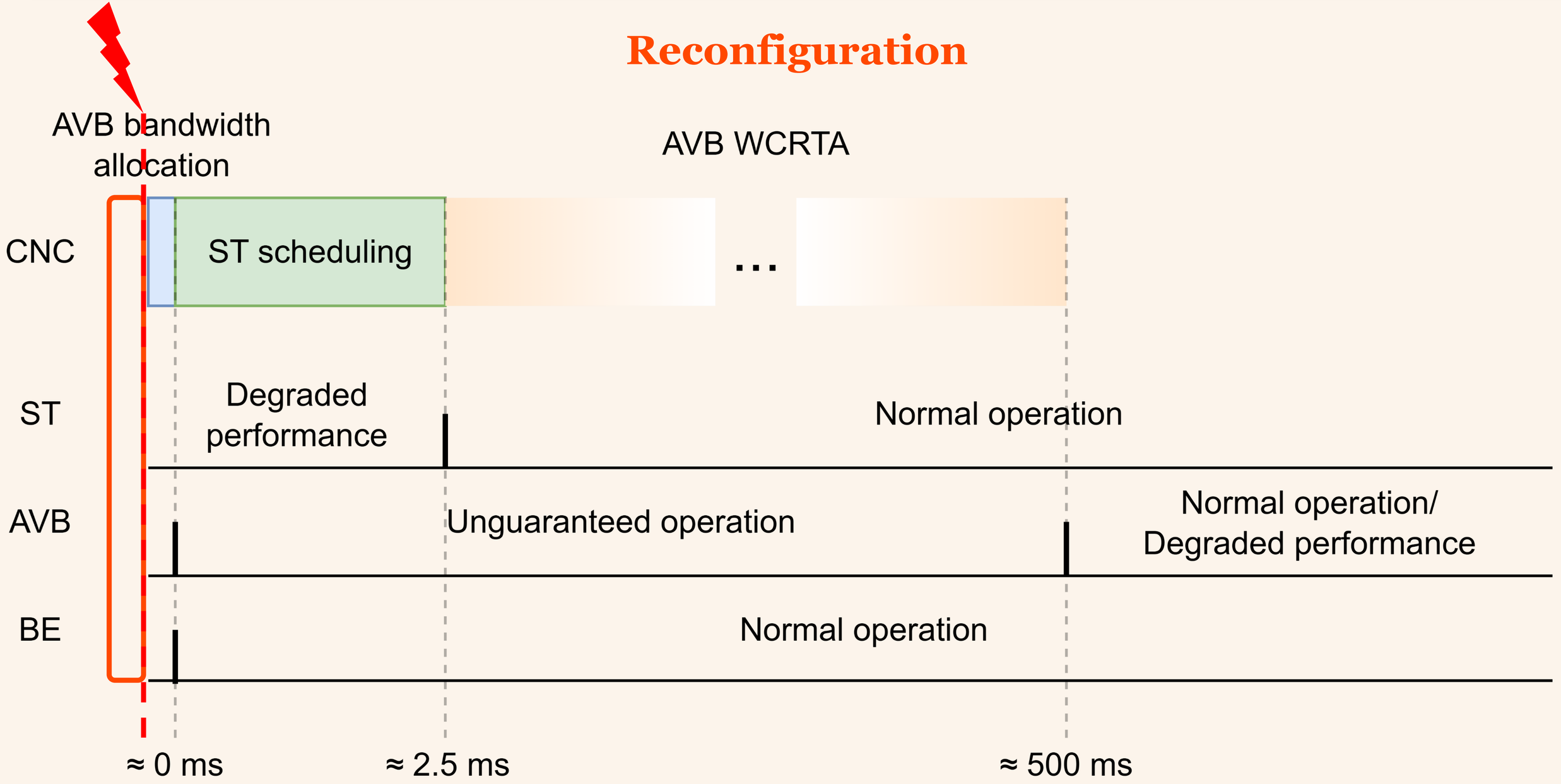

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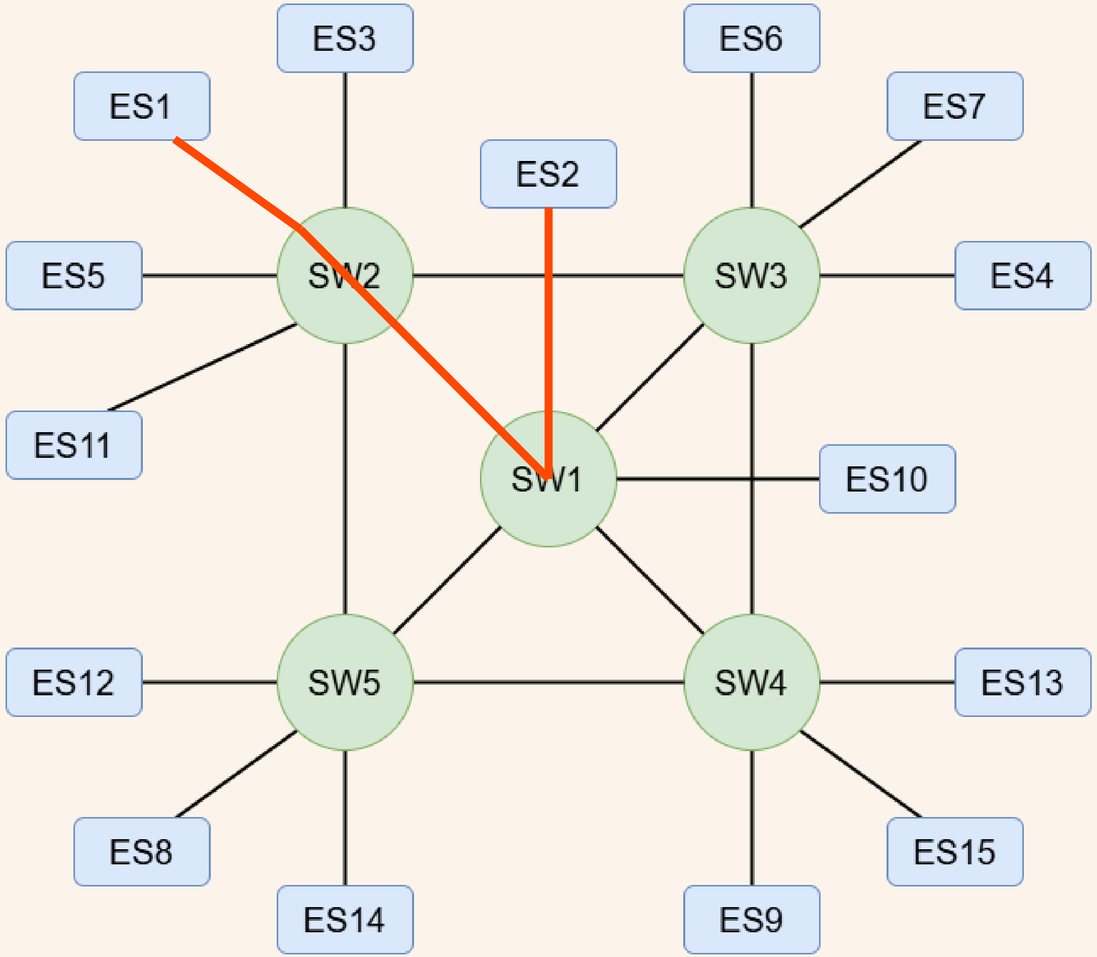

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STR_ES1_ES2_A.bpath = ES1 SW2 SW3 SW1 ES2
```

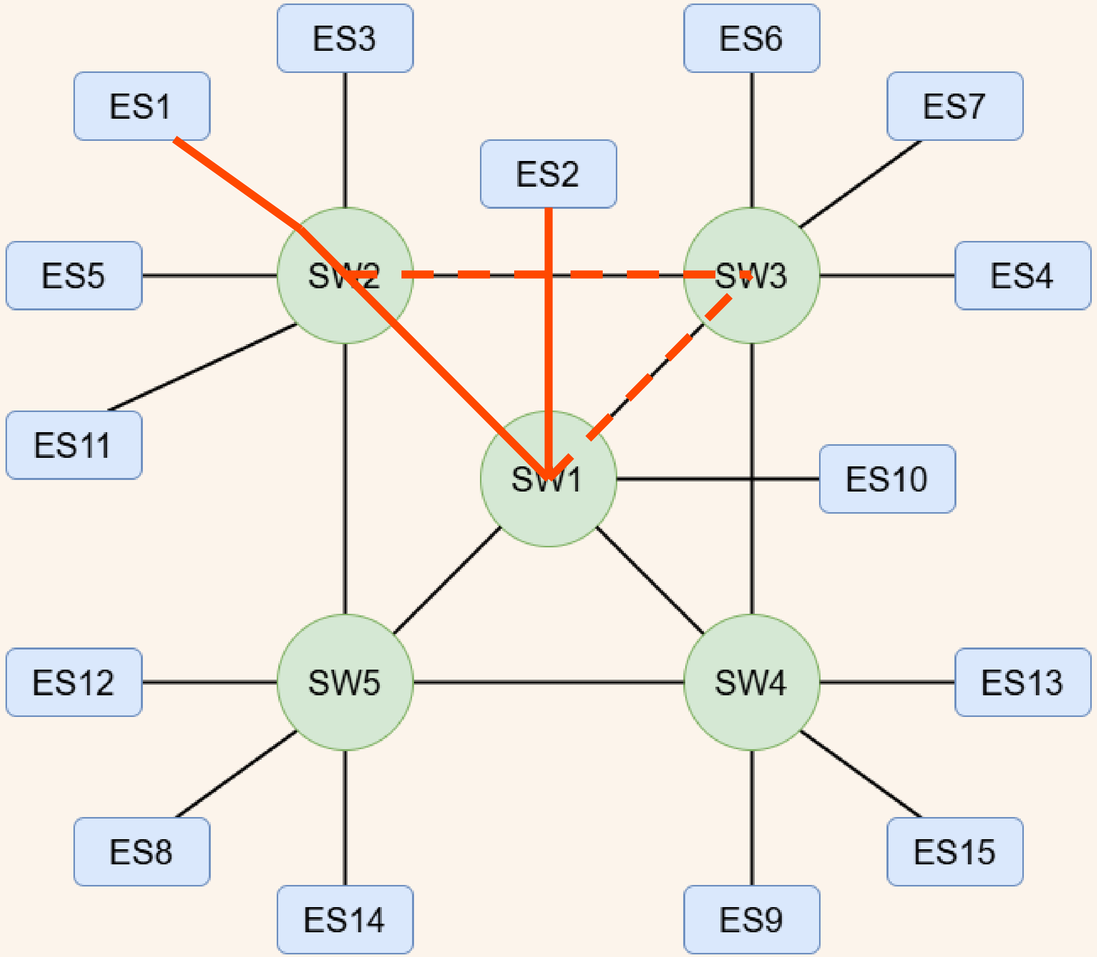

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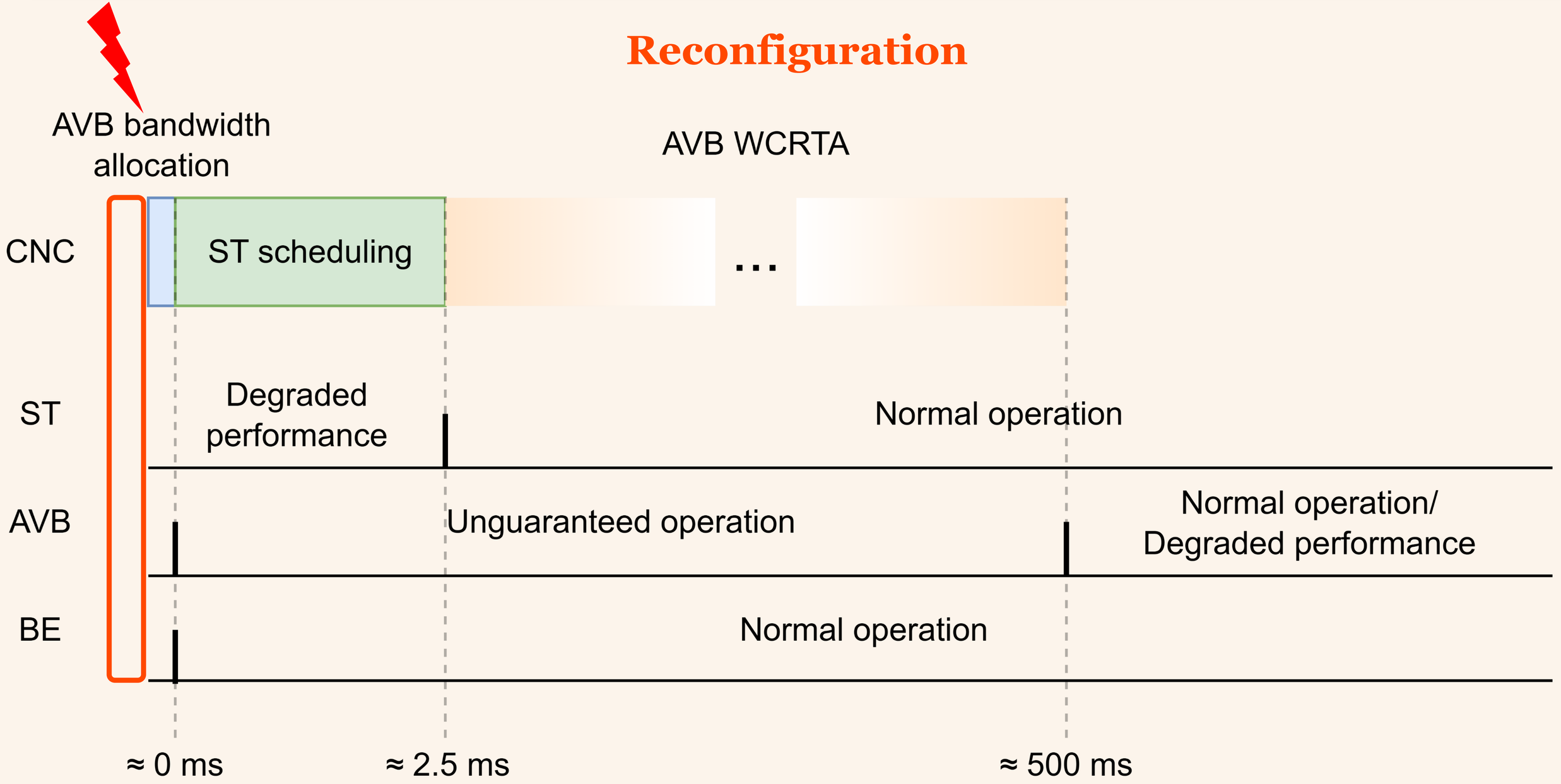

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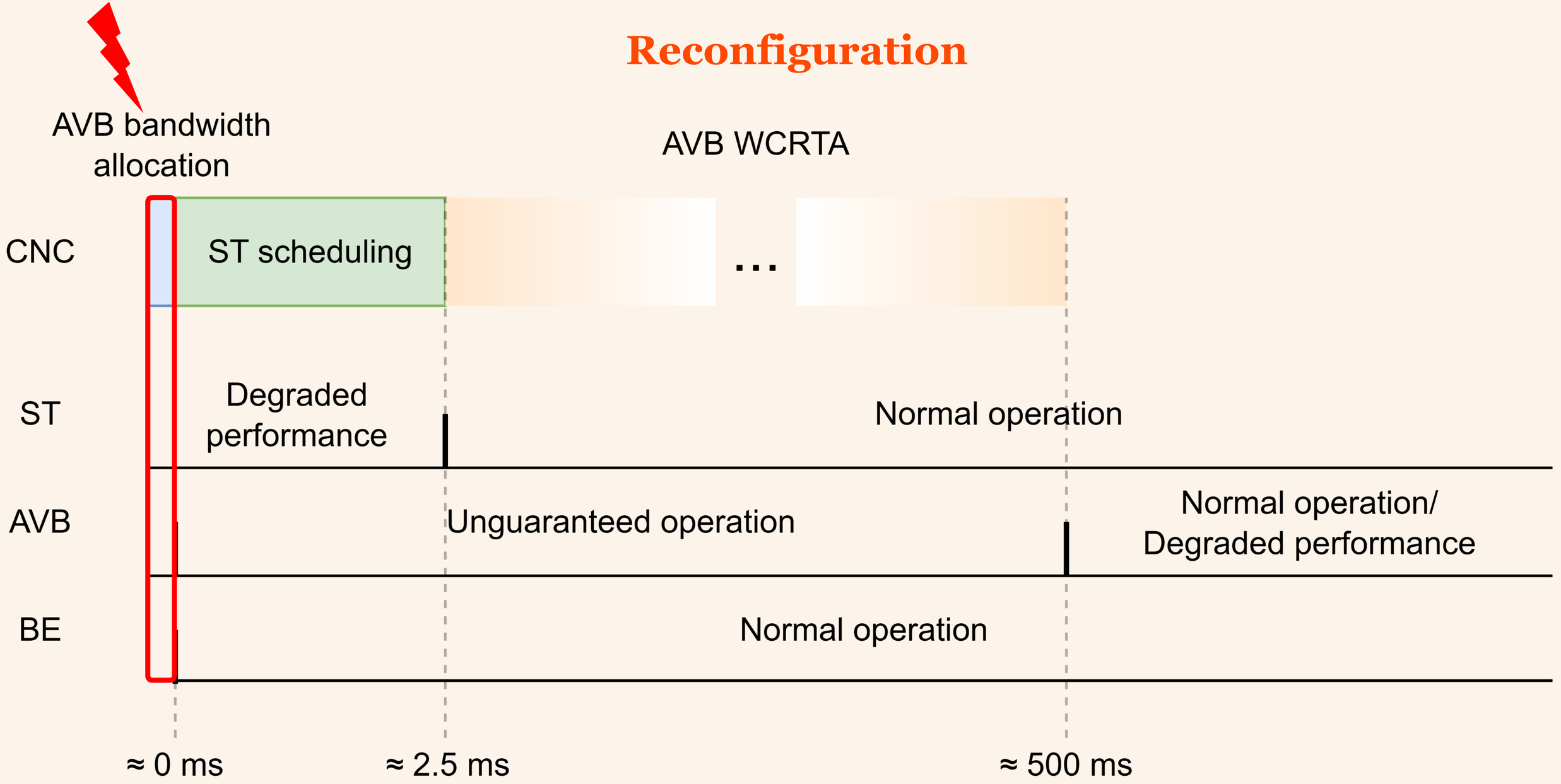
