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ETHERNOVIA

How to reign the Rings with TSN?

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AUTOMOTIVE ETHERNET CONGRESS

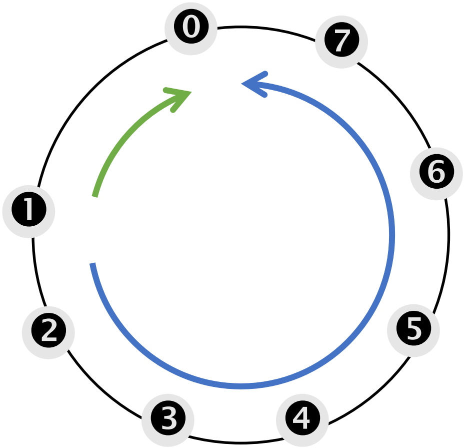
RTaW RealTime-at-Work

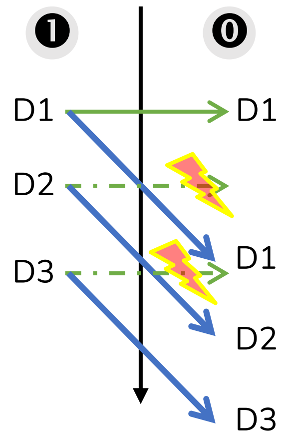
Why turn the IVN into a Ring? Assuming a Zonal Architecture

- All data everywhere
  - Log and Trace
  - Software Defined Vehicle upgrades
- Redundancy or Resiliency
  - Alternate path in case one path fails
- Increased Bandwidth
  - Two paths to send data
- Separate paths per data-type
  - Low latency small frames like audio in one direction
  - Large frames in the other

The Issue with different Path Length

- The path around a ring one way is usually significantly faster (shorter in number of hops) than the path around the other way
- If the faster (shorter) path fails, there will be a temporary interruption of sequential data, before the redundant communication has travelled along the slower (longer) path
- To ensure a (chronologically) seamless operation, the receiver would have to always wait for the later packet, before processing or taking action
- Such behaviour is not covered (solely) by redundancy concepts, like e.g. IEEE Std 802.1CB
- It requires buffering in the receiver or elimination point and
- knowledge about the timing in the receiver at the transmitter (compare IEEE Std 1722's Presentation-Time)

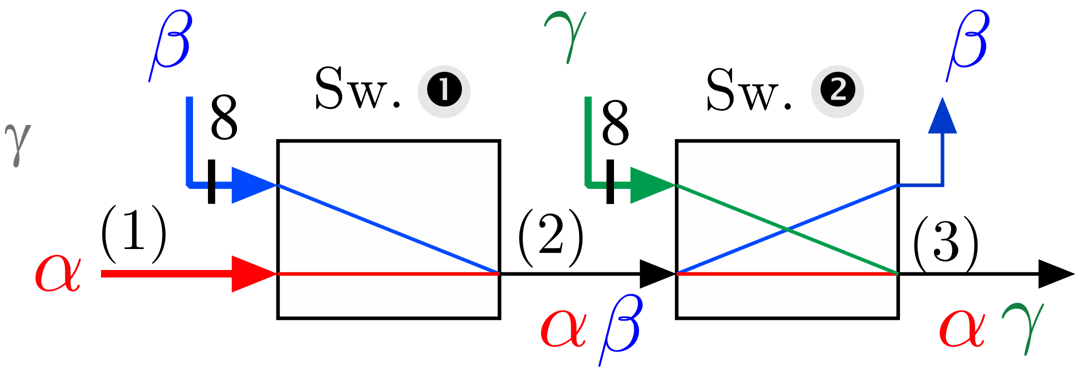


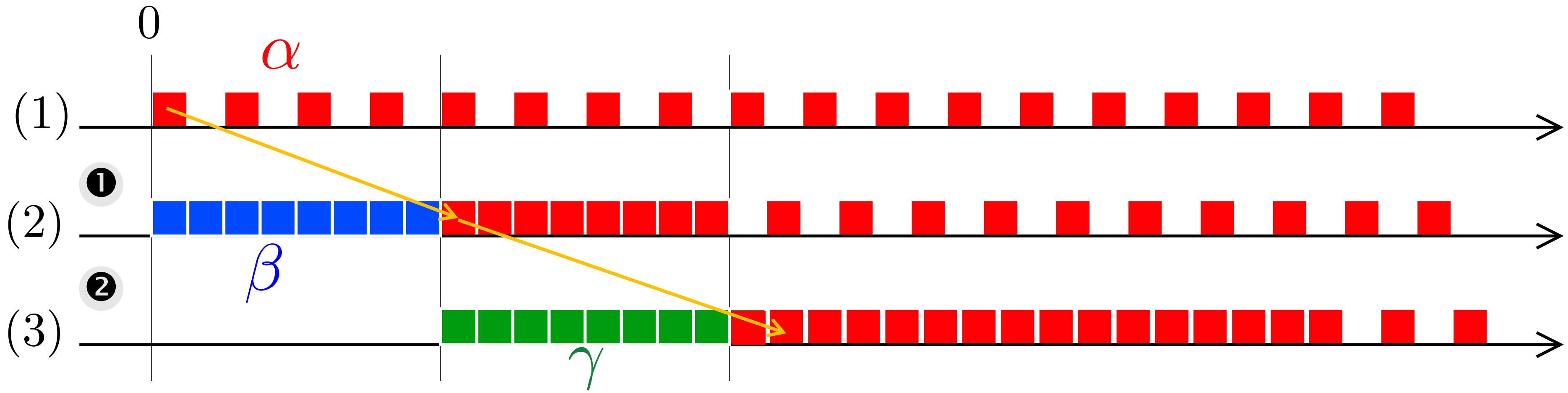


https://www.ieee802.org/1/files/public/docs2015/cb-nfinn-seamless-issues-1015-v02.pdf

