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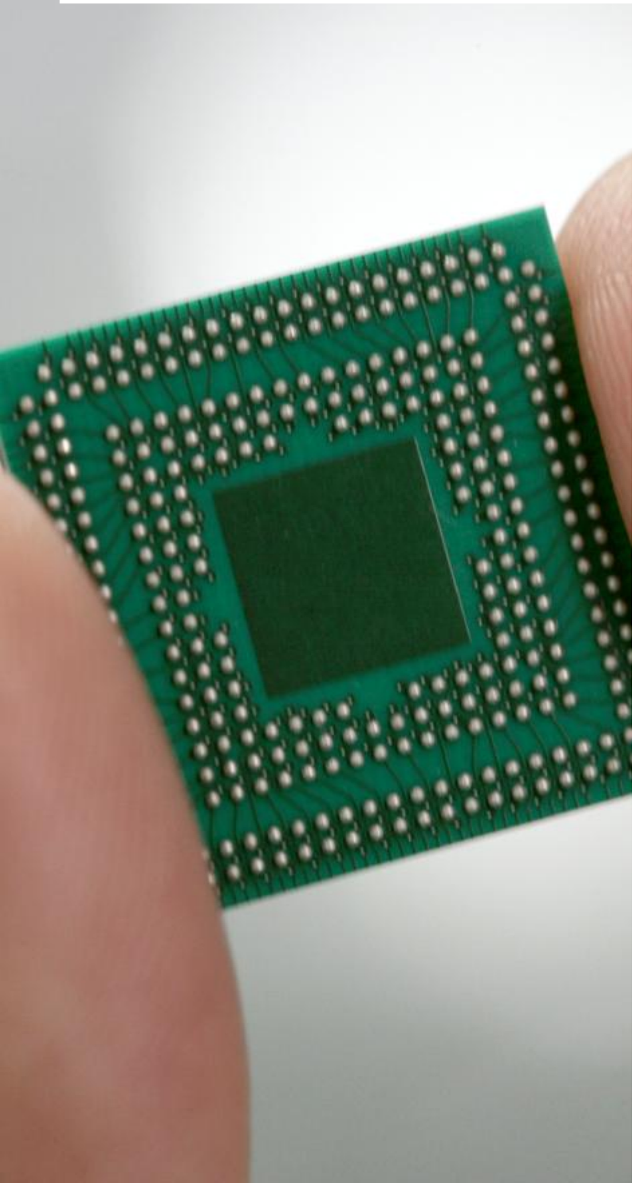

Guaranteed Latency for Control-Data-Traffic in Time Sensitive Networks

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Presenter:
Franz-Josef Goetz, Siemens AG

franz-josef.goetz@siemens.com

Structure of this Presentation

1. **Feature Diagram for Time Sensitive Networks @ Industrial**
2. **Proposed Mechanism to Support Low Latency**
3. **Which Control Applications using which proposed Mechanism**
4. **Comparison AV-Streams <-> CD-Streams**
5. **How to guarantee low latency for Control Data Traffic (CDT)**