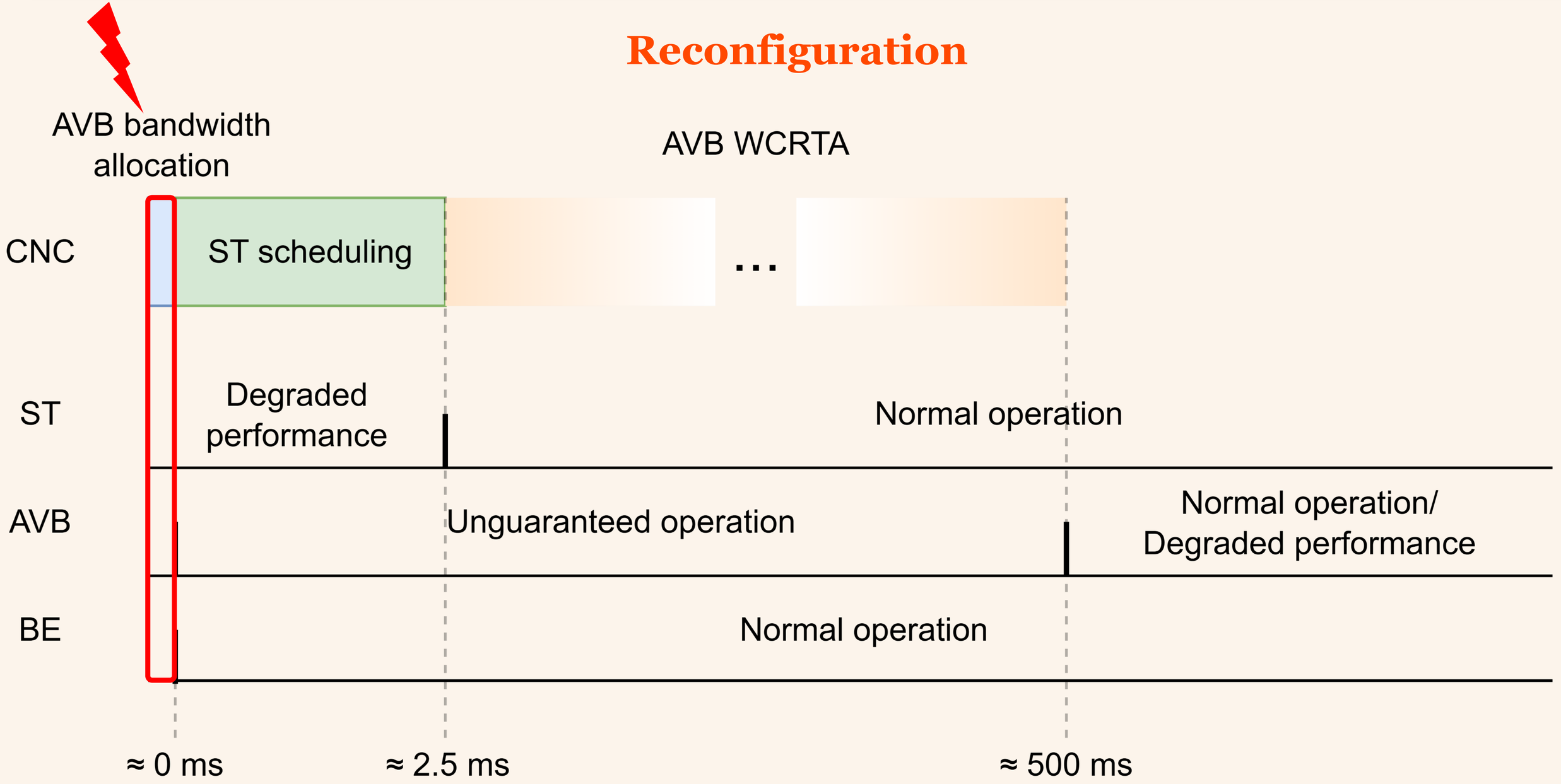


Reconfiguration

$$RBW_l^X = \left(1 - U_l^{BE} - U_l^{ST}\right) \times \frac{U_l^X}{U_l^{AVB}}$$

ST	Temp. ST	AVB Classes	BE
ST streams	New ST Streams	AVB Streams New AVB Str.	BE Streams New BE Streams

Reconfiguration



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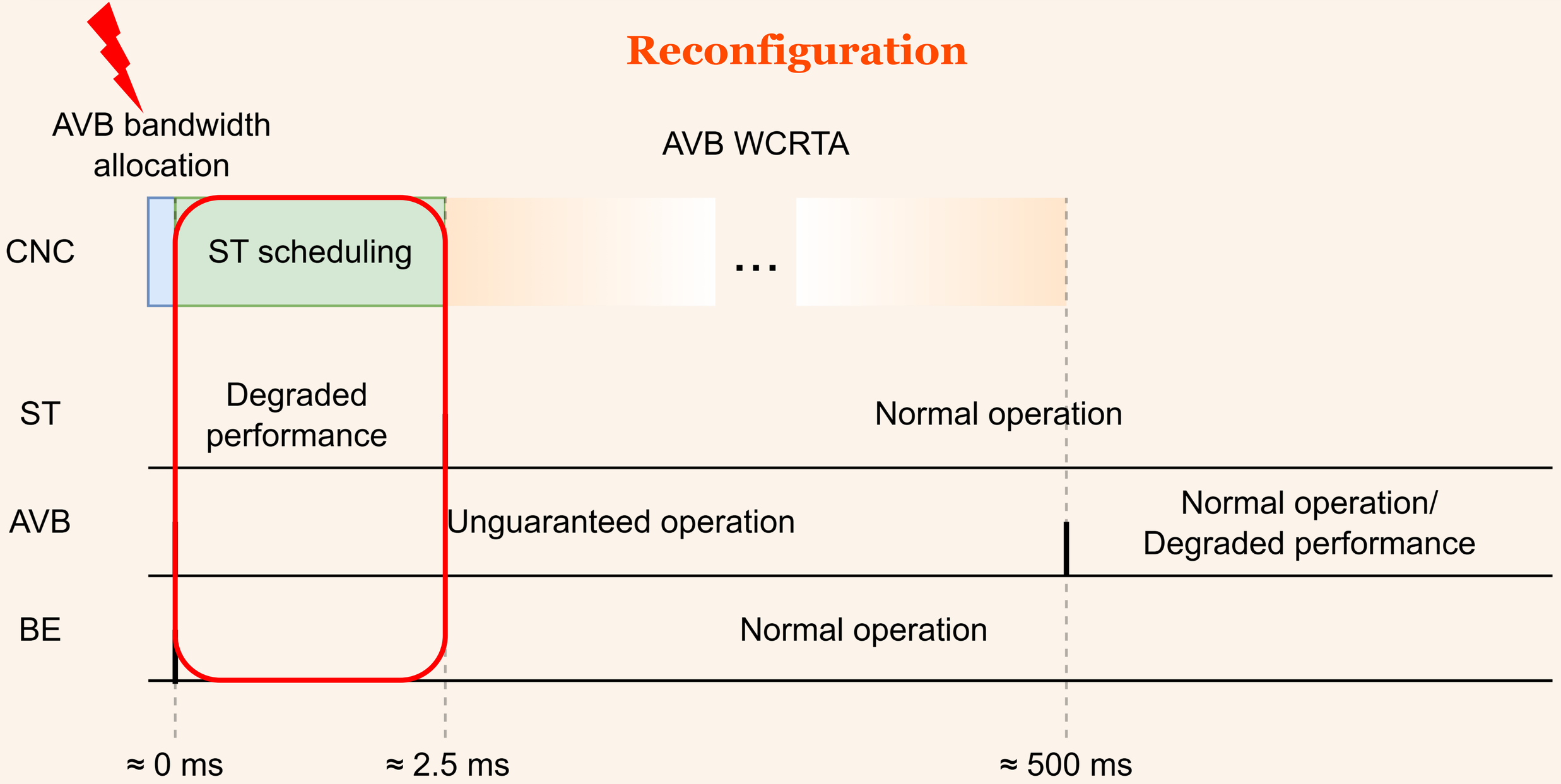
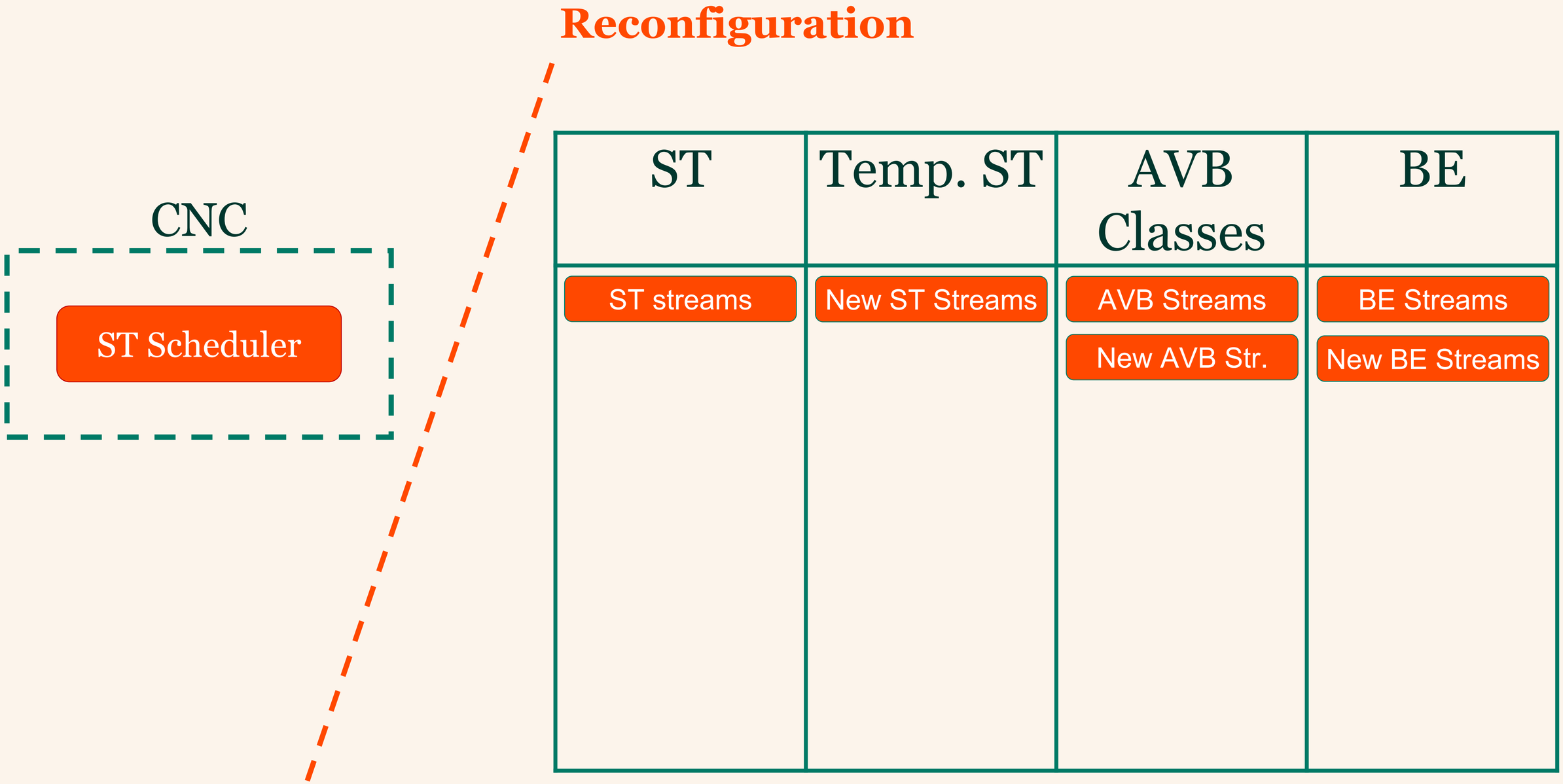
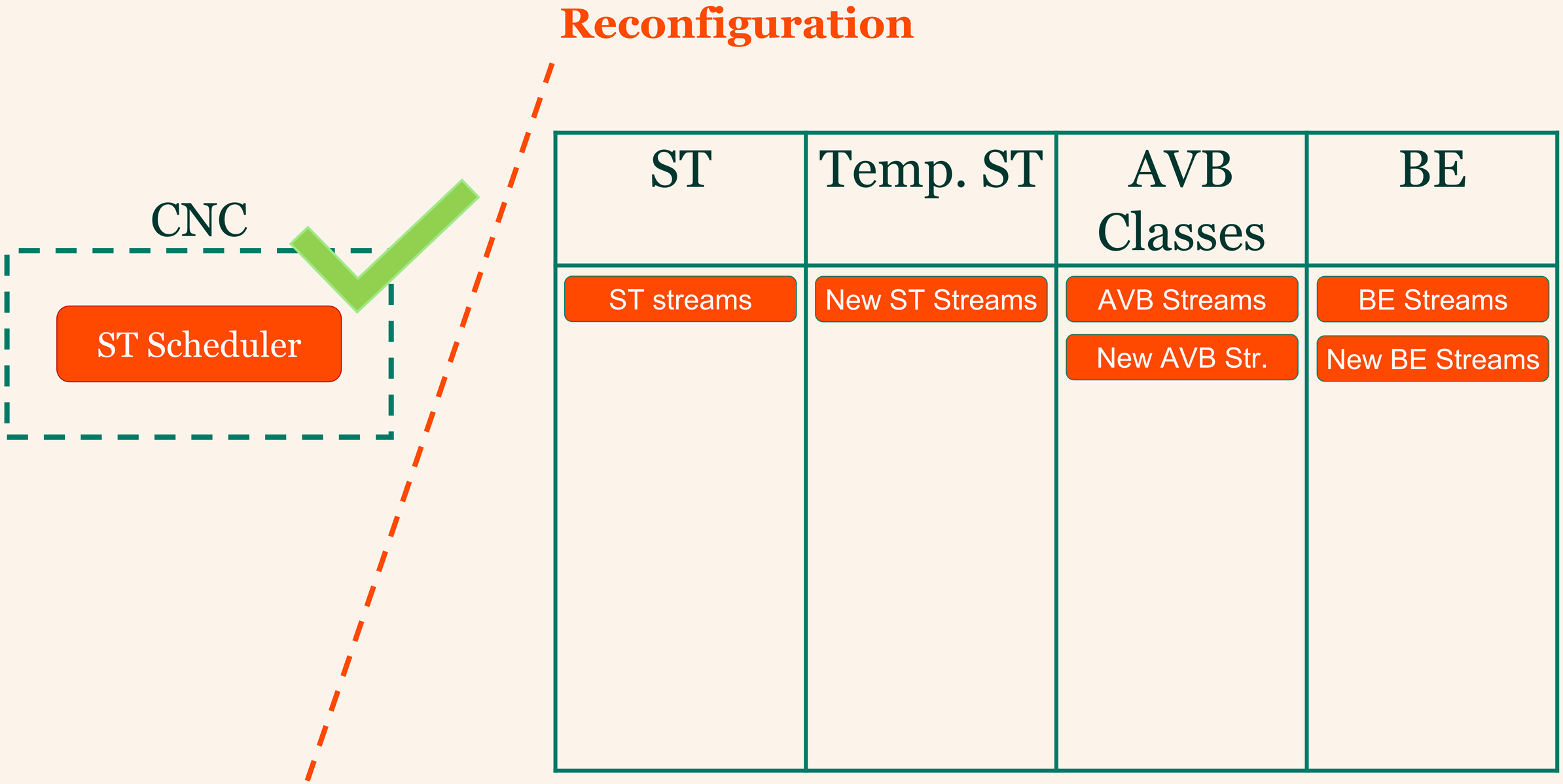



Reconfiguration
