FT2025
SWEDISH AEROSPACE AT THE CROSSROADS

The 12th Swedish
Aerospace Technology Congress
FT2025 in Stockholm
October 14-15, 2025

ROBUST PRIORITY ASSIGNMENT APPLIED TO AVIONICS FULL-DUPLEX SWITCHED ETHERNET NETWORKS

Edison Pignaton de Freitas and Marcelo Antônio Azeredo da Rocha

UFRGS
UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

HALMSTAD UNIVERSITY

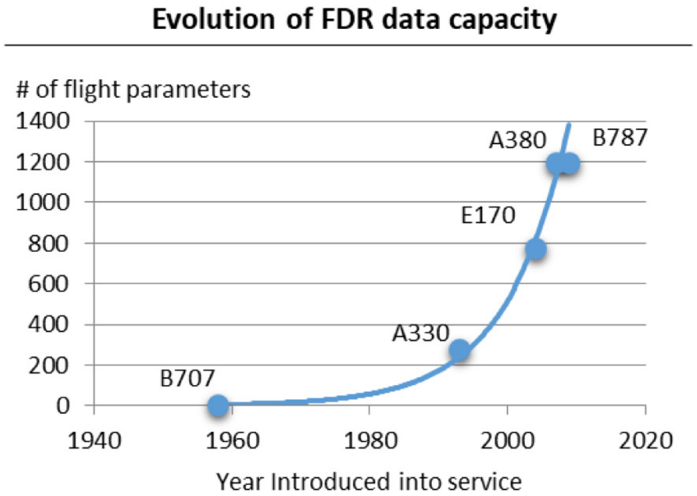
OUTLINE

- Introduction
- Background and Problem Statement
- AFDX Network
- OPA and RPA scheduling
- Experimental and Results
- Conclusion

INTRODUCTION

INTRODUCTION

- Increasing complexity of modern avionics networks



- From tens to thousands flight parameters to handle

- Number of networked devices embedded in an aircraft followed the same growth pace

UFRGS UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
HALMSTAD UNIVERSITY

INTRODUCTION

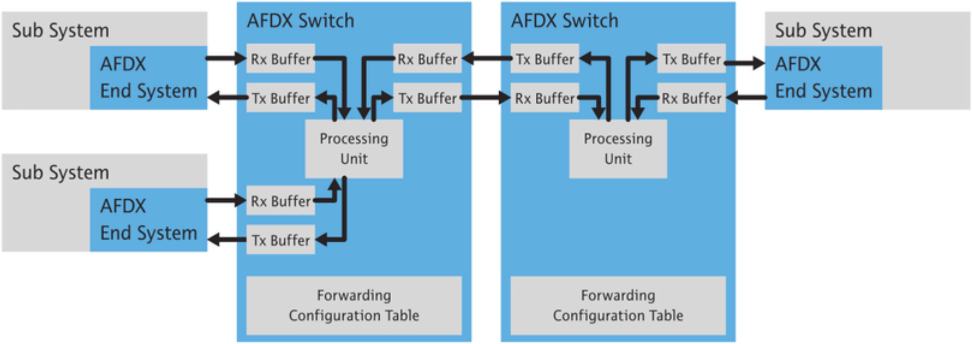
- These devices need deterministic and fault-tolerant data communication
- ARINC 429 limits scalability and efficiency
- ARINC 664 (AFDX) provides Ethernet-based multiplexing communication solution

UFRGS UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

HALMSTAD UNIVERSITY

INTRODUCTION

- Despite system-level deterministic, AFDX networks as the communication backbone introduces **indeterminism at the switch level**



- Switch processing delay variability (**jitter**)
- Output port contention

- **Challenge**: ensure bounded end-to-end delays in variable conditions

UFRGS UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
HALMSTAD UNIVERSITY

INTRODUCTION – GOAL AND CONTRIBUTION

- Study a Priority Assignment alternative that can handle the problem

- **Contribution**:
  - Proposal of integrating Robust Priority Assignment (RPA) into AFDX architecture
  - Comparative evaluation with Optimal Priority Assignment (OPA)

