Timing analysis of AVB Ethernet network using the Forward end-to-end Delay Analysis

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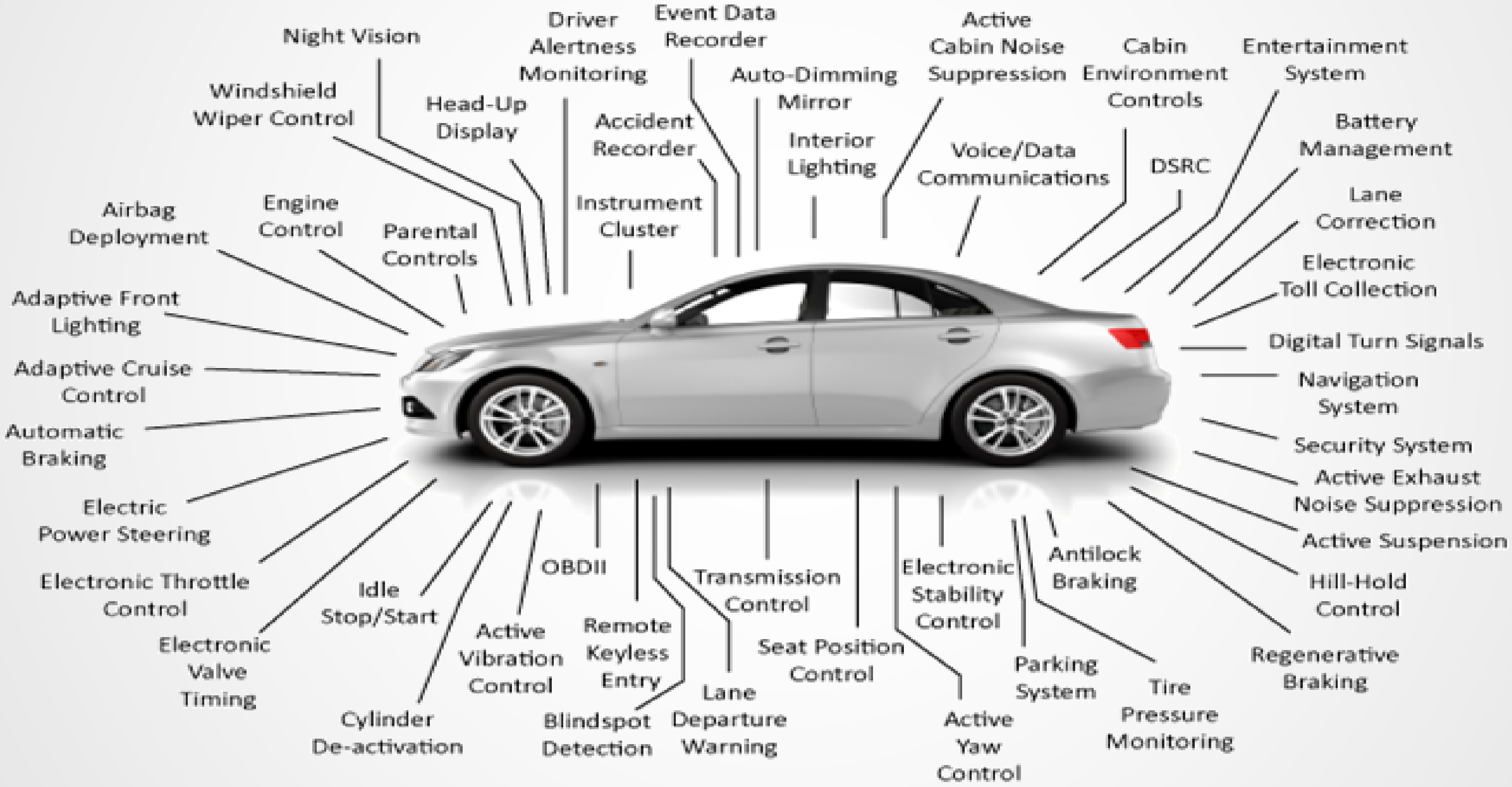
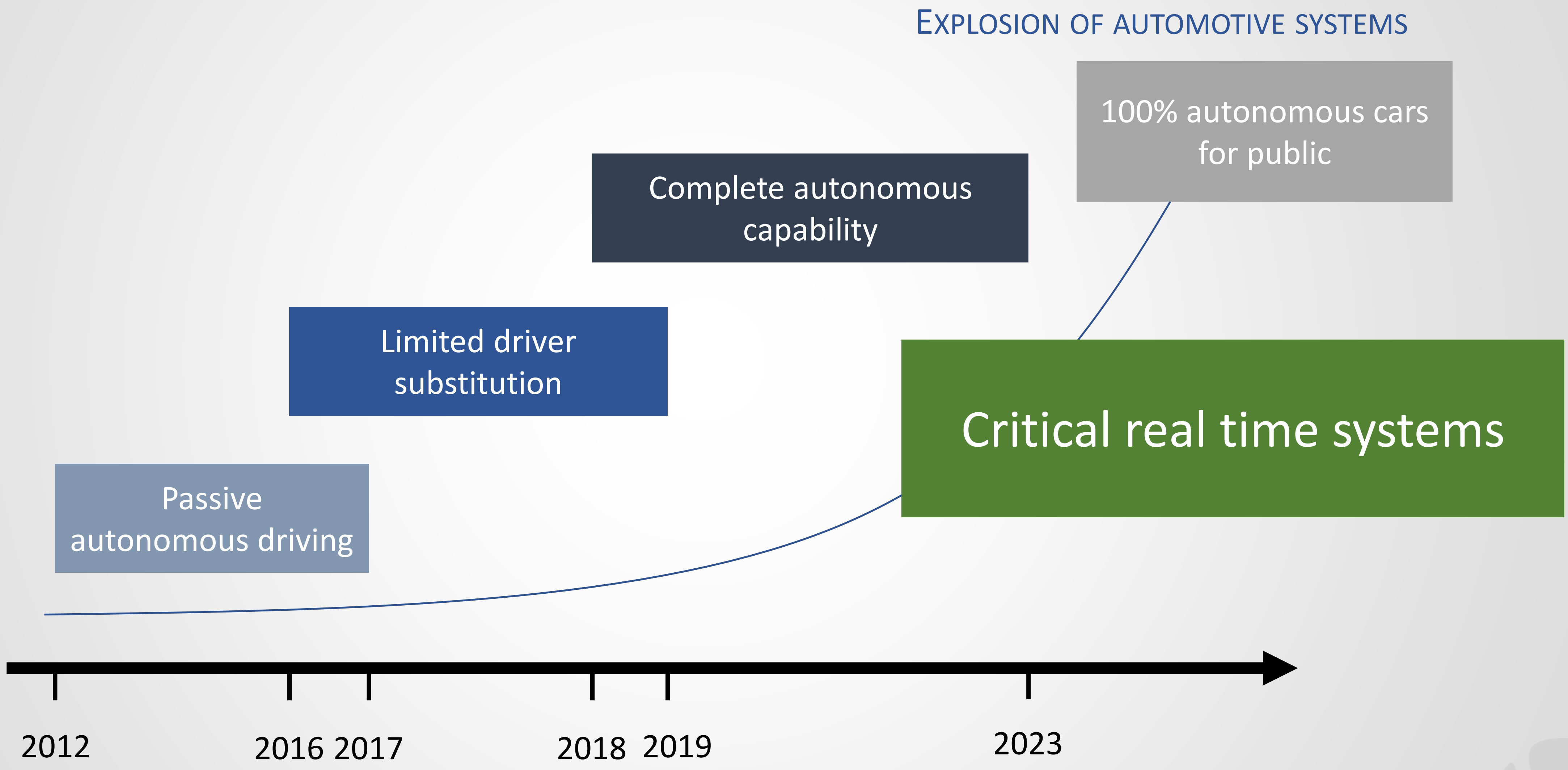
Context

Automotive System: ECUs



ECU : Electronic Control Unit

Context



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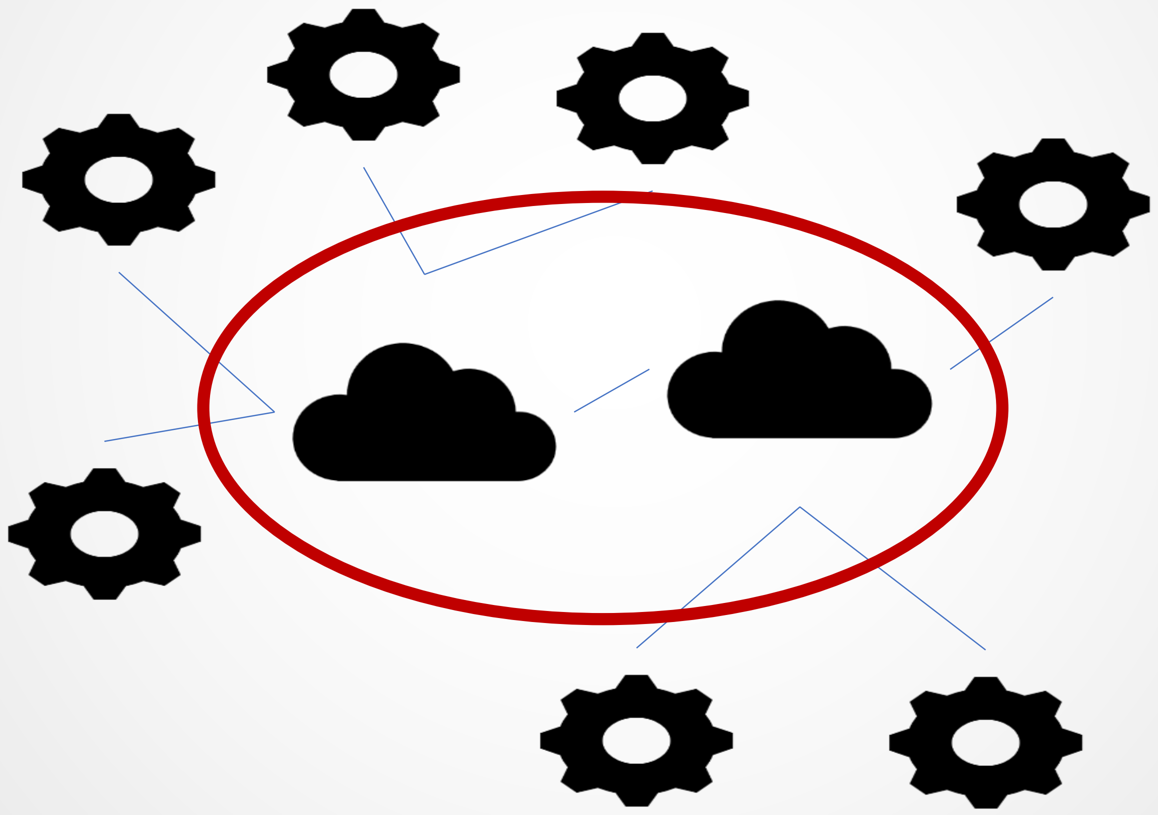
Context

