

Quantum assignment for QoS-aware AFDX network with Deficit Round Robin

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en Informatique de Toulouse



Université
de Toulouse



Context : Network architecture in modern aircraft

- Avionic backbone
 - Avionic **F**ull **D**uple**X** Switched Ethernet (AFDX) network
- Other Dedicated networks
 - based on CAN, ARINC429, Ethernet ...
 - Critical function
 - parking video,
 - cockpit-cabin/cabin-cabin communication,
 - smoke detection . . .
 - Non-critical function
 - in-flight entertainment

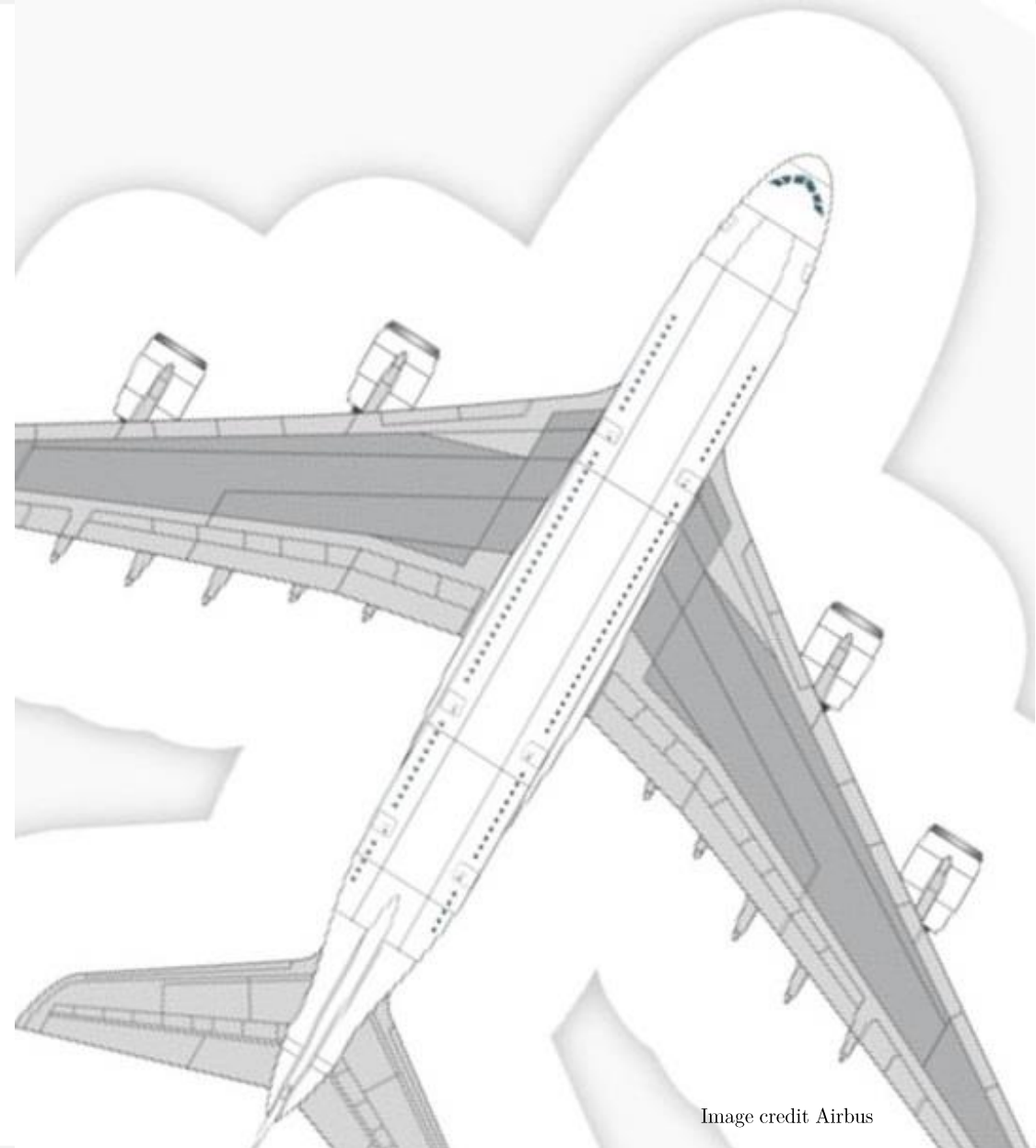


Image credit Airbus

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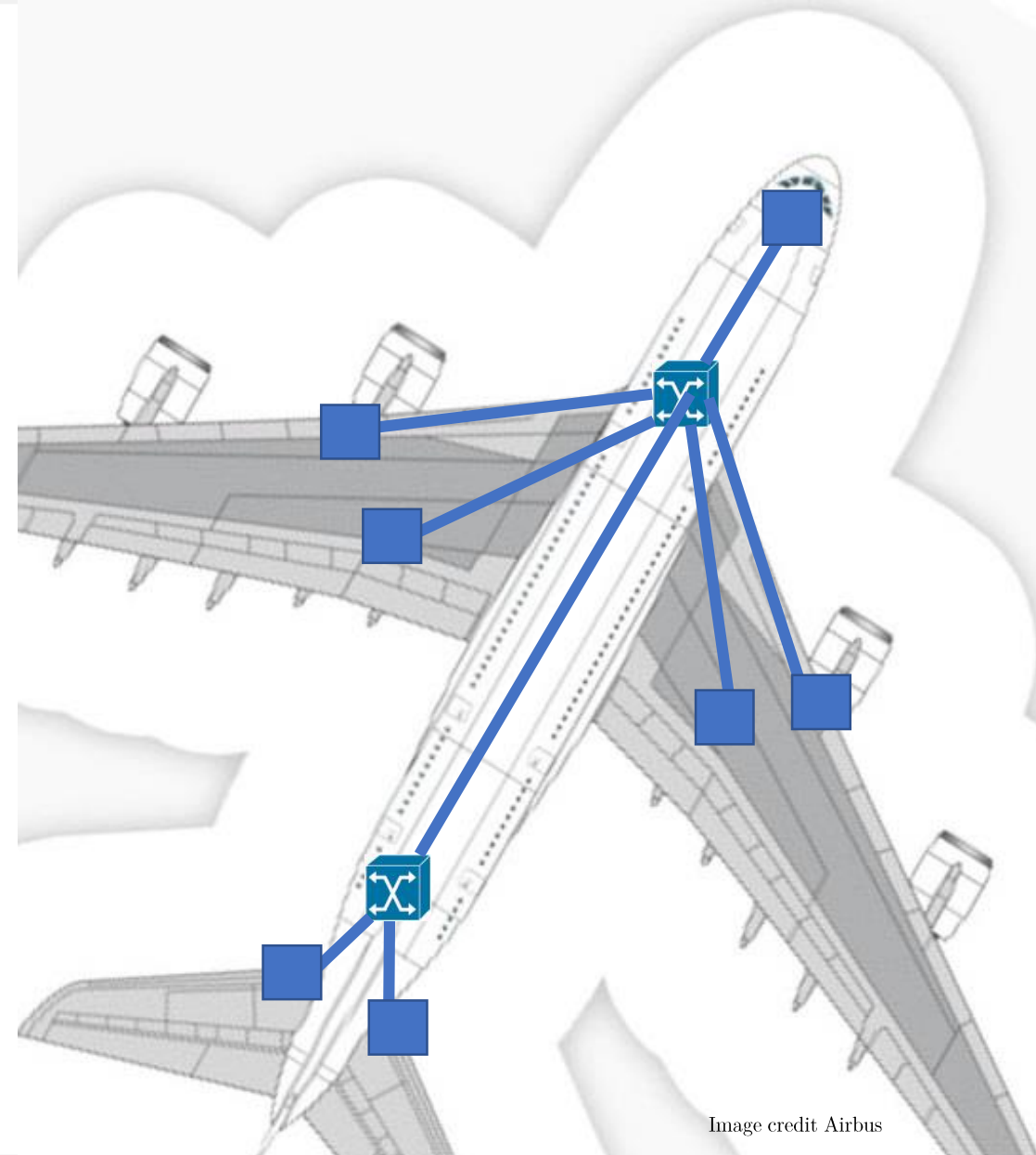


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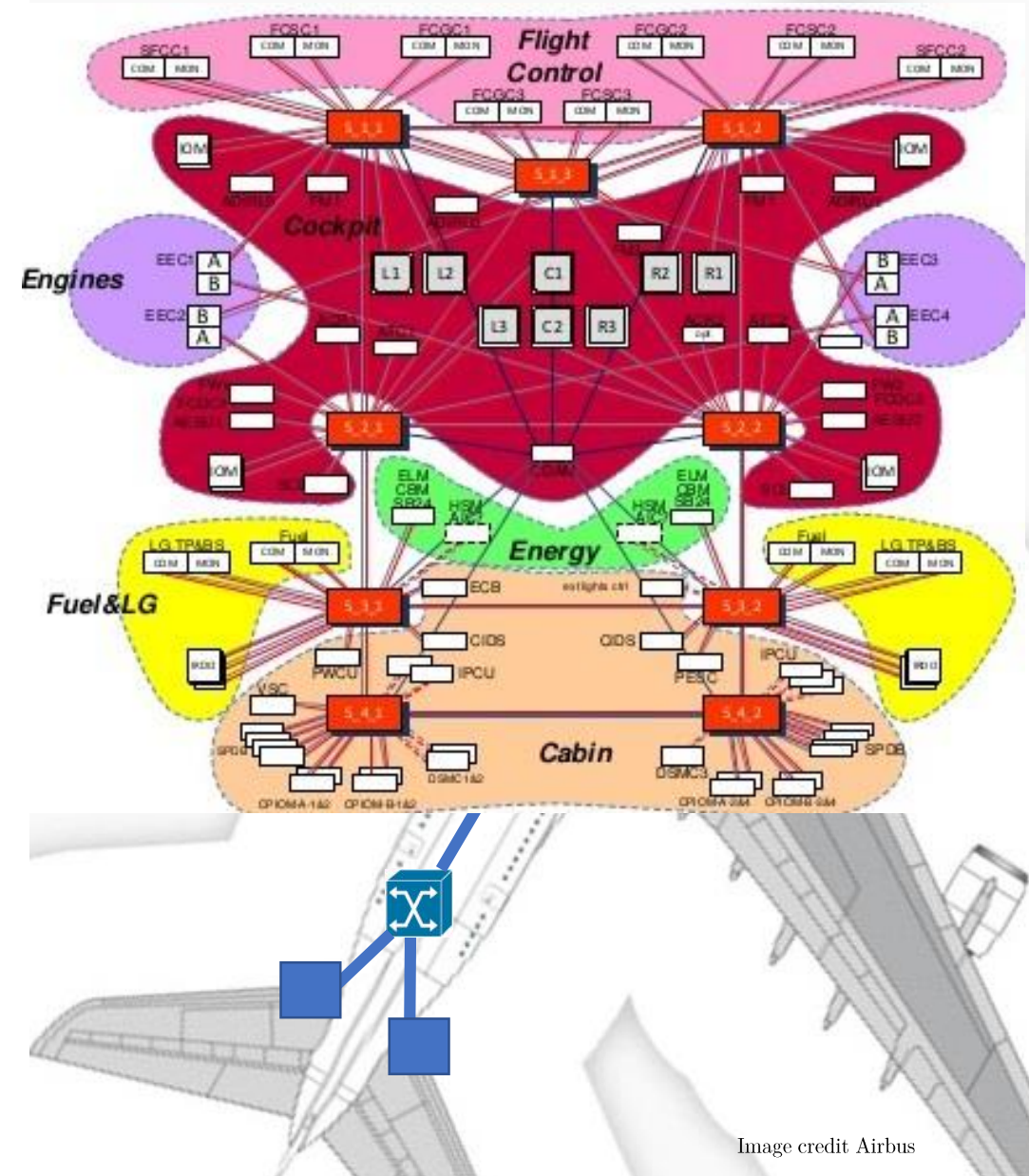


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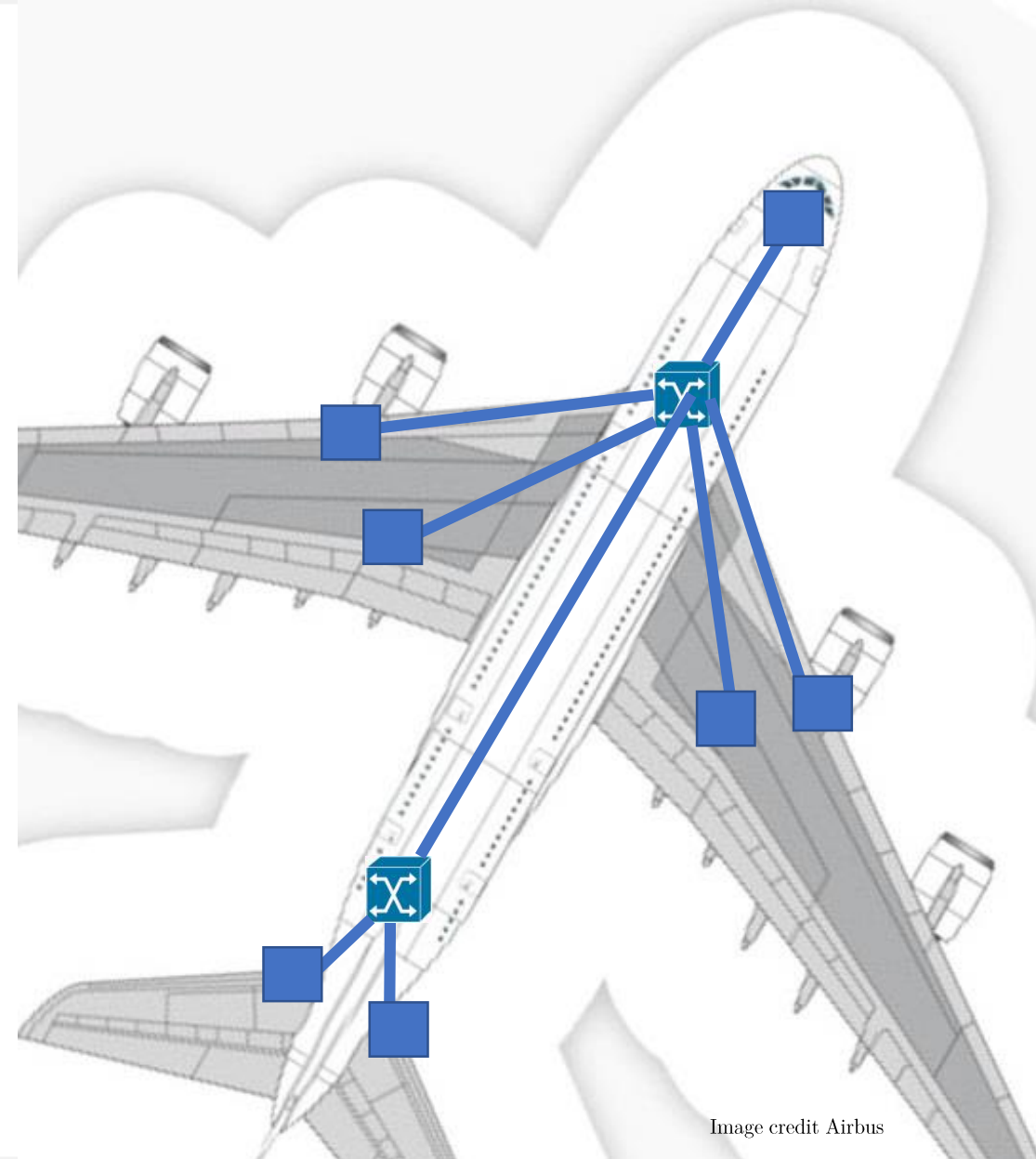


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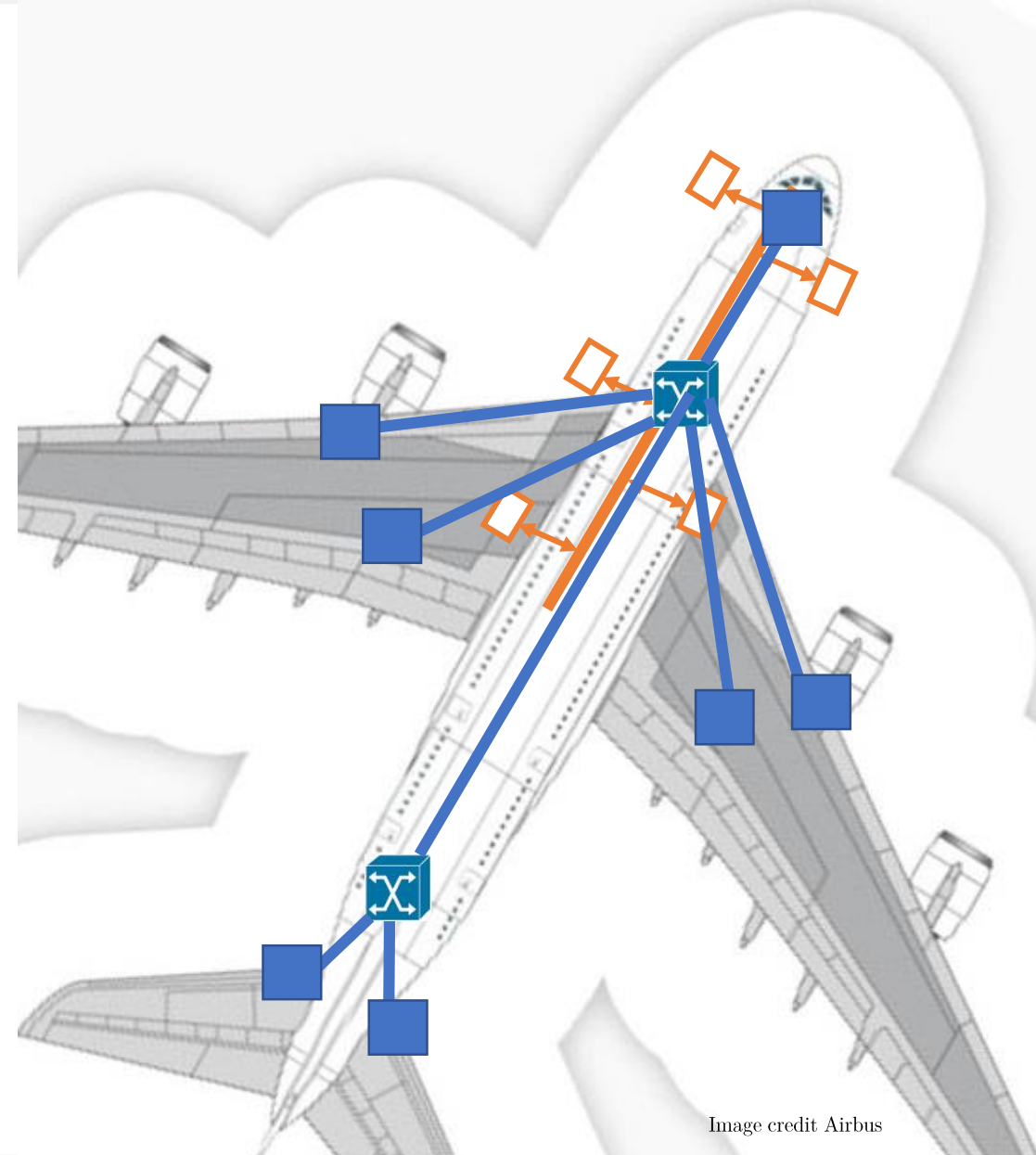


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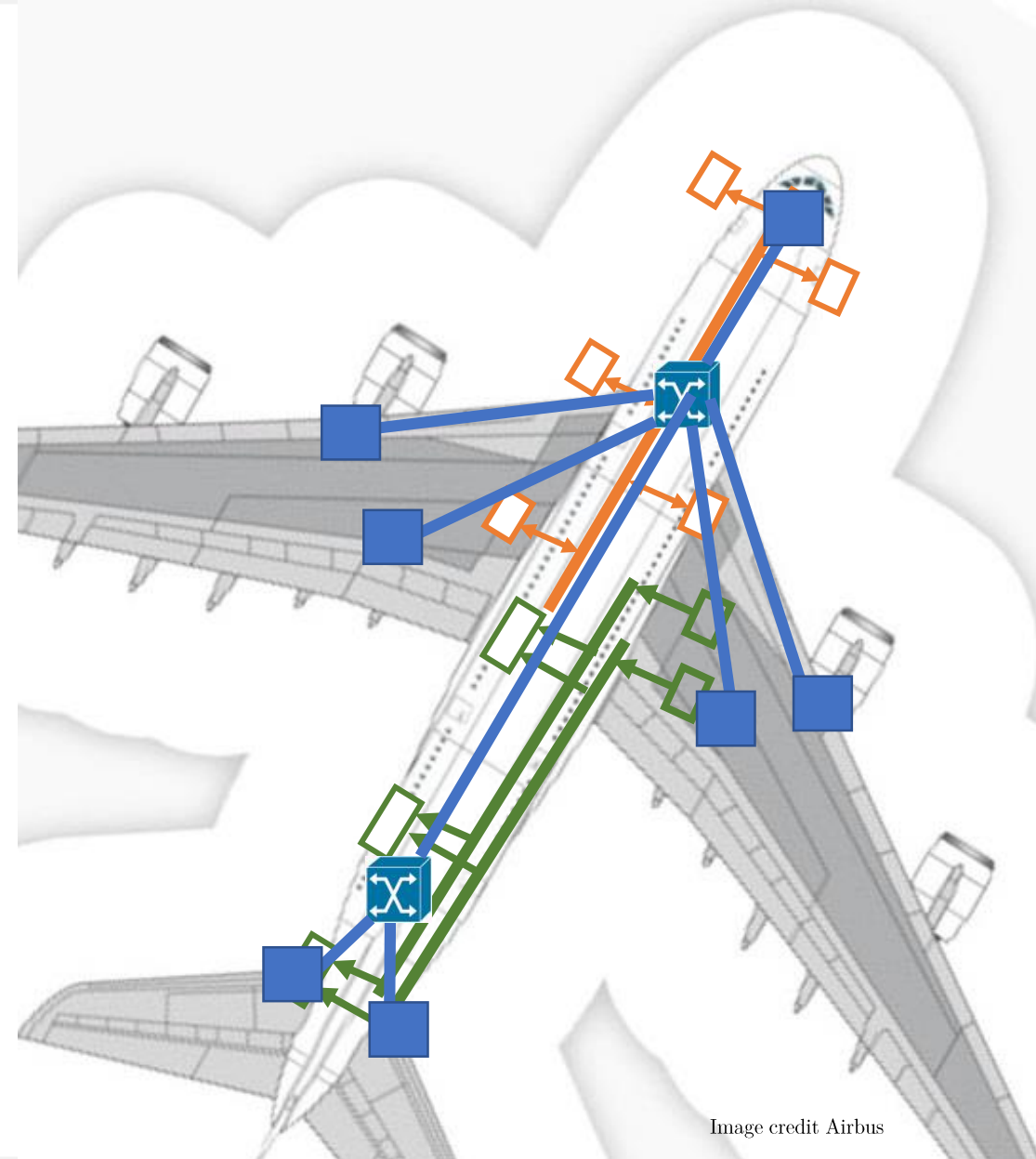


