

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

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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.

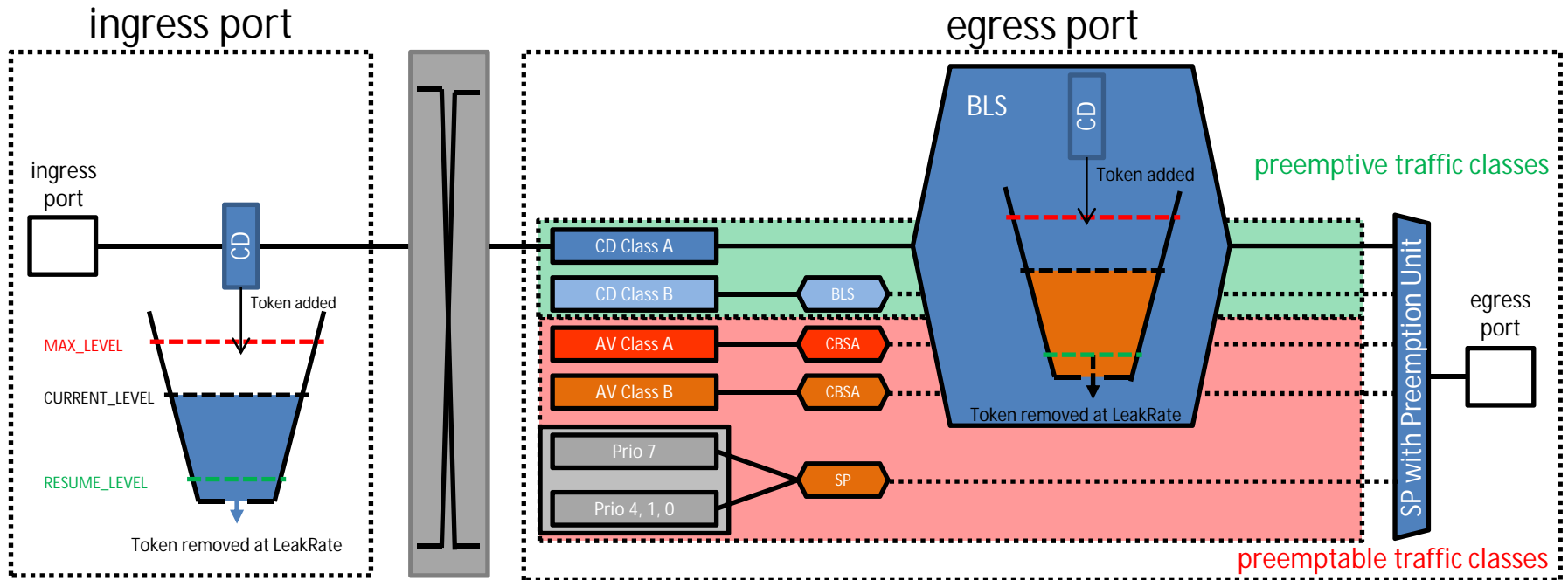
## Furthermore [3]:

- 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 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 diagnosis of overload situations (e.g. max. burst size)

