Optimizing Network Calculus for Switched Ethernet Network with Deficit Round Robin

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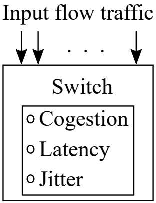
ÉCOLE D'INGÉNIEURS

Context : Evolution of Avionic Network

- Traditional aircraft network ARINC 429. (Airbus A320)
  - Mono-transmitter buses with limited performances (100 Kbits/s).
- **Avionics Full DupleX (AFDX) network.**
  - Switched Ethernet ARINC 664. (Airbus A380)
  - A backbone network for the avionics platform.
  - **100 Mbps**.
  - **FIFO/SP queues**.

Context : The Problem

- ARINC 664 : **Indeterminism at Switch level**.
  - Competition for the use of the resources.
    - Congestion = frame losses
    - Frame storage in queues = Latency and jitter.



- **Need of guaranteed bounds for certification.**

Context : The Problem

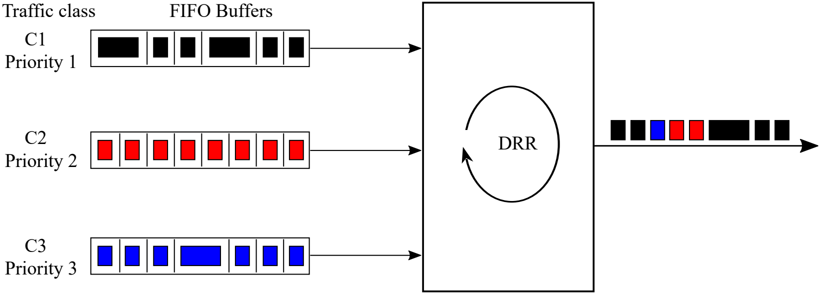
- Inefficient use of available bandwidth.[1]
  - Lightly loaded network (up to 10 % only).
    - Possibility to **share bandwidth among critical (avionic) and non-critical flow**.
    - Example:
      > Audio message from cockpit to cabin.
      > Parking video.
- Solution : Quality of Service (QoS) mechanism.

[1]] H. Charara, J-L.Scharbarg, J. Ermont and C.Fraboul, "Methods for bounding end-to-end delays on an AFDX network," ECRTS 2006.

Context: Objective 1

How to make better use of available bandwidth?

- QoS : Share bandwidth using Round Robin Scheduler.
  - **Deficit Round Robin (DRR) scheduling.**
  - Weighted Round Robin (WRR) scheduling.[1]

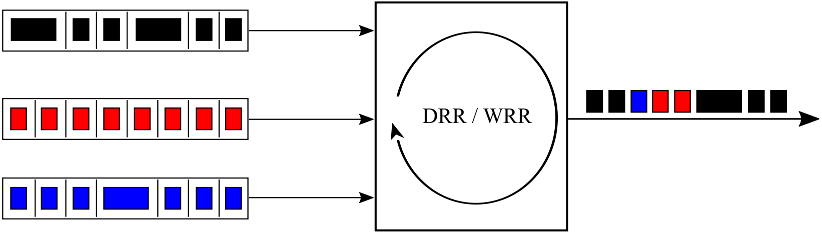


[1]] A. Soni, X. Li, J-L.Scharbarg, and C.Fraboul, "WCTT analysis of avionics Switched Ethernet Network with WRR Scheduling," RTNS 2018.

Context: Objective 2

Performance analysis of DRR and WRR scheduler in AFDX network.

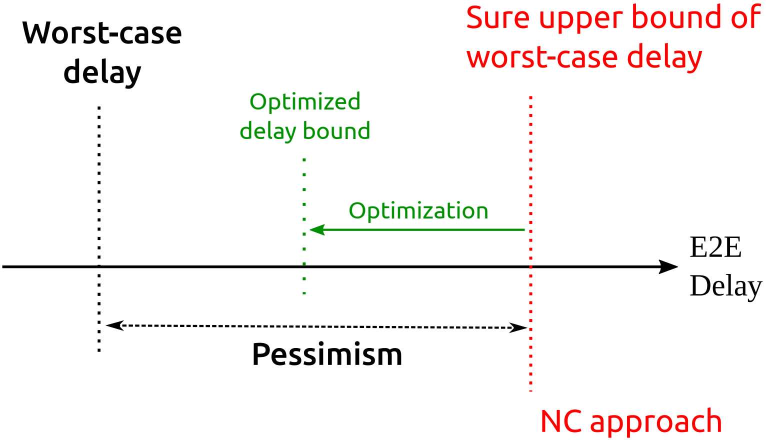
- Worst-case end-to-end delay.
- Fairness.



