Evaluation of admissible CAN bus load with weak synchronization mechanism

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ONERA – The French aerospace lab

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Context and goal

Context

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

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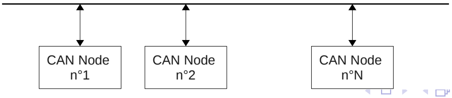
- new offest-based mechanism
- reduces delays
- only periodic flows

Open questions

- quantitative gain evaluation?
- in practice: sporadic, errors?

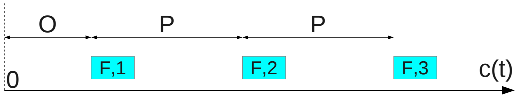


Flow model

Periodic flow

- N nodes
- Flow F_i: j_i (Source node), P_i (Period),S_i (maximal frame Size),O_i (Offset)
- Each node j has a clock: $c_j(t)$
- Sending k-th frame of flow F_i when:

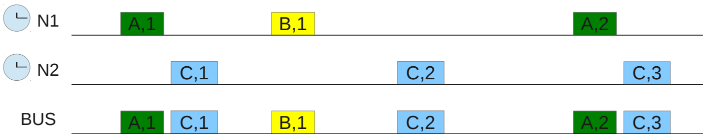
$$c_j(t) = O_i + kP_i$$



Global clock (aka TDMA)

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

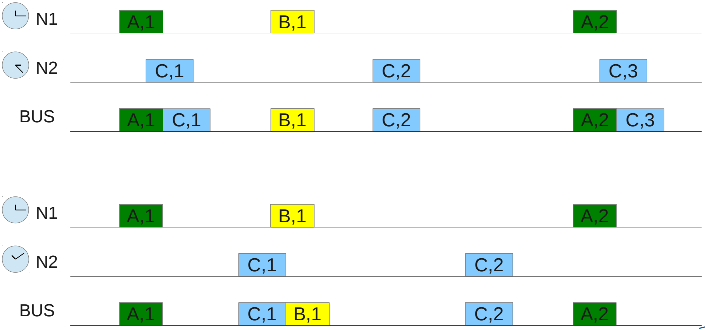
- Advantage: efficient global schedule $\Rightarrow$ no contention
- Drawback: perfect synchronization (HW/SW cost)



Local clocks

Advantages:

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

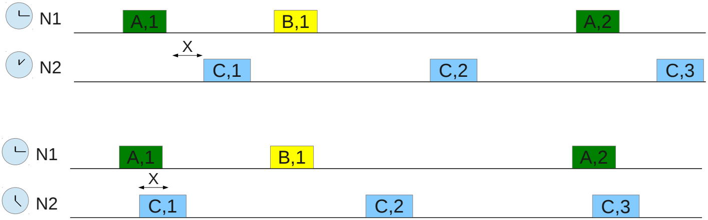


Bounded phases

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

Objectives:

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



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

CAN identifier encodes both label and priority

Each message contains an identifier unique to the whole system:

- used as **priority** to solved bus access contentions
  - ⇒ CAN bus used a non preemptive static priority policy
- used as **label**
  - ⇒ data semantics (engine speed, fuel pressure, etc.)
  - ⇒ filter the message at the reception

CAN, priorities and offset

Priorities greatly influence the bus latency:

Efficient priorities assignment ⇒ load close to 100%

Industrial context ⇒ some or all labels (priorities) are constrained by design constraints:

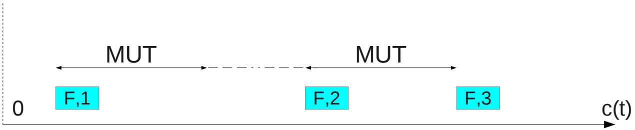
- reusability: try to maximize the reuse of components
- standard: ARINC 825, SAE J1939

Offsets can be used in complement or independently.

Sporadic flows and errors

Sporadic flows

- A frame is sent as soon as a specific event occurs
- Minimum update time *MUT* between two frames



Sporadic flows and errors

Errors are a random phenomenon ⇒ cannot be forecast

⇒ Hypotheses are made at design

Common error model

- N_{error}, the burst errors,maximal number of errors that could occur back-to-back
- T_{error}, the residual error interval

Maximal number of transmission errors during the duration d:

$$N_{error} + \left\lceil \frac{d}{T_{error}} \right\rceil - 1$$

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- Response time depends on several parameters: periods, priority, size, offsets, link speed, nb of nodes, etc,
- Ideal objective:
  - compare bounded phases wrt no offsets and local clocks
  - independently of other parameters
- Realistic but significant measurement:
  - single configuration criteria: breakdown utilisation
  - large number of random configurations
  - $\Rightarrow$ breakdown utilisation distribution