CNC
ST Scheduler
ST
Temp. ST
AVB Classes
BE
ST streams
New ST Streams
AVB Streams
New AVB Str.
BE Streams
New BE Streams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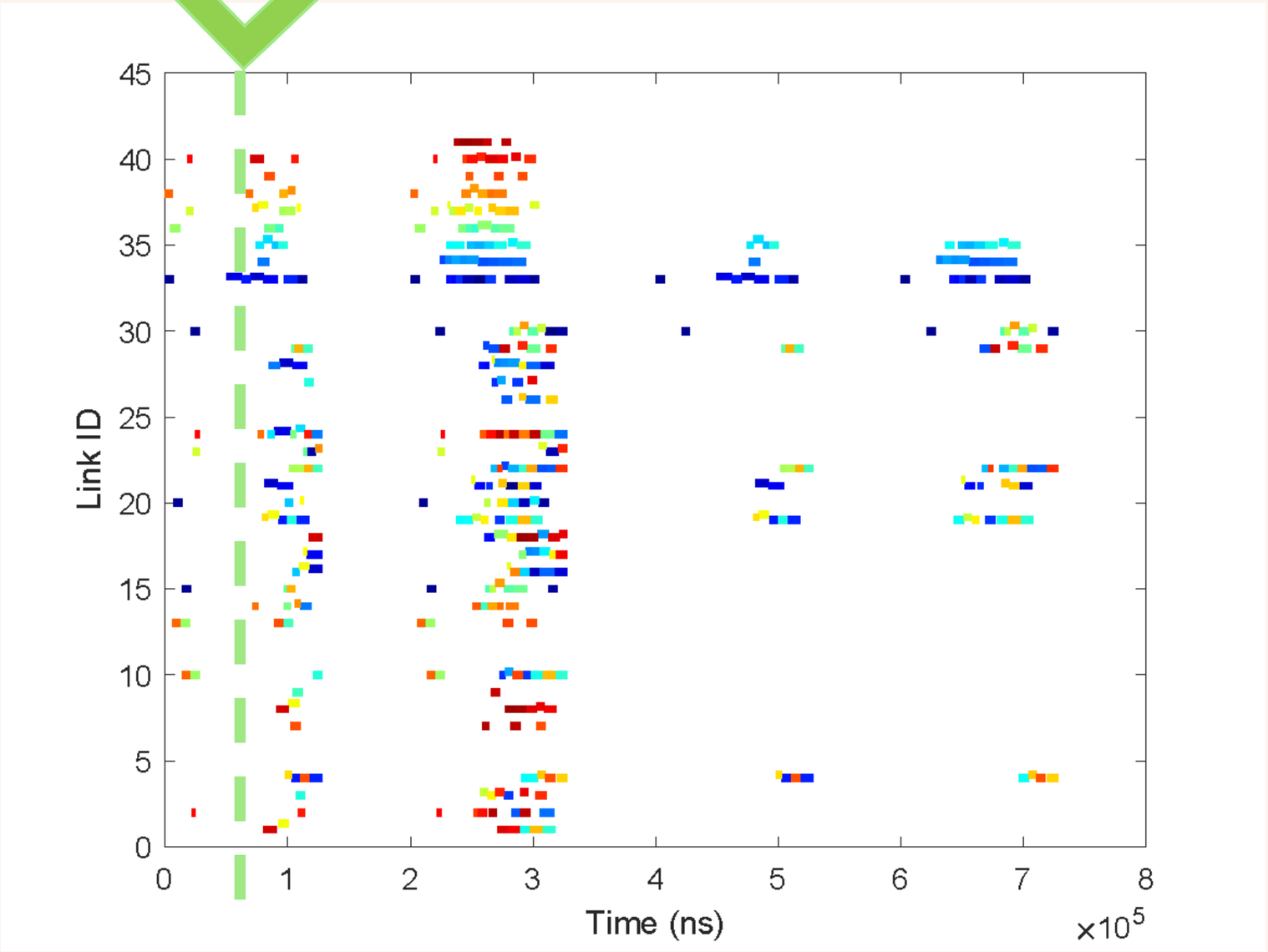

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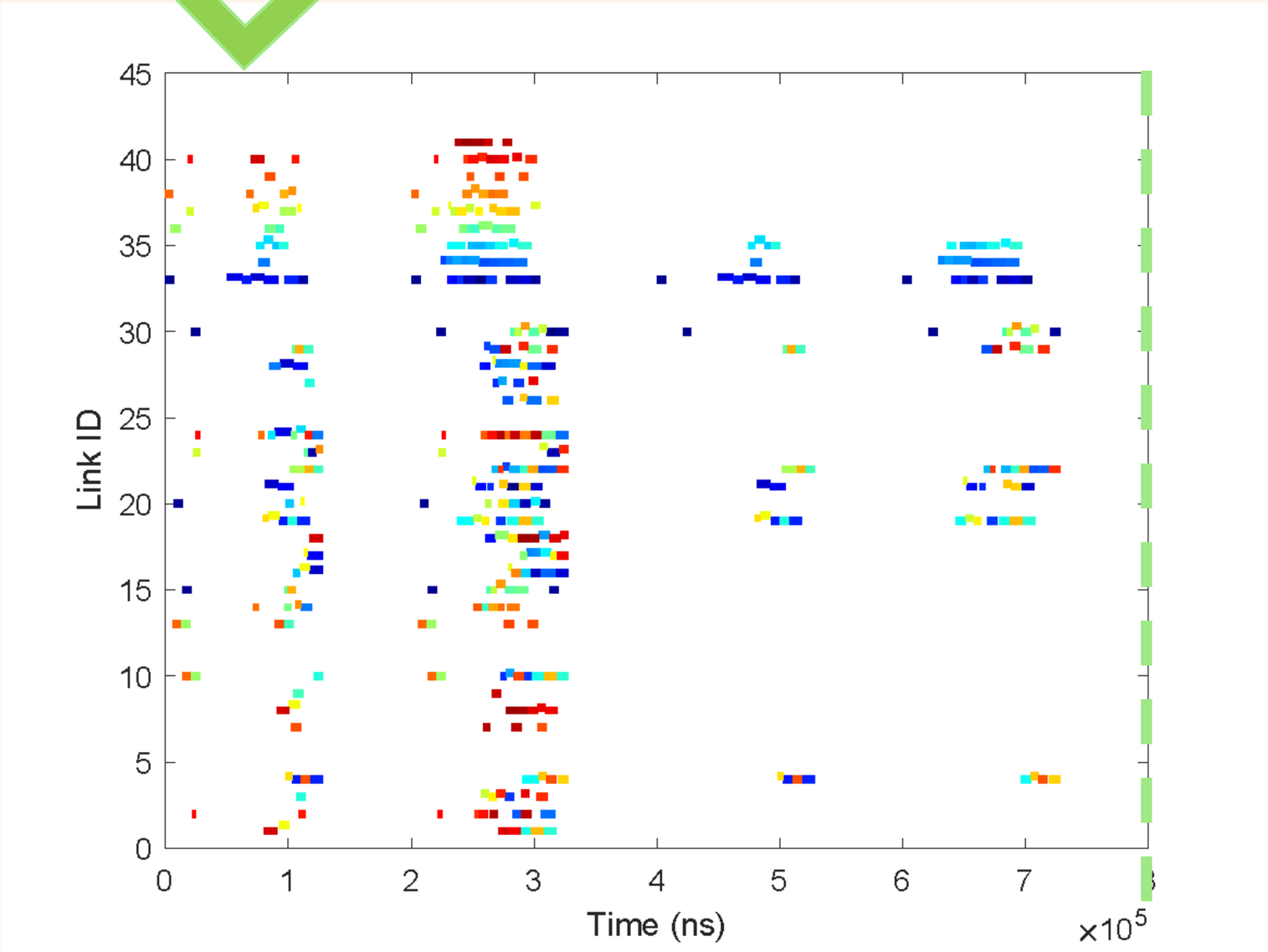

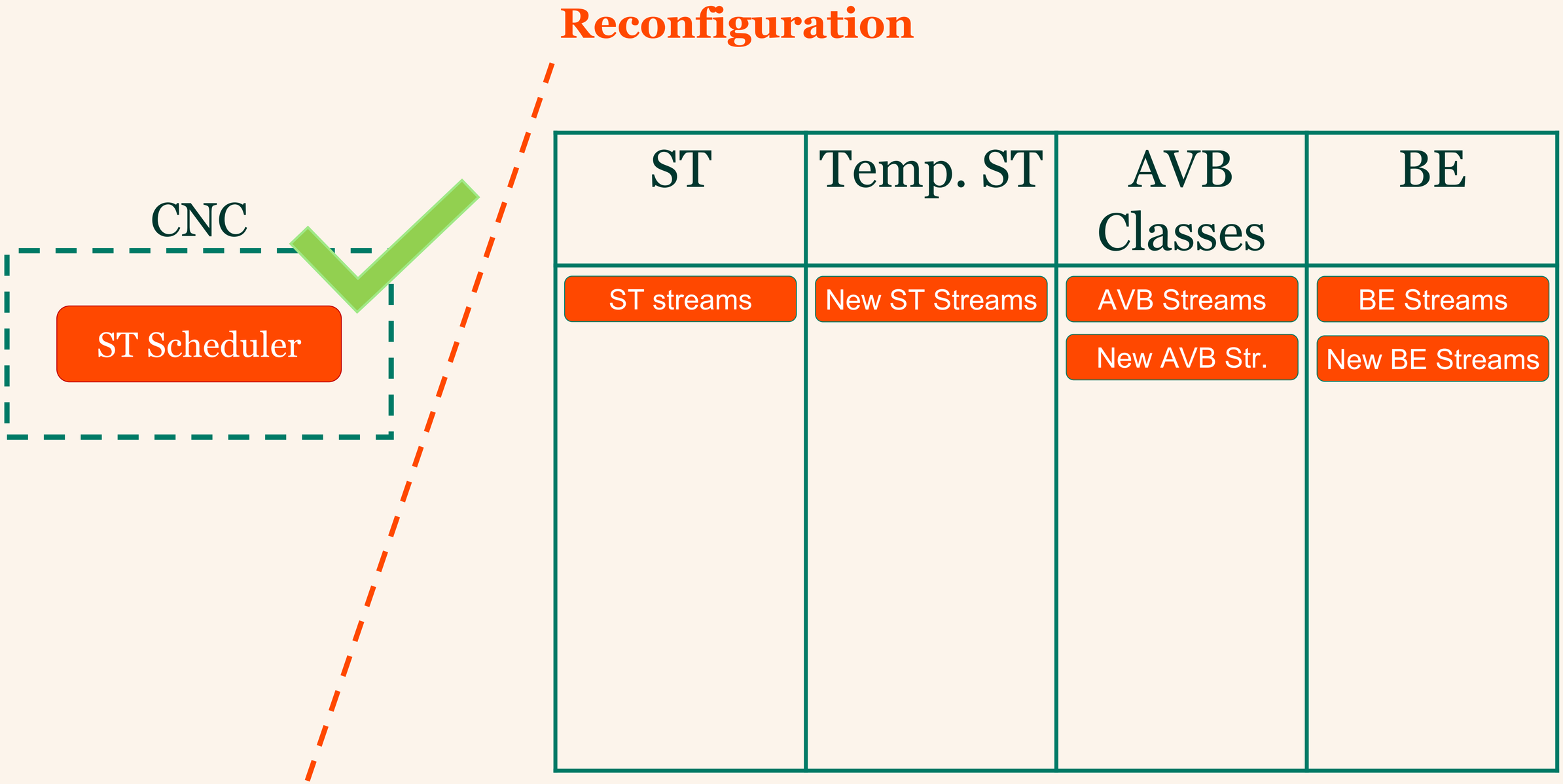
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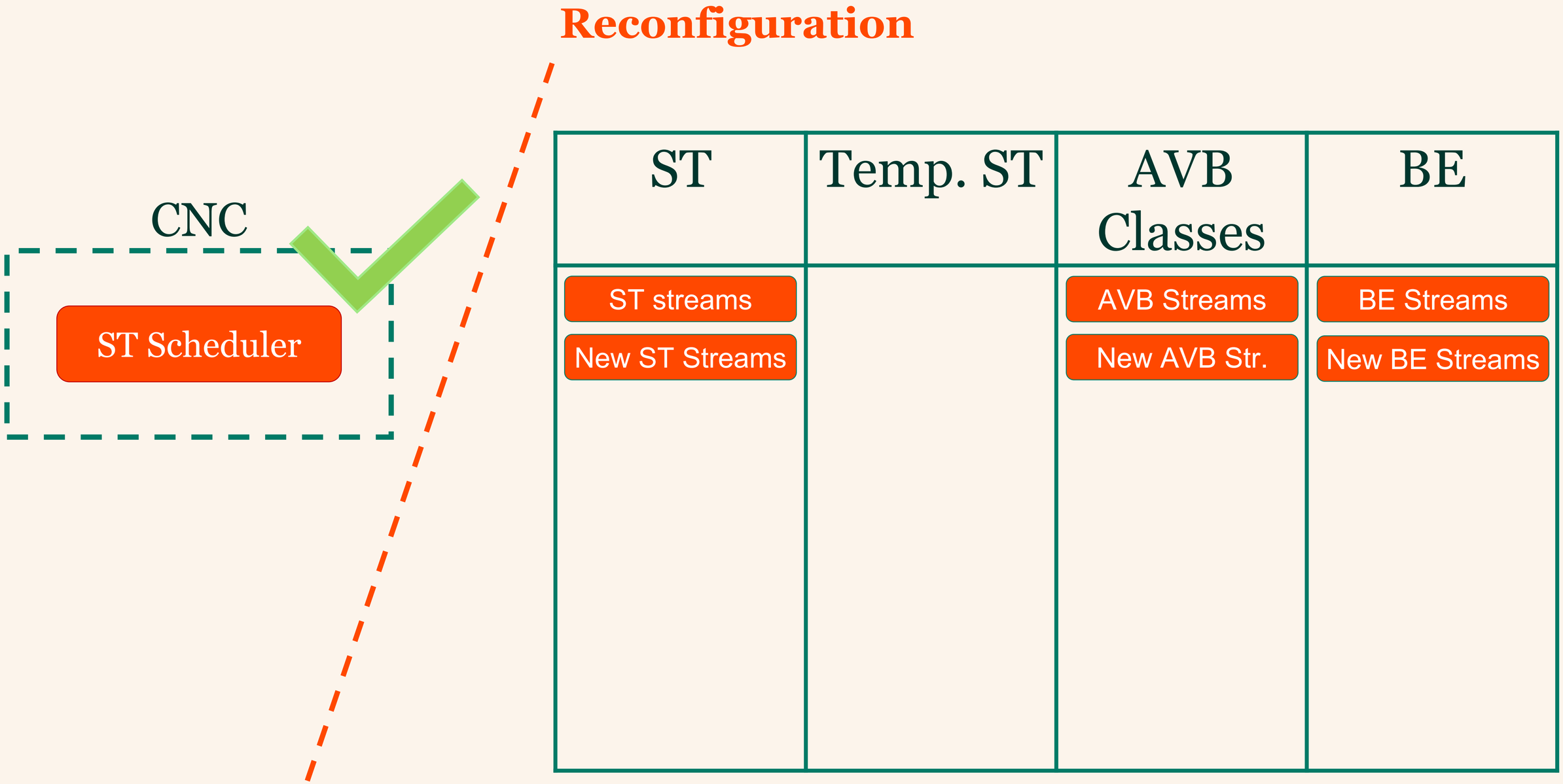