Feature Diagram for Time Sensitive Networks (TSN)@ Industrial

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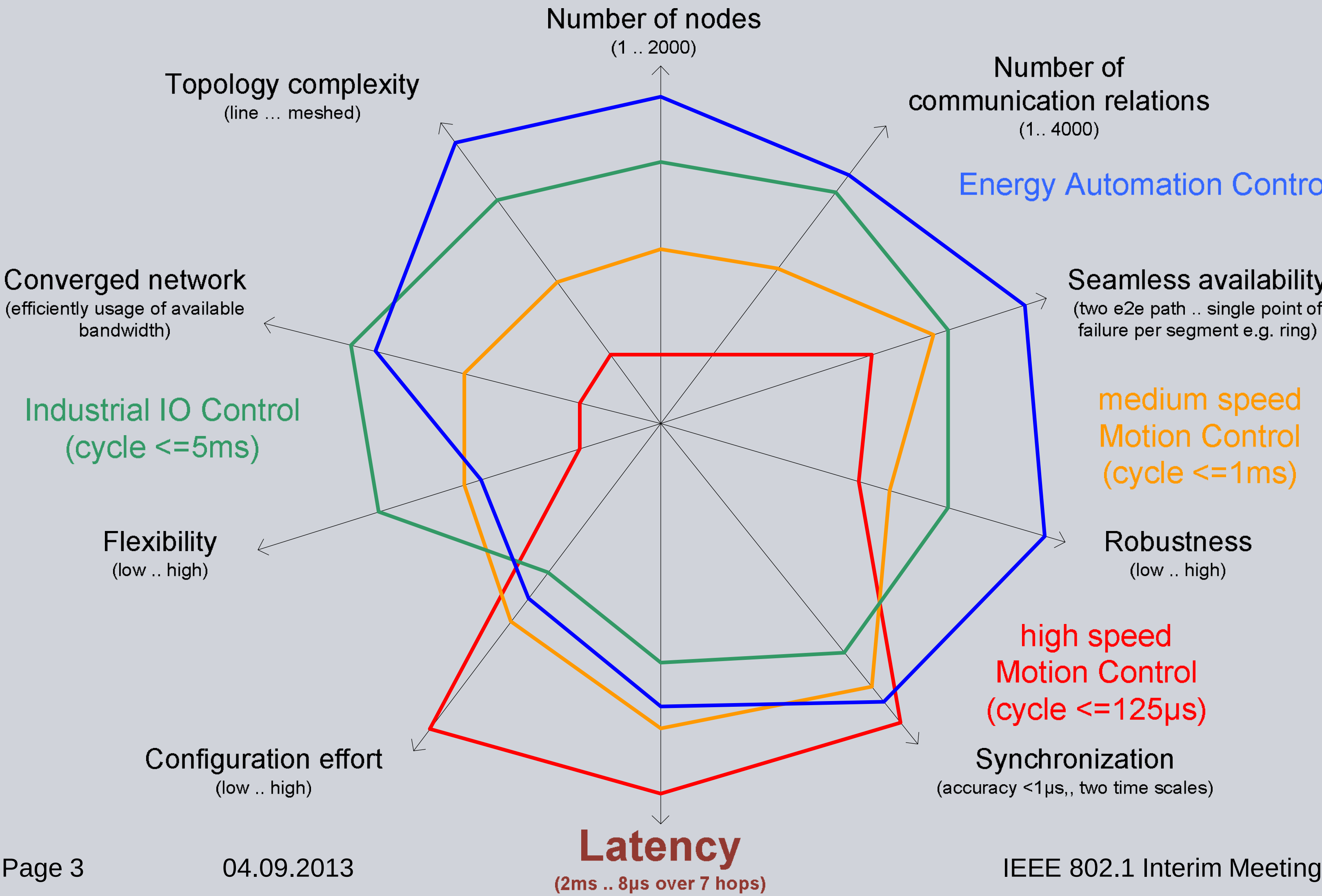
See: http://www.ieee802.org/1/files/public/docs2013/new-goetz-TSN-4-Industrial-Networks-20130115-v1.pdf



Proposed Mechanism to Support Low Latency for Control Data Traffic (CDT)

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Common:

- **Separate traffic class**
  Control Data Traffic Class A or B
- **Reserved bandwidth & resources**
  (own transmission queue)

TSN bridges

- **Shaper for Control Data Traffic**
  - TAS
  - BL (highest priority class & bandwidth limiting)
- **Pre-emption**
  - Option: always wait for $t_{max\ pre\text{-}emption}$ to minimize jitter
  - Option: fragment frame size
- **Cut-Through mode for Control Data Traffic**

End station (talker)

- **Buffered interface**
  - one transmit buffer per stream
  - Direct access from control application to write transmit buffer
- **Transmission modes**
  - Event based & rate constrained
  - Scheduled (burst)
  - Scheduled and coordinated (transmission time) to save resources in bridges and avoid miss ordering in network
    - Optimized make span
    - Optimize single CD-Stream (low latency)

End station (listener)

- **Buffered interface**
  - Static receive buffer per stream
  - Direct access from control application to read from receive buffer
  - Application is synchronized to end of exchange of all Control Data
  - Application is synchronized to single Control Data Stream

⇒ **There are many mechanism to support low latency which base on each other.**
Not each control applications has the need of using all listed mechanism.

Examples How Different Control Applications Using proposed TSN Low Latency Mechanism

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Application	TSN-Bridge	End Station Talker	End Station Listener	Comment
High speed motion control	- TAS - Pre-emption - Cut-Through	- Buffered Interface - Scheduled and coordinated transmission	- Buffered Interface - Control application is synchronized to end of Control Data exchange	- Static configuration to get lowest latency
Medium speed motion control	- BL (highest priority class & bandwidth limiting) - Pre-emption (min. fragment frame size) - Cut-Through	- Buffered Interface - Scheduled (burst)	- Buffered Interface Control application is synchronized to end of Control Data exchange	- Low latency and flexibility is required (add and remove nodes)
Industrial IO control	- BL (highest priority class & bandwidth limiting) - Pre-emption - Cut-Through	- Buffered Interface - Scheduled or not synchronized with fix transmission period	- Buffered Interface - Application cycle is independent of Control Data exchange – oversampling is expected	- Low latency and flexibility is required (add and remove nodes)
Process Automation	?	?	?	
Energy Automation	?	?	?	
Automotive	?	?	?	
…				

