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SB 503 - Avionics Technologies
Integrated Modular Avionics
Networks – ARINC 429, Arinc 664 (AFDX ™), Field Bus,…

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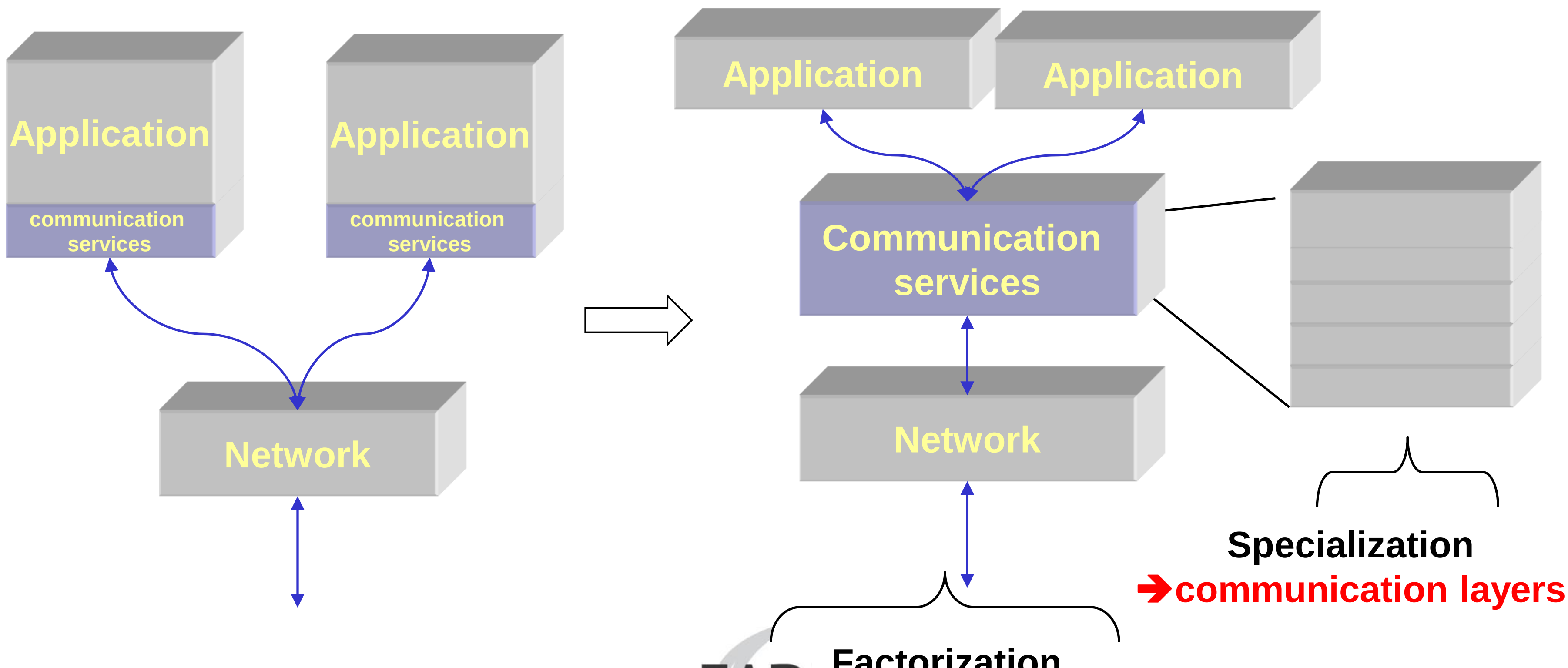
Outlines

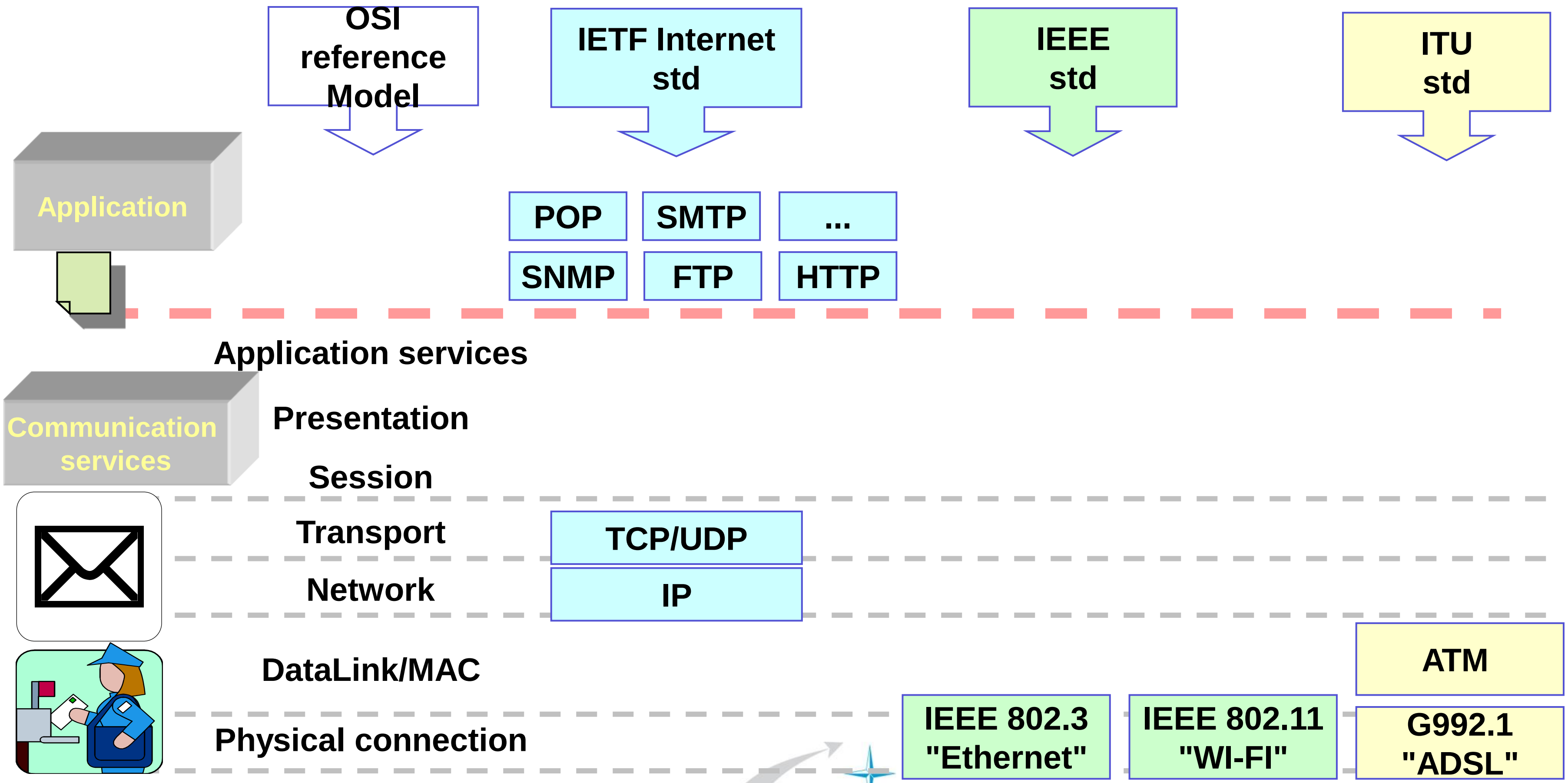
- The A664 Standard
  - Short reminder : Communication Principles
  - The aircraft communication context and constraints
  - The origin of the standard
  - Products
- Key Features
  - Open Standard
  - Virtual Link concept
  - “Firewalling” (Traffic Shaping / Policing /Filtering)
  - Redundancy
  - Latency / Determinism
- Network Architecture
  - Physical architecture design
    - Main drivers for physical architecture design
    - Safety constraints
  - Logical Architecture design
    - Logical architecture principles
    - ES Part / The different types of application port
    - ES Part / Different logical communications
    - SWM Part
- Performances optimisation and determinism
  - Several sources of latency
  - ES Latencies
    - descriptions / optimisation
  - SWM Latencies
    - descriptions / optimisation
- A664 addressing features
- Networks optimization & Field Bus technologies overview

Short reminder : Communication principles

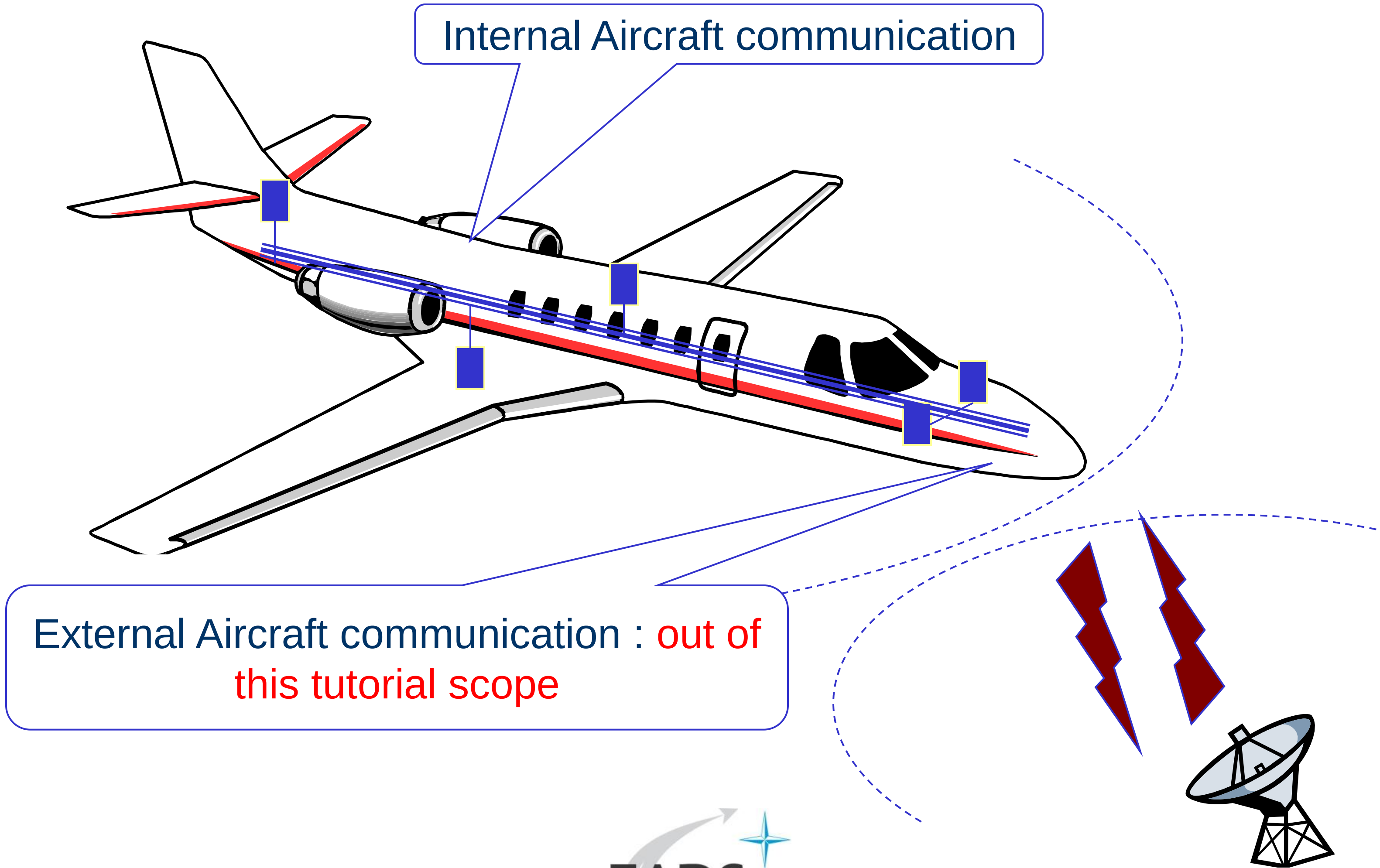
- The key driver for the definition of the Network layering is the implementation of <u>independence</u> between applications and communications means