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Context : Network architecture in modern aircraft

- Advantage
 - AFDX network for safety critical avionic data
 - **Full duplex links**
 - **High bandwidth : 100 Mbps**
 - Low cost
 - **Deterministic guarantee on delay**
 - Required by certification process
 - **End-to-end delay upper bound by Network Calculus approach.**
 - High fidelity : independent networks
- Disadvantage
 - Complex parallel cabling
 - Heavy weight
 - **Inefficient resource utilisation**

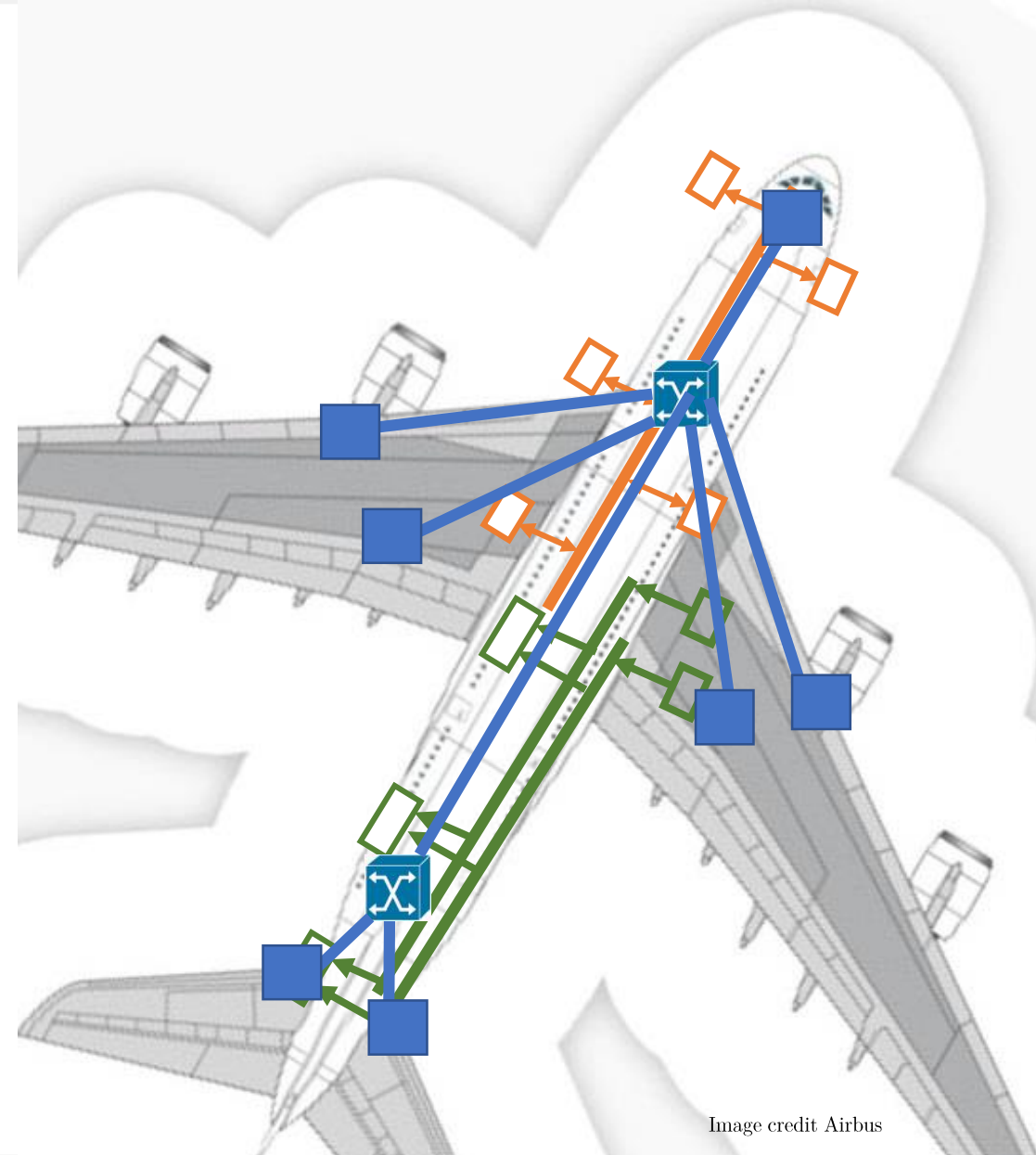


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Context : Network architecture in modern aircraft

- Inefficient resource utilisation
 - AFDX is lightly loaded (up to 25%)
 - Bandwidth 100 Mbps
 - Next generation AFDX switch with 1 Gbps

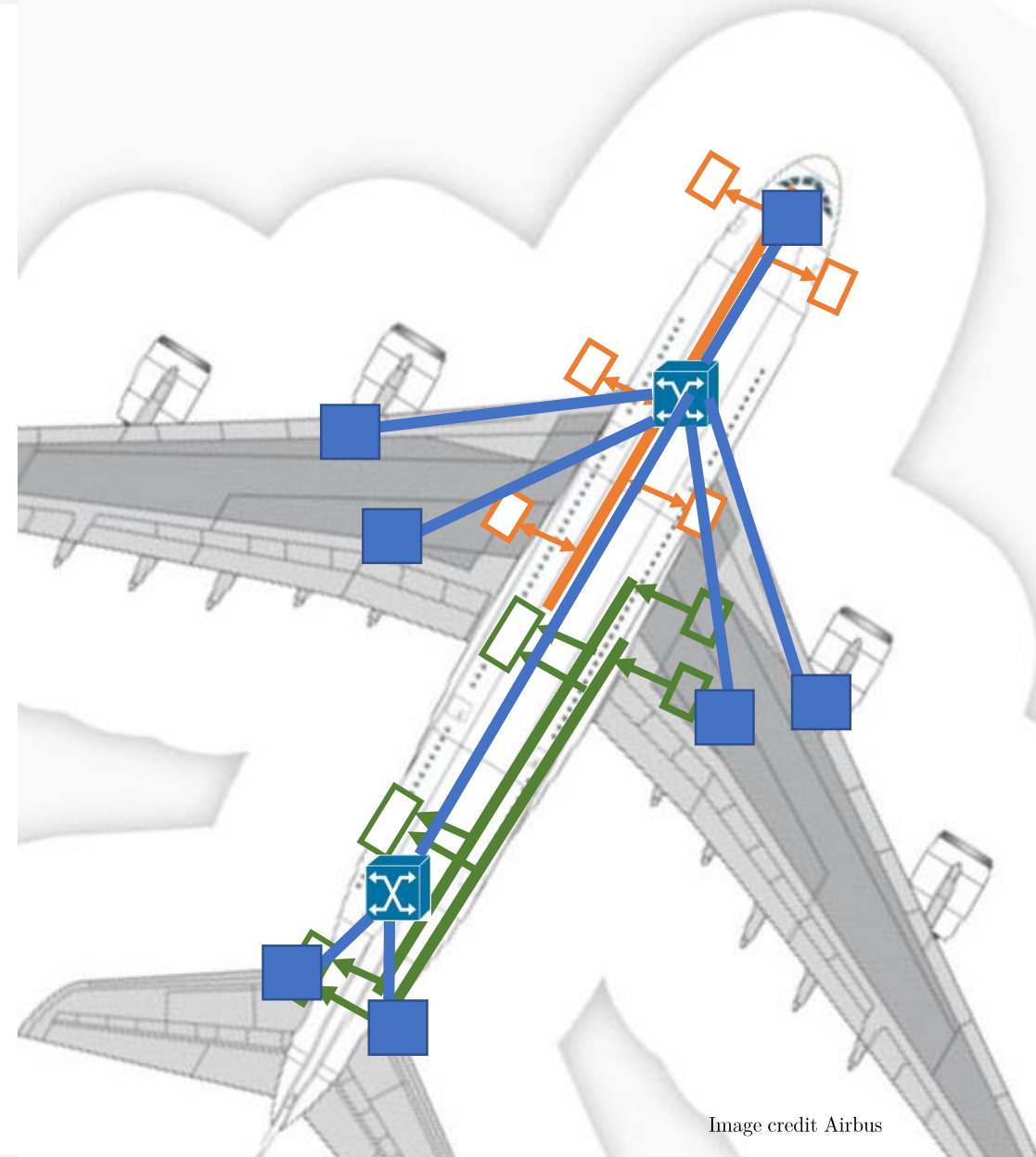


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- Integrate functions of parallel networks into AFDX network

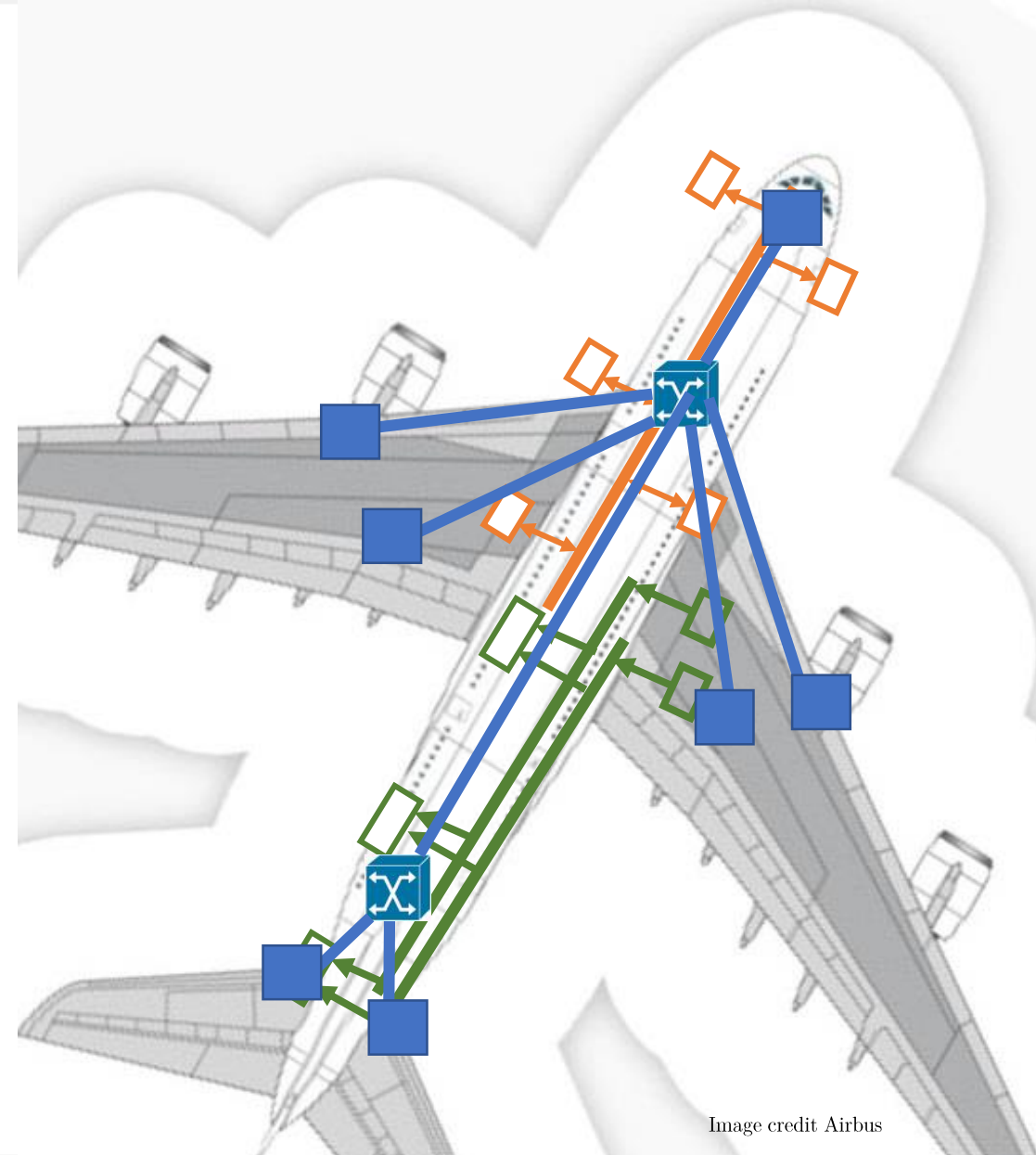


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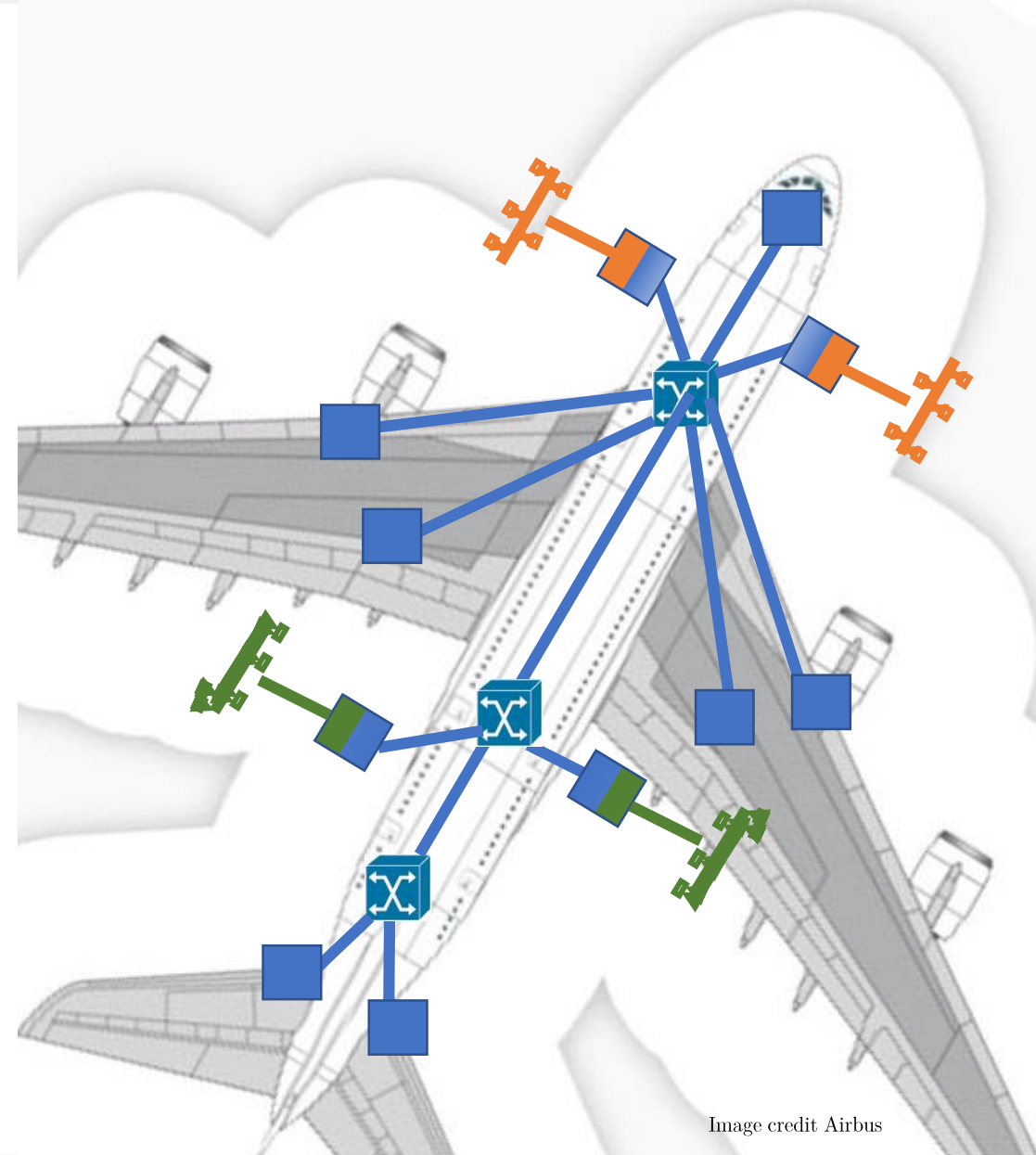


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- Integrate functions of parallel networks into AFDX network.
- **Increase load on AFDX network**
 - Avionic data (Safety critical)
 - Other critical data
 - Best-effort data ?

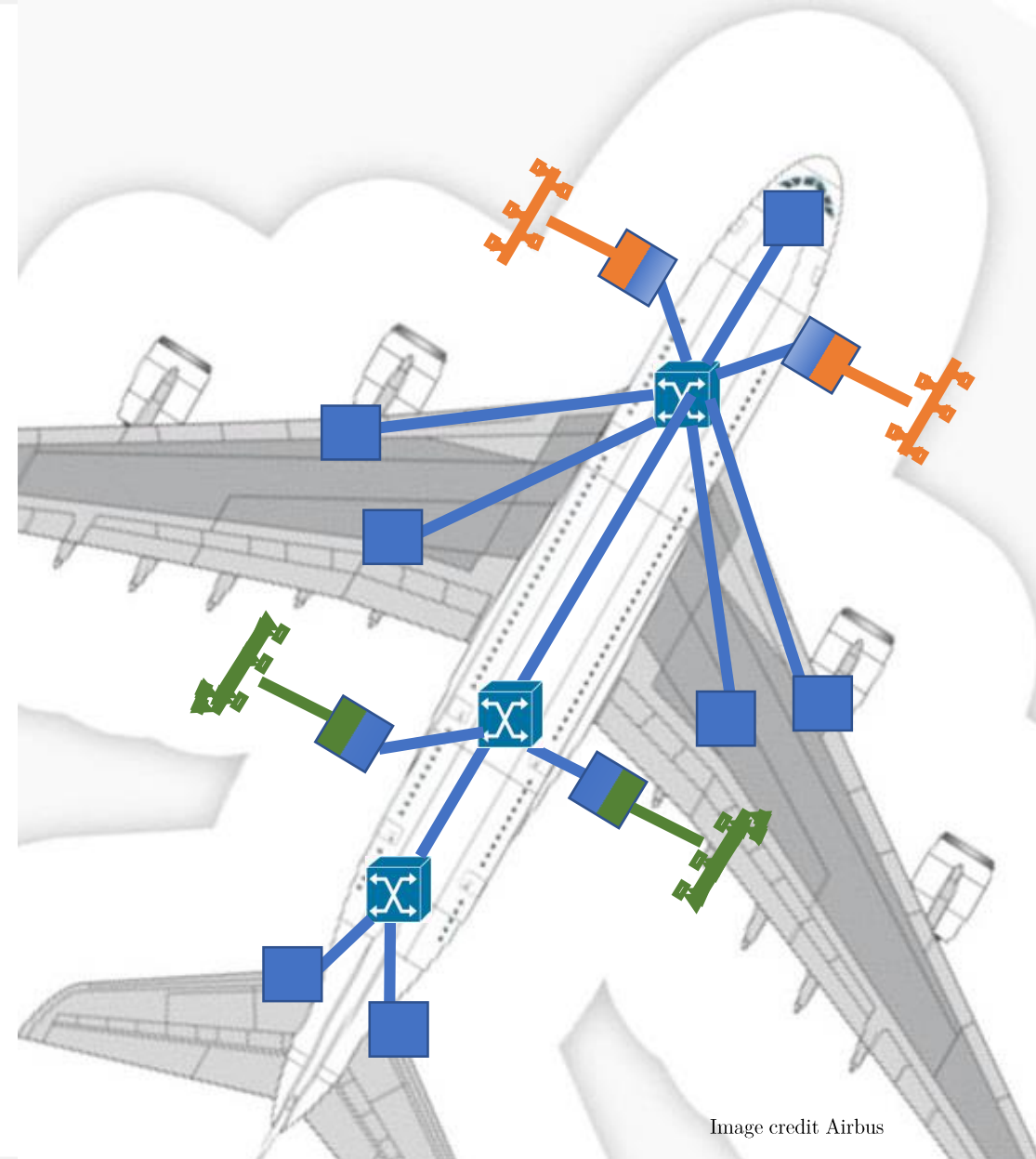
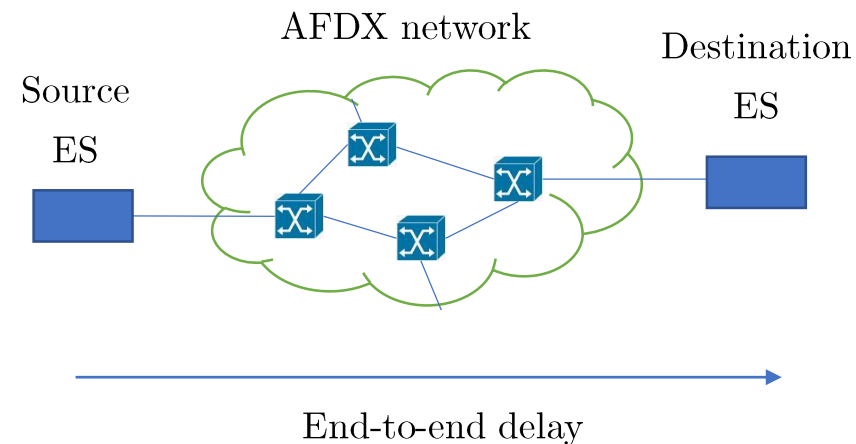
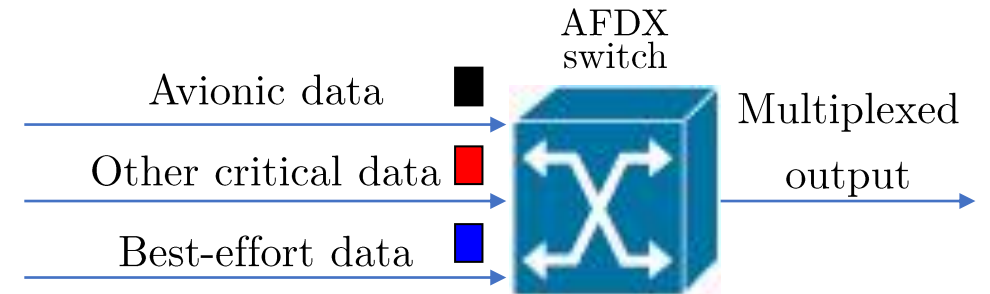


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Problem

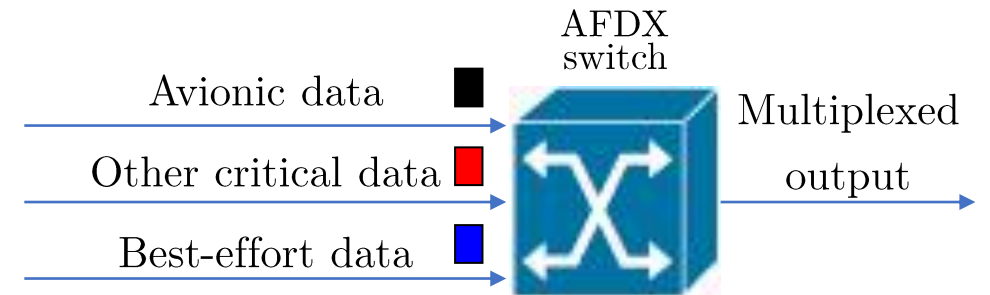
- Can a **reliable service** be provided to **additional data without degrading** the service of **avionic data** ?