Breakdown utilisation

Breakdown utilisation

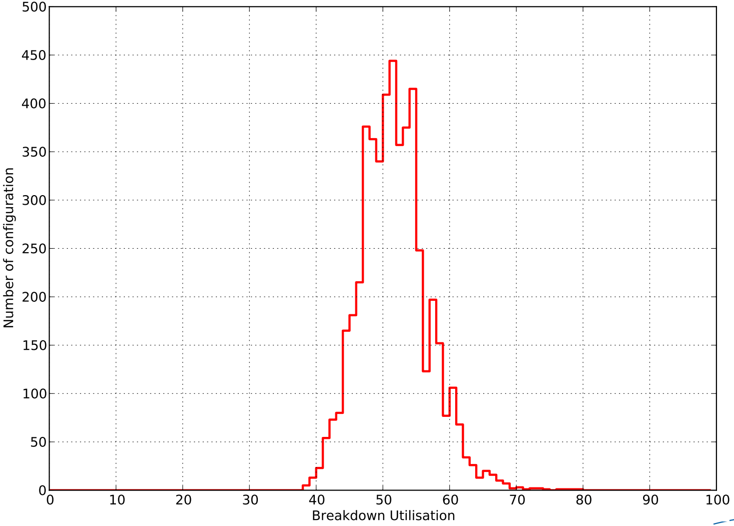
- The maximal load to guarantee that all deadlines are respected

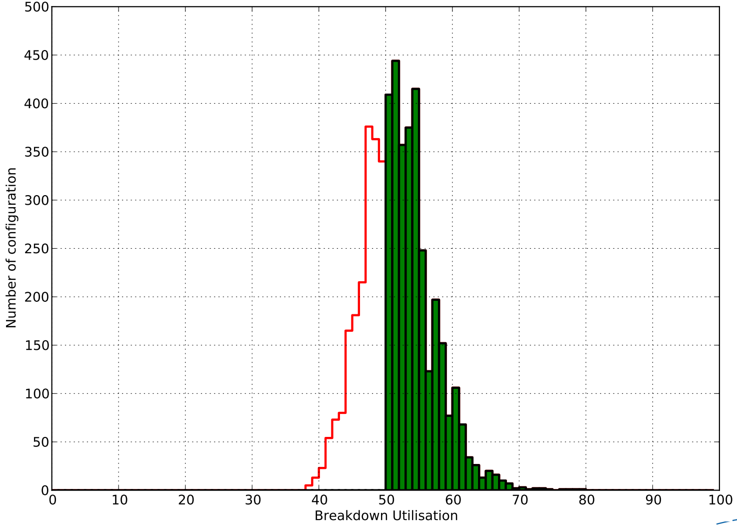
Example

Breakdown utilisation

- Data sent on the network: 150 kbit/s
- The link speed in order to respect all deadlines must be at least: 300kbit/s

$\Rightarrow$ The breakdown utilisation for this configuration is 50%.


500
450
400
350
300
250
200
150
100
50
0
Number of configuration
0
10
20
30
40
50
60
70
80
90
100
Breakdown Utilisation



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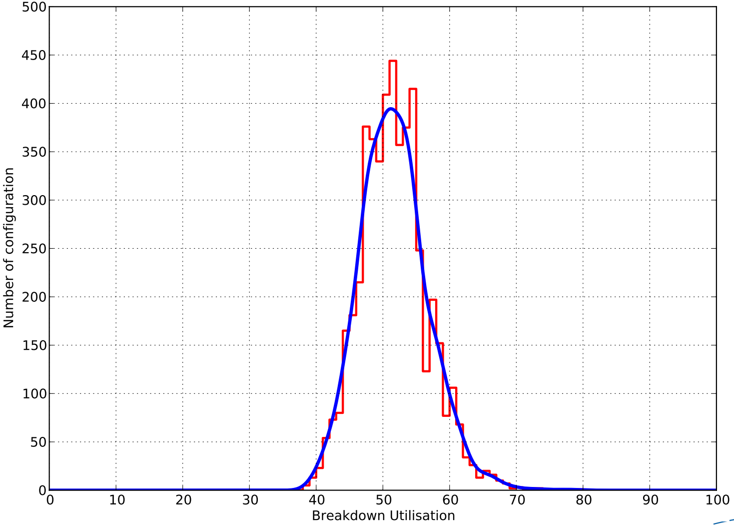

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Configuration pattern under study

Flows characteristics

- Sender: uniform choice between 16 nodes
- Periodic flows
- Period: uniform choice in $\{20, 25, 40, 50, 100, 200\}$ms
- Payload: 8 bytes
- Deadline: equal to their period, *i.e.* implicit deadlines

Nb of flows: such that $150 + \varepsilon$ kbit/s sent on the bus
Offsets chosen using the SOPA algorithm (RTaW-Pegase).

