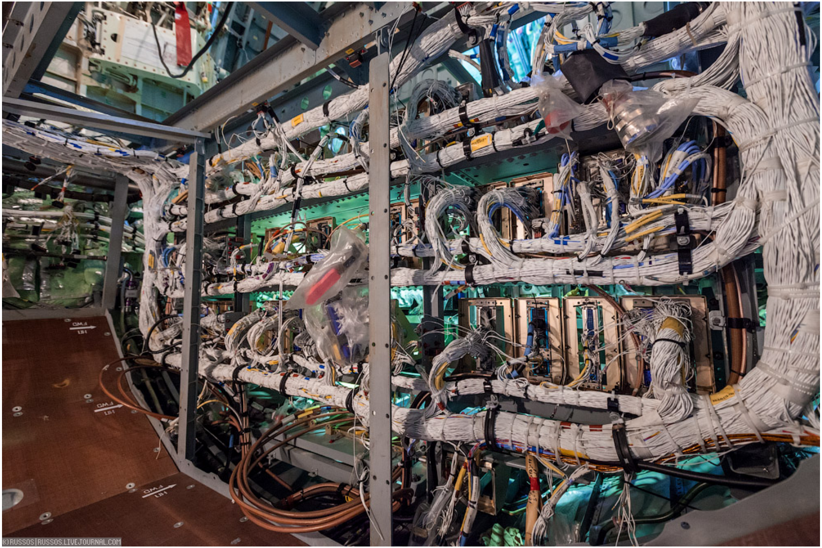
Performance Enhancement of Extended AFDX via Bandwidth Reservation for TSN/BLS Shapers

Anaïs Finzi, Ahlem Mifdaoui et al.

July 3, 2018, RTN'18

Context and Objectives



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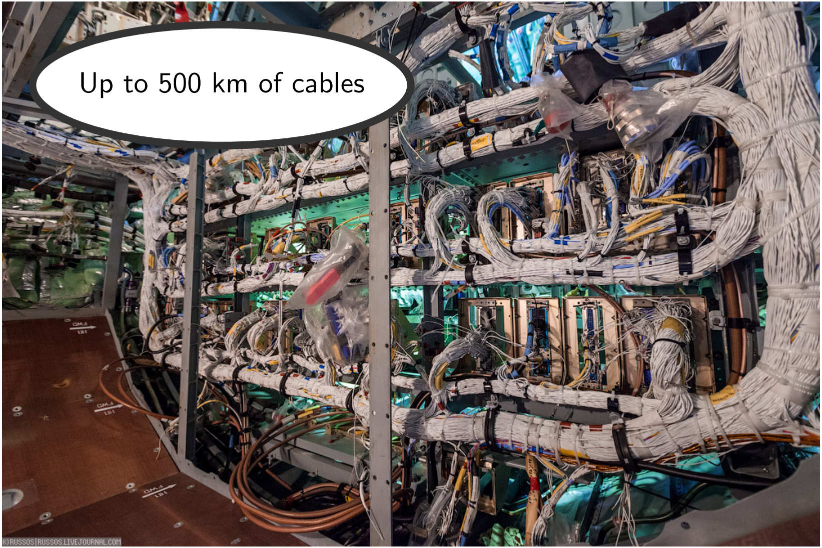

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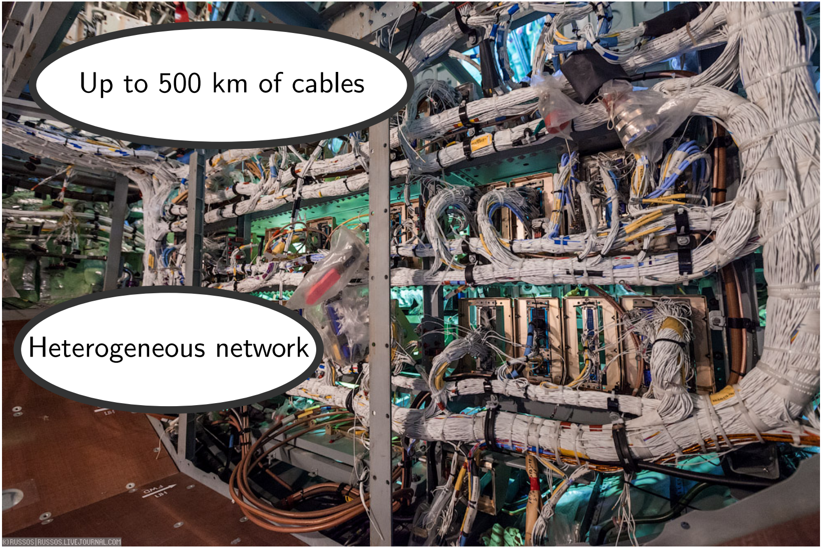