Background and Problem Statement

BACKGROUND

- It is mandatory to provide an **upper bound for the end-to-end delay** of a given frame carrying flight-critical data between end systems

- Different approaches were developed to perform the schedulability analysis and calculate the worst-case delay for AFDX

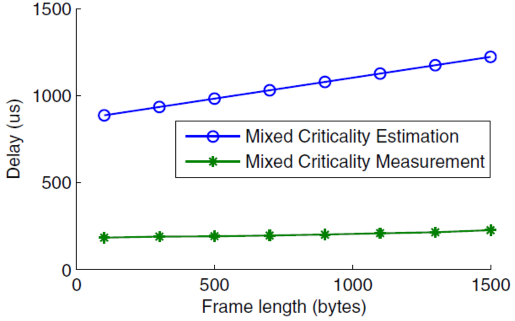
FEDERAL AVIATION ADMINISTRATION · FAA · CERTIFIED · EASA · EUROPEAN AVIATION SAFETY ASSOCIATION

BACKGROUND

- Network Calculus, the first, is **too pessimist**, leading to **underutilization of the network**

- Trajectory Approach (TA) was applied with better results compared to Network Calculus – less pessimistic, **closer to the experimental results**

Network Calculus



Yao et al, 2016

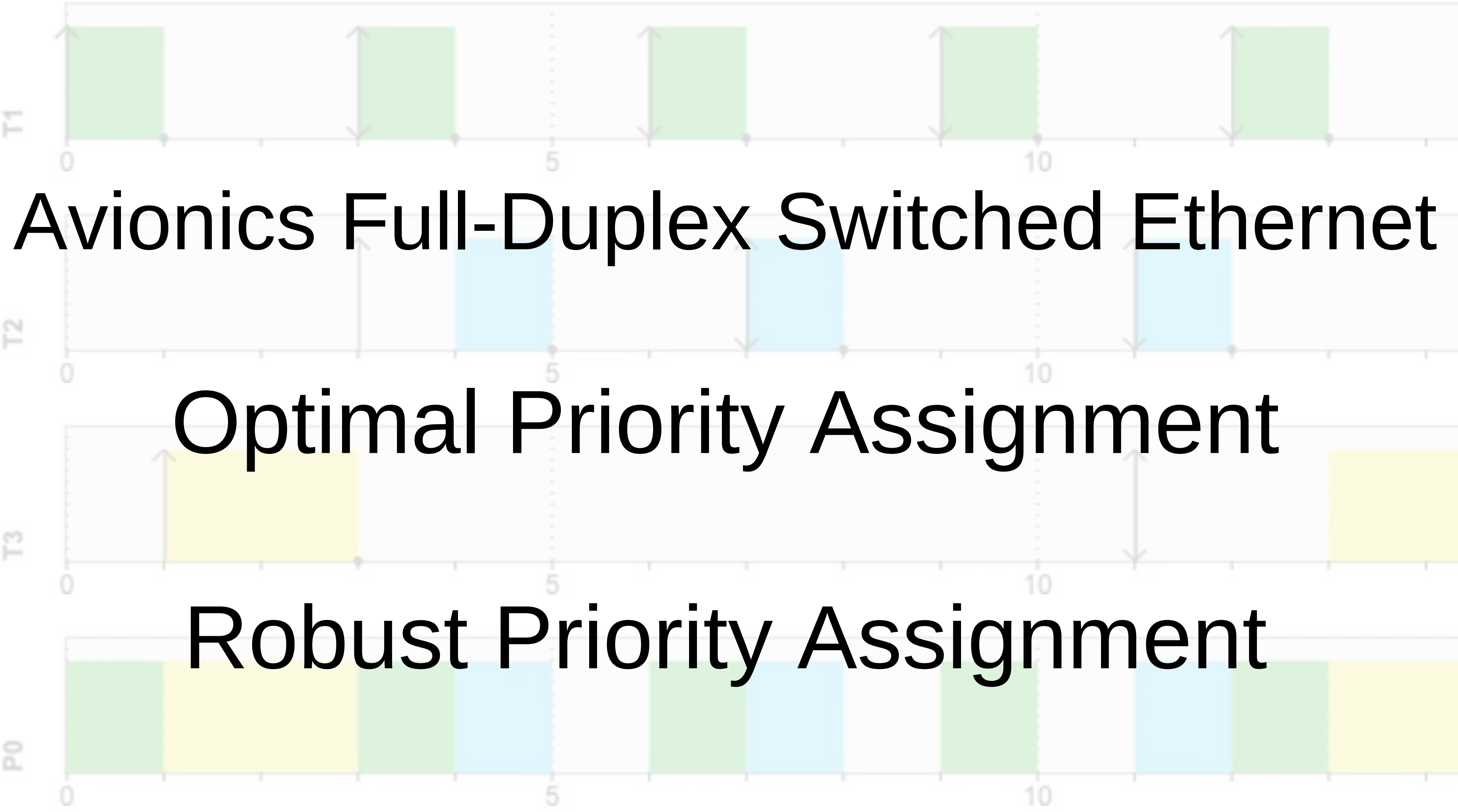
BACKGROUND

- Increased number of data → priority assignment is essential
  - Avoid hardware underutilization
  - Allow scalability
- First In First Out (FIFO) mostly used
- Optimal Priority Assignment (OPA) was proposed to AFDX
  - It is mathematically optimal, but fragile

PROBLEM STATEMENT

- **How to improve the AFDX determinism with priority assignment?**

- An alternative is the use of Robust Priority Assignment (RPA)
  - Based on OPA
  - Stable under uncertainty



Avionics Full-Duplex Switched Ethernet

Optimal Priority Assignment

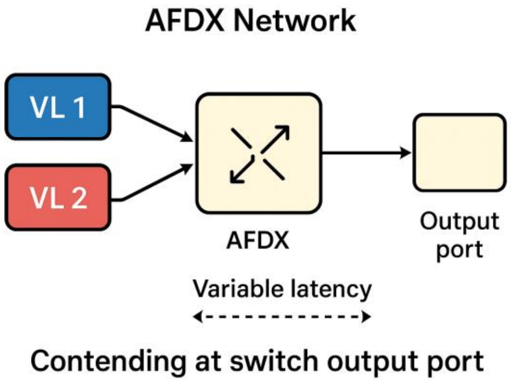
Robust Priority Assignment

AVIONICS FULL-DUPLEX SWITCHED ETHERNET - AFDX

- Described in ARINC 664 Part 7 (deterministic Ethernet)
