Avionics Full Duplex Ethernet and the Time Sensitive Networking Standard

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Agenda

Topics	Presented by
SECTION 1	
✓ Motivation to present at IEEE ✓ AFDX® Context ✓ AFDX® Historical Background ✓ AFDX® Concepts	***Bruno Pasquier***
SECTION 2	
✓ AFDX® Detailed Introduction and Mapping to TSN ✓ AFDX® Advantages and Challenges ✓ AFDX® Evolutions (Overcoming Challenges) – AFDX® + – µAFDX® ✓ Example: Network topology for Automotive ✓ Key Inventions & Benefits ✓ Conclusion AFDX® & µAFDX®	***Stefan Schneele***

SECTION 1

- ✓ Motivation to present at IEEE
- ✓ AFDX® Context
- ✓ AFDX® Historical Background
- ✓ AFDX® Concepts

Presented by Mr. Bruno Pasquier

Our Motivation to present to IEEE

General TSN goals are:

- Reliable communication over Ethernet
- Ultra-low latency
- Deterministic end-to-end latency

The Aeronautic Industry was in need for such technology some time ago

- Airbus proposed a solution called Avionics Full Duplex Ethernet (AFDX®)
- Solution was standardized in 2004
- The only deterministic Ethernet solution used for Avionics in Airbus aircrafts
- Presented in the following

Our hopes with this presentation:

- Indicate Aeronautic Industry’s interest in the TSN standardization
- Incorporate AFDX® parts into TSN to enable safety critical systems & certification

→ Discussion for Letter of Assurance (LOA) started

AFDX® Context

- ✓ **Focus on aeronautics but,**
  - ✓ **Similarities with other domains, in term of:**
    - **Networks Heterogeneity:**
      - – Multiple technologies,
    - **Complexity:**
      - – Architecture, configuration, upgrades,..
    - **Costs:**
      - – Design, maintenance,…

AFDX® Historical Background

End of 90's

✓ **Aircrafts are still using lot of analog signals and few digital busses like ARINC 419/429, MIL-STD 1553 and ARINC 629 …**

- Low bandwidths, from 12Kbs to 2Mbs
- Important wiring,
- Limited data format, difficulties to support sophisticated communication protocols

Necessary to consider new needs

AFDX® Historical Background

New needs:

- ✓ **Bandwidth**
  - Important exchanges of data: dataloading of equipment, data base…
- ✓ **Need for bidirectional communication to support complex protocol**
  - TFTP, ARINC 615, interactive mode, etc…
- ✓ **Access to all information**
  - Increase the sharing of data: interdependence of the systems are increasing, data base, clock
- ✓ **Flexibility of communication architectures**
  - Management of the options, modification of architectures
- ✓ **Use of standard protocols of communication**
  - Open communications: Systems in the A/C are not isolated, communication with open world

AFDX® Concepts

AFDX® = Avionics Full DupleX Switched Ethernet

- ✓ **Avionics** : Network adapted to the avionics constraints
- ✓ **Full DupleX** : the subscribers transmit and receive the data at the same time
- ✓ **Switched** : The data are switched, necessary to use AFDX® switch to connect the subscribers
- ✓ **Ethernet** : conformity to the standard Ethernet 802.3

- **Ready for safety critical functions**

AFDX® Concepts

- ✓ **A deterministic network:**
  - Each subscriber has a free access to the network
  - For each VL in Rx, the transfer time of the data is limited and computed by a formal approach (Network calculus)
- ✓ **Virtual Link (VL):**
  - Channel of communication between one transmitter and several receptors, with:
    - – Guaranteed bandwidth,
    - – Limited latency and jitter,
    - – Static path of VLs
- ✓ **It was specified under the nomination ARINC 664 Part 7**

SECTION 2

- ✓ AFDX® Detailed Introduction and Mapping to TSN
- ✓ AFDX® Advantages and Challenges
- ✓ AFDX® Evolutions
  - – AFDX®+
  - – µAFDX®
- ✓ Example: Network topology for Automotive
- ✓ Key Inventions & Benefits
- ✓ Conclusion AFDX® & µAFDX®

Presented by Mr. Stefan Schneele

AFDX® Standardization

Specified in Aeronautical Radio Incorporated (ARINC)

ARINC Specification 664, Aircraft Data Network

Defines an Ethernet data network for aircraft installation.