### Abbreviations:

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

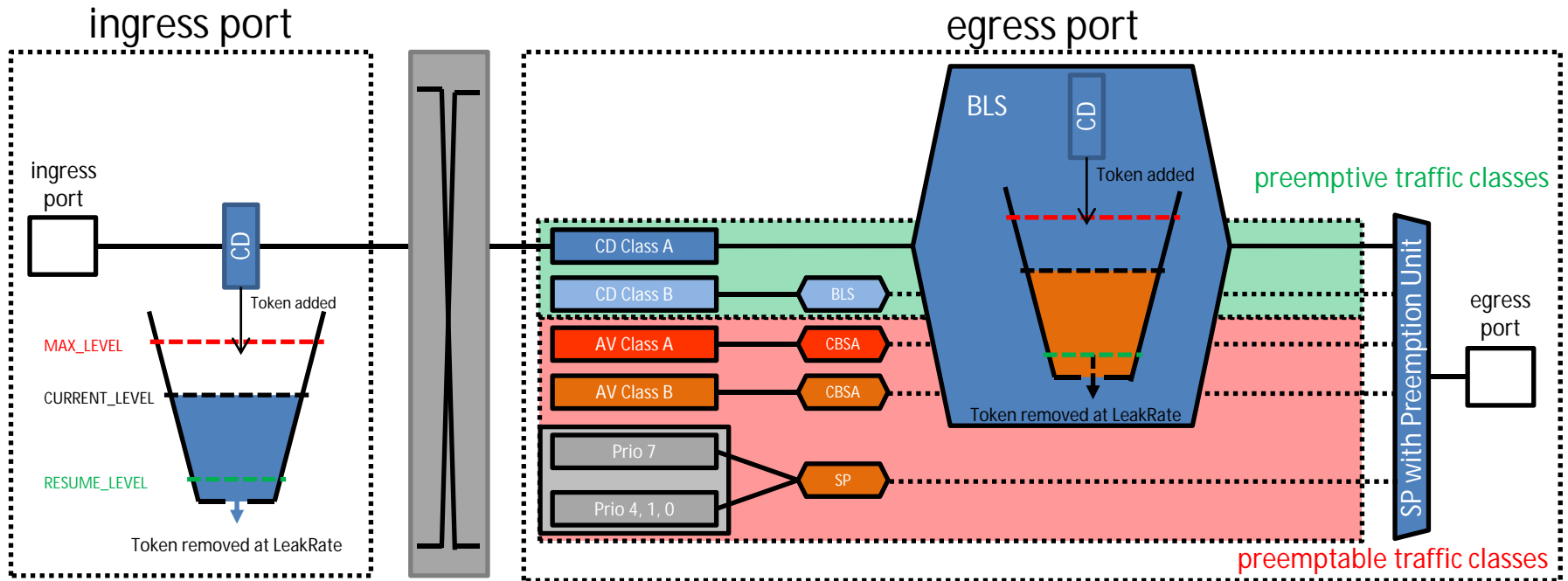
# Proposal for Bandwidth Metering at the ingress ports

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 observation 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

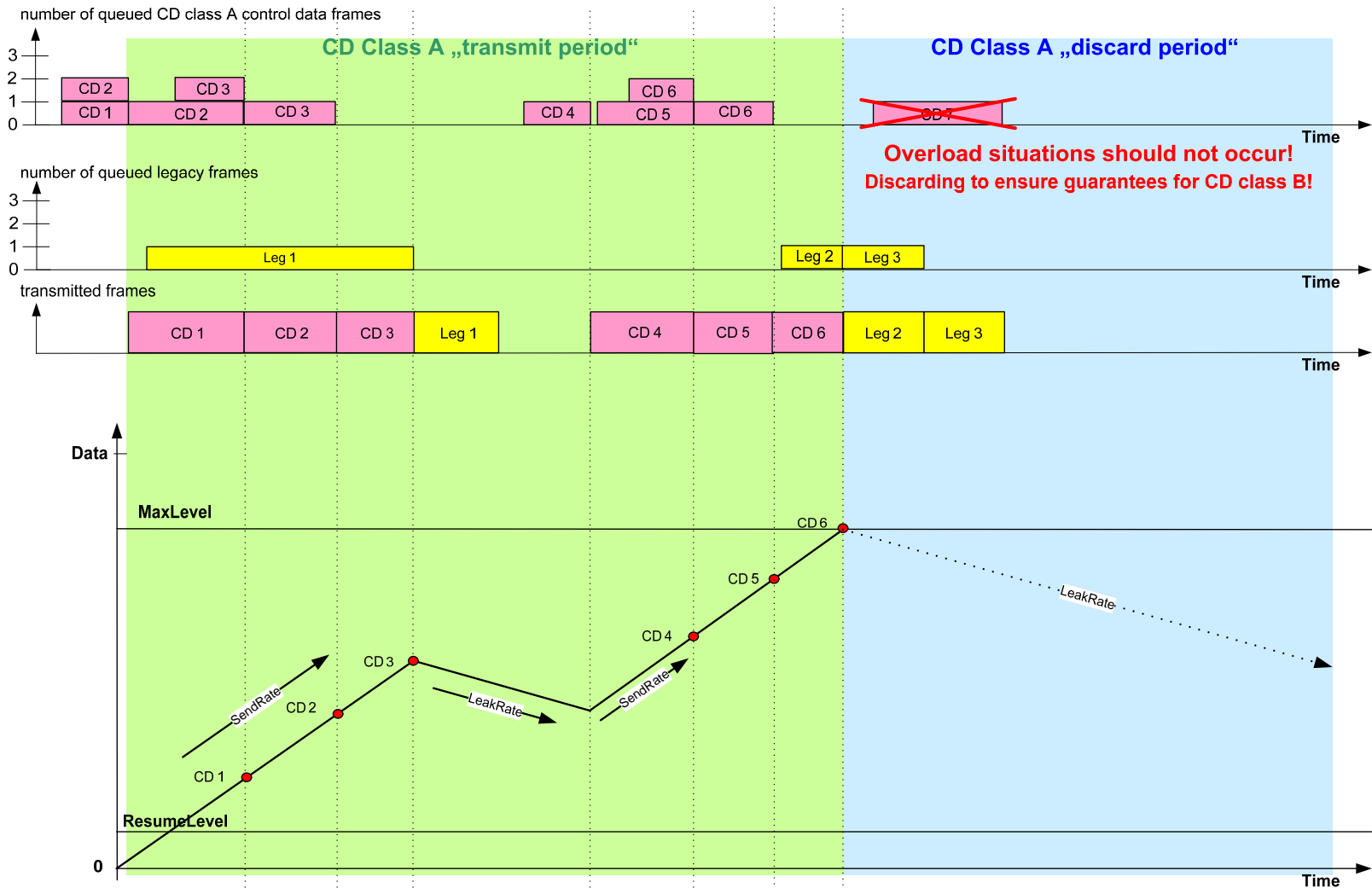
Reference: see [2]

