Why an additional Shaper?

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Structure of this Presentation

Recap of Shaper: CBS, TAS and BLS

Handling of Overload-Frames

Comparison: Time Aware Shaper (TAS) vs. Burst Limiting “Shaper” (BLS)

- Assumptions for the Comparison
- Optimization Goals for industrial/automotive control networks
- Previous Simulations
- ´ Calculation of optimized TAS Windows’s
- Simulation results
- Simplified TAS Windows calculation “algorithm”

Conclusion

Recap of CBS
BW Limitation and Delay

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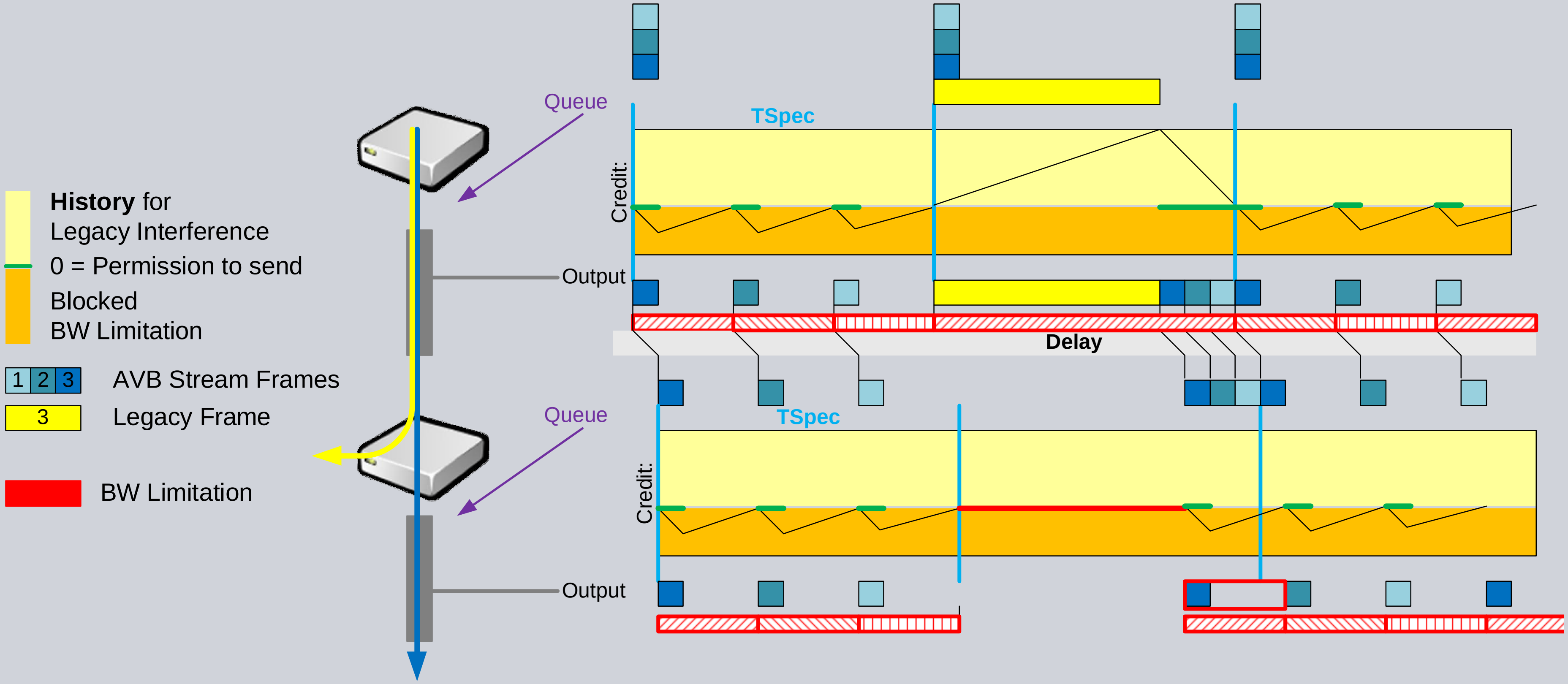
The Credit limits the bandwidth over a “frame” time

The Credit must be **set to 0**, if no AVB Frame is in the queue and **stays zero**!



TAS Shaper
Pro- and Cons

The Time Aware Shaper (TAS):

http://www.ieee802.org/1/files/public/docs2012/bv-boiger-time-aware-shaper-0912-v02.pdf

For TAS all network devices must be synchronized

- Synchronized End Stations for scheduled sending times
- Synchronized Switches with defined forwarding times

Pros:

- Best possible latency (immediately forwarding)
- No Jitter in arrival time (no congestion)

Cons:

- Reservation of Bandwidth must be exclusive (not useable for other Traffic)
- Effort for Calculation of scheduling

Performance of TAS compared to Preemption with Bandwidth Limitation

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The Burst Limiting “Shaper” (BLS):

http://www.ieee802.org/1/files/public/docs2013/new-goetz-TSN-4-Industrial-Networks-20130115-v1.pdf

- limits the bandwidth usage
  (ensures reservation of bandwidth and resources – AVB core feature)
- streams use highest priority
  (~strict priority with highest priority - transmitted immediately if frames available)
- is used with preemption
  (avoids waiting time due to congestion)

Other Names of these Shapers

Time Aware Shaper Options

http://www.ieee802.org/1/files/public/docs2013/new-tsn-sextonda-time-aware-shaper-options-20130316-v01.pdf

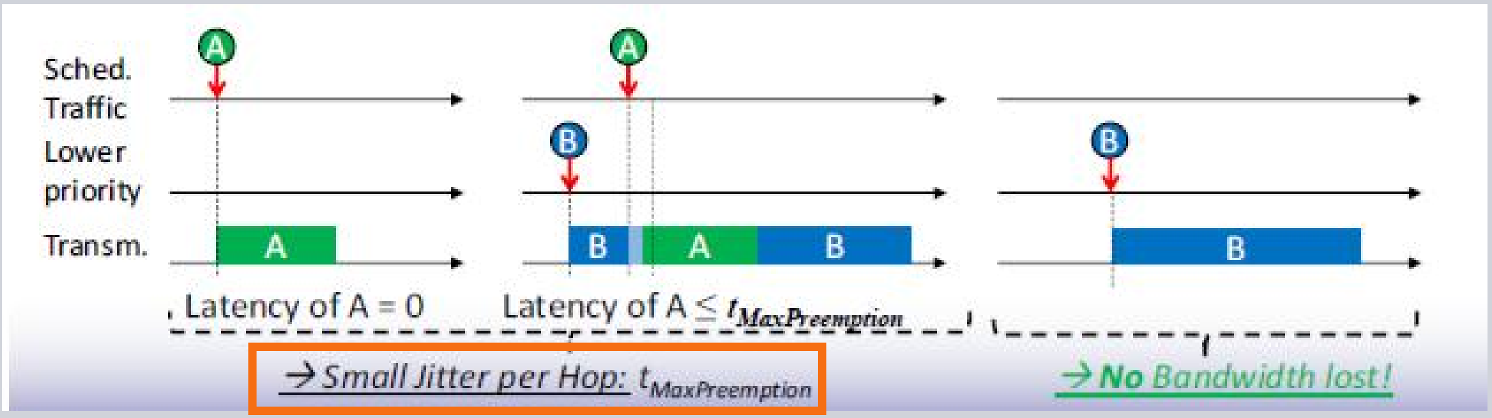
Talker Scheduled Traffic Support

http://www.ieee802.org/1/files/public/docs2013/new-tsn-specht-talker-scheduled-traffic-support-20130318.pdf