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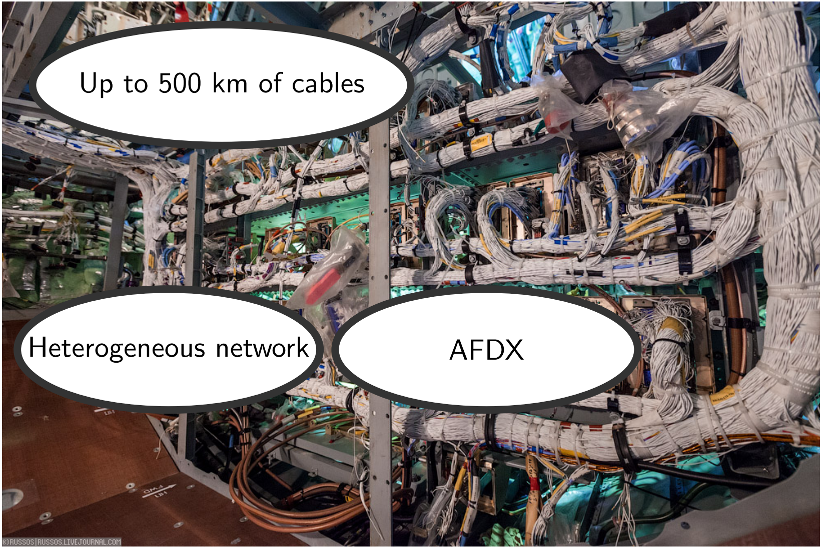

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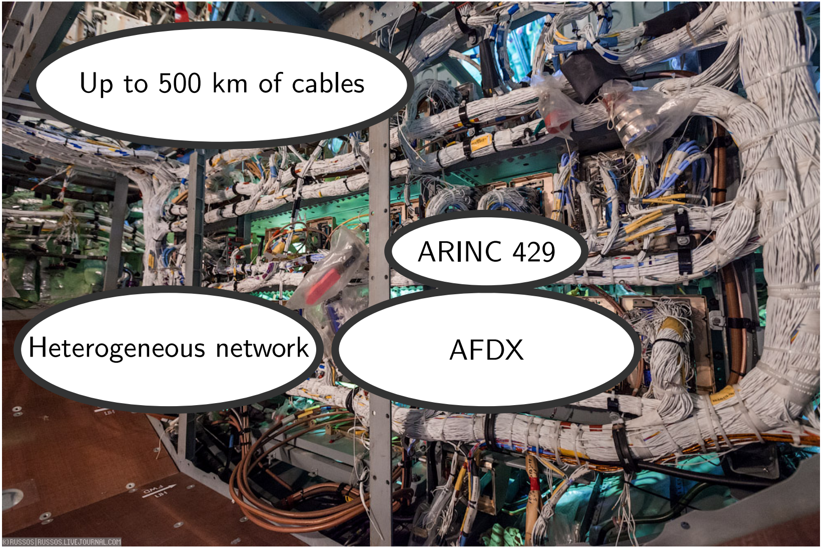

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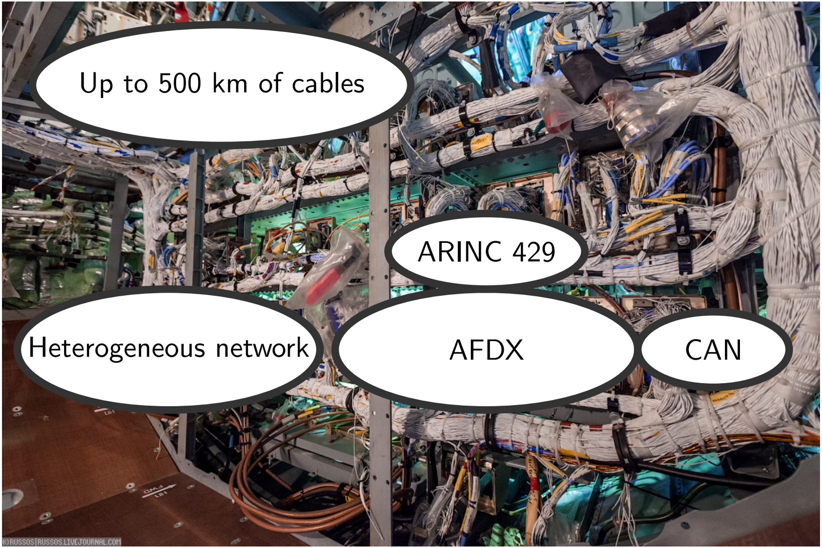