Short reminder : Usual communication layers

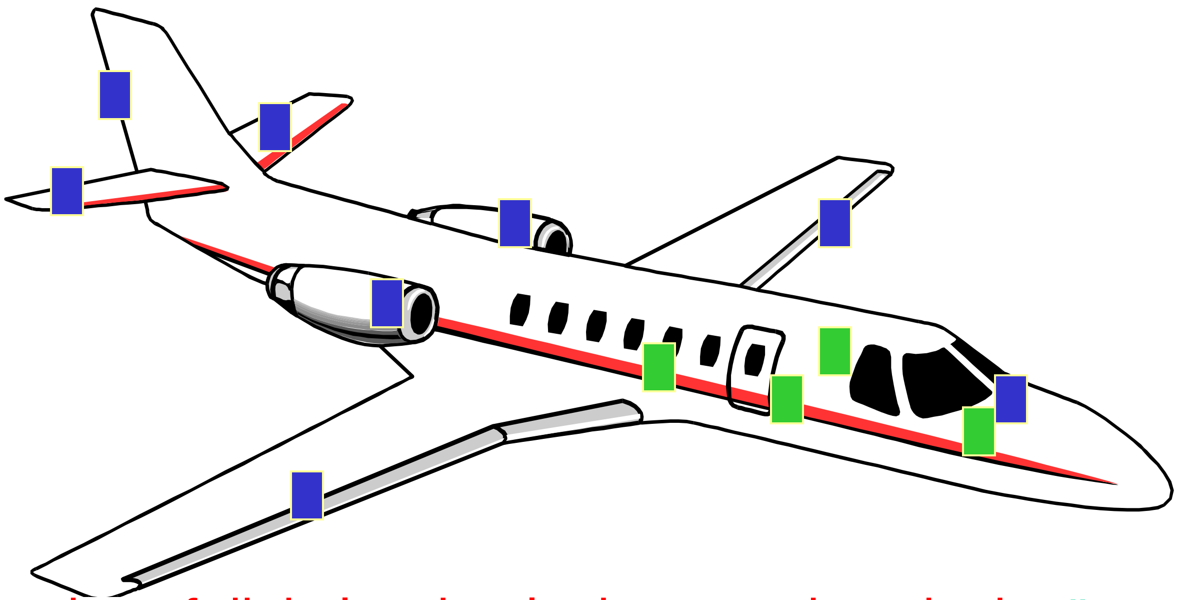


The aircraft communication context (1/2)



The aircraft communication context (2/2)

- Until 90's, there was never a strong need for networking inside an aircraft.
- When digital technologies were introduced, the communication was limited to digital data link



- The introduction of digital technologies was done in the "control of platform" area not in the "information" area.

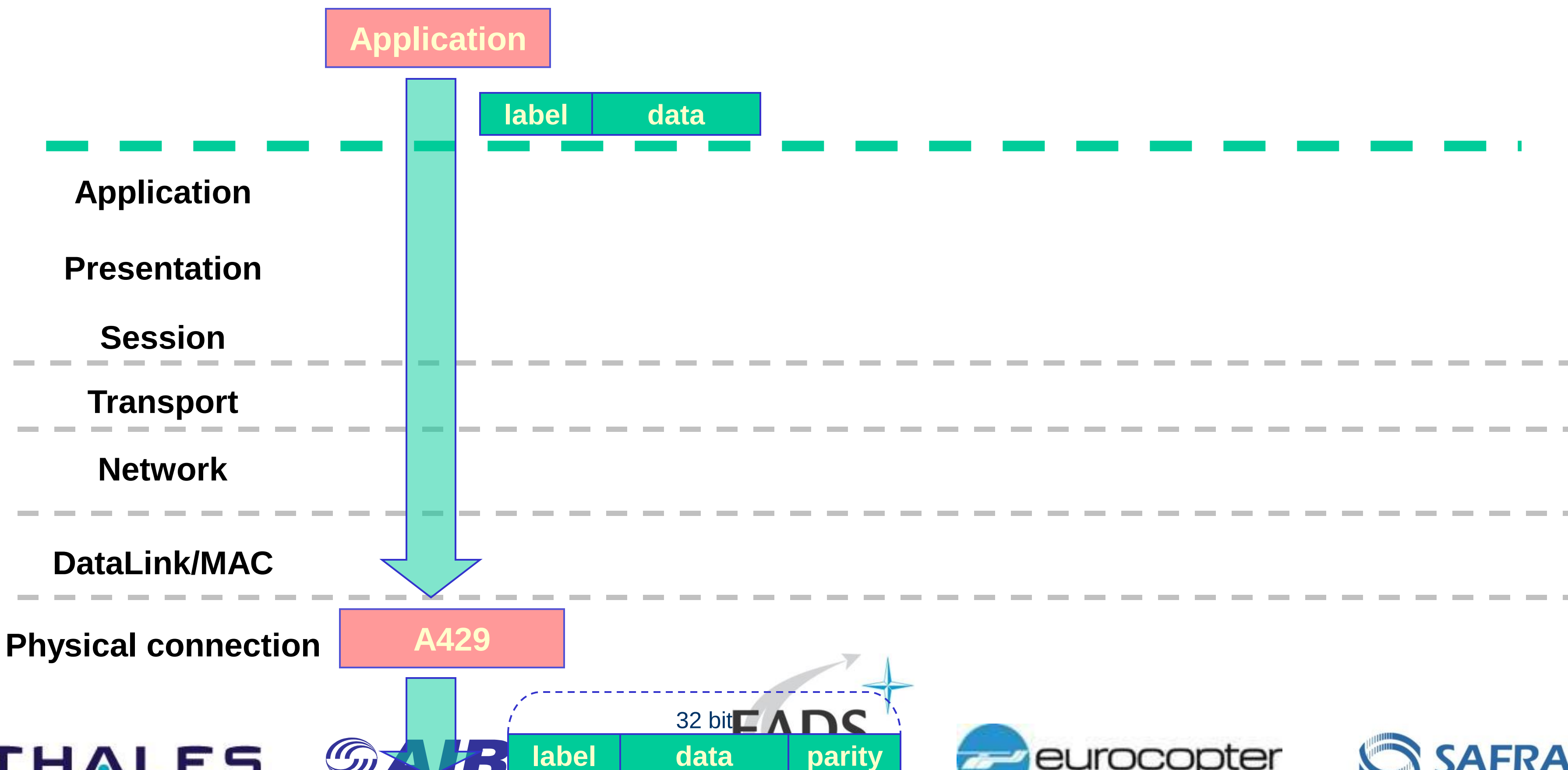
Process control requirements

- As the transmitted data are involved in process control, the transmission must be done with a minimum bounded delay
- The stability of the flight relies on this transmission
- Key drivers : Time, integrity and availability
- A few principles :
  - No common shared resource (limited risk of common failure)
    - one source, one line, several receivers
  - The transmitter does not need to know who receives data
  - No time synchronisation between transmitter and receiver
    - common shared time is a kind of common resource

Aeronautical Answer : ARINC 429 Digital Information Transfer System

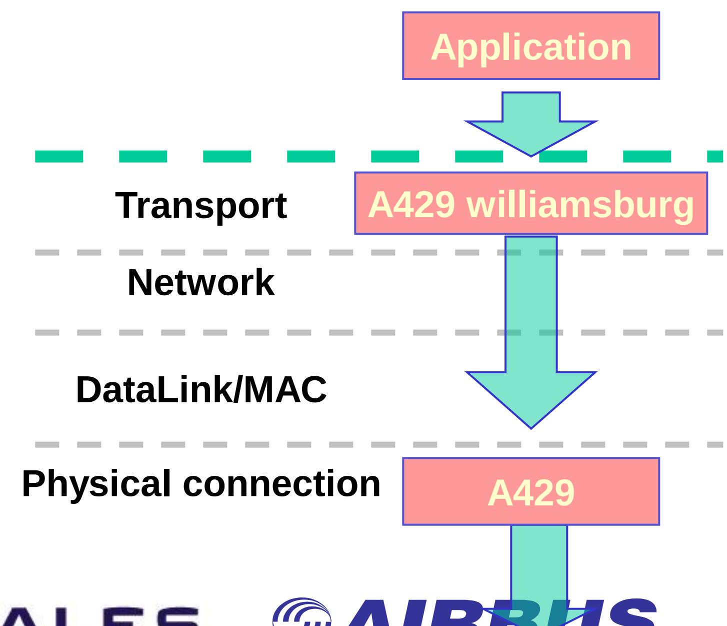
Process control requirements : ARINC 429 answer

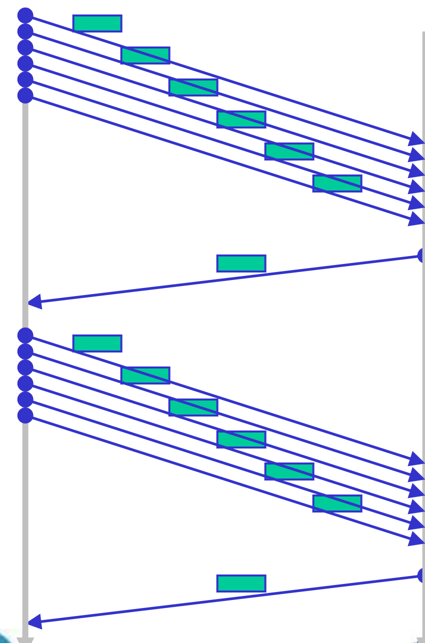
- Each line has only one source and is connected to every equipment that need the data transmitted by the source
- Each data is individually identified (by a label) and sent