“BLS”:

Talkers (End Stations) are Scheduled

Bridges support CT, Preemption and BW-Limitation (TSN) (**No TAS**)

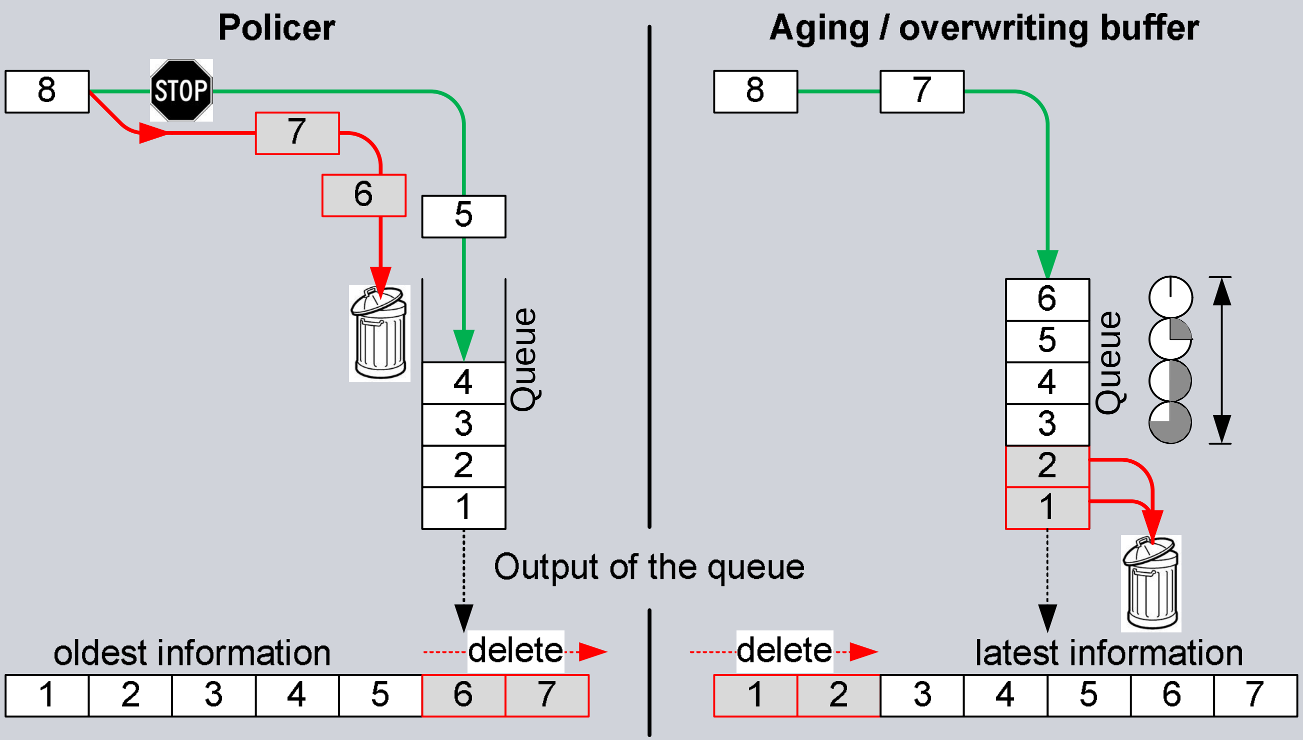


Bandwidth Limitation
Policer against aging

The limitation of the bandwidth can be done in different ways:

- use a policer to prevent frames getting in the queue
- “aging” / overwriting of frames inside the queue

But should only effect the transmission in case of errors (e.g. wrong configuration)



Performance of TAS compared to Preemption with Bandwidth Limitation

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ASSUMPTIONS for the comparison of the two Shaper:

- End Stations are always synchronized to get repeatable result
  (Not needed for BLS – only for comparison of achievable performance)
- Switches are only synchronized when using the TAS Shaper
  (TAS only works with accurate synchronized End station and Switches)
- Goal is a minimal time for transmitting **all information**
- Additional Transmission Delay for "Legacy" Traffic should be low
- Waste of Bandwidth should be minimal (e.g. Waste using Guard Time)
- Best achievable Performance is compared so that L2 must be used

Recap: Low Latency is required to minimize Transmission Time for Scheduled Traffic

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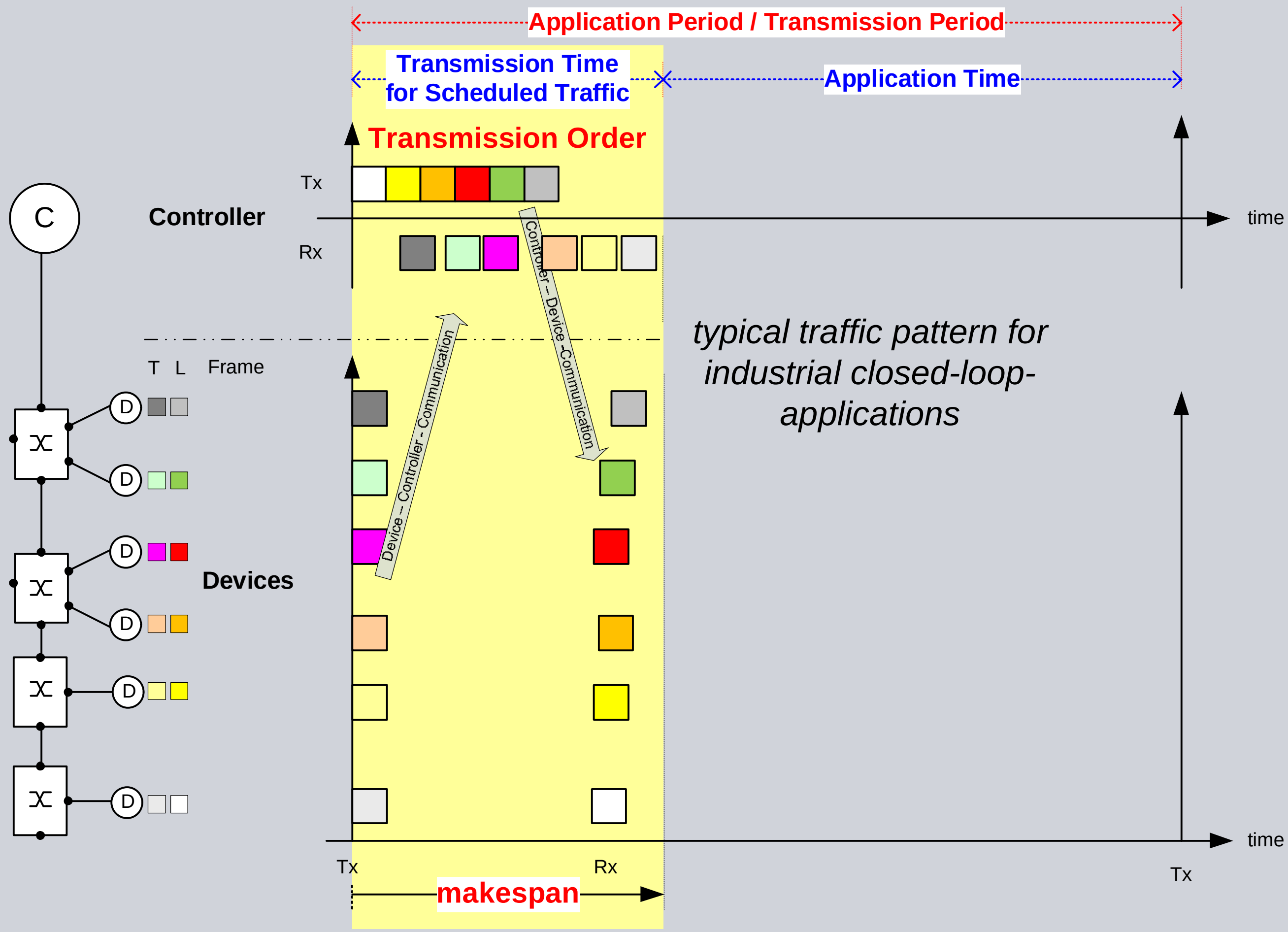
Scheduled Traffic for automation applications