## Abbreviations:

BLS: bandwidth limiting shaper  
 CBSA: credit-based shaping algorithm  
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# Example: BLS



# Performance Guarantees for CD class A

# Assumptions for mathematical model

## Assumptions:

- Store-and-Forward
- Full-duplex (FE, GE, ...)
- Homogenous link speed, but this model also works for inhomogenous link speeds within a 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 preemptable (see [2])
- Frame preemption: Maximal frame size that cannot be preempted, e.g. 105 Byte; depends on the minimal possible fragment size (see [2])
- CD streams 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 ( $d_{queue}$ ):

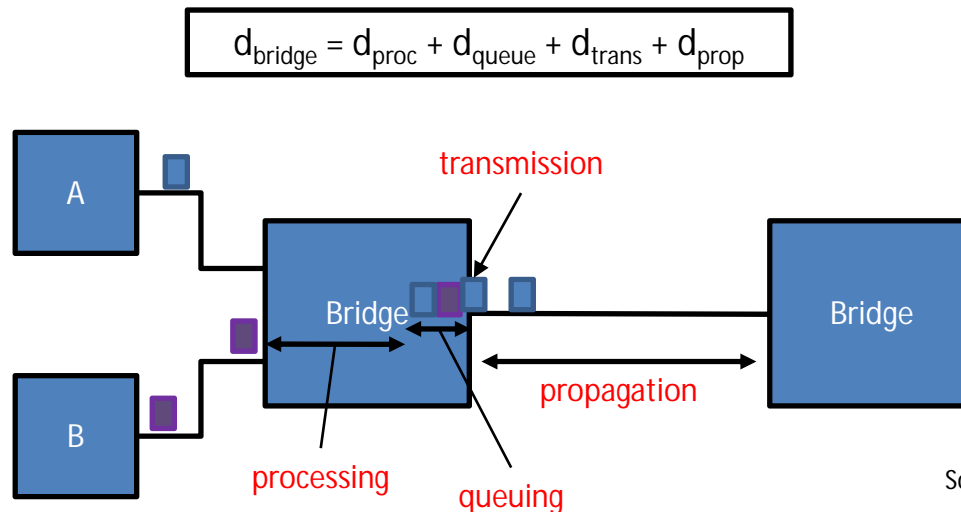
- time waiting at egress port for transmission
- depends on congestion level of output link