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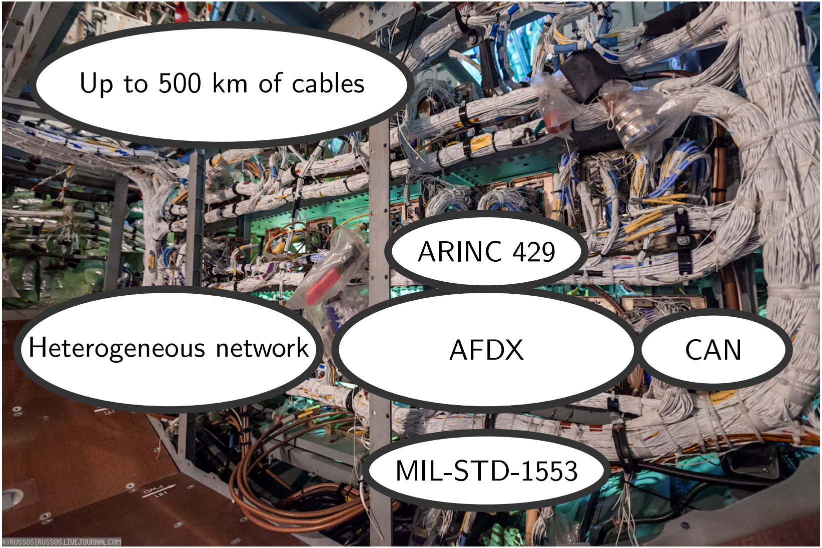

Context and Objectives

Current Avionics Communication Architecture limitations

- **Heterogeneity**: high complexity, delays and costs
- **One criticality level**: backbone supports only essential traffic
- **Unfair service policy**: strong impact of high priorities

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Main Objective

Homogenize avionics communication architecture

→ *Extend the backbone network to support* **Safety-Critical** *and* **Best-Effort** *Traffics*

Avionics Requirements and Challenges

Requirements

- **Predictability** : guaranteeing schedulability constraints, i.e. bounded delays respecting deadlines
- **Modularity** : minimizing the (re)configuration effort

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Challenges

- ↘**Complexity** : Reduce the implementation and configuration effort
- ↗**Fairness** : Limit the impact of high priorities on lower ones

Promising Solution

Solutions	TTE[1]	TAS[2]	PS[3]	UBS[4]	BLS[5]	CBS[6]	NP-SP[7]	DRR[8]
Modularity	X	X	X	✓✓	✓✓	✓✓	✓✓	✓✓
Predictability	✓✓	✓✓	✓✓	✓✓	✓✓	✓	✓✓	✓✓
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Existing solutions vs avionics requirements and challenges

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[1] Time Triggered Ethernet
[2] Time Aware Shaper
[3] Peristaltic Shaper
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Promising Solution

Schedulers

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TTTEch (TTE) — Schedulers (NP-SP, DRR)

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→ **the Burst Limiting Shaper is the most promising solution**

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Followed Methodology

Specification of an Extended AFDX

→ **Low complexity** and few hardware/software modifications[a]

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Formal timing analysis

→ New Network Calculus model with **good tightness** [a]

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Performance Enhancement

→ **Bandwidth Reservation** methods for TSN/BLS to enhance system **schedulability**

Outline

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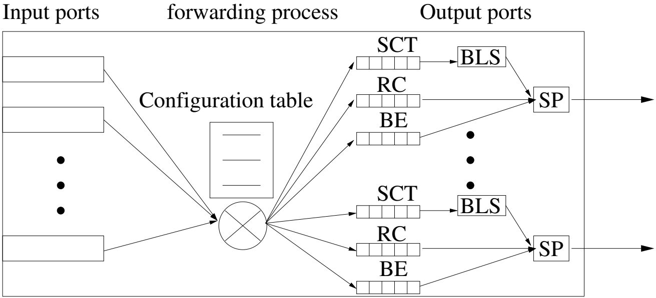
Extended AFDX Switch

1-Gigabit AFDX Switch architecture

We consider 3 types of traffics: Safety Critical Traffic (SCT), Rate Constrained (RC), and Best-Effort (BE).



