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Filtering Enhancements for Dependable Networks

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Purpose/Agenda

1. Use cases for dependable engineered networks
2. Per-Class and Per-Stream Scheduling for engineered networks
3. Proposed Filtering enhancements

References:

- IEEE Std. 802.1Q-2022
- Minimum Frame Size Filter for PSFP – presented at IEEE 2026 March Plenary https://www.ieee802.org/1/files/public/docs2026/new-jabbar-psfp-MinSDUsize-0326-v02.pdf

Different Use Cases

Engineered Networks (e.g., aerospace)

1. Stream Type: Cyclic Stream (e.g., control loops, parametric data, etc)
2. Frame Size: Fixed or small (< 100B) variation due to message/payload options
3. Latency Requirements: Bounded latency with very low jitter
4. Fault Tolerance: A faulty end station and/or stream shall not impact other streams and/or end stations in the network
5. Traffic Shaper: Enhancements for scheduled traffic
6. Policing: PSFP with stream filter and stream gates

Non-Engineered Networks

1. Stream Type: Acyclic streams (Audio, Video, etc)
2. Frame Size: Variable – 64 to 1500 Bytes
3. Latency Requirements: Bounded latency
4. Fault Tolerance: Nice to have, not a must have
5. Traffic Shaper: CBSA
6. Policing: PSFP with stream filter and flow meter

Dependable Engineered Neworks – Problem Statement(s)

Engineered Networks (e.g., aerospace)

1. Stream Type: Cyclic Stream (e.g., control loops, parametric data, etc)
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Non-Engineered Networks

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How to prevent a faulty end station from impacting the latency, determinism, reliability of other streams in the network?

How to efficiently support scheduled networks with small variability in the frame size ?

TSN Solutions for Dependable Networks

Engineered Networks (e.g., aerospace)

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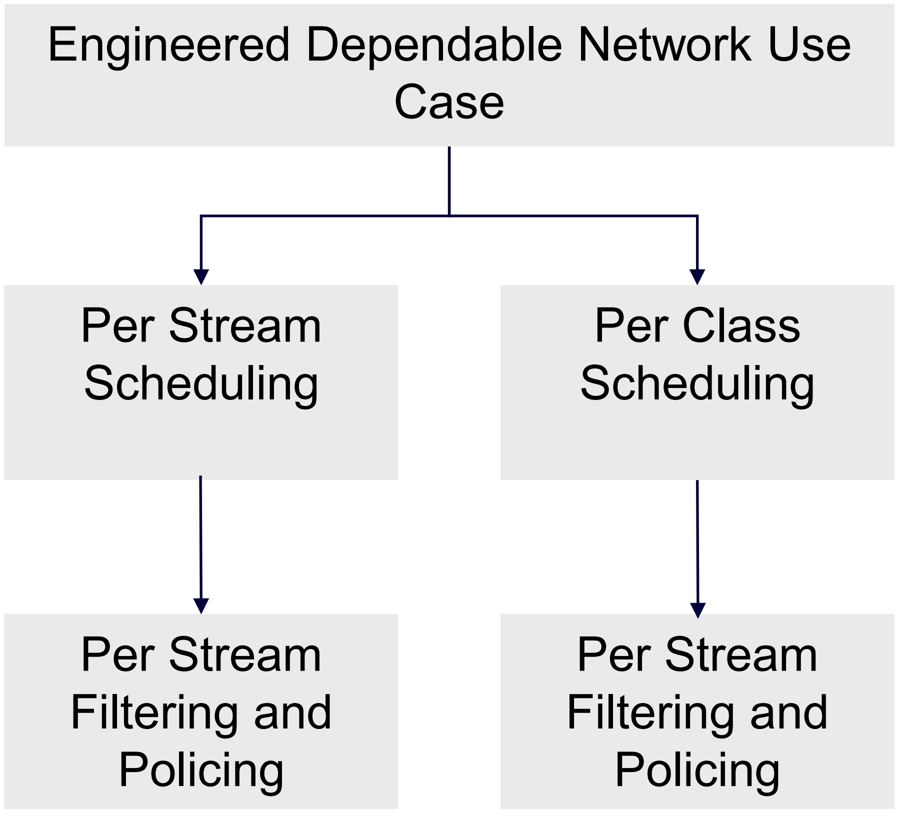
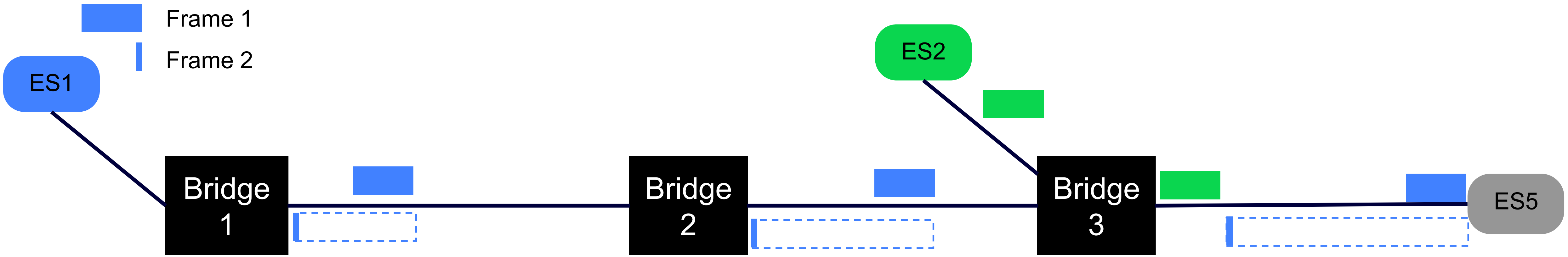


Recap: Per-Class Scheduling of Multiple Streams with variable frame size



Egress Time (1st bit) — Bridge 1:

Earliest: $t_1 + \Delta + 0.5usec$
Latest: $t_1 + \Delta + 12usec$

Egress Time (1st bit) — Bridge 2:

Earliest: $t_1 + 2\Delta + 1usec$
Latest: $t_1 + 2\Delta + 24usec$

Egress Time (1st bit) — Bridge 3:

Earliest: $t_1 + 3\Delta + 1.5usec$
Latest: $t_1 + 3\Delta + 36usec$

Blue Stream: ES1→ES5

SDU=64 to 1500 Bytes

MaxSDUSize = 1500 Bytes

TransmitOffset = t_1

Max SDU Filter = PASS

Green Stream: ES2→ES5

SDU=1500 Bytes

MaxSDUSize = 1500 Bytes

TransmitOffset = t_2

Max SDU Filter = PASS

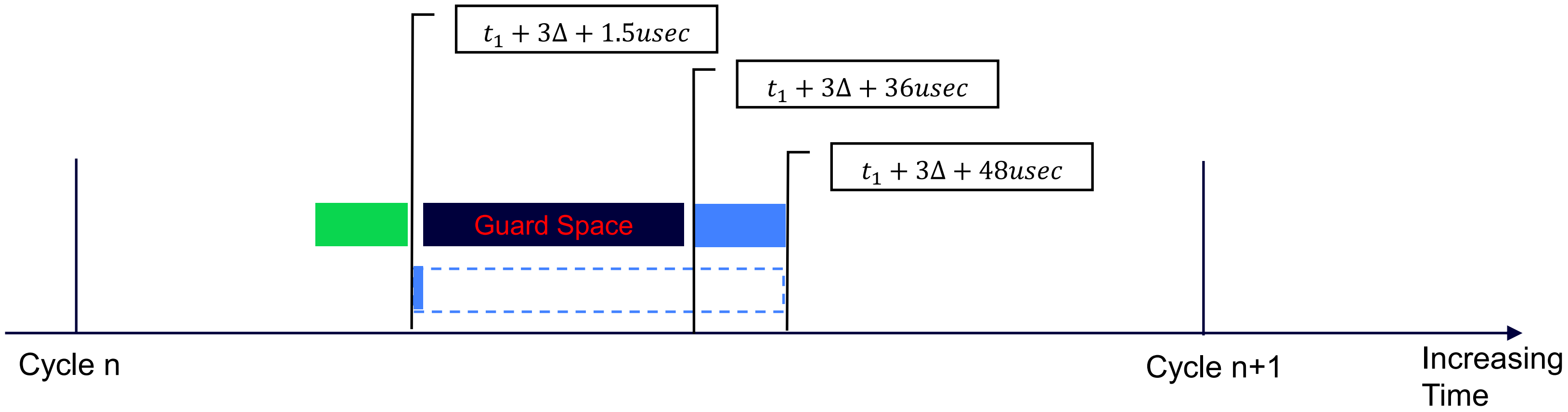
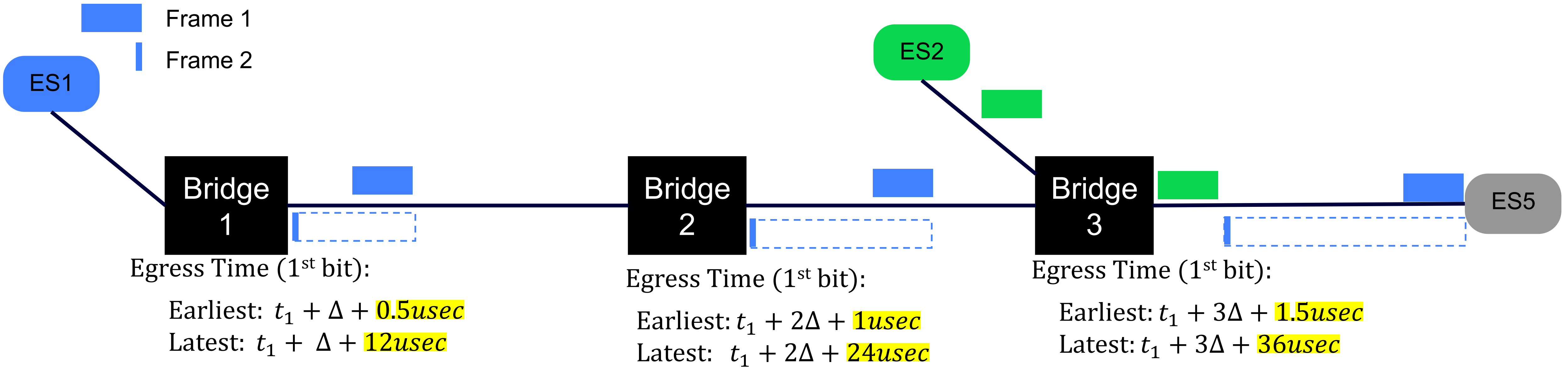
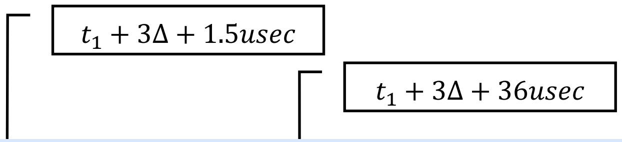


Illustration of scheduled transmissions on link between Bridge 3 and ES5 for one cycle

Reference: *Minimum Frame Size Filter for PSFP – presented at IEEE 2026 March Plenary*

Recap: Per-Class Scheduling of Multiple Streams with variable frame size





Blue Stream: ES1→ES5

SDU=64 to 1500 Bytes

MaxSDUSize = 1500 Byte

TransmitOffset = t_1

Max SDU Filter = PASS

Green Stream: ES2→ES5

SDU=1500 Bytes

Two comments from the Group:

1. Provide additional details on the impact of variable frames on the per-class scheduling with examples showing gate control lists
2. Consider if the “per-stream overlay” would address the issue of variable frame size. If not, show examples.

