Towards the Calculation of Performance Guarantees for BLS in Time-Sensitive Networks

IEEE802.1 TSN TG Meeting

November 10-15, 2013 - Dallas, Texas, USA

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Outline

- Motivation
- Recapitulation: Bandwidth Limiting Shaper (BLS)
  - Policing on ingress and bandwidth metering on egress port
  - Shaper model
- Calculation of Performance Guarantees provided by BLS for CD class A
  - Assumptions
  - Modeling of CD class A streams
  - Modeling of the BLS service for CD class A
  - Calculation of the latency and backlog
- Example: Line-Topology
- Conclusion and Future Work

Motivation [1,3]

Motivation

Recapitulation [1]:

- Scheduled Traffic is the first choice for time critical ultra low latency control applications
- Nonetheless, scheduled traffic has several disadvantages and restrictions w.r.t. flexibility, planning overhead, etc.

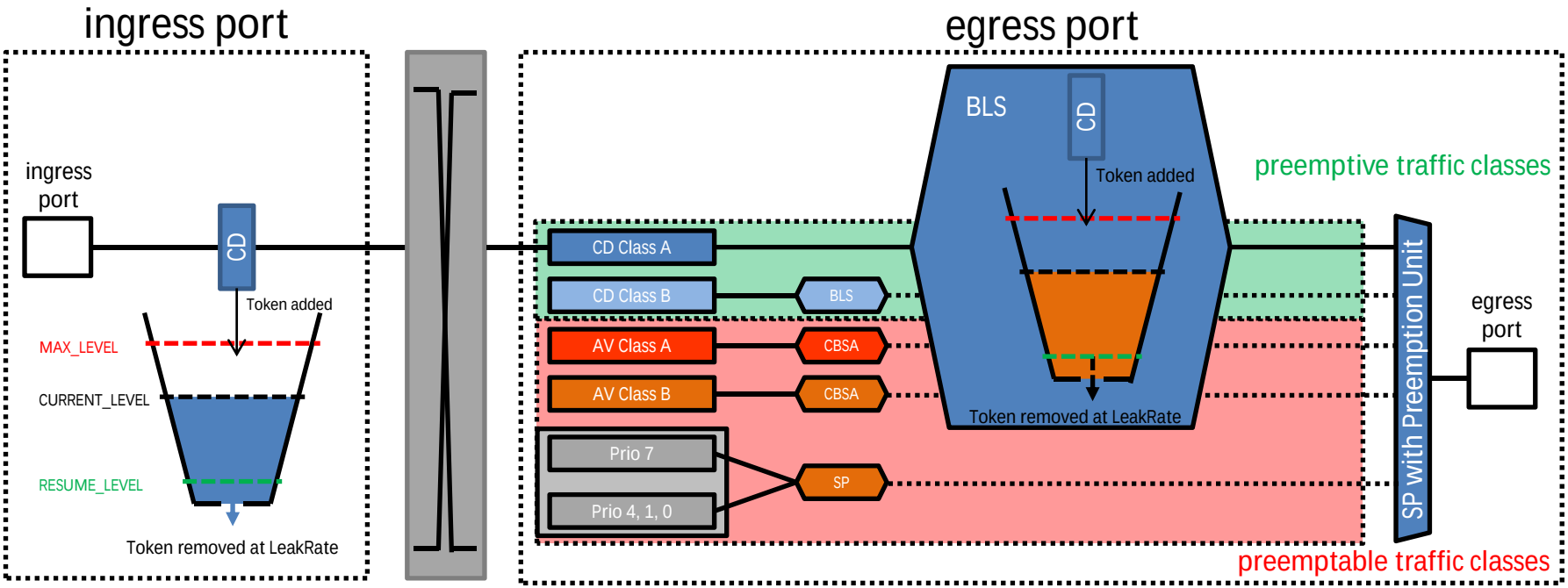
Furthermore [3]:

- Guaranteed deterministic low latency
- Flexible and less planning
- Minimize impact of other traffic classes on CD class A
- Overhead should be reduced to a minimum, i.e. no synchronization of bridges (and even talkers) required
- Support of different CD classes because of different QoS domains (e.g. motion control and process control, ultra low latency vs low latency)

Bandwidth Limiting Shaper (BLS) on egress port in combination with policing on ingress port can fulfill all these requirements!