Context: Objective 3

Improve delay bound computation.

- Reduce pessimism in analysis approach.



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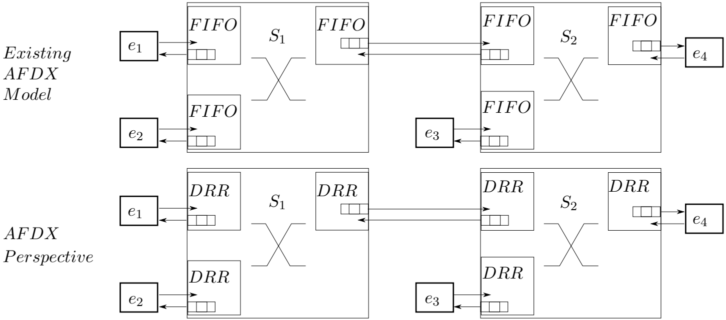
Switched Ethernet Network : AFDX Network Model

AFDX network model

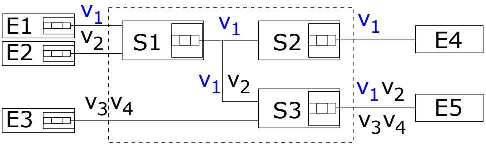
- End-Systems (e_x)
- Switches (S_x)
- FIFO output ports
- Statically defined flows.

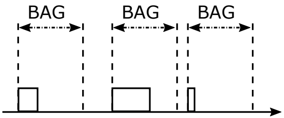


Switched Ethernet Network : AFDX Flow Model

Avionic flows are characterized as virtual links;

- Statically defined : predictable deterministic behavior.
- Maximum frame length: S_{max}
- Minimum delay between two consecutive frames: BAG (Bandwidth Allocation Gap)
- Multi-cast routing





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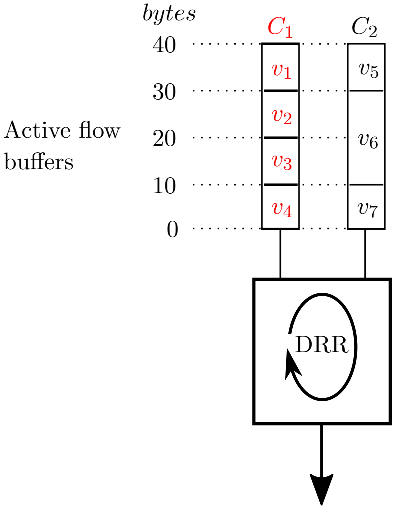
DRR Algorithm