The rest of this presentation addresses those two comments

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Increasing Time

5 for one cycle

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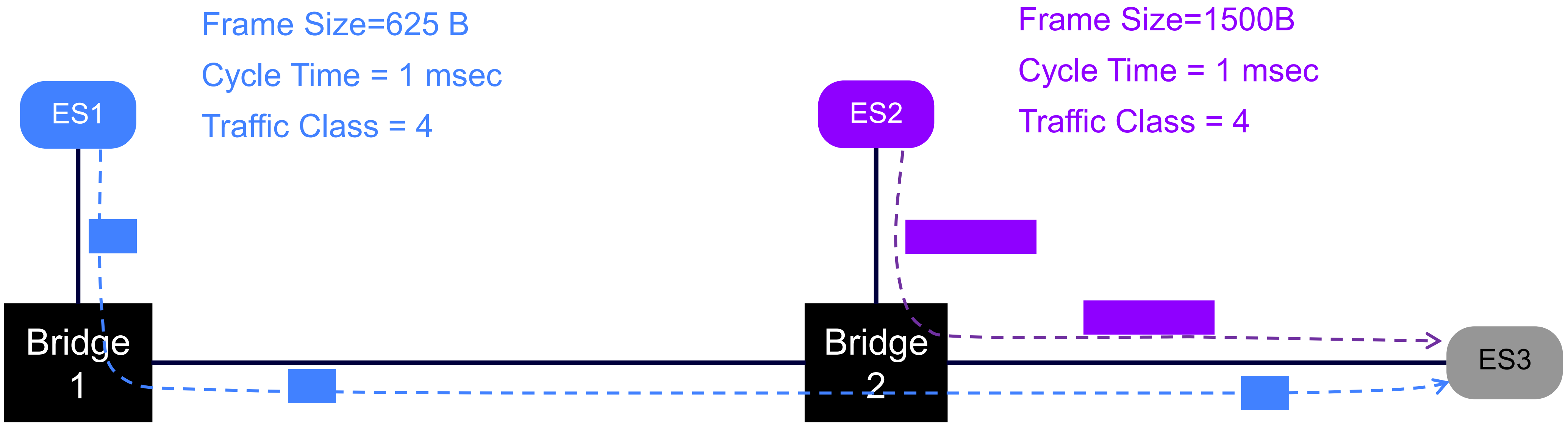
Per-Stream Scheduling

Example: Two scheduled streams in an engineered network (segment)



Simplifying assumptions that do not <u>materially</u> impact the topic under discussion

- Fixed bridge port-to-port delay of **2 microseconds**
- 1 Gbps Link Speed
- Negligible propagation delay
- The network segment shown is a part of a larger network

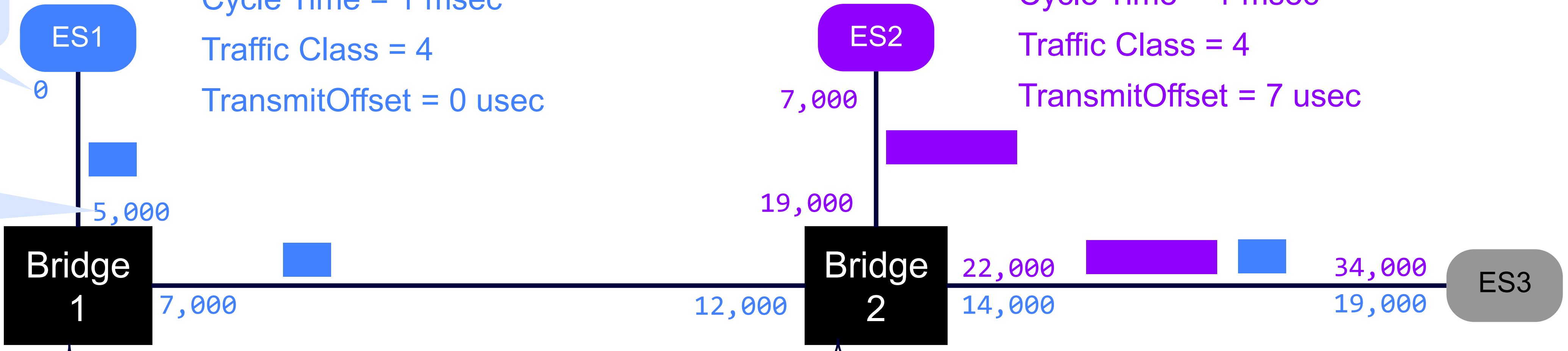
Example: Per-Stream Scheduling – Normal Case

First bit transmit time shown on egress ports

Last bit receive time is shown on ingress ports

Frame Size=625 B
Cycle Time = 1 msec
Traffic Class = 4
TransmitOffset = 0 usec

Frame Size=1500B
Cycle Time = 1 msec
Traffic Class = 4
TransmitOffset = 7 usec



Gate State	Duration	Cumulative Time
OOOCOOOO	7,000	7,000
CCCOCCCC	5,000	12,000
OOOCOOOO	988,000	1,000,000

Gate State	Duration	Cumulative Time	Normal Case
OOOCOOOO	14,000	14,000	
CCCOCCCC	5,000	19,000	
OOOCOOOO	3,000	22,000	
CCCOCCCC	12,000	34,000	
OOOCOOOO	966,000	1,000,000	

CNC schedules all the streams so that they transmit back-to-back or as close to back-to-back as possible while accounting for clock/time and delay variations.

In this example there is a 3 usec "gap" between the transmissions of the two scheduled streams

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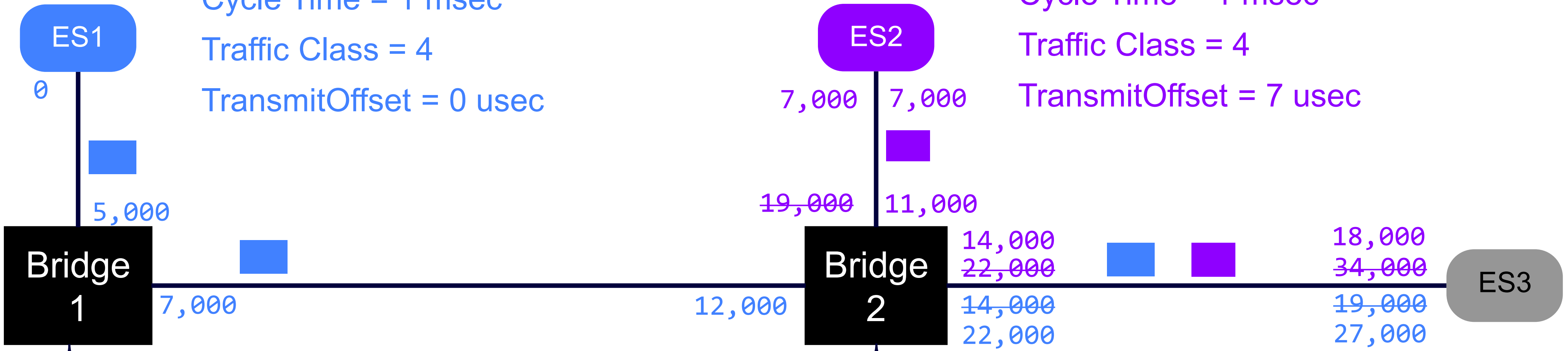
Example: Per-Stream Scheduling – Faulty Frame Size

Frame Size=625 B
Cycle Time = 1 msec
Traffic Class = 4
TransmitOffset = 0 usec

Frame Size=~~1500 B,~~ 500B
Cycle Time = 1 msec
Traffic Class = 4
TransmitOffset = 7 usec