Bandwidth Limiting Shaper (BLS) [2,3]

Policing@ingress & Metering@egress



Ingress Policing per stream!

- Ensure that all streams are conform to their traffic description!
- Avoid propagation of misbehaviour to egress ports / protect switching resources in bridges
- Diagnosis of misbehaved talkers/bridges

Egress Scheduler per class!

- Guaranteed latency for lower traffic classes, e.g. CD class B, AV streams class A,B and best effort
- Detection and diagnoses of overload situations (e.g. max. burst size)

Abbreviations:
BLS: bandwidth limiting shaper
CBSA: credit-based shaping algorithm
SP: strict priority

Proposal for Bandwidth Metering at the ingress ports

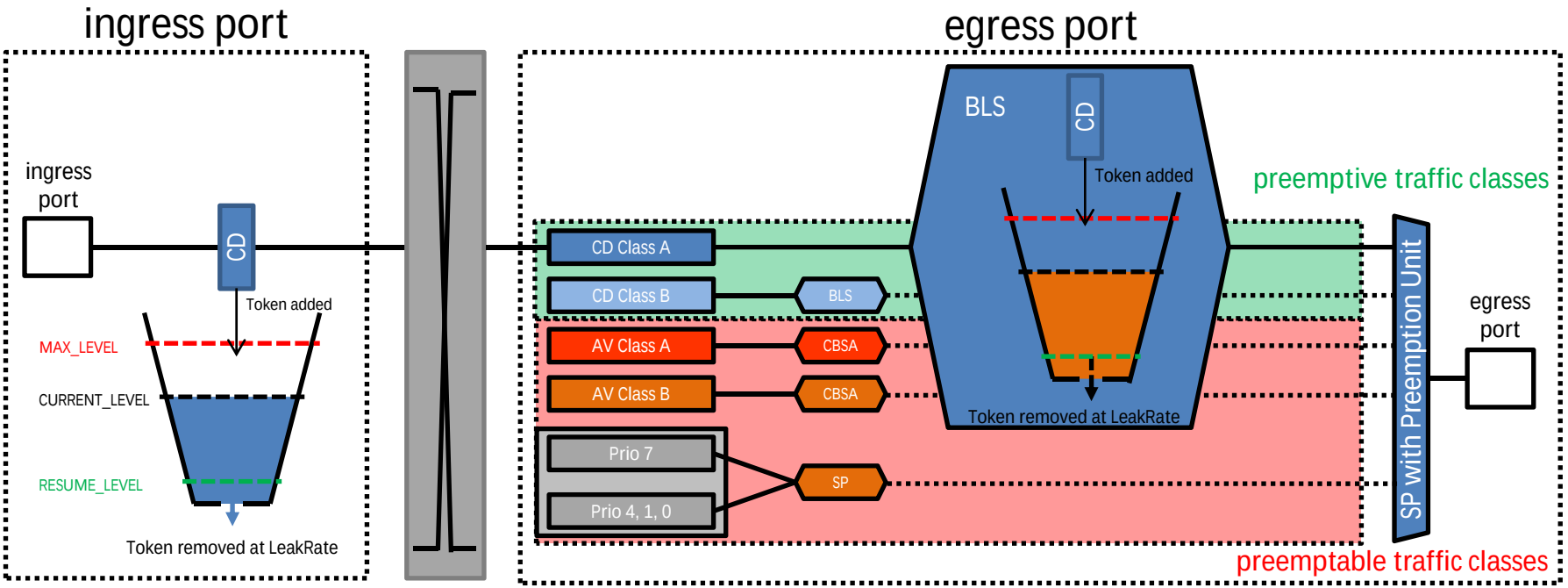
Per stream policing at the ingress ports, i.e. drop “not-conformant“ frames

Proposal: We have to distinct between ingress ports on edge bridges and bridges within the QoS domain:

- Ingress port on edge bridge: observation interval = transmission period
- Ingress port on bridge: observation interval = x * transmission period,

  i.e. the oberservation interval must be a multiple of the transmission period due to queuing effects within the network

Shaper model



Description:

- CD class A has highest priority
- CD class B cannot be preempted by CD class A
- CD class B has a maximal frame size to minimize the impact on CD Class A, e.g. 105 byte
- CD classes (A, B) can preempt AV classes A and B as well as legacy traffic

Reference: see [2]