It is developed in multiple parts, listed as follows:

- Part 1 – Systems Concepts and Overview
- **Part 2 – Ethernet Physical and Data Link Layer Specifications**
- Part 3 – Internet-based Protocols and Services
- Part 4 – Internet-based Address Structures and Assigned Numbers
- Part 5 – Network Interconnection Services and Functional Elements
- Part 6 – Reserved
- **Part 7 – Avionics Full Duplex Switched Ethernet (AFDX®) Network**
- Part 8 – Upper Layer Services

Defines Ethernet physical parameters & general and specific guidelines for the use of **IEEE 802.3** compliant Ethernet.

Defines a deterministic network on data link layer.

Technical Overview of AFDX® mechanisms

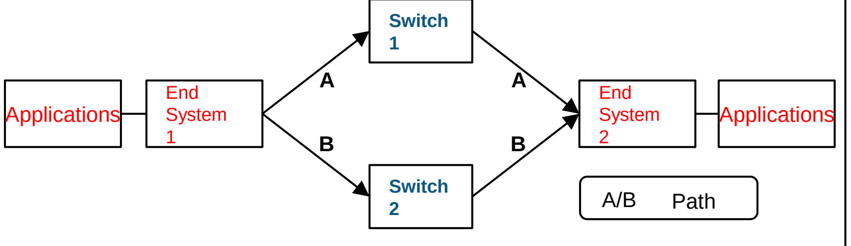
Standard	Group	Main Feature
Arinc 664 P7 - Section 3.2.6.1	Redundancy	Sequence Number
Arinc 664 P7 - Section 3.2.6	Redundancy	Two redundant Networks
Arinc 664 P7 - Section 4.4	Enforcement	Static Routes
Arinc 664 P7 - Section 4.1.1.1	Enforcement	Ingress Policing
Arinc 664 P7 - Section 3.2.1	Enforcement	Egress Transmission
Arinc 664 P7 - Section 3.2.1	Enforcement	Virtual Link
None	Certification	Formal verification

AFDX®: Technical Overview
Main Features

- AFDX® data network was developed by Airbus for the A380 to address real time issues for safety critical avionics developments
- Goals are:
  - **Reliable**
    - Through Duplication and Policing
    - Guaranteed Delivery
  - **Determinism**
    - Bounded Delay

Main Elements

- **AFDX® End Systems (E/S):**
  Network interface card (NIC) to send and receive messages
- **AFDX® Switches (SW):**
  Smart hardware equipment for frame policing

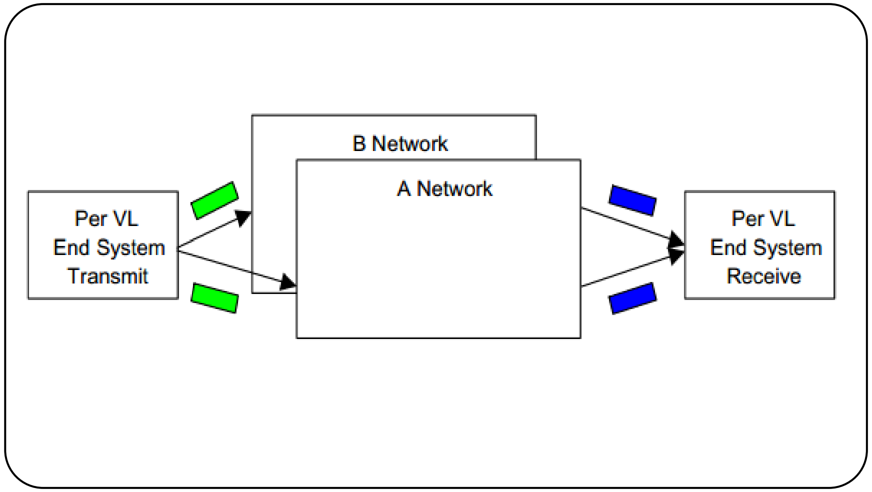


AFDX®: Technical Overview
Redundancy – Independent Networks

ARINC 664 P7 - Section 3.2.6

Two independent networks A + B

- Full duplication of network
  - separate power & different routing of cables
- End-Devices handle redundancy
- Packets duplicated on device only
- Network unaware of duplication / redundancy



Mapping to TSN:

- CB: does duplication/deduplication not just on end system but on switches too

Similar to Presentation http://www.ieee802.org/1/files/public/docs2014/cb-kiessling-CB-Layer2-Tag-0314-v01.pdf

