Traversal time for weakly synchronized CAN bus

Hugo Daigmorte, Marc Boyer

ONERA – The French aerospace lab

2ème Séminaire Toulousain en Réseaux (STORE)

Travaux présentés dans :

H. Daigmorte, M. Boyer, “Traversal time for weakly synchronized CAN bus”, RTNS 2016.

H. Daigmorte, M. Boyer, J. Migge, “Reducing CAN latencies by use of weak synchronization between stations”, ICC 2017.

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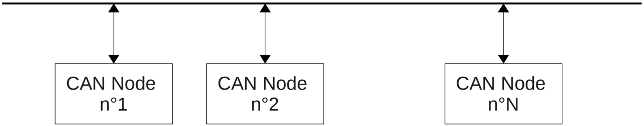
Context

Context

- Real-time networked system
- CAN bus
- Periodic flows with Offsets
  - reduces contentions $\Rightarrow$ reduces delays
  - requires synchronization



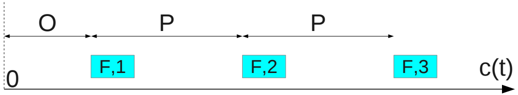
Model and Goal

Model

- Flow F_i: P_i (Period),S_i (maximal frame Size),O_i (Offset)
- N nodes, each node j has a clock: $c_j(t)$
- Sending frame k: $c_j(t) = O_i + kP_i$

Goal

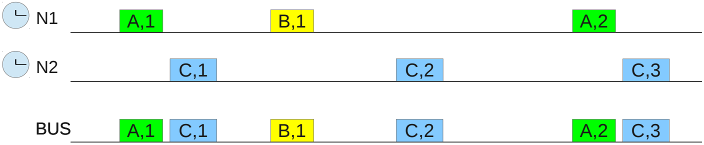
- Accurate bound on network traversal time
  aka Worst Case Traversal Time (WCTT)
- considering *bounded phases*



Global clock

$$\forall j, j' : c_j(t) \approx c_{j'}(t)$$

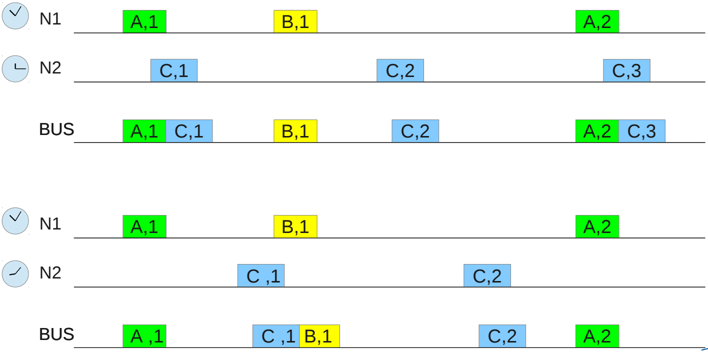
- Advantage: efficient schedule ⇒ no contention
- Drawback: perfect synchronization (HW/SW cost)



Local clocks

Advantage:

- efficient schedule ⇒ no contention intra-nodes
- efficient schedule ⇒ workload spread over time



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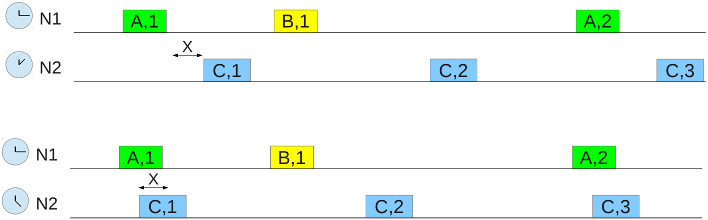
Bounded phases

$$\forall j, j' : c_j(t) - c_{j'}(t) \leq \Phi_{j,j'}$$

Objectives:

- Bounded phases: trade off between global and local clocks
- affordable synchronization
- reduces delays with regard to local clocks



$$|c_1(t) - c_2(t)| \leq x$$

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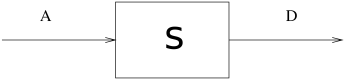
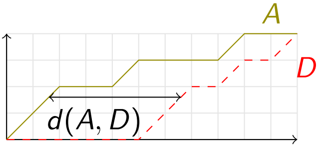
Reality modeling

Network Calculus is a theory designed to compute memory and delay bounds in networks.