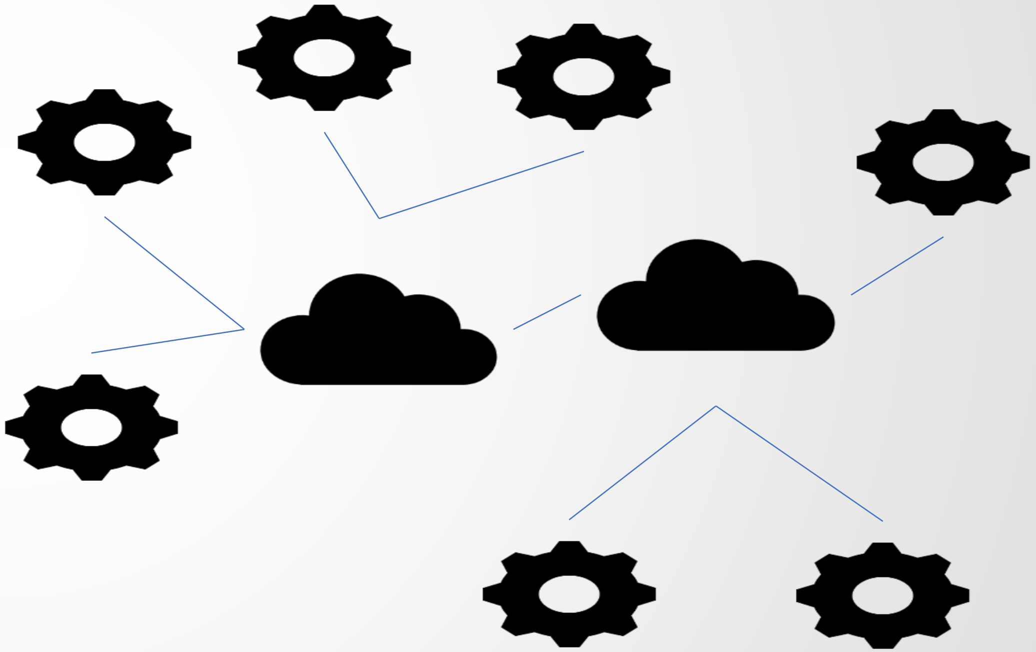
Distributed architecture



Context

Real time networks in Distributed architecture

- ✓ **Deterministic ;**
- ✓ Security, fault tolerance ;
- ✓ Bandwidth;
- ✓ Easy integration;
- ✓ Decrease wiring.



Context

Heterogeneous networking

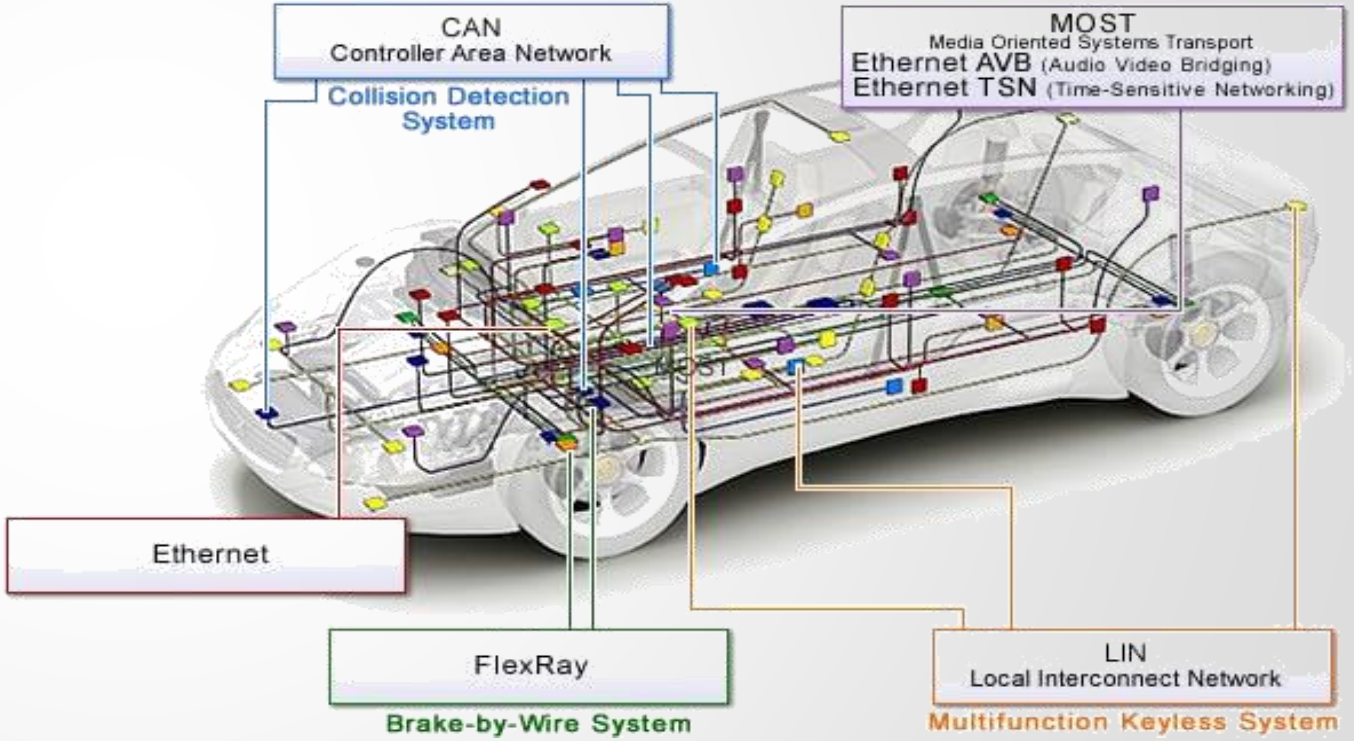
Complexity

Trends to Ethernet based standards

Audio Video Bridging Switched Ethernet (AVB)

Time Sensitive Networking (TSN)

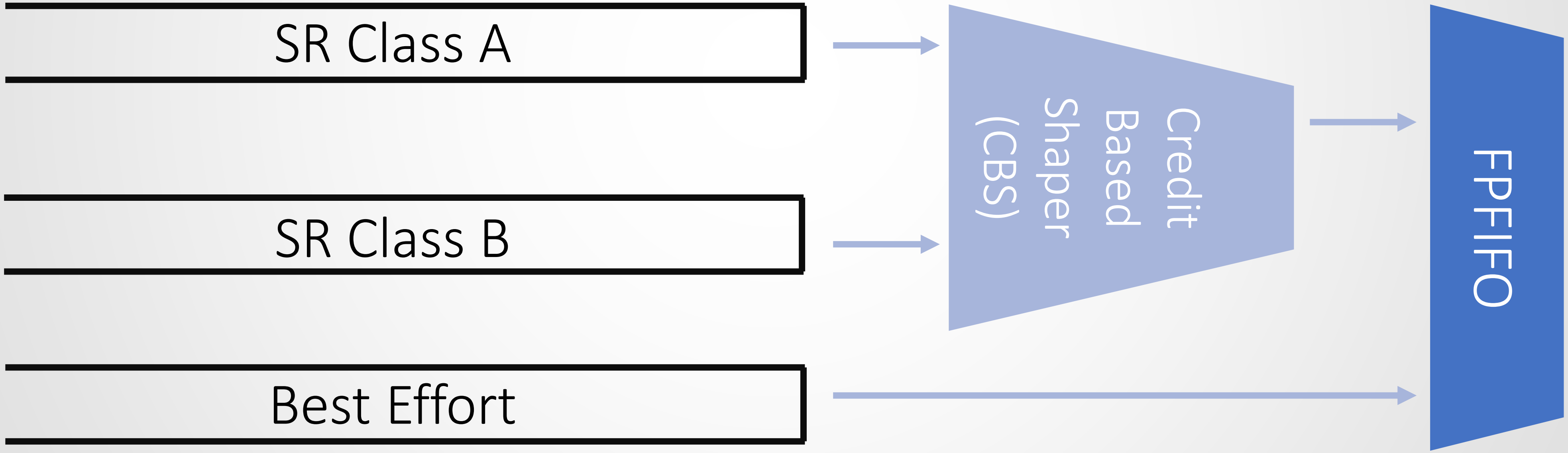
Automotive networking



Context

AUDIO VIDEO BRIDGING SWITCHED ETHERNET (AVB)