Information System requirement : ARINC 429 answer

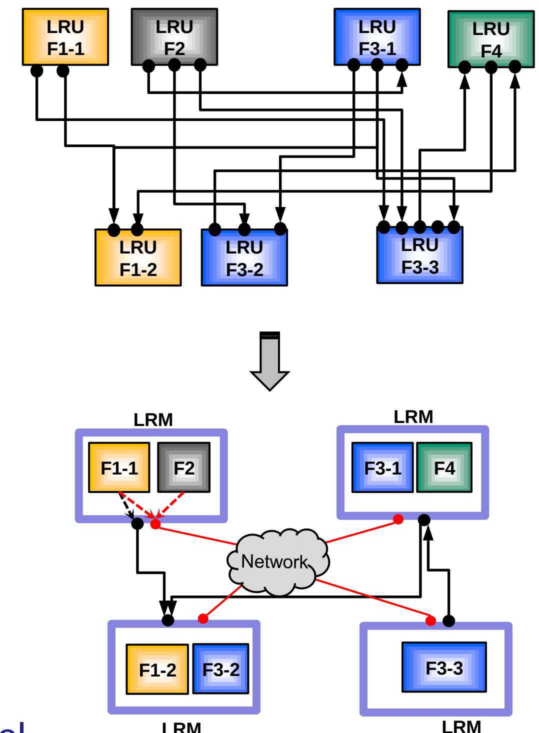
- In Information system, the major requirement is to insure that the information is transmitted without any error
- A few principles
  - Information should be acknowledged
  - Delay is not critical and messages can be sent again in case of error
- The former aircraft generation still used A429 but added acknowledged data block





Avionics Market Evolution

- The evolution of the avionics market is exposed to a great pressure for reducing cost.
  - Scaleability, Wiring simplification, P/N Rationalization
  - Maintenance, Interoperability, integration simplified
  - Connectivity to Open World networks (standardization)
  - Weight reduction



- In the same time, mature concepts arose:
  - Electronics Modularity
  - Operating System
  - Decision to re-use and share common resource

- Network design challenge & key drivers

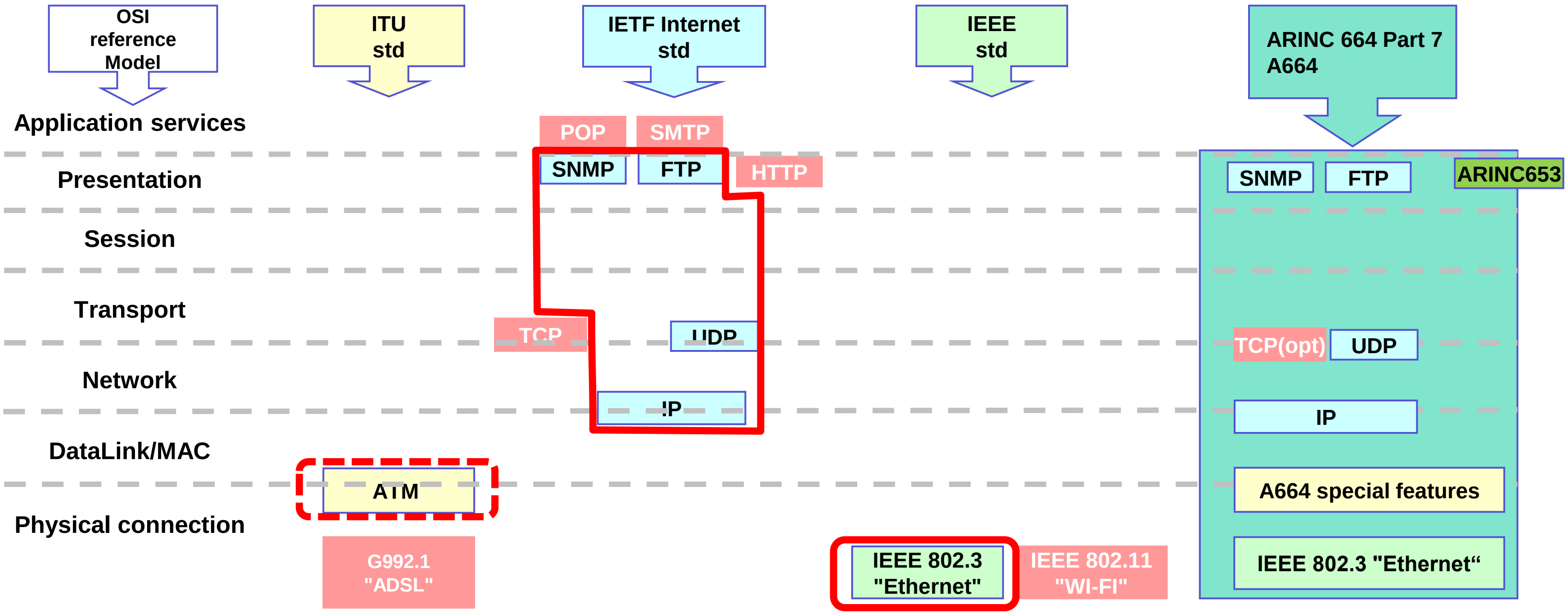
to satisfy contradictory objectives:
  - To transmit data under strong time constraint
  - To guarantee information exchange according to client/server model
  - To reduce cost by using/reusing commercial component (COTS: commercial off-the-shelf) under certification constraint

High integration of functions VS number of I/O access points
➔ From ‘point to point’ to ‘multiple emitters/multiple receivers’ model

Technological choices

- Communication technologies from desktop computing market
  - Best candidates :
    - Ethernet for Physical layer
    - Internet for upper protocol layer
- Communication technologies from multimedia telecom market
  - Best candidate :
    - ATM (backbone telecom and ADSL) and cell switching (channel concept)
- Key drivers
  - Heavy aeronautical background:
    - time constraint
    - safety
  - Arrival of Switched Ethernet (from ATM concept)
  - Low cost, market size of desktop computing versus small telecom market

Final choice



- and the winner is...

AFDX ^{TM} : Avionics Full Duplex switched(‘X’) Ethernet

Switched Full Duplex Ethernet <u>with some specific deviations</u> to cope with real time/certification constraints

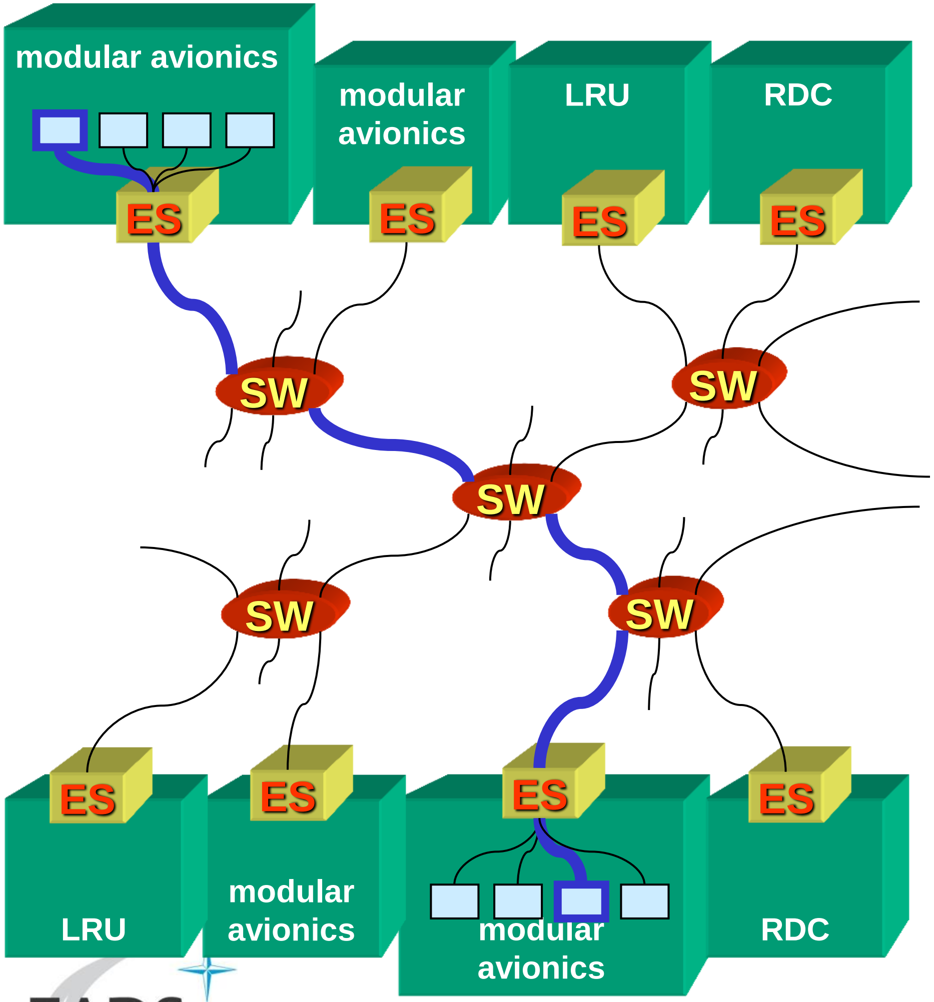
A664 standardization

- The standardisation body
  - ARINC 664 is undertaken by the civil aviation usual standardisation body: ARINC/AEEC ADN working group
    - ARINC : Aeronautical Radio Inc. funded by airlines, in charge of the definition of Aeronautical standards that ensure interchange ability and interoperability
    - AEEC : Airlines Electronic Engineering Committee
    - ADN : Aircraft Data Network working group

- The standard
  - AFDX TM is described as ARINC specification 664 part 7
  - The ARINC 664 covers in general, the usage of Ethernet as an airborne communication system, extended to the confidentiality issues and future IPv6 extensions