- Can we **upper bound end-to-end delay** for **critical flows**?
- Highest priority to avionic data
- Different functions have different delay constraints



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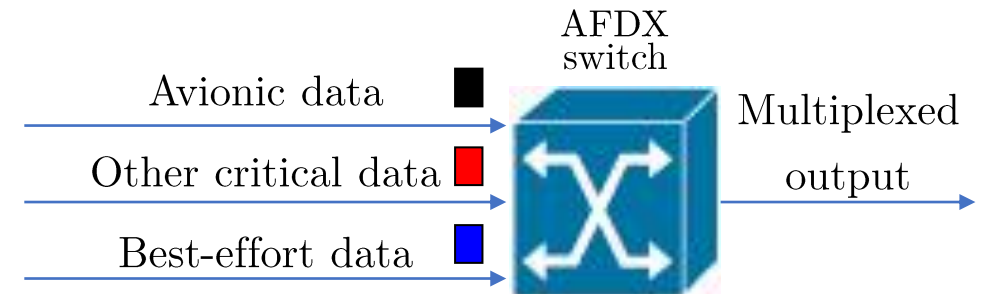
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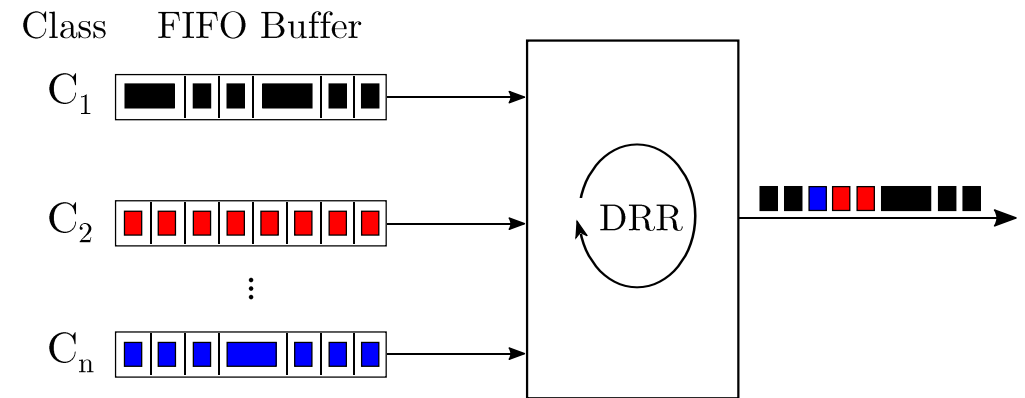
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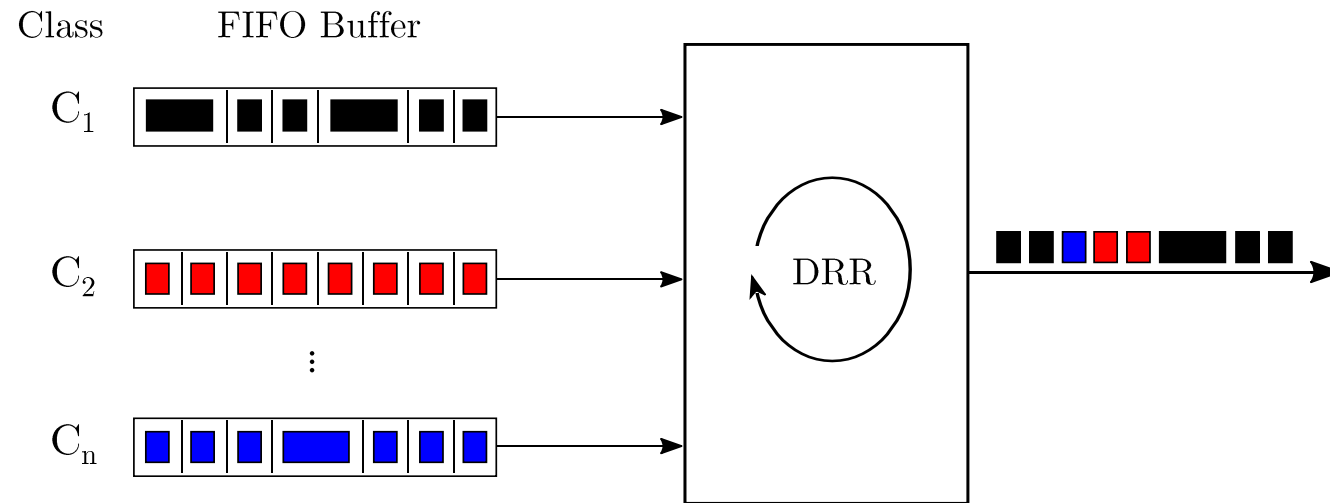
- **Deficit Round Robin (DRR) scheduling**

- Flow differentiation (C_1, C_2, \dots)
 - (n-1) critical classes, 1 non-critical class
 - Deadline $C_1 < \text{Deadline } C_2 < \dots$
- Service based on **credit per class**



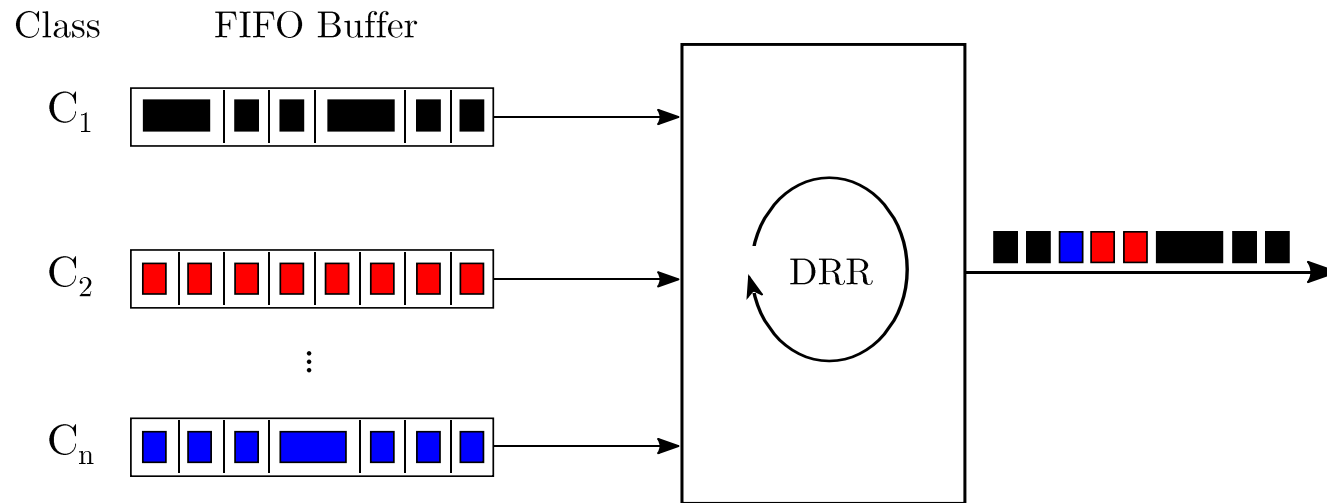
Objective

- **Assign credit** to each class, such that
 - **Delay deadlines are respected by all critical flows**
Delay $C_1 < \text{Deadline } C_1$, Delay $C_2 < \text{Deadline } C_2$, ... Delay $C_{n-1} < \text{Deadline } C_{n-1}$
 - **Maximum possible bandwidth is available to non-critical flows.**



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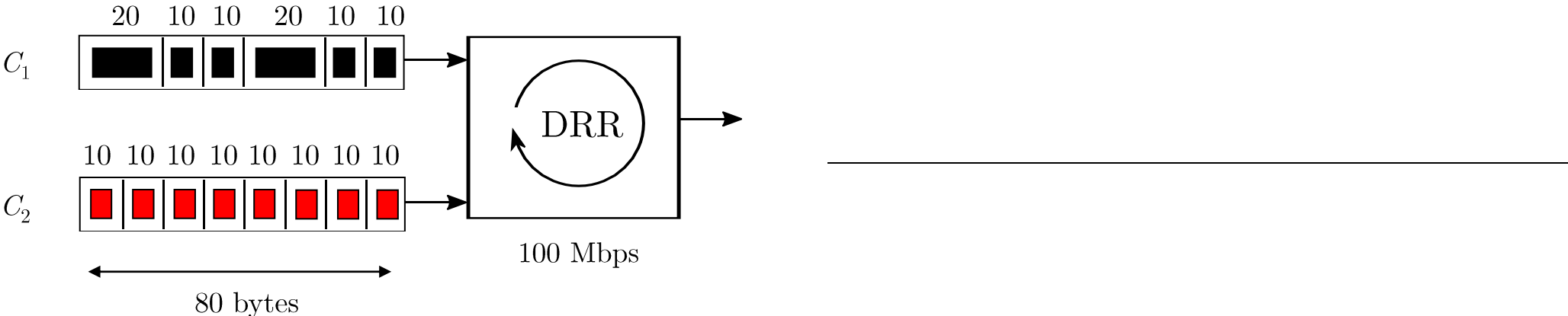


- Effect of credit (Quantum) on delays
- Delay computation method
 - Network Calculus

DRR Scheduling : General overview

Quantum $Q = 60$ bytes

$Q_1 : 30$ bytes, $Q_2 : 30$ bytes

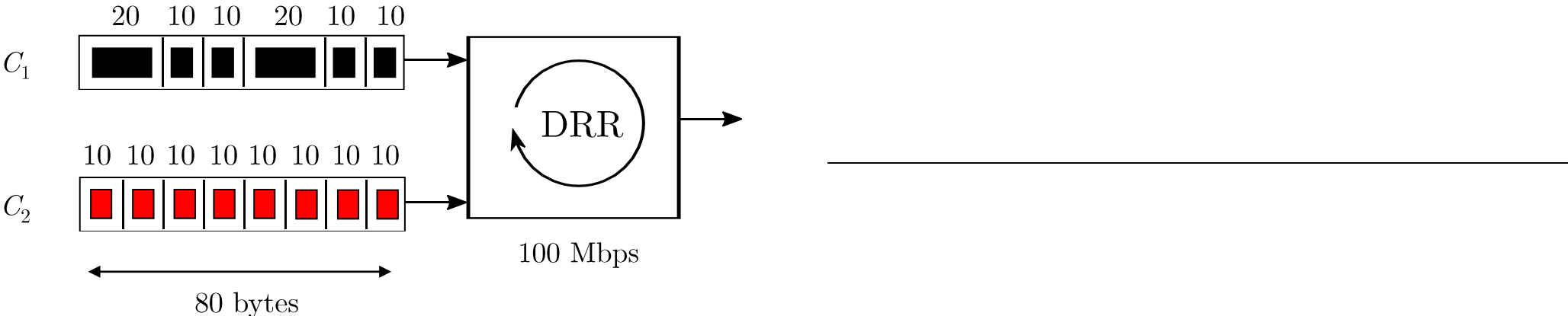


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Q_n
 C_1 30

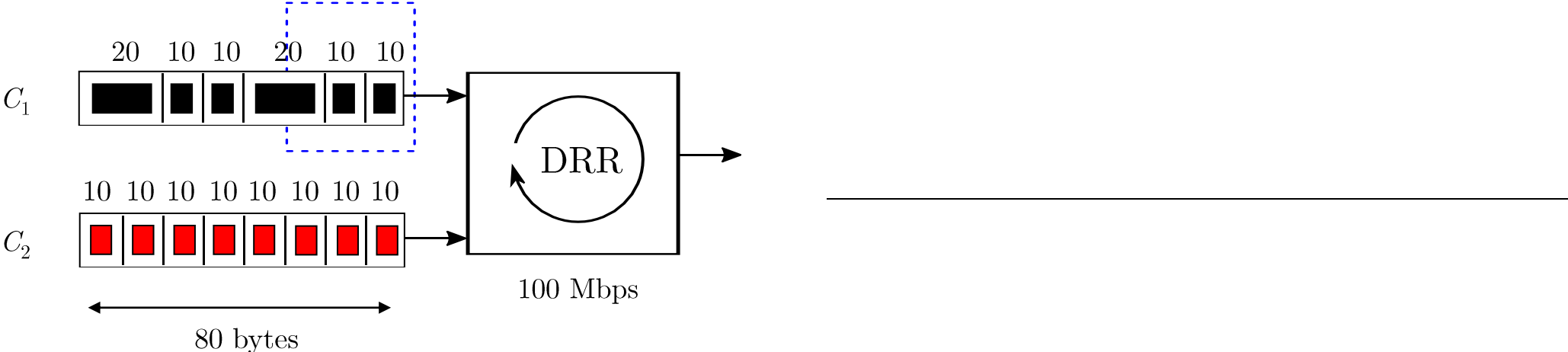


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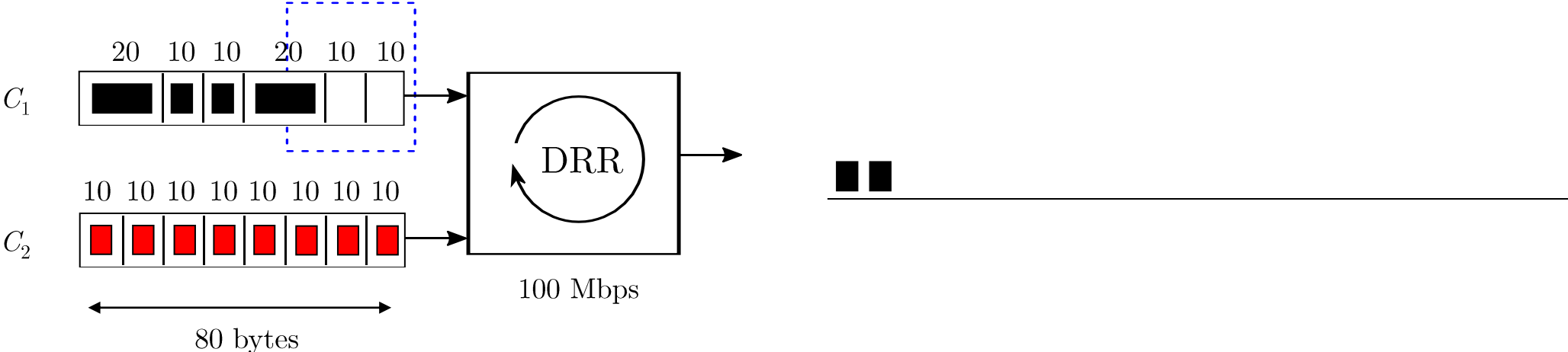


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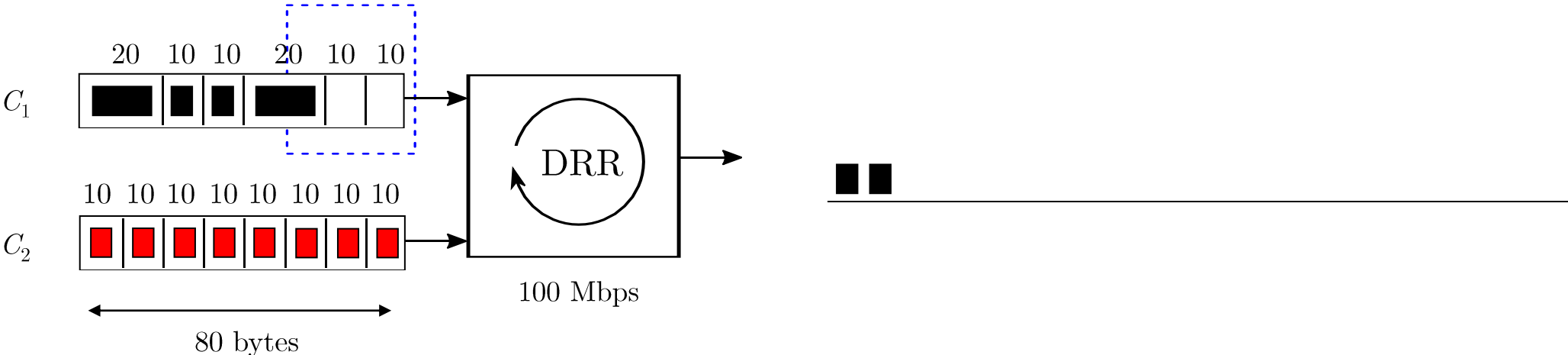


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C_1	30	10

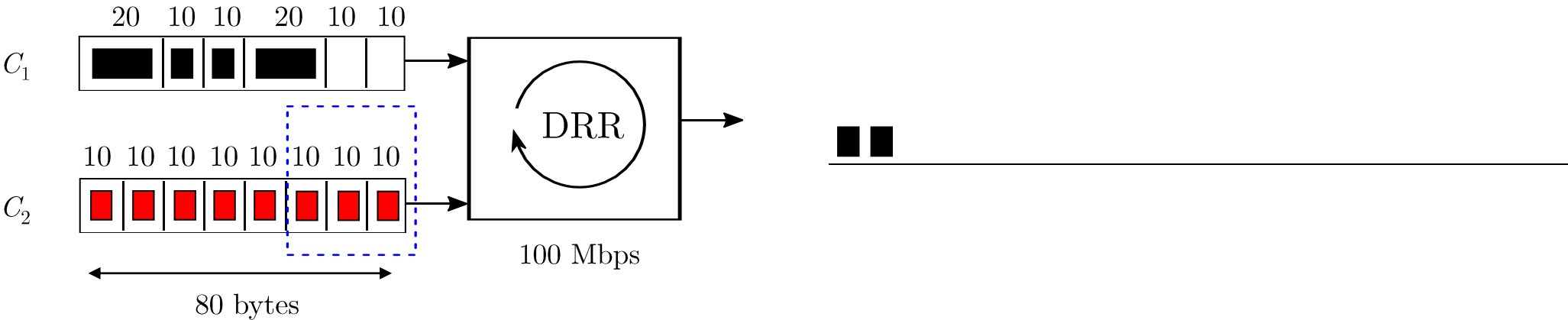


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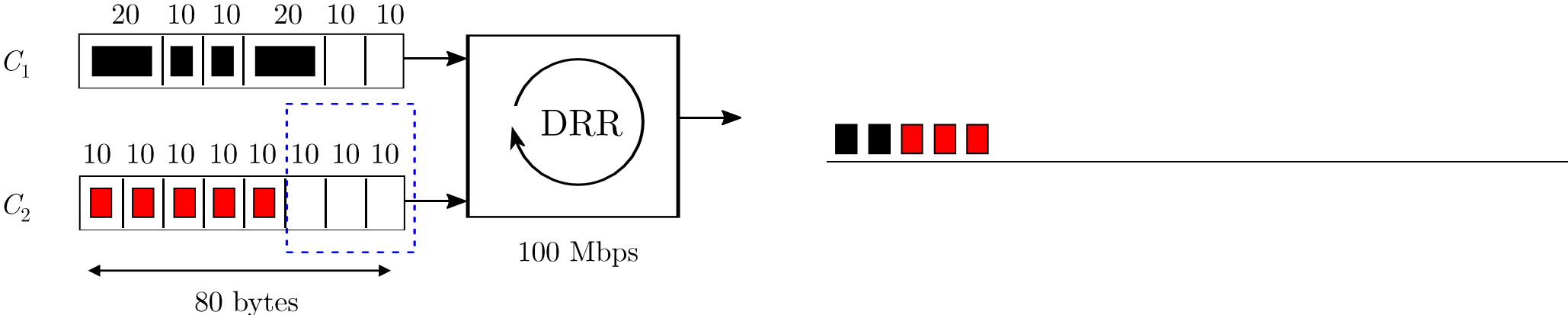