## 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

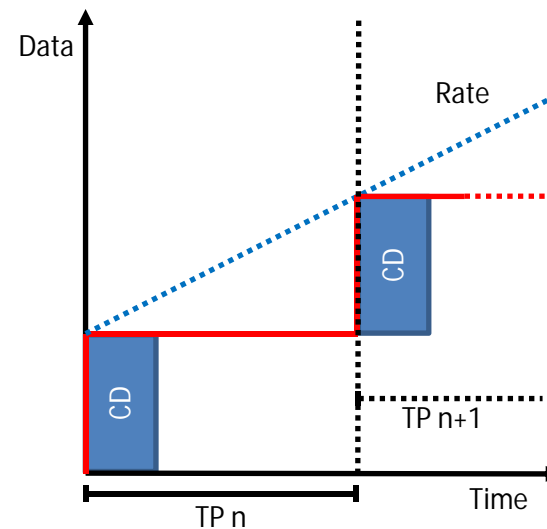
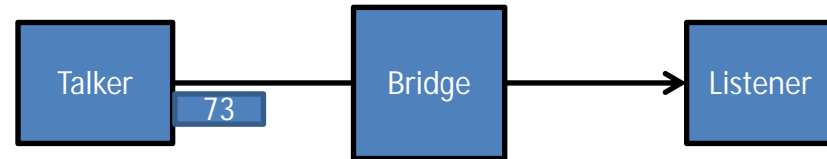


Source: James F. Kurose, Keith W. Ross:  
Computer Networking

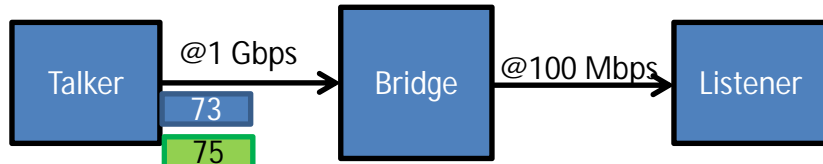
# Modeling of a single CD stream

## Modeling of a CD stream s:

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

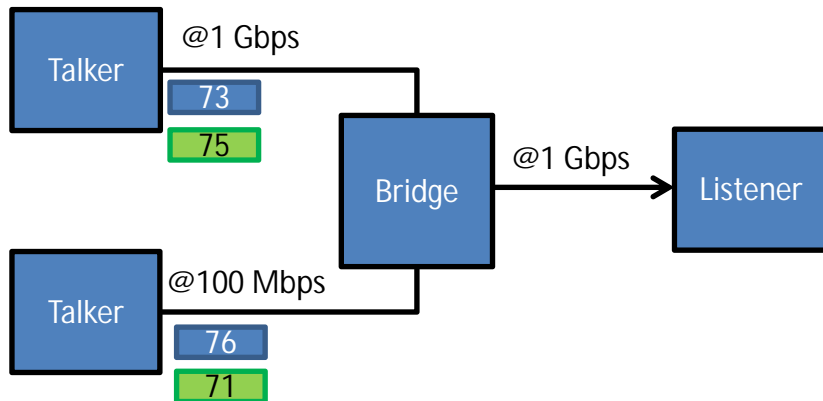


# Modeling of multiple CD streams



## 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

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

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

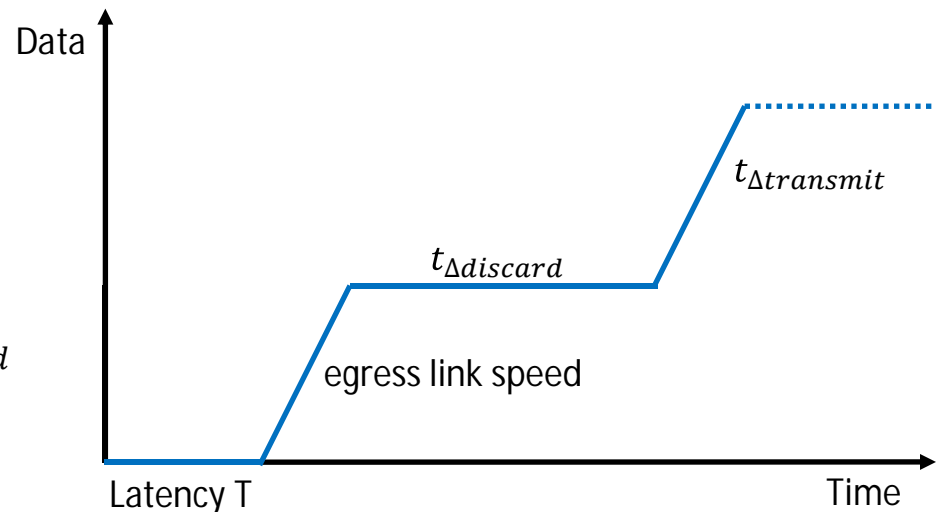
→ Average rate:  $R^{class A} = \frac{t_{\Delta transmit}}{t_{\Delta transmit} + t_{\Delta discard}} * LinkSpeed$

