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▶ **To cite this version:**

Tasnim Hamza, Jean-Luc Scharbarg, Christian Fraboul. QoS-aware AFDX: Benefits of an efficient priority assignment for avionics flows. IEEE Real-Time Systems Symposium : Work-in-progress session - RTSS 2013, Dec 2013, Vancouver, Canada. pp. 13-14. hal-01148017

HAL Id: hal-01148017
https://hal.science/hal-01148017

Submitted on 4 May 2015

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Eprints ID : 13179

To cite this version : Hamza, Tasnim and Scharbarg, Jean-Luc and Fraboul, Christian *QoS-aware AFDX: Benefits of an efficient priority assignment for avionics flows*. (2013) In: IEEE Real-Time Systems Symposium : Work-in-progress session - RTSS 2013, 3 December 2013 - 6 December 2013 (Vancouver, Canada).

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QoS-aware AFDX: benefits of an efficient priority assignment for avionics flows

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***Abstract*—AFDX (Avionics Full Duplex Switched Ethernet) standardised as ARINC 664 is a major upgrade for avionics systems. The certification imposes to guarantee that the end-to-end delay of any frame transmitted on the network is upper-bounded and that no frame is lost due to buffer overflow. This guarantee is obtained thanks to a worst-case analysis assuming a FIFO scheduling policy of flows on each output port.**

For future aircraft, it is envisioned to modify AFDX switch and to use a Fixed Priority scheduling policy of flows (QoS AFDX using IEEE 802.p mechanisms). A worst-case analysis of such a network has been proposed, based on the Trajectory approach.

But the remaining issue is to efficiently assign available priorities to the avionics flows inside the network without modifying the application knowledge. The objective is then to minimise overall the worst case end to end delay of flows and consequently to minimise needed buffer size at switch level.

The main contribution of this paper deals with the assignment of priorities to the flows using the well-know Optimal Priority Assignment algorithm (OPA) which was first defined for mono-processor preemptive systems. The schedulability test is then based on the worst case delay analysis of each flow allocated on the AFDX QoS network computed by the trajectory approach.

The proposed mechanisms have been applied on an industrial AFDX case study using two priority levels and the overall worst-case delay could be reduced by 20 %.

I. Context

Full duplex switched Ethernet eliminates the inherent indeterminism of vintage (CSMA-CD) Ethernet. Nevertheless, it shifts the indeterminism problem to the switch level where various flows can compete for output ports.

Avionics AFDX multicast flows are called Virtual Links (VLs) [1]. They are statically defined (burst and rate contract) and are statically mapped on the network of AFDX switches.

For a given VL, the end-to-end communication delay of a packet is the sum of transmission delays on links and latencies in switches. As the links are full duplex there is no packet collision on links. The transmission delay only depends on the transmission rate and on the packet length. But, the latency in switches is highly variable because of the confluence of asynchronous VLs, which compete on each switch output port (according to a scheduling policy).

Many work has been devoted to the worst case analysis of end-to-end delays on an AFDX network implementing FIFO scheduling policy. For certification reasons, a first tool, based on the Network Calculus theory and implemented by Rockwell Collins, has been proposed for the computation of an upper bound for the end-to-end delay of each VL. This approach models the traffic on the AFDX network as a set of sporadic flows with no QoS classes differentiation. A second approach based on the trajectory concept has been proposed [2]. It identifies for a given frame all the competing frames which can delay this frame in all the output ports visited.

This second approach has been generalised in order to implement a Fixed Priority scheduling policy of QoS-aware AFDX network [3]. A worst-case analysis of such a network has been proposed. It can be applied for any number of priority levels and gives tight end-to-end delay upper bounds.

The remaining issue is to assign priorities to VLs in order to demonstrate the efficiency of QoS aware switches. A relevant objective for this priority assignment consists in minimising the overall worst case end-to-end delay of VLs. Indeed, the worst-case end-to-end delay of a VL highly depends on its path. When all the VLs have the same priority, it leads to very different worst-case delays for different VLs. Assigning priorities to VLs should reduce this difference, leading to smaller higher delays. This priority assignment must be done without additional knowledge of avionics flows.