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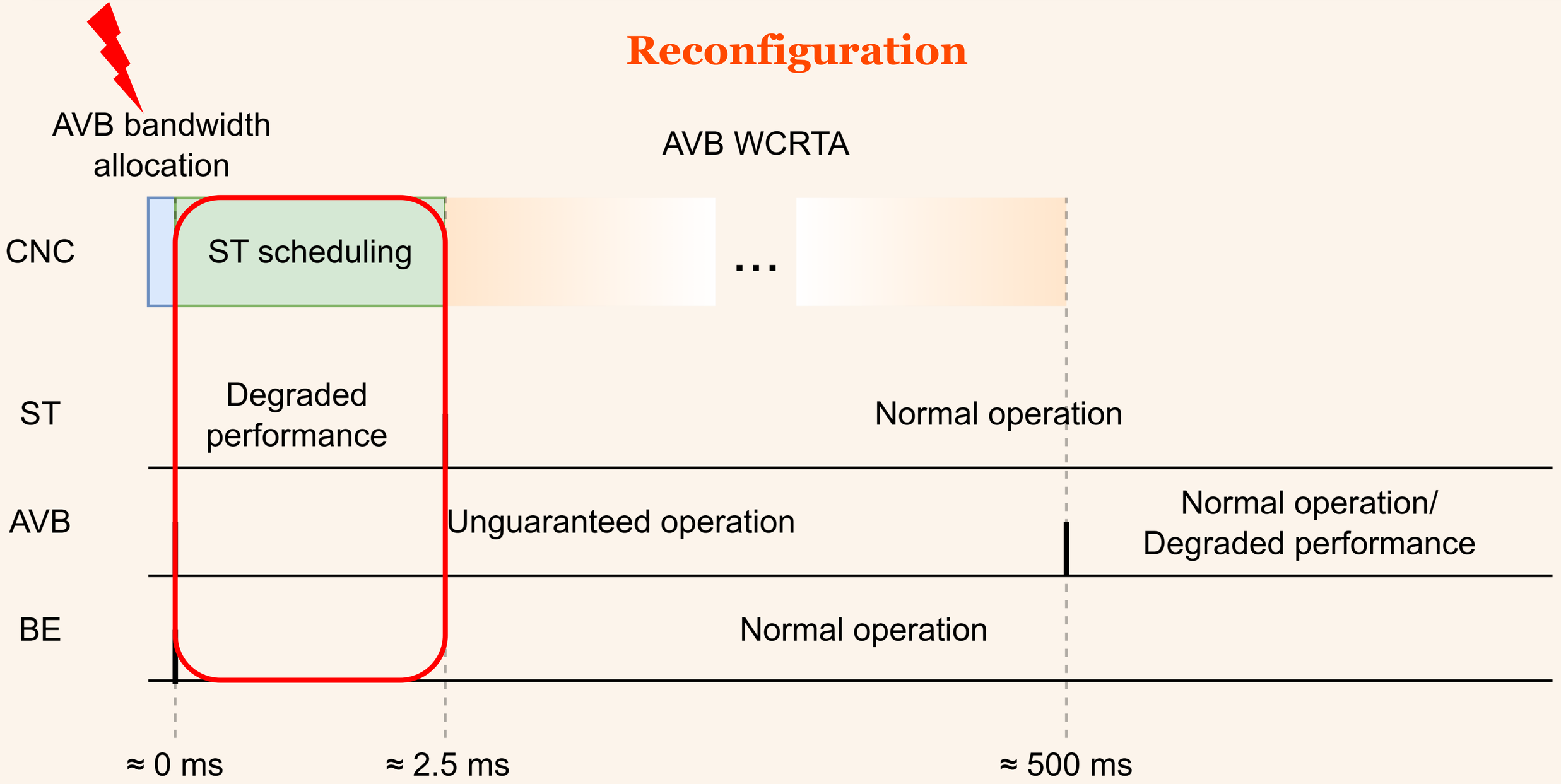

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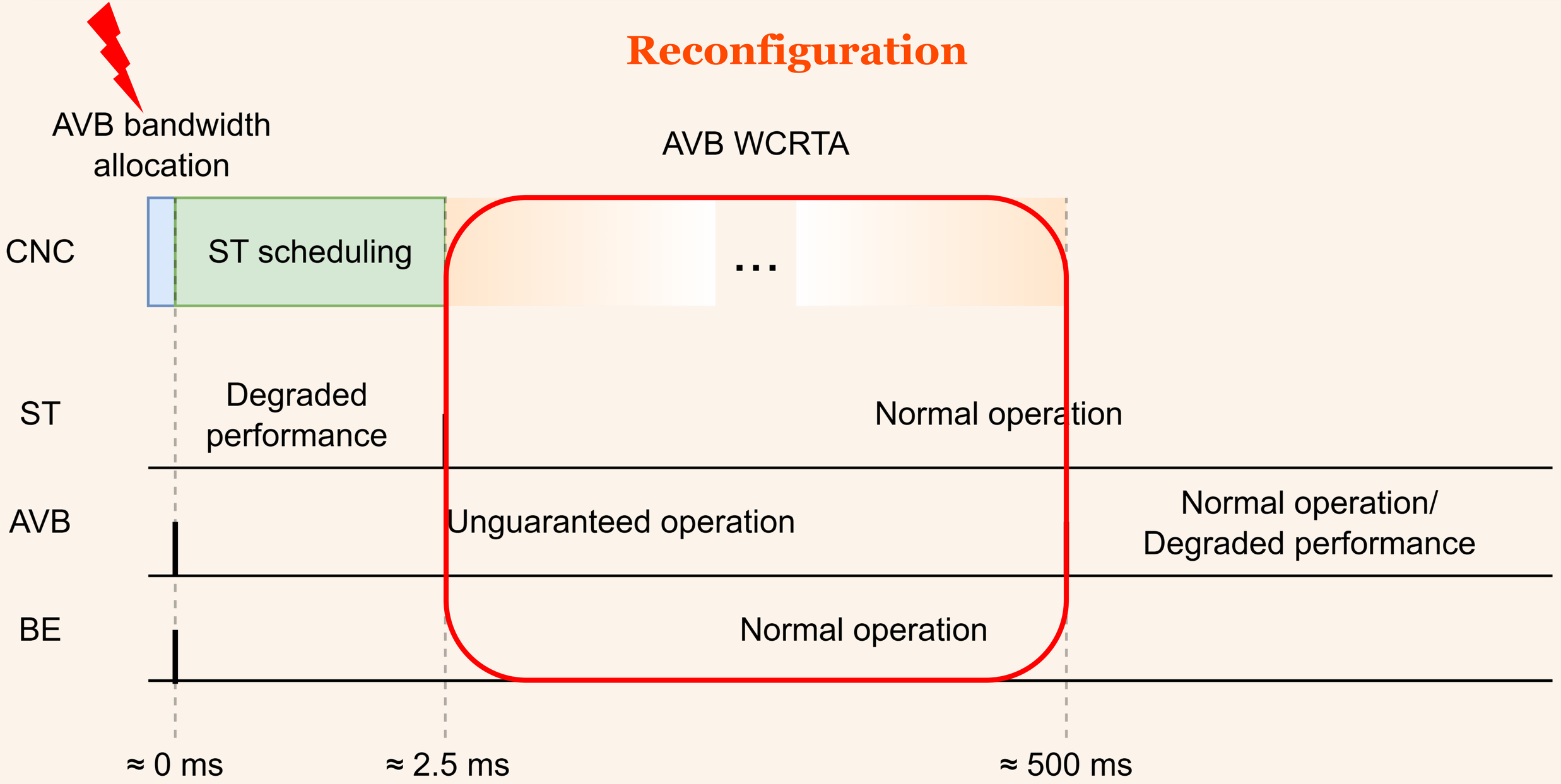
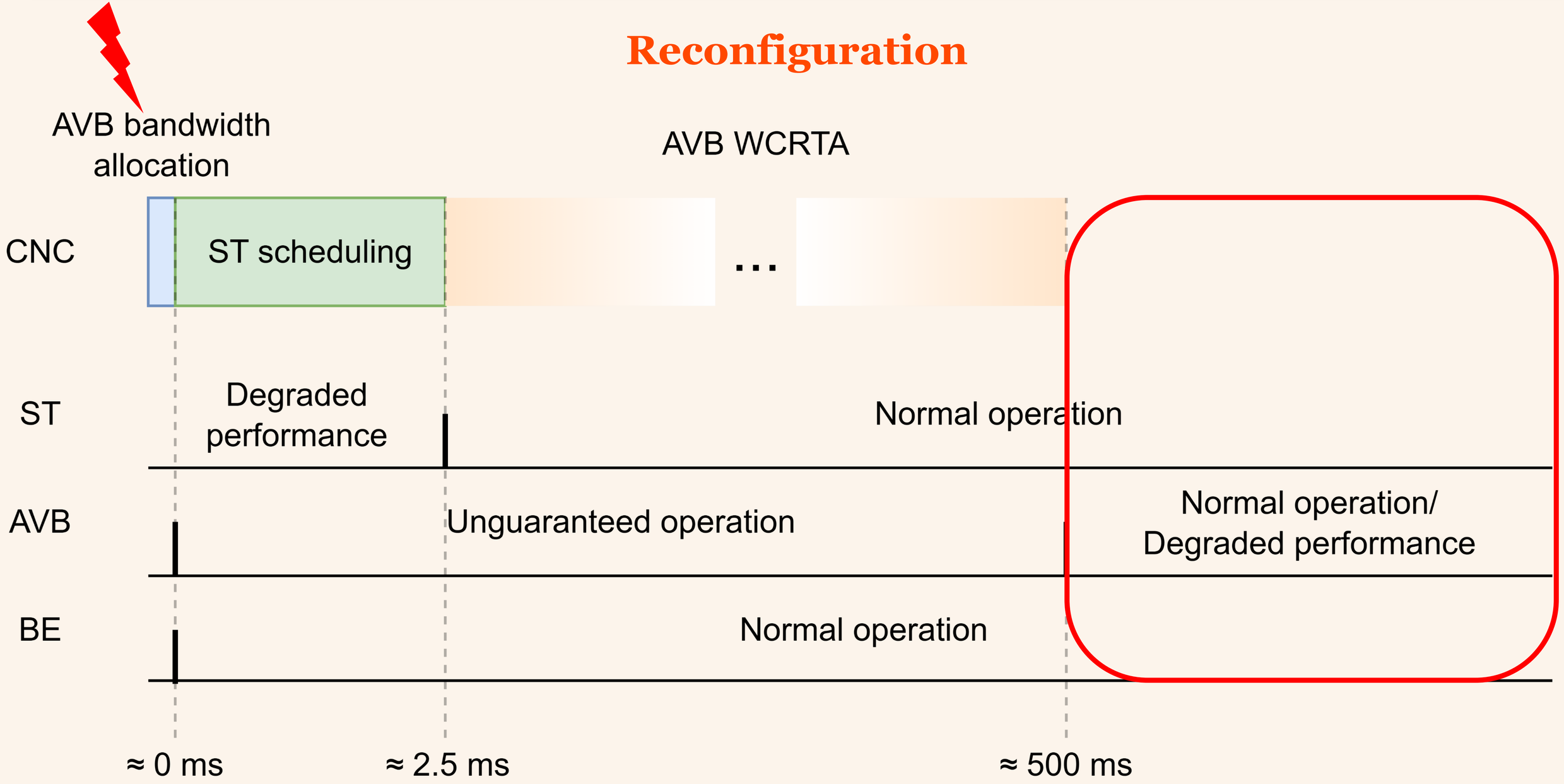
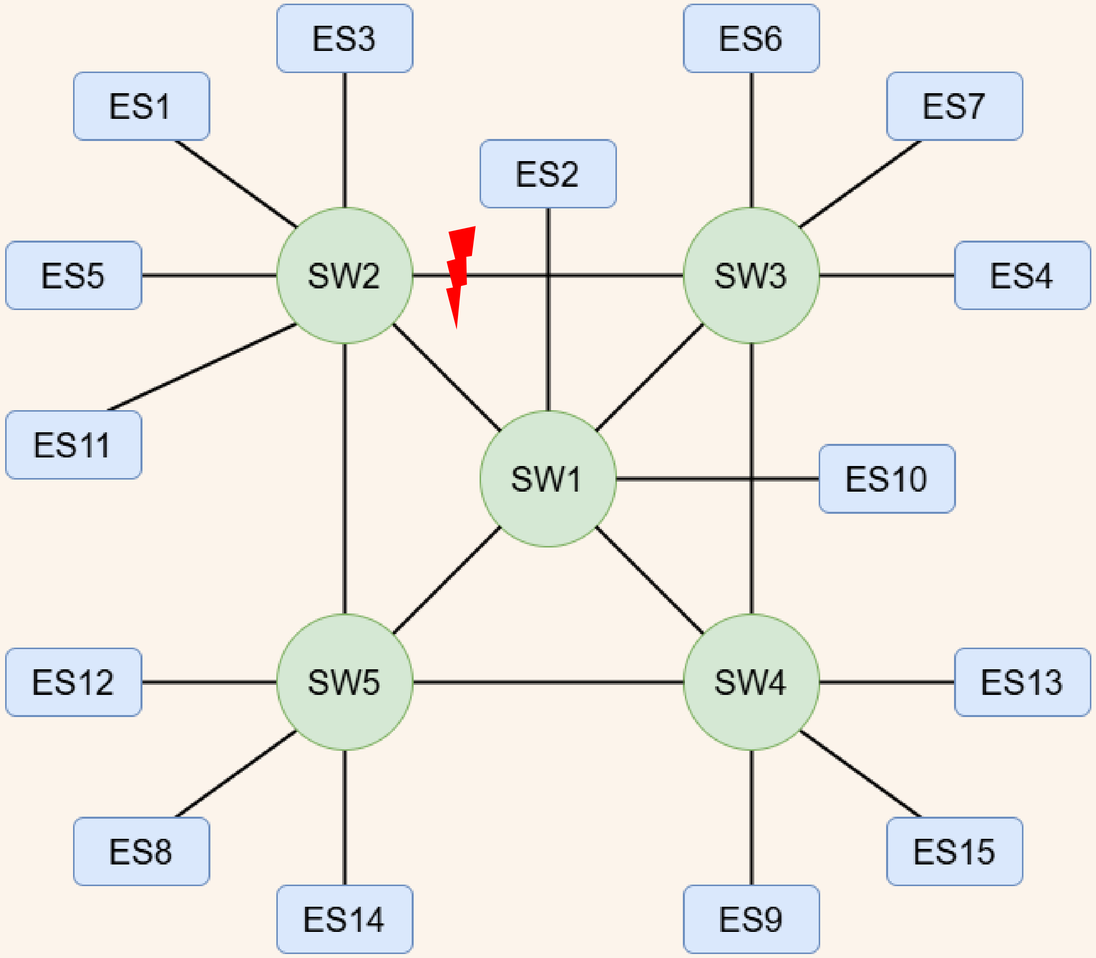


Reconfiguration



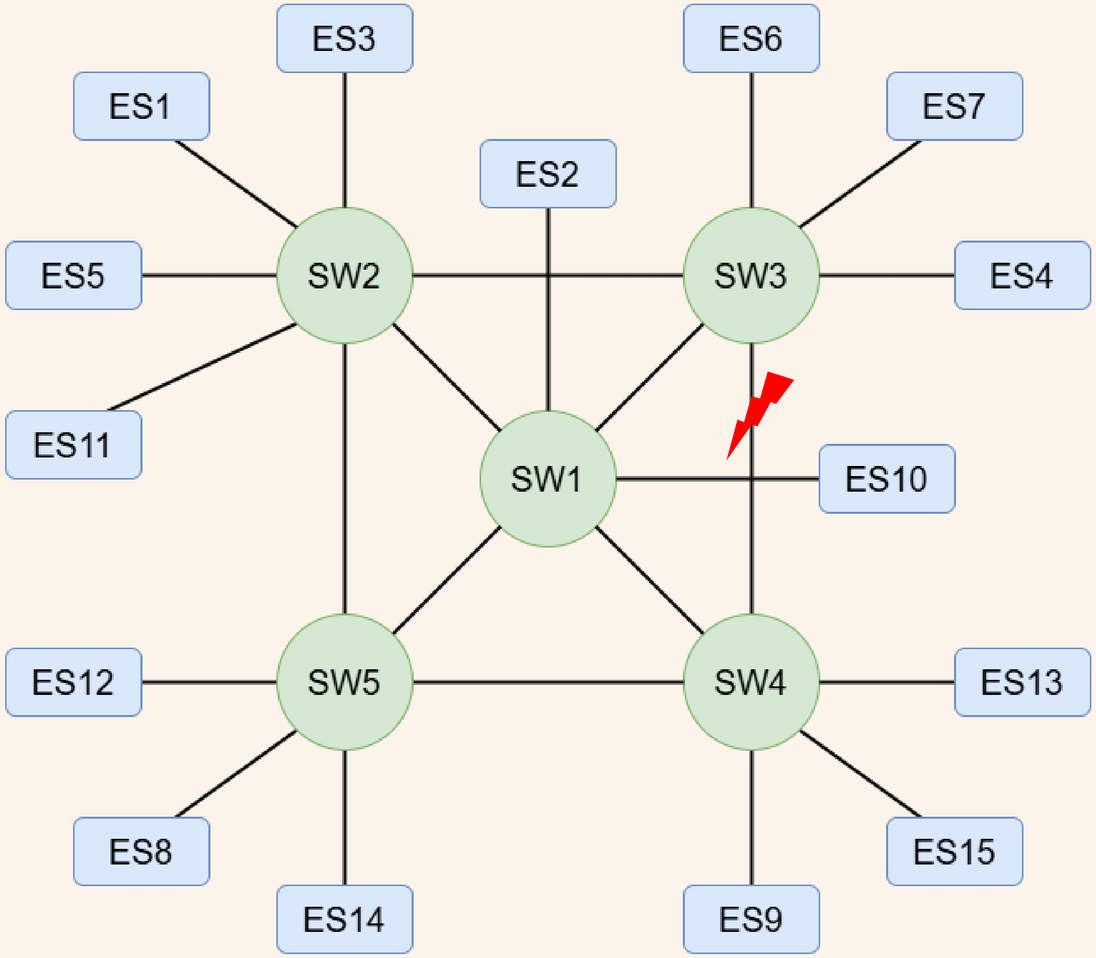
Evaluation and Conclusion



Normal behavior achieves after **3 ms**

guaranteed after **500 ms**

Evaluation and Conclusion