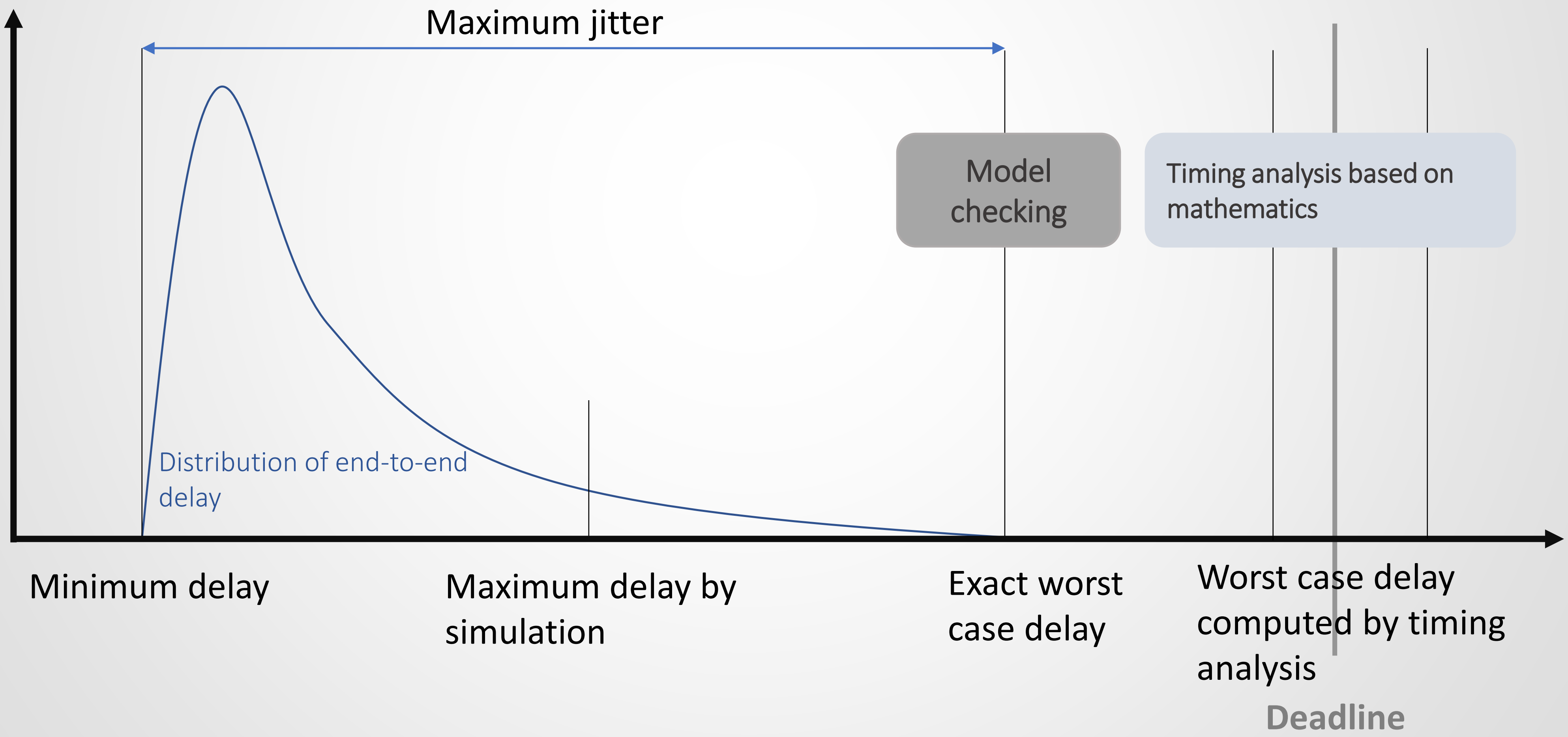
- Synchronization ;
- Quality of service ;
- SR : Stream reservation.



Problematic

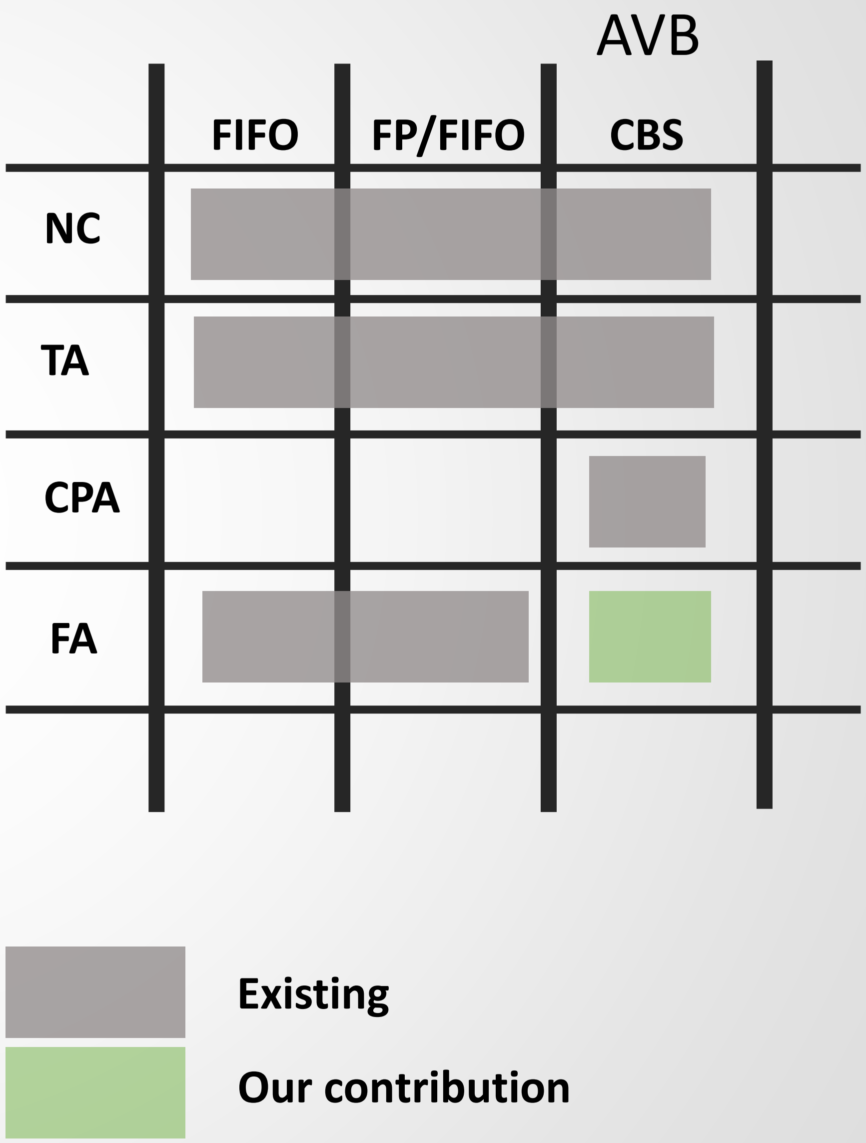
Traffic shaper → End-to-end delay → Real time constraints

Problematic



Motivations

- Network Calculus (NC)
- Trajectory approach (TA)
- Compositionnal Performance Analysis (CPA)
- Forward end-to-end delay Analysis (FA)