A664 : basic network architecture

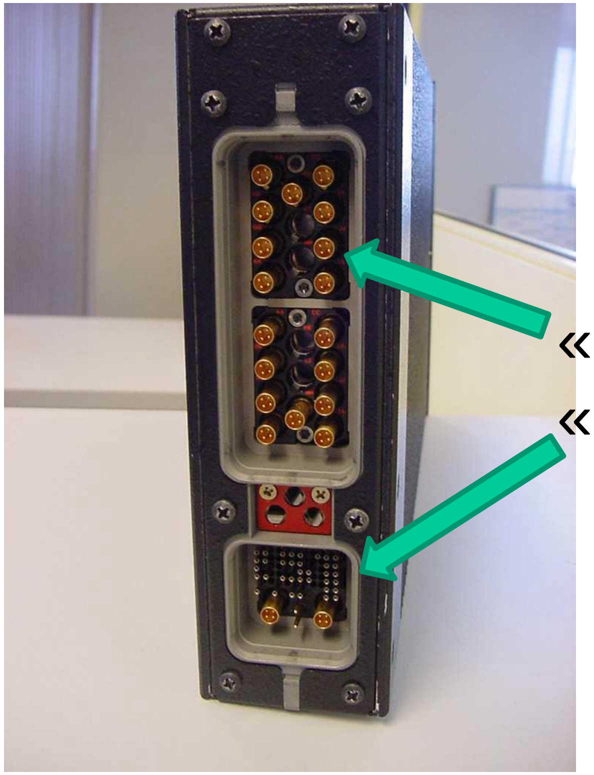
- A664 is based on the Ethernet switched network
- It is built with:
  - Switches, network devices in charge of data forwarding
  - End System, network devices in charge of data transmission/reception



A664 Physical Products (as an example…)

<u>A664 Switch</u>

<u>(Format ARINC 600)</u>



« Quadrax » ports SWM
« Quadrax » for E/S

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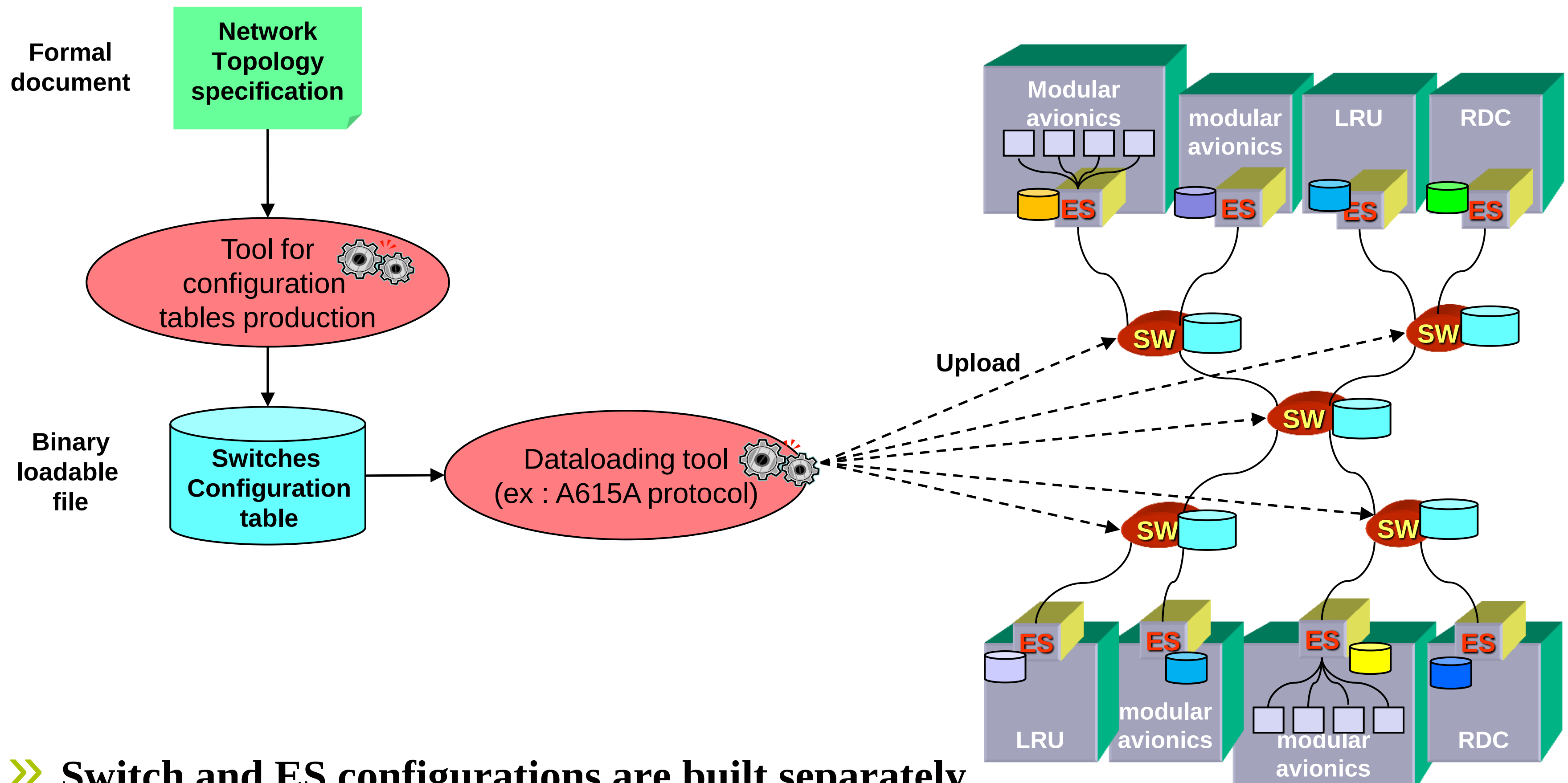
A664 Network Configuration



- Switch and ES configurations are built separately

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A664 Key features

- A664 is the common communication system used for modular avionics architecture

- It is compliant with the following design key features
  - It is based on **Open Standard**
    - as required by cost and commercial standard reuse objective
  - It provides "**Resource Sharing**"
    - as required by modularity, reuse, and cost objective
  - It provides "**Robust Partitioning**"
    - as required by resource sharing and safety, certification constraints
  - It provides "**Determinism**" and "**Availability**"
    - as required by safety, certification constraints

The A664 key features are mainly concentrated on the Data Link layer (MAC level)

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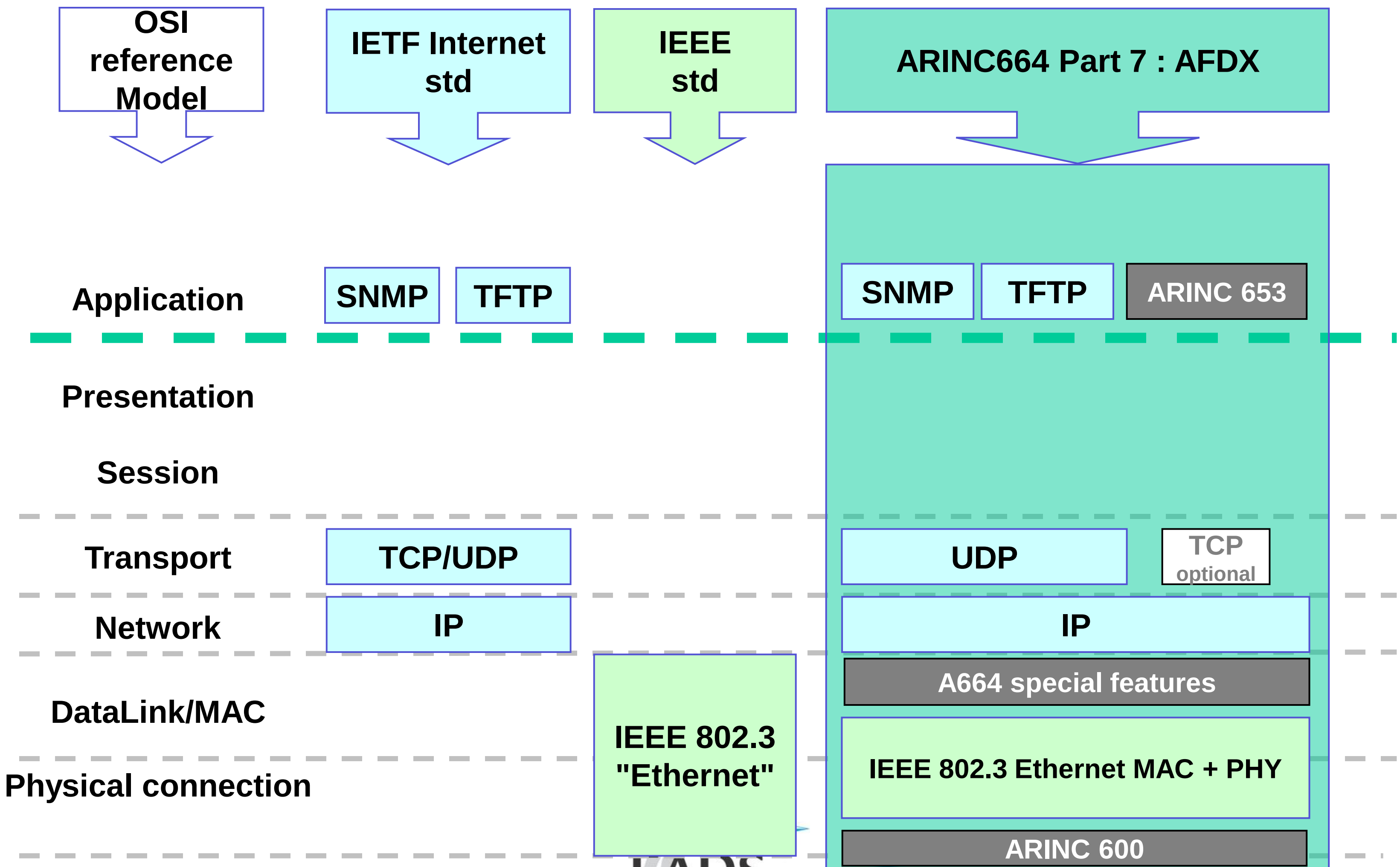
A664 : An “Avionics” Standard based upon Open Standard