Purple stream sends smaller than expected frames



Gate State	Duration	Cumulative Time
oooCoooo	7,000	7,000
CCCoCCCC	5,000	12,000
oooCoooo	988,000	1,000,000

Gate State	Duration	Cumulative Time	Normal Case	Faulty Case
oooCoooo	14,000	14,000		
CCCoCCCC	5,000	19,000		
oooCoooo	3,000	22,000		
CCCoCCCC	12,000	34,000		
oooCoooo	966,000	1,000,000		

Frame egress ordering and timing in the smaller than expected frame

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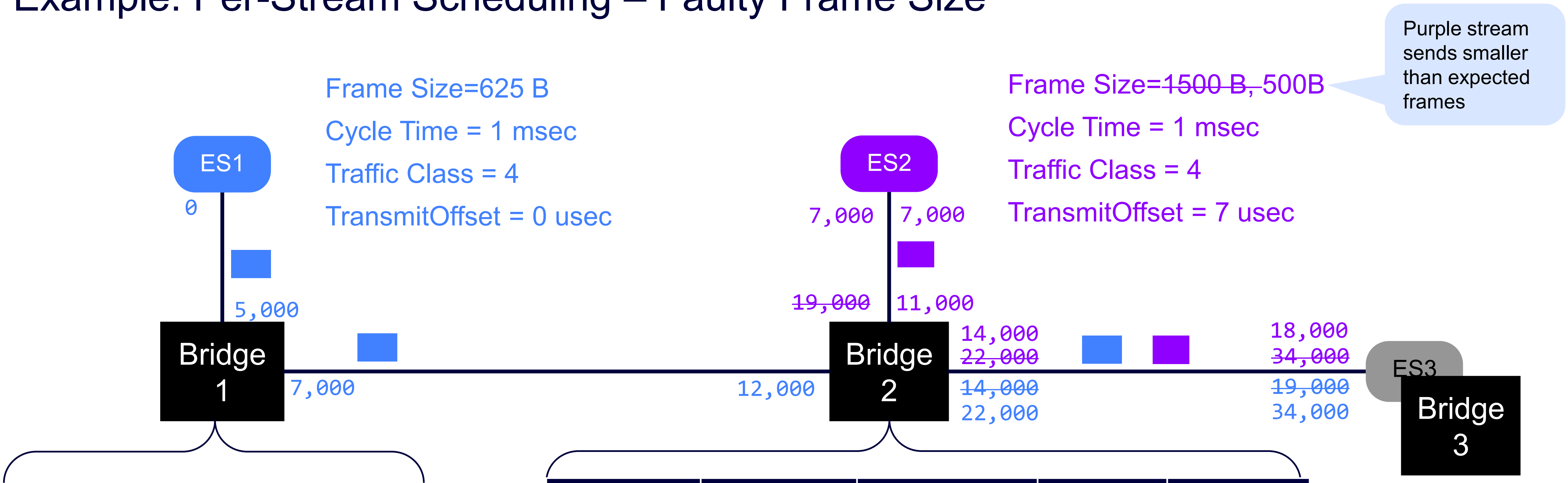
Example: Per-Stream Scheduling – Faulty Frame Size



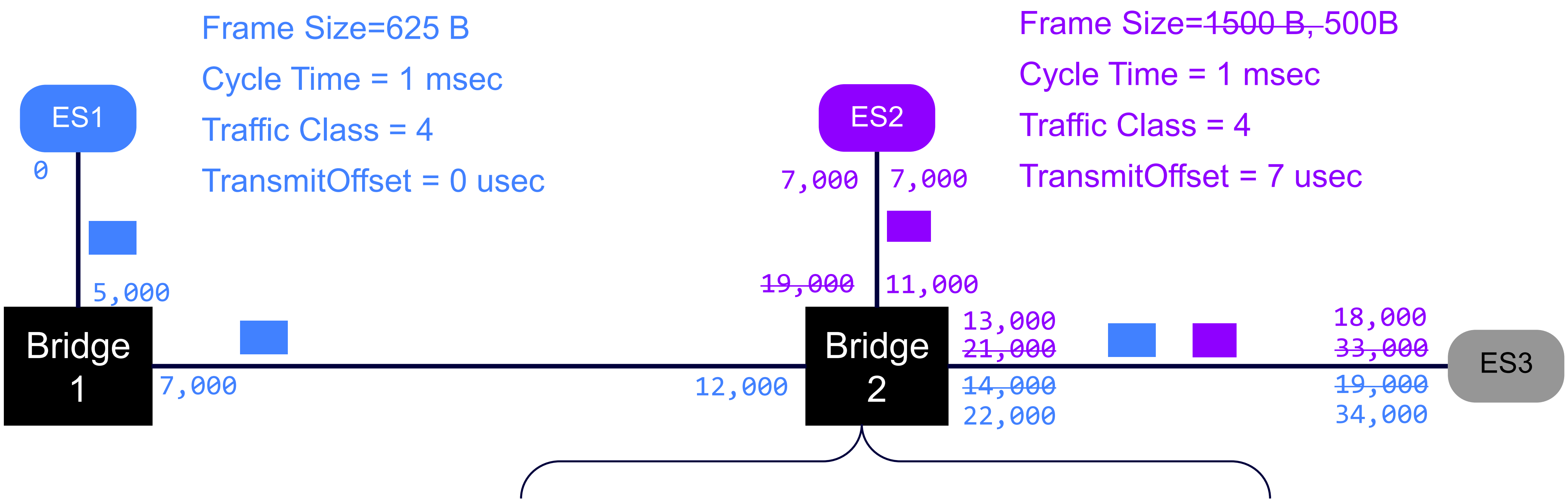
Observation:

The faulty purple stream takes the scheduled slot for blue stream causing reordering of frames and variable congestion delay for the blue stream.

If the example topology had another bridge (BR3) in the path (in place of ES3), the PSFP stream gates would drop both purple and blue frames. In that case, a fault in purple stream would have caused a drop in blue stream

Gate	Duration	Cumulative ...e	Normal Case	Faulty Case
		14,000		
		19,000		
		22,000		
		34,000		
		1,000,000		

Example: Per-Stream Scheduling – Faulty Frame Size
Do PSFP Stream Gates help?



Stream Gate for Blue

Gate State	Duration
Closed	7,000
Open	5,000
Closed	988,000

Stream Gate for Purple

Gate State	Duration
Closed	7,000
Open	12,000
Closed	981,000

Do PSPF Stream Gates help?