- 5,000 configurations generated.
- Breakdown utilisation for:
  - no offsets
  - local clocks
  - bounded phases (1ms)

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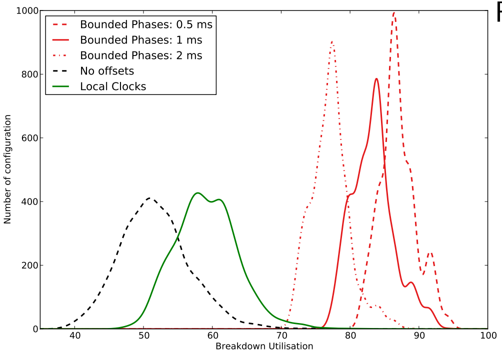
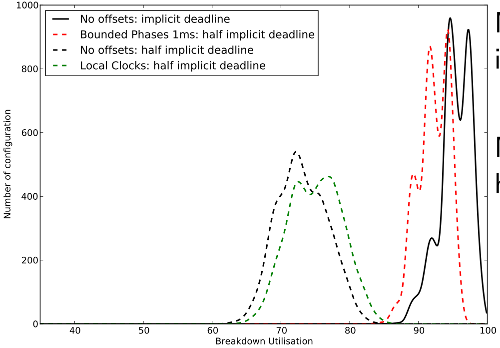
Phases bounded by 0.5-1-2ms



Random priorities:

- No offsets: 52%
- Local clocks: 58%
- Bounded phases 2ms: 77%
- Bounded phases 1ms: 83%
- Bounded phases 0.5ms: 87%

Combining priorities and offsets



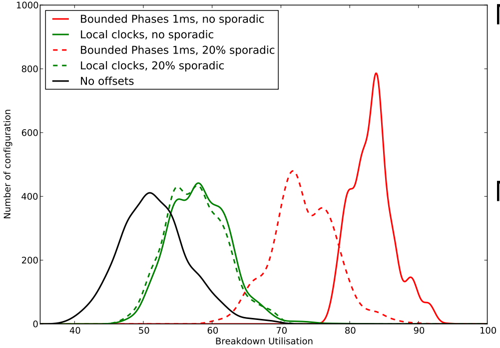
Monotonic assignment, implicit deadlines:

- No offsets: 95%

Monotonic assignment, half implicit deadlines:

- No offsets: 73%
- Local clocks: 75%
- Bounded phases: 92%

No errors, 20% sporadic



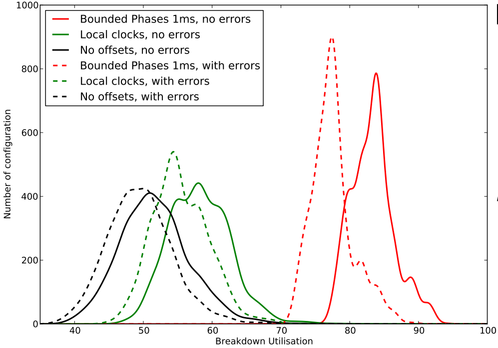
No errors, no sporadic:

- No offsets: 52%
- Local clocks: 58%
- Bounded phases: 83%

No errors, 20% sporadic:

- No offsets: 52%
- Local clocks: 57.5%
- Bounded phases: 73%

Errors, No sporadic



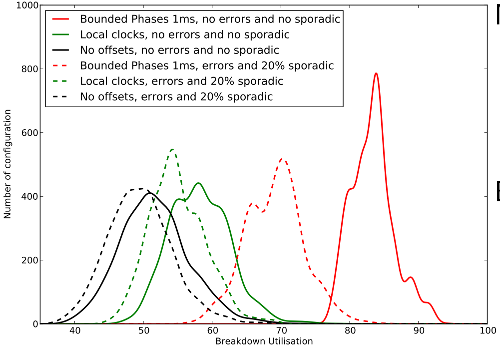
No errors, no sporadic:

- No offsets: 52%
- Local clocks: 58%
- Bounded phases: 83%

N_{error}=2, T_{error}=100ms:

- No offsets: 50%
- Local clocks: 55%
- Bounded phases: 77%

Errors, 20% sporadic



No errors, no sporadic:

- No offsets: 52%
- Local clocks: 58%
- Bounded phases: 83%

Errors, 20% sporadic:

- No offsets: 50%
- Local clocks: 55%
- Bounded phases: 69%

Conclusion

Offsets

- ☺ reduce contention and delays
- ☹ global clock has HW/SW cost

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⇒ Is there a benefit even with a weak inter-nodes synchronization?

RTNS 2016

Bounded phases:

- reduces delays
- only periodic flows

2017 contribution:

- breakdown utilisation distribution
- no offsets, local clocks, bounded phases
- purely periodic, mixing periodic and sporadic, with errors

Conclusion

- Results on 5,000 configurations:
  - very important gain with only periodic
    $\Rightarrow$ 25% wrt local clocks
  - complementary with priorities assignment
  - compatible with sporadic flows
    $\Rightarrow$ 15% wrt local clocks with 20% sporadic
  - significant impact of errors

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- Further work
  - offset assignment when some offsets are already set
  - combine the priorities assignment and the offsets assignment

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Local clocks and computation time

Two methods for bounds in the case local clocks:

- transaction based [1]
- network calculus based (contribution)

Only one plotted in this presentation (the best calculable one).

	Transaction based	Network calculus based
Accuracy	Exact (up to one frame length)	Upper bound
On test cases	same breakdown $\pm$ 3%	
Computation time	mn up to h	mn
On test cases	7mn-2h10	1-1.5mn
Sporadic	No (can be adapted)	Yes

Yomsi, P. M., Bertrand, D., Navet, N., & Davis, R. I. (2012, May). Controller area network (can): Response time analysis with offsets. In Factory Communication Systems (WFCS), 2012 9th IEEE International Workshop on (pp. 43-52). IEEE.