- Backbone of modern fly-by-wire systems
- It defines two priority levels
- It achieves determinism mainly through
  - **Virtual Links (VLs)**: predefined logical connections with guaranteed bandwidth
  - **Bandwidth Allocation Gap (BAG)**: ensures traffic shaping
  - **Redundancy**: dual networks for reliability

AVIONICS FULL-DUPLEX SWITCHED ETHERNET - AFDX

- **System level determinism**, but the **switches** are store-and-forward devices that can **introduce indeterminism**
  - Each received frame is processed and forwarded in a **non-constant time**
  - Frames that must be forwarded to the same port are placed in a queue
  - The frame order is preserved per VL, but the queuing time depends on how many frames are waiting
  - Result: **jitter**



OPTIMAL PRIORITY ASSIGNMENT - OPA

- Guarantees optimal ordering when feasible
- Based on exhaustive schedulability tests
- Minimizes worst-case response times
- But it is sensitive to evaluation order and **robustness is not addressed**
- Applied to AFDX
  - OPA does not specify the order of frames in each of the two AFDX priority levels
  - An unfavorable initial ordering may negatively impact the forwarding

ROBUST PRIORITY ASSIGNMENT - RPA

- Introduces interference tolerance model (errors, interrupts, etc…)
- Generates stable priority orders under timing variations
- Improves resilience to parameter and load fluctuations
- Increases feasibility margin in critical networks
- Suitable for mixed-criticality environments