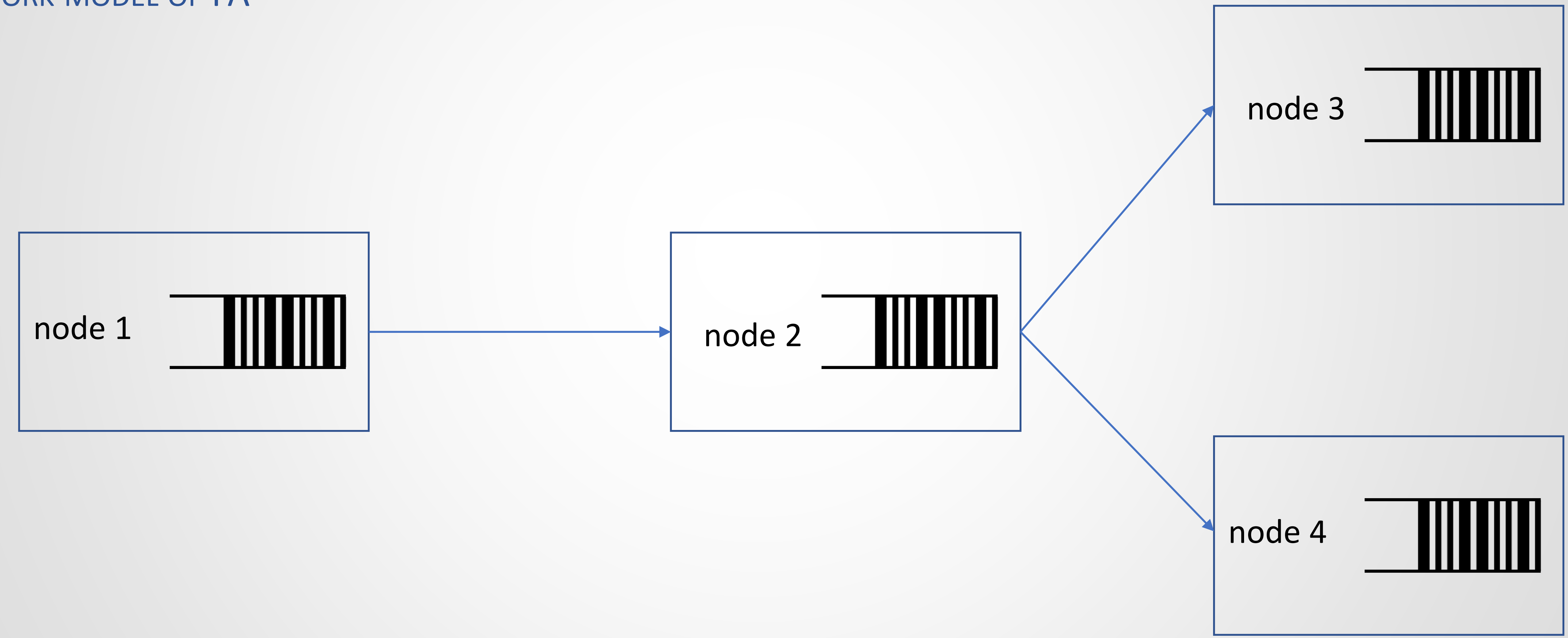


Summary

- FA method
- FA extension to CBS algorithm
- Experimentations
- Conclusion

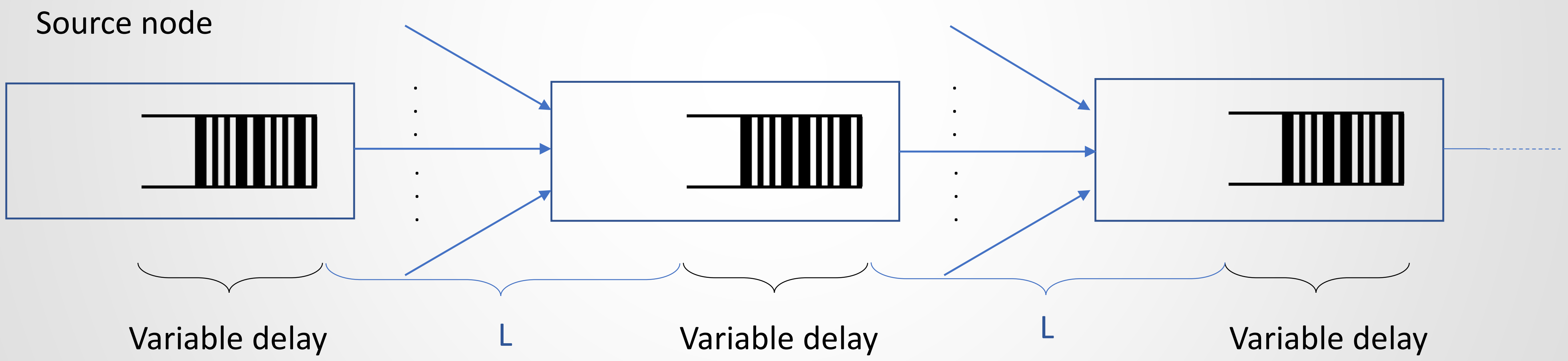
FA method

Network model of FA



Node = multiplexing point

END-TO-END DELAY ELEMENTS



L: technological latency

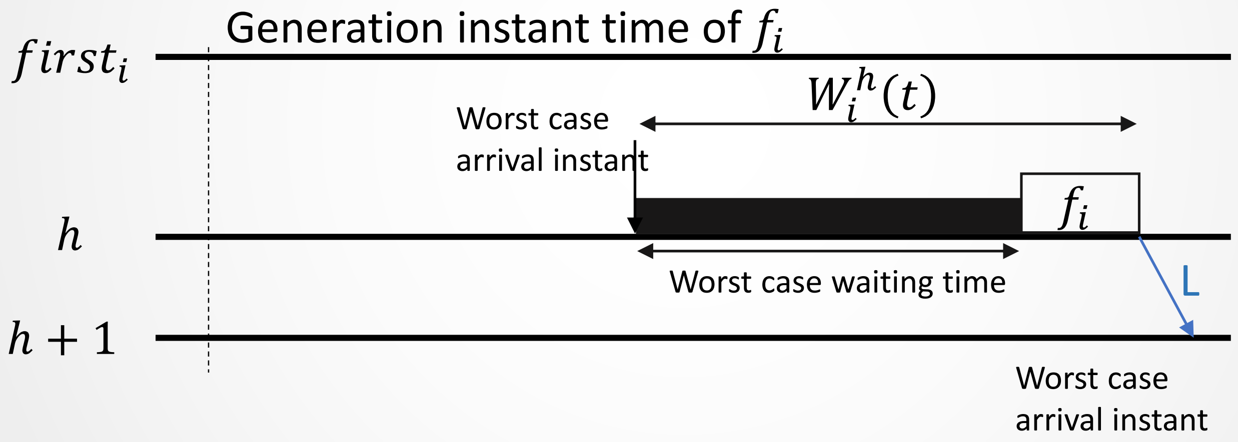
PROPERTIES

A flow v_i is defined by :

- C_i^h : maximum transmission time of a frame from v_i in the node h.
- T_i : period of v_i.
- $Path_i$: path of v_i.
- P_i: priority level of v_i.
- sp_i^h: set of flows $v_j \in \Gamma^h$ où $P_i = P_j$.
- hp_i^h: set of flows $v_j \in \Gamma^h$ où $P_i < P_j$.
- lp_i^h: set of flows $v_j \in \Gamma^h$ où $P_i > P_j$.

Fixed Priority First In First Out (FPFIFO)

Analysis of a frame with FA



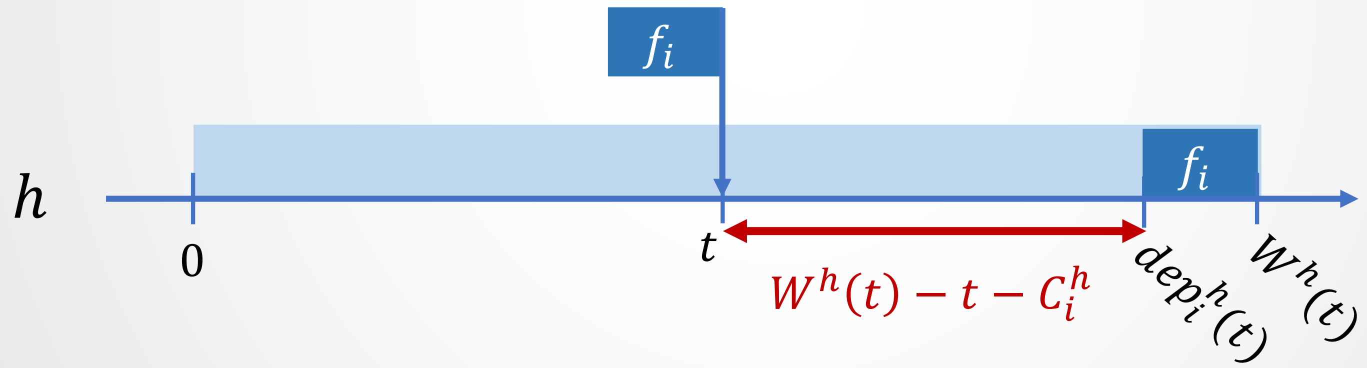
$$W_i^h(t) = WLP_i^h(t) + WSP_i^h(t) + WHP_i^h(t)$$

L: technological latency

Worst case waiting time for a frame in a node during a time interval

Assumption : one level of priority (FIFO)

- $rbf_j^h(t)$: transmission time of all frames generated from v_j in the node h during t.

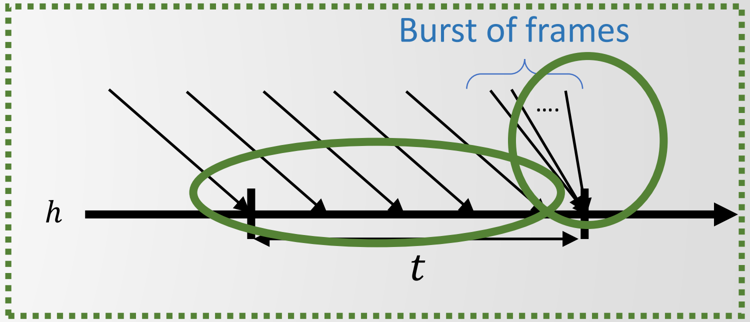


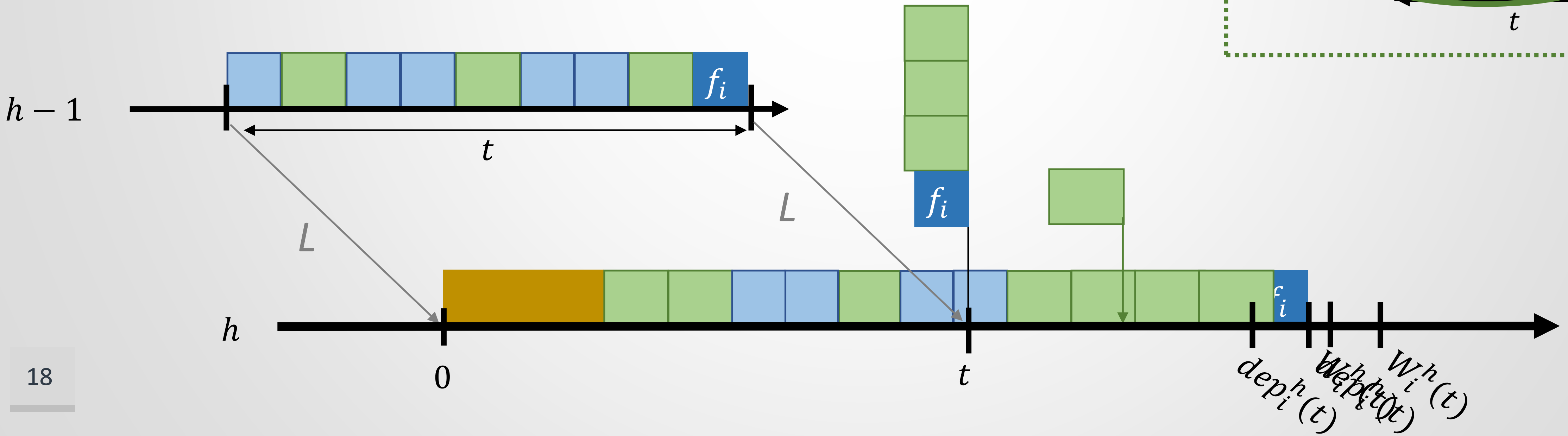
$$W^h(t) = \sum_{v_j \in \Gamma^h} rbf_j^h(t)$$

Maximum interference generated in a node during $[0, t[$

Given a frame f_i generated from v_i in the node h incoming from an imput port IP_1^h during t.

$$W_i^h(t) = WLP_i^h(t) + WSP_i^h(t) + WHP_i^h(t)$$



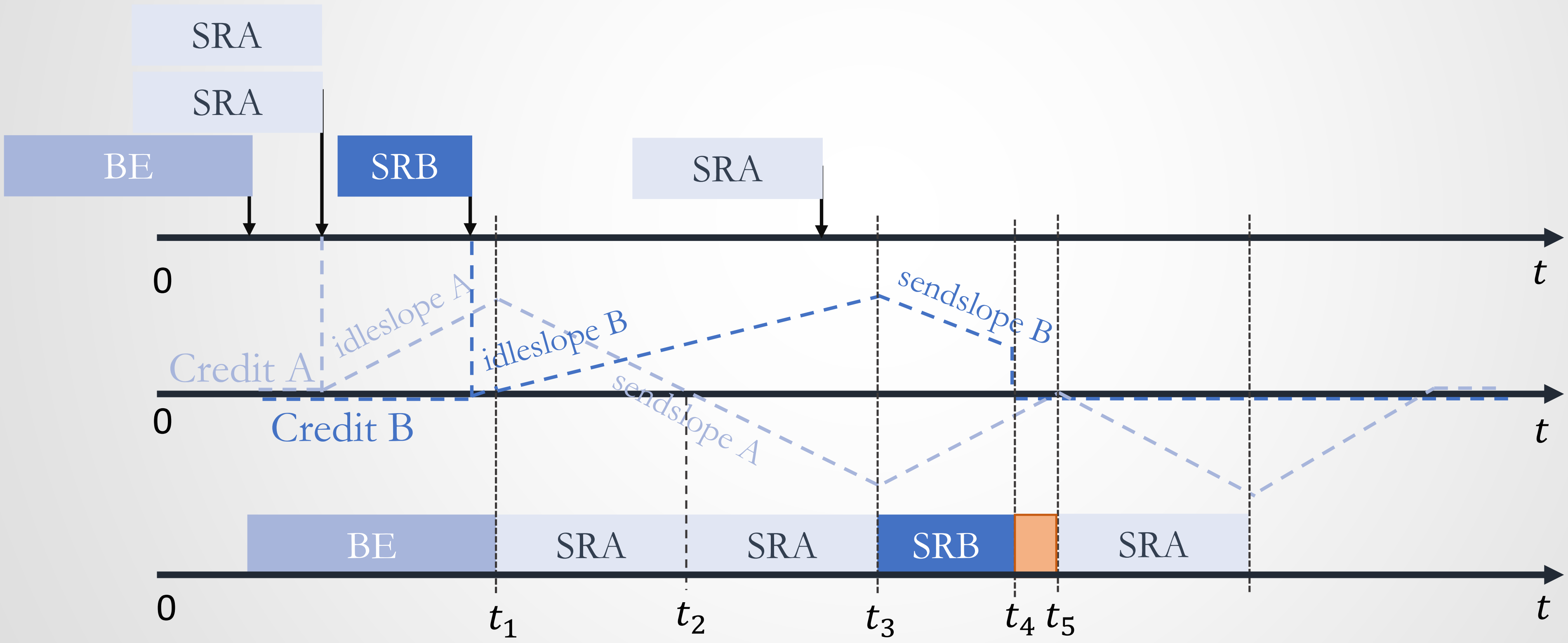


Worst case waiting time in a node

Maximum delay incurred in the node $h = max_{t \geq 0}(W_i^h(t) - t)$ While $W_i^h(t) \geq$ t