AFDX®: Technical Overview
Redundancy – Sequence Numbers

ARINC 664 P7 - Section 3.2.6.1

Use of sequence numbers for deduplication

- One-Byte sequence number suffix **per stream**
  - 0 RESET
  - 1-255 sequences
- End-Devices either use
  - "first-valid wins" and forward one packet to application (check for seq no {+0 +1 +2})
  - or forwards both packets to application

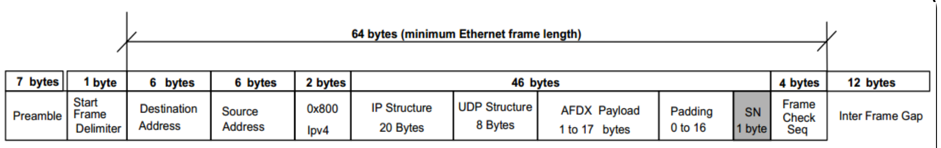


Fig 1.: AFDX® Frame Format

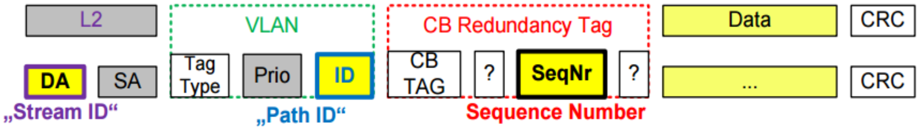


Fig 2.: TSN CB Frame Format

Mapping to TSN:

- CB: sequence number also per stream with 16 bit Ethertag
- CB: sequence history in AFDX® same as CB's tsnSeqRecHistoryLength = 3

Image from Presentation http://www.ieee802.org/1/files/public/docs2014/cb-kiessling-CB-Layer2-Tag-0314-v01.pdf

AFDX®: Technical Overview Enforcement

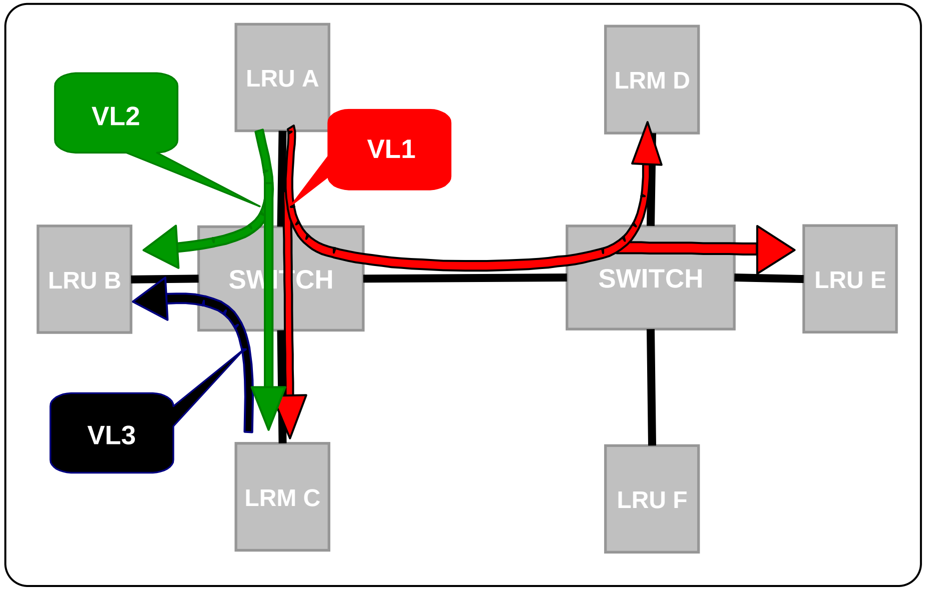
ARINC 664 P7 - Section 3.2

Virtual Link (VL)

- Multicast communication stream
- Following traffic specification
- Static engineered routes

Two lines of defence

- End-Device send conformant traffic (Shaping)
- Every switch enforces conformance (Policing)
- No “healing” of ill-behaving streams, just drop



Every communication in AFDX® is done through a VL

Traffic specification

- BAG (Bandwidth allocation Gap): minimum delay between two consecutive frames. (1ms..128ms)
- AFDX®+ allows lower BAGs
- MVLS (Maximum VL Size): maximum size of the frame : min 17 octets ; max : 1471 octets