UFRGS UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
HALMSTAD UNIVERSITY

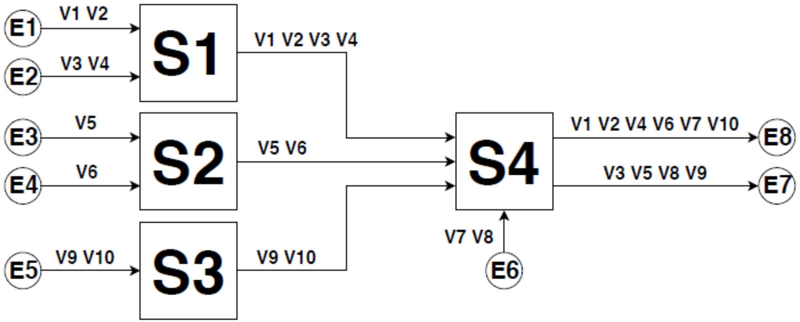
RPA TO AFDX

- Use of the two priority levels per switch allowed by AFDX
- RPA groups flows into tolerance classes
- With the improved ordering, it doesn't incur in the OPA's problem
- Enables practical implementation on avionics switches
- It can minimize the indeterminism in AFDX related to the switches

Experiments and Results

COMPARATIVE ANALYSIS

- OPA and RPA priority ordering is done over 10 VLs (VL1–VL10)
- Worst-case end-to-end delay (WCETED) of all VLs calculated with Trajectory Approach for both



COMPARATIVE ANALYSIS - PARAMETERS

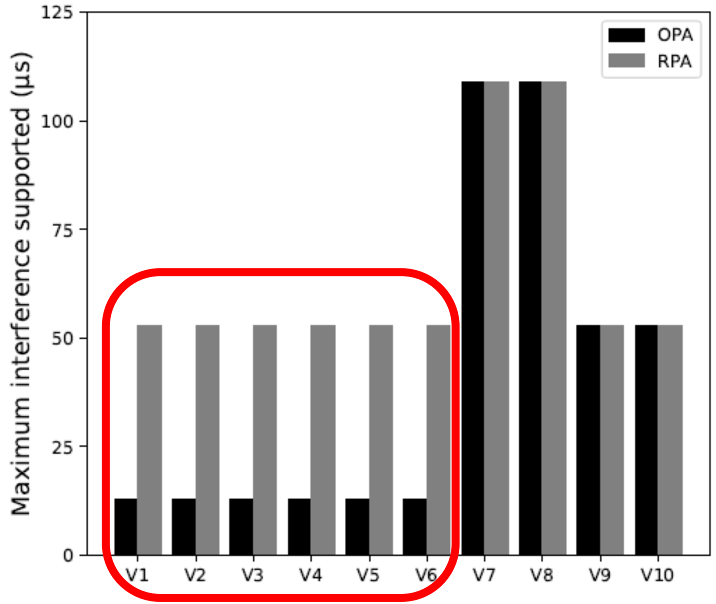
- BAG: 4000 µs, Frame size: 4000 bits
- Deadline (D): 325 µs (strict constraint)
- Simulates critical flight-control traffic patterns
- Metrics: delay and interference tolerance
- Interference Tolerance: D – WCETED
  - “Spare time” before missing the deadline
  - Any additional interference up to this amount still maintains schedulability

ASSIGNED PRIORITIES AND WCETED

Priority assignment and WCETED of OPA and RPA.

