Integrating end-system frame scheduling for more accurate AFDX timing analysis

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Outline

Context: bounding AFDX communication delay

Opening the end-system box

Gain evaluation on a case study

Conclusion
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Real-Time distributed systems:
- AFDX $\approx$ Ethernet technology for avionics
- $\approx$ hundred of computers
- $\approx$ 5–10 switches
- $\approx$ thousands of data flows
What is the worst-case network traversal time?

- Needed to ensure correct real-time behavior
- Used to dimension the system:
  - if unsatisfied, change the system
- Worst case based on AFDX behaviour
  - Input flows (VL: virtual link) are constrained
    - Maximal frame size
    - Known static routing
    - Minimal time interval between two frames (BAG: Bandwidth Allocation Gap)
  - Network behaviour is known
    - Full duplex: direct access
    - Queue policy: FIFO, Static Priority
WCTT bounds

**WCTT bound**

How to upper bound the WCTT?

- The exact WCTT is unknown
- Several methods exist:
  - network calculus: used for A380, A350 [5, 4]
  - event model (Symtavision) [7, 12]
  - holistic scheduling (MAST) [6]
  - trajectorial-based approaches [1, 9, 8]
  - ad-hoc methods
- Accuracy of results:
  - NC pessimism ($|WCTT_{bound} - realWCTT| \leq 20\%$ on “typical” configurations
  ⇒ not so much to gain
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What is the AFDX end-system?

- **End-System role**
  - multiplex access to the output
  - guarantee BAG respect
Why BAG guarantee is not trivial

Even if all VL are synchronous

- multiplexing introduced jitter
- jitter must be bounded
- the standard gives requirement on jitter ($\leq 500\mu s$)
Opening the black-box

More knowledge on the system
⇒ more accurate model
⇒ more accurate bounds
A periodic End-System

Assuming periodic output flows [11, 10]:

- VL $i$ can send frames at $t_k^i = \phi_i + k \times BAG_i$
- $\approx$ local TDMA
- adequate choice of offset $\phi_i$
- must synchronise applications and End-System or pay BAG as End-System Delay
- gain: decrease network delay up to 51%

![Diagram showing periodic output flows and offsets](image-url)
Removing end-system

Assuming no End-System [2, 3]:

- consider task scheduling (static priority)
- theoretical model
- AER: Acquisition - Execution - Restitution model (frame send at end of execution)
- no respect of jitter bound
- (local) gain: linear with number of tasks
The Thales End-System

- An implementation of the standard
- Exact behaviour is confidential
  - respect the $500\mu s$ jitter
  - some flows can be “prioritised”
    $\Rightarrow$ end-system delay $\leq 1ms$
- The behaviour is a scheduler
  $\Rightarrow$ use the “same” techniques as [2, 3]
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A realistic AFDX network

<table>
<thead>
<tr>
<th>Entities</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>End Systems</td>
<td>104</td>
</tr>
<tr>
<td>Switches</td>
<td>8</td>
</tr>
<tr>
<td>Virtual Links</td>
<td>974</td>
</tr>
<tr>
<td>Latency constraints</td>
<td>6501</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VL destinations</th>
<th>BAG</th>
<th>Maximal Packet Size</th>
<th>Traversed Switches</th>
<th>Latency Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>minimum</td>
<td>1.0</td>
<td>2 ms</td>
<td>100 bytes</td>
<td>1</td>
</tr>
<tr>
<td>average</td>
<td>6.6</td>
<td>60 ms</td>
<td>380 bytes</td>
<td>1.3</td>
</tr>
<tr>
<td>maximum</td>
<td>84.0</td>
<td>128 ms</td>
<td>1500 bytes</td>
<td>4</td>
</tr>
</tbody>
</table>
Experiment

- Purely periodic
  
  Configure ES to have purely periodic behaviour

- All VLs in local high-priority class
  
  - minimise ES delay for all VL
  
  - no more respect of 1 ms local delay
  
  - create bursts

- VLs with $\text{BAG} \leq 8\text{ms}$ in local high-priority class
  
  - select some VLs
  
  - allow to “shape” the output
Experiment

- Purely periodic
  Configure ES to have purely periodic behaviour
- All VLs in local high-priority class
  - minimise ES delay for all VL
  - no more respect of 1 ms local delay
  - create bursts
- VLs with $\text{BAG} \leq 8\text{ms}$ in local high-priority class
  - select some VLs
  - allow to “shape” the output

<table>
<thead>
<tr>
<th>End-systems configuration</th>
<th>Average gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purely periodic</td>
<td>42%</td>
</tr>
<tr>
<td>All VLs in local high-priority class</td>
<td>26%</td>
</tr>
<tr>
<td>VLs with $\text{BAG} \leq 8\text{ms}$ in local high-priority class</td>
<td>38%</td>
</tr>
</tbody>
</table>
Plotting delais

Plotting, for each VL:
- WCTT bound with black-box End-systems
- WCTT bound with Thales End-System
- sorted by Thales-WCTT
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- More information gives better bounds but often related to specific cases
- contribution:
  dramatic increase of bound accuracy

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