FA extension to CBS algorithm

CBS Algorithm

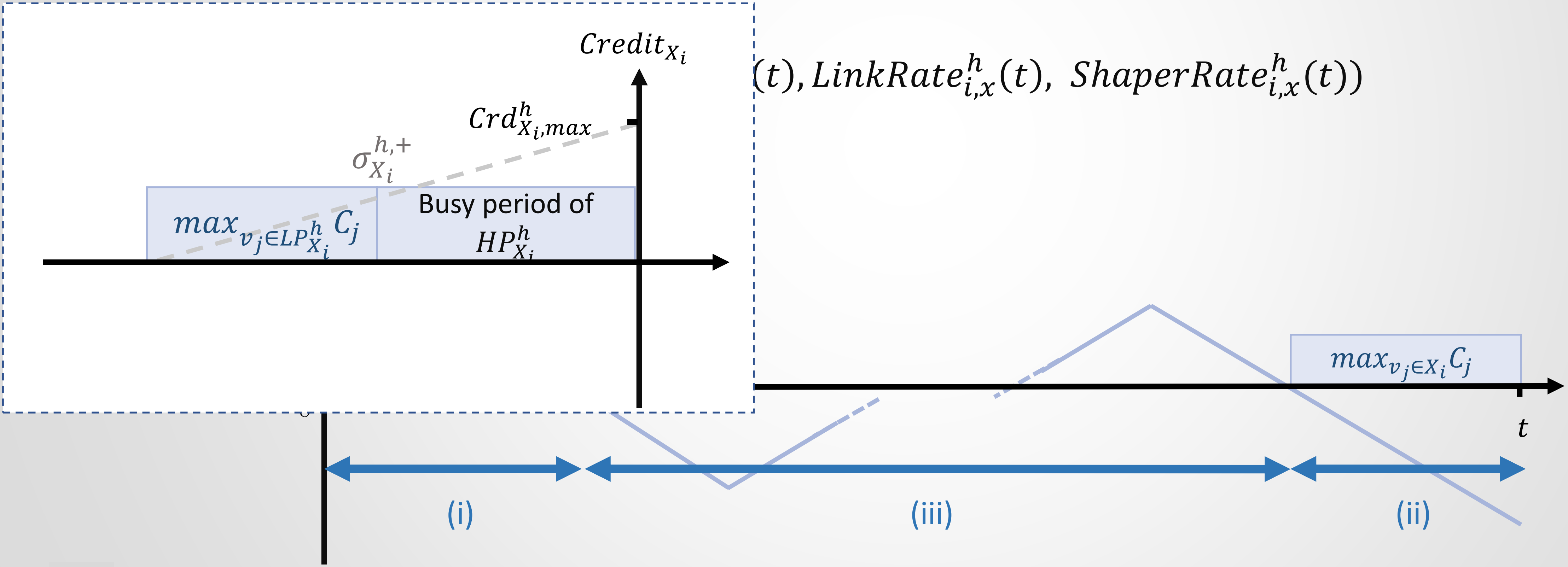


A flow v_i belongs to a SR class X_i

$$W_i^h(t) = WLP_i^h(t) + WSP_i^h(t) + WHP_i^h(t) + WNIL_i^h(t)$$

IMPACT OF SAME PRIORITY FLOWS

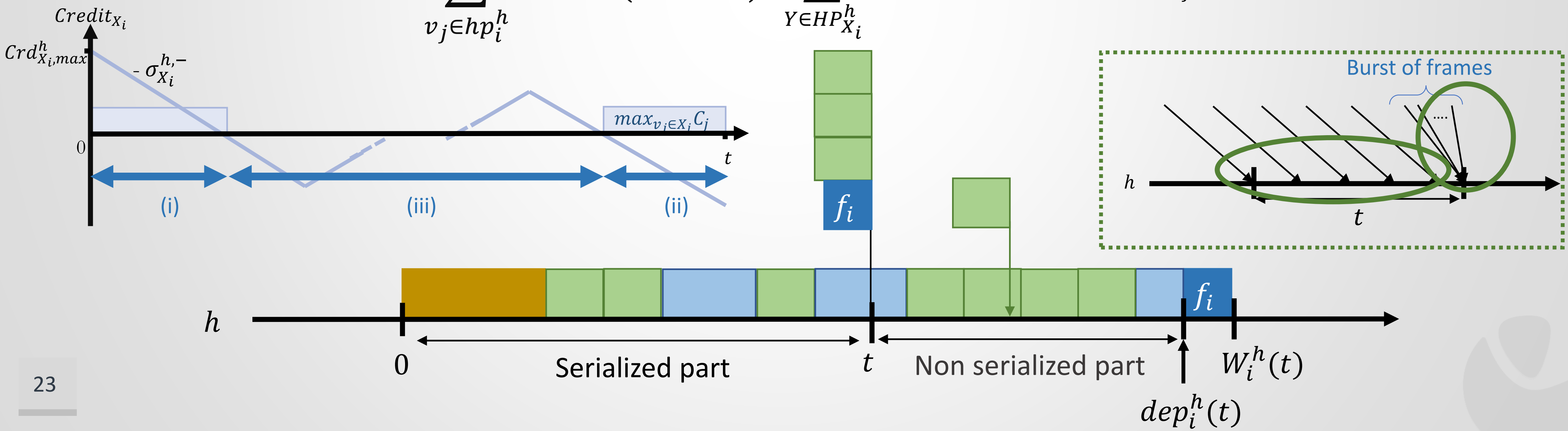
$(t), LinkRate^{h}_{i,x}(t),\ ShaperRate^{h}_{i,x}(t))$



Impact of high priority flows

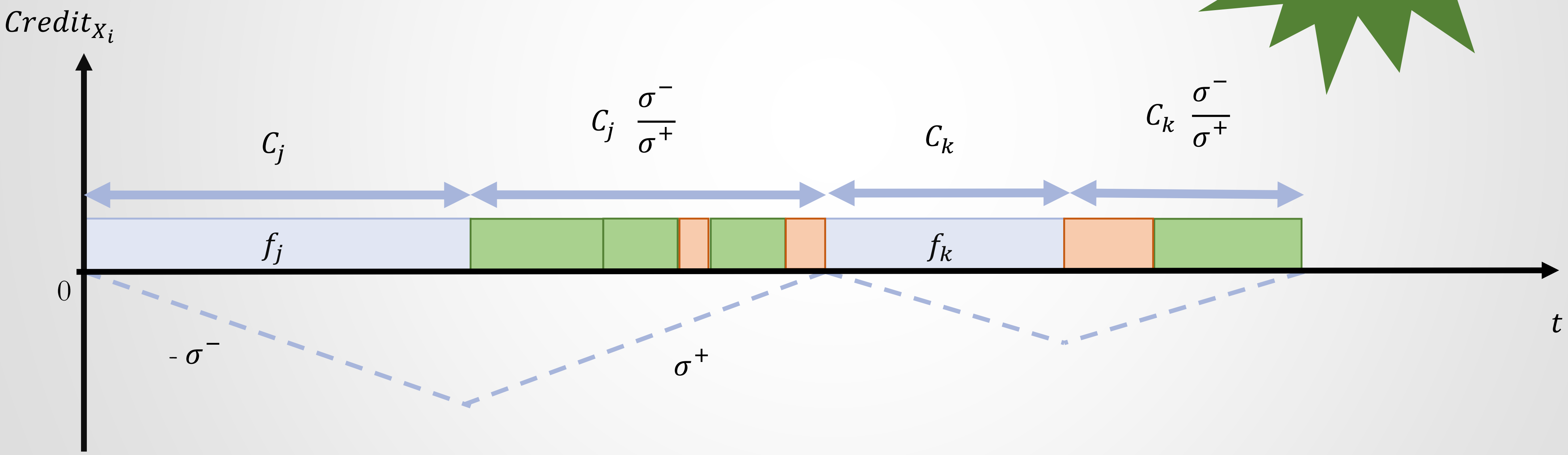
Given a frame f_i generated from v_i belonging to an SR Class X_i in the node h during t.

$$WHP_i^h(t) = min\left(\sum_{v_j \in hp_i^h} rbf_j^h \left(dep_i^h(t)\right), \sum_{Y \in HP_{X_i}^h} Bord_Y^h(dep_i^h(t) + max_{v_j \in SHP_Y^h} C_j)\right)$$



TAKING INTO ACCOUNT RESPLENISHING TIME OF THE CREDIT OF X_i

$WHP_i^h(t)$



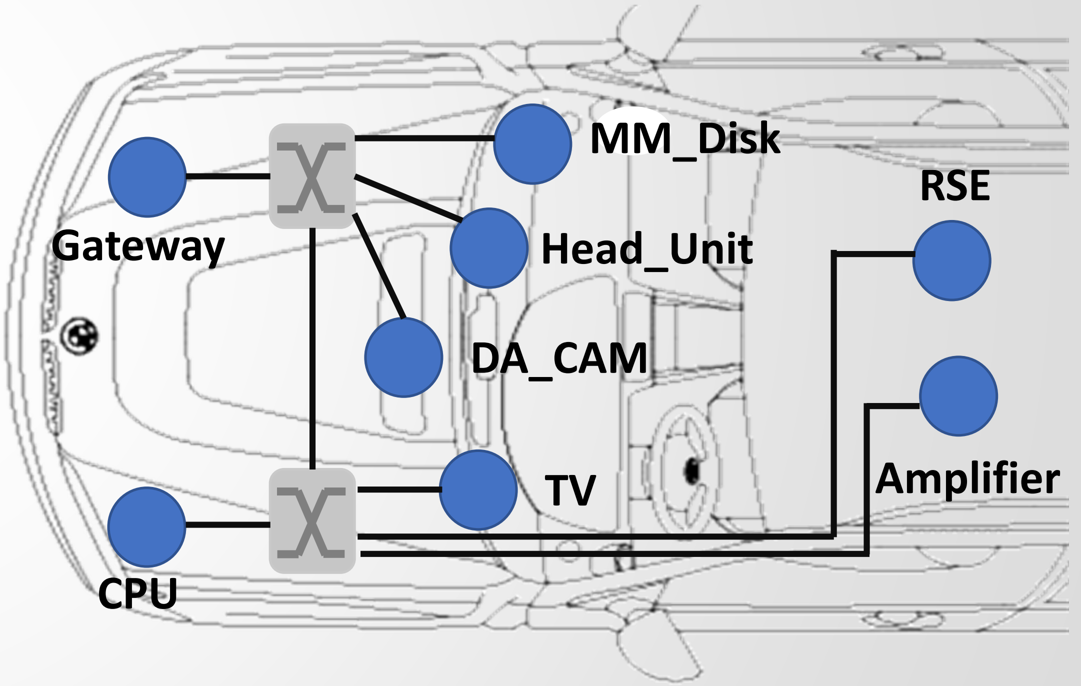
$$WSP_i^h(t)\left(1+\frac{\sigma^-}{\sigma^+}\right) \Rightarrow WSP_i^h(t) + WNIL_i^h(t)$$