Transmission of Scheduled Traffic within transmission time for Scheduled Traffic

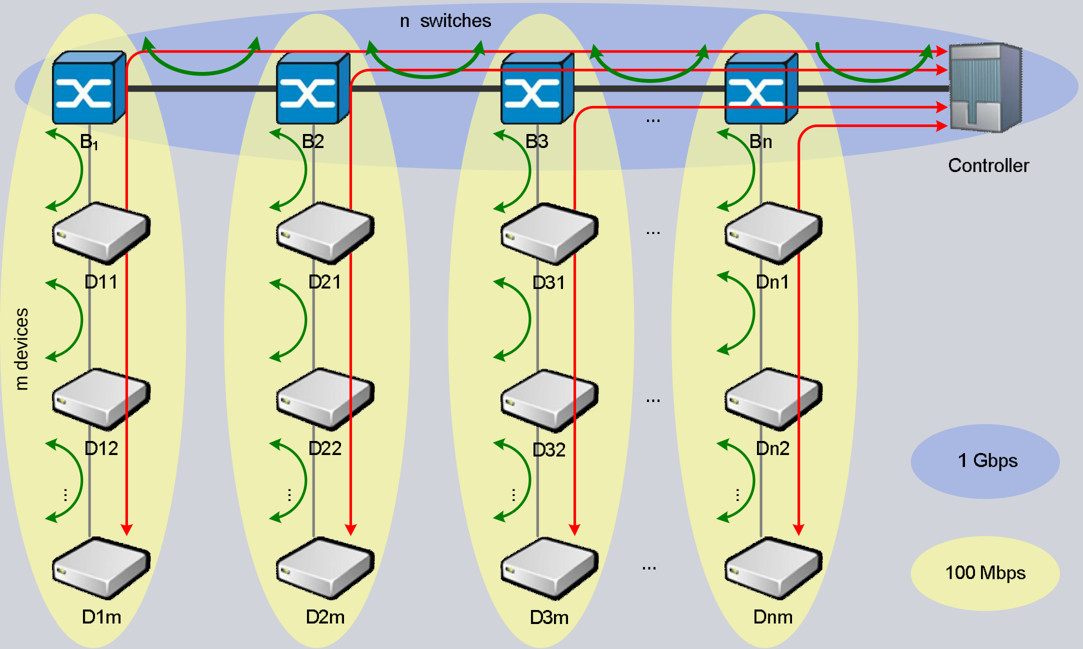
Previous Simulations

Performance <u>without optimized</u> TAS windows against BLS:

(http://www.ieee802.org/1/files/public/docs2013/new-goetz-TSN-4-Industrial-Networks-20130115-v1.pdf)

Simulated Use Case: *Time aware Shaper (TAS) <-> Burst limiting Shaper (BLS)*

- **a) Low Latency for Scheduled Traffic with constant Frame Size**
- **b) Low Latency for Scheduled Traffic with random Frame Size**
- **c) Low Latency for Scheduled Traffic with random Frame Size and optimized Window Size for TAS**



Simulation - Latency for Scheduled Traffic
TAS w/ multiple windows in GE for D->C

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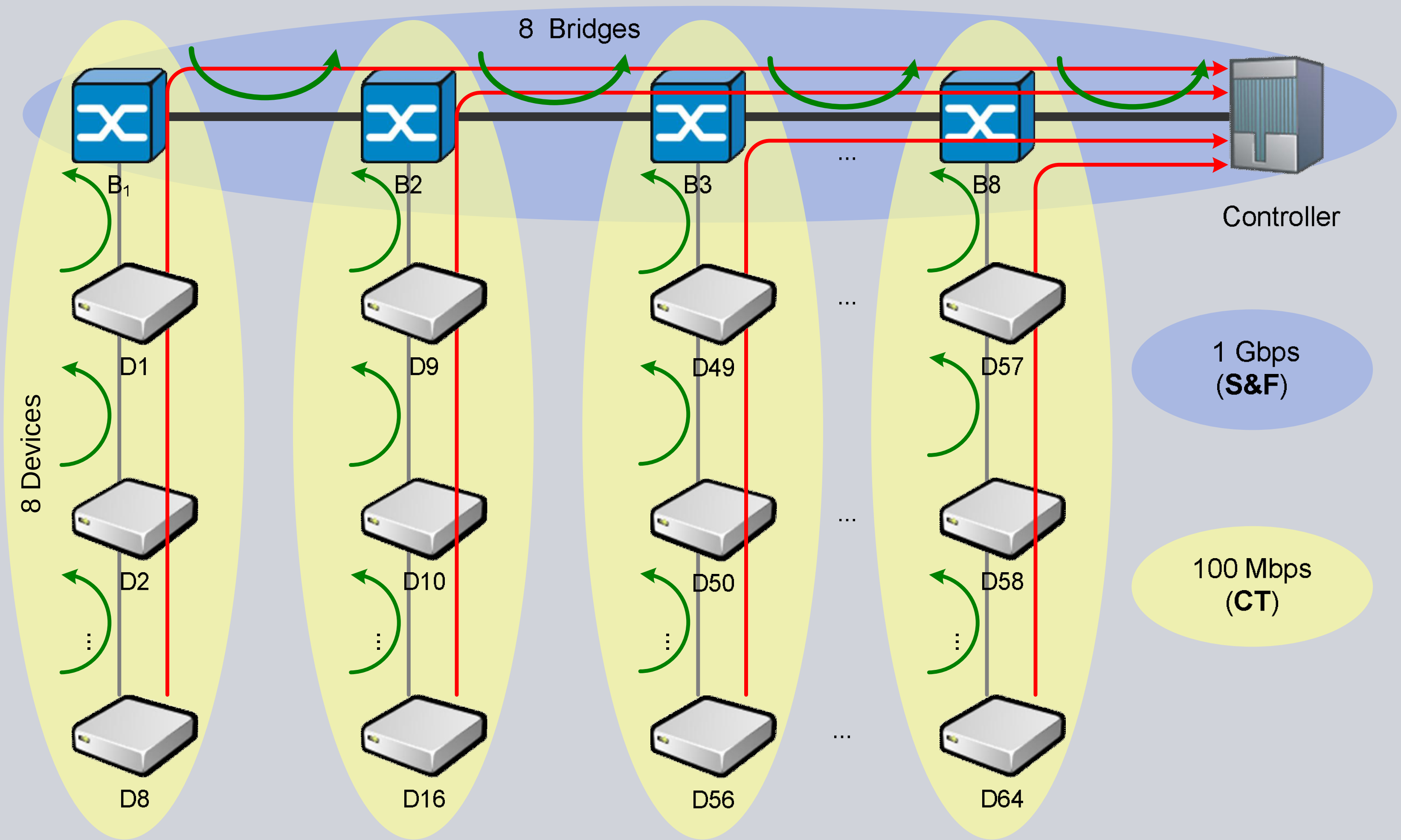