Proposed switch architecture

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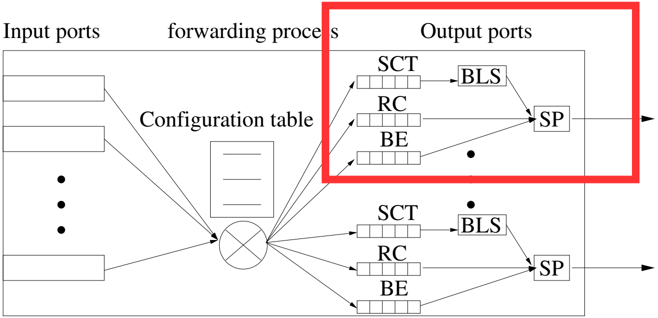
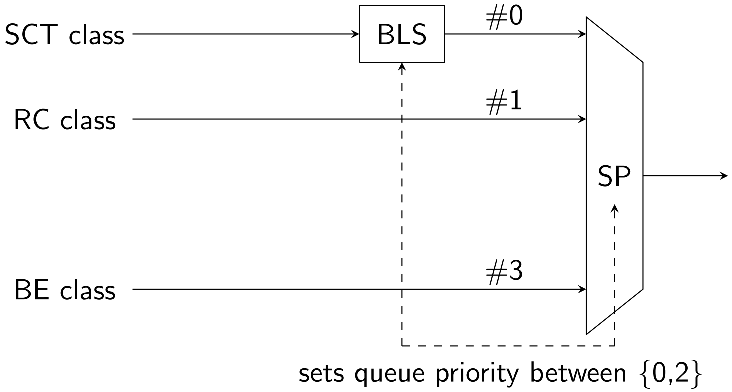


Proposed switch architecture

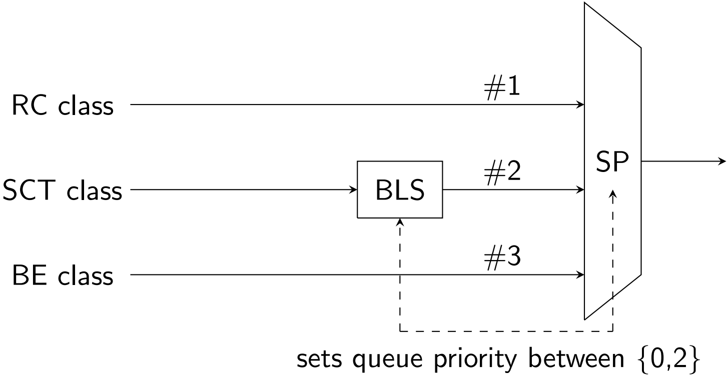
Extended AFDX output port

3-classes example: high BLS priority



Extended AFDX output port

3-classes example: low BLS priority



Burst Limiting Shaper Parameters

Each BLS credit has 3 parameters:

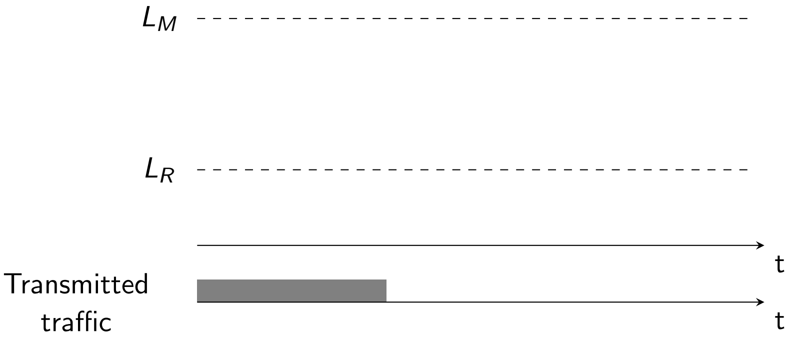
- Maximum Level (L_M)
- Resume Level (L_R)
- Reserved Bandwidth (BW)

BW is used with the output link capacity C to compute the credit slopes as follows:

- the sending slope, $I_{send} = (1 - BW) \cdot C$
- the idle slope, $I_{idle} = BW \cdot C$

Burst Limiting Shaper credit evolution

Bursty traffic



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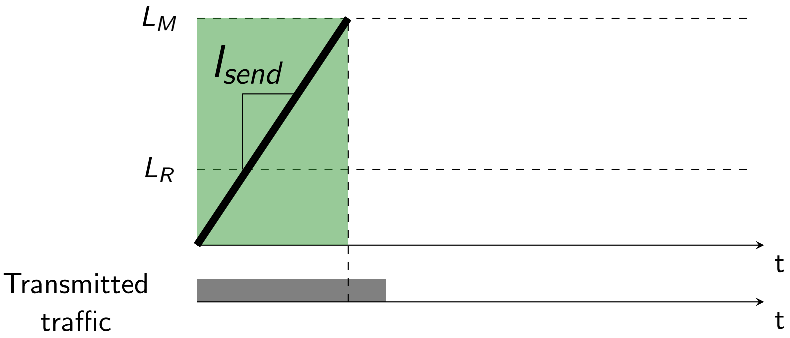