Parameters:

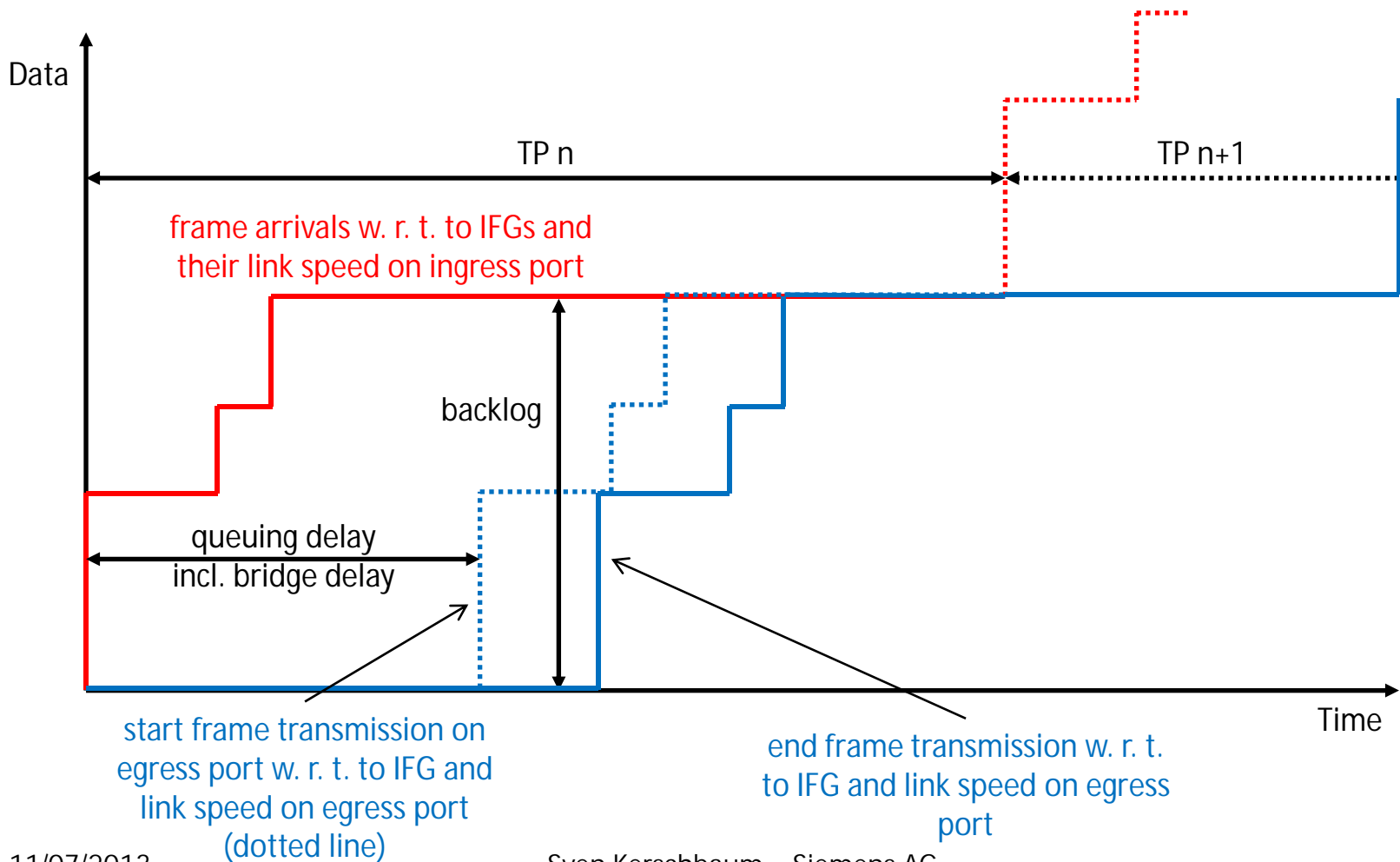
- BwF: Bandwidth fraction for CD class A
- MAX\_LEVEL
- RESUME\_LEVEL