Rings are fundamentally Daisy-Chains - Leading to Burst Accumulation

Flow α accumulates bursts due to bursts from interfering streams[1] β and γ



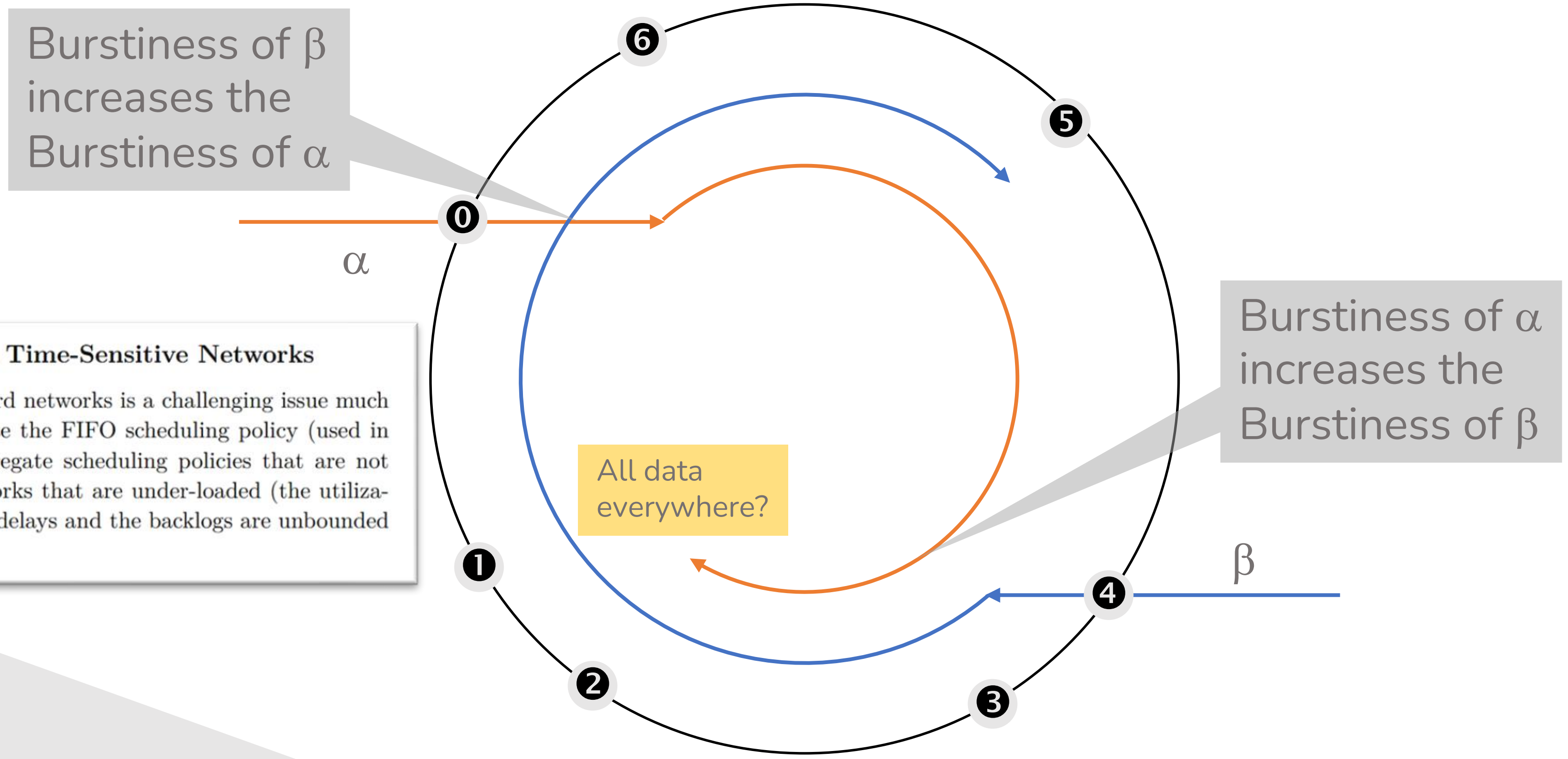


From: 2021 Ethernet & IP @ Automotive Technology Week, M. Turner & J. Walrand, "The "Free Rider Principle""

[1] Streams β and γ consist of 8 flows each

The benefit of shaping

Rings cause Circular Dependencies

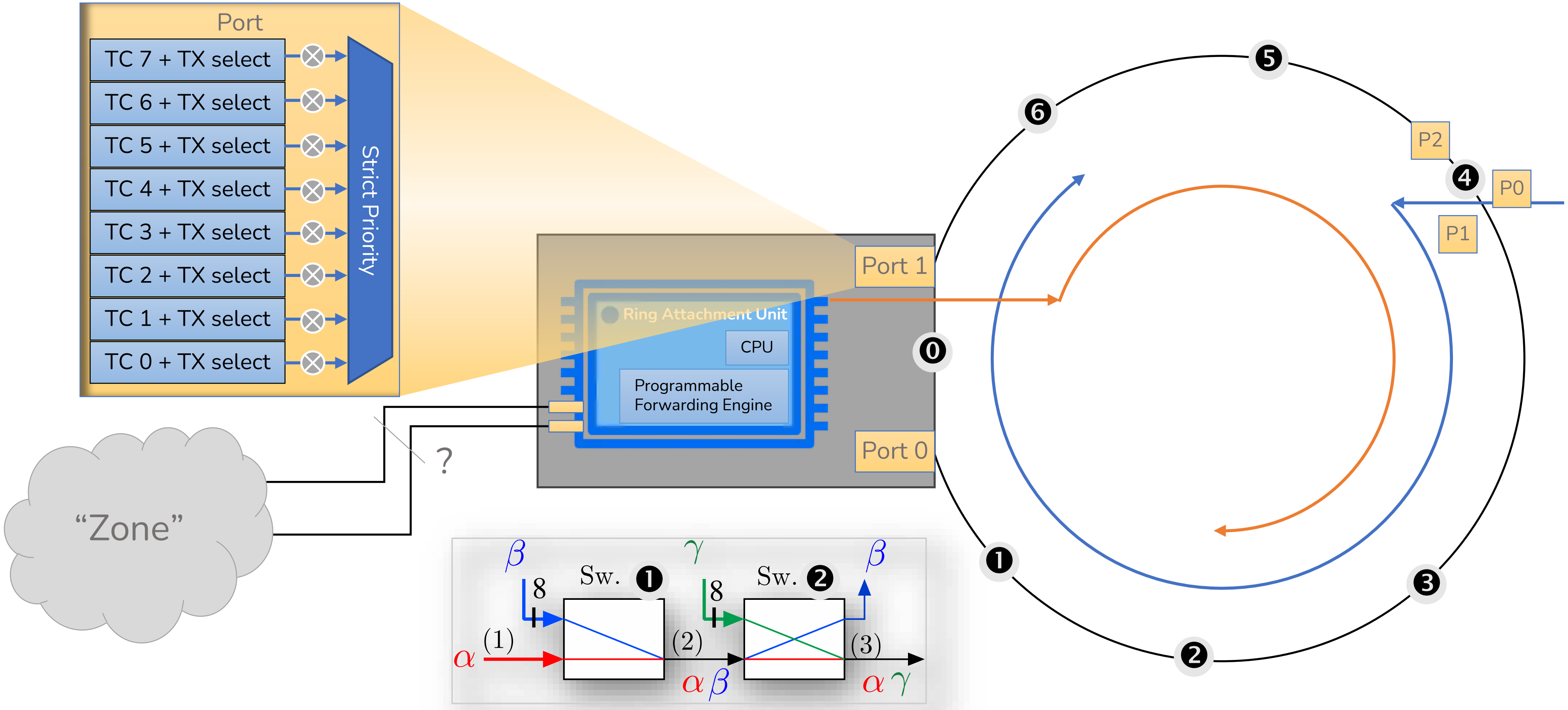


3.1.2 The Issue of Cyclic Dependencies in Time-Sensitive Networks

Obtaining performance guarantees on non-feed-forward networks is a challenging issue much more than for feed-forward networks. This is because the FIFO scheduling policy (used in FIFO-per-class networks) belongs to the set of aggregate scheduling policies that are not universally stable: There exists FIFO-per-class networks that are under-loaded (the utilization factor of each node is below 1) but in which the delays and the backlogs are unbounded [Andrews 2009].