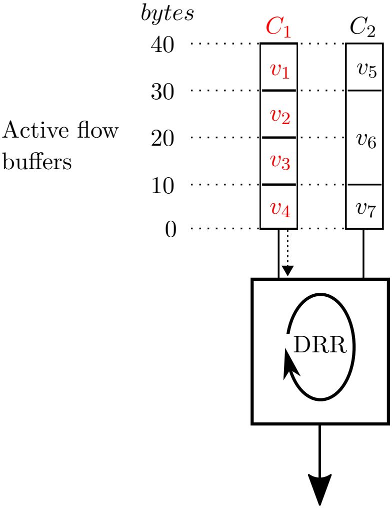
$Q = 20$

$\Delta : Deficit$

$Credit = Q + \Delta$

Q_{C_1}	Δ_{C_1}	Q_{C_2}	Δ_{C_2}

DRR Algorithm



$Q = 20$

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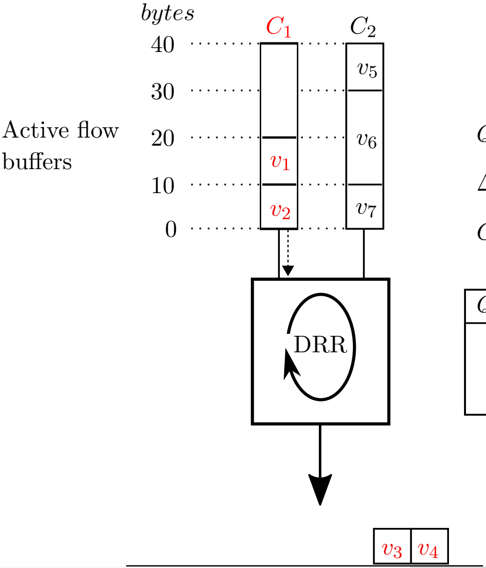
Q_{C_1}	Δ_{C_1}	Q_{C_2}	Δ_{C_2}
20			