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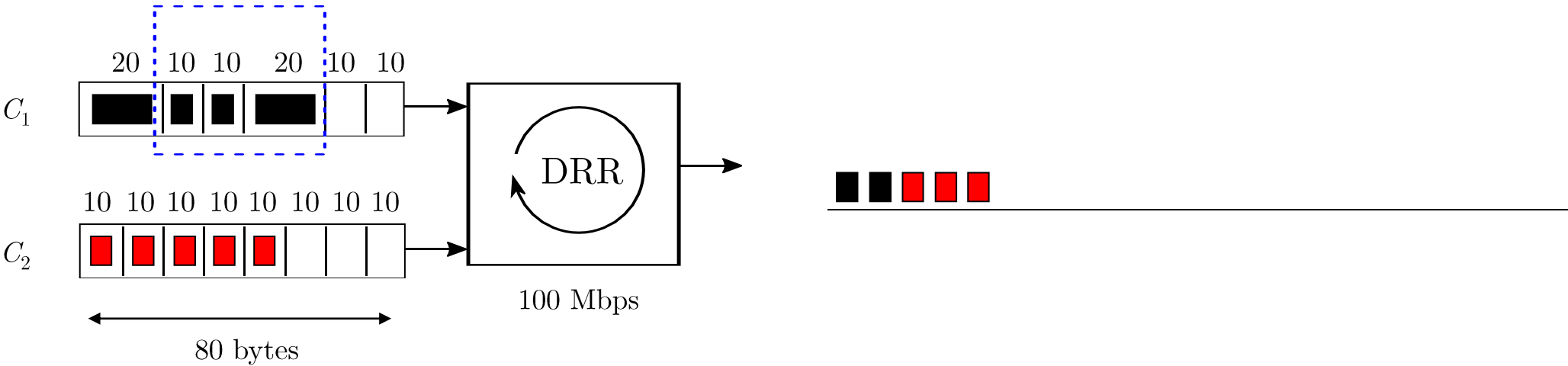


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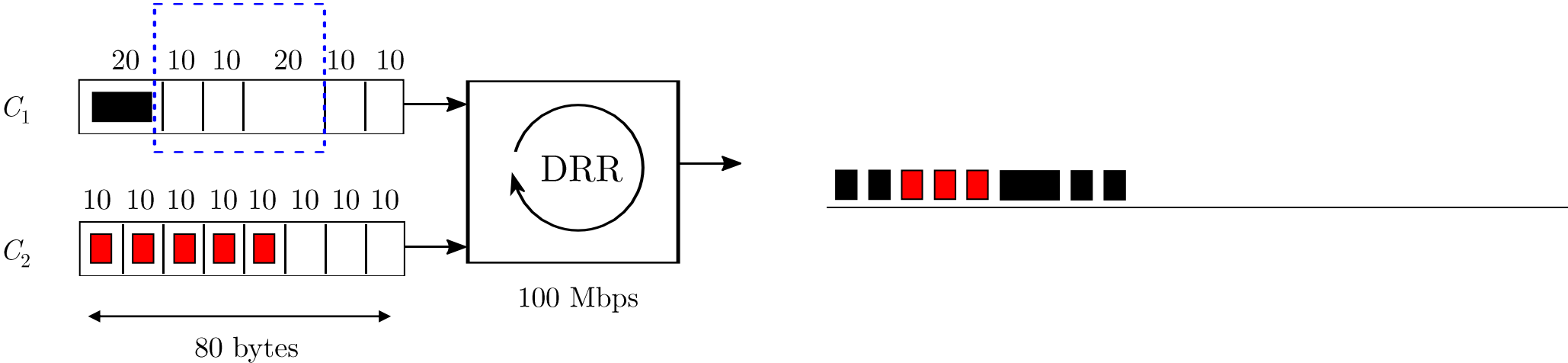


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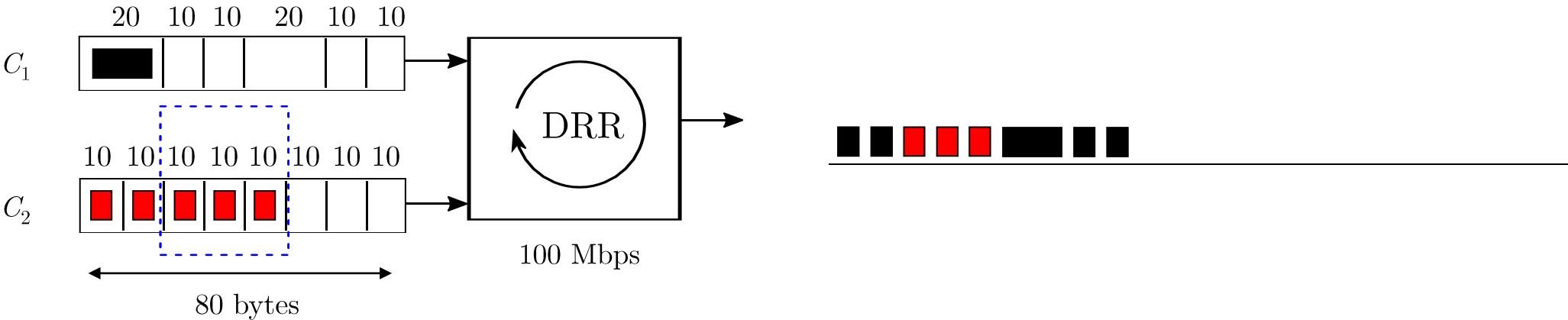


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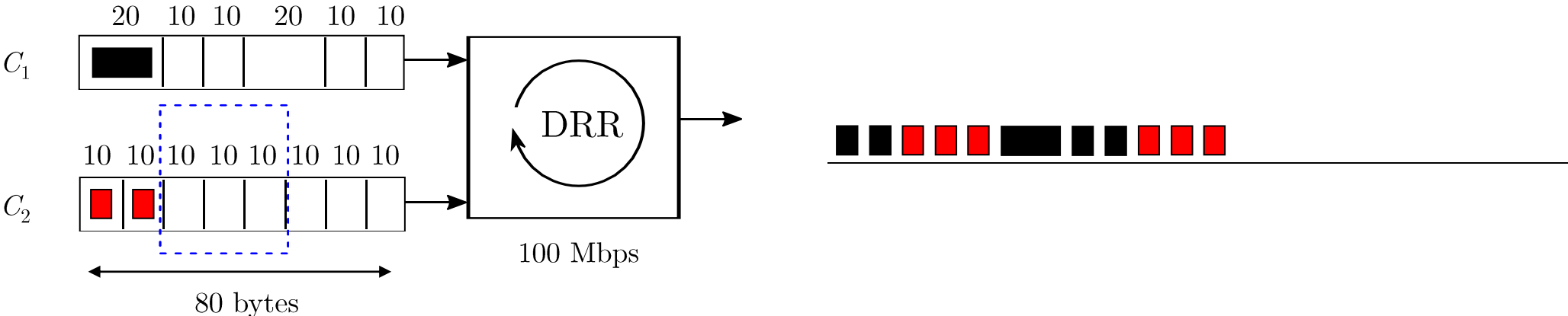


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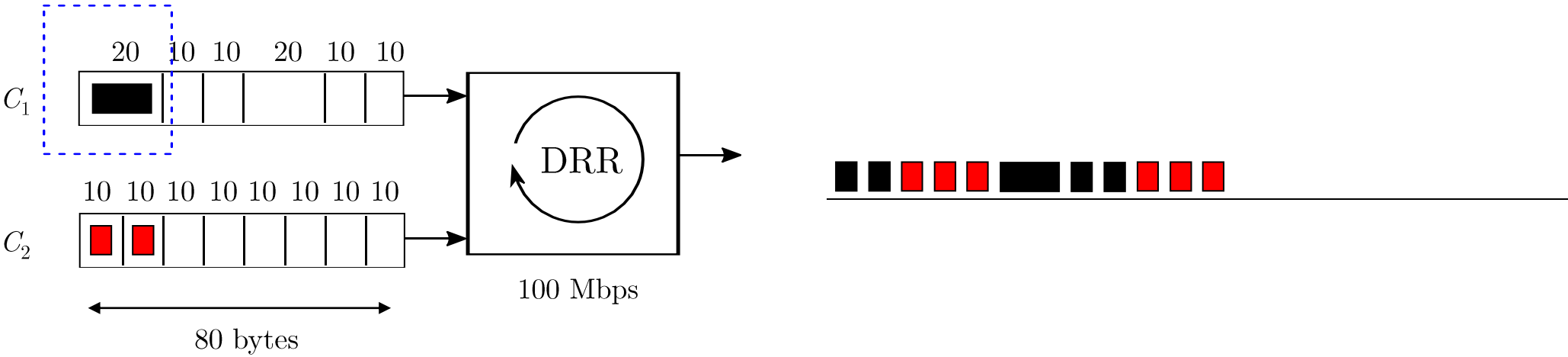


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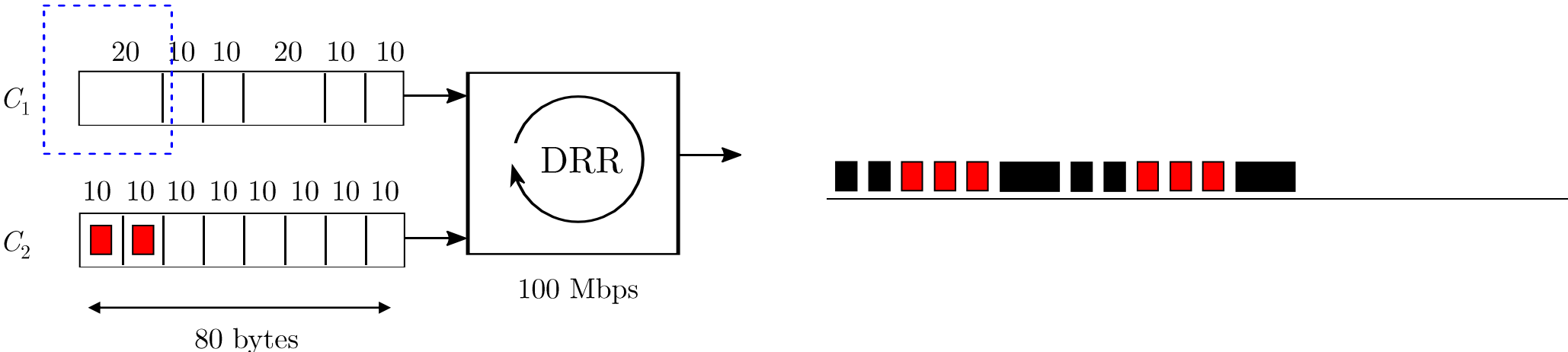


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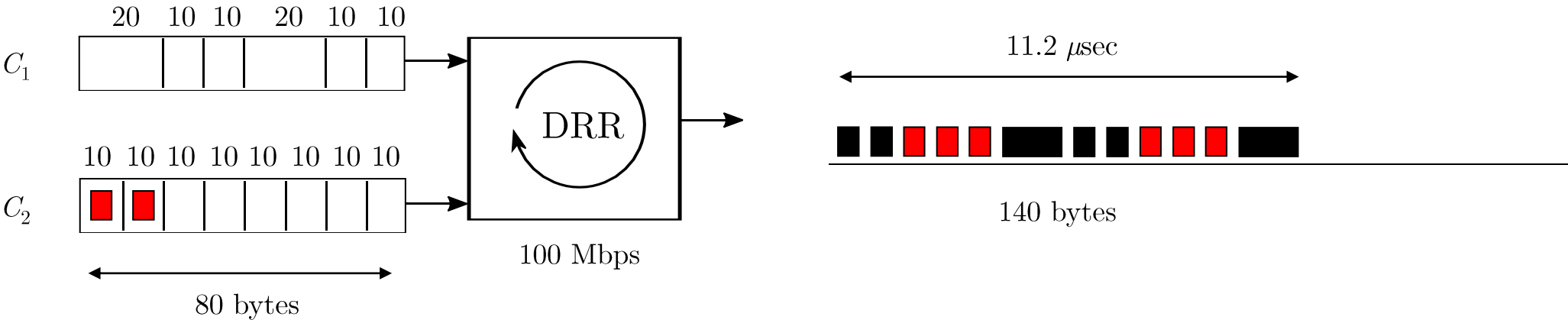


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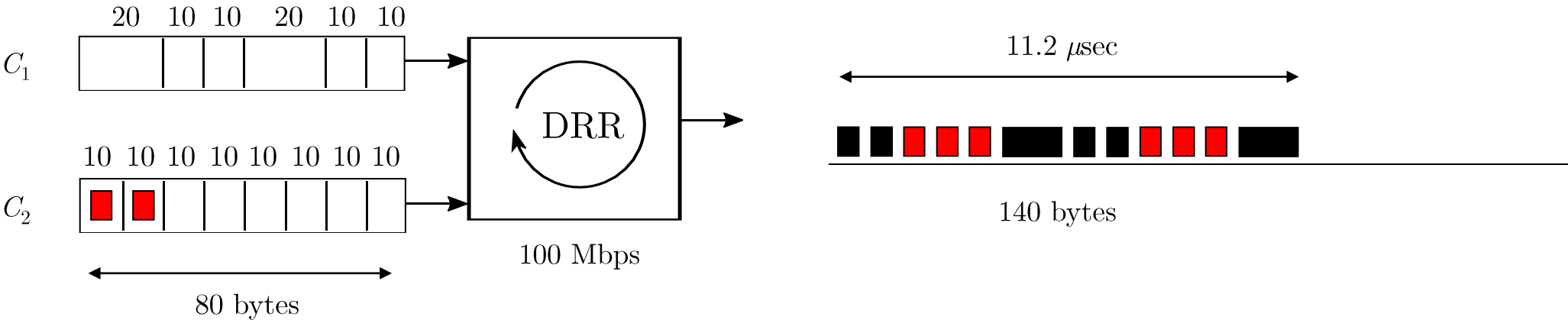


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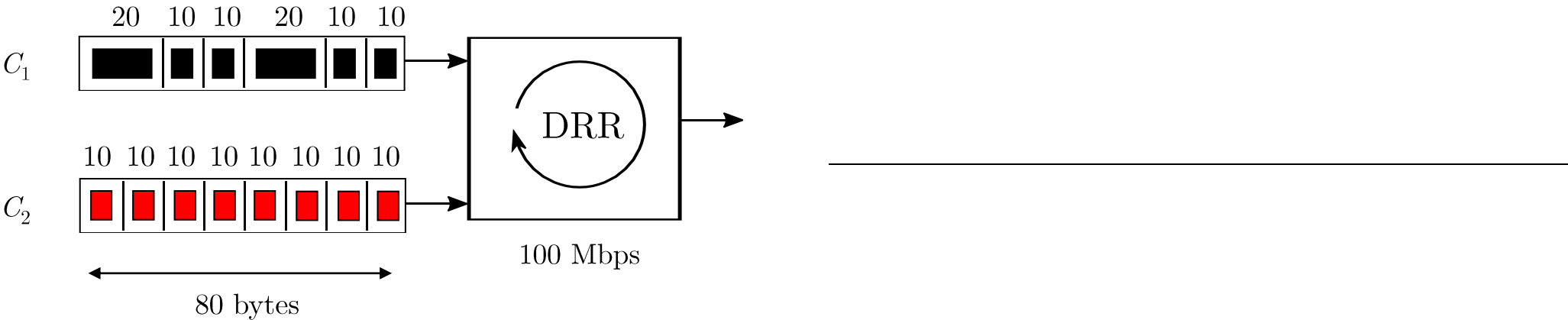
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C_1	30	0	C_1	$11.2 \mu\text{sec}$
C_2	30	0		