Abbreviations:
BLS: bandwidth limiting shaper
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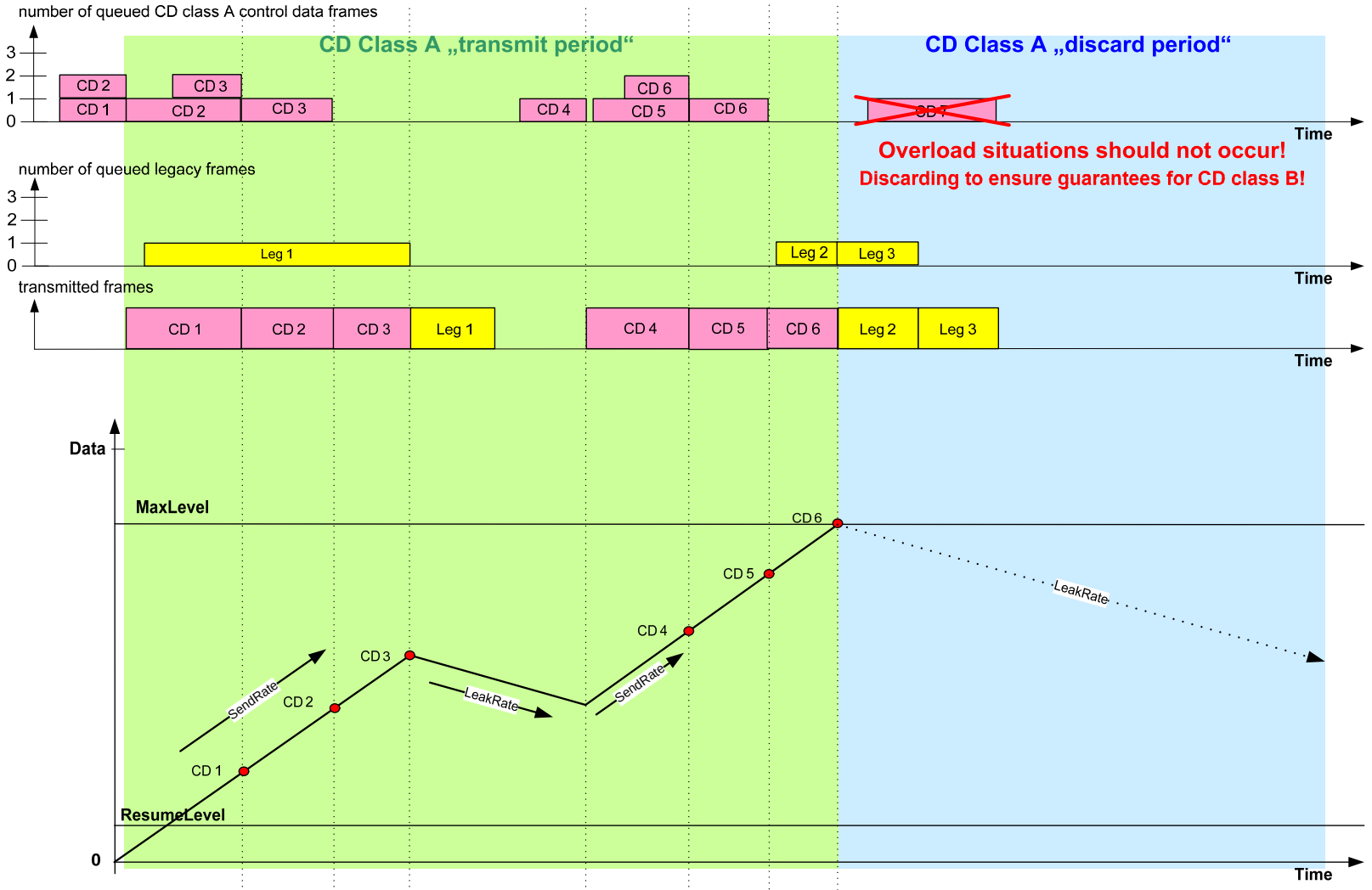
Example: BLS


number of queued CD class A control data frames
CD Class A „transmit period“
CD Class A „discard period“
CD 1
CD 2
CD 3
CD 4
CD 5
CD 6
CD 7
Time
Overload situations should not occur!
Discarding to ensure guarantees for CD class B!
number of queued legacy frames
Leg 1
Leg 2
Leg 3
transmitted frames
Data
MaxLevel
ResumeLevel
SendRate
LeakRate
0