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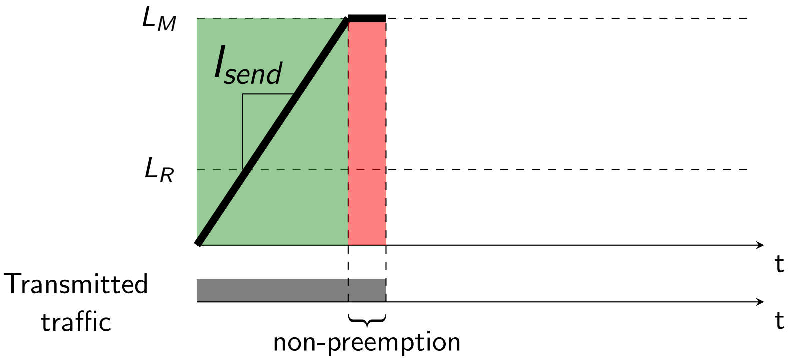

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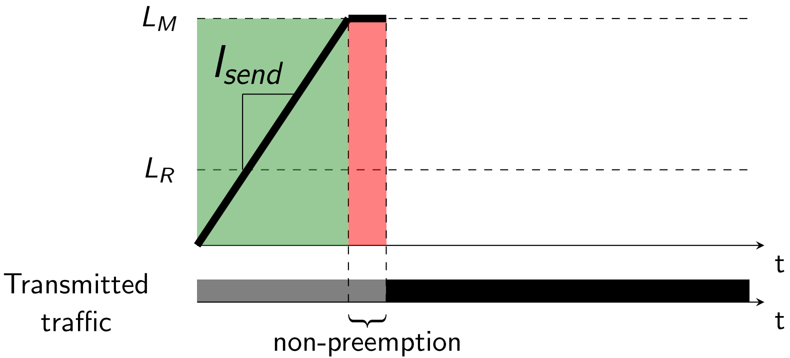

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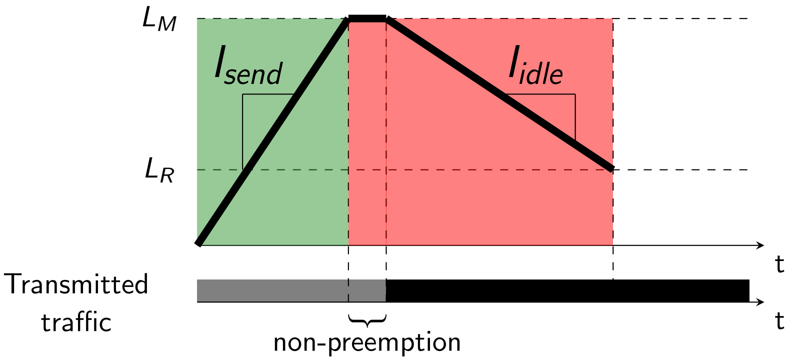

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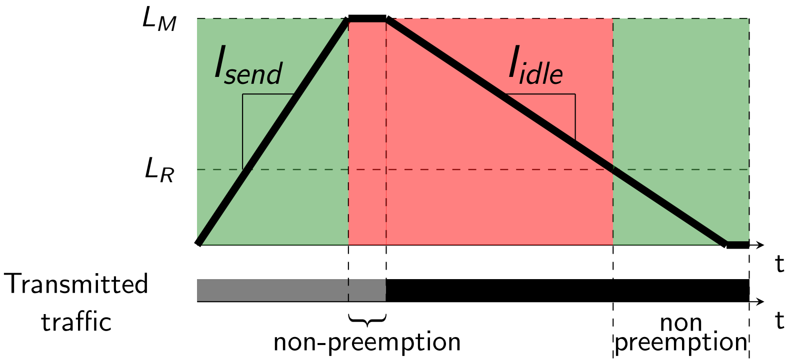
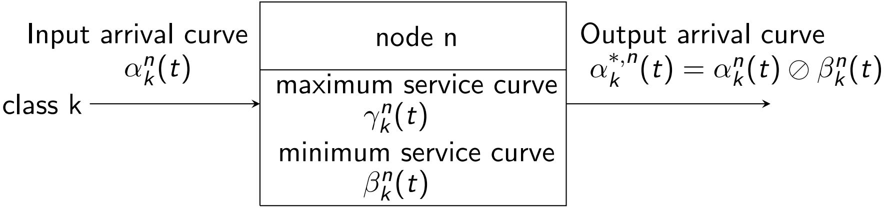


Network calculus

Characteristics of an aggregate traffic of class k crossing the node n



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$f \otimes g(t) = \inf_{0 \leq s \leq t}\{f(t-s) + g(s)\}$

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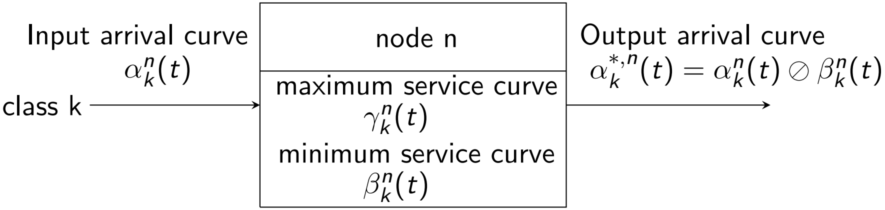

