Accuracy of Network Calculus for Embedded Systems: Successes and Challenges

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ONERA – The French Aerospace Lab

2nd Workshop on Network Calculus (WoNeCa-2)
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retour sur innovation

Outline

Disclaimer

Theses slides have been made for the support of an open workshop oral discussion, not as a robust and fair overview of the research area.
In particular:

- references have not been chosen to identify the first author(s) of a result, as is standard academic citation policy, but as the ones that I can quickly identify: I have done theses slides in a short time
- the "challenge" list is not a list of "no result" topics, but where, IMHA, lot exiting research is still to be done,
- a lot of interesting results have not been cited, and in particular:
  - all works of the MPA/RTC area [Wandeler and Thiele, 2006], since the advances in the considered period seems not directly apply on AFDX,
  - all works on Event Stream [Henia et al., 2005, Rox and Ernst, 2010], MAST [Gutiérrez et al., 2012] and trajectories [Bauer et al., 2010], even if is has been applied to AFDX, because this talk about network calculus

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Once upon a time (1999-2004)

Work done (2004-2014)
- Formal framework
- Tightness in theory
- Accuracy in practice

Challenges

Miscellaneous

Conclusion

Network calculus for AFDX

AFDX: Avionic Full DupleX

- Standard ARINC 664 P7
- Ethernet tailored for avionic needs
  - Flows: Virtual links (Token-Bucket + static routing)
  - Network: Full duplex, FIFO + SP

⇒ should have bounded delays ?

⇒ how to compute and prove it ?

- $\approx$ 1999 Rockwell Collins ($\approx$ Airbus) request to Fabrice Frances and Christian Fraboul (Univ. Toulouse, France)

⇒ Jérome Grieu PhD [Grieu et al., 2003, Grieu, 2004] use of *deterministic* network calculus

Network Calculus for AFDX ... in practice

From Grieu PhD

- AFDX model in network calculus
- Qualified tool (Rockwell Collins)
- Used to certify A380, A350, A400M

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Next steps:

- Better (smaller) bounds
- Modelling new buses, policies...
- Still in “trustable” framework

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  [Bouillard et al., 2009, Bouillard et al., 2010a, Bouillard, 2011]

  - a lot of *kind* of services exists (simple, strict, weakly strict, sufficiently strict, RTC, variable node capacity)
  - why using one or another?
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- Left or right continuity of flows? [Boyer et al., 2013]
  - Left-continuous for all proofs except the ones on packets.
  - Does not really matter...

Min-plus algorithms

Network calculus requires implementation of operations: minimum, sum, convolution, deconvolution, horizontal deviation

- Token-bucket and rate-ralenty ($\gamma_{r,b}(t) = rt + b$, $\beta_{R,T} = R[t - T]^{+}$: analytical solutions
- Concave/convex piecewise linear functions (CPL, [Cruz, 1998])
  - natural representations
  - long list of implementations (too long for this slide)
  - simple implementation of convolution
- Ultimately pseudo-periodic functions (UPP, [Bouillard and Thierry, 2008])
  - set of any segments
  - with a finite prefix and a periodic "pattern"
- Containers [Le Corronc et al., 2014]
  - efficient "approximation" of operations
  - complexity $O(n)$ or $O(n \log(n))$

Outline

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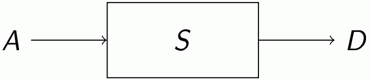
Graal: exact delay

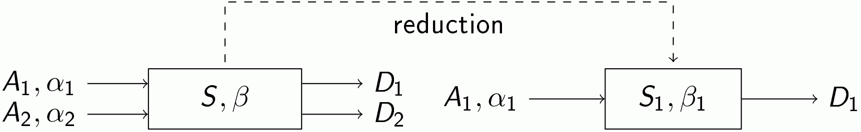
Tightness

The computed bound is *the* worst case, *i.e.* it exists a configuration such that the bound is reached.



Well known for single server, single flow system: for any arrival curve α and service curve β, it exist A_α and S_β such that $d(A_\alpha, D_\beta) = d(\alpha, \beta)$.