Answer: No

Example: Per-Stream Scheduling – *Does spacing the streams help? Normal Traffic*

Frame Size=625 B

Cycle Time = 1 msec

Traffic Class = 4

TransmitOffset = 0 usec

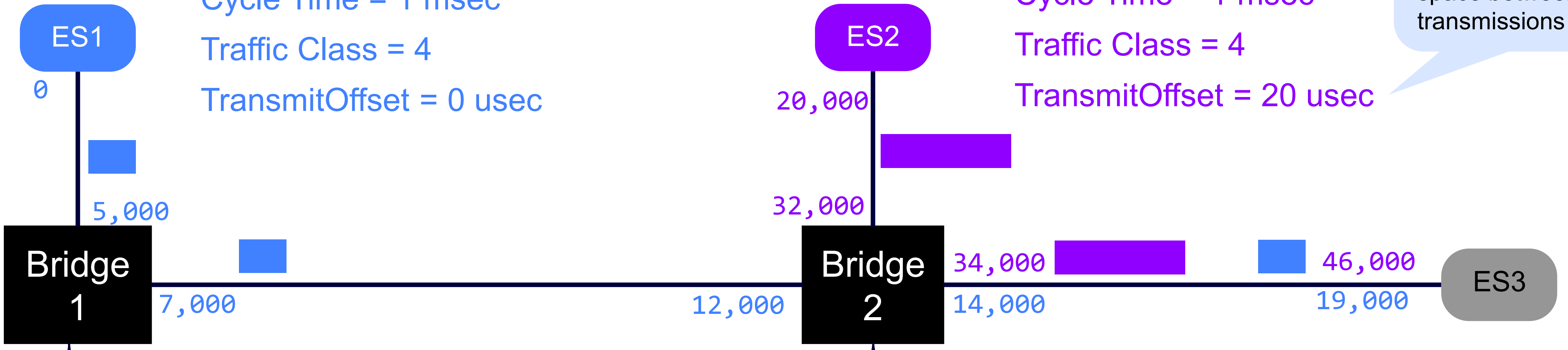
Frame Size=1500B

Cycle Time = 1 msec

Traffic Class = 4

TransmitOffset = 20 usec

Pushing back the TransmitOffset to allow for more dead space between transmissions

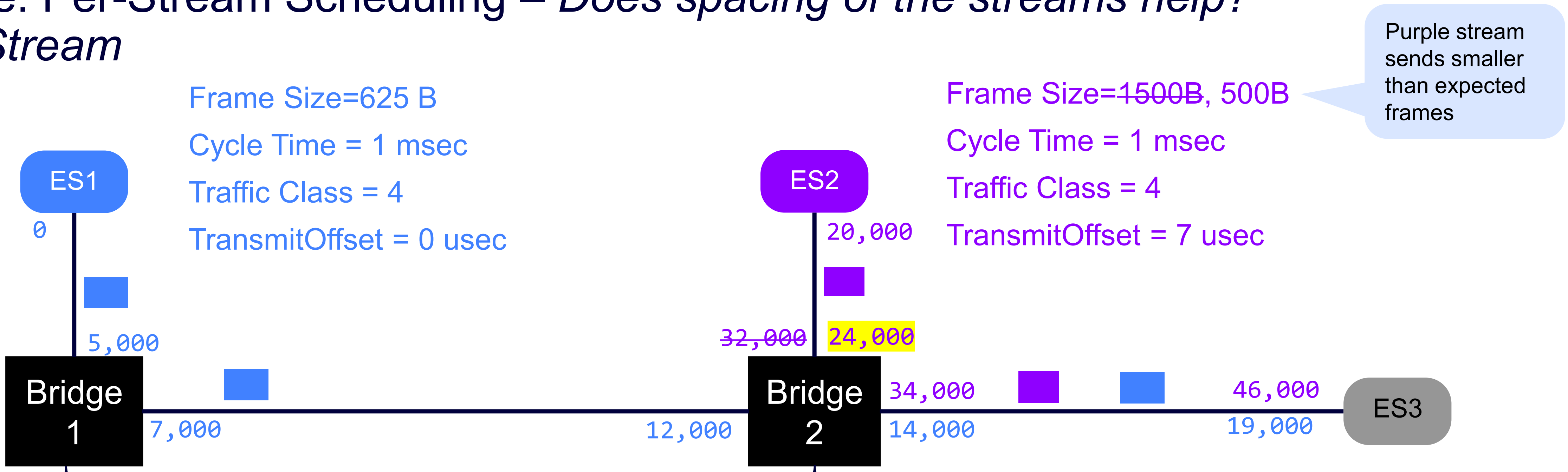


Gate State	Duration	Cumulative Time
OOOCOOOO	7,000	7,000
CCCOCCCC	5,000	12,000
OOOCOOOO	988,000	1,000,000

Gate State	Duration	Cumulative Time	Normal Case
OOOCOOOO	14,000	14,000	
CCCOCCCC	5,000	19,000	Blue Stream
OOOCOOOO	15,000	34,000	
CCCOCCCC	12,000	46,000	Purple Stream
OOOCOOOO	954,000	1,000,000	

Using a much larger "gap" between the two streams.

Example: Per-Stream Scheduling – *Does spacing of the streams help? Faulty Stream*



Observation:

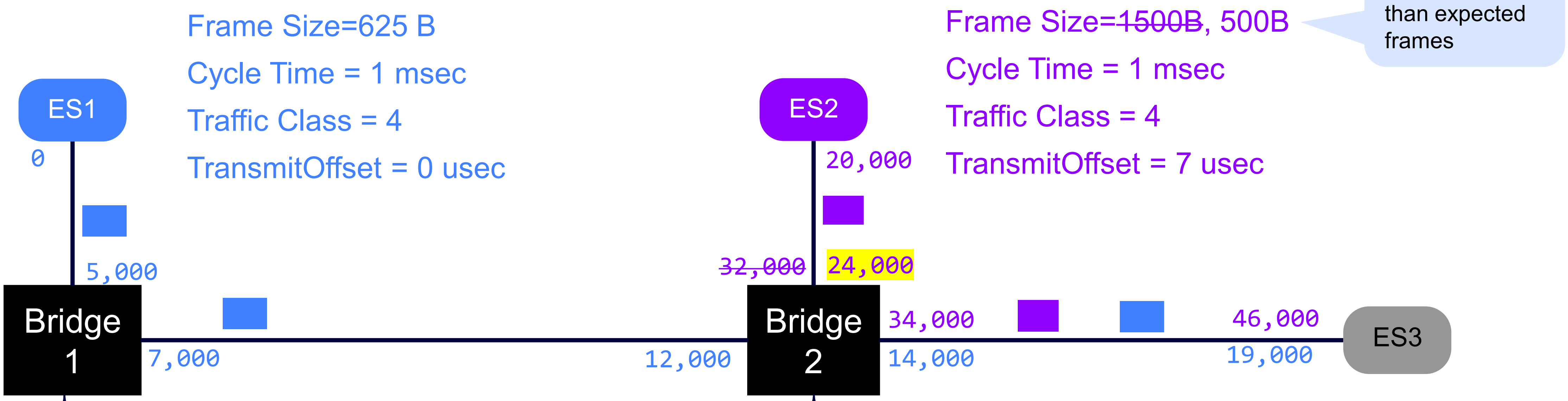
The large gap (dead space) between the two transmissions helps absorb the variation in the frame size and prevents out of order frames.