Latency for Scheduled Traffic
Time aware Shaper (TAS)<-> Burst limiting Shaper (BLS)

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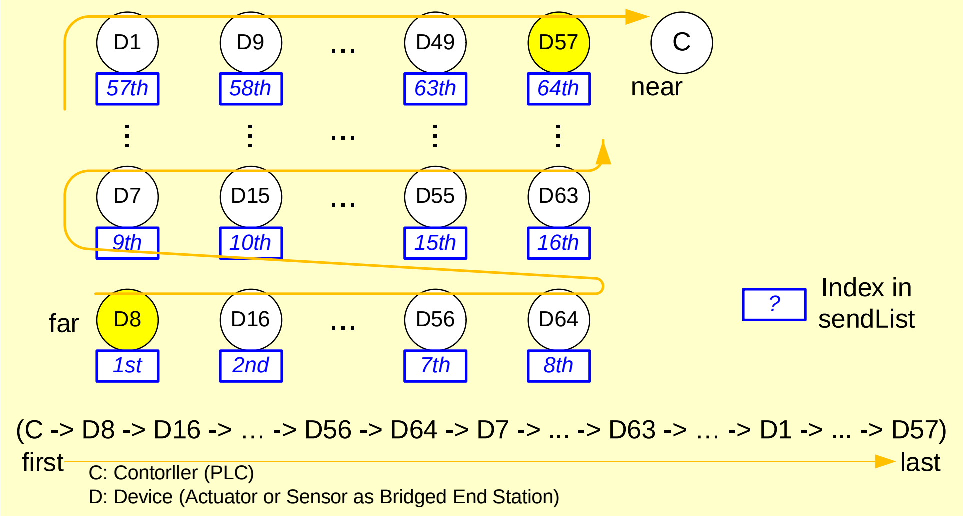
General Settings (1):

Network: 8 bridges,
8x8 devices (bridged end stations)



- **Real time application (synchronized)**
  - Transmission order (C->D):
    farthest first, nearest last
  - Traffic load for Scheduled Traffic < 50%
  - Frame Size: **UC 1** constant size: 64 Bytes (**Identical** I/O Data Size)

    UC 2 random size: 10% 64 Bytes / 10% 512 Bytes / 80% between 128~384 Bytes (**Random** I/O Data Size)

- **Best effort traffic:**
  - Traffic load < 30%
  - Frame size: 25% max_size, 25% min_size, 50% between 250~1250 Bytes

    25% burst (frames in chain), 75% non-burst

Latency for Scheduled Traffic
Time aware Shaper (TAS)<-> Burst Limiting Shaper (BLS)

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General Settings (2)

BLS & TAS

- Transmission period: 250 us for Scheduled Traffic with constant frame size,
  500 us for Scheduled Traffic with random frame size,
- **Window size (only for TAS):**
  - **UC 1** – Window size is 72 us for Scheduled Traffic with constant frame size
  - **UC 2** – Window size is 400 us for Scheduled Traffic with random frame size
  - **Optimized UC1 and UC 2** – Window size optimized
    - **Window start time always at the beginning of cycle**
    - **Window close time varies for different location of station**
    - **Window close time right after the station has transmitted the last Scheduled frame**
  - **Cut-through only for Scheduled Traffic:** 48 bytes Delay

Bridging delay: 500 ns; cable + PHY delay: 750 ns

Pre-emption in combination with TAS or BLS

Latency for Scheduled Traffic
Optimized Time aware Shaper (TAS) Window Size

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Goal: find a scheduling scheme splitting the long RED phase into e.g. two short ones for each bridge,

in order to reduce bandwidth waste, while keeping worst-case latency (e.g. at stream[8]) unchanged.

Latency for Scheduled Traffic
Optimized Time aware Shaper (TAS) Window Size

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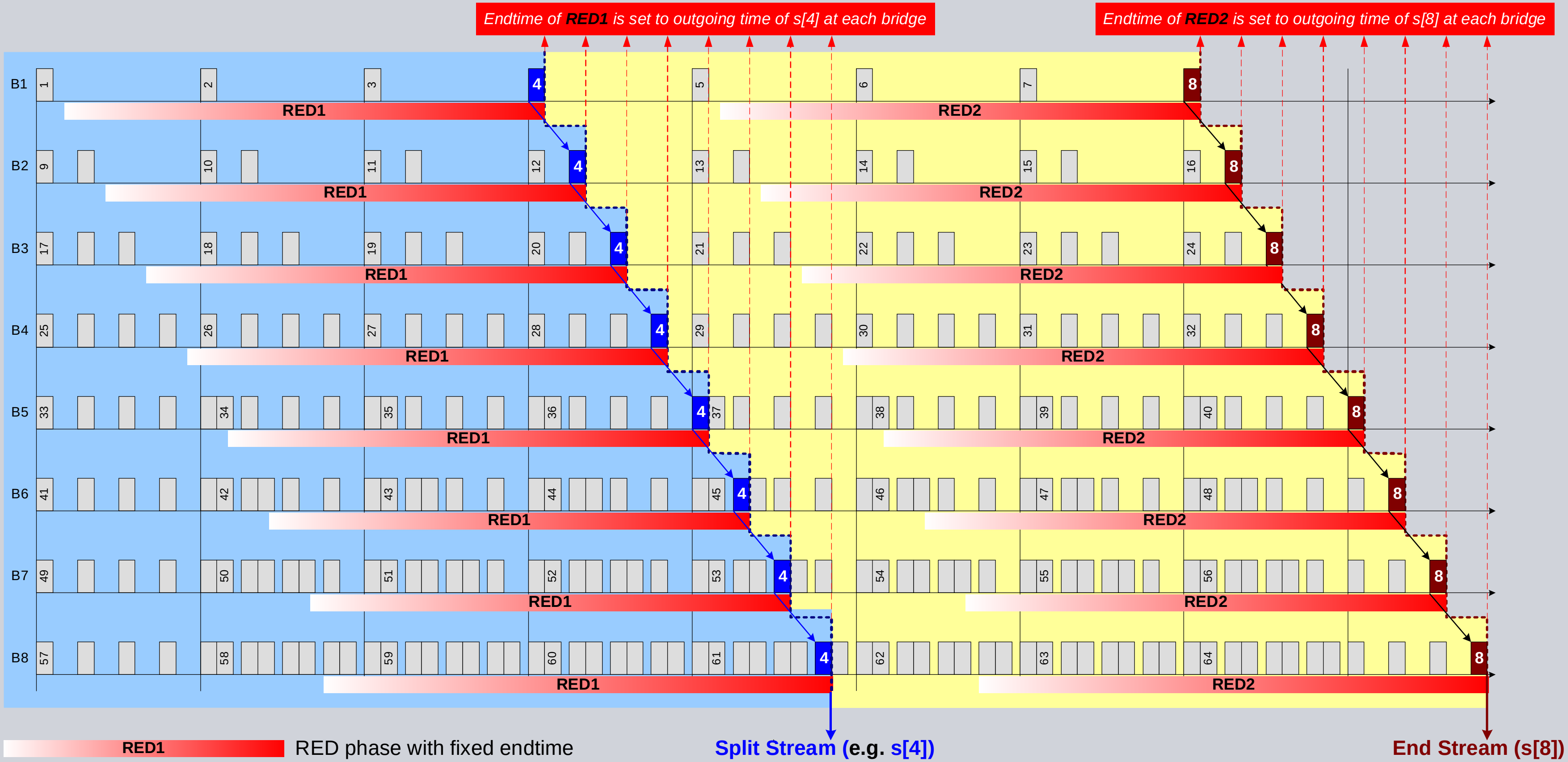