- Flow : Cumulative curve A
  - A(t) : amount of data sent up to time t
  - Properties: null at 0 (and before), non decreasing
- Server: simple arrival/departure relation:
  - Property: departure produced after arrival:
    $A \xrightarrow{S} D \implies A \geq D$
- Worst delay: $d(A, S)$

Arrival curve and services

Real behaviors are unknown at design time $\Rightarrow$ use of contracts

Traffic contract: arrival curve

A flow A has arrival curve α iff:

$$\forall t, d \in \mathbb{R}^+ : A(t+d) - A(t) \leq \alpha(d)$$

Server contract: service curve

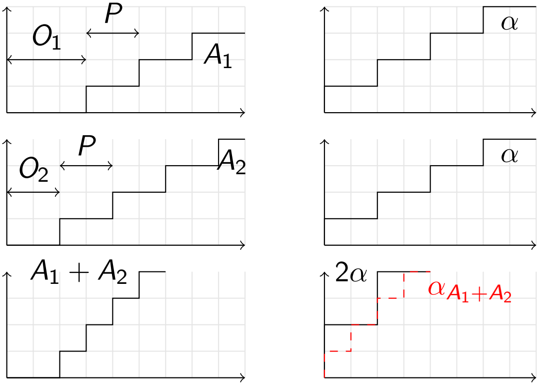
For t, s in the same busy/backlogged period, a server S offers a strict minimal service of curve β iff:

$$D(t) - D(s) \geq \beta(t-s)$$

Arrival curve modeling synchronization

Consider two periodic flows: A_1, A_2:

- what is the arrival curve of each A_i?
- what is the arrival curve of each $A_1 + A_2$?



Arrival curve aggregated flow

Arrival curve for $\sum_{k=1}^{i} A_k$

- $\sum_{i=1}^{k} \alpha_i$ is an arrival curve
  - accurate for *sporadic* messages
  - does not model synchronization
- Capture the synchronization: $\alpha_{1..k}$ (Theorem 5)
  - intra-node (exact)
  - inter-node (bounded)
  - $\alpha_{1..k} << \sum_{i=1}^{k} \alpha_i$
- Efficient algorithm
- Requires common period (flow transformation)

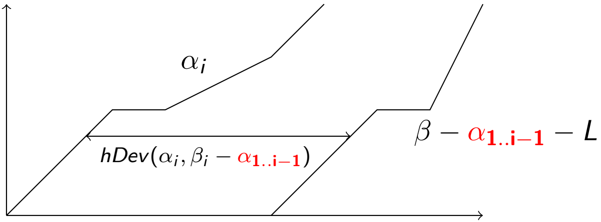
Bounding delay

Consider a flow of interest A_i

- $\sum_{k=1}^{i-1} A_k$ is the aggregate higher priority flow
- 3 methods to upper bound $d(A_i, D_i)$

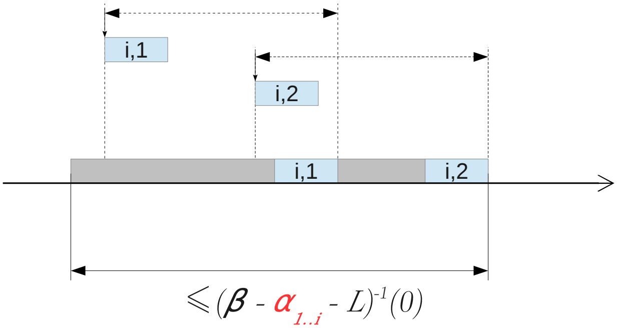
Method 1: higher priority aggregate arrival curve

- State of the art: $hDev(A_i, D_i) \leq hDev(\alpha_i, \beta - \sum_{j<i} \alpha_j - L)$
- Method 1: $hDev(A_i, D_i) \leq hDev(\alpha_i, \beta - \alpha_{\mathbf{1..i-1}} - L)$
  - Taking into account synchronization between flows $A_1..A_{i-1}$
  - Synchronization $A_i \leftrightarrow A_k$ $(k < i)$ is not considered