Experimentations

INDUSTRIAL CASE

v_i	$T_i(\mu s)$	$C_i(\mu s)$	Class	$R_i(\mu s)$	Source	Destination
v_1	5000	5,12	A	2762,72	Gateway	CPU
v_2	5000	5,12	A	2994	Gateway	RSE
v_3	125	32,64	A	188,96	DA_CAM	Heand_Unit
v_4	280	115,68	B	631,9	MM_Disk	RSE
v_5	1400	115,68	B	618,67	MM_Disk	Amplifier
v_6	560	115,68	B	395,68	TV	Head_Unit

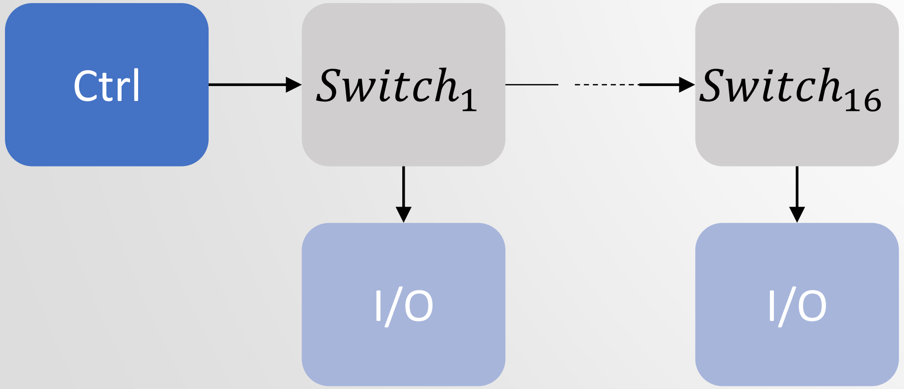
- Technological latency= $8\mu s$.
- Service rate= 100 Mbit/s.



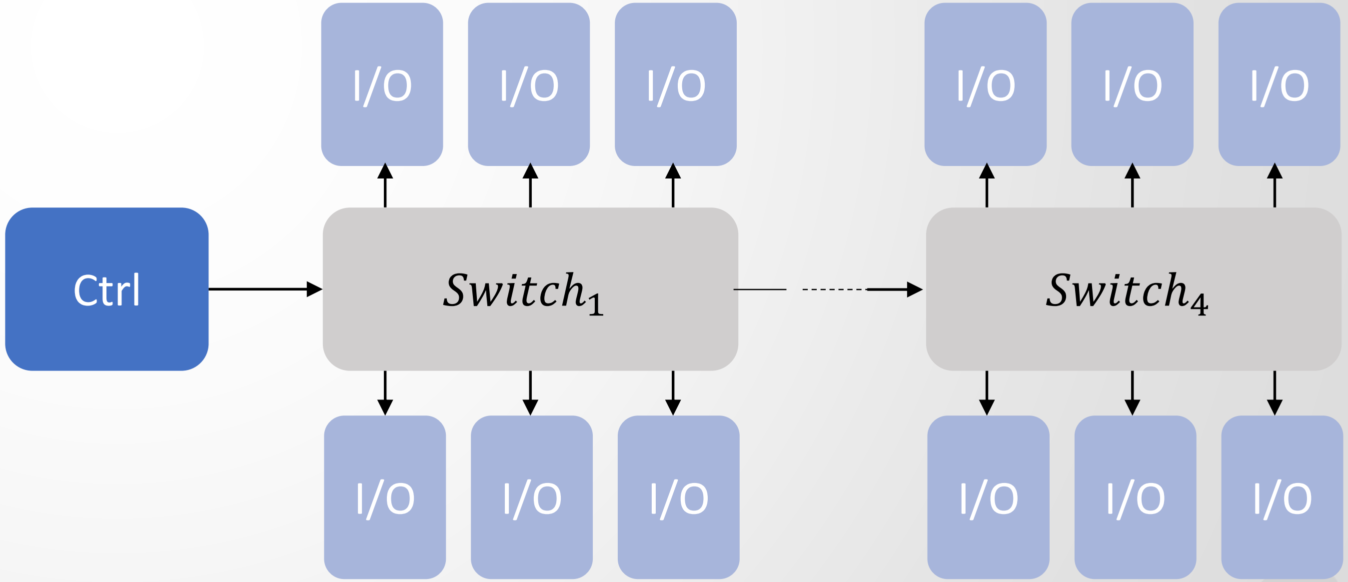
[Li et al., Henia *et al.*, Steinbach *et al.*]

Comparison with CPA

- Technological latency = $0{,}33\mu s$.
- Service rate = 1 Gbit/s.



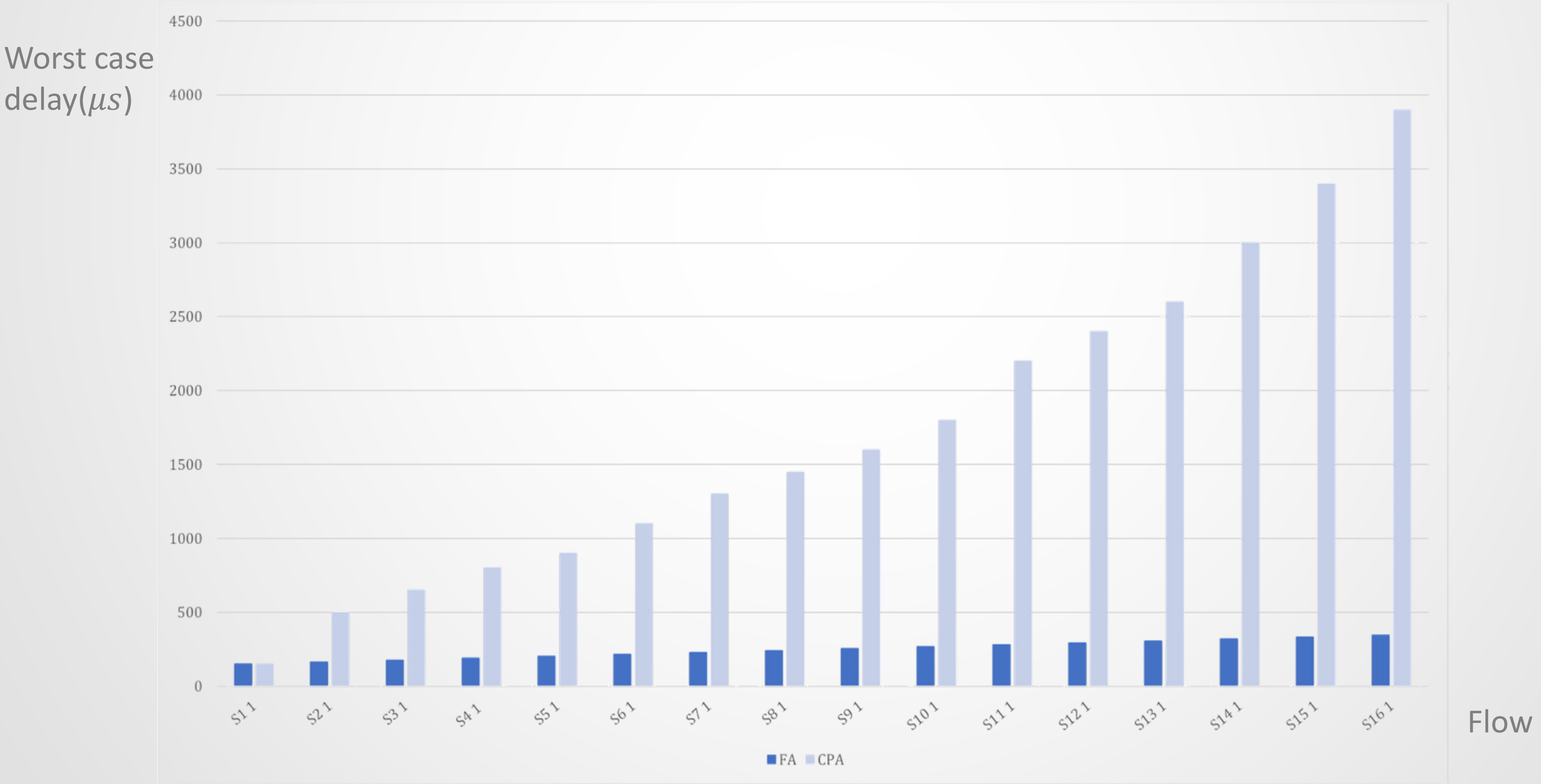
Linear topology



[Diemer *et al.*]