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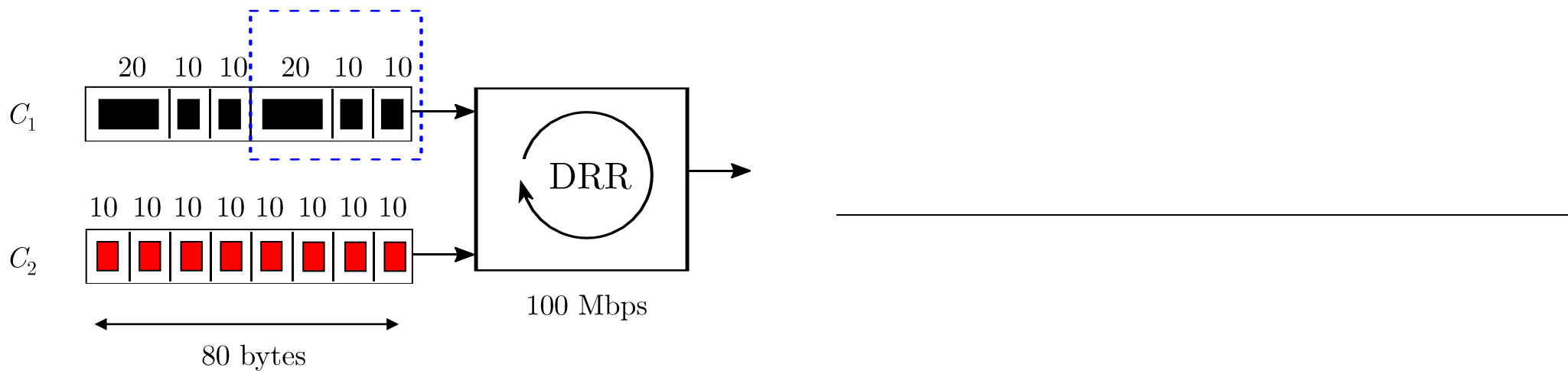
	Q_n	Deficit
Quantum $Q = 70$ bytes	C_1	40
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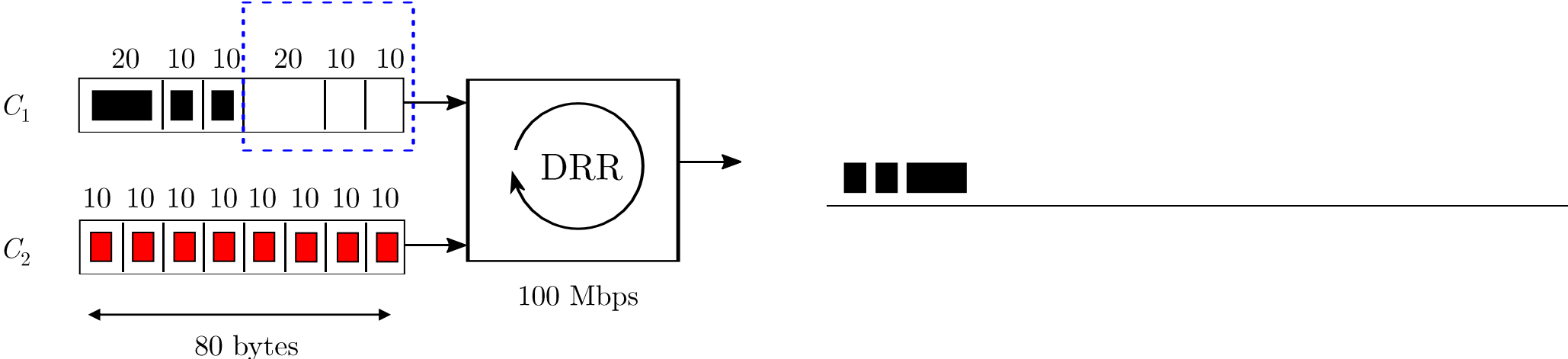
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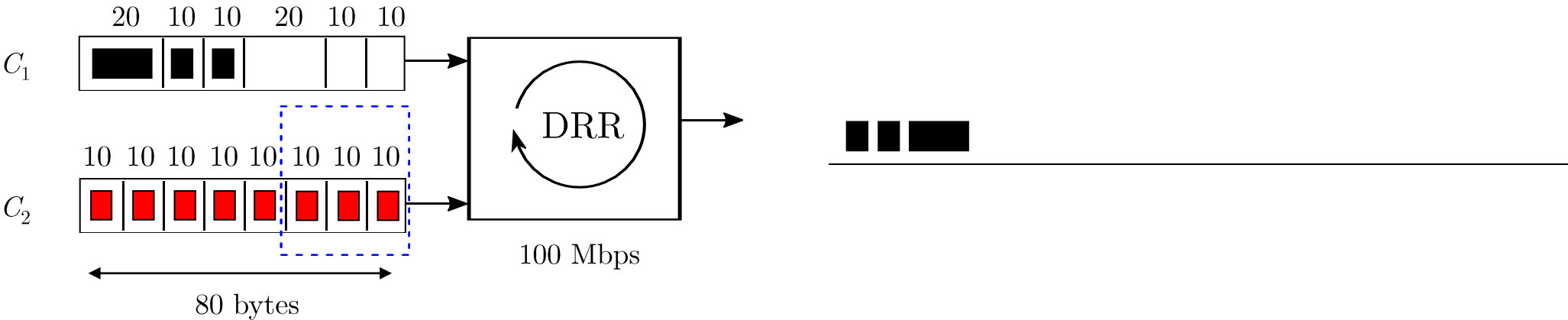
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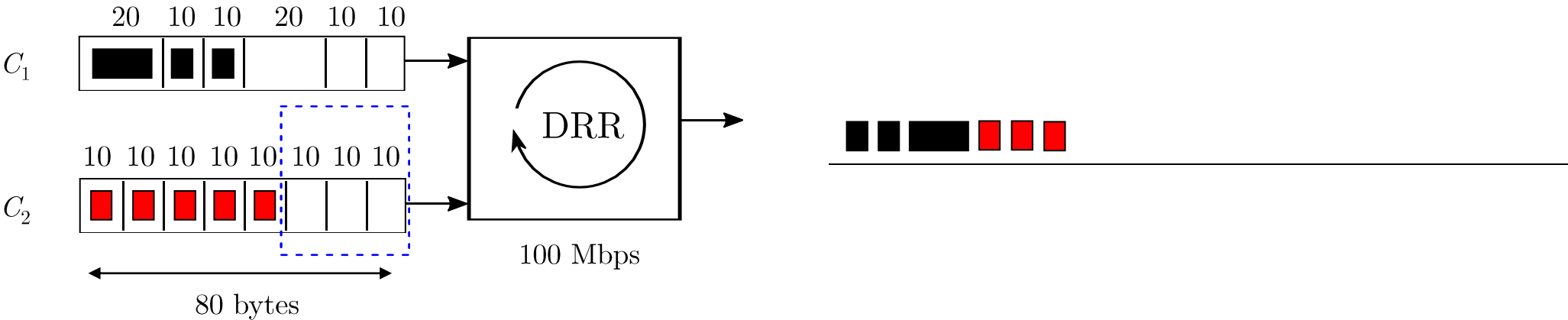
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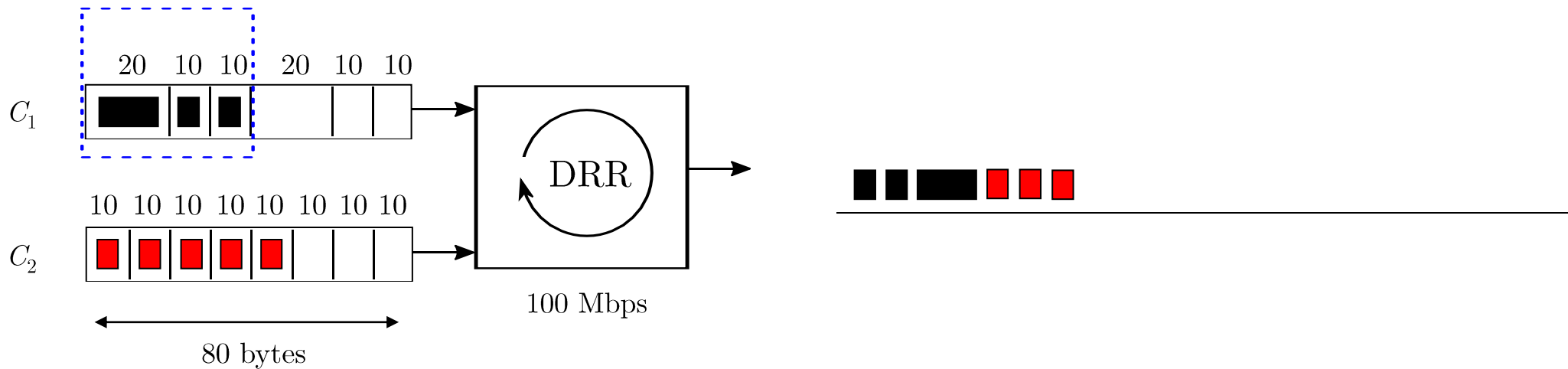
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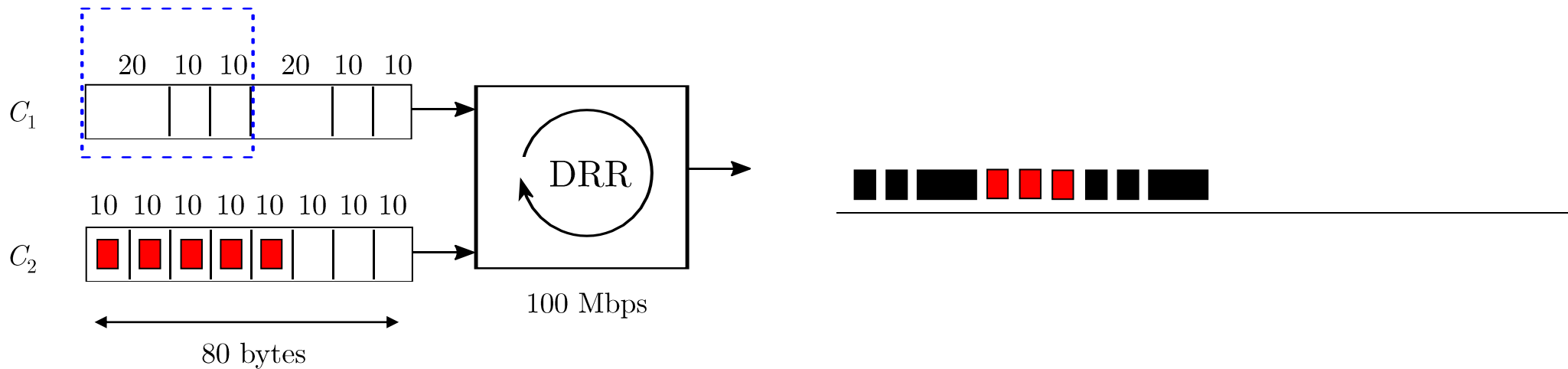
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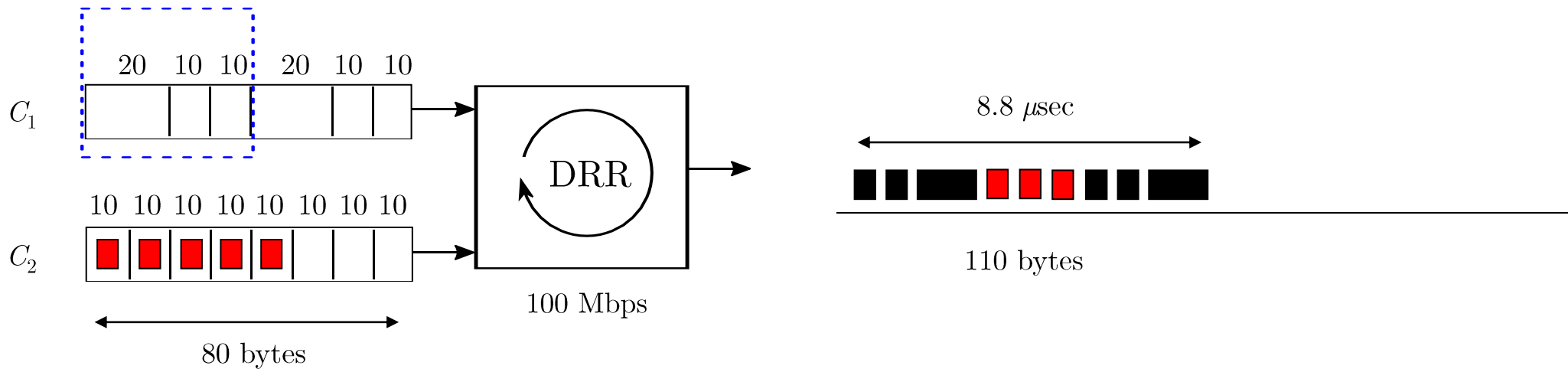
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Network Calculus

- Computes the **upper bound** on
 - **Worst-case end-to-end delay**
 - **Jitter**
- **Pessimistic** : model based on over-approximated envelopes.

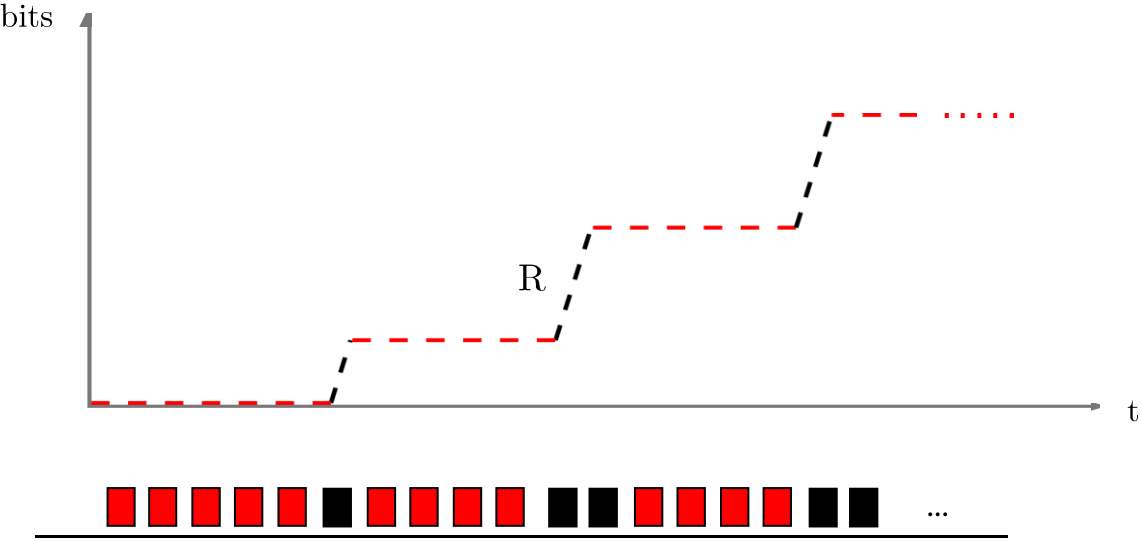
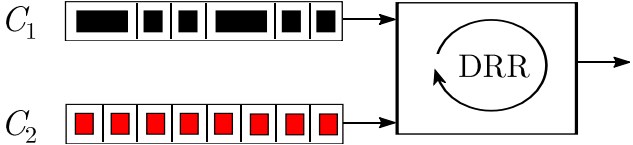
AFDX model in Network Calculus

AFDX

- Switch output port
 - DRR scheduling
 - Maximum service rate R

Network Calculus

- Service curve β
 - DRR scheduler latency Θ
 - Service rate ρ



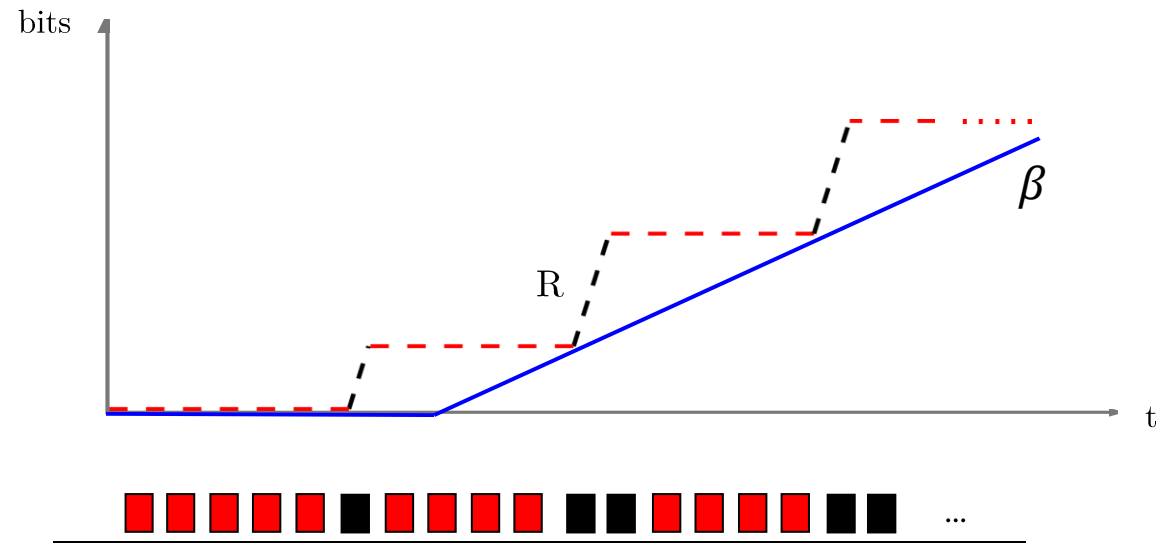
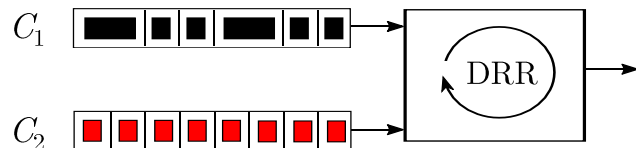
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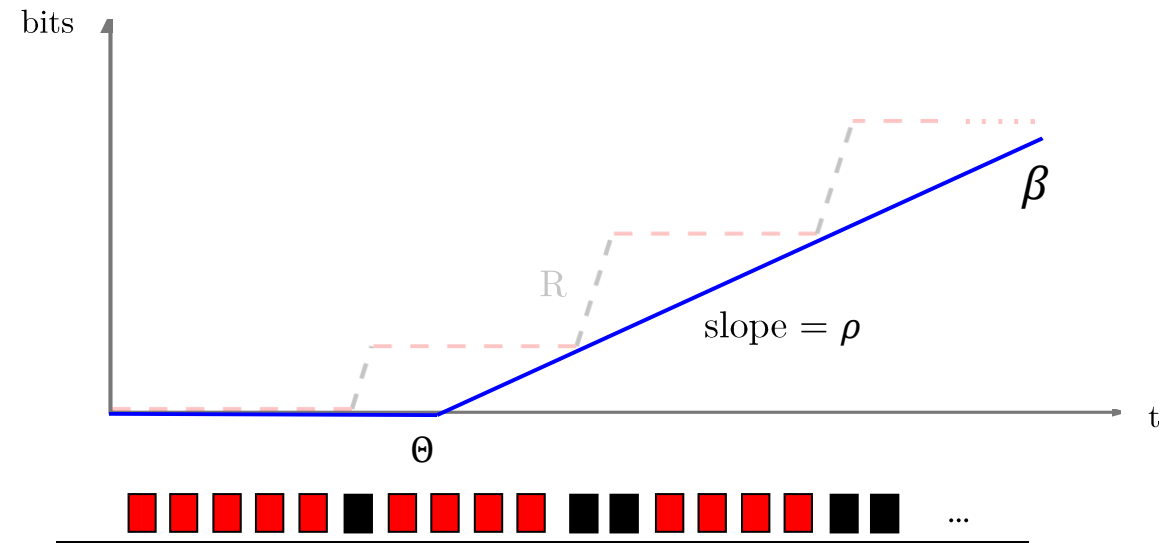
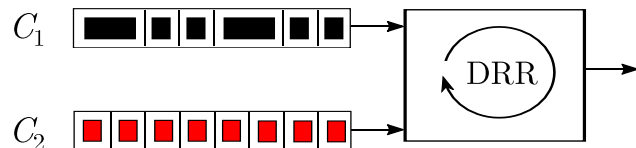
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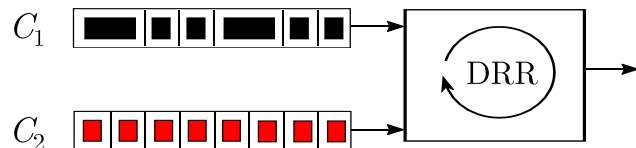
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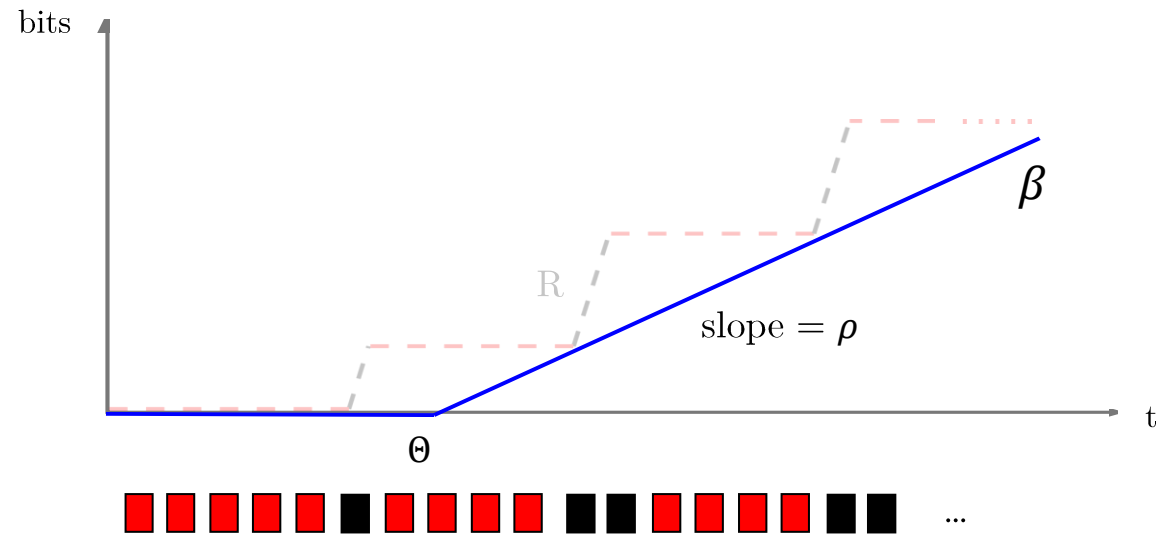
AFDX

- Switch output port
 - DRR scheduling
 - Maximum service rate R
- Flow
 - Frame length (Min – Max)
 - Inter-frame duration (BAG)



Network Calculus

- Service curve β
 - DRR scheduler latency Θ
 - Service rate ρ
- Arrival Curve α
 - Burst (Max)
 - Arrival rate $\frac{Max}{BAG}$



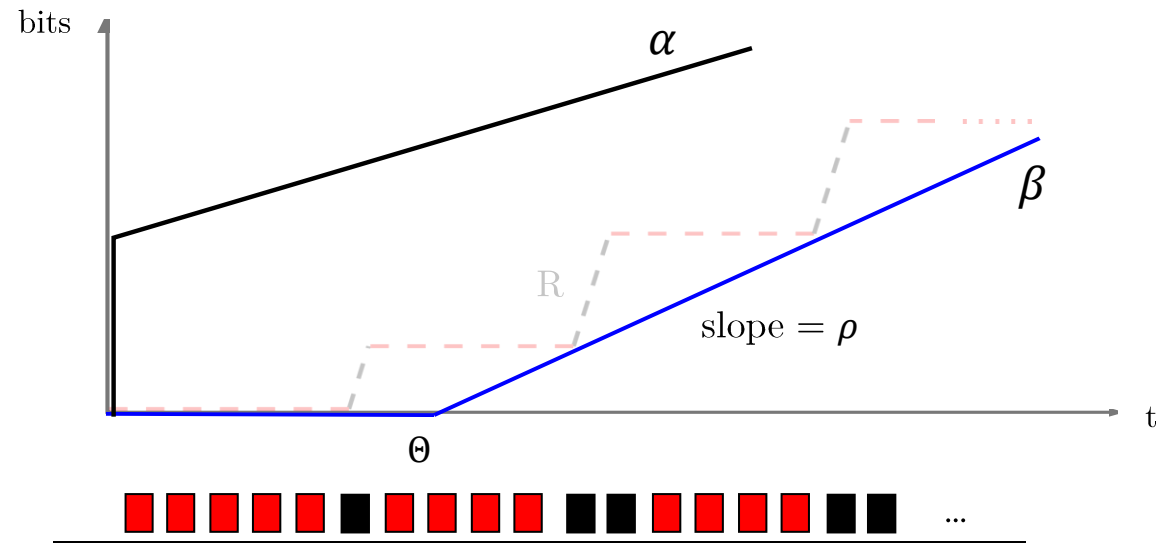
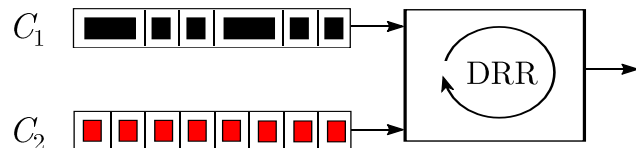
AFDX model in Network Calculus

AFDX

- Switch output port
 - DRR scheduling
 - Maximum service rate R
- Flow
 - Frame length (Min – Max)
 - Inter-frame duration (BAG)