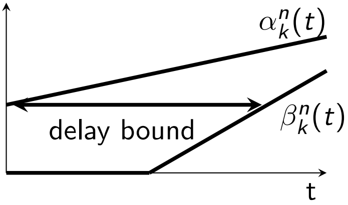

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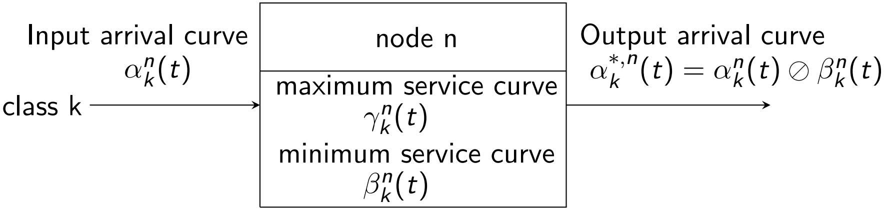

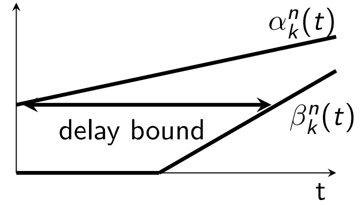

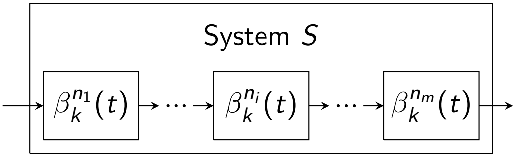

$$\beta_k^S(t) = \beta_k^{n_1}(t) \otimes \ldots \otimes \beta_k^{n_i}(t) \otimes .. \otimes \beta_k^{n_m}(t)$$

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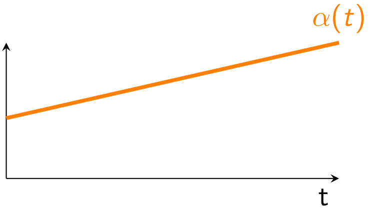
Traffic and Network Model

Traffic modelisation: **leaky buckets**



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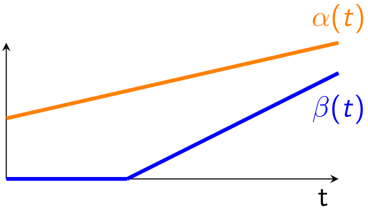

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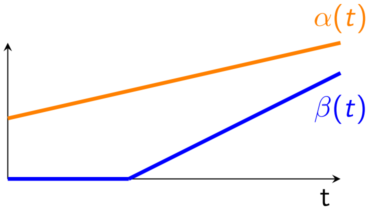

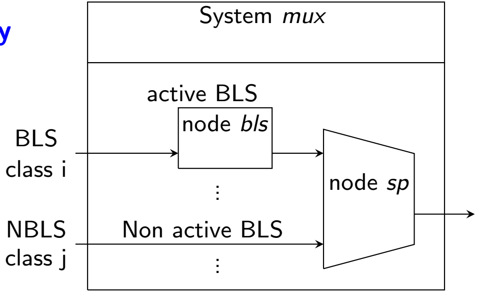

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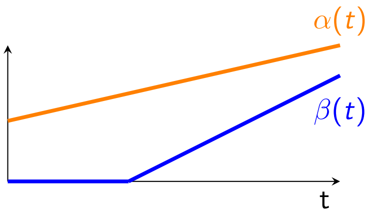

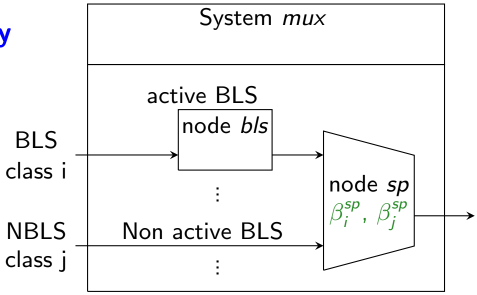

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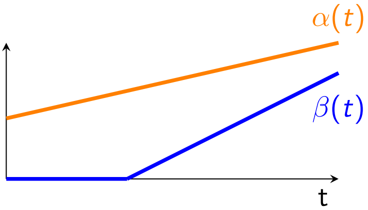