Formulas:

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



# Calculation of the queuing delay (incl. bridge delay)





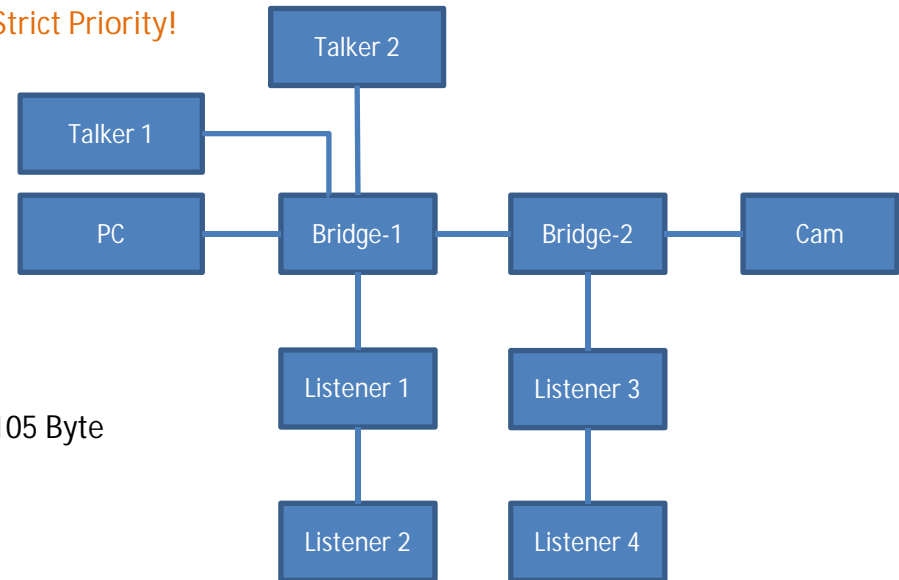
# Example: Line Topology

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## Assumptions:

- Full-Duplex
- Link speed: 1 Gbps
- Bridge delay: 1  $\mu$ s
- 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

In this scenario, BLS behaves like Strict Priority!



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

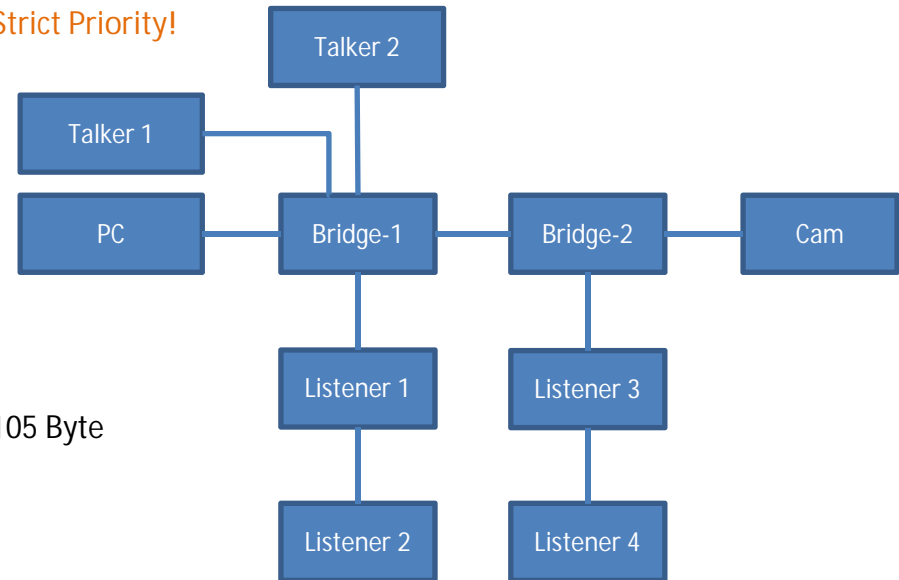
→	Listener 1	Listener 2	Listener 3	Listener 4	Cam
Talker 1 (CD class A)	TP: 125 $\mu$ s Frame: 64 Byte	TP: 125 $\mu$ s Frame: 73 Byte	TP: 125 $\mu$ s Frame: 64 Byte	TP: 125 $\mu$ s Frame: 64 Byte	
Talker 2 (CD class B)	TP: 1 ms Frame: 64 Byte	TP: 1 ms Frame: 73 Byte			
PC (Legacy traffic)					Keepalive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