Performance Guarantees for CD class A

Assumptions for mathematical model

Assumptions:

- Store-and-Forward (worst case)
- Full-duplex (FE, GE, …)
- Homogenous link speed, but this model also works for inhomogenous link speeds within an network
- Talkers need not to be synchronized
- CD class A has its own dedicated queue
- Within a queue, frames are served in a FIFO manner
- Maximal frame sizes of CD class B to reduce the impact on CD class A, e.g. 105 byte (see [2])
- CD classes (A, B) are preemptive, remaining queues are preamptable (see [2])
- Frame preemption: Maximal frame size that cannot be preempted; depends on the minimal possible fragment size, e.g. 105 Byte (see [2])
- CD streams are conform to their traffic description
- Max latency for CD stream < transmission period (TP) of CD traffic class (typically for industrial automation)
- Sum of all CD class A stream rates must be smaller than the average rate offered by BLS for CD class A, otherwise more traffic than service!

Focus of this talk: Performance guarantees for CD class A

- Worst case latencies for CD class A streams
- Worst case CD class A queue backlog

Four sources of packet delay

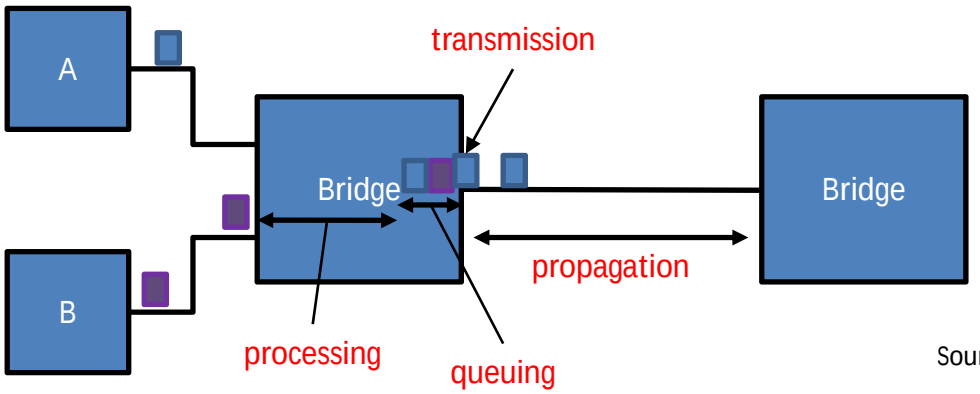
Bridge delay (d_{proc}):
- check bit errors
- determine egress port

Queuing (d_{queue}):
- time waiting at egress port for transmission
- depends on congestion level of output link

Transmission (d_{trans}):
- store-and-forward vs. cut-through delay
- time to send bits into link

Propagation (d_{prop}):
- time that it takes a signal change to propagate through the communication media from a node to the next node

$$d_{bridge} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

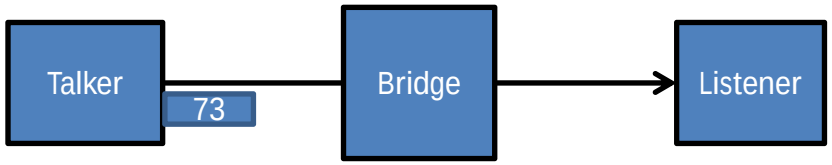


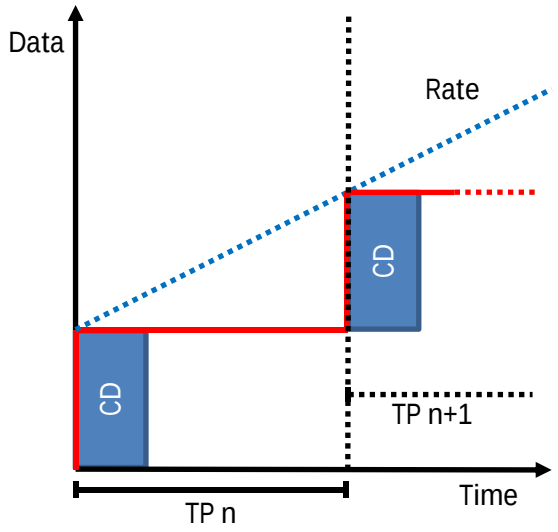
Source: James F. Kurose, Keith W. Ross: Computer Networking