Ludovic THOMAS, THÉSE En vue de l'obtention du DOCTORAT DE L'UNIVERSITÉ DE TOULOUSE, “Analysis of the side-effects on latency bounds of combinations of scheduling, redundancy and synchronization mechanisms in time-sensitive networks.”, 12 Sep. 2022

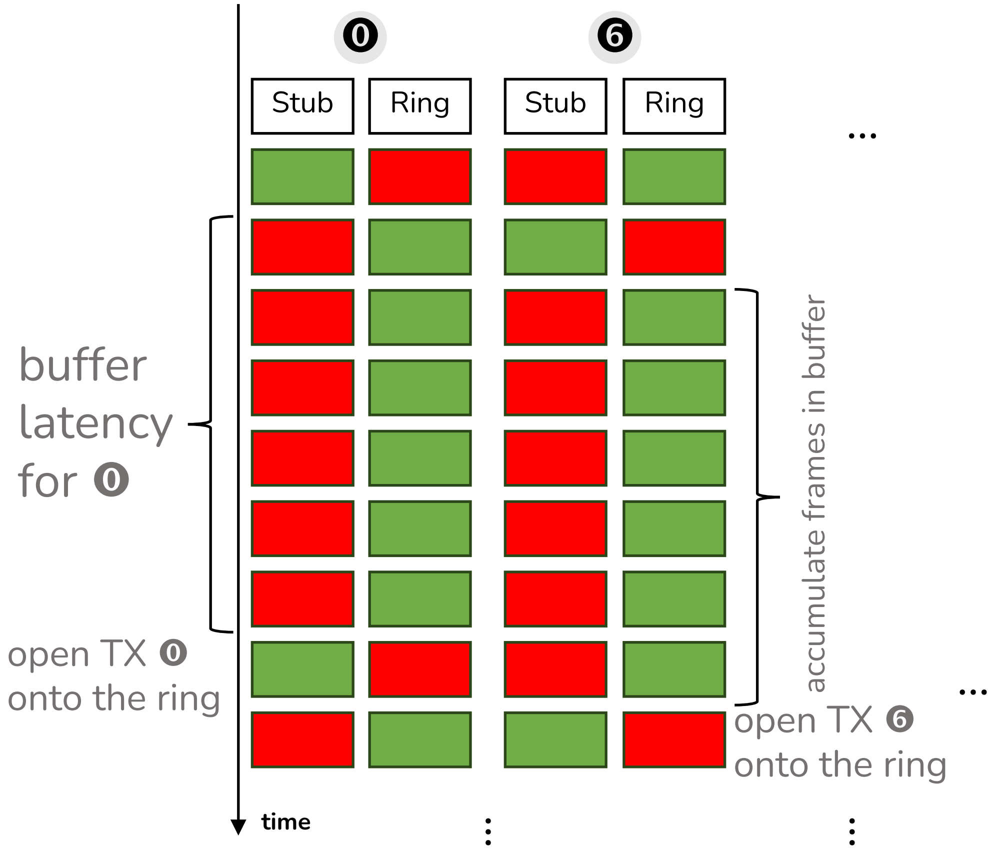
Designing the Ring Attachment Unit and the connections into the Zone

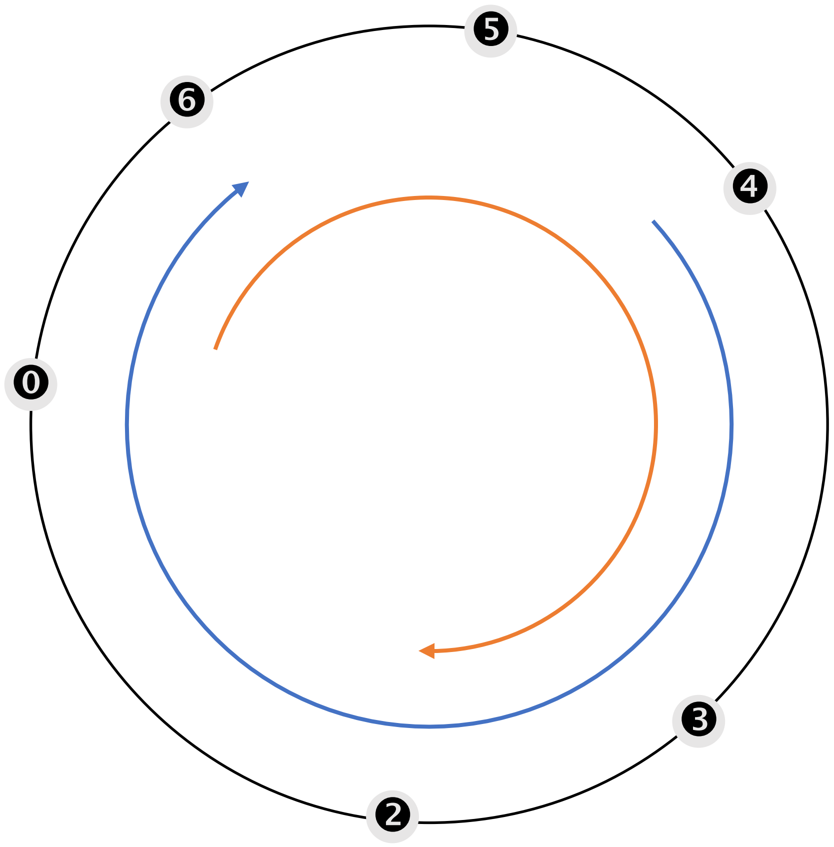


Can Cut-Through-Forwarding reduce the latency around the ring?