Virtual Link	Priority (OPA)	Priority (RPA)	WCETED (OPA) (µs)	WCETED (RPA) (µs)
V1	LOW	HIGH	312	272
V2	LOW	HIGH	312	272
V3	LOW	HIGH	312	272
V4	LOW	HIGH	312	272
V5	LOW	HIGH	312	272
V6	LOW	HIGH	312	272
V7	LOW	LOW	216	216
V8	LOW	LOW	216	216
V9	LOW	LOW	272	272
V10	LOW	LOW	272	272

MAXIMUM INTERFERENCE SUPPORTED



- RPA achieved a +40µs robustness gain in V1-V6

STRESSING THE SYSTEM

- Deadlines of two VLs (VL1 and VL6) were decreased from 325 to 300 to stress the system
- Force the change in the VLs priorization
- All the remaining parameters continue the same, as well as the topology

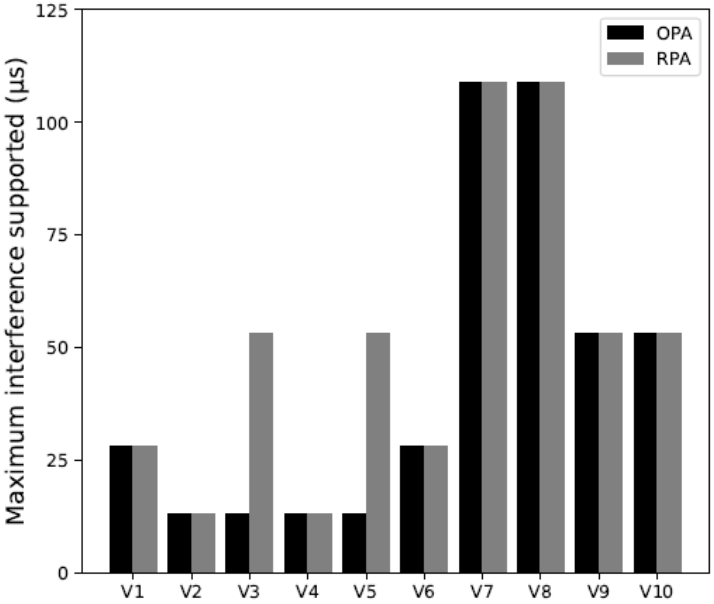
ASSIGNED PRIORITIES AND WCETED – STRESSED SYSTEM

Priority assignment and WCETED of OPA and RPA after decreasing deadlines of V1 and V6.

Virtual Link	Priority (OPA)	Priority (RPA)	WCETED (OPA) (μs)	WCETED (RPA) (μs)
V1	HIGH	HIGH	272	272
V2	LOW	LOW	312	312
V3	LOW	HIGH	312	272
V4	LOW	LOW	312	312
V5	LOW	HIGH	312	272
V6	HIGH	HIGH	272	272
V7	LOW	LOW	216	216
V8	LOW	LOW	216	216
V9	LOW	LOW	272	272
V10	LOW	LOW	272	272

- OPA changes the priorization of V1 and V6
- RPA changes the priorization of V2 and V4

MAXIMUM INTERFERENCE SUPPORTED – STRESSED SYSTEM



The gains provided by RPA diminish, only V3 and V5 present increased interference support

LESSONS LEARNED AND PROPOSAL

- The most robust priority assignment was achieved with RPA
- But the overall robustness of the system could not be increased
- RPA is a viable strategy
  - To enhance robustness: parameters of the network must be analyzed
- **Proposal: Robustness Booster Module**
  - Make redistributions of the slack time according to priority promotions
  - AI methods can be explored for this

Conclusion

CONCLUSION

- RPA enhances AFDX robustness and delay tolerance
- Significant gains were reported in the provided robustness (supported interference)
- The use of RPA complains with certifiable robust scheduling
- The approach can be used as a foundation for the future proposed Robustness Booster Module exploring AI-based methods

ACKNOWLEDGMENTS

The authors thank to the Brazilian National Council for Scientific and Technological Development (CNPq), Project 311773/2023-0, and the ELLITT Strategic Research Network, Sweden for the provided support.

THANK YOU!

Contact

Edison Pignaton de Freitas and Marcelo Antonio Azeredo da Rocha

edison.pignaton@hh.se,

marcelo.pilot.aeroengineer@gmail.com

UFRGS UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
HALMSTAD UNIVERSITY

BACKUP SLIDES