Network Calculus

- Service curve β
 - DRR scheduler latency Θ
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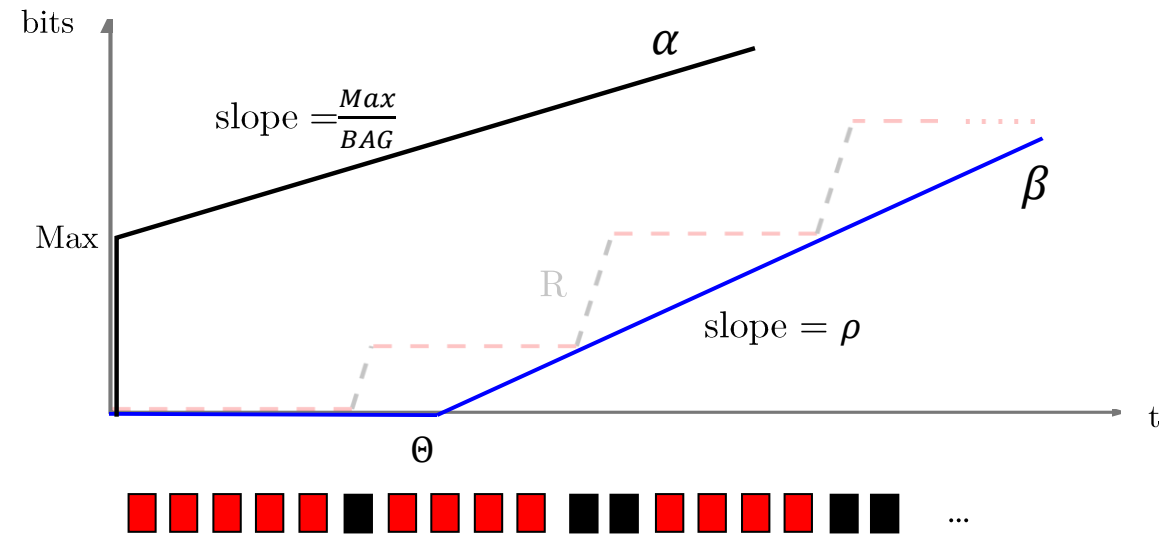
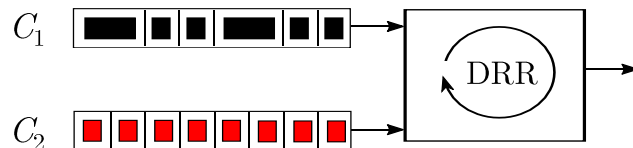
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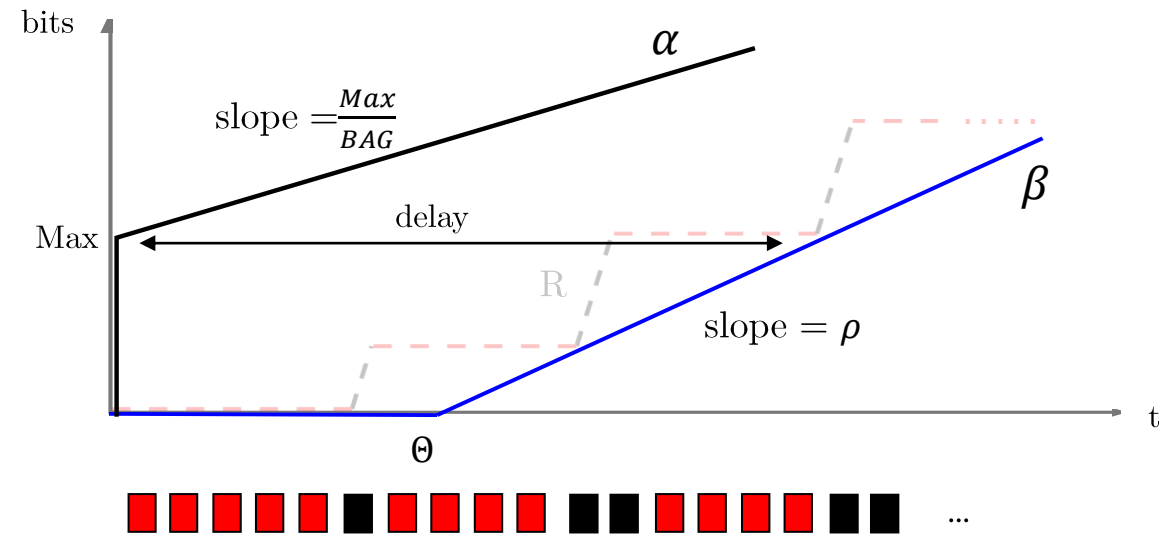
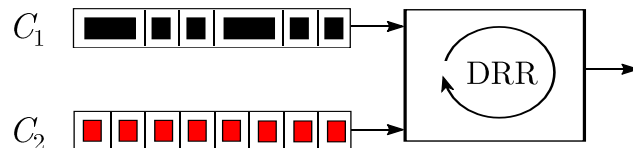
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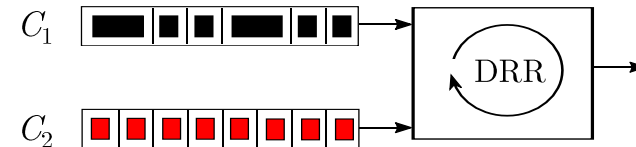
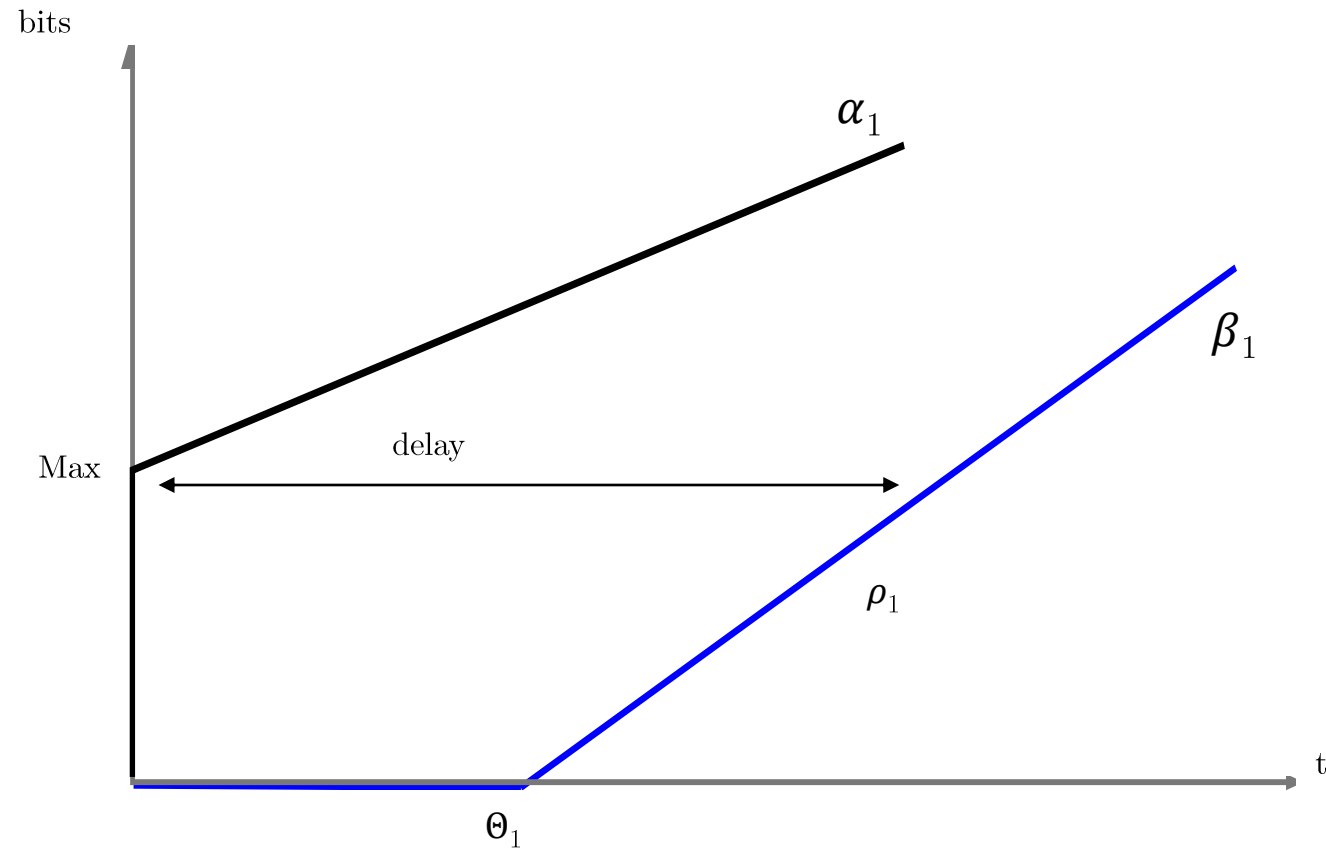
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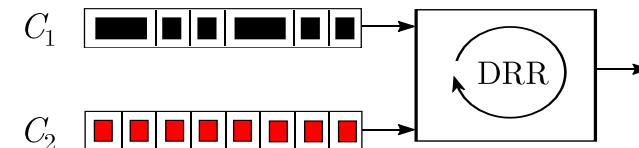
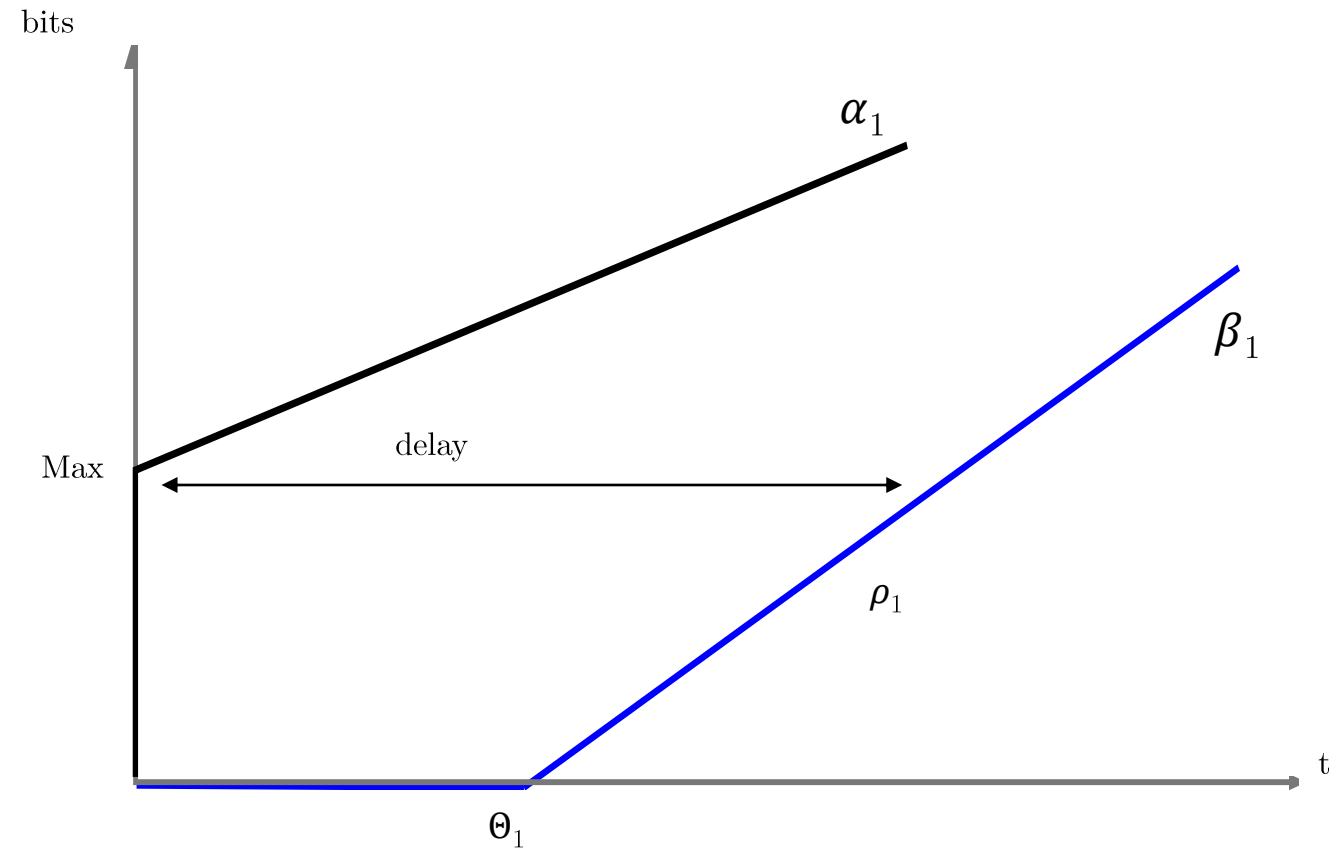
AFDX model in Network Calculus : Effect of Quantum value on delay

- Total quantum Q
 - Distribution Q_1, Q_2
 - $Q_1 + Q_2 = Q$



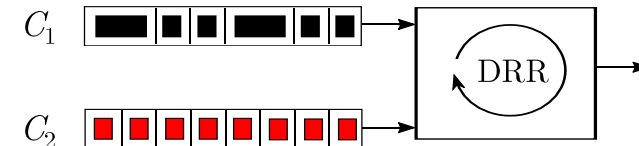
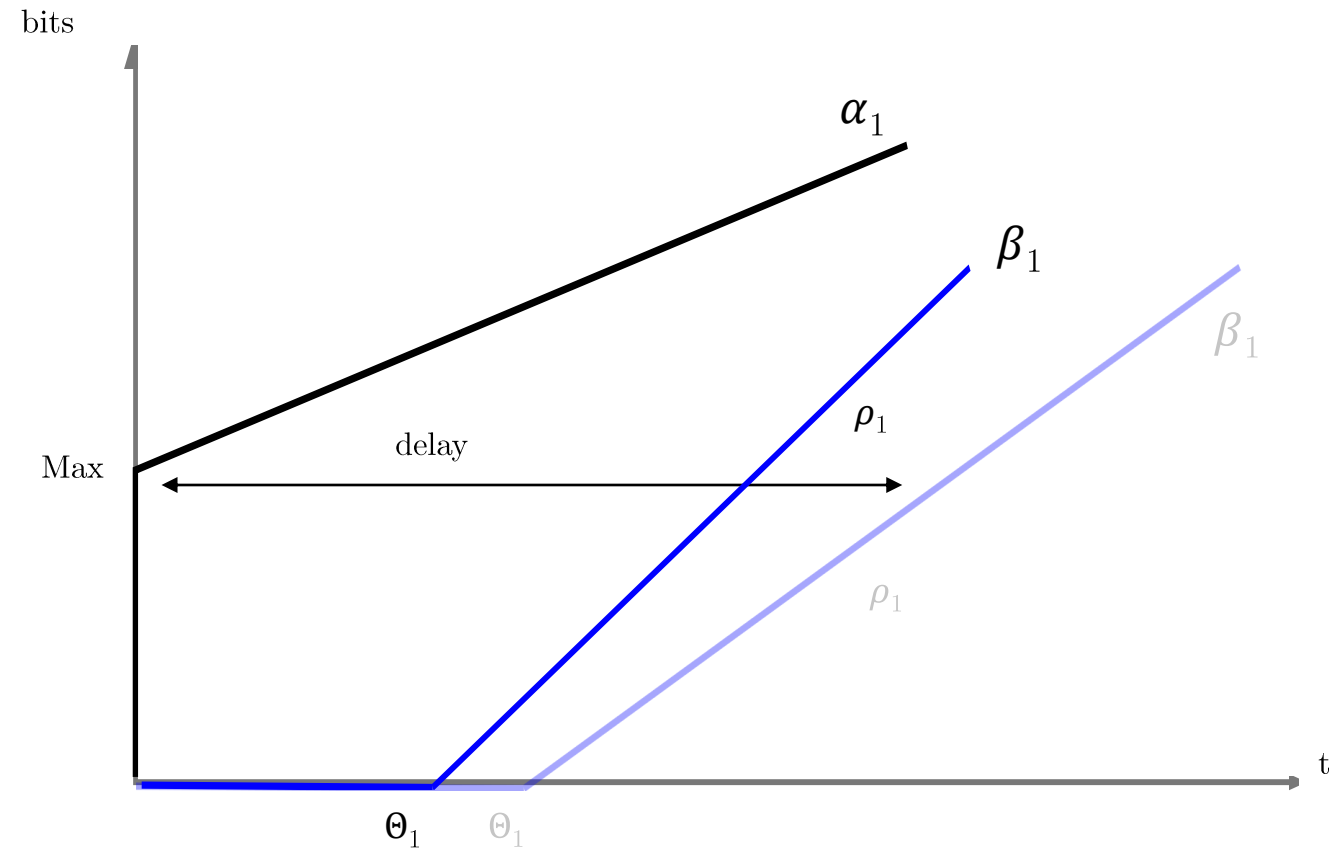
AFDX model in Network Calculus : Effect of Quantum value on delay

- Total quantum Q
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- Variation in Q_1
(Q_1 Increase) (Q constant)
 - Scheduler latency $\Theta_1 \downarrow$
 - Service Rate $\rho_1 \uparrow$
 - β_1 moves left
 - Delay in $C_1 \downarrow$



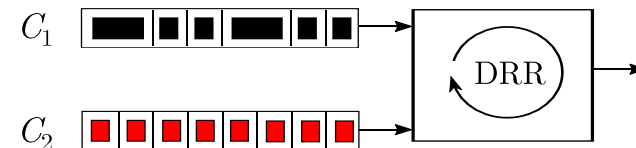
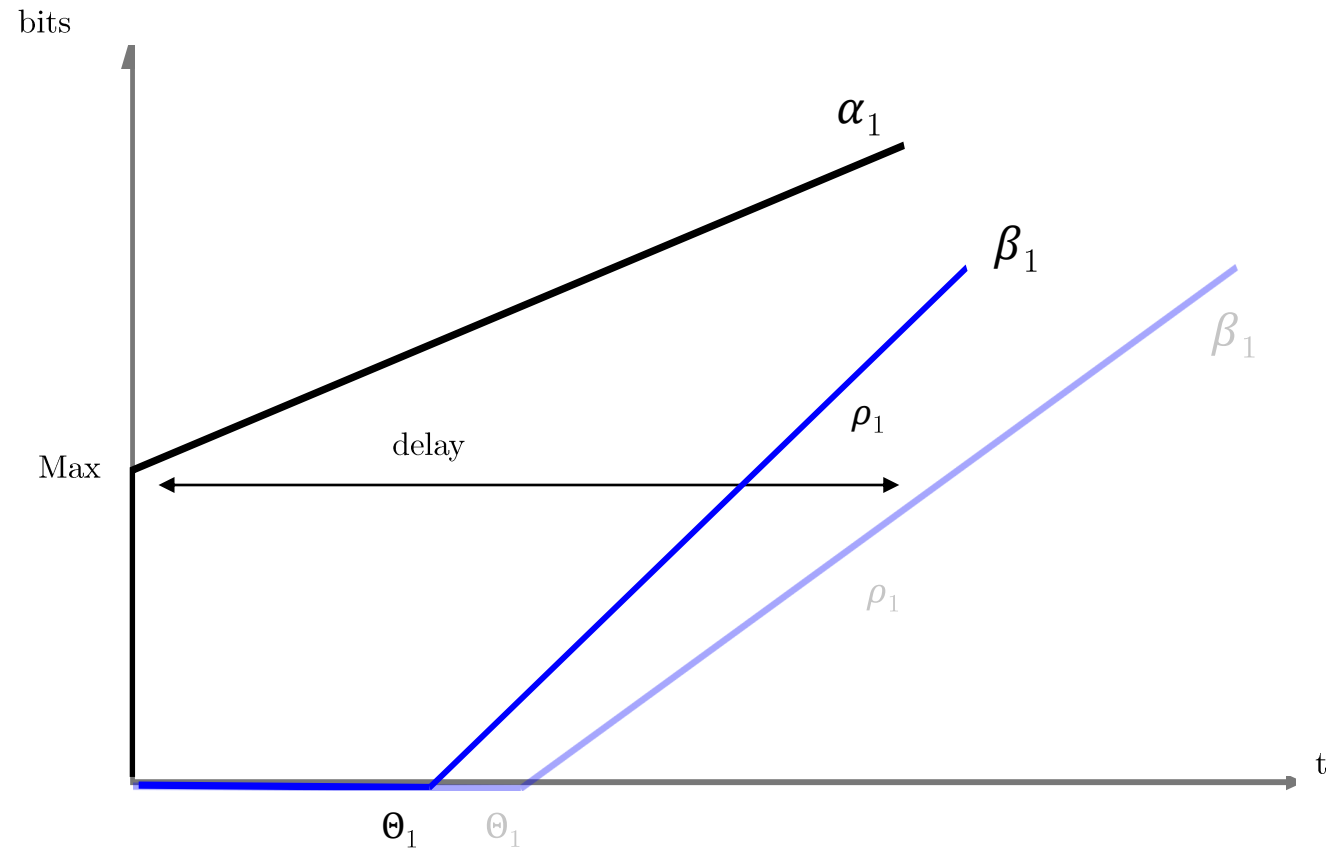
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 - β_1 moves left
 - Delay in $C_1 \downarrow$
- Variation in total Q
 (Q Decrease) ($Q_1:Q_2$ constant)
 - Scheduler latency $\Theta \downarrow$
 - Overall delay is less.