II. Priority assignment for QoS-aware AFDX

An Optimal Priority Assignment algorithm (OPA) has been proposed in the context of monoprocessor preemptive systems [4]. For an asynchronous periodic task set, OPA generates an optimal priority ordering while using a polynomial number of schedulability tests. It first assigns the lowest priority to one task which respects its deadline with this lowest priority. It continues till the remaining unassigned set of tasks is empty. If at a step no task can be assigned the current priority, no feasible priority assignment exists. At each step, a schedulability test is applied to the task which is assigned the current priority in order to determine whether it respects its deadline or not. The schedulability test has to be OPA compatible. It means that it has to respect the following conditions:

- *Condition 1:* Schedulability of a task may, according to the test, be dependent on the set of higher priority tasks, but not on their relative priority ordering.
- *Condition 2:* Schedulability of a task may, according to the test, be dependent on the set of lower priority tasks, but not on their relative priority ordering.
- *Condition 3:* When the priorities of any two tasks of adjacent priority are swapped, the task being assigned the higher priority cannot become unschedulable according to the test, if it was previously deemed schedulable at the lower priority.

A first extension of OPA has been proposed in order to minimise the number of priority levels [4]. Indeed concrete systems support a limited number of priority levels. The minimisation is achieved by successively maximising the number of tasks assigned to priority levels from the lowest one to the highest one. OPA has also been extended to other types of systems (e.g. multiprocessor systems) [5]. In most cases the priority assignment is no more optimal since the schedulability test is not exact. However OPA-based solutions are often better than solutions considering heuristic priority assignment [5].

Algorithm 1: Proposed approach algorithm

```
for (each priority level i, lowest first) do
    for each unassigned VL v do
        if (v feasible with priority i assuming that all
        unassigned VL have higher priority) then
            assign priority i to v;
        end
    end
    if (no VL is feasible with priority i) then
        return unschedulable ;
    end
    if (no unassigned VL remains) then
        break ;
    end
end
return schedulable ;
```

In this paper, we propose the extension of OPA for the assignment of priorities to VLs transmitted on a QoS-aware AFDX. The approach is summarised in Algorithm 1. Since the goal is to minimise the overall worst-case delay of any VL transmitted on the network, the proposed solution consists in considering that this overall worst-case delay is the deadline of all the VLs. The approach minimises priority levels: as proposed in [4], it assigns as many VLs as possible to each priority level. The remaining issue is to get an OPA-compatible schedulability test. Such a test is presented in the next paragraph.

III. Schedulability test

The trajectory approach computes a sure upper-bound of the end-to-end delay of a VL transmitted on an AFDX network implementing either FIFO scheduling [2] or Fixed Priority (FP) scheduling [3]. The solution proposed in this paper is based on the trajectory approach for FP. The trajectory computation includes all the delays encountered by a frame of a given VL on its trajectory, namely:

- transmission time of the considered frame on links,
- switching latencies,
- delay due to the workload of the competing VLs with the same priority as the VL under study,
- delay due to the workload of the competing VLs with higher priority than this of the VL under study,
- delay due to the workload of the competing VLs with lower priority than this of the VL under study.

This computation is OPA-compatible.

- The workload of higher priority VLs is computed without considering their relative priority order. Thus condition 1 is respected.
- The workload of lower priority VLs is the largest frame with lower priority. Thus it does not depend on the relative priority order of these VLs and condition 2 is respected.
- Increasing the priority of a VL has two impacts. First, higher priority VLs can become same priority VLs or lower priority VLs. Second same priority VLs can become lower priority VLs. It can be shown that none of these impacts can increase the overall workload of competing VLs. Thus condition 3 is respected.

IV. First results

The proposed approach has been applied to a realistic AFDX configuration including 8 switches and 984 VLs (see [6] for a description of the configuration). The worst-case delays of VLs assuming FIFO scheduling are between 0.2 ms and 15.4 ms. Thus we fix the deadline for any VL to 12.3 ms (roughly 80 % of the worst-case delay with FIFO). The approach proposed in this paper is able to assign priorities such that all the VLs respect their deadlines. Only two priority levels are needed.

V. Conclusion

First results on priority assignment of avionics flows on a realistic AFDX configuration are promising: the overall worst-case delay is reduced by 20 % with two priority levels.

Further evaluation is still needed in order to better estimate the improvement that could be obtained with of a larger number of priority levels.

Moreover the minimisation of the overall worst-case end to end delay is interesting in order to minimise the size of needed buffer of a QoS aware switch. Then the test should concern the maximum backlog in any switch. Such a test has been proposed in [7] for two priority levels. It has to be extended to any number of priority levels.

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