Clustered topology

RESULTS



Linear topology

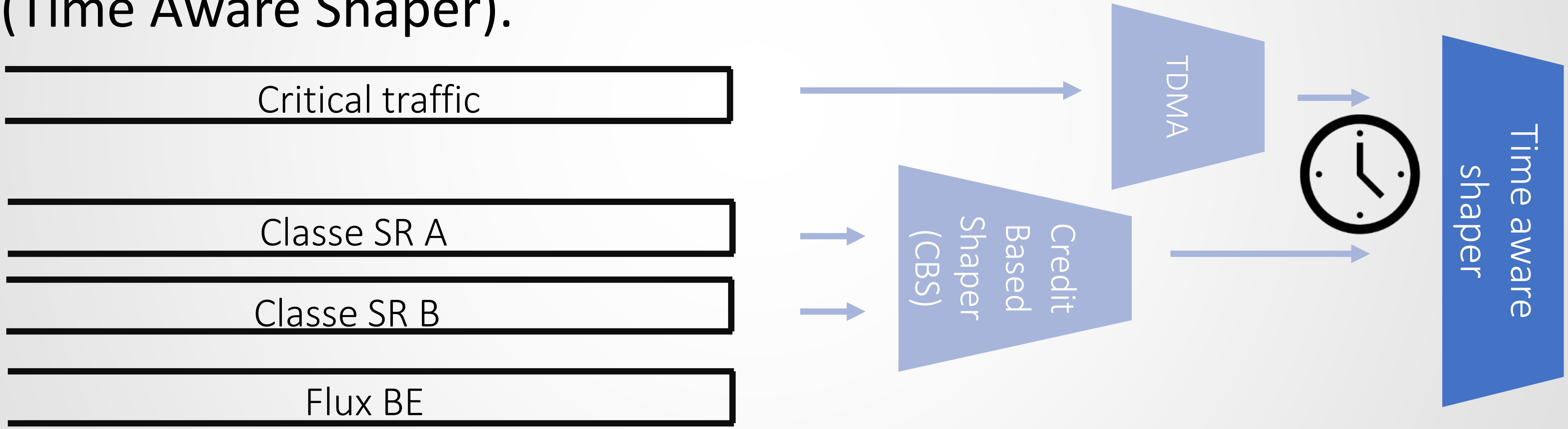
Conclusion

Conclusion

- Tight bounds when taking into account :
  - the serialization effect ;
  - the shaper on the maximum interference from high and same priority flows ;
  - and the resplenishing time of the credit without counting twice the interference of high priority flows.
- Interesting results compared to CPA.

PERSPECTIVES

- Extension of FA method to the servicing policy of TSN standard (Time Aware Shaper).



Thank you for your attention

Questions?

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COMPLEXITY OF AUTOMOTIVE SYSTEMS : DISTRIBUTED ARCHITECTURE

https://www.st.com/en/solutions-reference-designs/automotive-solutions.html

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Annexe

La fonction request bound function

Un flux sporadique non préemptif v_i est défini par :

- C_i , T_i, $Path_i$
- $Smax_i^h$: le délai de traversée maximum pour une trame de v_i à partir de son node source pour atteindre le node h.
- $Smin_i^h$: le délai de traversée minimum pour une trame de v_i à partir de son node source pour atteindre le node h.

Le nombre de trames maximum générées par v_i dans le node h durant $[t_0, t_1]$ avec $(t_0 + \mathrm{t} = t_1)$

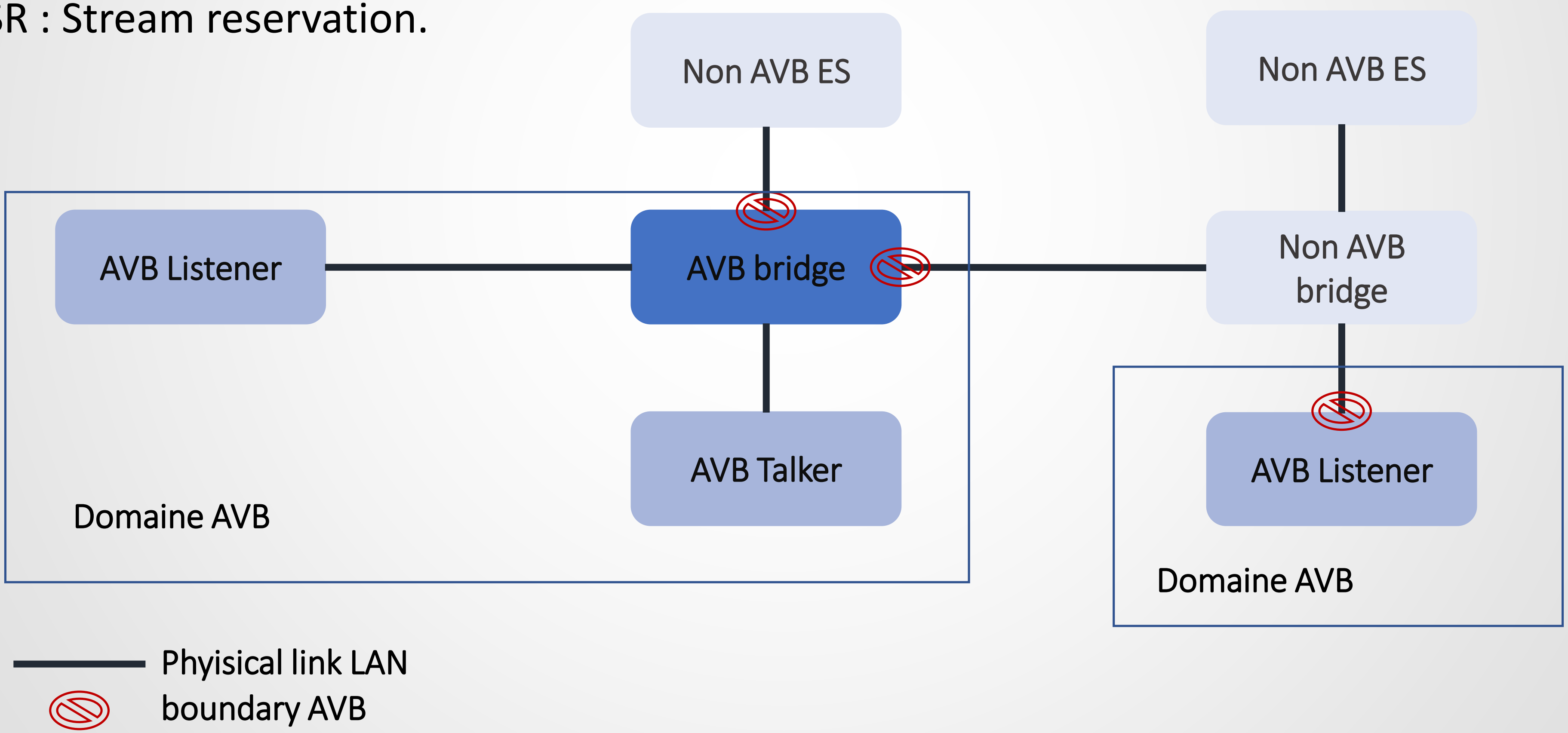
$$\leq \quad 1 + \left\lfloor \frac{t_1 - t_0}{T_\mathrm{i}} \right\rfloor$$

$$\leq \quad 1 + \left\lfloor \frac{t + (Smax_i^h - Smin_i^h)}{T_\mathrm{i}} \right\rfloor$$

Car $(t_0 - Smax_i^h) + \mathrm{t} = t_1 - Smin_i^h$

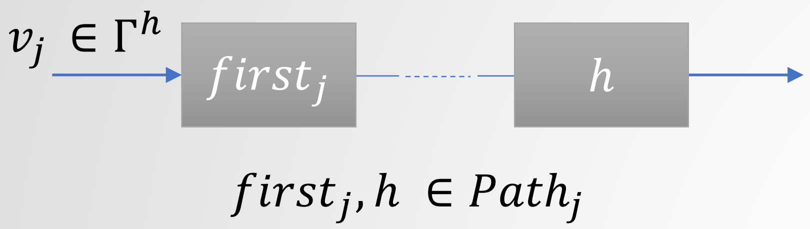
$$RBF_i^h(t) = \left(1 + \left\lfloor \frac{t + (Smax_i^h - Smin_i^h)}{T_\mathrm{i}} \right\rfloor \right) C_i$$

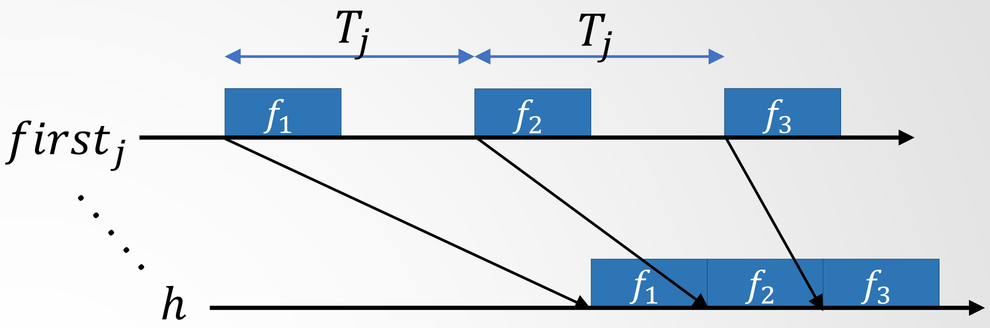
- Synchronization ;
- Quality of service ;
- SR : Stream reservation.

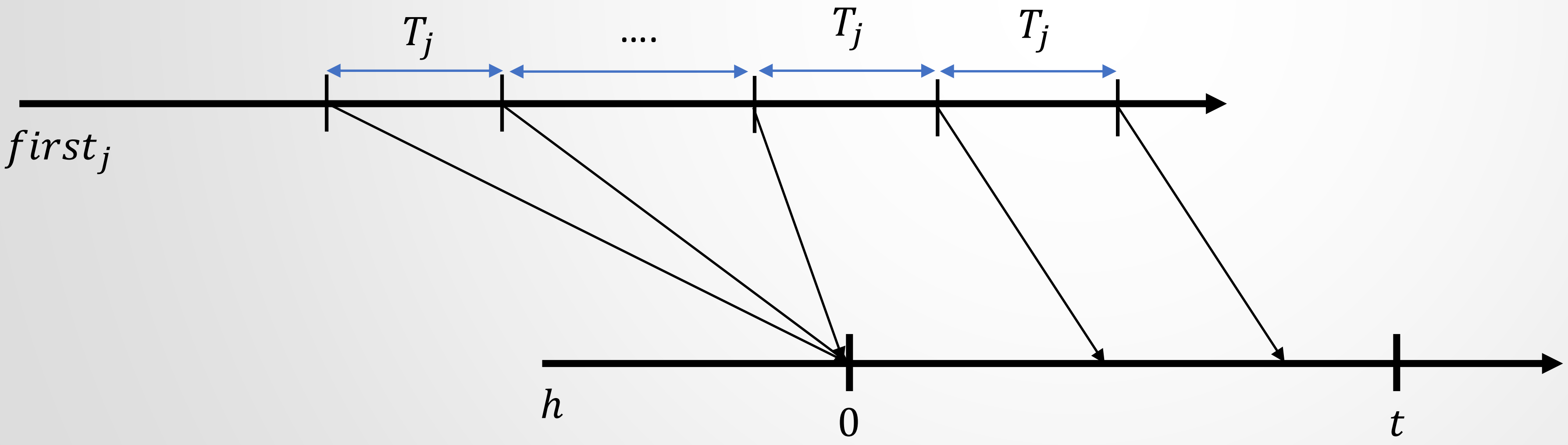


Maximum interference generated from a flow

Supposition : one level of priority (FIFO)