Modeling of a single CD stream

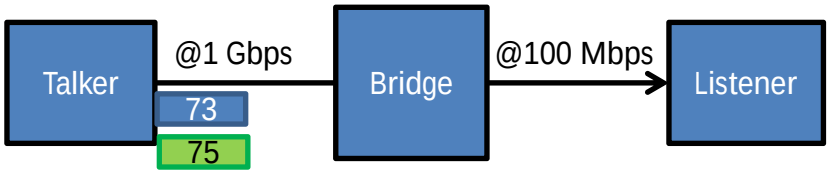
Modeling of a CD stream s:

- Transmission period (TP)
- 1 frame per stream
- Rate r = $\frac{\text{frame size}}{\text{TP}}$



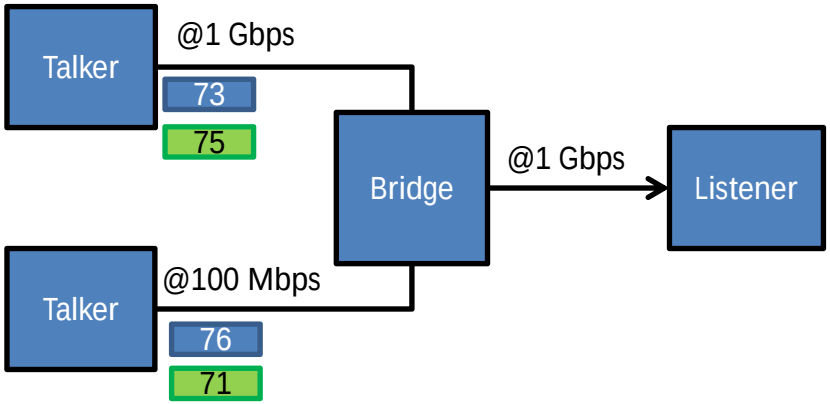


Modeling of multiple CD streams



1 Fan-in, Multiple Streams

- Serialize the CD streams by creating a new CD stream
- This new CD stream contains all frames from all CD streams w.r.t. to their TPs (least common multiple)
- Sort the frames in descending order by their frame size
- Calculate for each frame its earliest possible arrival time starting with t=0 w.r.t. to the ingress link speed and a IFG between frames
- Caution: Only merge streams which belong to the same QoS class!



Multiple Fan-in, Multiple Streams

- Create for each input link a new CD stream like described above
- Merge these newly created CD streams by their calculated CD frame arrival times in ascending order; if 2 or more frames have the same arrival time, take their frame size into account (longer frames first)

Modeling of the BLS service for CD class A

Latency T = bridge delay + interference delay

- Maximum interference due to frames that are already in transit + plus interframe gap:

```
max
(
    maximum frame size @preemptive classes,
        min
        (
            maximal frame size that cannot be fragmented,
            maximal frame size @preemptable classes
        )
)
```

Rate: BLS can have 2 states: transmit and discard

- $t_{\Delta discard} = \frac{MAX\_LEVEL - RESUME\_LEVEL}{LeakRate}$
- $t_{\Delta transmit} = \frac{MAX\_LEVEL}{SendRate}$

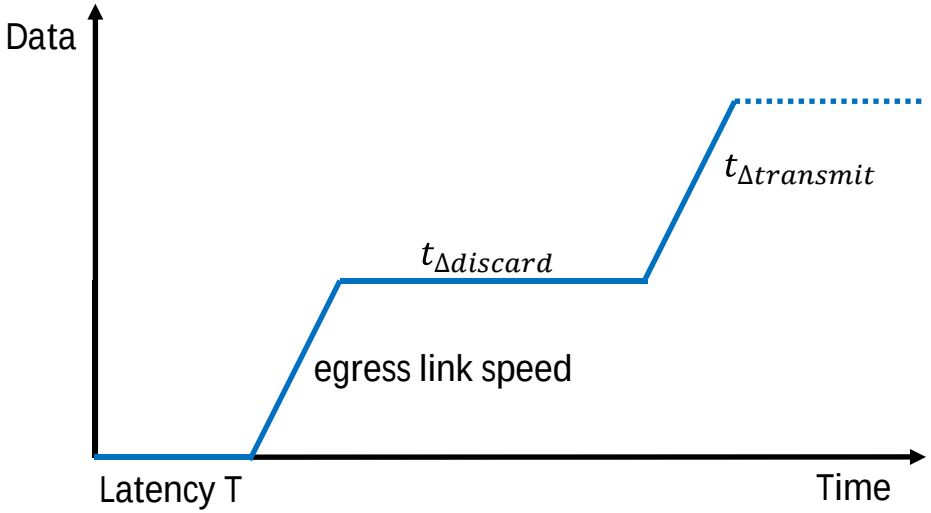
➔ Average rate: $R^{class\ A} = \frac{t_{\Delta transmit}}{t_{\Delta transmit} + t_{\Delta discard}} * LinkSpeed$