DRR Algorithm



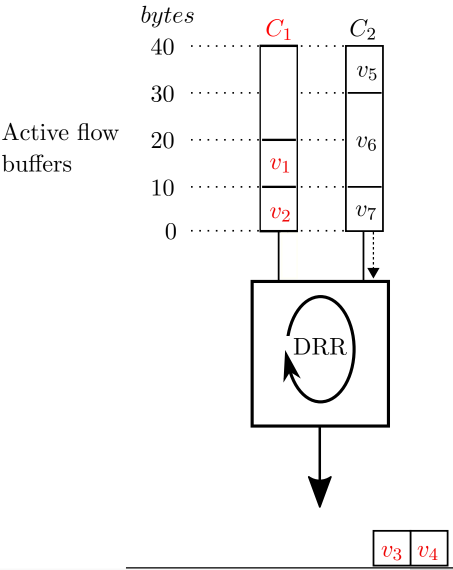
$Q = 20$

$\Delta : Deficit$

$Credit = Q + \Delta$

Q_{C_1}	Δ_{C_1}	Q_{C_2}	Δ_{C_2}
20	0		

DRR Algorithm



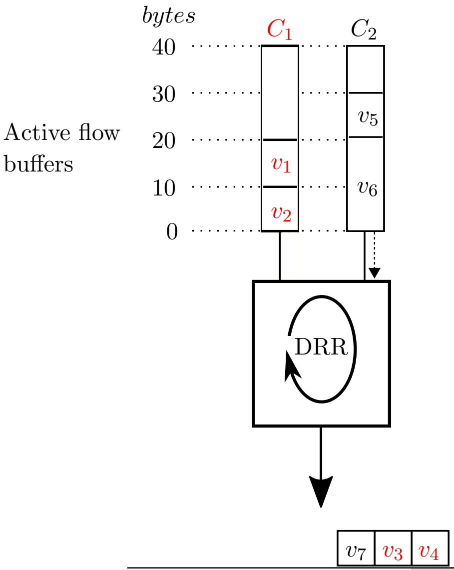
$Q = 20$

$\Delta : Deficit$

$Credit = Q + \Delta$

Q_{C_1}	Δ_{C_1}	Q_{C_2}	Δ_{C_2}
20	0	20	

DRR Algorithm



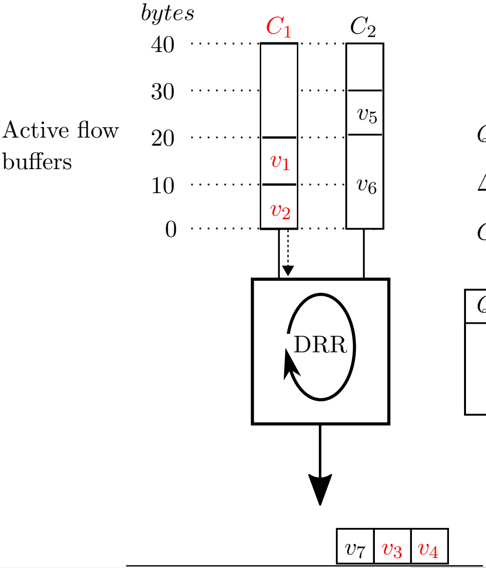
$Q = 20$

$\Delta : Deficit$

$Credit = Q + \Delta$

Q_{C_1}	Δ_{C_1}	Q_{C_2}	Δ_{C_2}
20	0	20	10

DRR Algorithm



$Q = 20$

$\Delta : Deficit$

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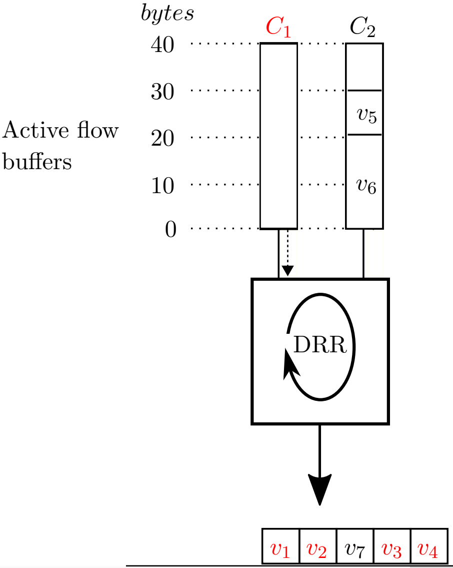
Q_{C_1}	Δ_{C_1}	Q_{C_2}	Δ_{C_2}
20 20	0	20	10

DRR Algorithm



$Q = 20$

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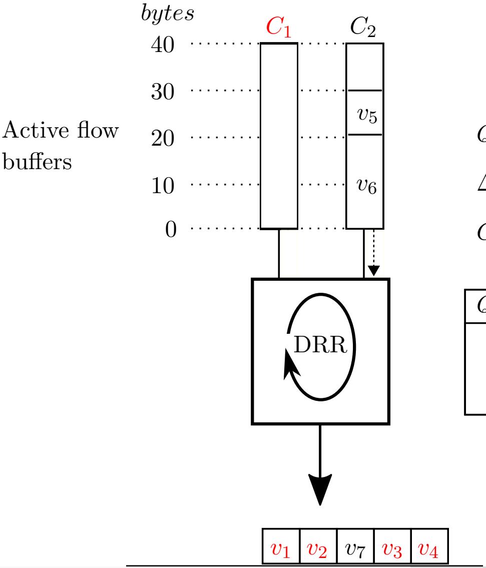
$Credit = Q + \Delta$

Q_{C_1}	Δ_{C_1}	Q_{C_2}	Δ_{C_2}
20	0	20	10
20	0		

DRR Algorithm



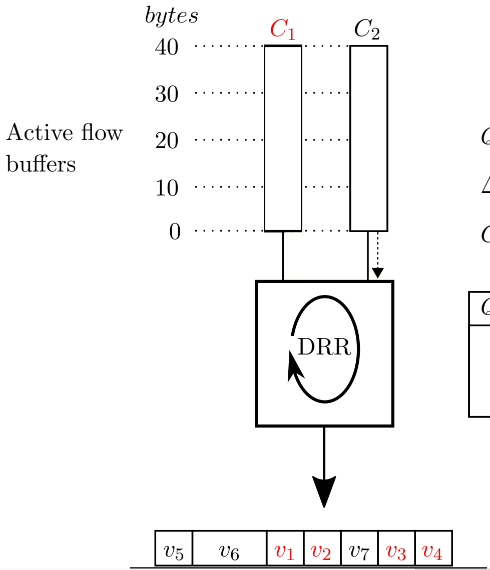
$Q = 20$

$\Delta : Deficit$

$Credit = Q + \Delta$

Q_{C_1}	Δ_{C_1}	Q_{C_2}	Δ_{C_2}
20	0	20	**10**
20	0	**20**	

DRR Algorithm



$Q = 20$

$\Delta : Deficit$

$Credit = Q + \Delta$

Q_{C_1}	Δ_{C_1}	Q_{C_2}	Δ_{C_2}
20	0	20	10
20	0	20	0

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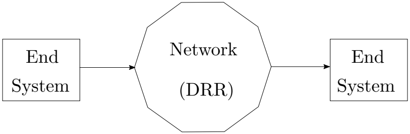
Network Calculus