Step 1: locate a split stream (from farthest branch) and divide the RT transmissions into two segments (of similar loads)

Step 2: align the ***EndTime*** of RED1 and RED2 with the outgoing time of split stream and end stream at each bridge

Latency for Scheduled Traffic
Optimized Time aware Shaper (TAS) Window Size

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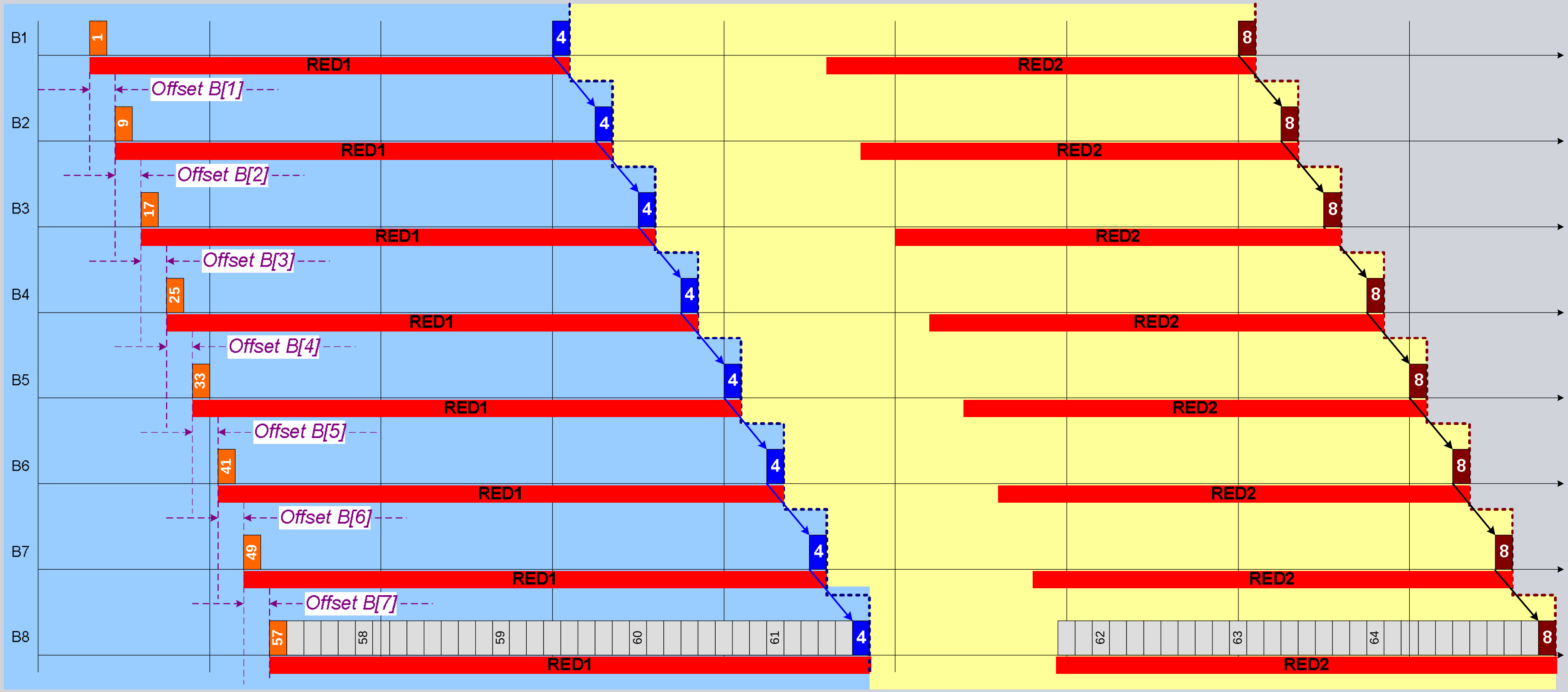


Step 3: determine RED phase starttime of last bridge (B[8]): set length of RED1/RED2 equal to the total transmission time of all streams that start before (incl.) split stream (S[4])/end stream (S[8])

How to determine this value?

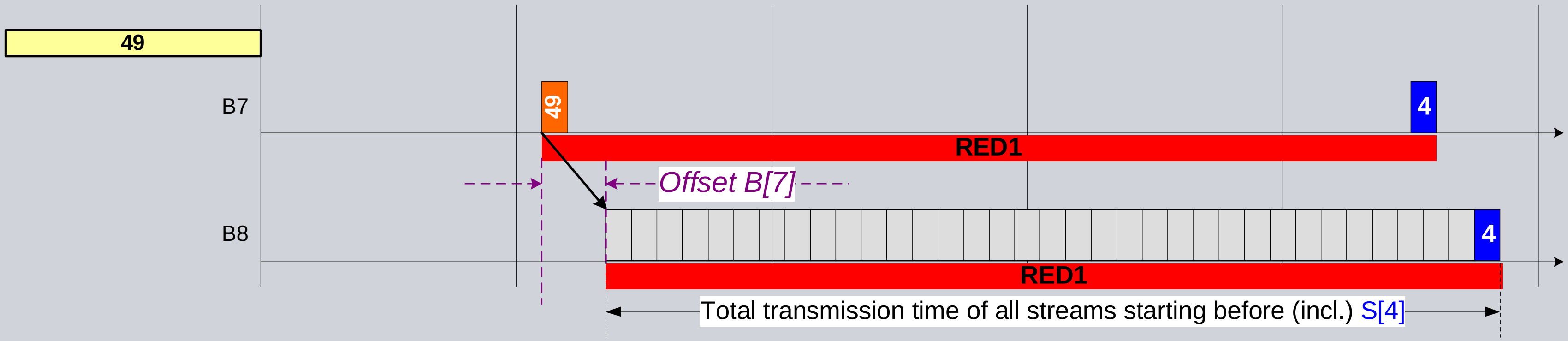
Step 4: calculate RED phase starttime of rest bridges recursively in **reverse** order using

$$StartTime_{RED\_B[i]} = StartTime_{RED\_B[i+1]} - Offset_{B[i]}$$

Latency for Scheduled Traffic
Optimized Time aware Shaper (TAS) Window Size

Calculation of $Offset_{B[i]}$ ***Rule 1***: Red phase of B[i] must start at an earlier time than that of B[i+1], so that the first outgoing stream of B[i] is ready for transmission at the beginning of Red phase of B[i+1]

(e.g. calculate RED1´s starttime of B[7] using B[8]‘s info)



49 First stream received by B[7] from its FE branch

49 First stream transmitted by B[7] in RED1

$$Offset\_Start_{B[7]} = D_{Line+PHY} + D_{switch} + D_{trans\_S[49]}$$

For scenarios with different stream size, this value can be simply replaced by a constant max. stream trans. duration