Parameters:

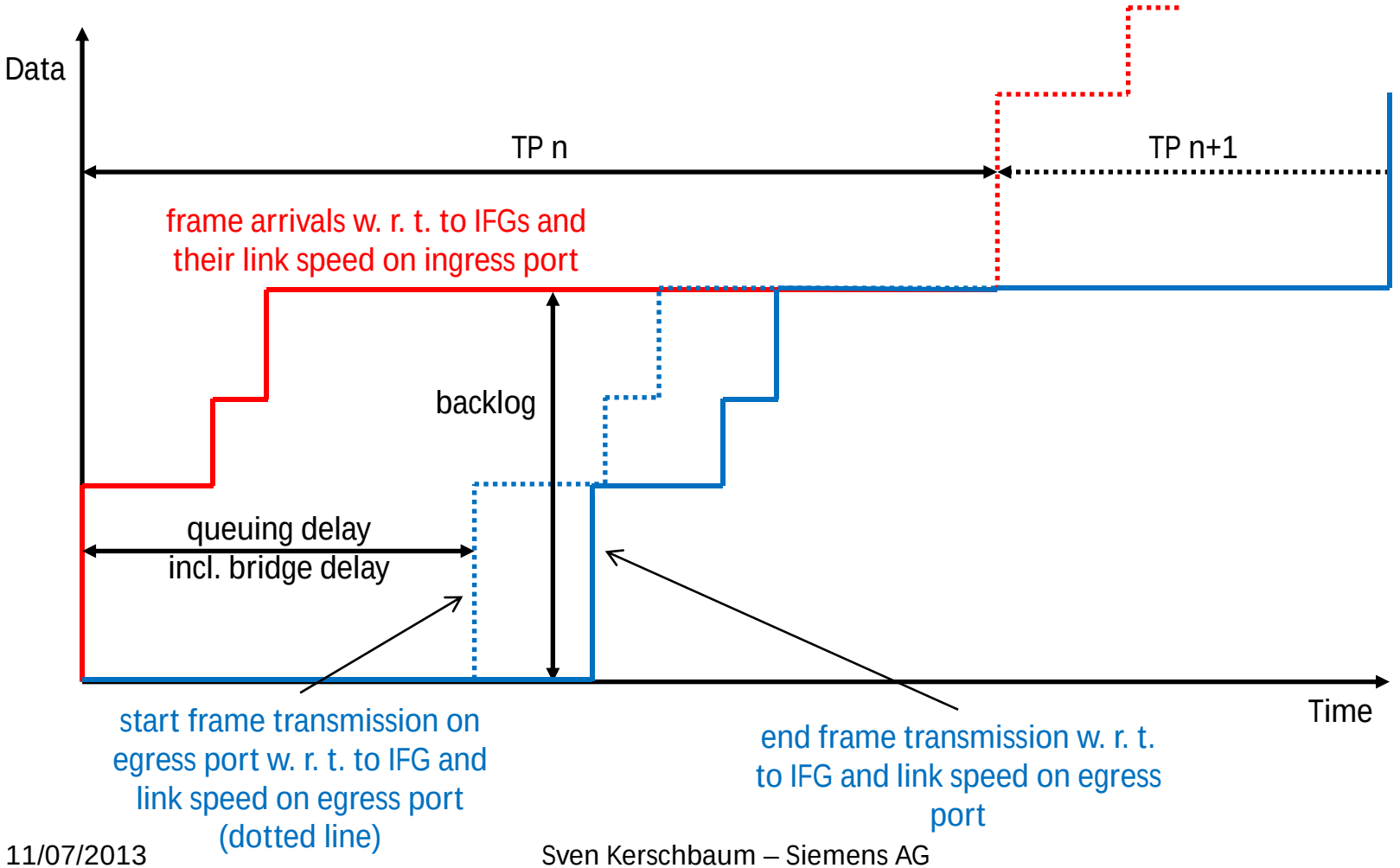
- BwF: Bandwidth fraction for CD class A
- MAX_LEVEL
- RESUME_LEVEL