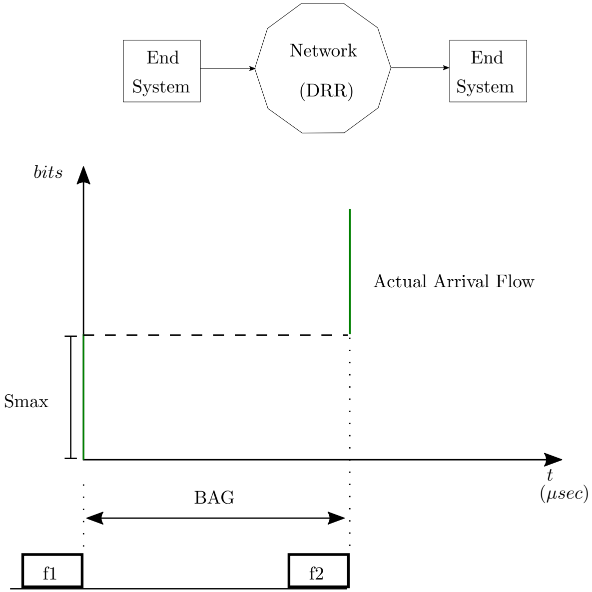
Network calculus

- Computes **upper bounds** on:
  - End-to-end delay.
  - Jitter.
- Pessimism: models network based on **traffic envelops**.
  - Overestimated flow traffic.
  - Underestimated network service.

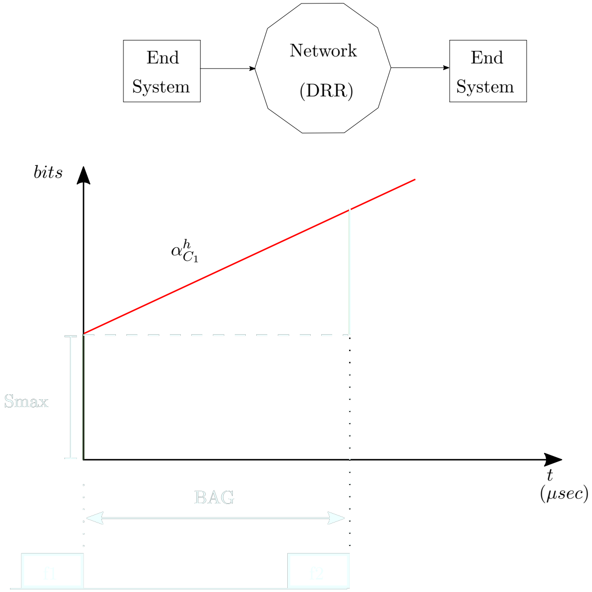
Network Calculus: Traffic Envelops



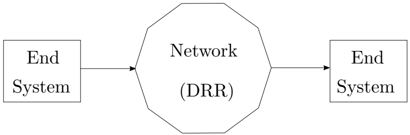
Network Calculus: Traffic Envelops : Arrival Traffic