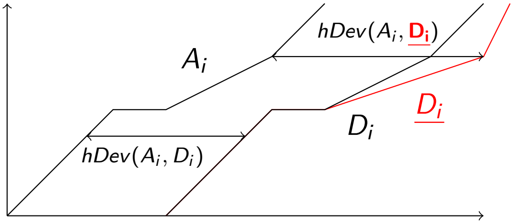
Method 2: bound busy period

- $hDev(A_i, D_i) \leq (\beta - \alpha_{\mathbf{1..i}} - L)^{-1}(0)$
  - Bound busy period for high priority flows (1..i)
  - Pessimistic if several messages of the same flow are in the same busy period



Method 3: bound D

3. Method 3 (Theorem 3): $hDev(A_i, D_i) \leq hDev(A_i, \underline{\mathbf{D_i}})$
    - No arrival curves
    - Accuracy of result depends of knowledge of A_i



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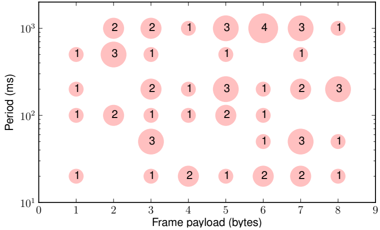
Configuration under study

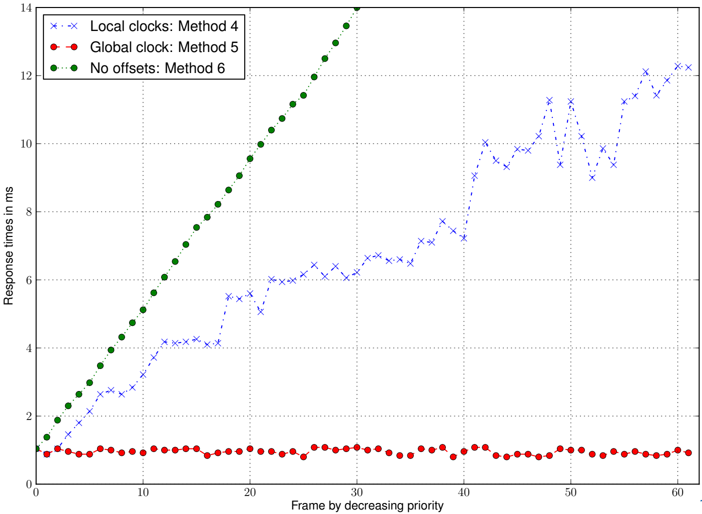
- 250 kbit/s
- 10 nodes
- 62 flows
- Load: 35%
- Period: {20,50,100,200,500,1000}
- Payload: 1-8 bytes



Method	Synchronization	WCTT
Method 1	Phases	Bound
Method 2	Phases	Bound
Method 3	Phases	Bound
Method 4	Local clocks	Exact
Method 5	Global clock	Bound
Method 6	No offsets	Exact

Phases : $c_j(t) - c'_j(t) \leq \Phi$, *Local clocks* : $\Phi = \infty$,
Global clocks : $\Phi = 0$, *No offset* : $O_i = 0/unknown$