Formulas:

- $LeakRate = BwF * LinkSpeed$
- $SendRate = LinkSpeed - LeakRate$



Calculation of the queuing delay (incl. bridge delay)



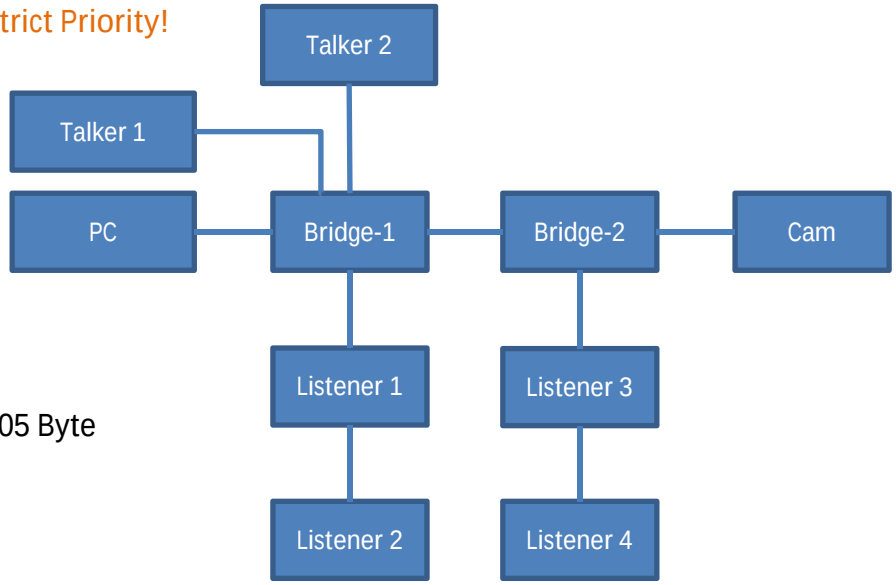
Example: Line Topology

Example: Line topology

In this scenario, BLS behaves like Strict Priority!

Assumptions:

- Full-Duplex
- Link speed: 1 Gbps
- Bridge delay: 1 µs
- BLS CD class A bandwidth fraction: 15%
- BLS CD class A MAX_LEVEL: 1024 Byte
- BLS CD class A RESUME_LEVEL: 64 Byte
- Preemptive class: CD class A
- Frame preemption: maximal not preemptable frame size: 105 Byte
- Store & forward
- No link/propagation delay



Communication: 4 CD class A streams, 2 CD class B streams, 1 Legacy stream

→	Listener 1	Listener 2	Listener 3	Listener 4	Cam
Talker 1 (CD class A)	TP: 125 µs Frame: 64 Byte	TP: 125 µs Frame: 73 Byte	TP: 125 µs Frame: 64 Byte	TP: 125 µs Frame: 64 Byte	
Talker 2 (CD class B)	TP: 1 ms Frame: 64 Byte	TP: 1 ms Frame: 73 Byte			
PC (Legacy traffic)					Keepalive once a second: 512 Byte

Latency bounds

In this scenario, BLS behaves like Strict Priority!

Assumptions:

- Full-Duplex
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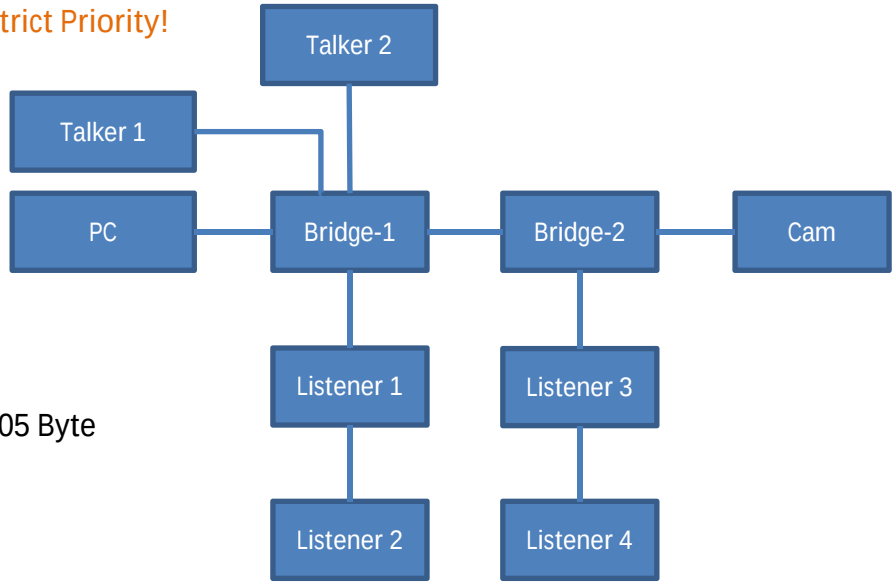