Latency for Scheduled Traffic
Optimized Time aware Shaper (TAS) Window Size

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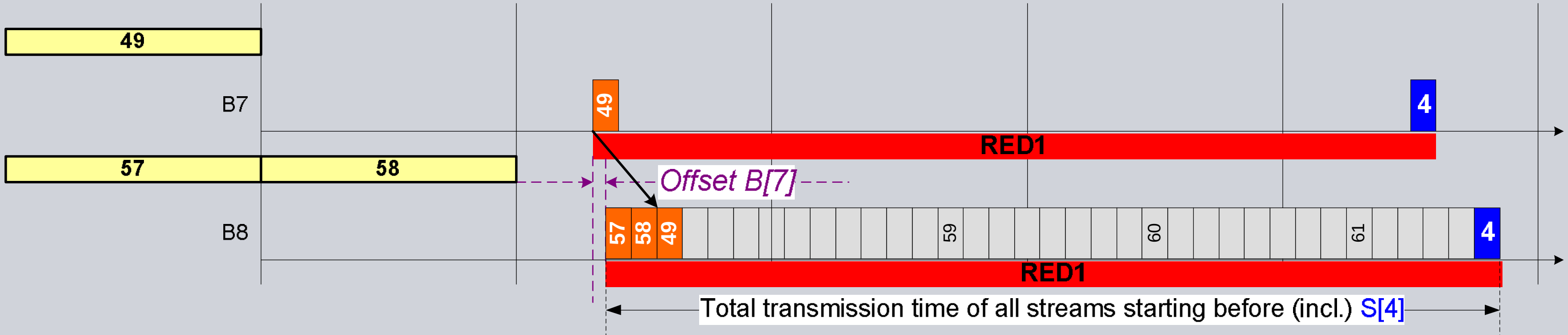
Calculation of $\text{Offset}_{B[i]}$ ***Rule 2***: length of Red phase of B[i] calculated by ***Rule 1*** can be further shortened by considering the RT transmissions that are already scheduled at the beginning of B[i+1]'s RED phase



49	1st stream received by B[7] from its FE branch
57 / 58	1st and 2nd streams received by B[8] from its FE branch before RED1 of B[8] begins
49	1st stream transmitted in RED1 of B[7]
57 / 58	1st and 2nd streams transmitted in RED1 of B[8]

$$Offset\_Start_{B[7]} = D_{Line+PHY} + D_{switch} + D_{trans\_S[49]} - D_{trans\_S[57]} - D_{trans\_S[58]}$$

Rule 2 yields better results than ***Rule 1***, but needs more computational overhead

UC 1 Simulation - Low Latency for Scheduled Traffic with constant Frame Size of 64Bytes, CT@GE

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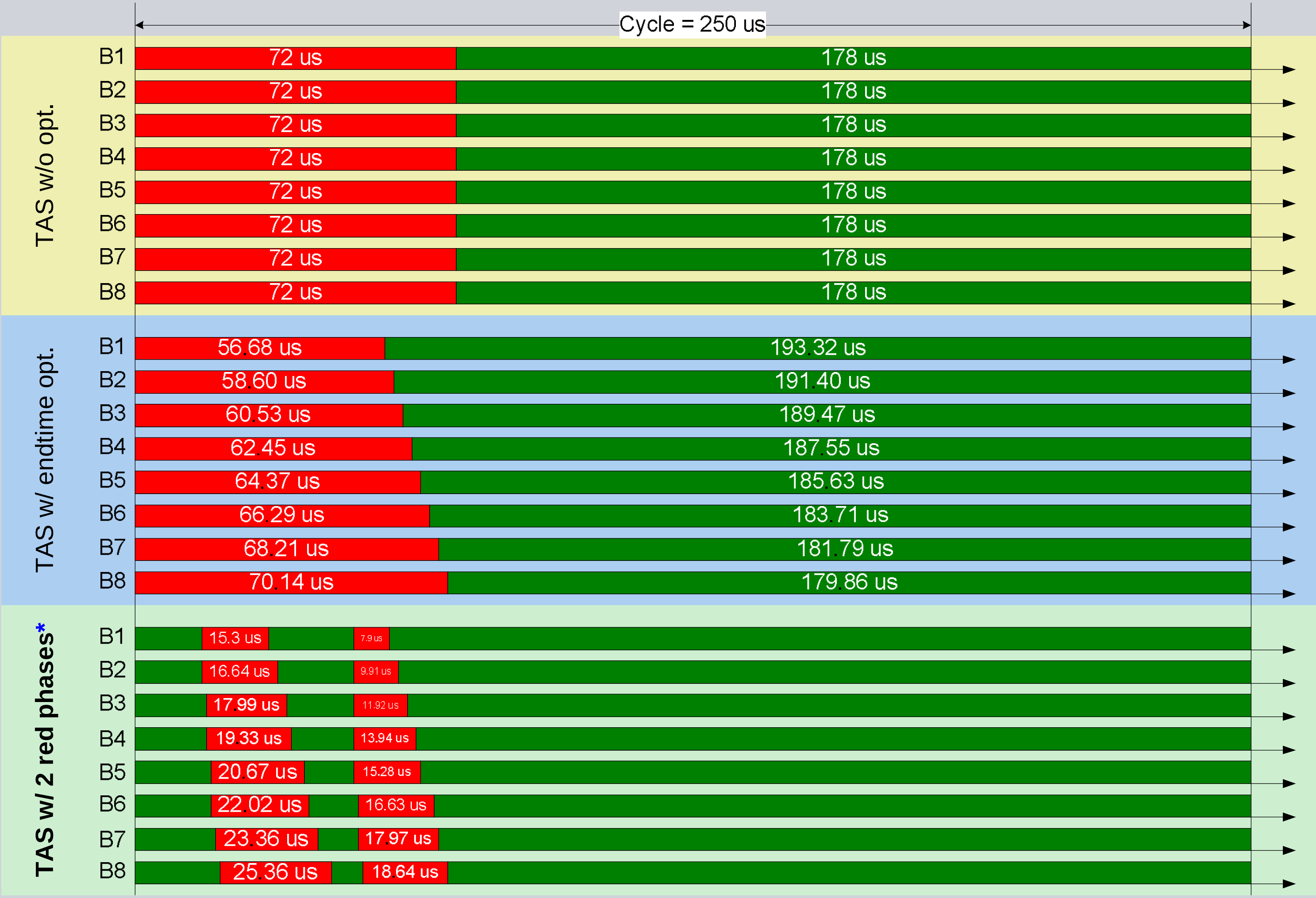

** Red phases calculated with **Rule 2***

(Drawn to scale)

UC 1 Simulation - Low Latency for Scheduled Traffic with constant Frame Size of 64Bytes, CT@GE