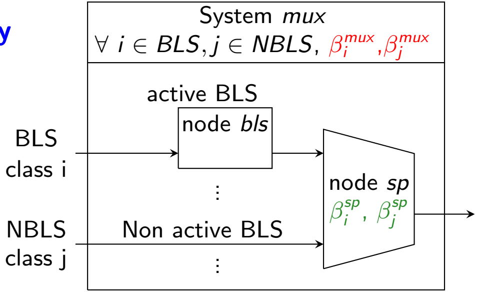

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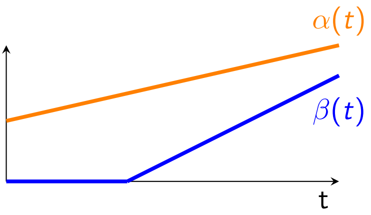

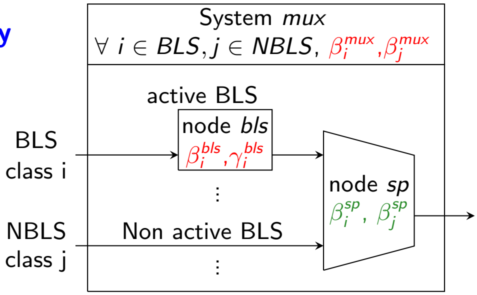

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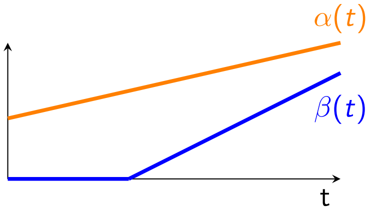

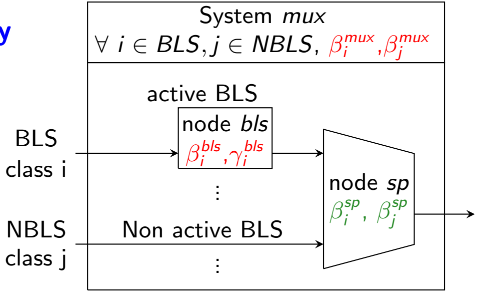

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Constraints

- **Class rate constraint**: in each output port, the class rate is lower than the guaranteed service rate
- **Aggregate rate constraint**: the total load of an output port is lower than the total capacity C
- **Deadline constraints**: the delay bound of each traffic class is lower than its deadline

Problem Formulation

$$\forall f \in RC, \forall mux \in path_f,$$

$$\underset{L_M^{mux}, L_R^{mux}, BW^{mux}}{minimize} EED_{RC,f}(L_M^{mux}, L_R^{mux}, BW^{mux})$$

$$\text{s.t. } \forall f \text{ in } j \in \{SCT, RC\}, \forall mux \in path_f :$$

$$R_j^{mux} \geqslant \sum_{f \in F_j^{mux}} r_f$$

$$\sum_{g \in F_{SCT}^{mux}} r_g + \sum_{f \in F_{RC}^{mux}} r_f \leqslant C$$

$$DI_f \geqslant EED_{j,f}(L_M^{mux}, L_R^{mux}, BW^{mux})$$

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A complexity of $O(I^m \cdot N^{3 \cdot m})$ for m ports and I flows.

Problem Solving

Relaxed Objective

Find the reserved BLS bandwidth **minimizing RC delay bounds** for each **class** within each **output** port

→ Reducing the complexity down to $O(m \cdot N^3)$

→ Need to define a **local Deadline** within each output port

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Solving the problem based on Heuristics

- The optimisation problem is a **non-linear** problem
- Take advantage of conducted **sensitivity analysis** of the analytical model to deduce **heuristics**

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Two proposed methods to compute the local deadlines

- **Heuristic Deadline**: defined proportionally to the port load
- **Dichotomous Deadline**: defined accurately in each port

Outline

1. System Model
2. Bandwidth Reservation Methods
3. Performance Evaluation
4. Conclusion and perspectives

1-Gigabit Avionics Case study

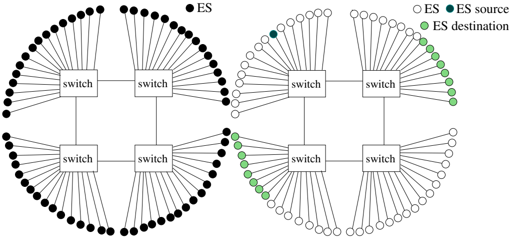

Figure: Multi-hop network and traffic communication pattern

1-Gigabit Avionics Case study

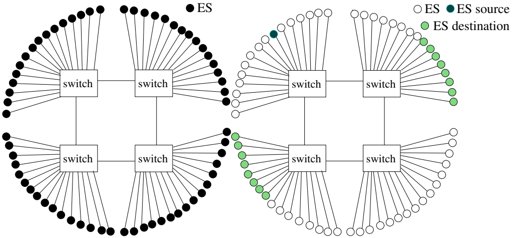

Figure: Multi-hop network and traffic communication pattern

Priority	Traffic type	MFS (Bytes)	BAG (ms)	deadline (ms)	jitter (ms)
0/2	SCT	64	2	2	0
1	RC	320	2	2	0
3	BE	1024	8	none	0.5