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Comparison AV-Streams <-> CD-Streams (1)

Features	AV-Streams	CD-Streams
Max. used bandwidth	- 75% of available bandwidth	- 20% of available bandwidth
Transmission period (TP)	TSpecMaxIntervalFrames = frames per observation interval - Gen 1: 1 – 2^16 / 125µs (250µs) - Gen 2: flexible observation interval	- Assumption: CD-Stream class defined by application, periodical transmission - Range between 31,25µs …1ms
Typical max. frame size	- 64 … 1500 Bytes	- **64** ... 500 Bytes

Max latency	- Gen 1: 2ms for class A / 50ms for class B
	- Gen 2: defined by application (?)
	  - range between 2ms …50ms over 7 hops
		- Defined by the application
		  - In range between 8µs …1ms over 7 hops (max latency typical 50% of transmission period)

Transmission path	- Gen 1: MSRP reservations along the RSTP Tree
	- Gen 2: Given path by ISIS PCR (optional)
		- Given path by
		  - restricted topology (e.g. line)
		  - preconfigured path(s) (engineered, static)
		  - ISIS PCR for single path
		  - redundant routed paths (ISIS PCR)

Bandwidth reservation	- Guarantee resources in TSN bridges to avoid packet lost - Determinism for Streams	

Transmission by end station (talker)	- Talkers are not synchronized	- One fixed transmission period per CD-Stream class
		- Transmission mode defined by application (time based)
		  - *Event based & rate constrained (not synchronized)*
		  - *Scheduled (synchronized, bursts)*
		  - *Scheduled and coordinated (transmission time per CD-Stream)*

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Comparison AV-Streams <-> CD-Streams (2)

Features	AV-Streams	CD-Streams
Transmission by TSN bridge	CBSA, spread over observation interval - Gen 1: 125µs, 250µs - Gen 2: flexible, other shaper an in discussion	Currently in discussion: - TAS, BL (highest priority class + bandwidth limiting), Preemption, Cut-Through, ….
Discover overload situations by metering to guarantee latency	- Gen 1: Per class on egress port by CBSA (avoid overload but can lead to additional delay)	In discussion: - Policing on ingress port per stream / per class (only on edge port per stream?) - Bandwidth metering on egress port (per class) (discover and signal overload situations, avoid overload situations by limiting bandwidth per stream)
Receive by listener	- receive queue - store for delayed presentation time (2ms … 50ms) - listener(s) is/are synchronized to talker (option)	- buffered interface – static receive buffer for each stream (no delay, direct access form application) - listener(s) is/are synchronized to talker (option)
Synchronization	- Optional	- Optional

How to guarantee low latency for Control Data Traffic (CDT)

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See: http://www.ieee802.org/1/files/public/docs2013/new-tsn-jochim-ingress-policing-0813-v01.pdf

- **Misbehave Talker**
  - Transmitting CD-Stream(s) with higher bandwidth consumption as reserved (bubbling talker, misconfiguration)
  - Transmitting CD-Stream without reservation
  - …
- **Misbehave TSN Bridge**
  - CD-Stream forwarded over wrong communication path (misconfiguration, wrong destination port decision)
  - CD-Stream is delayed can lead to temporary overload situations
  - Adding bytes (tags, padding) -> more bandwidth per stream
  - Bubbling bridge (transmitting same stream multiple times)
  - CD-Streams can be delayed -> traffic congestion
  - …

⇒ **To guarantee low latency and to get robustness for CD-Streams a concept and mechanism are required for discovering, signaling and eliminating error situations as described**

Where to do Bandwidth Metering to get a Robust Control Data Traffic Class?