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Identical 64bytes		Bridge	Cycle length (us)	Red Phase Length (us)	Green Phase Length (us)	Max. RT trans. delay (us)	NRT-GE E2E delay (us) (mean, max)	Max RT queue size (at GE bridges)	Gained bandwidth for NRT vs. w/o opt *(relative to cycle len.)*	Consumed bandwidth for RT trans. (us) per cycle	Bandwidth waste in RED phase *(relative to cycle len.)*
BLS		1..8	250	n/a	n/a	73.03	15.50 (151.59)	3 (at B[7,8])	n/a	n/a	n/a
TAS	w/o opt.	1	250	72	178	70.89	37.00 (327.27)	1 (at all bridges)	0.00%	5.38	26.65%
		2								10.75	24.50%
		3								16.13	22.35%
		4								21.50	20.20%
		5								26.88	18.05%
		6								32.26	15.90%
		7								37.63	13.75%
		8								43.01	11.60%
	Opt. of Red Phase end time	1	250	56.68	193.32	70.89	31.73 (268.71)	1 (at all bridges)	6.13%	5.38	20.52%
		2		58.60	191.40				5.36%	10.75	19.14%
		3		60.53	189.47				4.59%	16.13	17.76%
		4		62.45	187.55				3.82%	21.50	16.38%
		5		64.37	185.63				3.05%	26.88	15.00%
		6		66.29	183.71				2.28%	32.26	13.61%
		7		68.21	181.79				1.51%	37.63	12.23%
		8		70.14	179.86				0.75%	43.01	10.85%
	opt w/ two Red phases	1	250	22.23	227.77	70.89	16.01 (174.32)	3 (at B[7,8])	19.91%	5.38	6.74%
		2		25.58	224.42				18.57%	10.75	5.93%
		3		28.94	221.06				17.22%	16.13	5.12%
		4		32.29	217.71				15.88%	21.50	4.32%
		5		34.98	215.02				14.81%	26.88	3.24%
		6		37.66	212.34				13.74%	32.26	2.16%
		7		40.35	209.65				12.66%	37.63	1.09%
		8		43.02	206.98				11.59%	43.01	0.00%

UC 1 Simulation - Low Latency for Scheduled Traffic with random Frame Size of 64Bytes, CT@GE

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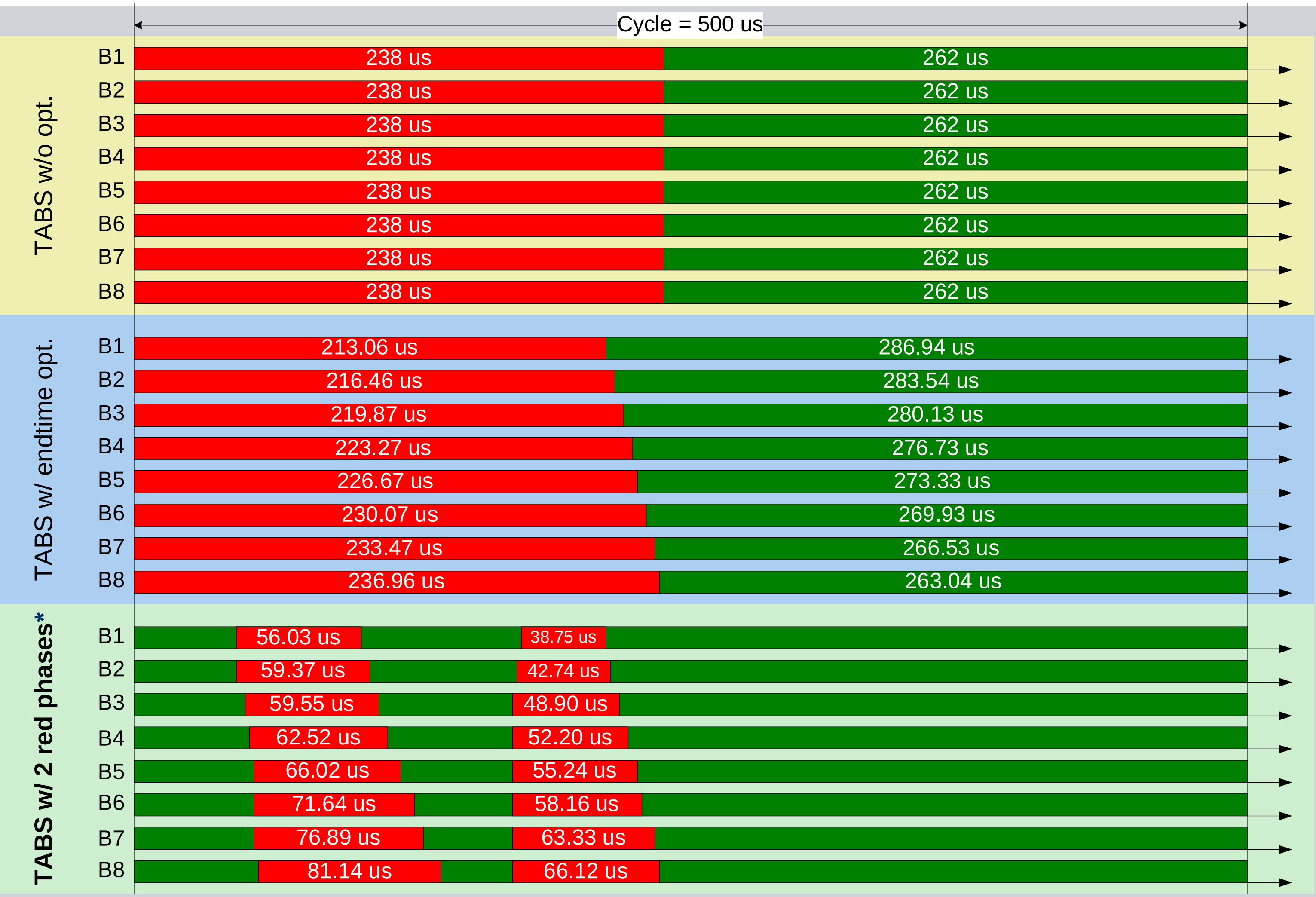

** Red phases calculated with **Rule 2***

(Drawn to scale)

UC 1 Simulation - Low Latency for Scheduled Traffic with random Frame Size of 64Bytes, CT@GE

