Trends in avionics Switched Ethernet networks

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A full-duplex switched Ethernet network with classical IEEE 802.1d forwarding mechanism

Each node uses traffic shaping technique
  - Flows are statically defined
  - All flows have the same priority
  - A sporadic flow \( i \) is characterized by a maximum frame size and a minimum inter frame gap

Each switch uses static routing mechanism (static allocation of flows on the network)

Each output port has a buffer and supports FIFO policy (in fact two buffers are implemented)
Waiting time in output buffers

- FIFO buffers: highly variable delays and possible overflows

```
IN   OUT
Switch FIFO Queue
VS
```

= Backlog
Interconnect aircraft functions in avionics domain using IMA

- Two redundant networks
- 8 switches per network, each switch has 24 ports
- 123 end systems
- 984 VLs, 6412 paths
- 100 Mbits data rate
Taxonomy of AFDX Network

- Most of VLs have BAG $\geq$ 16 ms
- Most VLs have max packet size $\leq$ 300 bytes
- Mostly VLs cross 2 to 3 switches

<table>
<thead>
<tr>
<th>BAG (ms)</th>
<th>Number of VLs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>8</td>
<td>78</td>
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<td>16</td>
<td>142</td>
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<tr>
<td>32</td>
<td>229</td>
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<tr>
<td>64</td>
<td>220</td>
</tr>
<tr>
<td>128</td>
<td>225</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Packet size (bytes)</th>
<th>Number of VLs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-150</td>
<td>561</td>
</tr>
<tr>
<td>151-300</td>
<td>202</td>
</tr>
<tr>
<td>301-600</td>
<td>114</td>
</tr>
<tr>
<td>601-900</td>
<td>57</td>
</tr>
<tr>
<td>901-1200</td>
<td>12</td>
</tr>
<tr>
<td>1201-1500</td>
<td>35</td>
</tr>
<tr>
<td>$&gt;1500$</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No of crossed switches</th>
<th>Number of paths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1797</td>
</tr>
<tr>
<td>2</td>
<td>2787</td>
</tr>
<tr>
<td>3</td>
<td>1537</td>
</tr>
<tr>
<td>4</td>
<td>291</td>
</tr>
</tbody>
</table>
End to end delay analysis methods

- Different techniques for End-to-End communication delay analysis
- Estimation using simulation techniques. Under approximation
- Sure upper-bounds using analytical methods such as network calculus approach and Trajectory approach. Over approximation
- Exact worst case delays computation using Model Checking
Network Calculus delay analysis

- How NC handle huge amount of cases
  - Pessimistic models based on over approximation; to reduce computation complexity
How Trajectory handle huge amount of cases

- Pessimistic models based on over approximation; to reduce computation complexity

**Trajectory delay analysis**

**Exact vs Trajectory**

- Sum of all packets & largest packet twice:
  - Exact: $100 + 100 + 100 + 100 + 100 = 500$
  - Trajectory: $50 + 100 + 100 + 100 + 100 = 450$
Model Checking approach

- Computing exact worst case E2E delay of industrial scale AFDX network is complex and huge.
- Modified Model checking approach is able to compute exact WC E2E delays for 64% of the network VL paths: 4099 paths out of 6412;
- Allows computation of exact pessimism in analytical approaches such as NC and Trajectory;
- Modified model checking approach could be applied to large scale application, to find exact worst case scenarios.
Pessimism of delay analysis

- Under approximation of reachable scenarios can be compared with NC/Trajectory results to analyze their pessimism
Pessimism analysis

- Exact pessimism of NC and Trajectory for 64% of paths
  - Avg pessimism of Trajectory = 6%, NC = 13%

- Consequently AFDX is under used in average
- Sizing of buffer has to take into account very rare events
Synchronisation of AFDX flows

• Flows emitted by the same End System can be synchronized
• Offsets can be introduced on periodic flows
• Near-optimal offset assignment algorithm
• Integration in Network Calculus and Trajectory approach
• End to end delay improvement
Synchronisation of AFDX flows

Network calculus approach

- Normalized reference values (100): classical approach
- Normalized comparison values: modified approach
- Average improvement: 49.7%, Maximum improvement: 83%
Synchronisation of AFDX flows

Network calculus approach

- A scenario with partial dependencies
- 2964 paths with known offsets, 3448 paths without known offsets
- Average improvement: 16.7%
- Dependent paths: 17.2%, independent paths: 16.1%
Synchronisation of AFDX flows

Trajectory approach

<table>
<thead>
<tr>
<th>Improvement (%)</th>
<th>Nb of ES output ports</th>
<th>Nb of switch output ports</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>0</td>
<td>72</td>
</tr>
<tr>
<td>10-20</td>
<td>0</td>
<td>44</td>
</tr>
<tr>
<td>20-30</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>30-40</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>40-50</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>50-60</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>60-70</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>70-80</td>
<td>42</td>
<td>0</td>
</tr>
<tr>
<td>80-90</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>90-100</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

- Most end system output ports have a reduced burst workload of more than 70%.
- Most switch output ports have a reduced burst workload of 10%.

- Average improvement 50%, maximum improvement 82%
- Scenario with partial dependancies: average improvement of 17%
QoS aware AFDX Network

Static Priority multi FIFO Queuing
Trajectory approach and QoS
Trajectory approach and QoS
QoS aware switch optimisation

- Priority assignment to VLs (without any additional knowledge on existing Vls)
- Overall worst case delay reduction objective 20%
- Assignment on two priority levels (Optimal priority Assignment)

- Further evaluation on larger number of priority levels
- Minimisation of the size of needed buffers (QoS Switch) : maximum backlog
Perspectives

• Further Improvement on end to end delay evaluation
  • More properties (e.g. Indirect Interference)?
    • Some VLs don’t share port with packet under study but they are taken into account

• Generalization to other switched Ethernet based networks (e.g. QoS aware networks)
  • IEEE 802.1p, TTEthernet, EtherCAT

• Application to other embedded networks (e.g. wormhole routing such as SpaceWire, NoC)
  • Not only knowledge of previous packets but also of packets that will arrive after on the path
Perspectives

• Heterogeneous networks: CAN + AFDX
  • Easy to model each network independently
• Integration in the global avionics design and development system: IMA
  • Application level E2E delay
• Extension to probabilistic end to end bounds?
  • Exact WC is rare scenario
  • Objective is to fully utilize resources
    • WC=2ms, Application Constraint=1.5ms
    • What is probability to exceed given constraint?
  • Still an open problem, consider other criteria