# Latency bounds

## Assumptions:

- Full-Duplex
- Link speed: 1 Gbps
- Bridge delay: 1  $\mu$ s
- 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

In this scenario, BLS behaves like Strict Priority!



## Calculated latency: CD class A

Talker 1 → ...	Listener 1	Listener 2	Listener 3	Listener 4
Minimum 1 Gbps = 1000 Mbps	2.02 $\mu$ s	3.75 $\mu$ s	3.53 $\mu$ s	5.04 $\mu$ s
Maximum (guaranteed worst case)	2.70 $\mu$ s	4.43 $\mu$ s	4.47 $\mu$ s	5.98 $\mu$ s

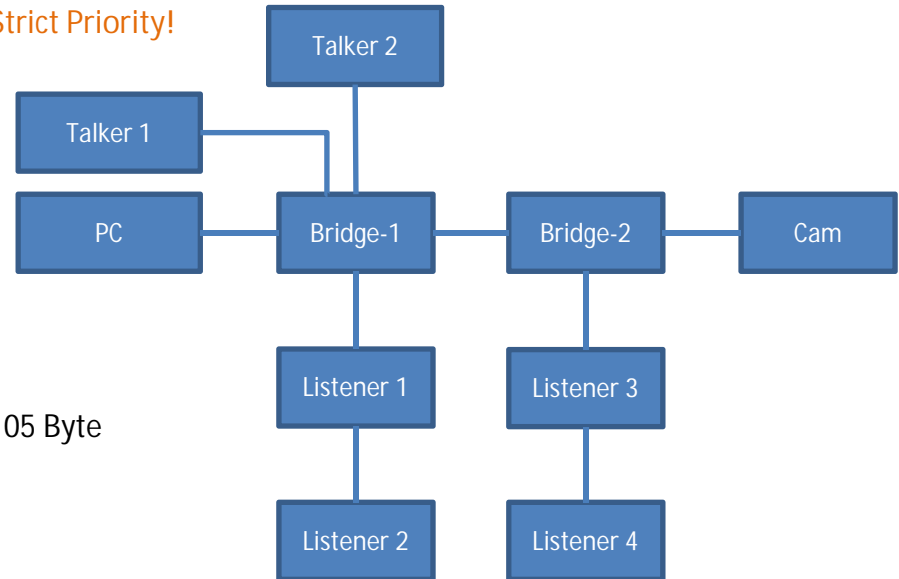
Our previous assumption 'max latency < transmission period' is fulfilled for all CD class A streams!

# Backlog bounds

## Assumptions:

- Full-Duplex
- Link speed: 1 Gbps
- Bridge delay: 1  $\mu$ s
- 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

In this scenario, BLS behaves like Strict Priority!



## 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

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## 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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# References

#	Description
[1]	J. Specht, M. Jochim: Urgency based Scheduler – Considerations for Low Latency Reserved Streams. (2013) <a href="http://www.ieee802.org/1/files/public/docs2013/new-tsn-specht-urgency-based-scheduler-20130320.pdf">http://www.ieee802.org/1/files/public/docs2013/new-tsn-specht-urgency-based-scheduler-20130320.pdf</a>
[2]	F.-J. Götz: Robustness for Control-Data-Traffic in Time Sensitive Networks. IEEE802.1 Plenary Meeting, Geneva, Switzerland (2013) <a href="http://www.ieee802.org/1/files/public/docs2013/bv-goetz-TSN-RobustControlDataTraffic-0717-v1.pdf">http://www.ieee802.org/1/files/public/docs2013/bv-goetz-TSN-RobustControlDataTraffic-0717-v1.pdf</a>
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