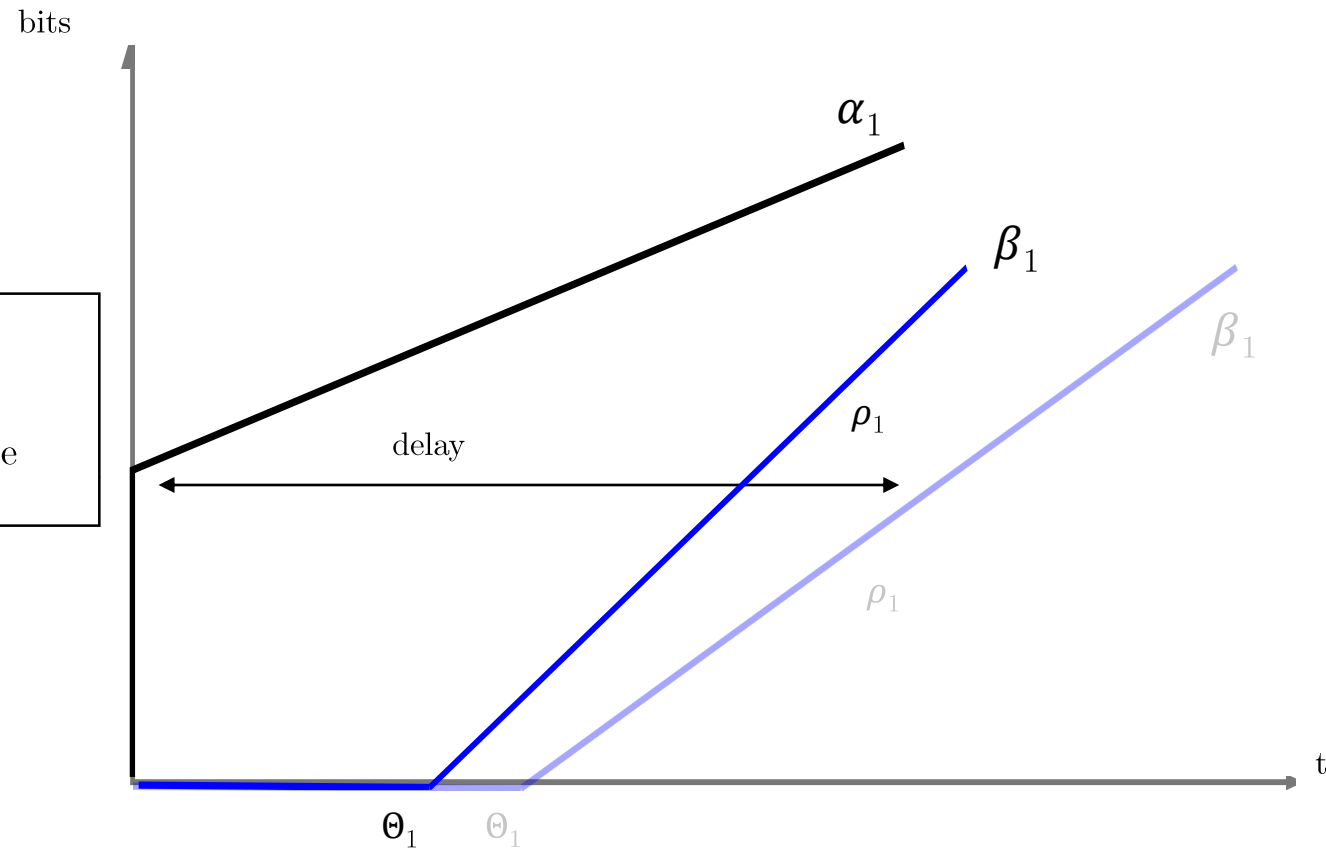
AFDX model in Network Calculus : Effect of Quantum value on delay

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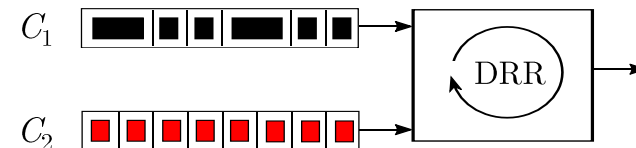
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Smallest Q_1

- Delay $C_1 <$ Deadline



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AFDX model in Network Calculus : Effect of Quantum value on delay

- Total quantum Q
 - Distribution Q_1, Q_2
 - $Q_1 + Q_2 = Q$
- Variation in Q_1

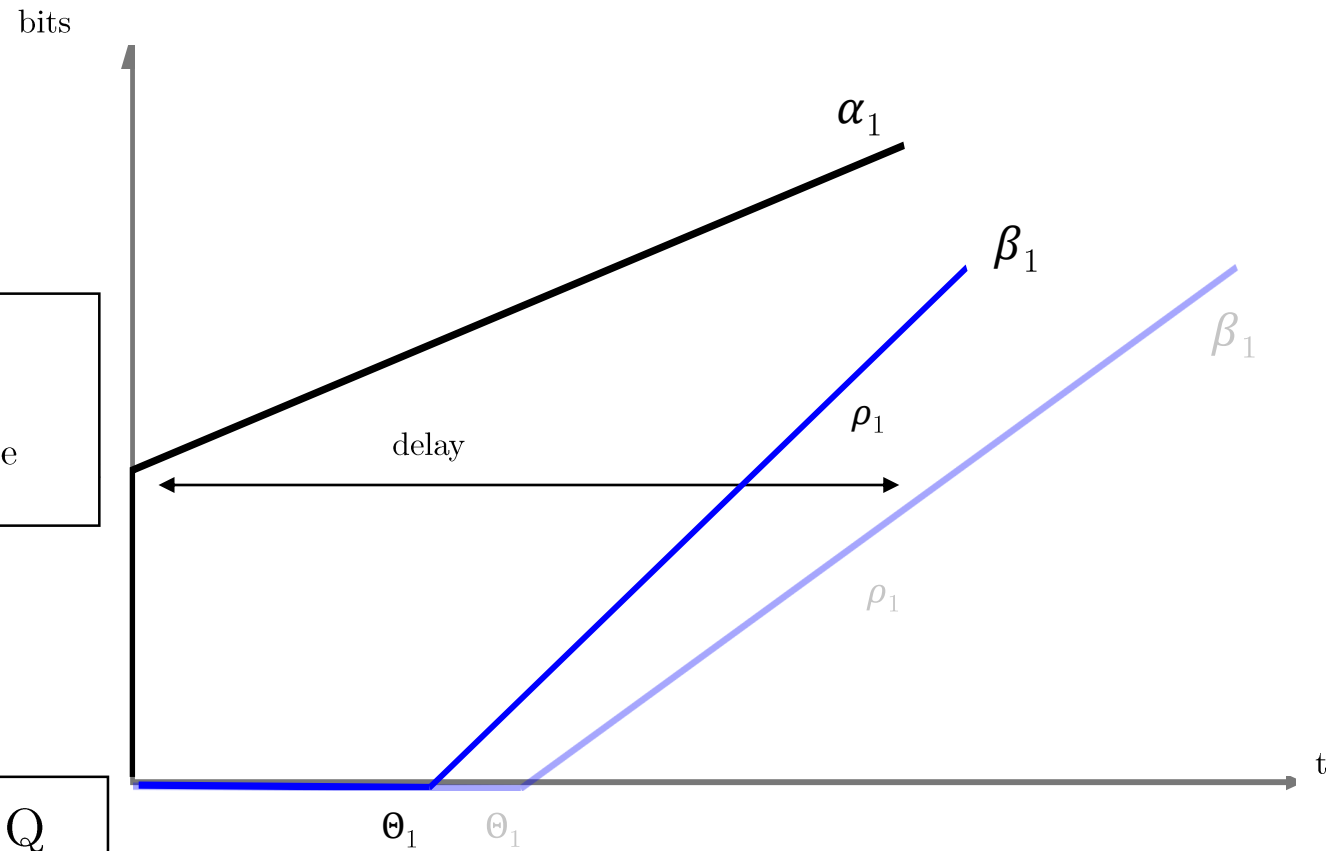
(Q_1 Increase) (Q constant)

 - Scheduler latency $\Theta_1 \downarrow$
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Smallest Q_1

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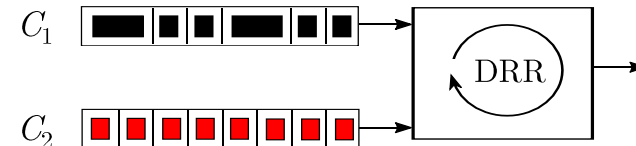
Minimum Q



- Variation in total Q

(Q Decrease) ($Q_1:Q_2$ constant)

 - Scheduler latency $\Theta \downarrow$
 - Overall delay is less.



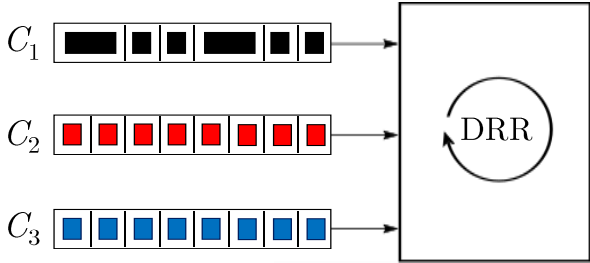
Credit Assignment

Initialize

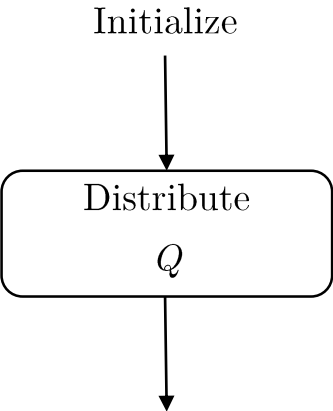


Input:

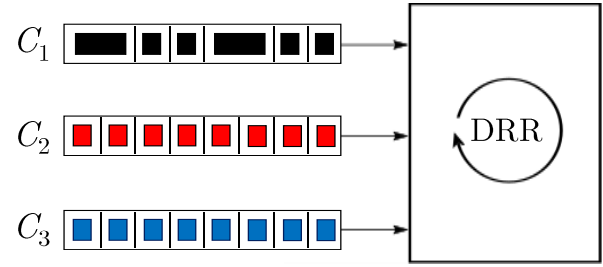
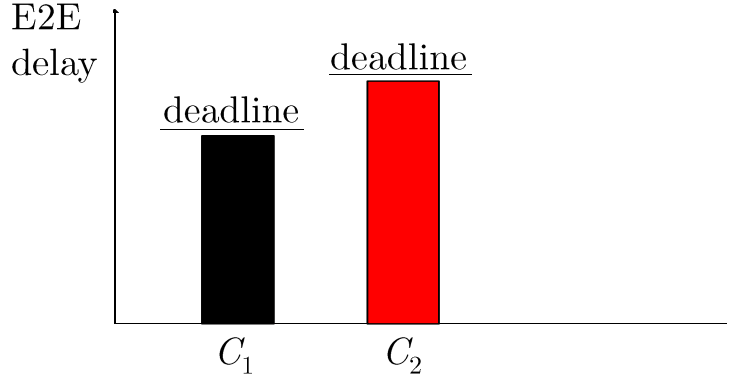
- Sum $Q = 3000$
- Critical class deadline C_1, C_2



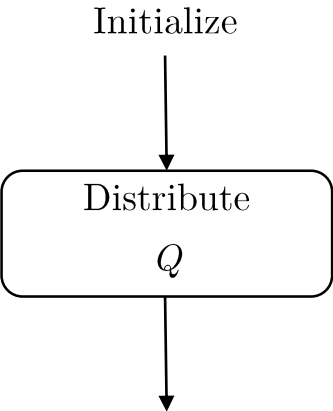
Credit Assignment



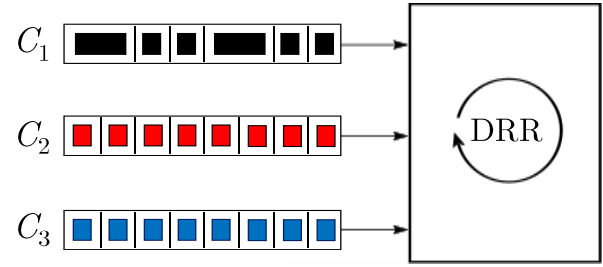
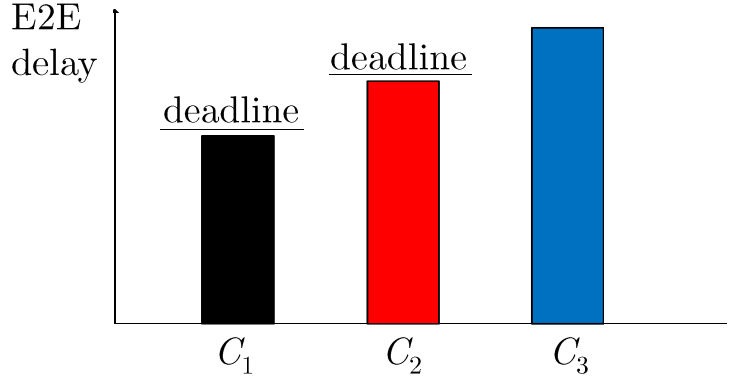
- Input:
- Sum $Q = 3000$
 - Critical class deadline C_1, C_2, \dots, C_{n-1}
 - Delay computation by NC
 - Delay $C_x < \text{deadline}$
 - $Q_1 = 1200, Q_2 = 800$



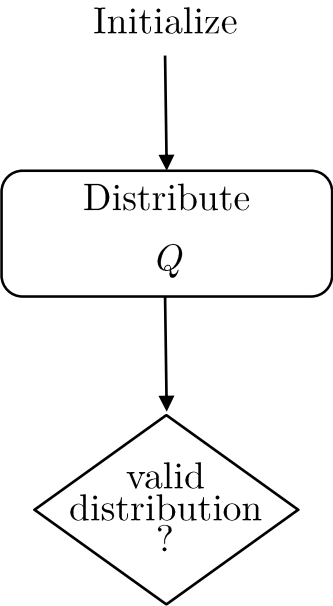
Credit Assignment



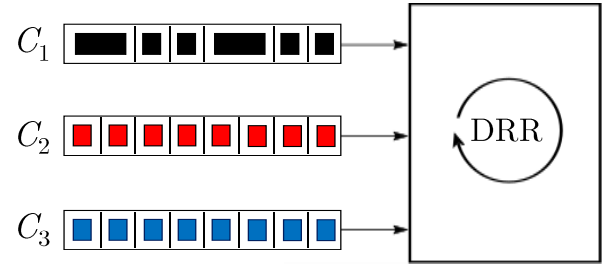
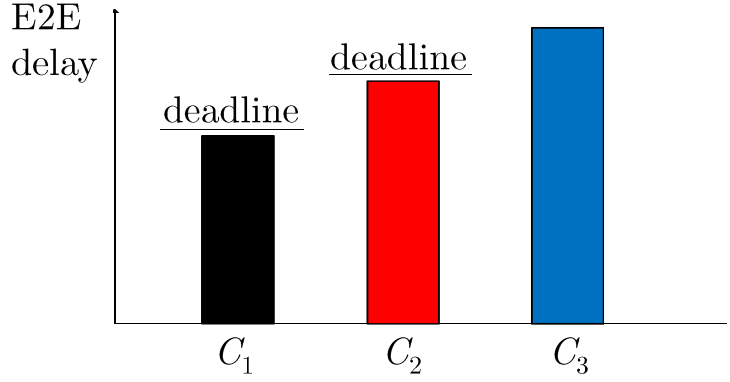
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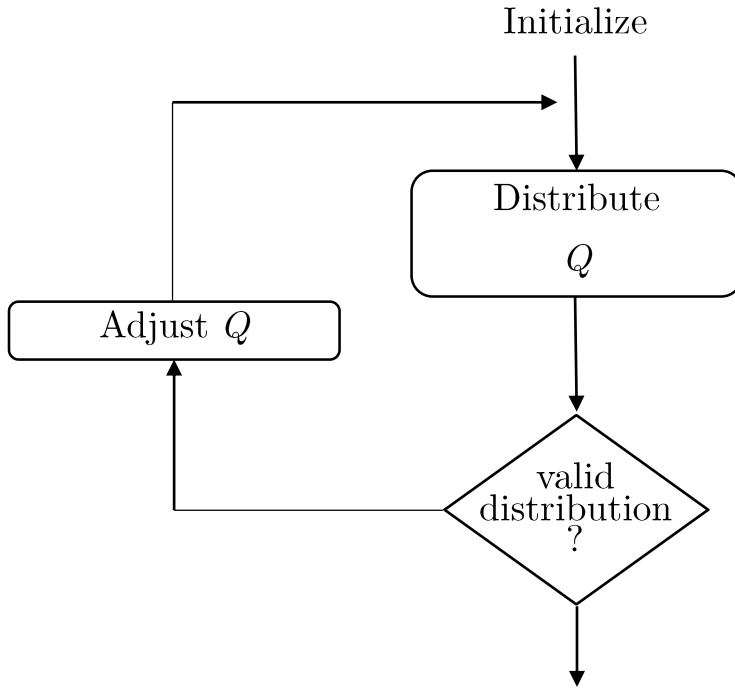
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 - Enough quantum per class?

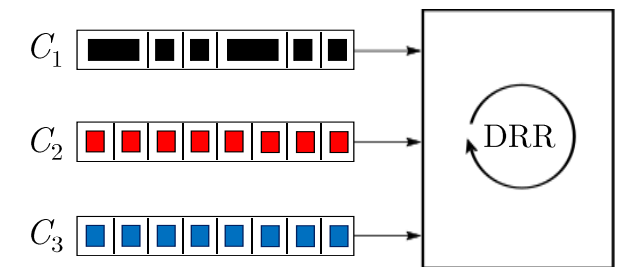
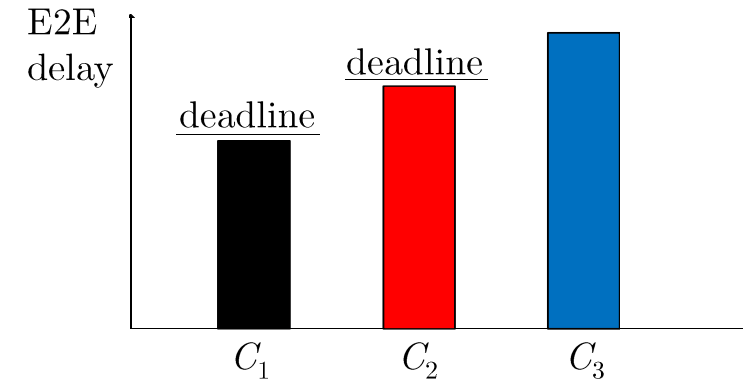


Credit Assignment

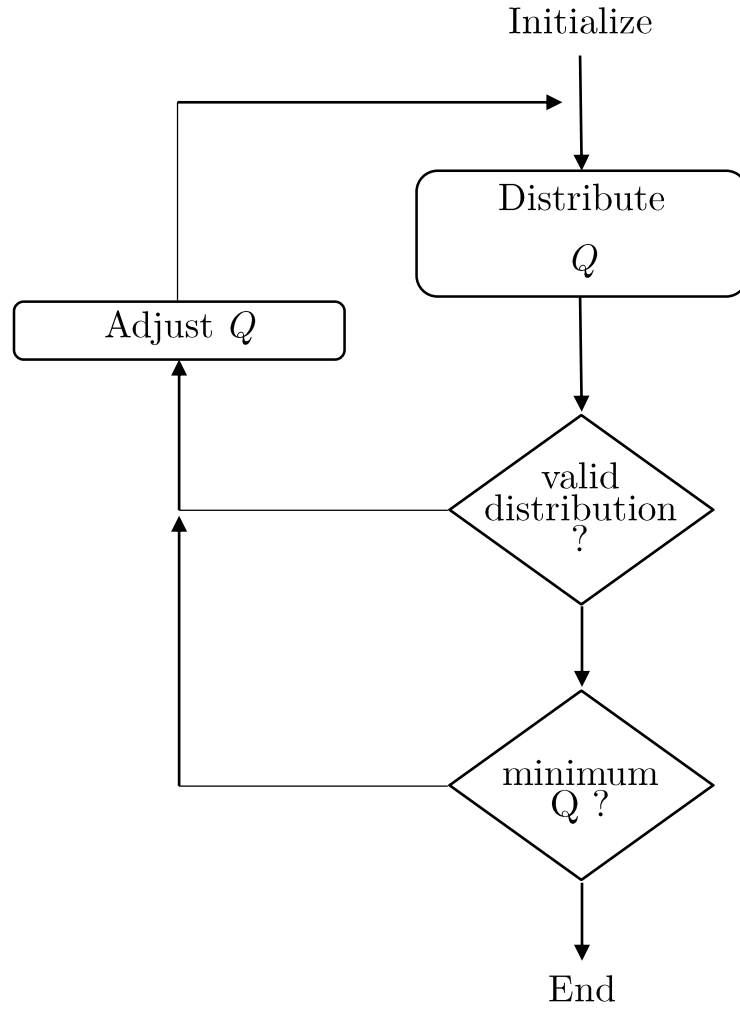


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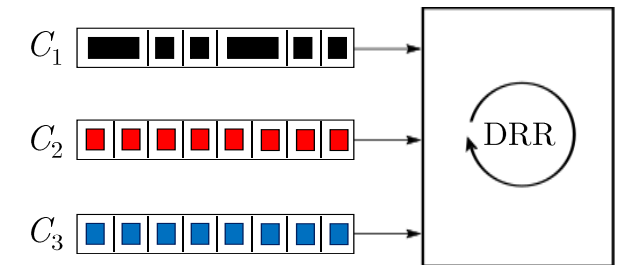
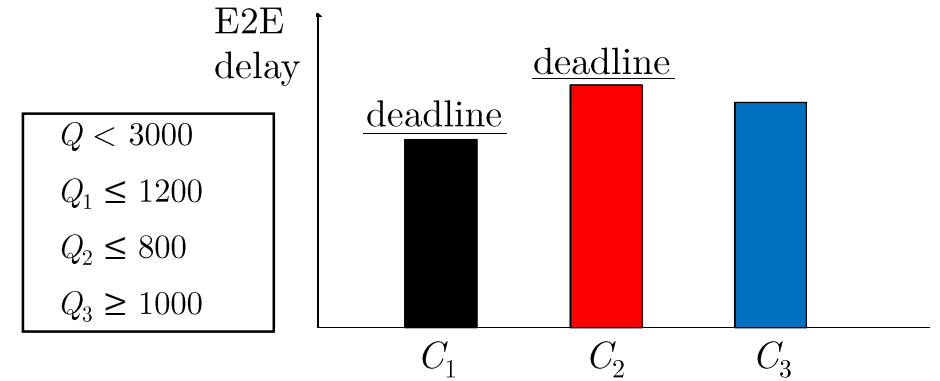
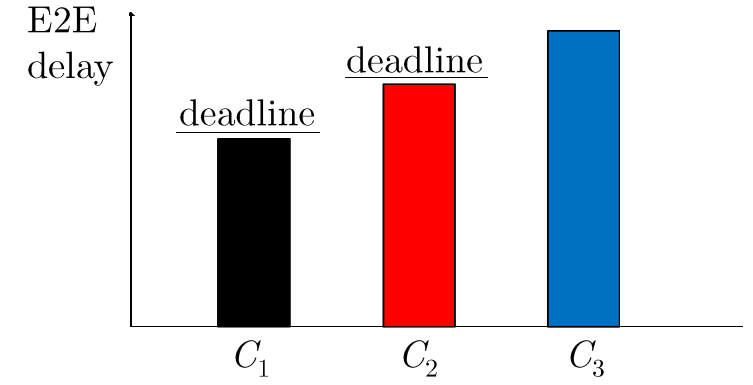