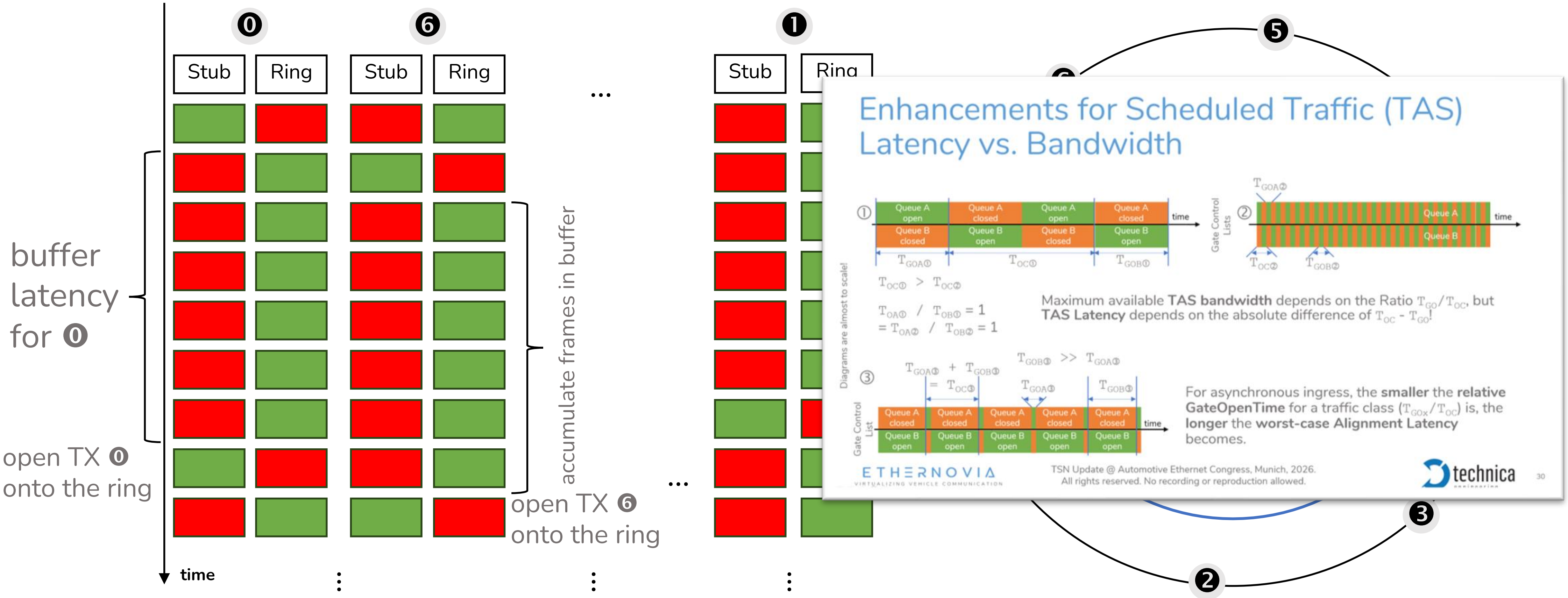
- Assuming mostly unicast communication, frames on the Ring have one specific destination, i.e. they should pass through all the other RAU bridges with minimum delay
- Assuming the stub links to be lower line-rate, only the ring can do cut-through-forwarding, while this removes the issue of erronious forwarding it can lead to infinite circulation of frames
- Is the ingress from the stubs short enough to not mostly be in the way?

Can Cyclic-Queueing-and-Forwarding limit the interference to Cut-Through-Forwarding on the ring?

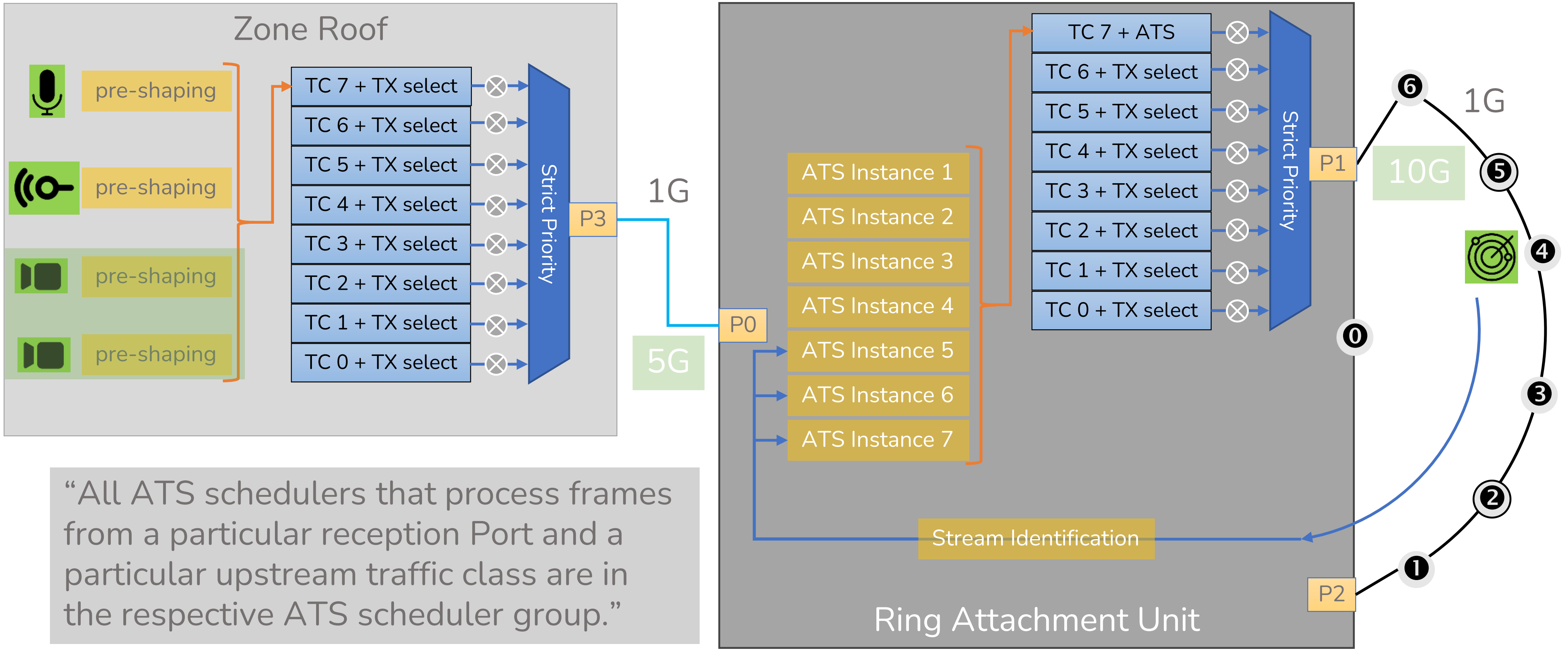




Can Cyclic-Queueing-and-Forwarding limit the interference to Cut-Through-Forwarding on the ring?



Queue Structure FIFO/FIFO for 1G and 10G!



"All ATS schedulers that process frames from a particular reception Port and a particular upstream traffic class are in the respective ATS scheduler group."