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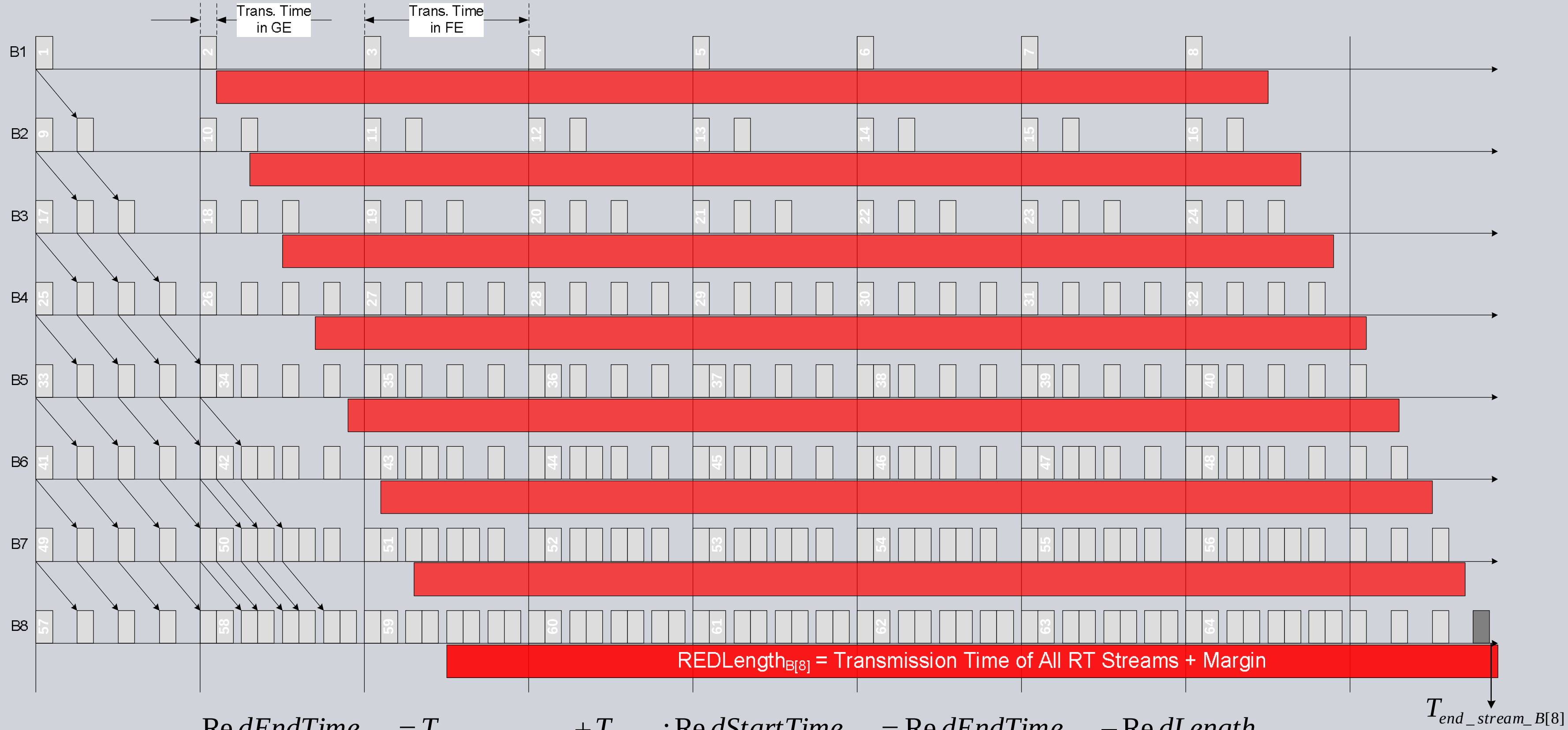
Random Size (seed = 0)		Bridge	Cycle length (us)	Red Phase Length (us)	Green Phase Length (us)	Max. RT trans. delay (us)	NRT-GE E2E delay (us) (mean, max)	Max RT queue size (at GE bridges)	Gained bandwidth for NRT vs. w/o opt *(relative to cycle len.)*	Consumed bandwidth for RT trans. (us) per cycle	Bandwidth waste in RED phase *(relative to cycle len.)*
BLS		1..8	500	n/a	n/a	239.36	23.49 (331.95)	4 (at B[8])	n/a	n/a	n/a
TAS	w/o opt.	1	500	238	262	237.2	109.12 (602.03)	4 (at B[8])	0.00%	20.82	43.44%
		2								35.58	40.48%
		3								52.90	37.02%
		4								72.27	33.15%
		5								88.62	29.88%
		6								106.87	26.23%
		7								129.31	21.74%
		8								147.25	18.15%
	Opt. of Red Phase end time	1	500	213.06	286.94	237.2	99.29 (577.98)	4 (at B[8])	4.99%	20.82	38.45%
		2		216.46	283.54				4.31%	35.58	36.18%
		3		219.87	280.13				3.63%	52.90	33.39%
		4		223.27	276.73				2.95%	72.27	30.20%
		5		226.67	273.33				2.27%	88.62	27.61%
		6		230.07	269.93				1.59%	106.87	24.64%
		7		233.47	266.53				0.91%	129.31	20.83%
		8		236.96	263.04				0.21%	147.25	17.94%
	opt w/ two Red phases	1	500	94.78	405.22	237.2	31.92 (252.93)	4 (at B[2,5,6,7,8])	28.64%	20.82	14.79%
		2		102.12	397.88				27.18%	35.58	13.31%
		3		108.46	391.54				25.91%	52.90	11.11%
		4		114.73	385.27				24.65%	72.27	8.49%
		5		121.27	378.73				23.35%	88.62	6.53%
		6		129.80	370.20				21.64%	106.87	4.59%
		7		140.21	359.79				19.56%	129.31	2.18%
		8		147.26	352.74				18.15%	147.25	0.00%

Calculation of TAS Window Size

TAS Optimization: Simplified Algorithms for Engineering Systems

Example: one RED phase with minimal calculation overheads



$$\mathrm{Re}\,dEndTime_{B[8]} = T_{end\_stream\_B[8]} + T_{margin}; \mathrm{Re}\,dStartTime_{B[8]} = \mathrm{Re}\,dEndTime_{B[8]} - \mathrm{Re}\,dLength_{B[8]}$$

$$\mathrm{Re}\,dStartTime_{B[i]} = \mathrm{Re}\,dStartTime_{B[i+1]} - (D_{Line+PHY} + D_{switch} + D_{trans\_\max\_stream}), i \in [1,7]$$

$$\mathrm{Re}\,dEndTime_{B[i]} = \mathrm{Re}\,dEndTime_{B[i+1]} - (D_{Line+PHY} + D_{switch} + D_{trans\_\min\_stream}), i \in [1,7]$$

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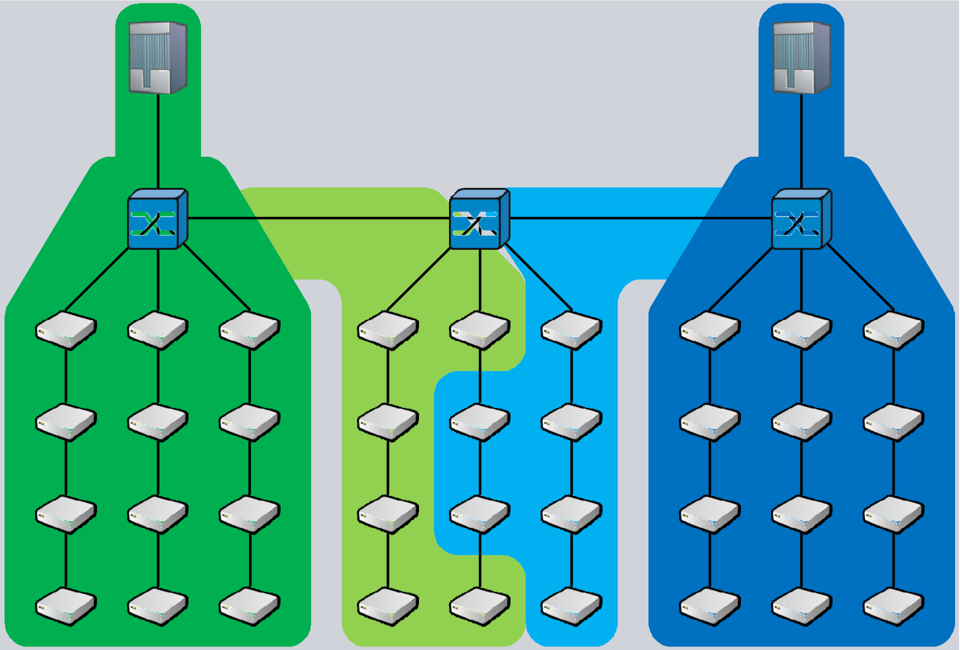
Conclusion

- TAS
  - Leads to optimal latency
  - Window Size Optimizations lead to better legacy performance
  - Easy to calculate TAS windows in small topologies (line, star)
  - Huge Effort to calculate TAS windows in **complex** Topologies



- BLS
  - can lead with an optimal Scheduling to nearly same performance (Preemption)
  - legacy performance is good without optimizations
  - Doesn’t require time aware scheduling inside the bridges
  - Work’s also without scheduled send times in end devices (lower performance)

Unique Names are needed for the Traffic Class / Shaper combination

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Thank you for your attention!

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