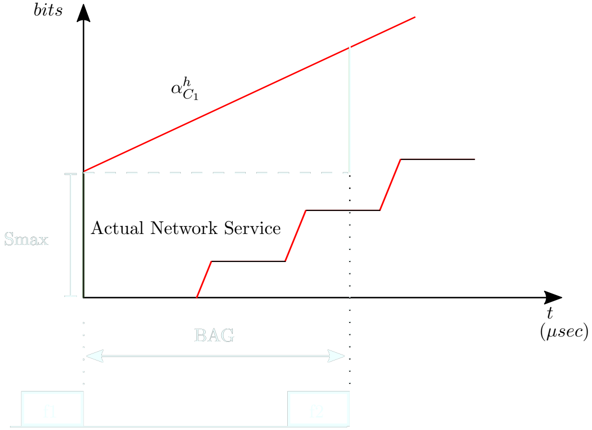


Network Calculus: Traffic Envelops : Arrival Curve

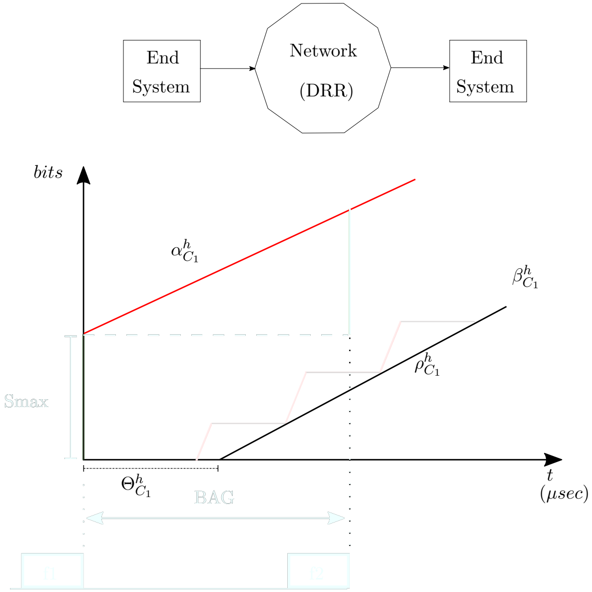


Network Calculus: Traffic Envelops : Network Service

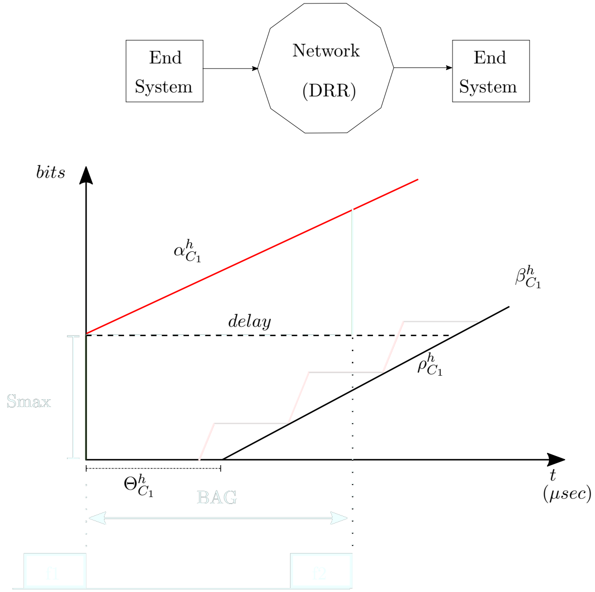




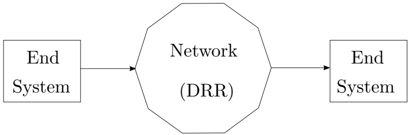
Network Calculus: Traffic Envelops : Service Curve