A Ring example and some Simulations

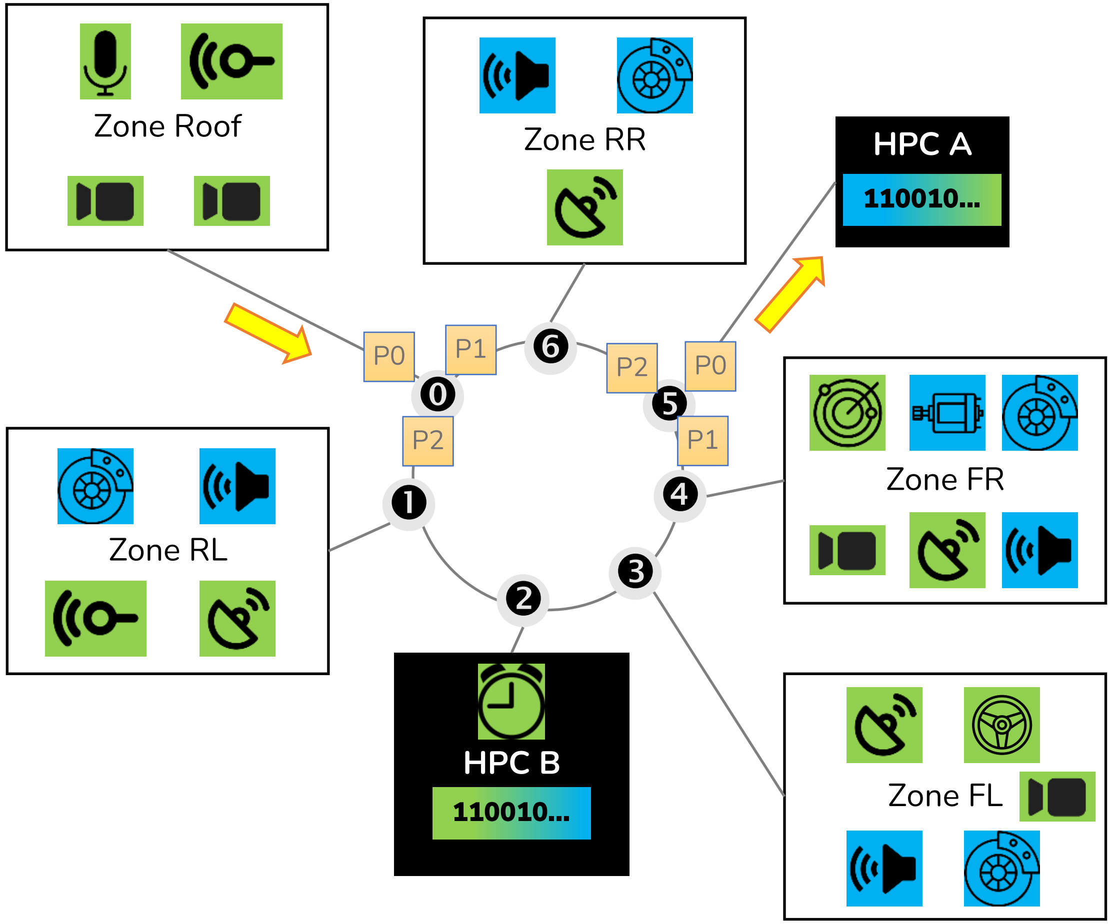
Consider
- short path: 3 hops
- long path: 6 hops

Which delay ratio would you expect ?
Approximately a factor of 2?

Actually, they may be almost the same or the longer path delay may be much higher!

Source				LIDAR				Location RADAR										data
0	2	2,5	2,5	2,5														
1					2,5										2,5			
2														0		1,3, 4,6		5
3											2,5	2,5	5					
4								2,5	2,5	2,5								
5						1,3, 4,6	4											2
6																	2,5	

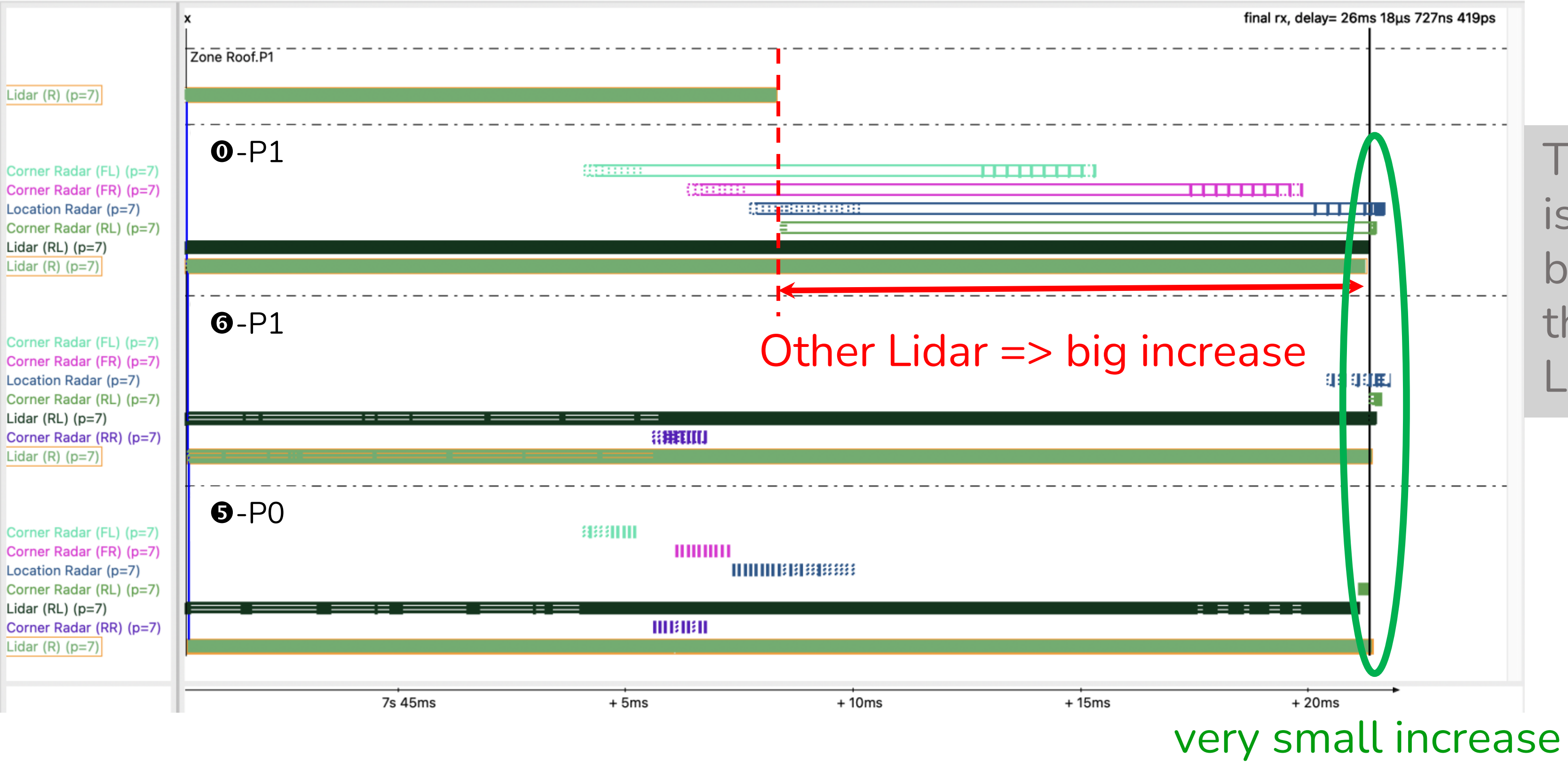
Communication Matrix



sensor/actuator symbols are examples only and not meant to be all-encompassing
the same is true for number of zones and HPCs