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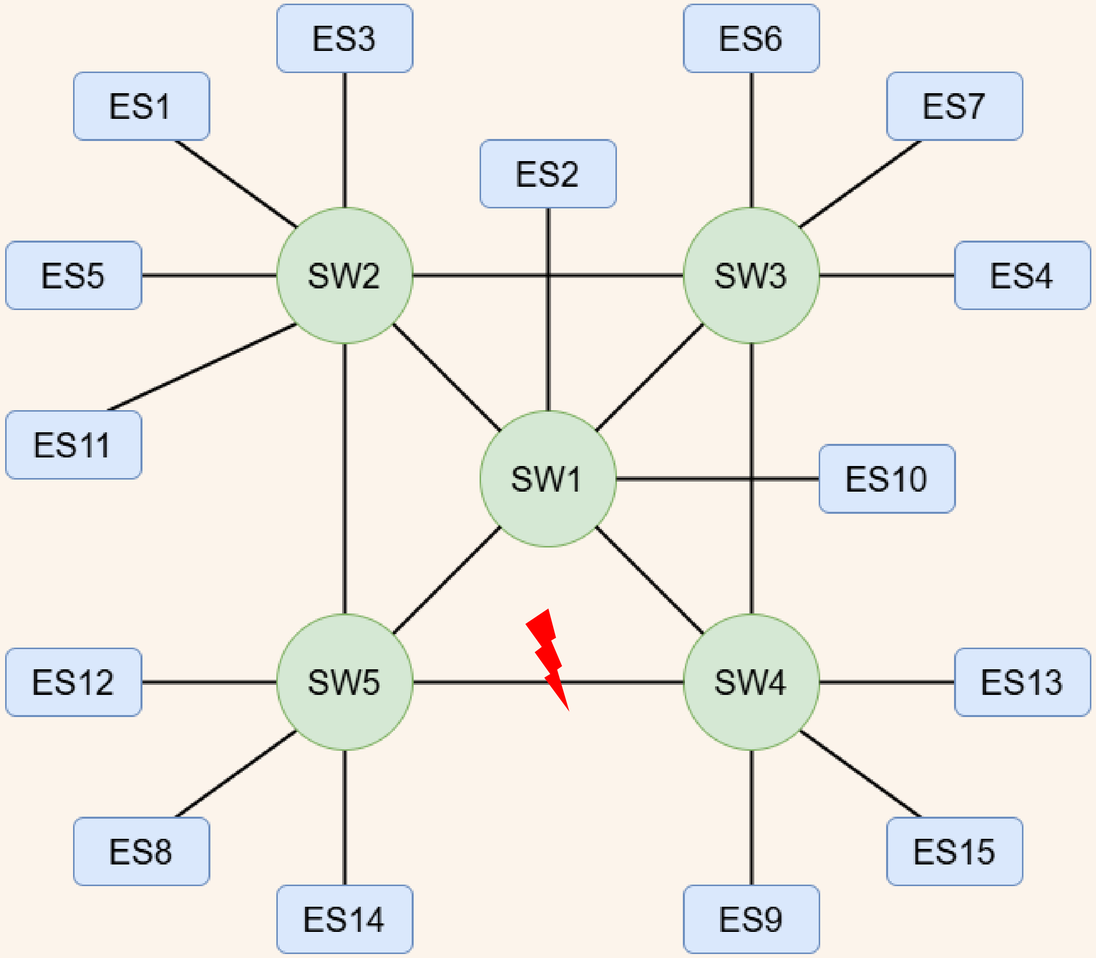

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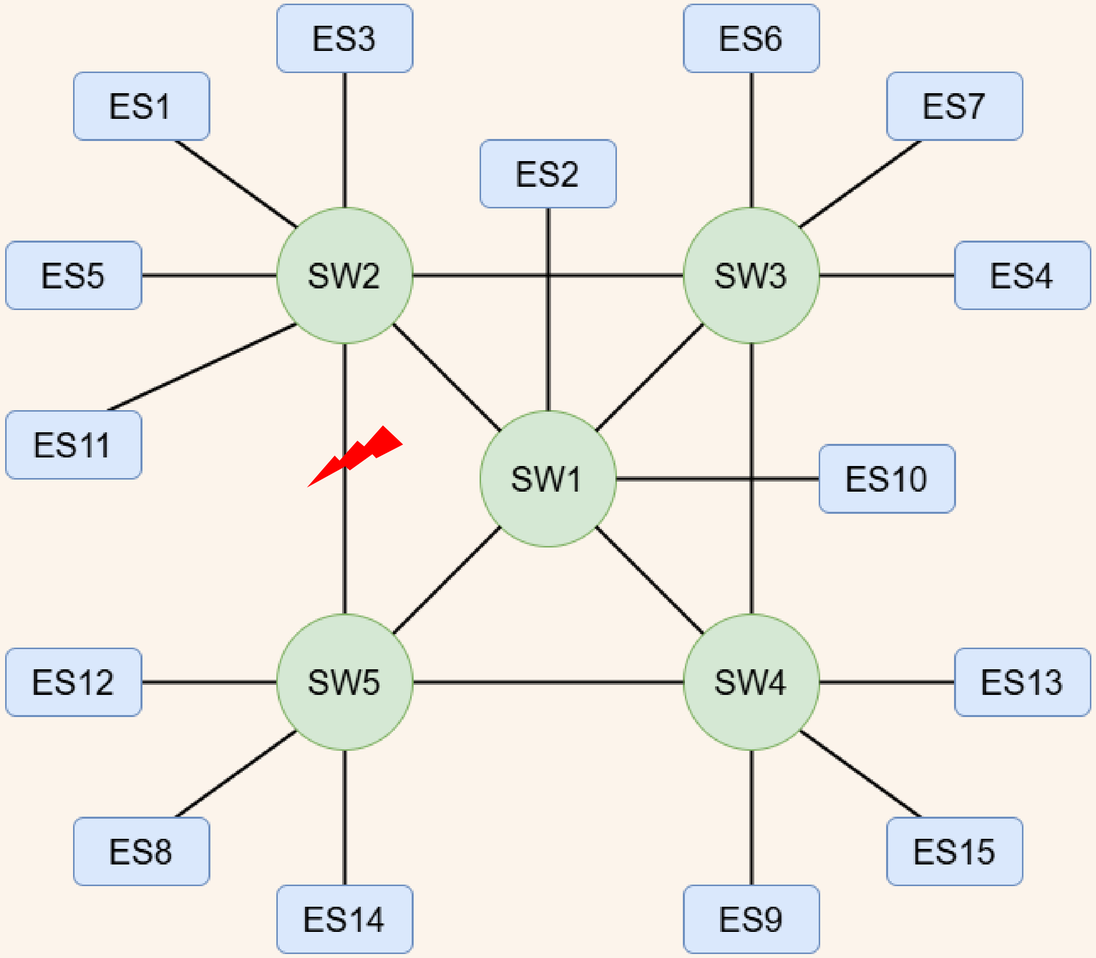

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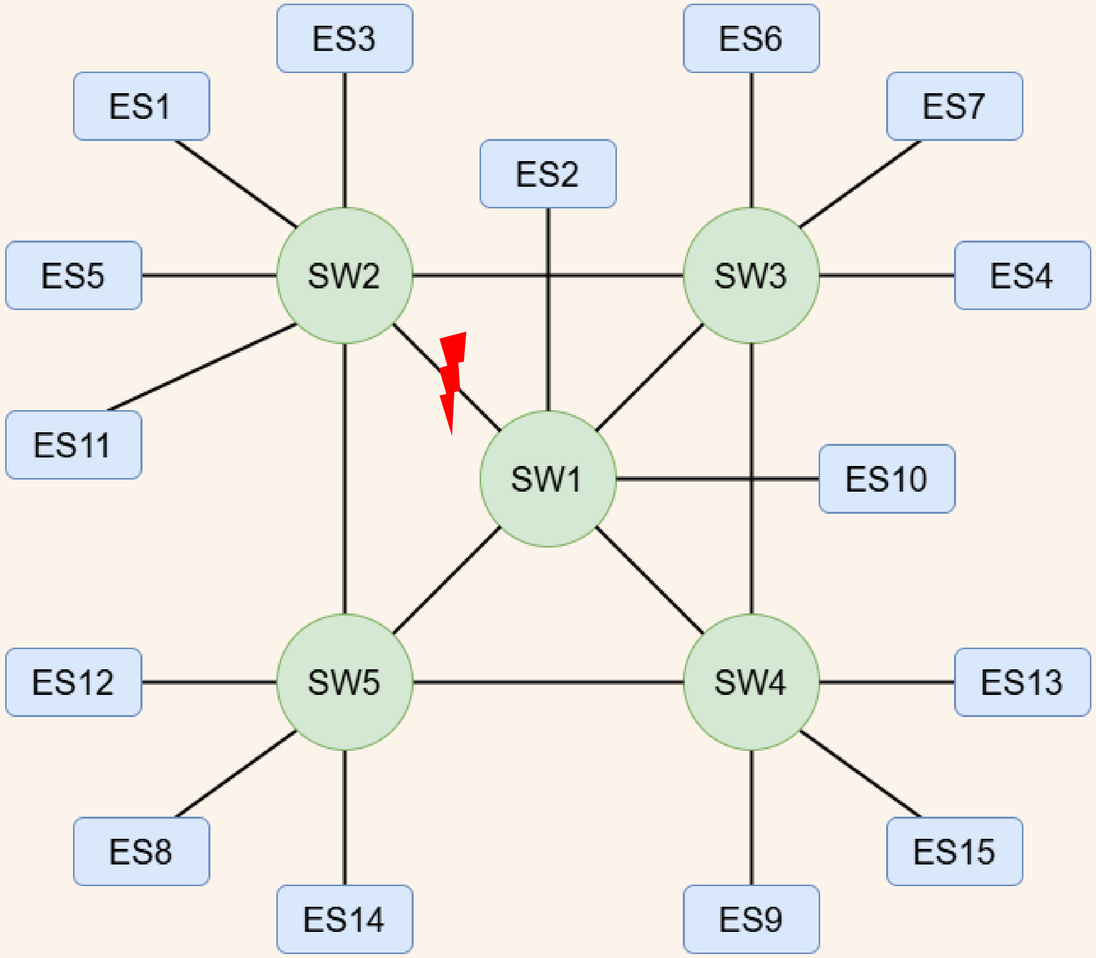

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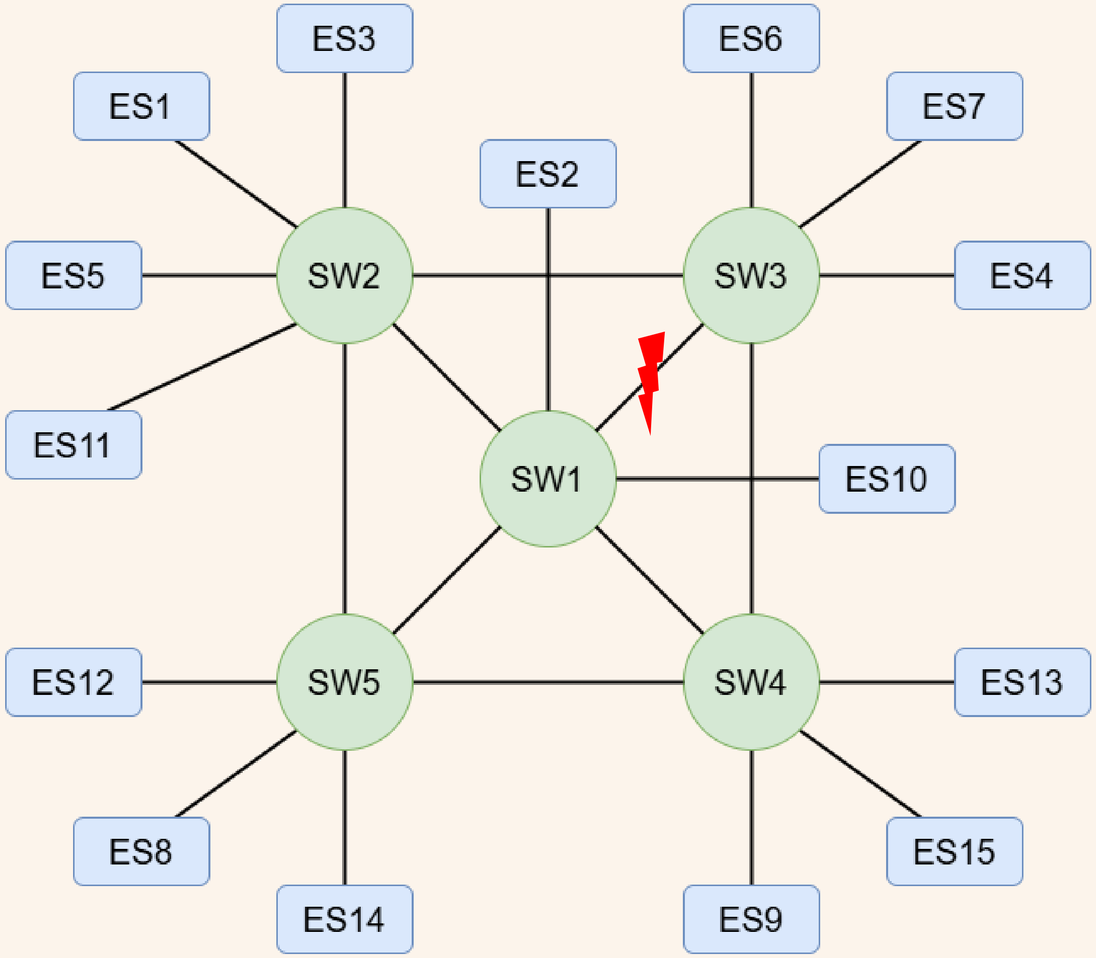

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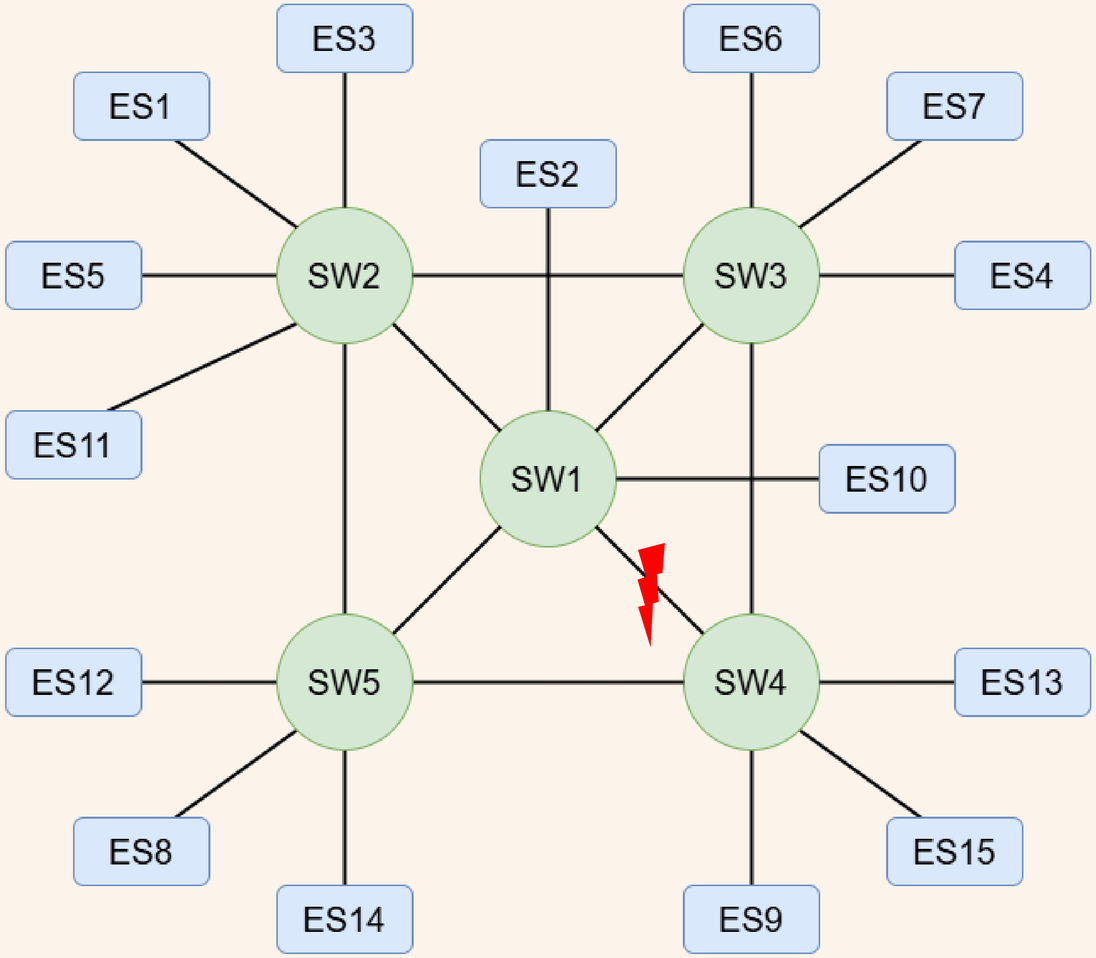