Numerical results

Intuitive parameters: $BW = UR_{SCT}^{bn}$, $L_R = MFS_{RC} \cdot BW$ and $L_M = 80 \cdot (1 - BW) \cdot MFS_{SCT}$

UR_k^{bn}: bottleneck utilisation rate of class k

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$Scenario_{SCT} = \left(UR_{SCT}^{bn} \in [0.4 : 80], UR_{RC}^{bn} = 20\right)$

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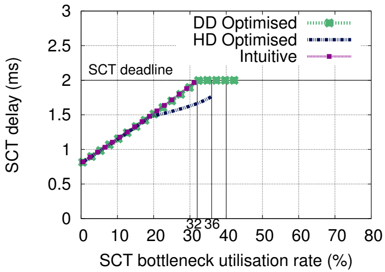

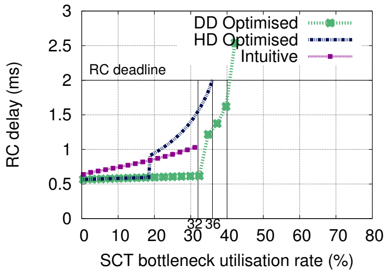

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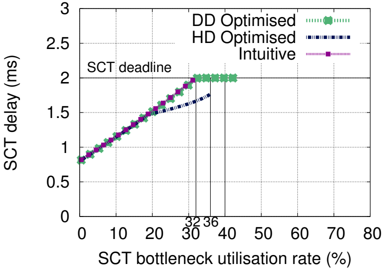

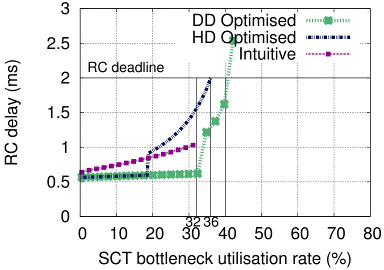

→ SCT schedulability is increased by up to 31% under Dichotomous Deadline method

UR^{bn}_k: bottleneck utilisation rate of class k

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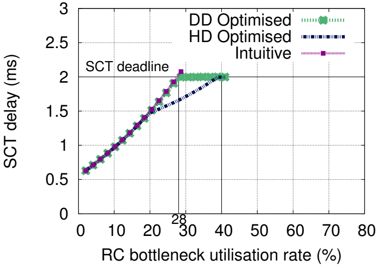

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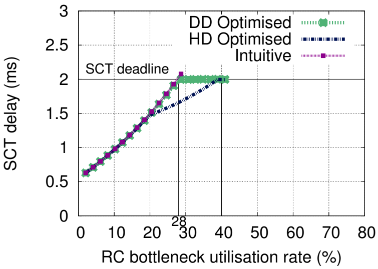

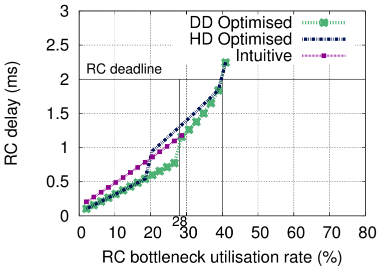

→ RC delay bounds decreased by up to 50% under Dichotomous Deadline method

Numerical Results

		improvement compared to SP(%)				computation times (s) of Scenario	
		maximum RC delay at		maximum			
		$UR^{bn}_{SCT} = 33\%$	$UR^{bn}_{RC} = 28\%$	UR^{bn}_{SCT}	UR^{bn}_{RC}	SCT	RC
HD	BLS	18	22	33	21	**57**	**9**
DD	BLS	**77**	**55**	**52**	**24**	117	233

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$\rightarrow$ **Higher Complexity for Dichotomous Deadline method**

Outline

Conclusion and prespectives

Two optimized bandwidth reservation methods for TSN/BLS

→ Heuristic Deadline: simple but average performances
→ Dichotomous Deadline: complex but good performances

Conducted Performance evaluation on a realistic avionics case study

→ Enhanced SCT schedulability (up to 31%) under DD
→ Enhanced RC delay bounds (up to to 50%) under DD

Conclusion and prespectives

Two optimized bandwidth reservation methods for TSN/BLS

→ Heuristic Deadline: simple but average performances
→ Dichotomous Deadline: complex but good performances

Conducted Performance evaluation on a realistic avionics case study

→ Enhanced SCT schedulability (up to 31%) under DD
→ Enhanced RC delay bounds (up to to 50%) under DD

Approach Generalization to multiple TSN/BLS classes

→ Offer higher configuration flexibility

Q&A

Thank you for your attention