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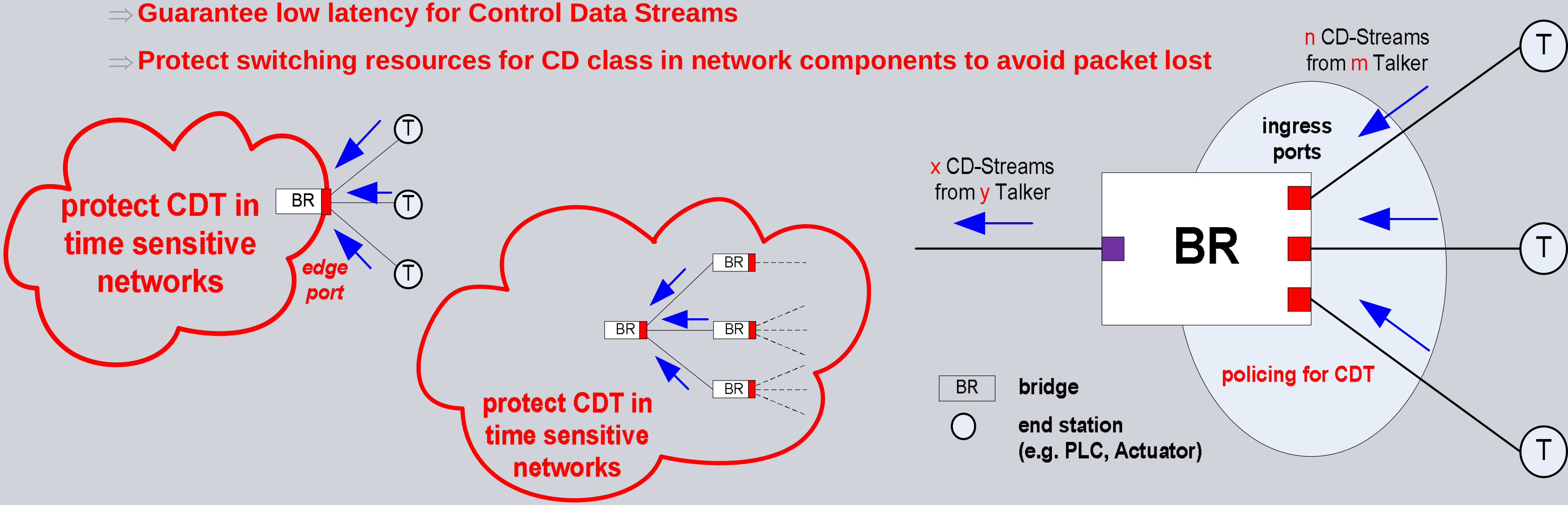
- **Policing (bandwidth metering) on the ingress port**
  - Detect misbehave talker
    - Bubbling talker
    - Misconfigured talker
  - Detect misbehave TSN bridge
    - Bubbling bridge (transmitting same stream multiple times)
    - Adding bytes (tags, padding) -> more bandwidth per stream

⇒ **Guarantee low latency for Control Data Streams**

⇒ **Protect switching resources for CD class in network components to avoid packet lost**



Where to do Bandwidth Metering to get a Robust Control Data Traffic Class?

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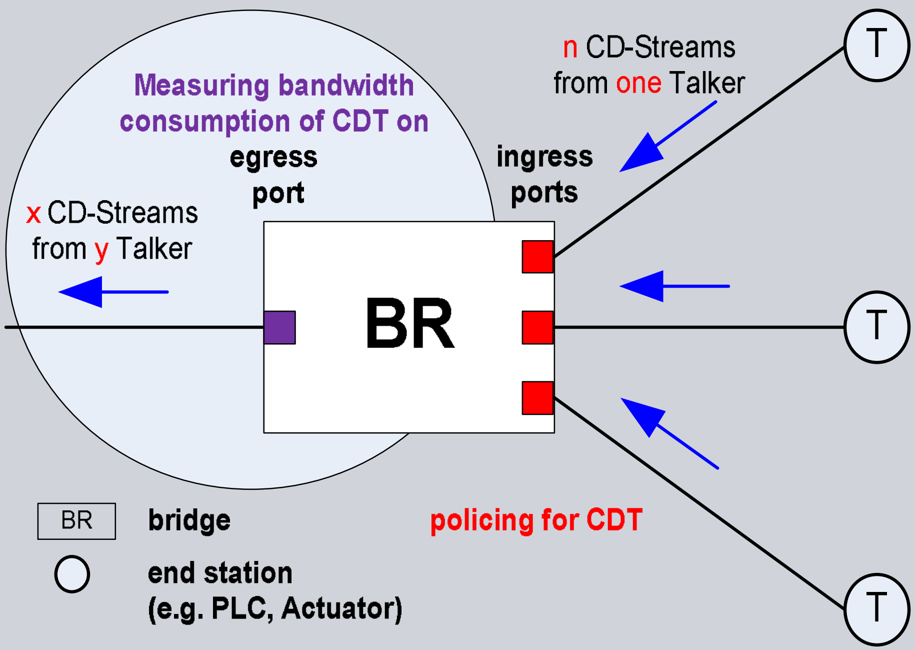
- **Bandwidth metering on egress port – Traffic Class**
  - Detection of temporary overload situations (e.g. delayed streams)