The gaps should be large enough to absorb the time/delay variations as well as frame size variation

The gap required is proportional to the difference in the size of the smallest and largest frame.

Gate State	Duration	Cumulative Time	Normal Case	Faulty Case
oooCoooo	14,000	14,000		
CCCoCCCC	5,000	19,000		
oooCoooo	15,000	34,000		
CCCoCCCC	12,000	46,000		
oooCoooo	954,000	1,000,000		

Example: Per-Stream Scheduling – *Does spacing of the streams help? Faulty Stream*



Observation:

Does spacing of streams help?

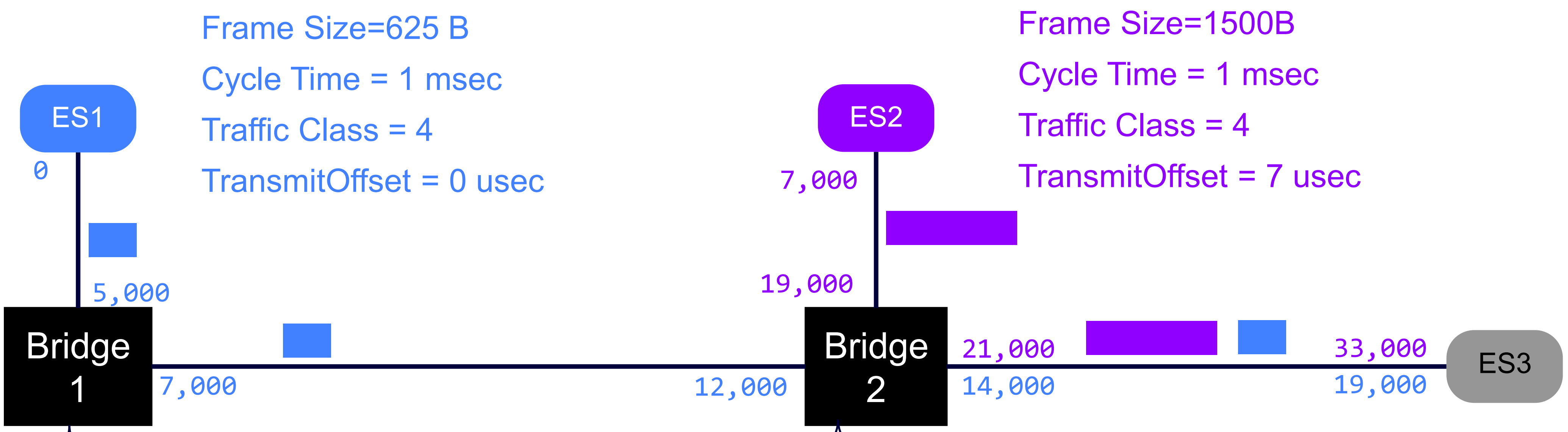
Yes, if you are willing to allocate a scheduled window/slot that is double the size of actual transmission.

This implies, in general, a 50% bandwidth utilization on the link if the entire link bandwidth were to be used by scheduled traffic.

Gate State	Duration	Cumulative Time	Normal Case	Faulty Case
OOOCOOOO	14,000	14,000		
CCCOCCCC	5,000	19,000		
OOOCOOOO	15,000	34,000		
CCCOCCCC	12,000	46,000		
OOOCOOOO	954,000	1,000,000		

– Per-Class Scheduling

Example: Per-Class Scheduling – Normal Case



Gate State	Duration	Cumulative Time
OOOCOOOO	7,000	7,000
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OOOCOOOO	988,000	1,000,000

Gate State	Duration	Cumulative Time	Normal Case
OOOCOOOO	14,000	14,000	
CCCOCCCC	**20,000**	19,000	
		21,000	
		34,000	
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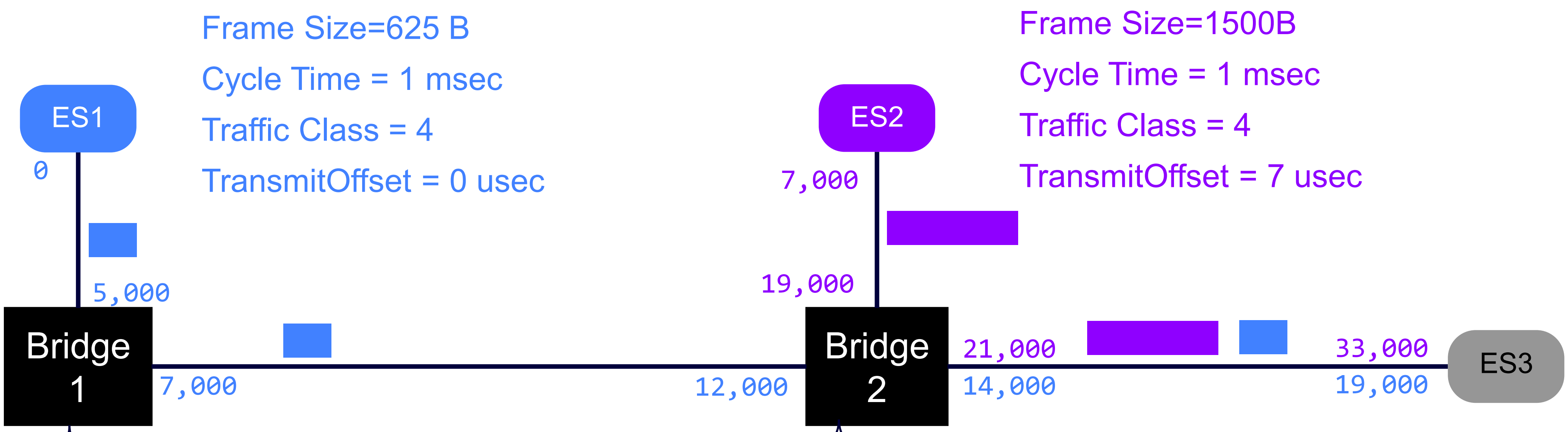
Example: Per-Class Scheduling – Normal Case



Gate State	Duration	Cumulative Time
000C(		00
CCCO		00
000C		00

Per-Class Scheduling opens the queue corresponding to appropriate traffic class for the <u>entire duration</u> during which both streams are scheduled to egress the port.