Calculated latency: CD class A

Talker 1 → …	Listener 1	Listener 2	Listener 3	Listener 4
Minimum 1 Gbps = 1000 Mbps	2.02 µs	3.75 µs	3.53 µs	5.04 µs
Maximum (guaranteed worst case)	2.70 µs	4.43 µs	4.47 µs	5.98 µs

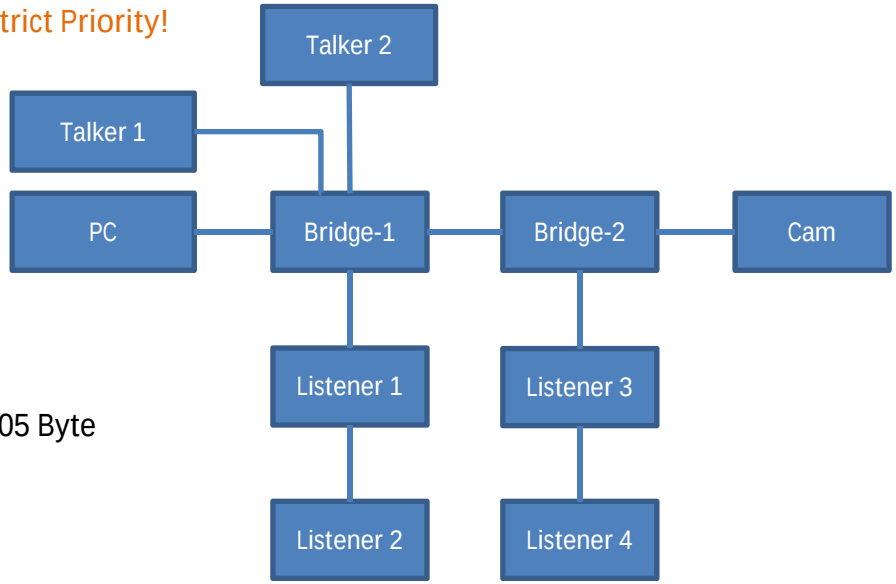
Our previous assumption `max latency < transmission period´ is fulfilled for all CD class A streams!

Backlog bounds

In this scenario, BLS behaves like Strict Priority!

Assumptions:

- Full-Duplex
- Link speed: 1 Gbps
- Bridge delay: 1 µs
- BLS CD class A bandwidth fraction: 15%
- BLS CD class A MAX_LEVEL: 1024 Byte
- BLS CD class A RESUME_LEVEL: 64 Byte
- Preemptive class: CD class A
- Frame preemption: maximal not preemptable frame size: 105 Byte
- Store & forward
- No link/propagation delay



Guaranteed worst case backlog: CD class A egress ports

→	Bridge-1	Bridge-2	Listener 1	Listener 2	Listener 3	Listener 4
Bridge-1		128 Byte	137 Byte			
Bridge-2					128 Byte	
Listener 1				73 Byte		
Listener 2						
Listener 3						64 Byte
Listener 4						

Conclusion & Future Work

Conclusions & Future Work

Conclusions

- Recapitulation of the Bandwidth Limiting Shaper
- Formal method for the calculation of performance guarantees provided by BLS for CD class A (“static calculation“: known application, topology, paths, flows, communication relations incl. frames and transmission period):
  - Worst case latencies for each stream
  - Worst case queue backlog for each CD class

Future Work

- Calculation of latency and backlog bounds for CD class B and AV traffic?
- Comparing the numerical results with real measurements
- „Flexible calculation model“: Unknown Application, only max bandwidth for control data class, e.g. CD Class A 5%, CD Class B 10% for GE, and max burst size is known

THANK YOU for your attention!

Questions, Comments, Ideas?

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