Mapping to TSN

- BAG: RFC 2210 Tspec Token bucket rate r = MVLS / BAG
- MVLS: RFC 2210 Tspec Max. Frame size M

AFDX®: Technical Overview Enforcement

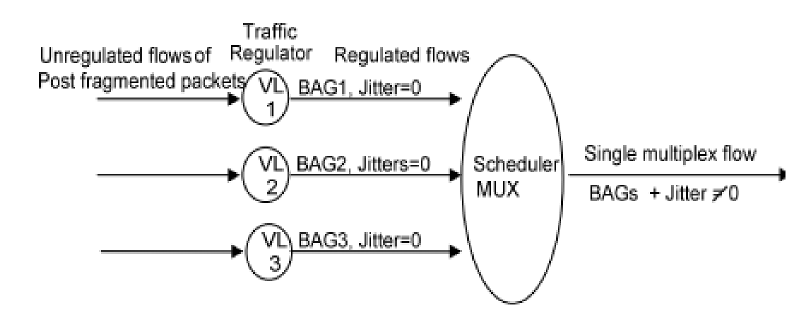
ARINC 664 P7 - Section 4.1.1.1

Scheduling in AFDX®

- Standard switching
- Two FIFO queues (high/low) per outgoing port
  - Some shaping on end-devices to keep BAG

Policing per Virtual Link

- Token Bucket filtering per Virtual Link
  - Up to 4k virtual links on current aircraft
- NO time synchronization



Mapping to TSN:

- Standard Ethernet Scheduling
- Ingress Policing with Qci or egress UBS shaping

AFDX®: Technical Overview Enforcement

Formal Verification

- Network Calculus is used to find upper bound for:
  - Latency / Jitter
  - Buffer Size
- Accepted for certification in DAL-A Aircraft systems
  - Similar levels to SIL-4 or ASIL-D

- Additional requirement:
  - Network hardware needs to meet guaranteed maximum static latency and jitter (technology delay) considering most data are multicast transfer
  - Demonstrate all failure modes / absence of unused functions / dead code

AFDX® Advantages

- ✓ High Bandwidth with an upgrade of the data size
- ✓ Protocols and physical layers nearest to COTS standards (Ethernet, IP and tools: network analysers)
- ✓ Determinism is ensured by the set of the AFDX® switches and not by the subscriber behaviour
- ✓ Simplification of the evolution of communication by the loading of a new configuration and by the access to all data
- ✓ Asynchronous approach between the functions which allow a high independence between the subscribers (simplification of the Safety demonstrations)

AFDX® Challenges

- ✓ Request for further simplification of the technology: AFDX® End System and Switch
- ✓ 1st Implementation of AFDX® End System and Switches are not compatible with "simple" equipment (e.g.. sensors/actuators)
- ✓ Necessity to manage the configuration (definition of the VL set and its static path on the topology) and validation of its determinism to answer to certification demonstration
- ✓ Latency time (Pessimist approach of the Network Calculus, ms)

Necessary to propose a solution to extend the AFDX® concept usage domain by µAFDX® and AFDX®+

AFDX® Evolutions

AFDX®+: Federative ADCN mixing AFDX® and best effort Ethernet

- ✓ Increase the bandwidth to 1 / 10 / .. Gbps (high transfer and decrease the latency)
- ✓ Mix on the same support operational (AFDX® traffic) and service (TCP/IP/ Ethernet) communication
- ✓ Remove Gateway function between Avionics & Cabin World = unified network