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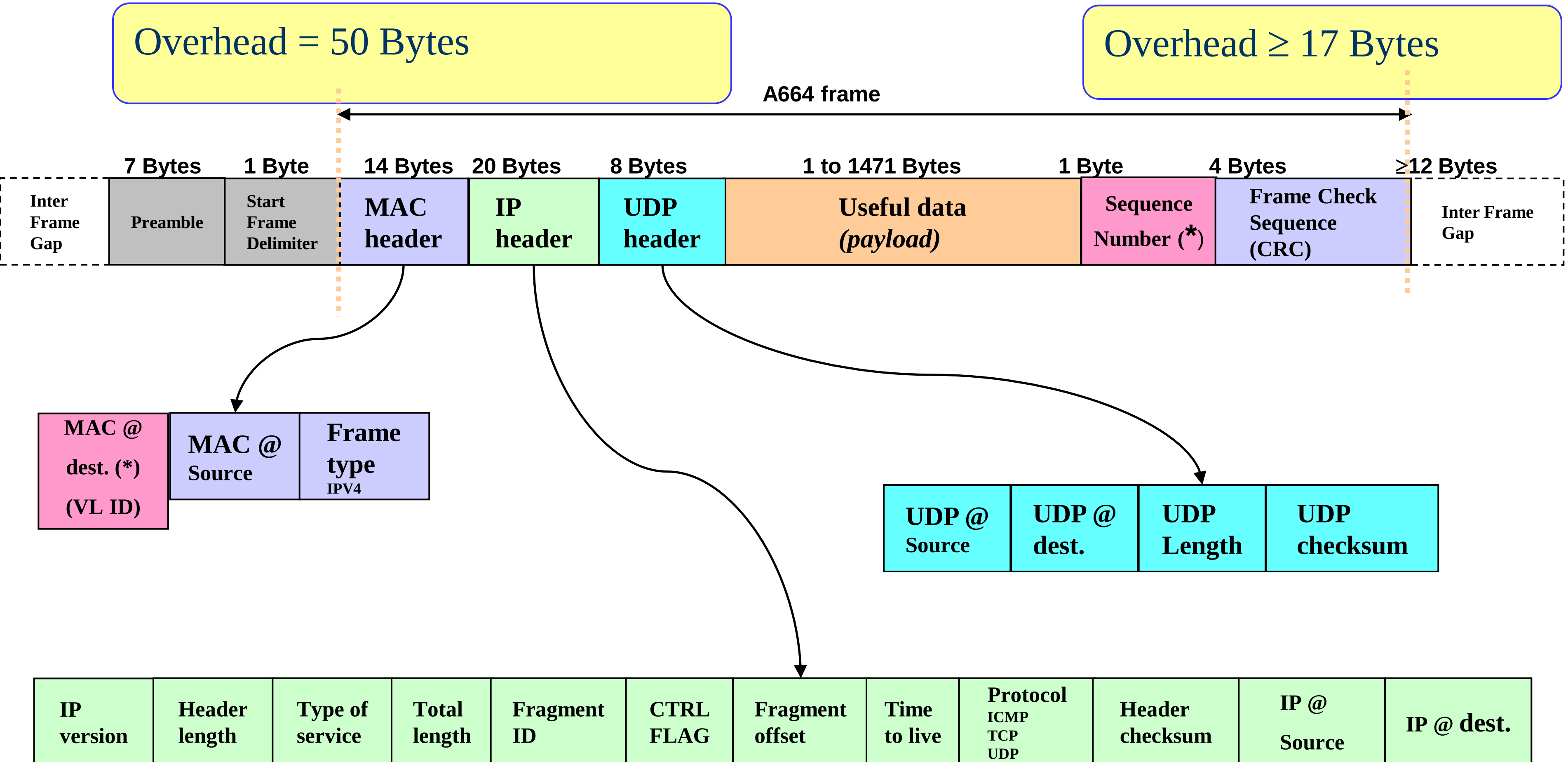
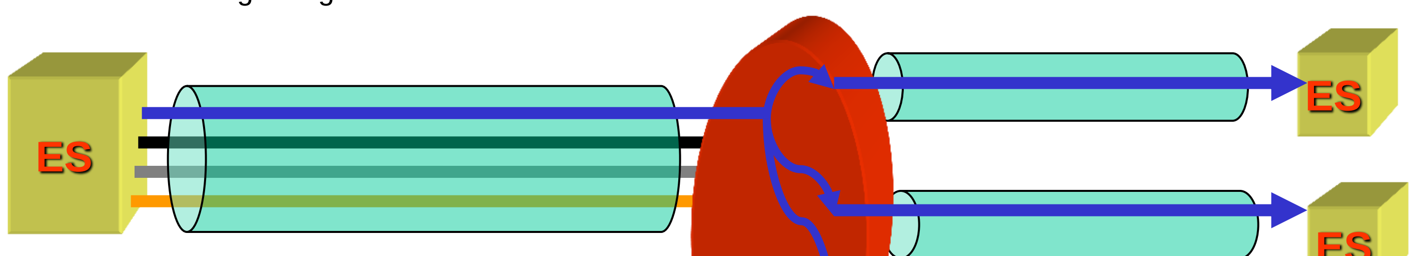


(*): Specific A664

A664 key feature : Virtual Link (1/2)

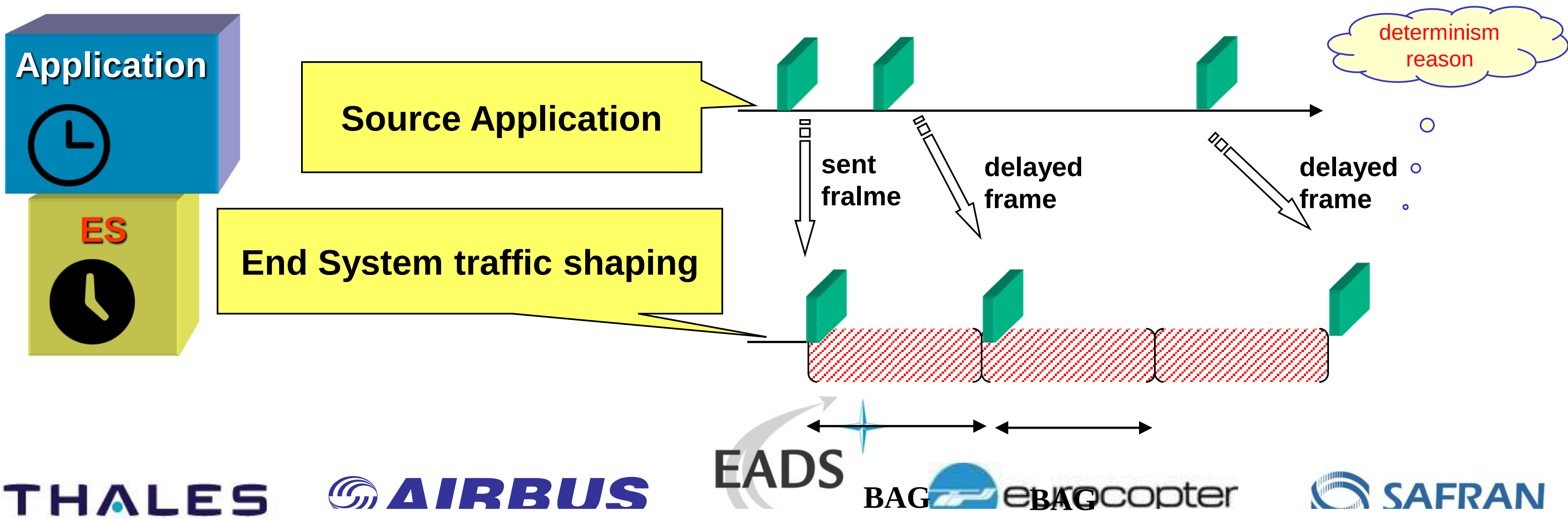
- The robust partitioning for networking is applied on bandwidth allocated to "communication channel".
- The VL model is ARINC429 "single wire" and the ATM "Virtual Channel"
  - one wire/channel for one data source, distributed to all who needed
  - The A664 response is:
    - one channel (named VL "Virtual Link") for one data source, distributed with multicast Ethernet address channels are merged together on one Ethernet data link



A664	ARINC 429
Ethernet data link	N/A
Virtual Link	twisted pair copper wire

A664 key feature : Virtual Link (2/2)

- The VL receives a "Bandwidth contract".
- This contract is named Bandwidth Allocation Gap (BAG)
- It is expressed in terms of :
  - Maximum Frame Size (MFS) (in bytes)
  - Minimum time between two frames (in ms)
- Contractual bandwidth [kbit/s] = MFS[bit]/BAG[ms] (incl headers)
- Max bandwidth for a single VL ≈ 12,5Mb/s (=1571 bytes * 8 / 1ms)
- No correlation between application clock and End system clock

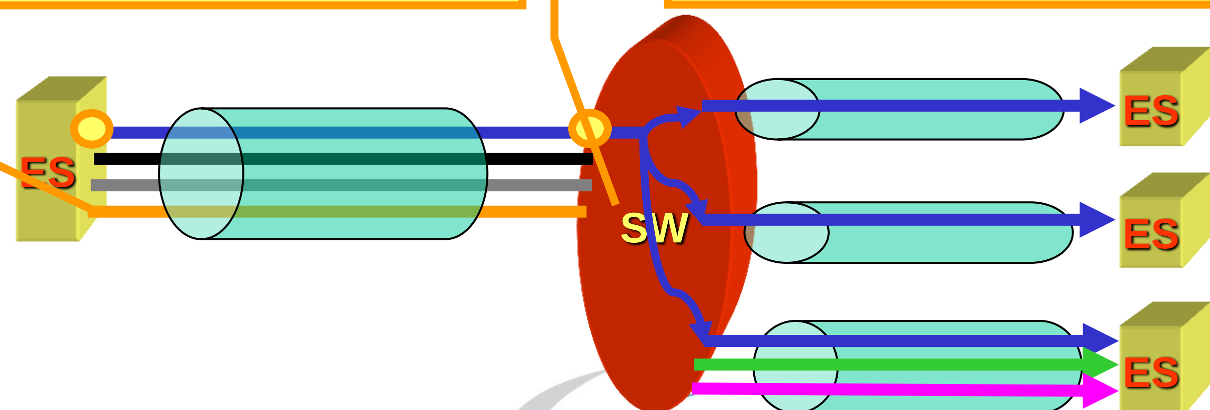


A664 key feature : “Firewalling” (1/2) Traffic Shapping / Traffic Policing

- The robust partitioning relies on "Bandwidth contract“(BAG) granted to each Virtual Link
- The ES has Bandwidth Contract for each Virtual Link and must comply with this contract (constraint on emission – not reception)
- The Switches know the term of the contract for each Virtual Link and monitor the traffic to check if contract is respected