Redundancy: similar delays on **shorter** and longer path

Name	MaxSize	Sender	Receiver	Min	Average	Max	WCTT	Constraint	Route
Lidar (R)	1100 x 1400 byte	Zone Roof	HPC A	24,511 ms	24,749 ms	25,028 ms	40,535 ms	40 ms	Zone Roof | 0 | 1 | 2 | 3 | 4 | 5
Lidar (R)	1100 x 1400 byte	Zone Roof	HPC A	24,384 ms	25,383 ms	26,019 ms	38,578 ms	40 ms	Zone Roof | 0 | 6 | 5



The end-to-end delay is mainly determined by the "collision" with the other heavy burst Lidar stream!

Redundancy: similar delays on shorter and **longer** path

Name	MaxSize	Sender	Receiver	Min	Average	Max	WCTT	Constraint	Route
Lidar (R)	1100 x 1400 byte	Zone Roof	HPC A	24,511 ms	24,749 ms	25,028 ms	40,535 ms	40 ms	Zone Roof | 0 | 1 | 2 | 3 | 4 | 5
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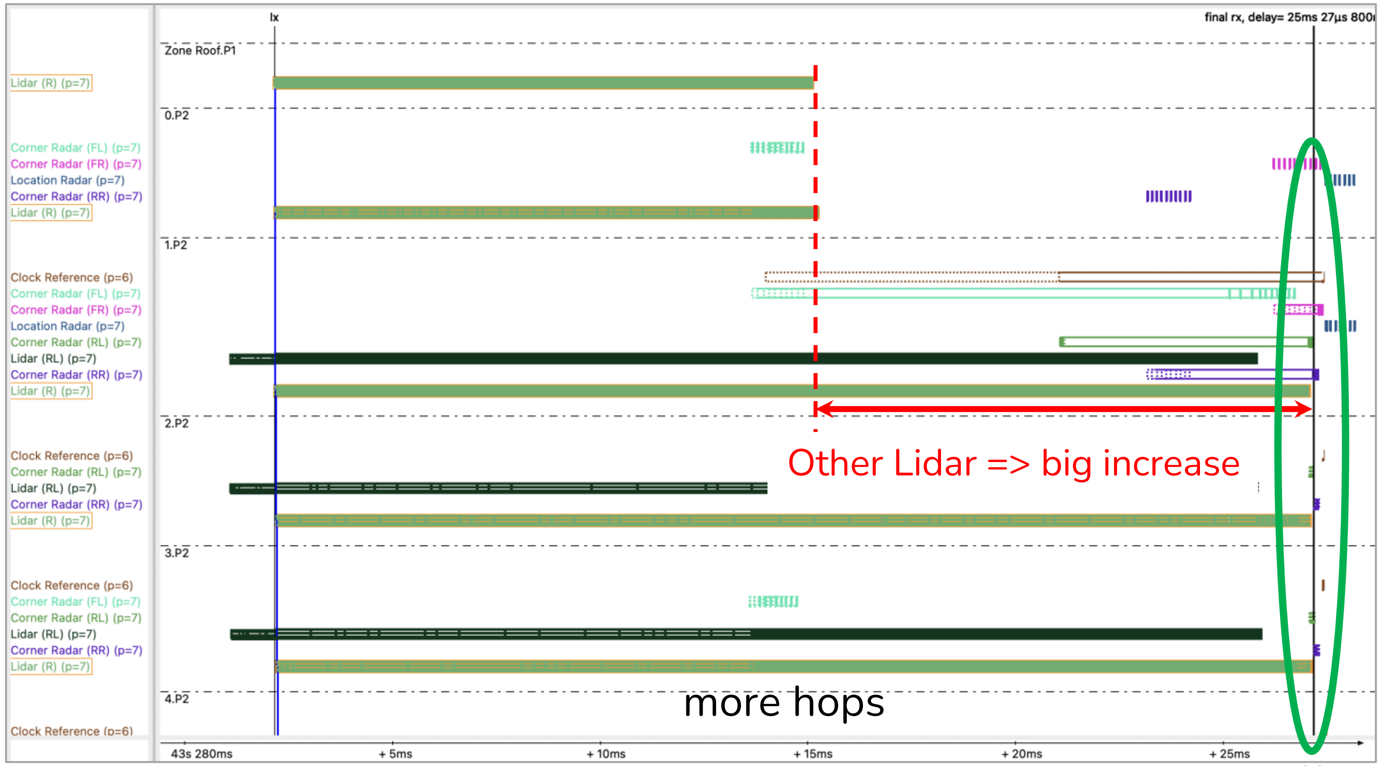


very small increase

Same "collision" effect as on the short path.

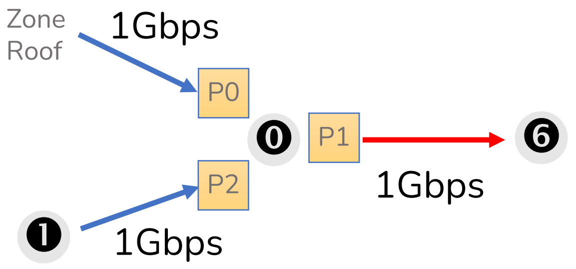
The delay due to the additional hops is negligible.

Redundancy: delay on longer path much higher

Name	MaxSize	Sender	Receiver	Min	Average	Max	WCTT	Constraint	Route
Location Radar	22 x 1400 byte	Zone Front|Right	HPC A				31,245 ms	50 ms	Zone Front|Right | 4 | 3 | 2 | 1 | 0 | 6 | 5
Location Radar	22 x 1400 byte	Zone Front|Right	HPC A	2,515 ms	3,264 ms	4,022 ms	4,754 ms	50 ms	Zone Front|Right | 4 | 5