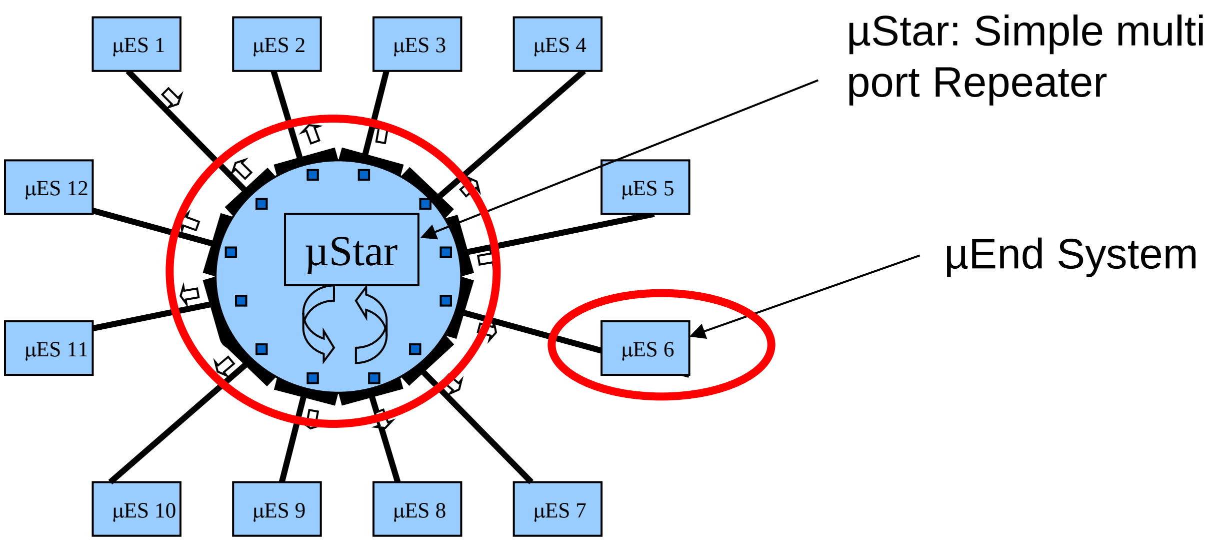
COTS, Ethernet **IMA, LRU**

µAFDX® Principle

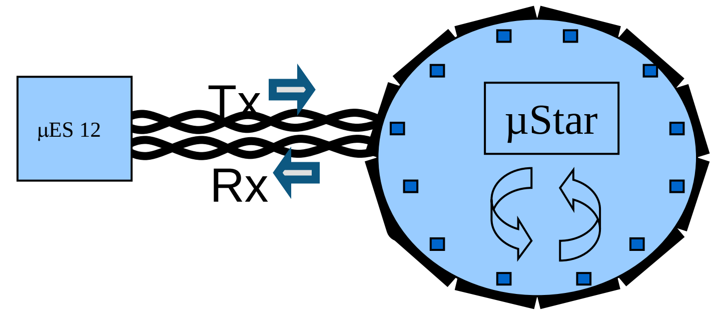
The µAFDX® network is based on Ethernet frames from one subscriber switched by µStar toward all the other subscribers.

The mains properties of the µAFDX® technology are:

- Communication without any collision
- Guaranteed latency
- A communication without Master
- A broadcast communication, which allows all subscribers to receive all data ex-changed



µAFDX® Robustness



The Robustness of µAFDX® is based on:

- Communication without any collision.

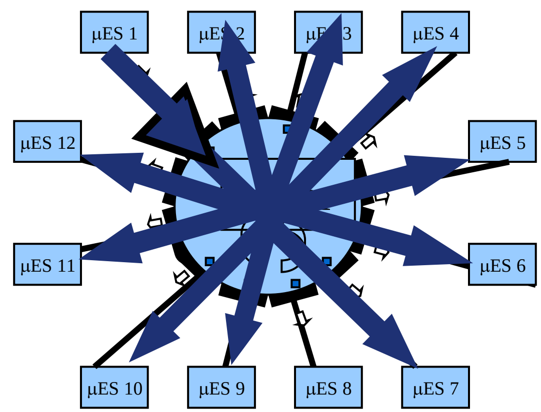
- Simplification of the mechanism in the µStar
  - The mechanism in Rx is limited to a round robin to read the frame
  - The mechanism in Tx is limited to repeat on each output port the frame (A broadcast communication)
  - No configuration
  - No verification of Ethernet frame through the CRC
  - Limitation of the buffer to 1 frame in each Rx port (avoid babbling)

- No propagation failure in case of problem on a subscriber or on the cable.