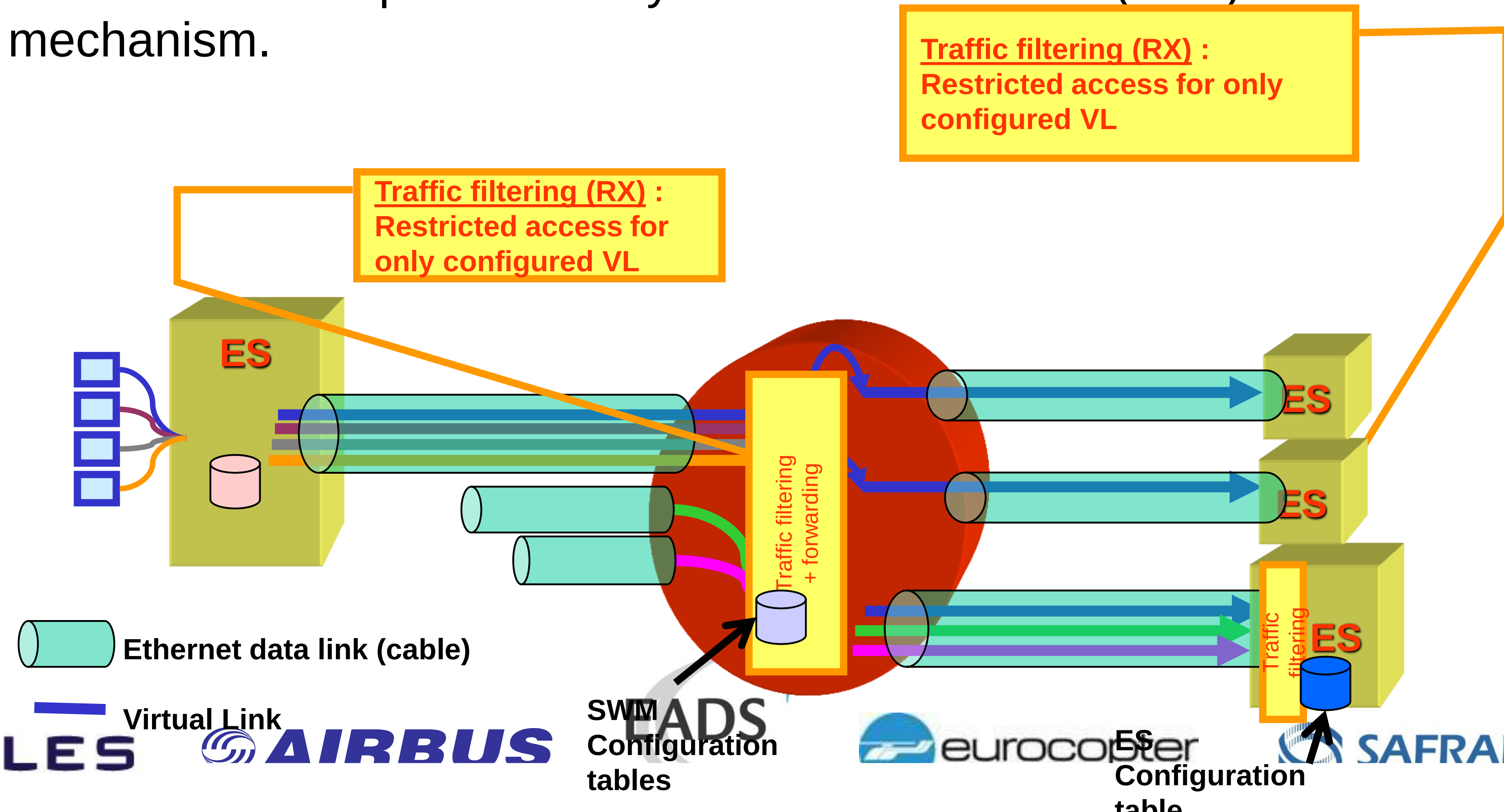
Key feature : Traffic shaping (TX)
the traffic is generated according to bandwidth contract

Key Feature : Traffic policing (RX)
the traffic is monitored according to bandwidth contract



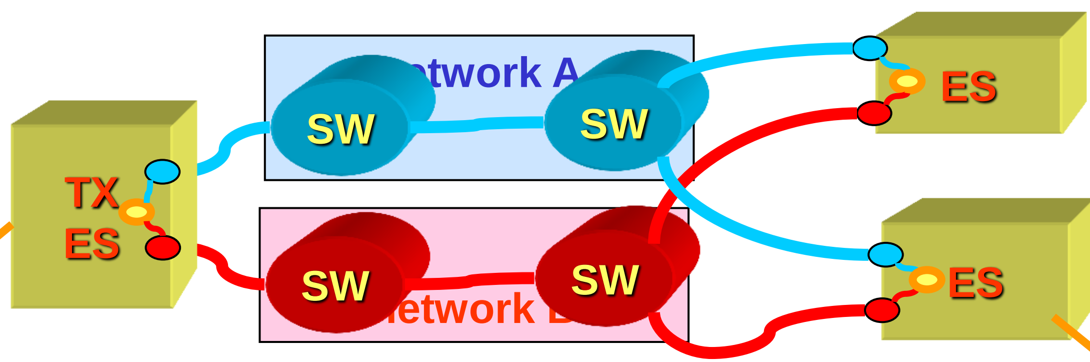
A664 key feature : “Firewalling” (2/2)
Traffic filtering

- Another feature related to robust partition and safety is the integrated "firewall" provided by the A664.
- This firewall is implemented by Access Control List (ACL) mechanism.



A664 key feature : Redundancy

- In response to the "Availability" requirement A664 network is basically redundant.
- Each End-System has the capability to send/receive twice each message toward to independent set of switches.
- Both TX frames are identified with a Sequence Number used at reception
- Reception algorithm based on “First Valid wins” principle



Key Feature : Redundancy Management
=> each frames are numbered when transmitted.

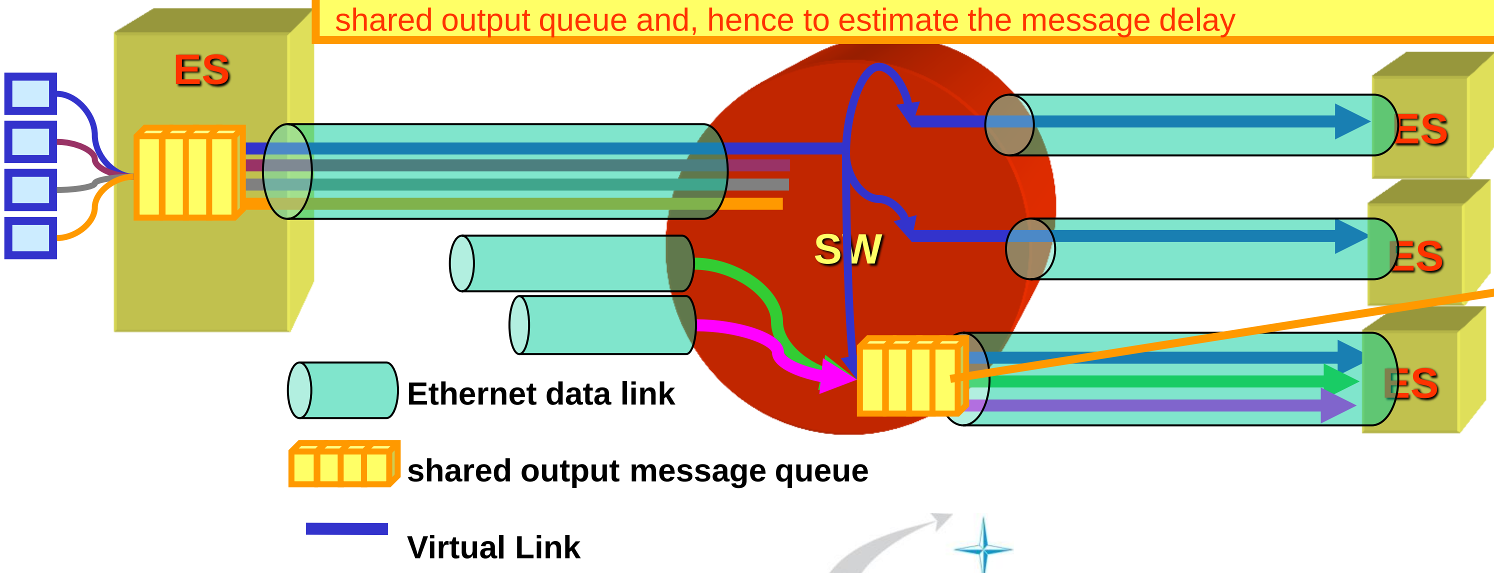
Key Feature : Redundancy Management
=> each frames are sorted when received.

A664 key feature : Latency Management

- In A664 context the determinism is defined as the control of maximum transmission delay through the network
- The enabler of such control is precisely the bandwidth contract
- Ethernet Switch provides better capability for determinism than usual Ethernet Hub because there is no collision and no transmission random retry

Key feature : Bounded latency

The knowledge of bandwidth contract allows to evaluated the worst case filling level of shared output queue and, hence to estimate the message delay