Gate State	Duration	Cumulative Time	Normal Case
000C0000	14,000	14,000	
CCCOCCCC	**20,000**	19,000	
		21,000	
		34,000	
000C0000	966,000	1,000,000	

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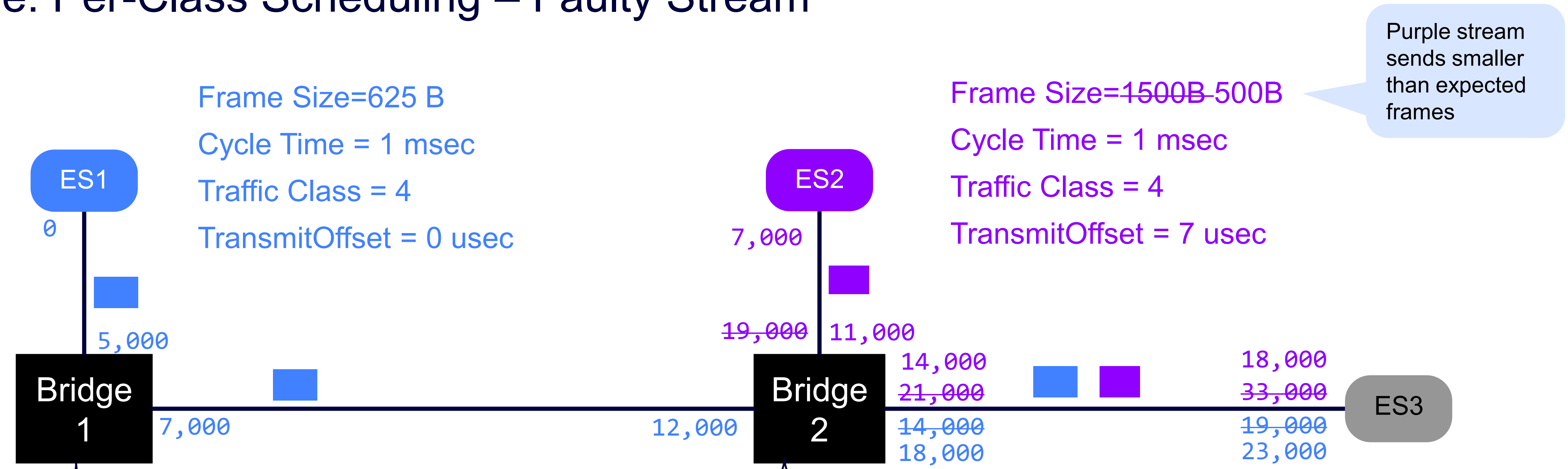
Example: Per-Class Scheduling – Faulty Stream



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Gate State	Duration	Cumulative Time	Normal Case	Faulty Case
OOOCOOOO	14,000	14,000		
		19,000		
CCCOCCCC	**20,000**	21,000		
		34,000		
OOOCOOOO	966,000	1,000,000		

Purple stream arrives earlier than expected and gets ahead of the blue stream changing the order of frames w.r.t the schedule.

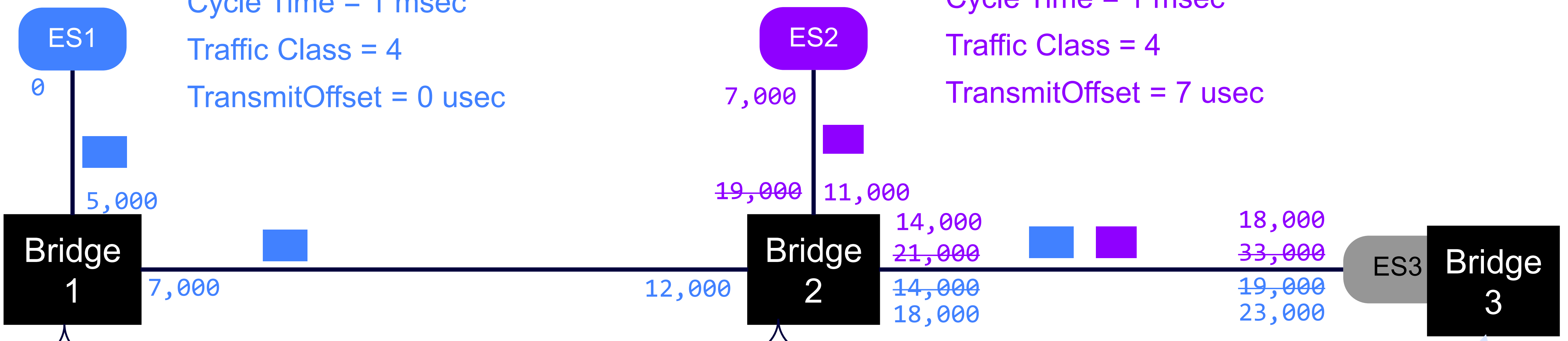
Blue stream experiences variable congestion delay

Example: Per-Class Scheduling – Faulty Stream

Frame Size=625 B
Cycle Time = 1 msec
Traffic Class = 4
TransmitOffset = 0 usec

Frame Size=~~1500B~~ 500B
Cycle Time = 1 msec
Traffic Class = 4
TransmitOffset = 7 usec

Purple stream sends smaller than expected frames



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Gate State	Duration	Cumulative Time	Normal Case	Faulty Case
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		19,000		
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		34,000		
OOOCOOOO	966,000	1,000,000		