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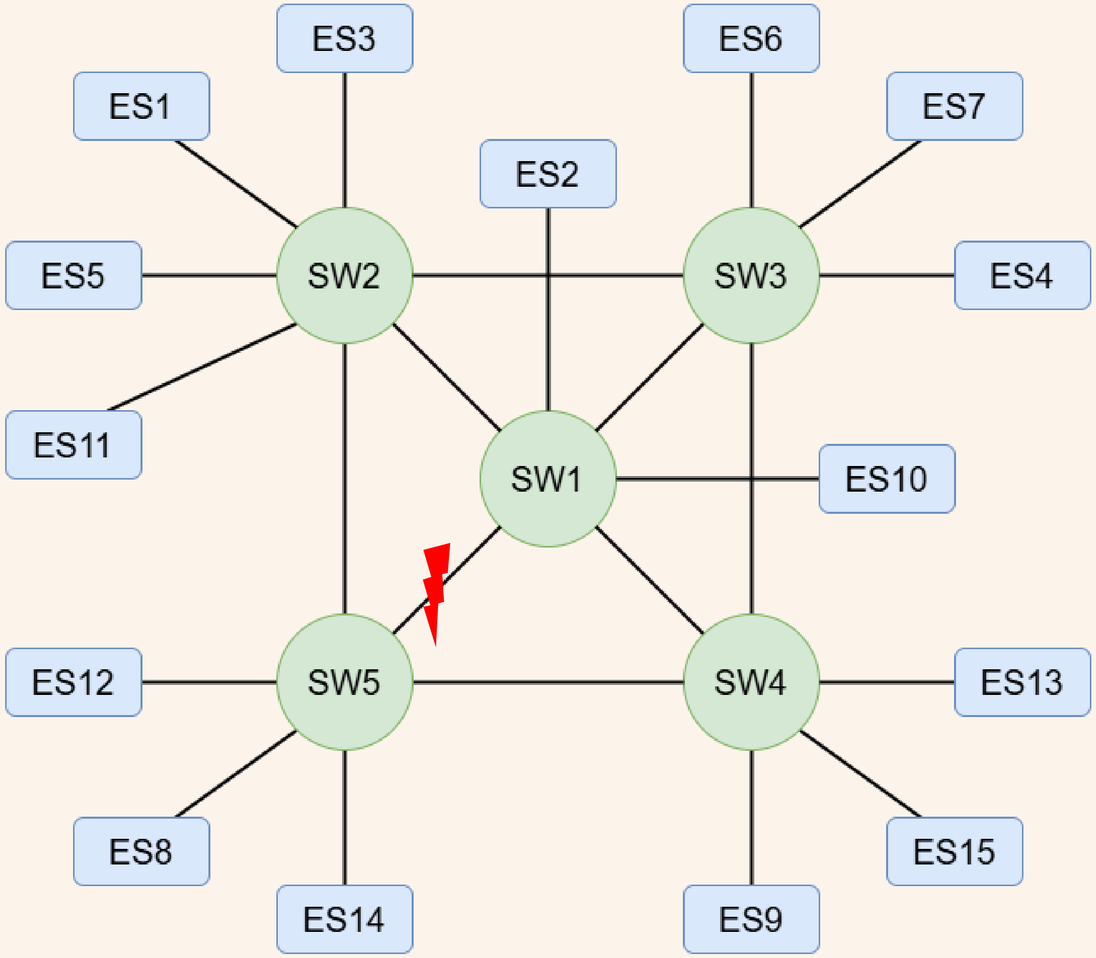

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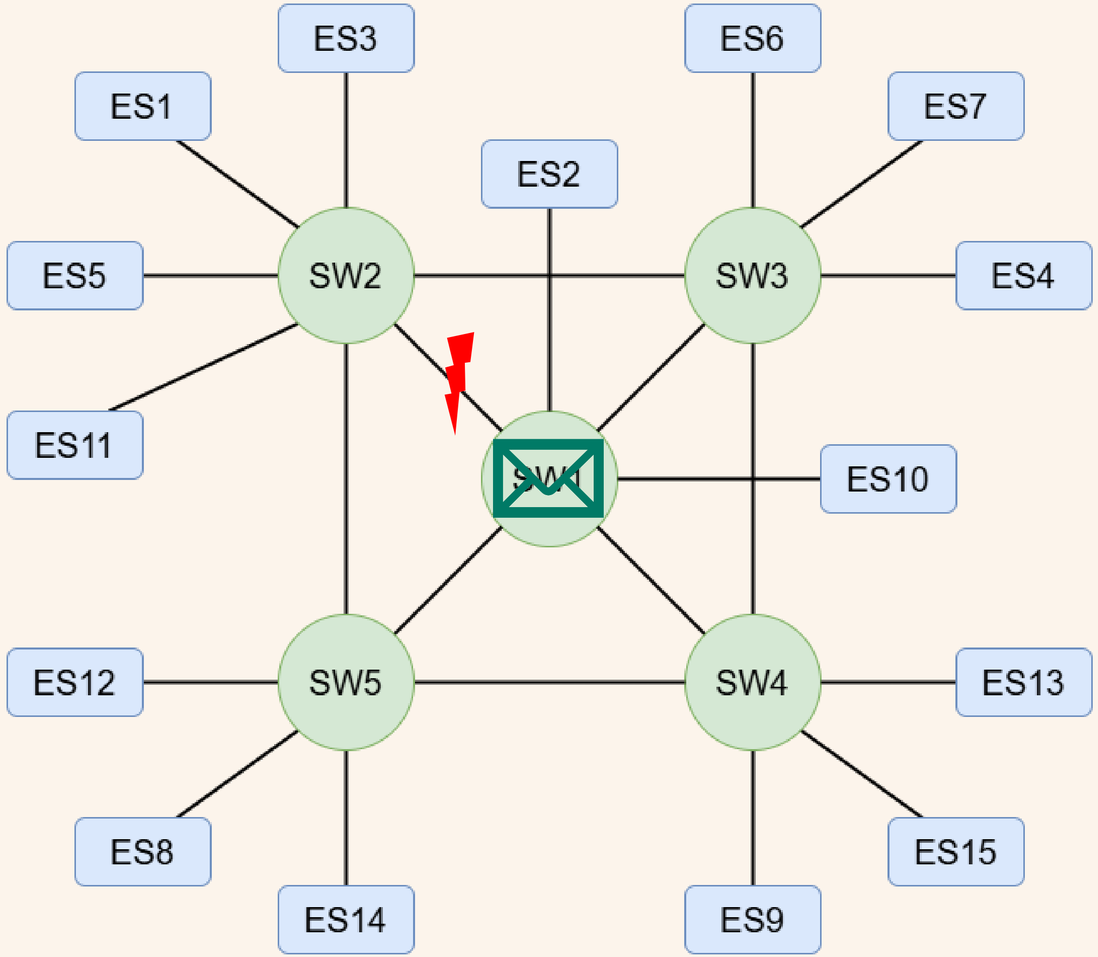
Reconfiguration



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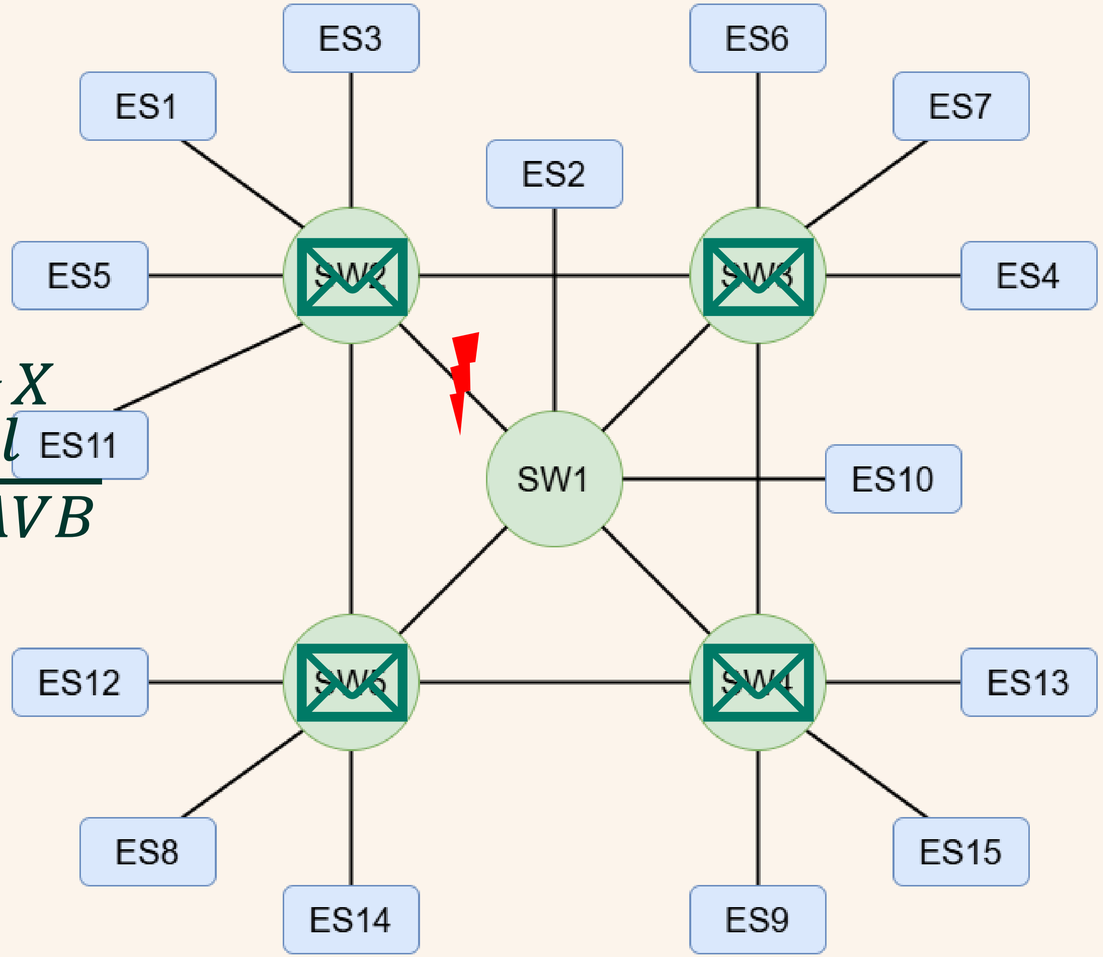
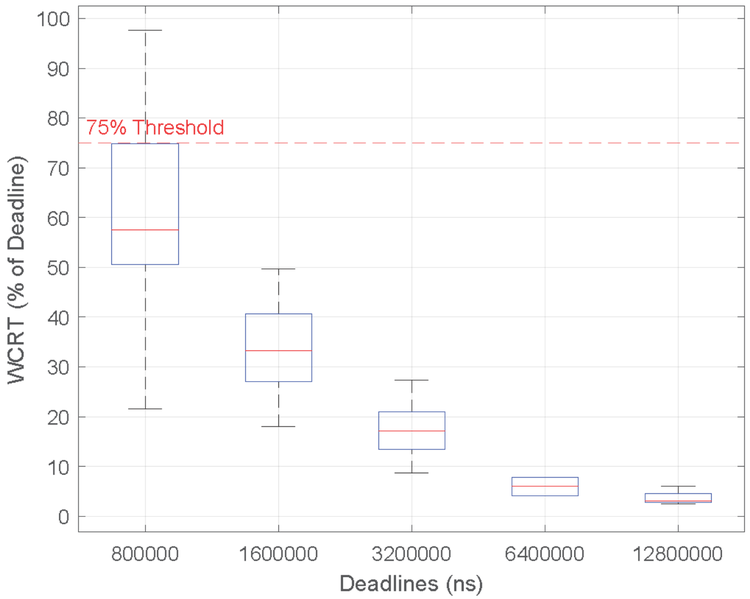
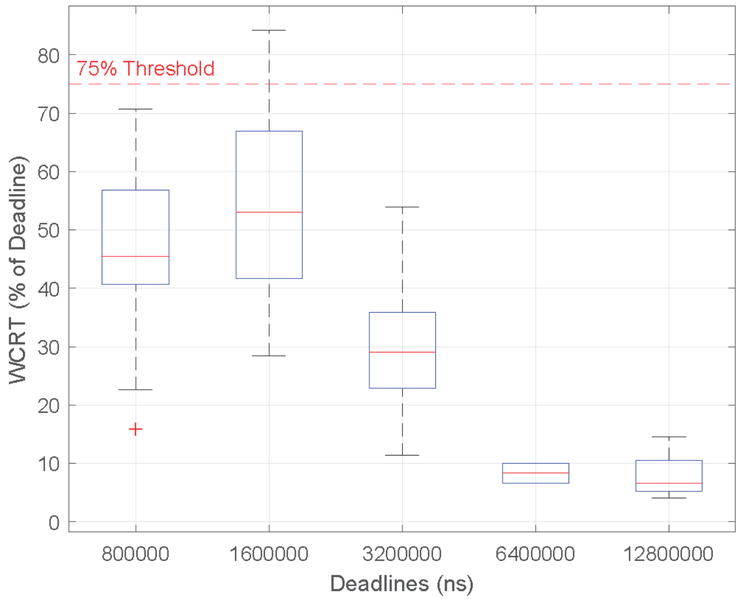


Configuration

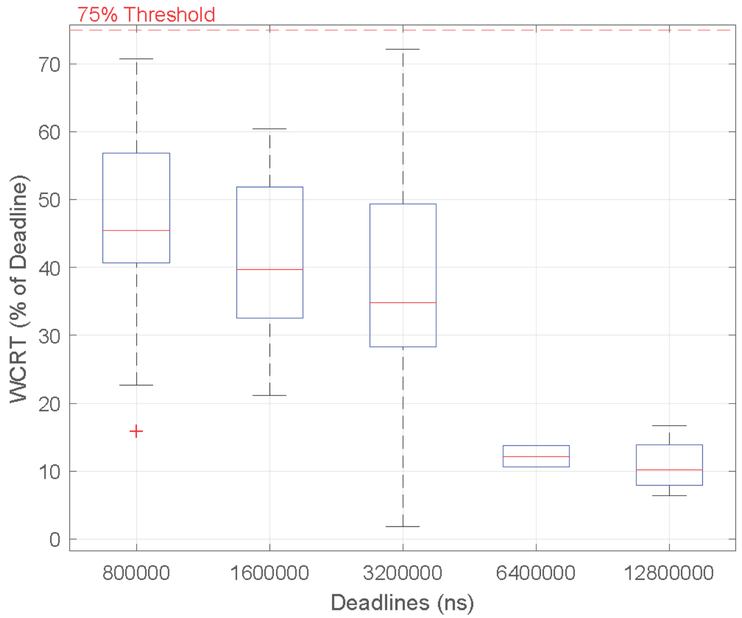
1st iteration