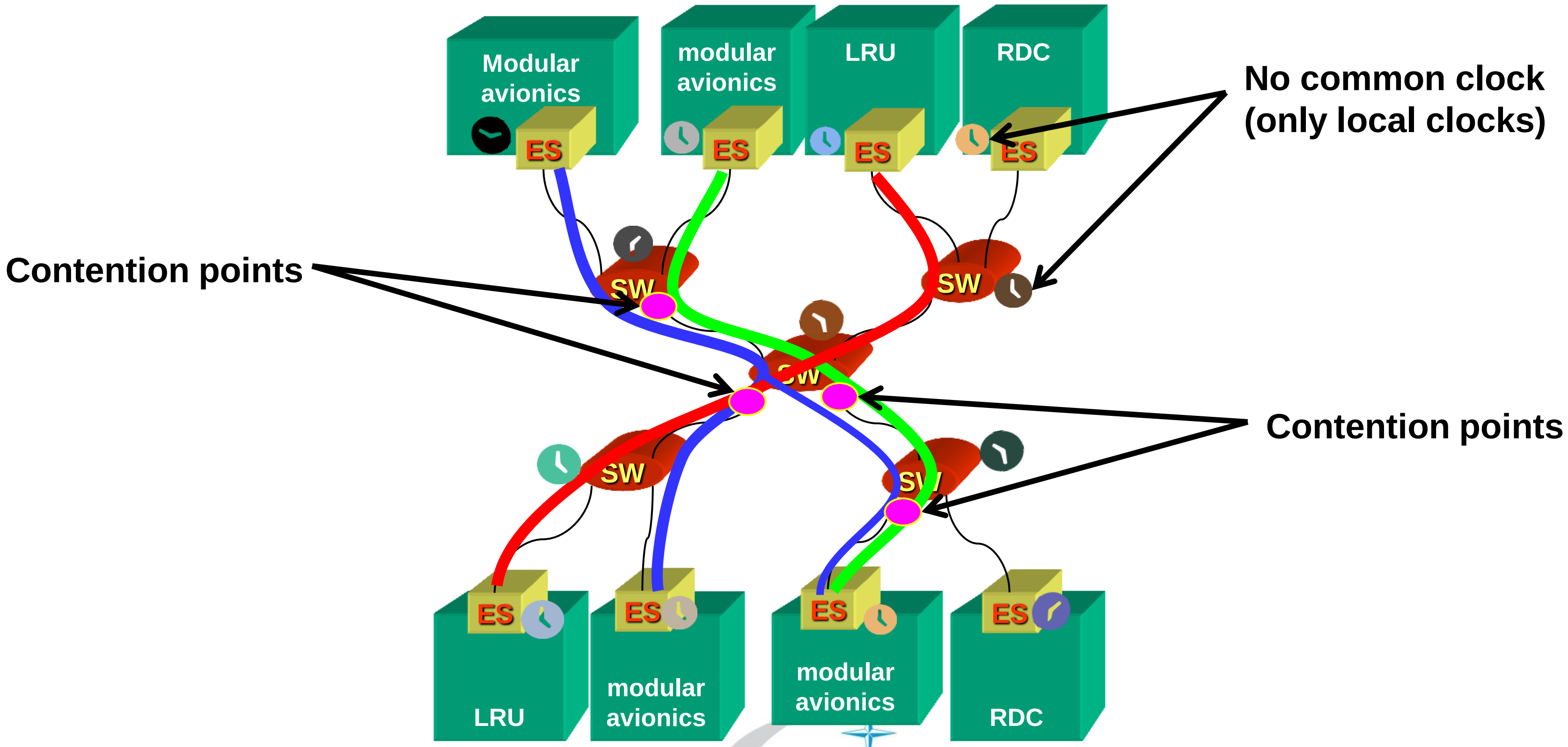


A664 key feature : Determinism (1/2)

- Determinism Definition
  - According to Standard ARINC A664, the ADN determinism can be defined as :
    - Compliance with the user requirement on time spent for network transit (latency and jitter)
    - Assurance that the ADN does not change the frames sequence
    - Compliance with the ADN feature capabilities (e.g. max allowable switch output buffer size) => no frame lost
  - To summarize , determinism aims at mastering and warranty :
    - transit time (latency) (WCTT < user latency),
    - Jitter
    - without data loss

A664 key feature : Determinism (2/2)

- Determinism should be proven for each topology
- Objective is to formally prove that all functionnal flows are temporally satisfied regarding to user requirements and without loss of frame



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Network architecture

Physical architecture

(equipment list, positions,…)

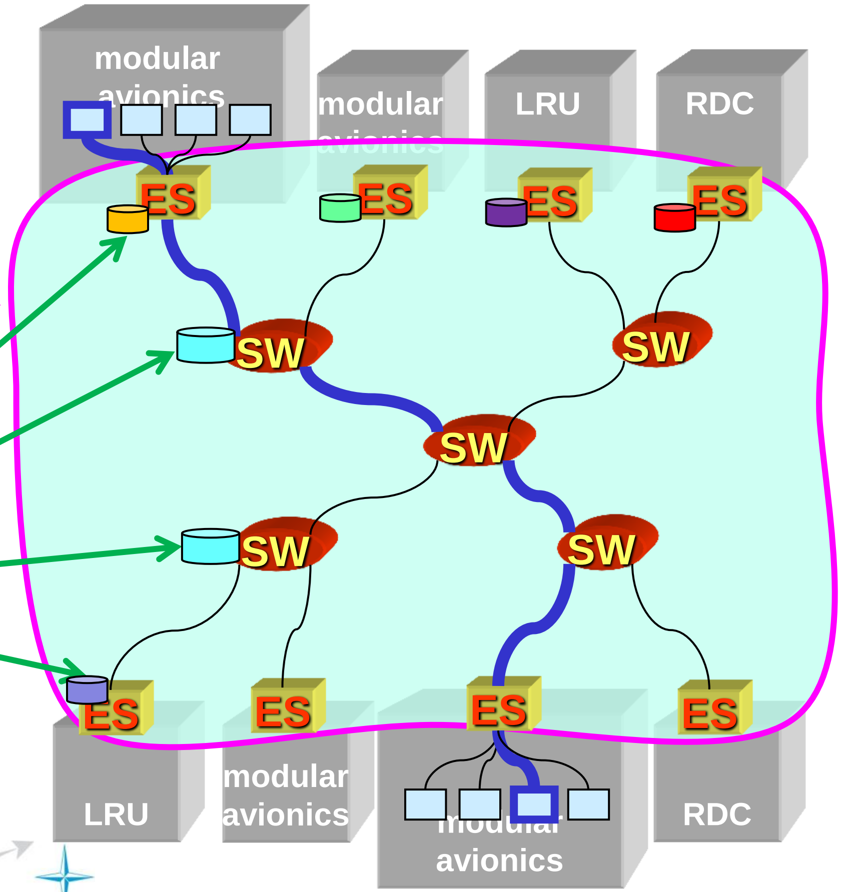
=> Wiring/installation

Logical architecture

(flow adressing, routing)

=> -configuration of ES

-configuration of SWM



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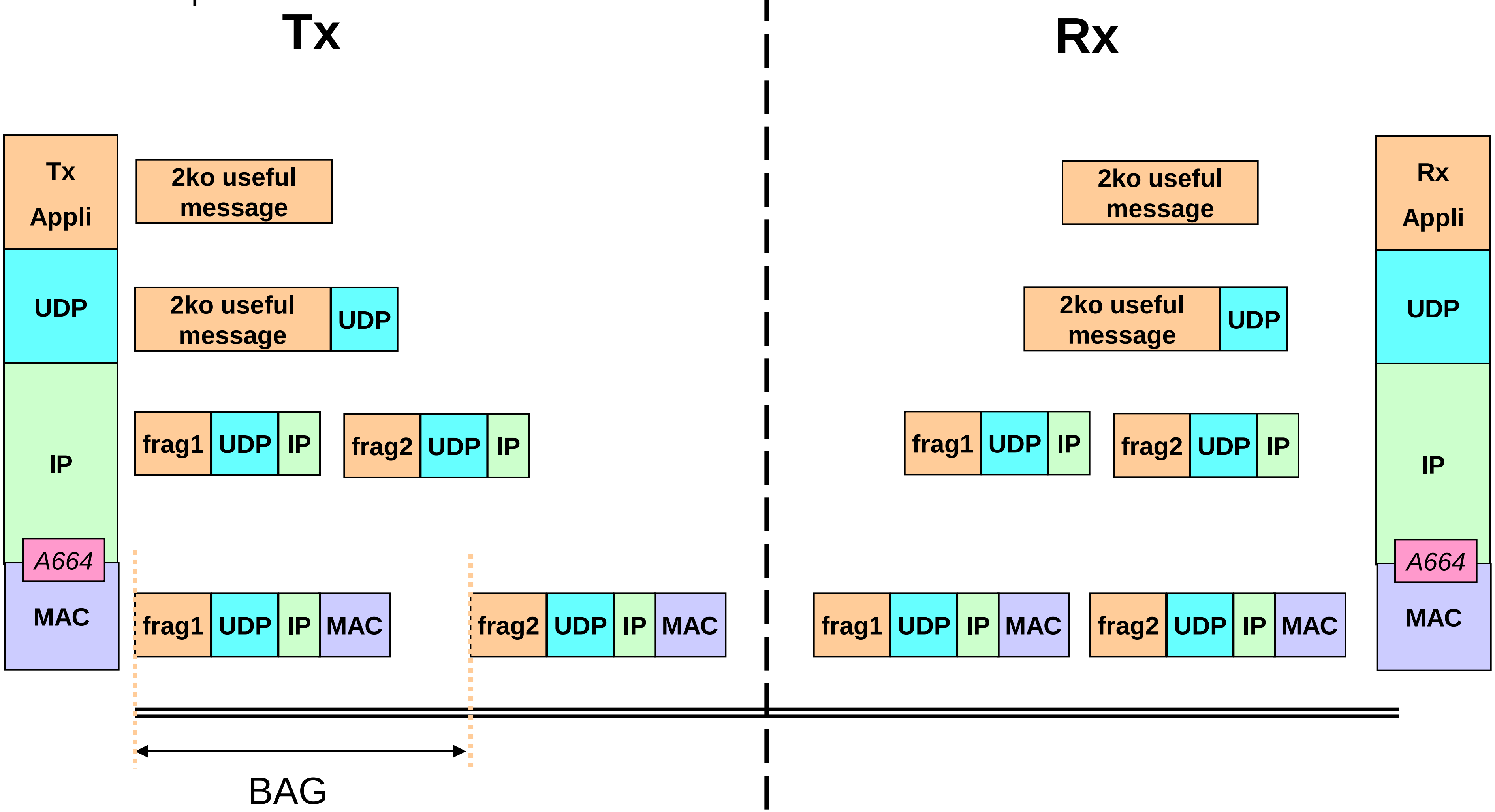
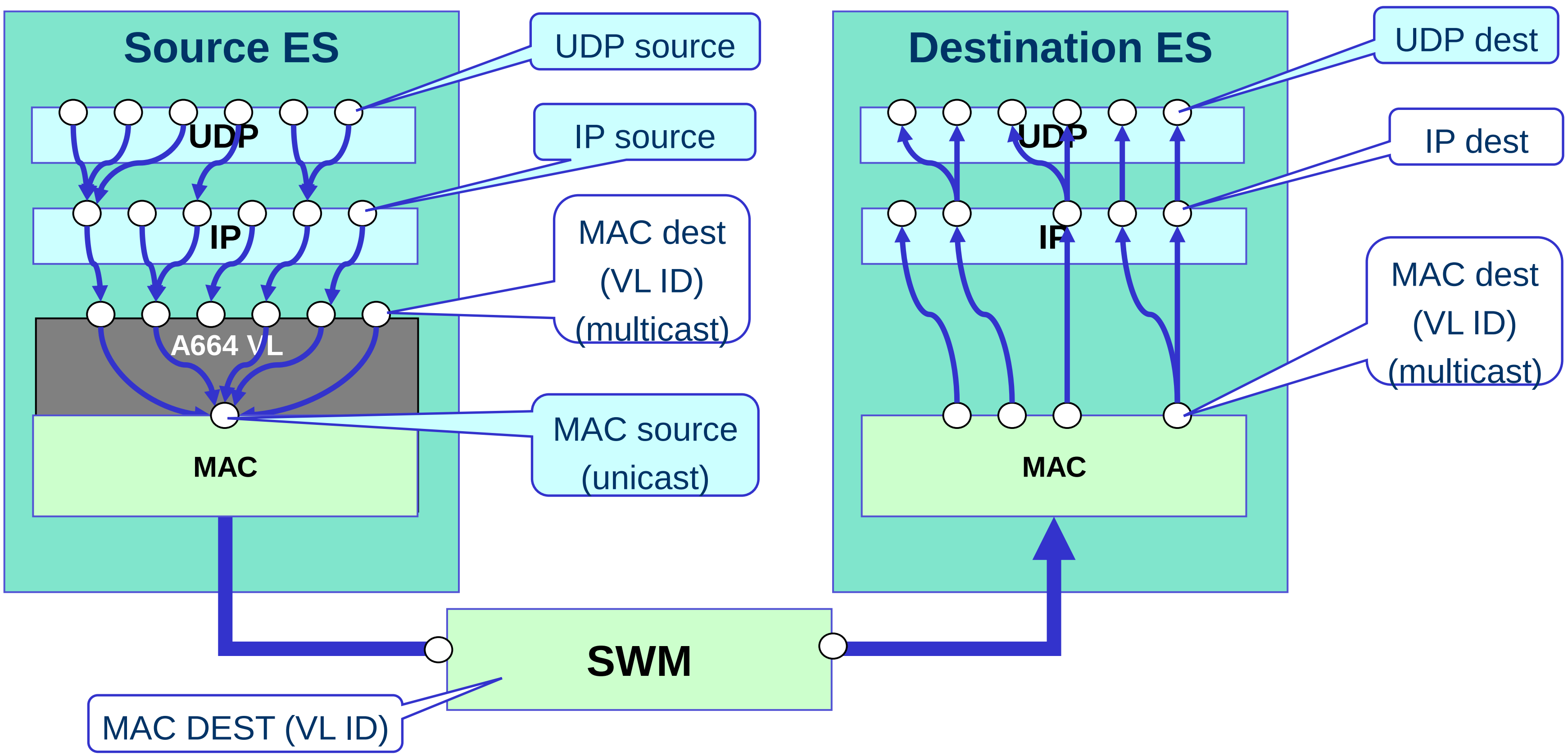
➔ Example of a 2 ko useful data transfer