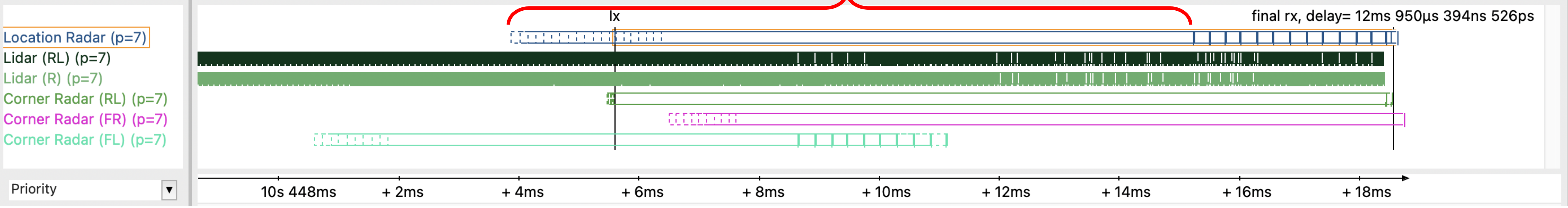
Segment	Min	Average	Max	WCTT
Zone Front|Right-> 4	0,113 ms	1,875 ms	3,637 ms	3,637 ms
4-> 3	0,011 ms	0,122 ms	0,378 ms	1,106 ms
3-> 2	0,011 ms	0,043 ms	0,129 ms	0,356 ms
2-> 1	0,011 ms	0,012 ms	0,014 ms	0,015 ms
1-> 0	0,011 ms	0,067 ms	0,480 ms	0,493 ms
0-> 6	0,011 ms	4,171 ms	12,951 ms	25,274 ms
6-> 5	0,011 ms	0,087 ms	0,129 ms	0,356 ms
5-> HPC A	0,004 ms	0,005 ms	0,010 ms	0,011 ms

The two heavy burst Lidar streams are arriving at 1Gbps peak rate each and are merged into one single 1Gbps link



⇒ Huge amounts of memory needed in the switch port to not loose any frame!

Transmitted only after 12 ms …



Shaping of bursty streams

We have seen that with heavy bursty traffic

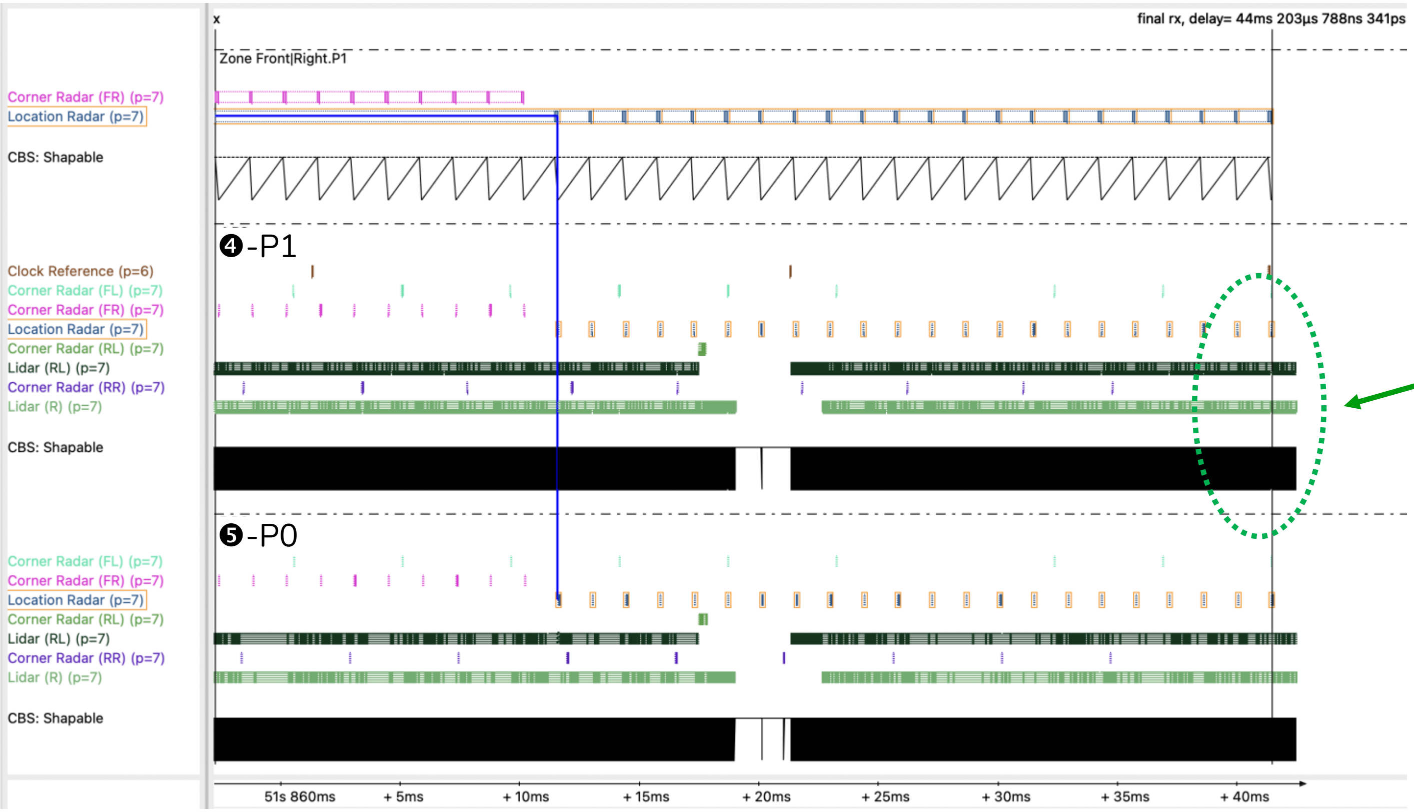
- The number of hops is not a good indicator of the transmission delay to expect.
- In "collision" scenarios of heavy burst a huge frame backlog may builds up and require a lot of memory.

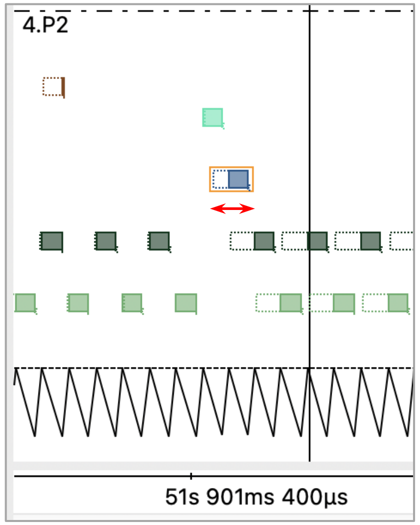
We added TSN shaping in further simulations to reduce latency caused by burst accumulation.

Shaping of bursty streams: CBS, end-to-end

Name	MinDistance	MaxSize	Sender	Receiver	Min	Average	Max	WCTT	Constraint	Route
Location Radar	50 ms	22 x 1400	Zone Front|Right	HPC A				45,509 ms	50 ms	Zone Front|Right | 4 | 3 | 2 | 1 | 0 | 6 | 5
Location Radar	50 ms	22 x 1400	Zone Front|Right	HPC A	29,957 ms	37,078 ms	44,204 ms	44,218 ms	50 ms	Zone Front|Right | 4 | 5

Systematically low delay skew between shorter and longer path

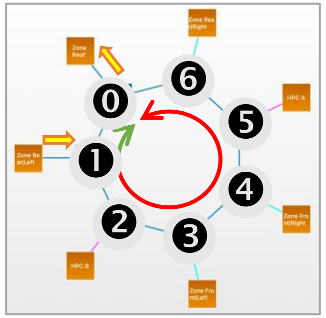




The two **shaped** Lidar streams let the Radar through quickly!