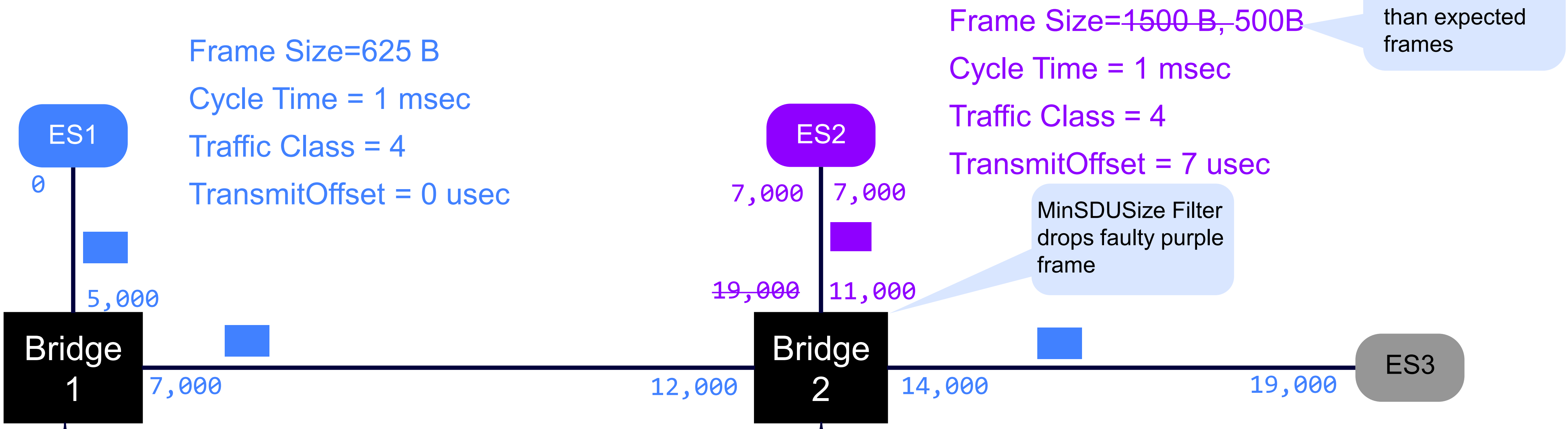
If there were a BR3 at the next hop, the purple frame will arrive much earlier than expected and the “gap” will continue to increase hop by hop as presented in slide 6.

If PSFP stream gates are implemented along with per-class scheduling, BR3 would drop both purple and blue frames.

Fault in purple stream causes a drop in blue stream

MinSDUSize Filtering

Example: Per-Stream Scheduling – Faulty Frame Size



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OOOCOOOO	966,000	1,000,000		

Purple stream blocked

Blue stream is not impacted by the faulty purple stream

Fault Isolated

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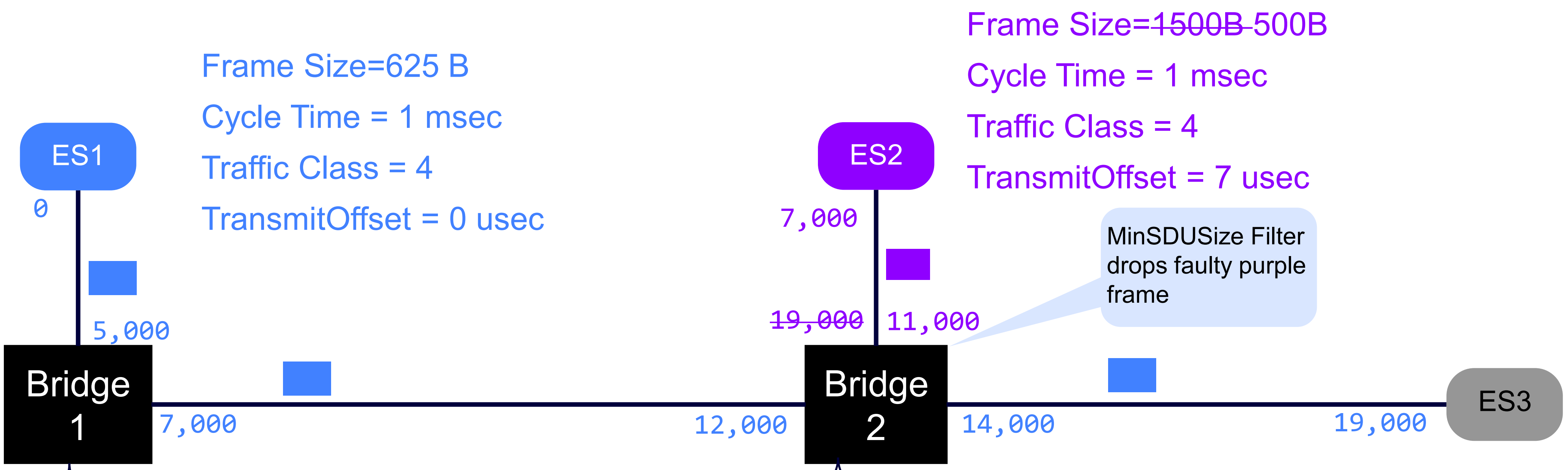
Example: Per-Class Scheduling – Faulty Frame Size



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CCCOCCCC	**20,000**	19,000		
		21,000		
		34,000		
OOOCOOOO	966,000	1,000,000		

Purple stream blocked

Blue stream is not impacted by the faulty purple stream

Fault Isolated

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Summary

1. Demonstrated the impact of variable frames on both per-class and per-stream scheduled network
2. In both cases, a faulty stream with smaller than configured/expected frames can disrupt other streams by a) changing frame ordering, b) causing variable congestion delays, and c) causing frame drops due to stream gate violations
3. Additional bandwidth, in terms of gap between scheduled transmission, can be allocated to overcome this fault mode. However, the impact on link utilization can be severe.
4. For allocation of additional gap between transmission, there is no parameter to indicate the range of the acceptable frame sizes, which affects the size of the gap. It must be assumed that the smallest frame is 64 Bytes, even if the designers intend to have a larger value for minimum frame size.
5. Without MinSDUSize filtering, TSN enhancements for scheduled traffic and low bounded latency are not effective in two conditions:
    a. Faulty streams with unexpected frame sizes
    b. Small expected variation in frame sizes
6. MinSDUSize filtering addresses the problem directly – frames violating the configured size are dropped without impacting any other traffic
7. It is recommended to include MinSDUSize filtering option for Stream Filters to 802.1Q 8.6.5.3 to enable engineered network use cases (e.g., aerospace)

QUESTIONS | DISCUSSION

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