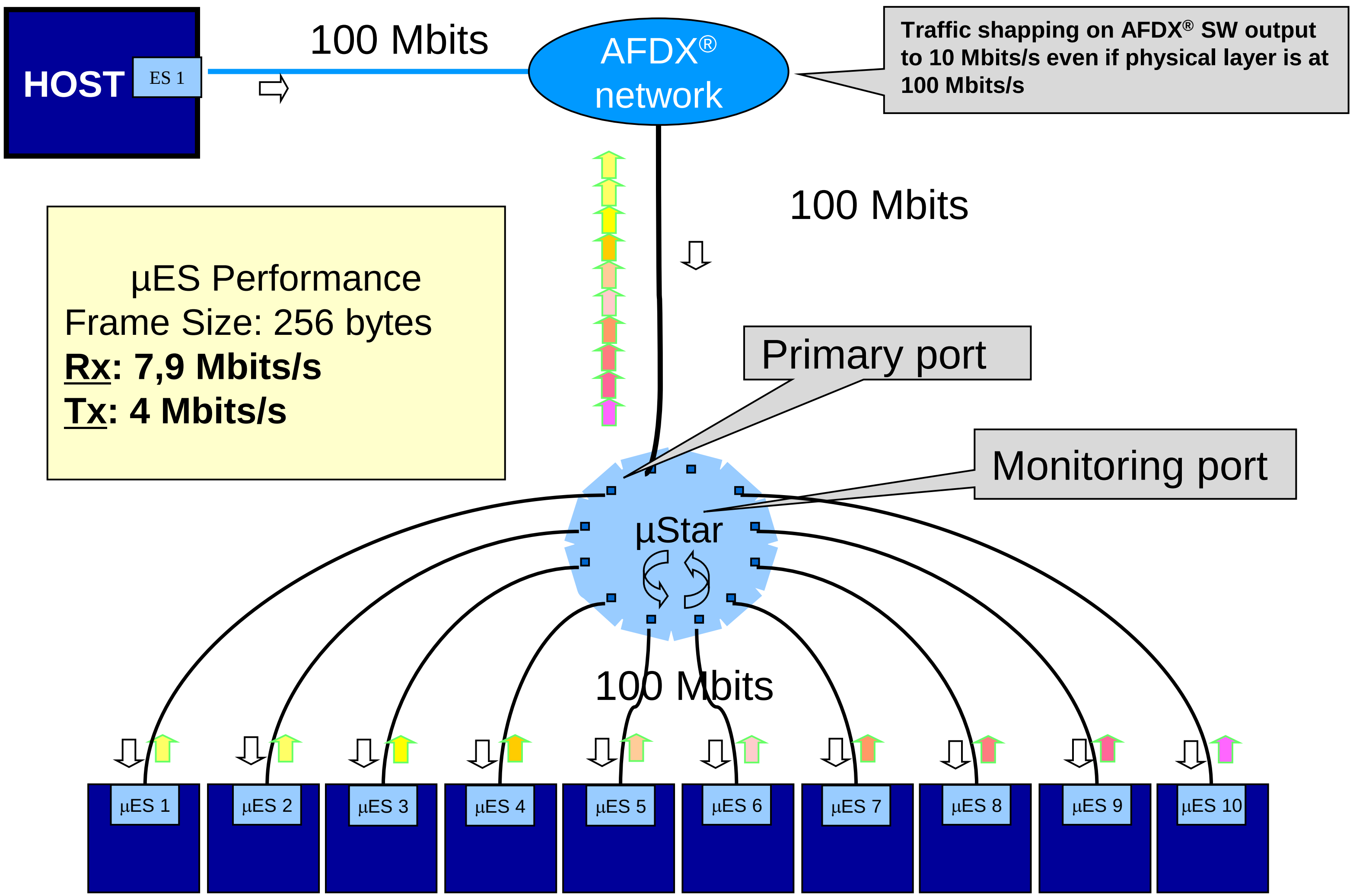
Mapping to TSN:

- E/S to Star communication:
  - similar to Cyclic queueing and forwarding (Qch)

- Star to E/S communication:
  - similar to Time-Aware-Shaper (Qbv)

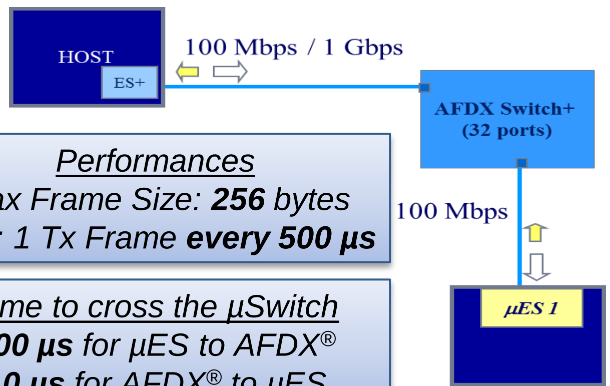


µAFDX® Hybride ADCN - µStar Configuration "Link 1 to 10 "