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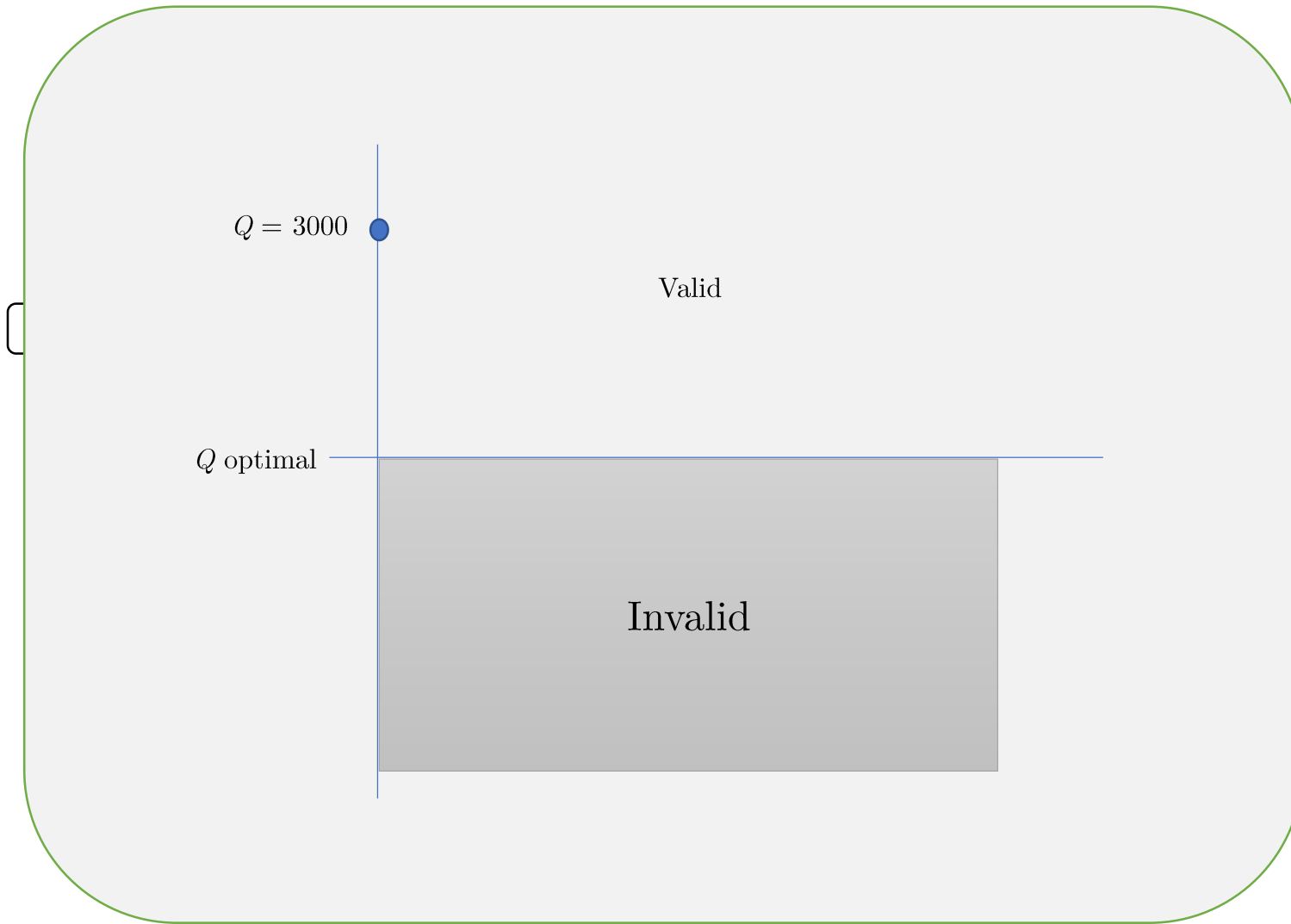


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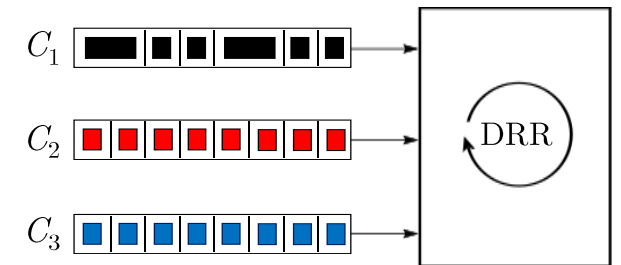
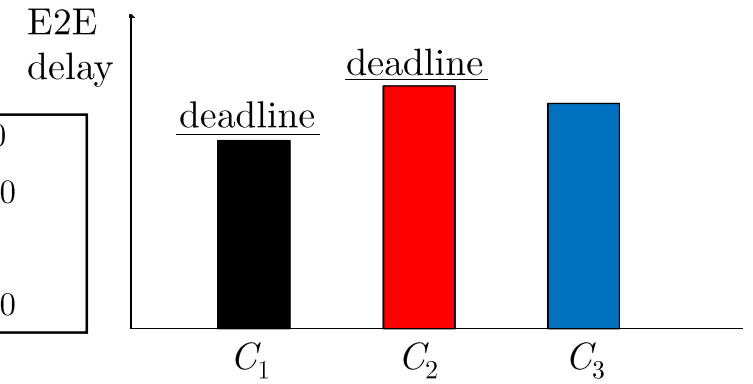
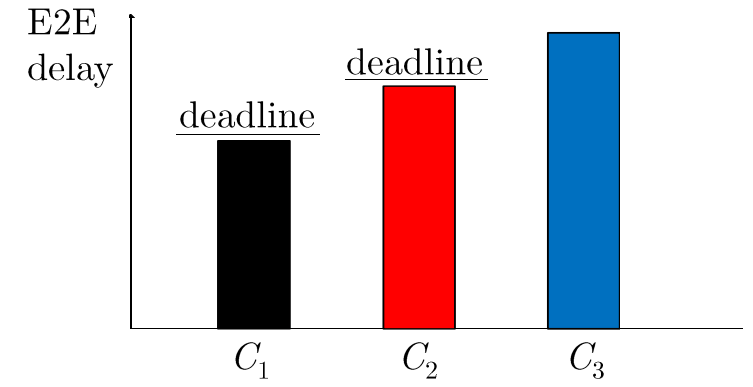
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- Enough quantum per class?
- Can reduce Q ?



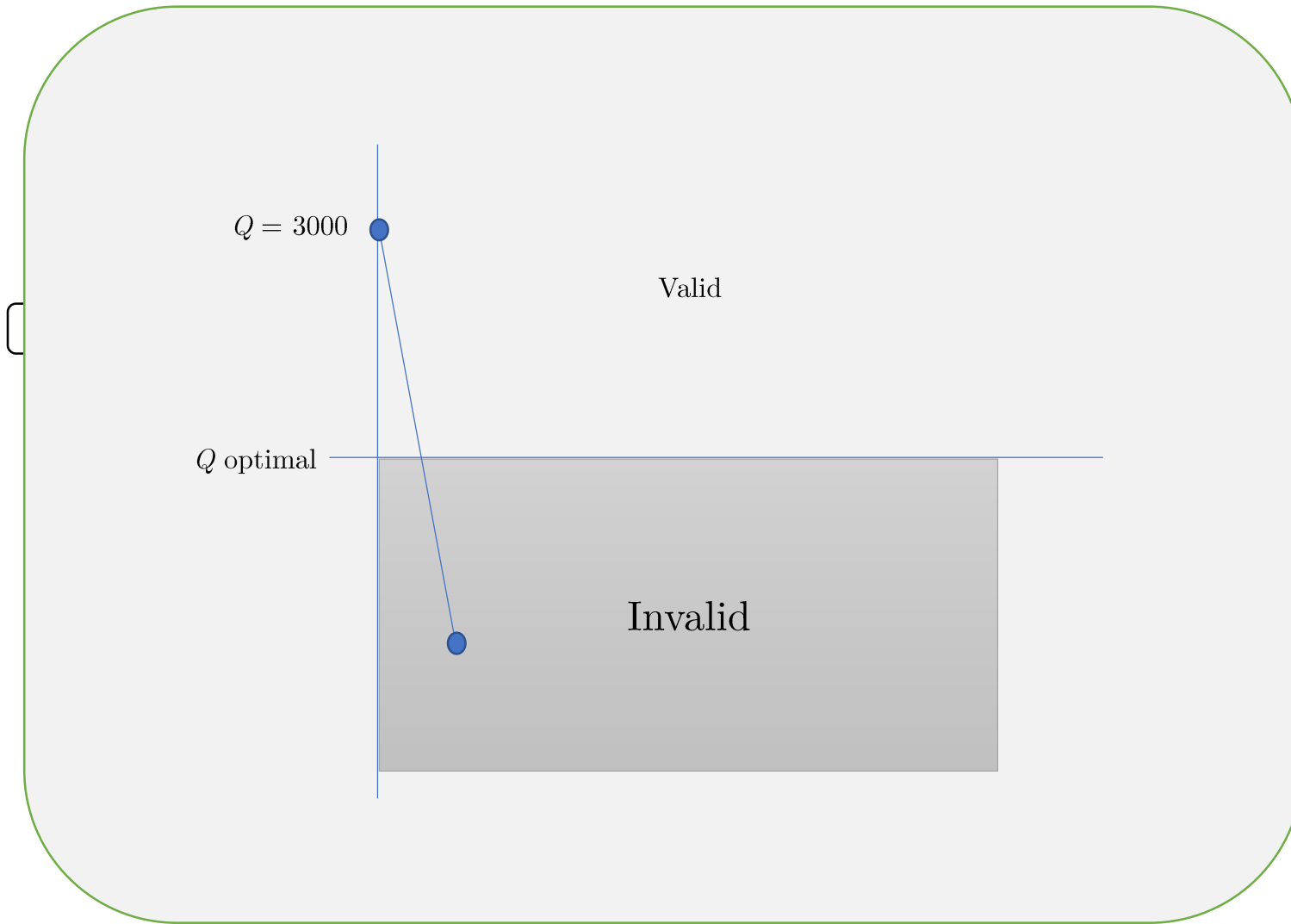
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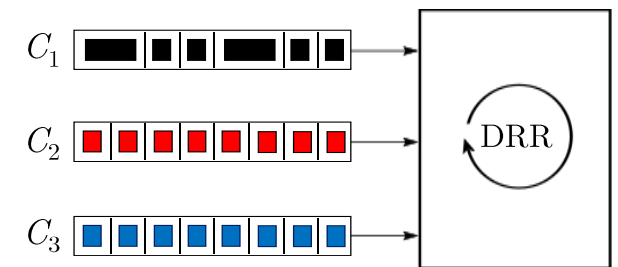
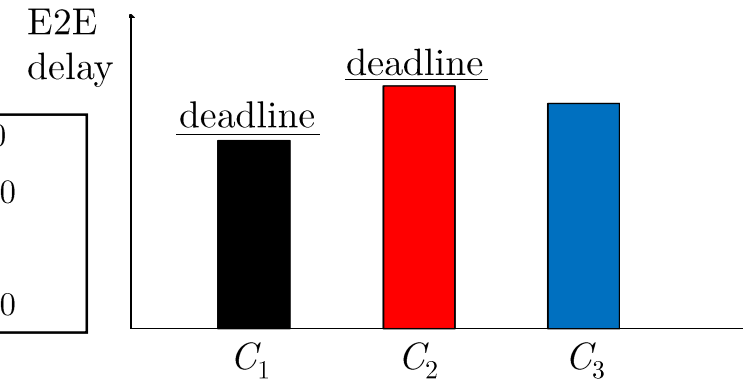
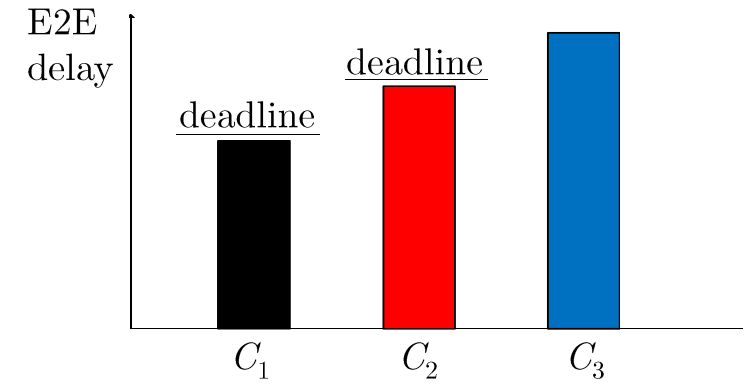
- $Q < 3000$
- $Q_1 \leq 1200$
- $Q_2 \leq 800$
- $Q_3 \geq 1000$



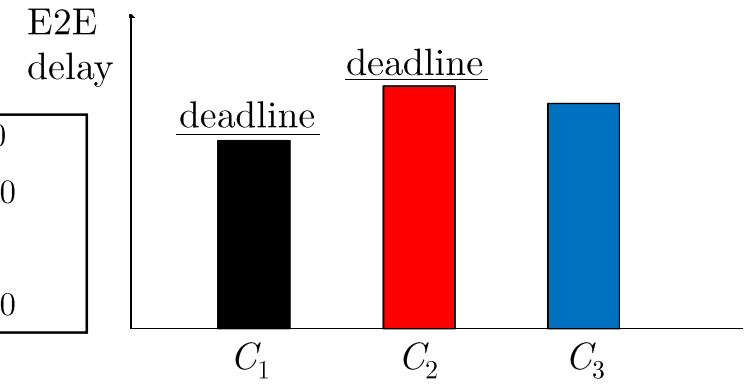
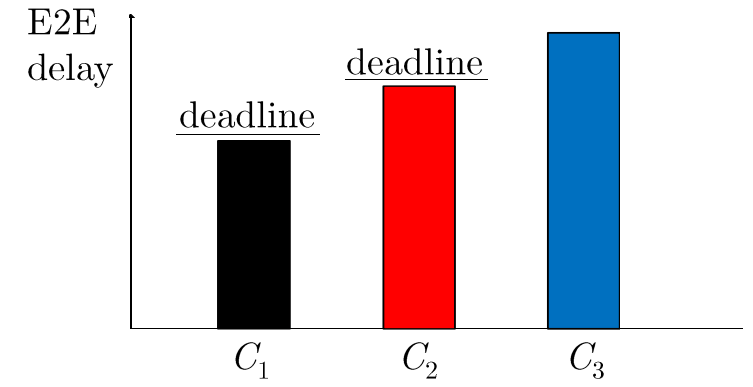
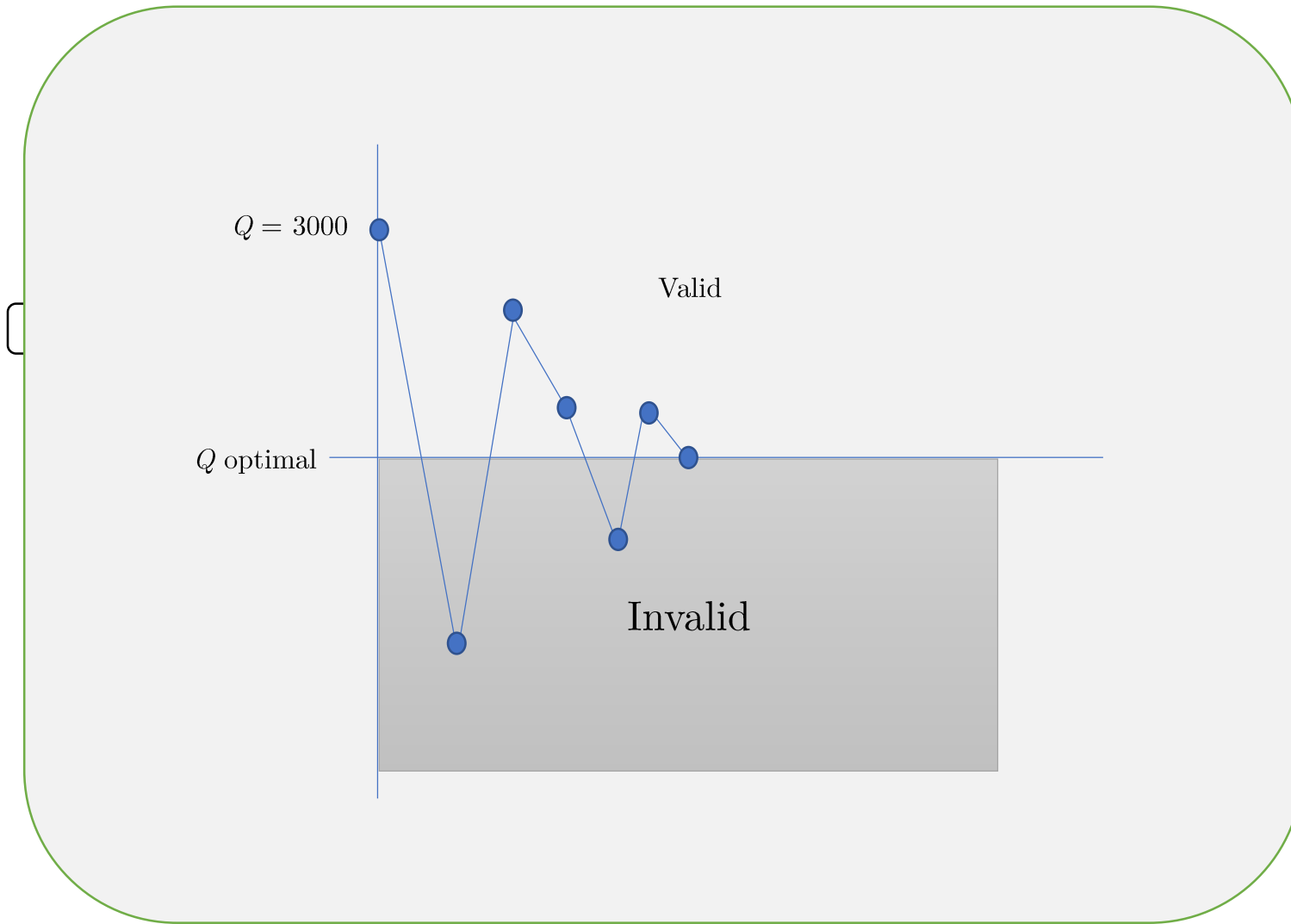
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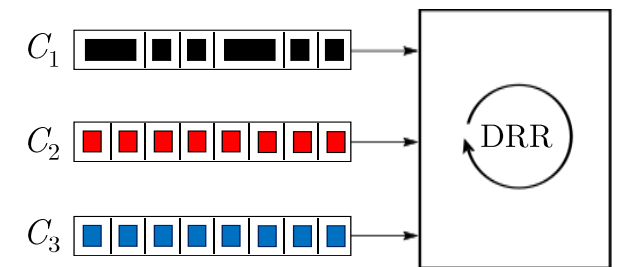
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Credit Assignment



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Results

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

Class	Flow count	BAG (msec)	Frame length (bytes)	Deadline (μ sec)
Critical C_1	280 (1681 paths)	2 – 16	84 – 1497	12573
Critical C_2	704 (4595 paths)	32 – 128	84 – 1535	50292

Additional flows

Non-critical C_3	40 (120 paths)	4 – 8	84 – 963	-
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Results

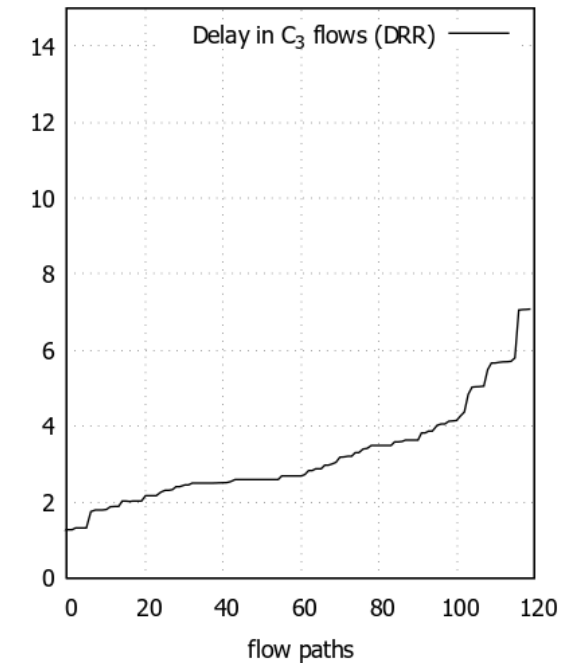
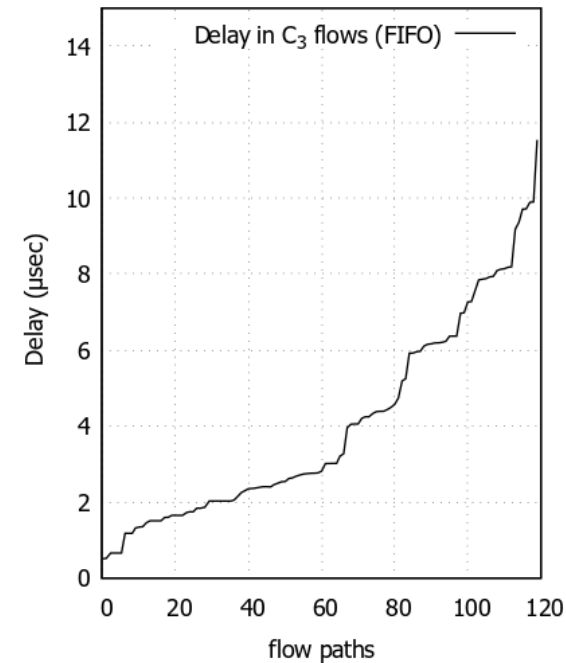
- Effect of additional C_3 flows on critical classes

	Max E2E delay (μ sec)		Deadlines missed
	C_1	C_2	
FIFO	13659.9	11535.4	9 C_1 flows
DRR	12549.2	50215.7	0

Deadlines	12573	50292
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FIFO (without C_3)	12572.6	11535.4
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- Gain on C_3 flows in DRR



Conclusion

- It works !

Conclusion

- DRR allows efficient utilization of network service.
- Delay guarantee can be provided to critical flows.
- **Quantum distribution** has direct influence on end-to-end delay.
- By efficient quantum distribution:
 - **Delay on additional flows can be reduced**
 - **Number of additional flow can be increased.**
- Perspective
 - **Reduce pessimism** introduced by Network Calculus approach.
 - Optimize **number of classes and flow distribution.**
 - **Weight assignment** in Weighted Round Robin scheduling