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Trends in avionics switched Ethernet networks

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The AFDX (Avionics Full Duplex switched Ethernet) which has been standardized as ARINC 664 is based on Ethernet technology. Using full duplex links eliminates the inherent indeterminism of vintage Ethernet due to frames collision, but it shifts in fact the problem to the switch level where various flows enter in competition when using the same output port. Thus main problem is due to the indeterminism of the switching mechanisms and a network designer must prove that no frame will be lost by the AFDX (no switch queue overflow) and must evaluate the end-to-end transfer delay through the network (guaranteed upper bound and distribution of delays) according to a given avionics applications traffic.

AFDX specific assumptions deal with the static definition of avionics flows called Virtual Links (VL) that have to respect a bandwidth envelope (burst and rate) at network ingress point. Transmitting an Ethernet frame from one end system to other ones is based on a (mono-emitter and multi-receiver) VL identifier which is used for deterministic routing of each VL (the switch forwarding tables are statically defined after allocation of all VL on the AFDX network architecture). A VL definition includes the Bandwidth Allocation Gap (*BAG*) value, the minimum and the maximum frame size. The *BAG* is the minimum delay between two consecutive frames of the associated VL (sporadic flow). Thus the *BAG* and the maximum frame size values guarantee an allocated bandwidth for each VL.

The end-to-end delay analysis of a path (multicast link) of a given VL has to take into account all the possible scenarios (due to random conflicts with other VL). The smallest possible value of the end-to-end delay corresponds to the scenario where the VL emits a frame with minimal length which never waits in output ports. The highest possible value of the end-to-end delay corresponds to the worst-case scenario (which is a key point for the certification of the avionic network).

In the general case, finding this worst-case scenario requires an exhaustive analysis of all the possible scenarios. Such an exhaustive enumeration (as undertaken by the Model Checking approach) is limited by the combinatorial explosion problem, since the number of possible scenarios is huge, due to the number of VLs (around 1000) of industrial configuration [1].

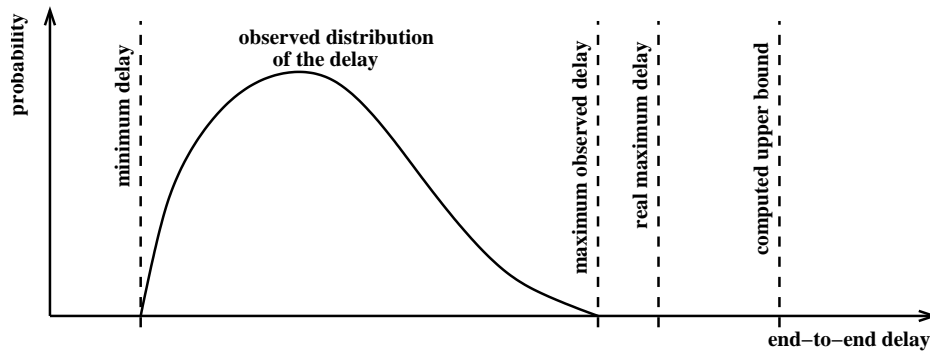
An alternative solution is the computation of a safe upper bound of the end-to-end delay, based on a modelling of the configuration which over-estimate the traffic and/or under-estimate the service offered by the network (pessimistic assumptions). Two approaches have been proposed for computing a pessimistic safe upper-bound of the end-to-end delay of any VL of an industrial AFDX configuration.

-The first one is based on Network Calculus theory. It has been applied and is optimized for AFDX, since it integrates the serialisation of frames on links. It has been used for the certification of the A380. It gives safe (but pessimistic) upper-bounds on the end-to-end delays of flows [3].

- The second one uses the Trajectories theory that has been developed to get deterministic upper-bounds on end-to-end response time in distributed systems. It computes the maximum workload faced by any frame of a given flow on its trajectory. It also gives safe upper-bounds which are slightly tighter compared with the network calculus approach [4].

Moreover the distribution of the end-to-end delay between its smallest and its highest possible values is also valuable when prototyping the whole system. This distribution can be obtained thanks to a simulation approach [1].

The following figure summarizes the end-to-end delay analysis global approach. This delay is always between a minimum and a maximum value. Most of the time, the exact maximum value cannot be computed and it is lower-bounded by the maximum observed value and upper-bounded by the computed safe upper-bound.



Measurements on real AFDX networks (or simulated configurations) show that the end-to-end delays are always much smaller than the computed upper-bounds. Thus the network is over-dimensioned. However it has been shown that both worst-case approaches (Network Calculus and Trajectories) provide tight upper bounds on typical industrial configurations. These two results seem contradictory but they are not: the worst-case delay for a given VL corresponds to very rare scenarios [6].

So a first trend for minimizing the worst-case delay is to minimize the number of scenarios by taking into account the fact that some of the flows are synchronised. Up to now we considered that all the VLs are independent. This is true for VLs generated by different end systems. This is not true for VLs generated by the same end-system. Indeed each end-system implements a scheduling which can generate constraints on the generation times of the VL frames. Some work has been conducted in order to integrate these constraints in the worst-case delay analysis. It seems to be a promising direction in order to limit the over-dimensioning of the network [3].

A second trend for a better utilization of available resources is to integrate Quality of Service (QoS) mechanisms in the network. Indeed, for future aircraft, the addition of other type of flows (audio, video, best-effort) on the AFDX network is envisioned. These new flows have different timing and criticality constraints. Thus, they have to be differentiated and handled by a QoS-aware AFDX switch which implements other service disciplines, such as static priority queueing or weighted fair queueing. The issue is to integrate efficiently these QoS mechanisms in the worst-case delay analysis [5].

A third trend concerns the model-checking approach. One valuable feature of this approach is to be able to exhibit a worst-case scenario. Obtaining such a scenario on a medium-size configuration can bring interesting information on worst-case scenario features. Thus work has been done in order to mitigate the combinatorial explosion problem [7].

Finally, a fourth trend deals with the sporadic characteristic of avionics flows that could be described by a probabilistic model. This leads to a probabilistic analysis of the worst-case delay of flows as it has been done for a preliminary study in the context of probabilistic Network Calculus [2].

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