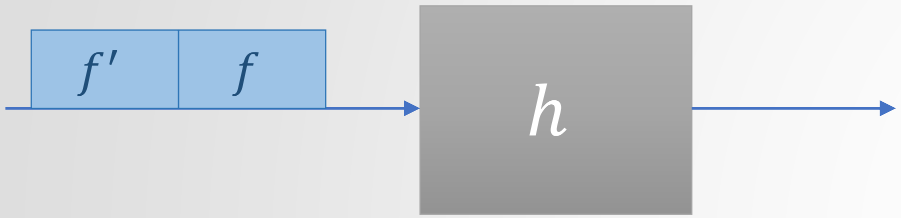


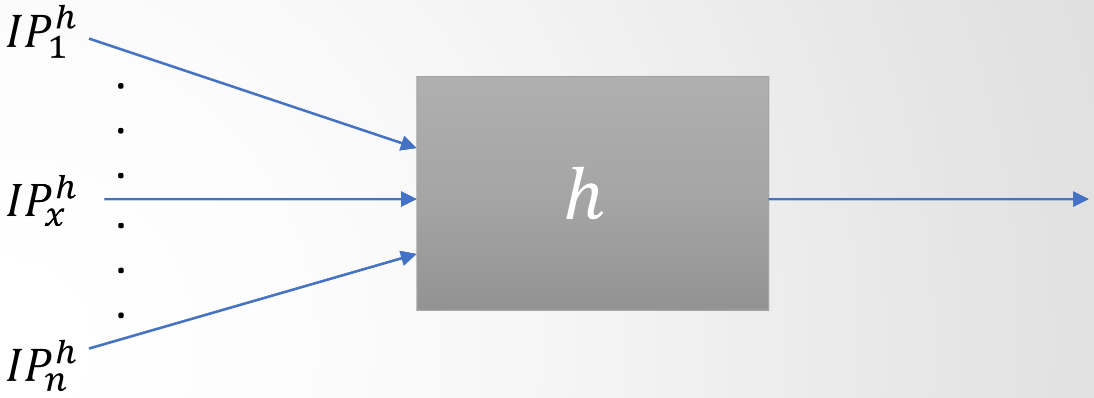




Serialisation effect

Assumption : one level of priority (FIFO)





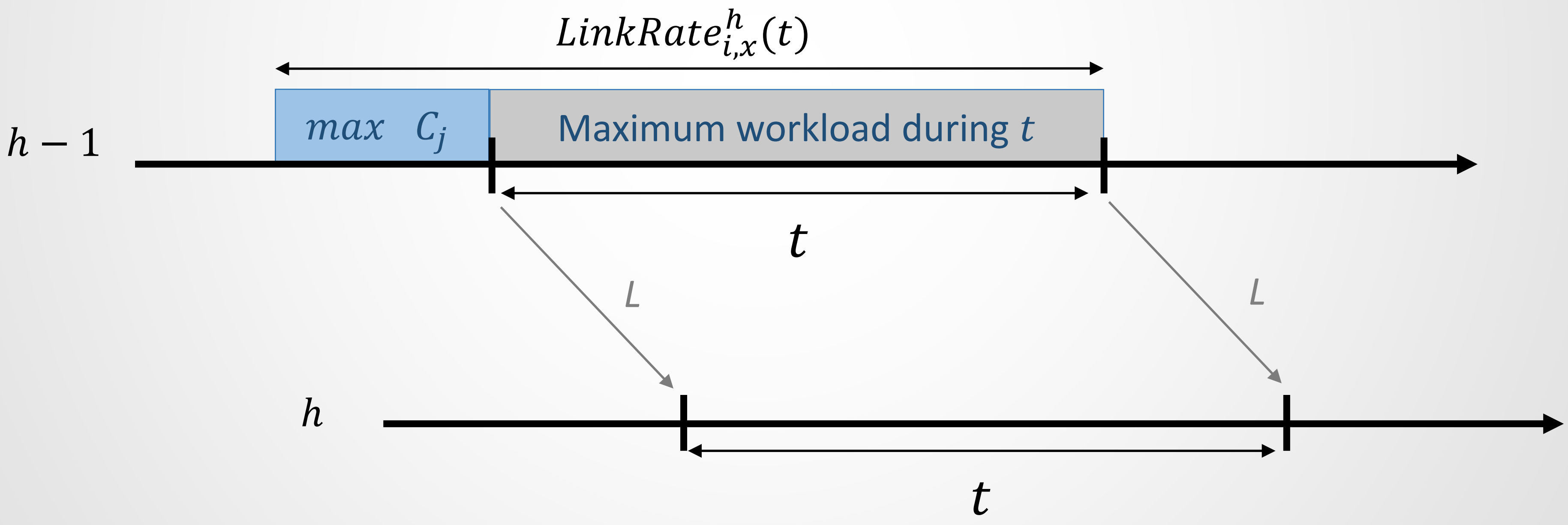
$$W^h(t) = \sum_{x=1}^{n} W_x^h(t)$$

Maximum interference incoming from one input port

Supposition : one level of priority (FIFO)

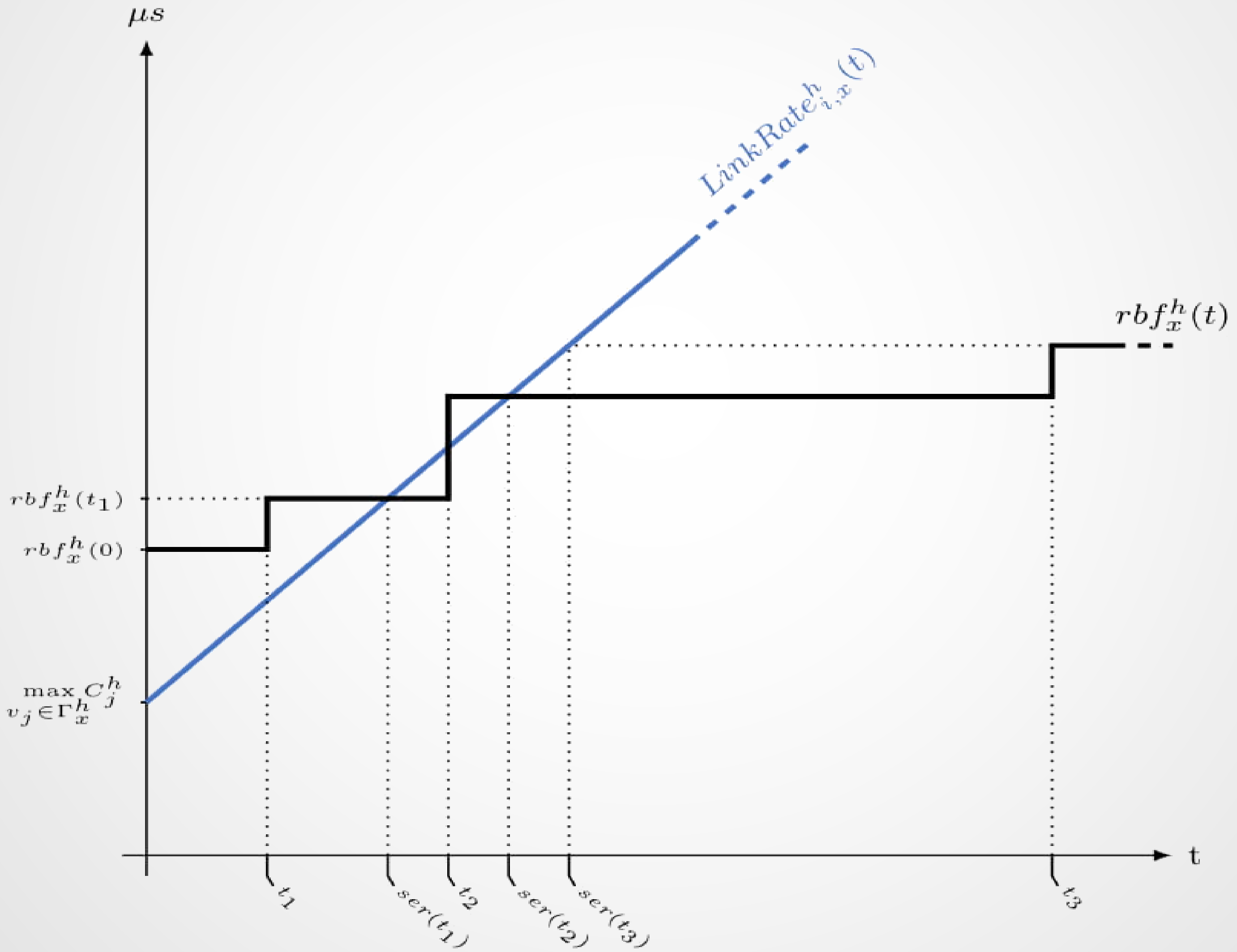
$$W_x^h(t) \leq \sum_{v_j \in \Gamma_x^h} rbf_j^h(t)$$

$$W_x^h(t) \leq LinkRate_{i,x}^h(t)$$



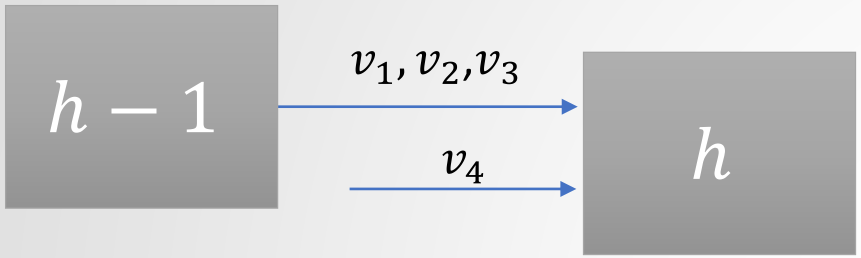
Annexe

Testing time



Annexe

DIFFÉRENCE DE RÉSULTATS POUR DEUX SCÉNARIOS ÉQUIVALENTS



	v_1	v_2	v_3	v_4
C_i	10	10	40	10
P_i	1	2	3	2