Existing methods



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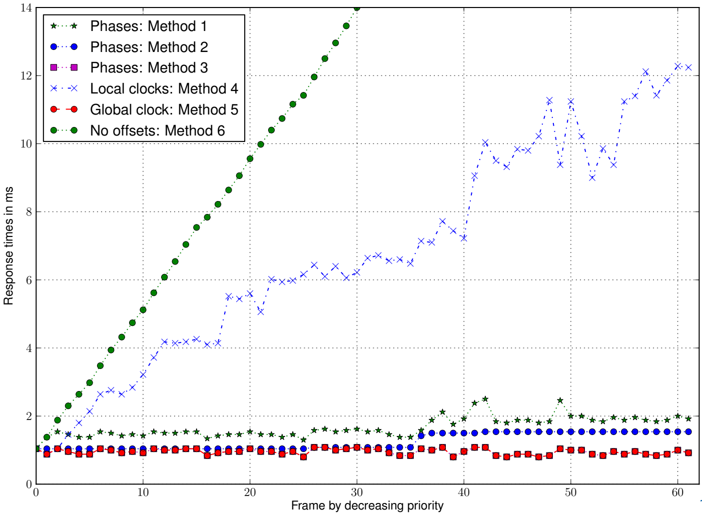
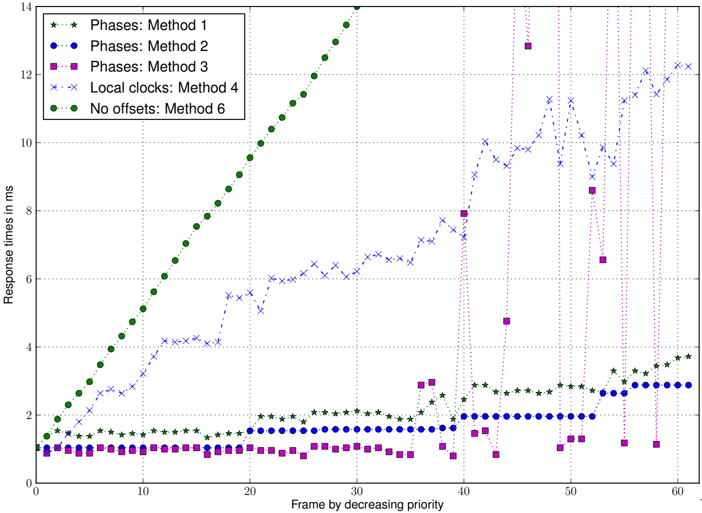
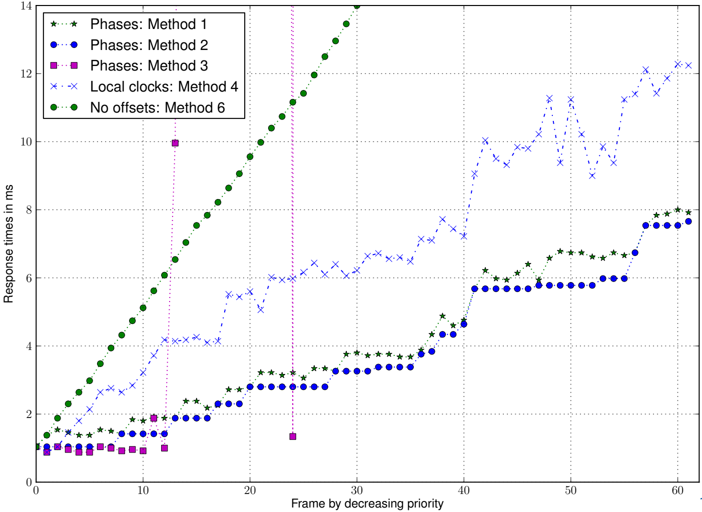
Phases bounded by 0ms



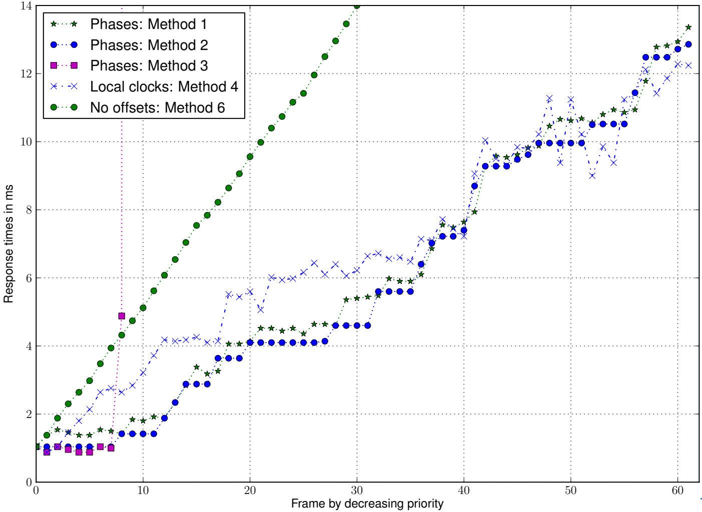
Phases bounded by ± 1ms



Phases bounded by $\pm$5ms



Phases bounded by $\pm$10ms



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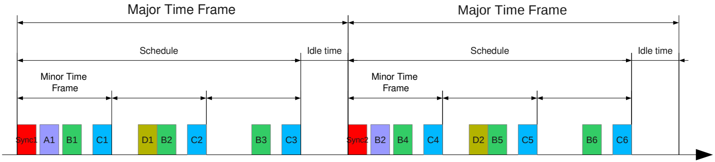
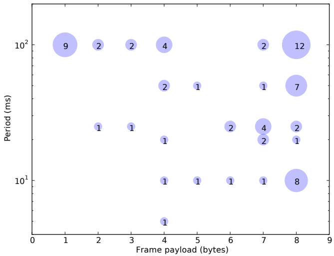
Additional considerations