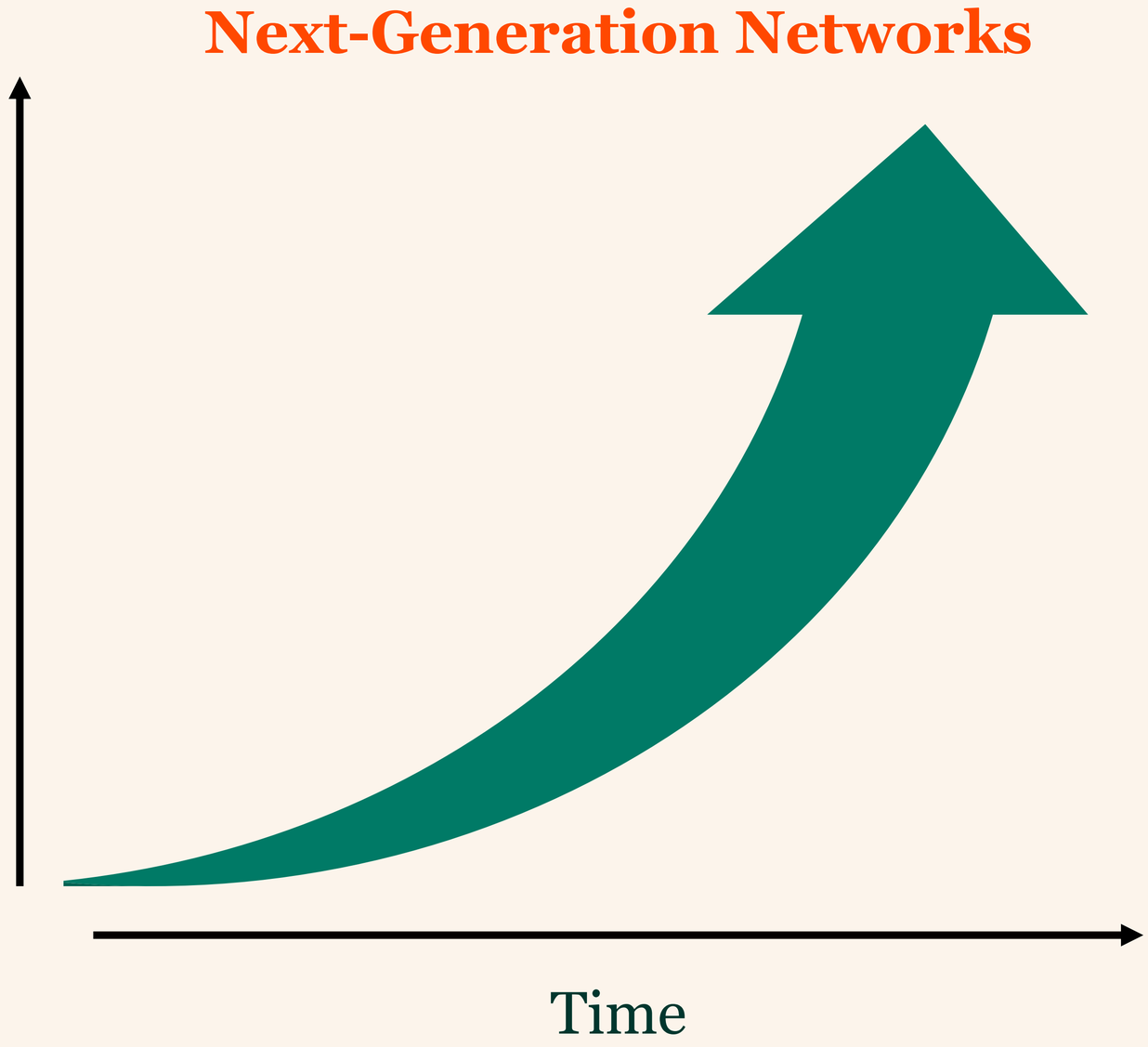
2nd iteration



3rd iteration



+Bandwidth
+Complexity
+Integrability
+Dependability
+Reconfigurability




Car
Industry
Hand-operated
Industry 4.0
Autonomous Car
Automation


Car
Industry
Hand-operated
TSN
Industry 4.0
Autonomous Car
Automation

TSN

Ethernet with
Hard and soft real-time capabilities,
Fault tolerance mechanisms and
Flexibility of the traffic for critical applications

TSN traffic

Scheduled Traffic	Audio-Video Bridging (AVB) Traffic	Best Effort (BE) Traffic
+ periodic traffic + low jitter + different schedulers can optimize different parameters + simple analysis - aperiodic traffic - low adaptability	+ periodic and aperiodic traffic + high adaptability + real-time capabilities + good QoS for lower priorities - high jitter - complex analysis	+ low resource consumption - No real-time guarantees

Motivation

Why would the industry be interested in adopting TSN?