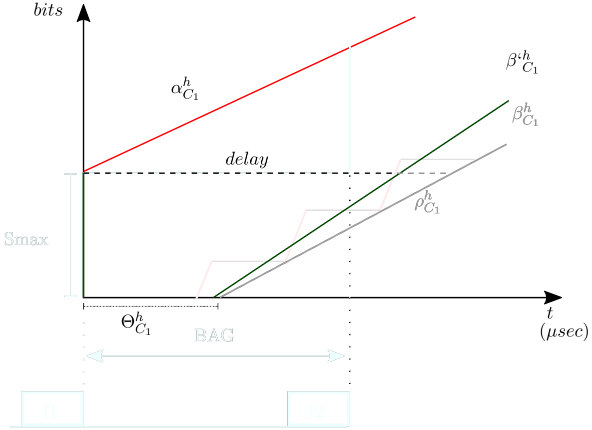


Network Calculus: Traffic Envelops : Delay

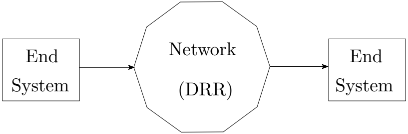


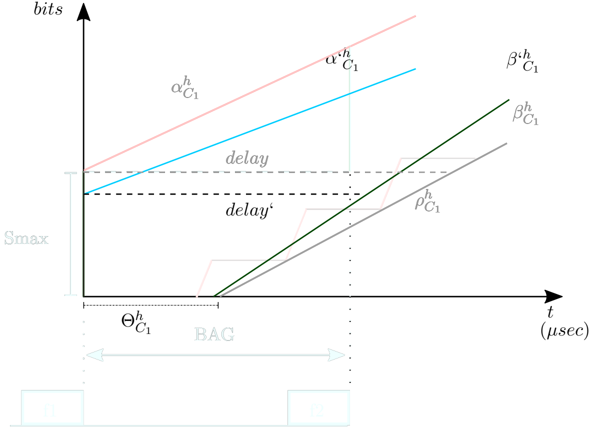
Network Calculus: Traffic Envelops : Optimization





Network Calculus: Traffic Envelops : Optimization





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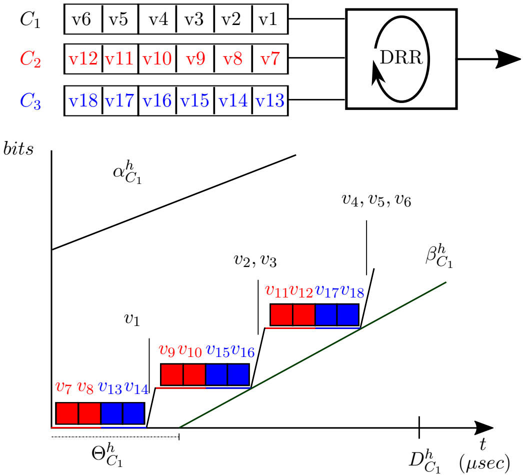
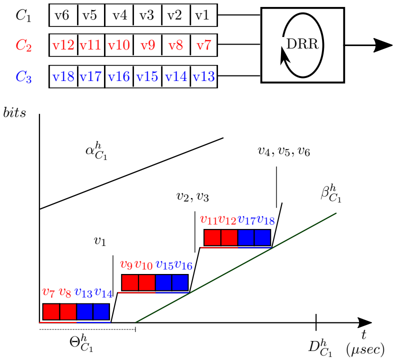
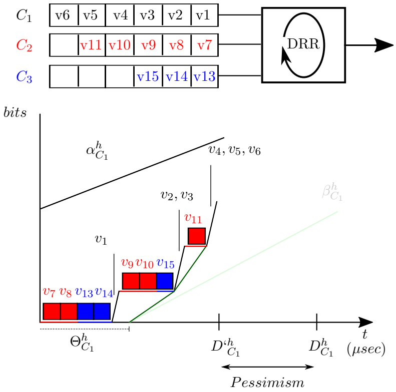
Pessimism in computed network service