End-to-end delay determined by shaping in Node!

Partial shaping of bursty streams: lower priority delays



Let us look at the impact on the transmission delay of a low priority frame: "Clock Reference"

No shaping

Name	MinDistance	MaxSize	Sender	Receiver	Min	Average	Max	WCTT	Constraint	Route
Clock Reference	20 ms	48 byte	Zone Rear|Left	Zone Roof				302,884 ms	20 ms	Zone Rear|Left | 1 | 2 | 3 | 4 | 5 | 6 | 0
Clock Reference	20 ms	48 byte	Zone Rear|Left	Zone Roof	0,002 ms	3,495 ms	13,543 ms	26,586 ms	20 ms	Zone Rear|Left | 1 | 0

CBS: end-to-end

Name	MinDistance	MaxSize	Sender	Receiver	Min	Average	Max	WCTT	Constraint	Route
Clock Reference	20 ms	48 byte	Zone Rear|Left	Zone Roof	0,024 ms	0,024 ms	0,025 ms	0,136 ms	20 ms	Zone Rear|Left | 1 | 2 | 3 | 4 | 5 | 6 | 0
Clock Reference	20 ms	48 byte	Zone Rear|Left	Zone Roof	0,002 ms	0,013 ms	0,029 ms	0,033 ms	20 ms	Zone Rear|Left | 1 | 0

CBS: only in nodes

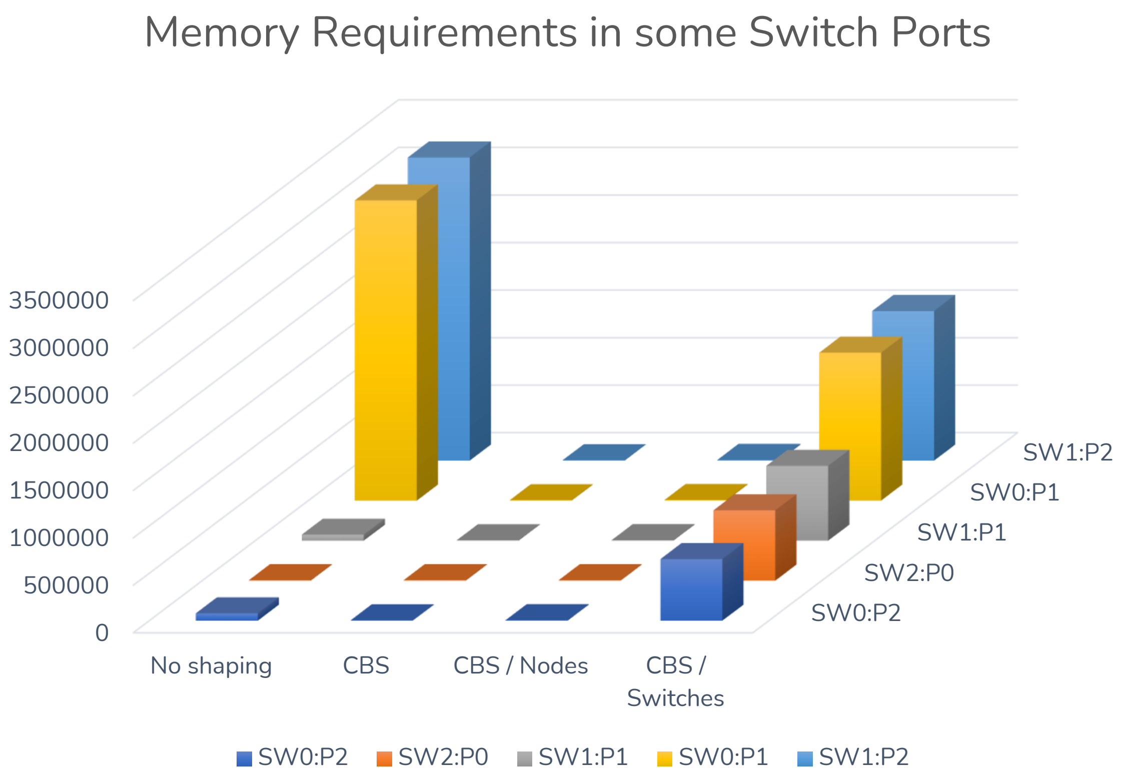
Name	MinDistance	MaxSize	Sender	Receiver	Min	Average	Max	WCTT	Constraint	Route
Clock Reference	20 ms	48 byte	Zone Rear|Left	Zone Roof				1,557 ms	20 ms	Zone Rear|Left | 1 | 2 | 3 | 4 | 5 | 6 | 0
Clock Reference	20 ms	48 byte	Zone Rear|Left	Zone Roof	0,002 ms	0,017 ms	0,040 ms	0,077 ms	20 ms	Zone Rear|Left | 1 | 0

CBS: only in switches

Name	MinDistance	MaxSize	Sender	Receiver	Min	Average	Max	WCTT	Constraint	Route
Clock Reference	20 ms	48 byte	Zone Rear|Left	Zone Roof	0,011 ms	3,274 ms	13,063 ms	28,414 ms	20 ms	Zone Rear|Left | 1 | 2 | 3 | 4 | 5 | 6 | 0
Clock Reference	20 ms	48 byte	Zone Rear|Left	Zone Roof	0,002 ms	3,457 ms	13,067 ms	13,079 ms	20 ms	Zone Rear|Left | 1 | 0

⇒ Shaping before or in nodes is crucial!

Partial shaping of bursty streams: memory requirements



No shaping:
- the "collisions" seen before induce high requirements in some ports

CBS – In nodes and switches:
- shaped streams require much less

CBS – Only in Nodes
- shaped streams require much less

CBS – Only in Switches
- High requirement even where not needed before

=> Shaping before or in nodes is crucial!

Summary:
Rings are fundamentally Daisy-Chains

- Bursty traffic will cause more bursty traffic
- Transmission delay around the ring can be dominated by busts, rather than hop count
- Once traffic is bursty, it takes a lot of memory to re-shape it
- Proper shaping close to the actual source can reduce the skew between short and long path
- TSN offers a lot of tools to do this, choosing may be harder than expected
- Per-Stream shaping with ATS can resolve circular burst and latency dependencies, if you watch out for traps
- The ring should have higher line-rate than the combined ingress ports
- Egress from the ring can require significant memory, if bursty traffic accumulates
- Do not underestimate the importance and complexity of designing the RAU!

Thank you very much for your attention!

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