µAFDX® Performance Data for different use case examples

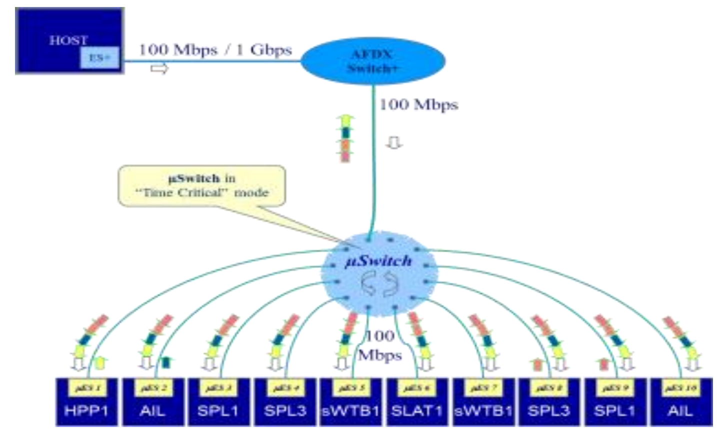
Direct Connection



Performances
*Max Frame Size: **256** bytes*
*µES: 1 Tx Frame **every 500 µs***

Time to cross the µSwitch
***500 µs** for µES to AFDX®*
***10 µs** for AFDX® to µES*

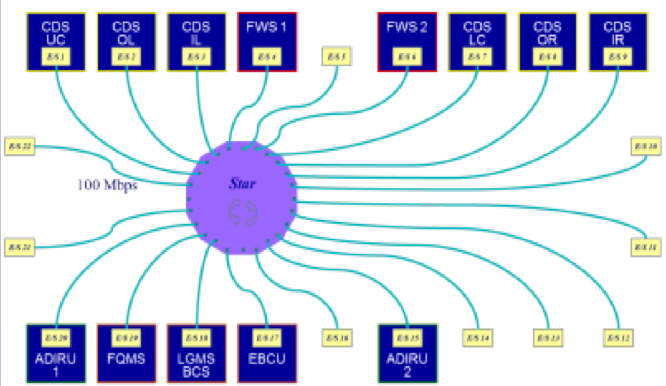
Hybrid AFDX®



Performances
*Max Frame Size: **128** bytes*
*µES: 1 Tx Frame **every 250 µs***

Time to cross the µSwitch
***200 µs** for µES to µES/AFDX®*
***100 µs** for AFDX® to µES*

Simple Star



Performances
*Max Frame Size: **256** bytes*
*µES: 1 Tx Frame **every 1 ms***

Time to cross the µSwitch
***1 ms** between 2 µE/S*

Key Inventions and Benefits

	Inventions	Capabilities	Benefits
AFDX®	Virtual Links to transfer data	Reduced Physical Links	Reduces Weight
	Maximum bandwidth allocation to each virtual link	Controlled Date Flow	Uninterrupted Flow of Data
	Deterministic behavior of Packet Switching Network	Guaranteed data delivery within bounded delay	Mixed Critical Applications
	Redundancy Check	Higher Reliability of Network	No Information Loss
	Data integrity check	Error Free data	No Malfunction
µAFDX®	Reduced Complexities of an End System	Cater to applications with low communication requirements	Reduced Size and Cost
	Facilitation of synchronization via network	Synchronous Data Transmission	Time- critical Applications
	Simple and Safer µSwitch	Master Slave, Private Bus	Replace CAN and ARINC429

Conclusion AFDX® and AFDX®+ and µAFDX®

- AFDX® is a mature technology for safety critical system used in several A/C programs by Airbus and e.g. Boeing
- AFDX® + and µAFDX® are completely specified and demonstrated up to TRL 6
- µAFDX® is a solution for real time systems with very few complexity and almost zero configuration
- Low latencies in µseconds can be achieved with µAFDX®
- Several mechanisms TSN targets for are similar to the AFDX®, AFDX®+ and µAFDX® solutions

Our proposal:

- Have AFDX® and µAFDX® in TSN standard
- **We are open for discussion and looking forward to your feedback**

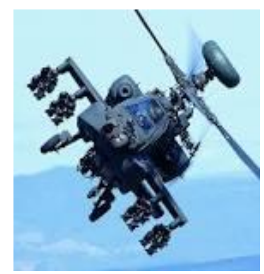
Who is using AFDX®?