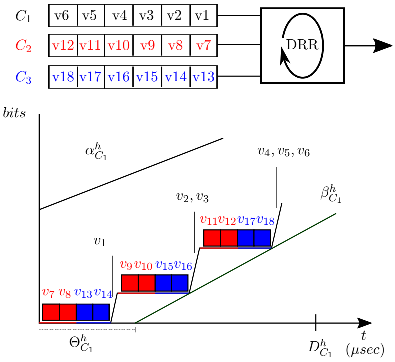


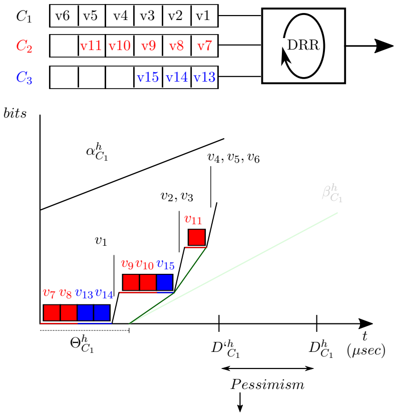
Pessimism in computed network service





Upper bound on interfering traffic





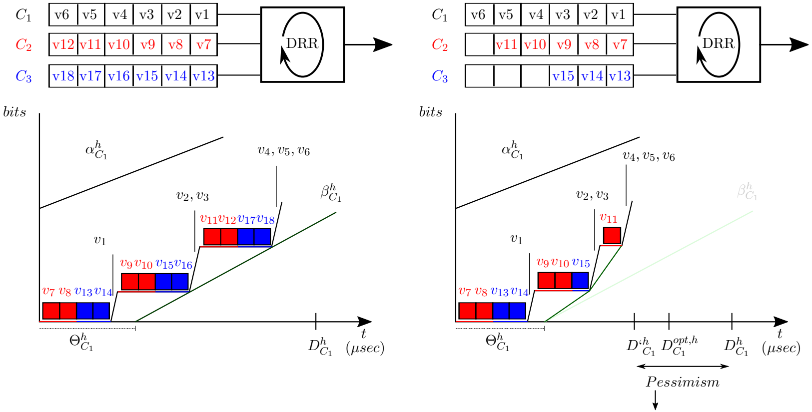
C_2 Flow traffic in $\beta^h_{C_1}$ $-$ Actual traffic from C_2 before $D^h_{C_1}$ $=$ $Extraload_{C_2}$

$(\alpha^h_{C_2}(D_{C_1}))$

C_3 Flow traffic in $\beta^h_{C_1}$ $-$ Actual traffic from C_3 before $D^h_{C_1}$ $=$ $Extraload_{C_3}$

$(\alpha^h_{C_3}(D_{C_1}))$

More accurate delay computation



C_2 Flow traffic in $\beta^h_{C_1}$ $-$ Actual traffic from C_2 before $D^h_{C_1}$ $=$ $Extraload_{C_2}$

$(\alpha^h_{C_2}(D_{C_1}))$

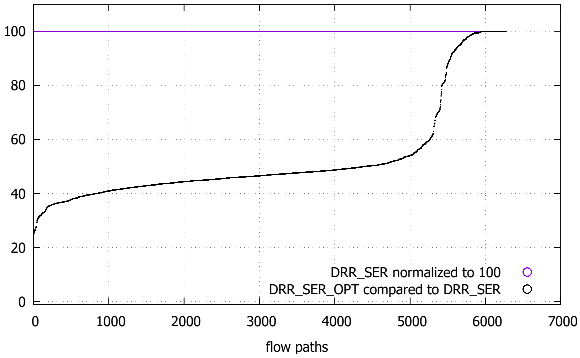
C_3 Flow traffic in $\beta^h_{C_1}$ $-$ Actual traffic from C_3 before $D^h_{C_1}$ $=$ $Extraload_{C_3}$

$(\alpha^h_{C_3}(D_{C_1}))$

$$D^{opt,h}_{C_1} = D^h_{C_1} - tr\{Extraload_{C_2} + Extraload_{C_3}\}$$

Evaluation

- Airbus A350 configuration
- 984 flows, 96 end systems, 8 switches, 6412 paths



- Average gain: 48%.
- Max gain 75%.

Class	Flows	S_{max} (byte)	Q_x	Category
C_1	718	475	$2 \times L_{max}$	Critical
C_2	194	971	L_{max}	Multimedia
C_3	72	1535	L_{max}	Best-effort

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Performance Analysis

class	No. of flows	DRR Quantum (bytes)	WRR weight (no. of packets)	frame size range
C_1	718	4 x l_{max}	4	415-475
C_2	194	2 x l_{max}	2	911-971
C_3	72	1 x l_{max}	1	1475-1535

class	DRR vs WRR	
	avg difference (%)	max difference (%)
C_1	29.16	52.7
C_2	29.6	52.3
C_3	-35.4	-68.8

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Conclusion

- NC on AFDX network with mixed criticality
- QoS: DRR scheduling.
- Evaluation of improved NC approach.
- Performance comparison of DRR and WRR schedulers.
- What's next?
  - Exact worst case delay using model checking approach.
    - Classical MC Appraoch => upto 32 flows
    - Improved Appraoch => 300+ flows
  - Evaluation of pessimism of NC for avionic network with DRR and WRR scheduler.
  - Weight/Quantum allocation in Round Robin scheduler (WRR/DRR)

Questions

- Thank you for your attention!

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