- Synchronization protocol
  - Periodic message send to each node
- Sporadic/Asynchronous flows and alarms
  - $\beta - \sum_{sporadic} \alpha_i$
- Transmission errors
  - $\beta - \left(N_{error} + \left\lceil \frac{t}{T_{error}} \right\rceil - 1\right)(L_{max} + L_{error})$



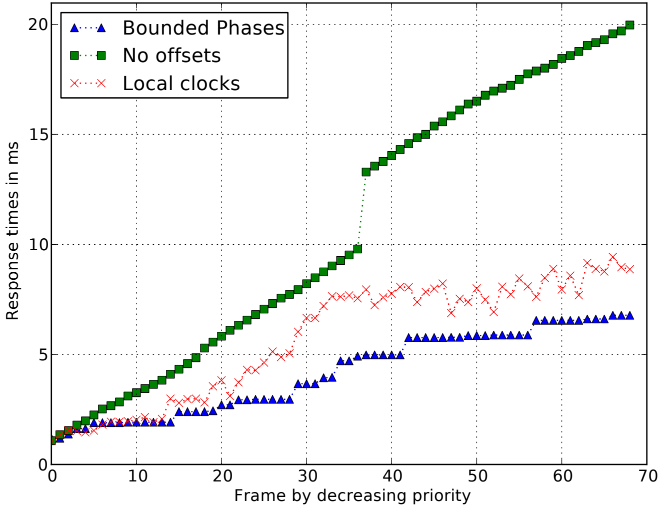
Configuration under study : a real CAN bus configuration [1]

- 500 kbit/s
- 6 nodes
- 69 flows
- Load: 60.25%



Zeng, H., Di Natale, M., Giusto, P., Sangiovanni-Vincentelli, A. (2010). "Using statistical methods to compute the probability distribution of message response time in controller area network." IEEE Transactions on Industrial Informatics 2010.

100% Periodic flows

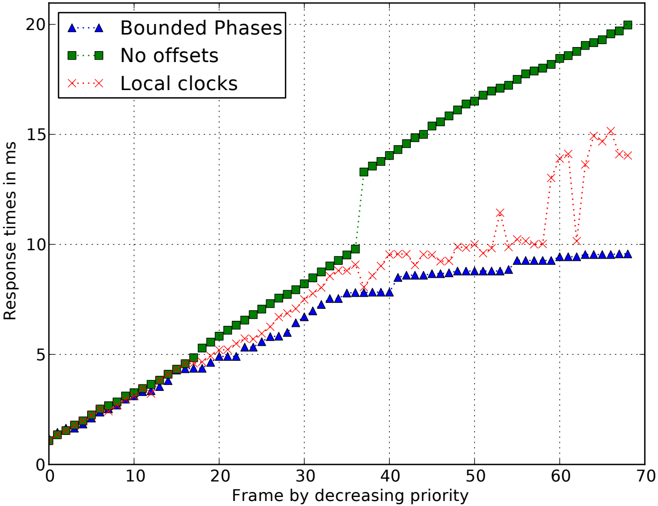


Periodic and Sporadic flows

		Periodic	Sporadic
Priorities	**1-17**	50%	50%
	18-34	75%	25%
	35-69	100%	0%
Part of the load		60%	40%

Distribution between periodic and sporadic messages

Periodic and Sporadic flows



Conclusion

- Offsets pro/cons
  - Pro: reduced contention and delays
  - Cons: global clock has HW/SW cost
- Is there a benefit even with a weak inter-nodes synchronization ?

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- Results : only periodic and no error
  - Phases 10% minimal period ⇒ Gain 75%
  - Phases 50% minimal period ⇒ Gain 45%

Conclusion

- Offsets pro/cons
  - Pro: reduced contention and delays
  - Cons: global clock has HW/SW cost
- Is there a benefit even with a weak inter-nodes synchronization ?
- Results : only periodic and no error
  - Phases 10% minimal period $\Rightarrow$ Gain 75%
  - Phases 50% minimal period $\Rightarrow$ Gain 45%
- Further work
  - Use a large set of configurations
  - Extend the results, obtained on a bus, to a multi-link network.