- ✓ **Airbus: A380, A350, A400M**
- ✓ **Boeing: B787**
- ✓ **Sukhoi: RRJ100**
- ✓ **COMAC: ARJ21**
- ✓ **Agusta Westland: AW101, AW149, AW 169, AH64**
- ✓ **Bombardier: Global Express, Cseries**
- ✓ **Irkut: MS-21**
- ✓ **…**



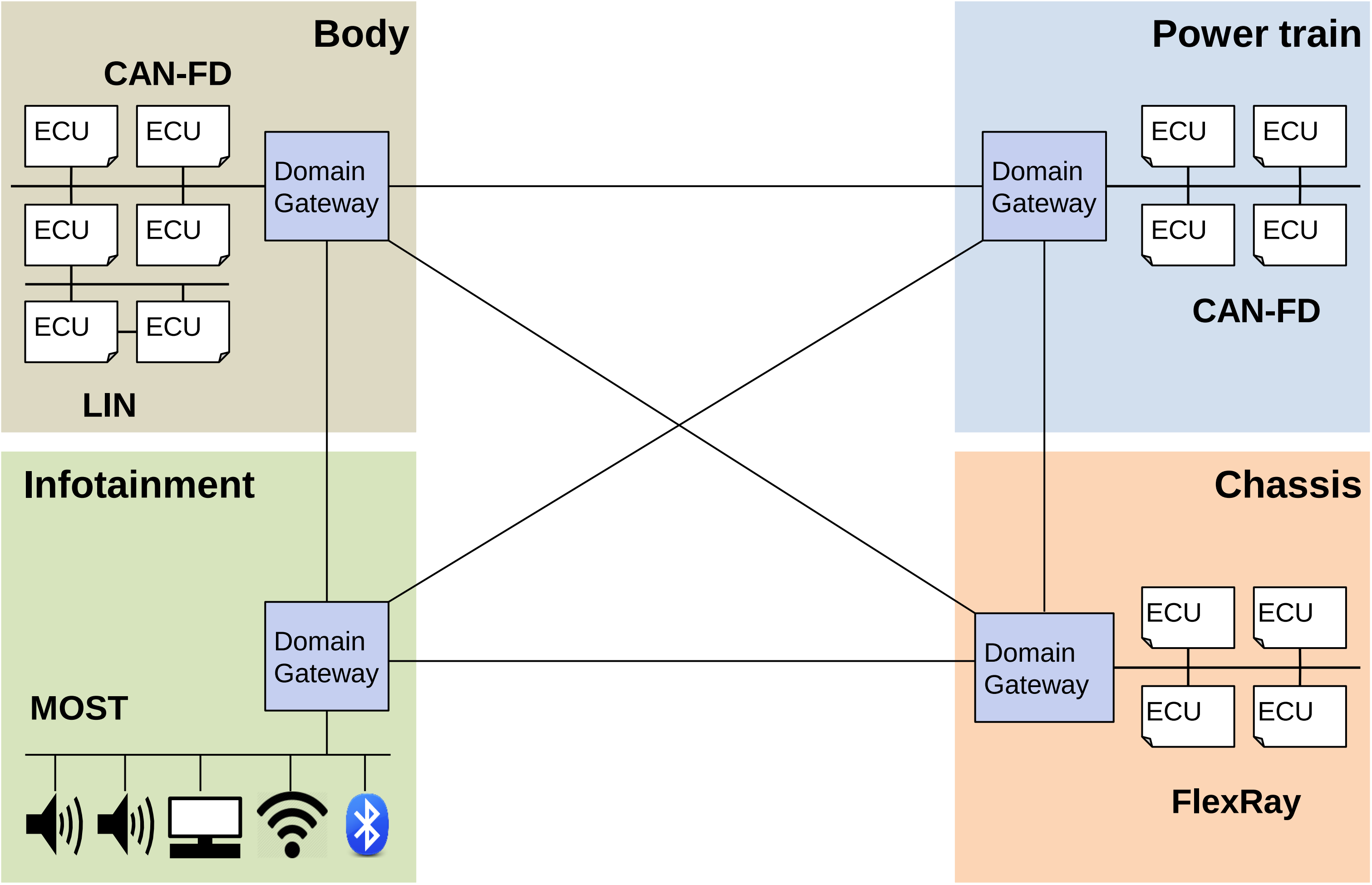




Thank you

Example: Current Network Topology in Automotive



Example: The Ethernet Backbone Idea for Automotive