⇒ **Guarantee low latency for Control Data Streams**

⇒ **Protect switching resources for CD class in network components**



Proposal: Mechanism to guarantee low latency for Control Data Streams

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General: CD-Streams without reservation are blocked by TSN-Bridges

Same behavior as AV streams – streams without a reservation are blocked

Location	Discover overload situations	Action	Signaling for Diagnosis
Ingress Port	- Ingress Policing per ***CD-Stream***	- Discard CD-Frames to limit stream bandwidth reserved bandwidth for ***CD-Stream***	- CD-Stream exceeds reserved bandwidth
Egress Port	- Bandwidth metering per ***CD-Class*** of multiple transmission periods (e.g. average over 3 TP)	- Discard CD-Frames to limit bandwidth to reserved bandwidth for ***CD-Class***	- Count discarded CD-Frames
….			

Proposal: A further Mechanism to guarantee low latency and get a robust Control Data Class

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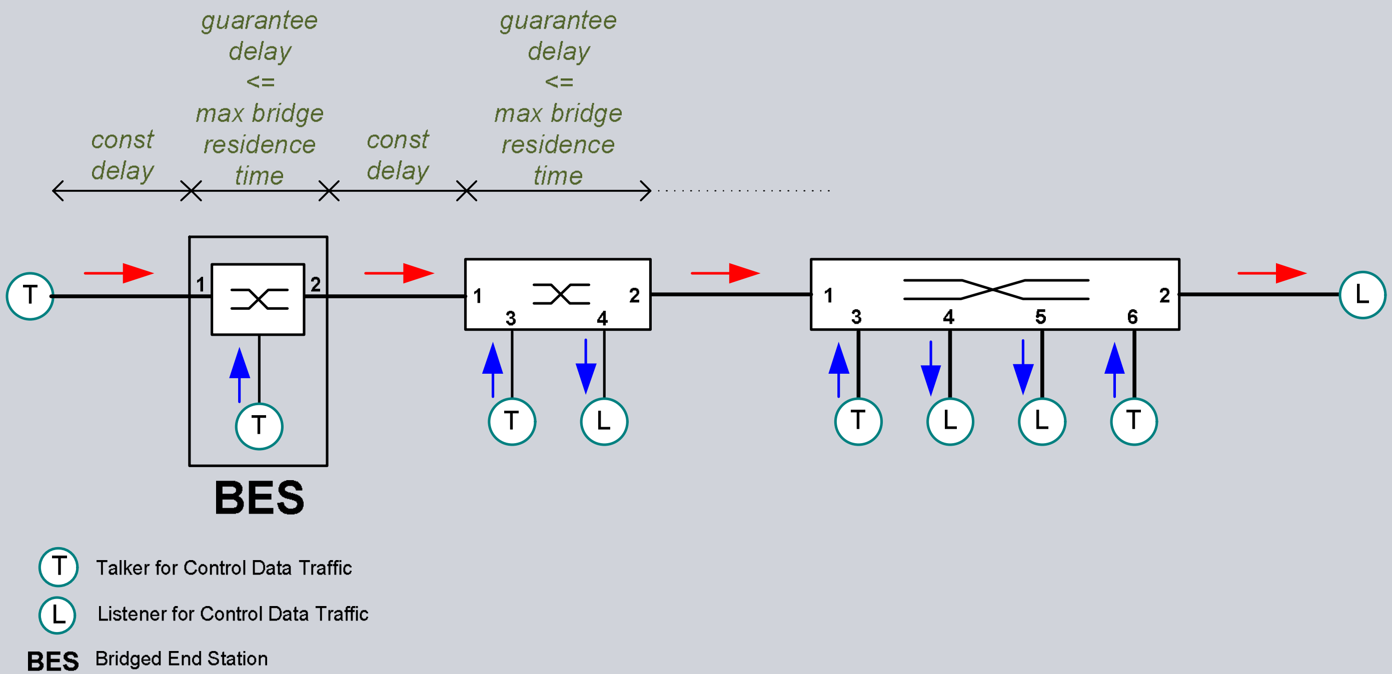
Proposed mechanism to discover and resolve congestions:

- Timestamp CD-frames on ingress port $T_{maxTx} = T_{Rx} + maxResTime$
- Check residence time on egress port
  - $T_{Tx} <= T_{maxTx}$ -> forward CD-frame
  - $T_{Tx} > T_{maxTx}$ -> discard CD-frame + signal event



THANK YOU for your attention!

Need for a mathematical model to calculate latency based on the mechanism which are in discussion!

Questions?