Tightness and service policies



Exact delay for

- Blind, SP [Bouillard et al., 2010b]
- FIFO [Bouillard and Stea, 2012]

Conjecture of exactness for

- Non-preemptive SP with fixed sizes [Mangoua Sofack and Boyer, 2012, Chokshi and Bhaduri, 2008]
- Deficit Round Robin [Boyer et al., 2012b]

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- Algebraic solutions can be arbitrary large [Schmitt et al., 2008]
- Solutions
  - identification of specific sub-cases (topology, policy...)
  - optimisation problem [Schmitt et al., 2008, Lenzini et al., 2004, Bouillard et al., 2009, Lenzini et al., 2004, Bouillard and Stea, 2012]

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  - restriction to piecewise concave/convex functions

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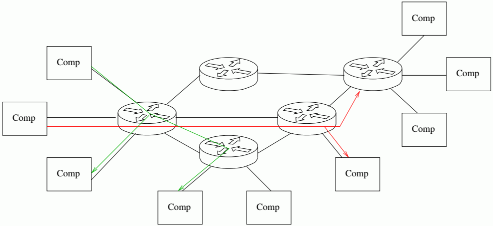
Accuracy on AFDX configurations



AFDX configurations:

- $\approx$ 100 sources/sink
- $\approx$ 5-10 switches $\Rightarrow$ $\approx$ 100 “servers”
- $\approx 10^4$ data flows (Virtual links)
- load $\approx 10\% - 20\%$
- cycle free

AFDX analyses with NC: 2004-2014

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Implemented in RTaW-PEGASE.

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Formal challenges (IMHA)

- Packets
  - packets results are based on maximal size
  - how to mix small and large packet?
  - for packet-based policies
  - first model [Bouillard et al., 2011, Bouillard et al., 2012]
- Feeback
  - Protocols with feedback: Wormhole routing, TCP
  - Applicative feedback
- Cyclic dependencies [Jonsson et al., 2008]
- Inversion problem [Le Corronc et al., 2010]
  - classical approach: from flows and servers, computes delay/memory bounds
  - synthesis problem: which flows/servers to guarantee a bound?

Applicative challenges

- New networks
  - AVB/TSN
  - ARINC 825
- Network on chip
- Integration scheduler/task and network/messages
  - task release by message reception
  - task duration independent of message size
  - messages send at end of task
- Design help
  - synthesis (inversion)
  - sensitivity analysis
  - ...

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- Coming soon: another book on *deterministic* network calculus
  - Anne Bouillard, Marc Boyer, Euriell Le Corronc
  - Summing up last 10 years
- NetAirBench
  - configuration generator
  - creation of public test benches

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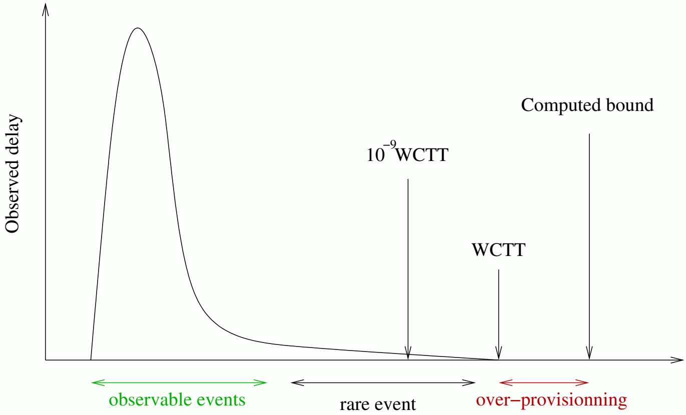
Questions?

Stochastic bounds for embedded system



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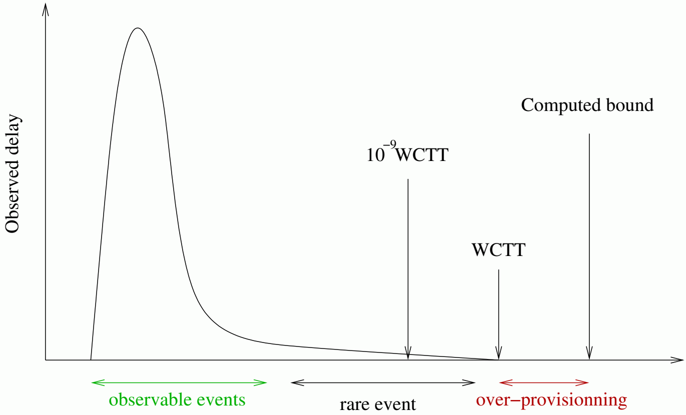

- How to get input probabilities?
- Where are the stochastic bounds wrt deterministic bounds?

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