Logical interconnection / ES Part (1/3)



Several addressing levels which support data multiplexing and demultiplexing

Port type : Sampling (ES Part)

Sampling Ports are defined by ARINC 653 API specification and by A664

- Correspond to a data from "**process control**" (non protocol)
- Data is sent as a single transmission unit
- Source and destination addresses are statically defined

- Rx Sampling port
  - The last received data overwrites the previous one
  - Several application can read the data
  - A "freshness" is attached to the data for each applications that use it
- Tx Sampling port
  - The last produced data overwrites the previous one

Port type : Queuing (ES Part)

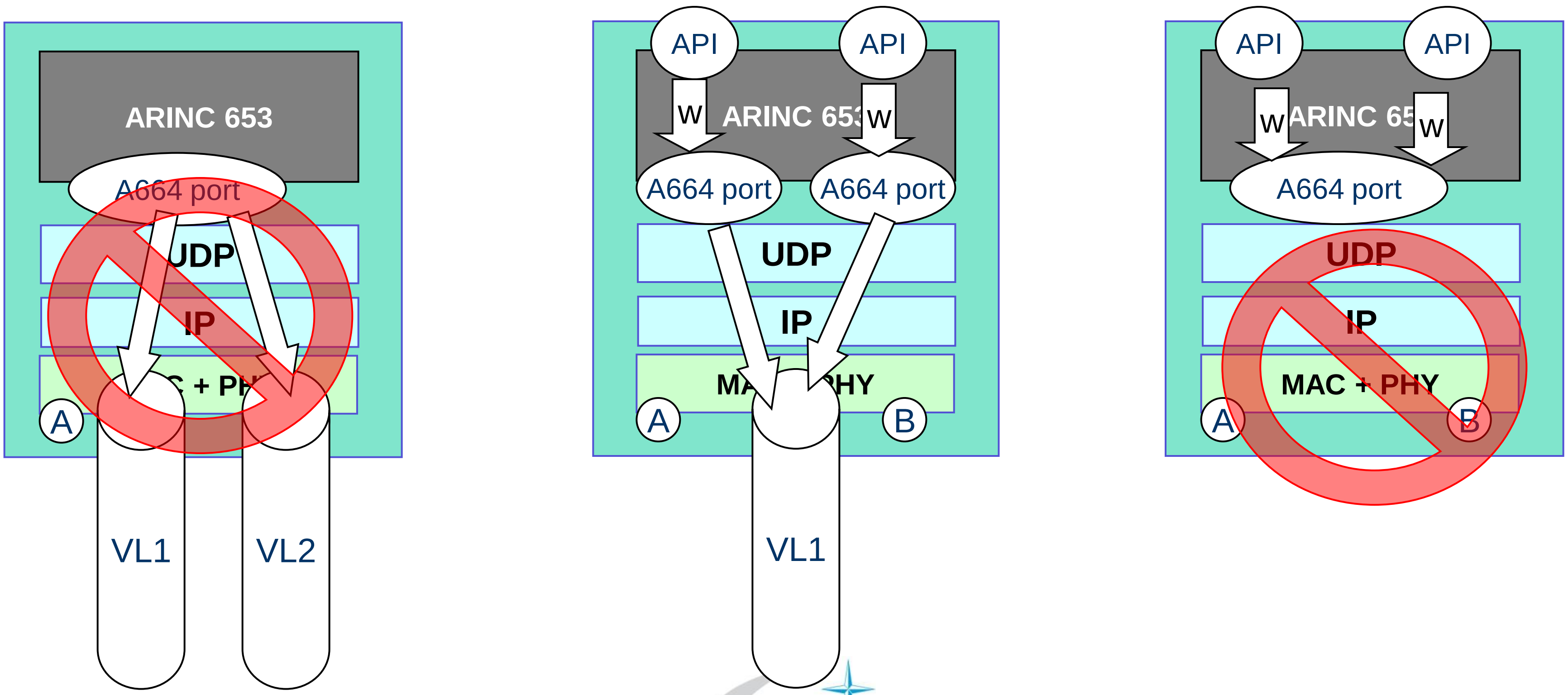
- Queuing Ports are defined by ARINC 653 API specification and by A664

  - Correspond to data from "information system" (protocol)
  - protocol defined in a specification (A615A, A661, tftp Airbus, …)
  - protocol of standard TCP/IP (SNMP, …)

  - data can be larger than the transmission unit and can be fragmented into a sequence of transmission unit and reassembled at reception
  - data are managed by FIFO policy
  - only one application can read the data
  - Overflow can occur when producer is faster than consumer
  - source and destination addresses are still defined statically

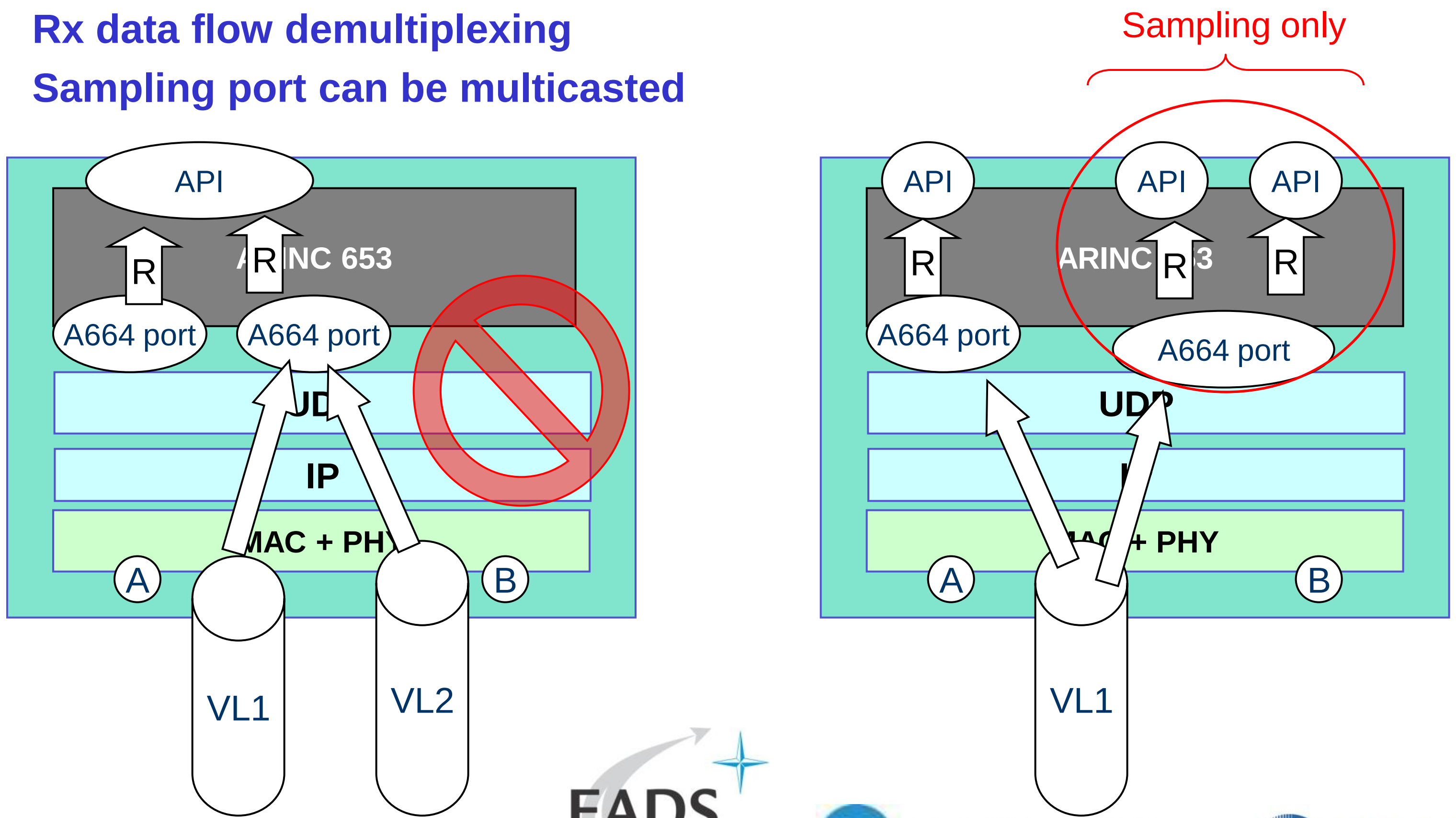
Authorized logical communication : Tx side (ES Part)

- In Tx, there is a one to one mapping between Application port (API) and A664 port
  - **Tx = data flow multiplexing**



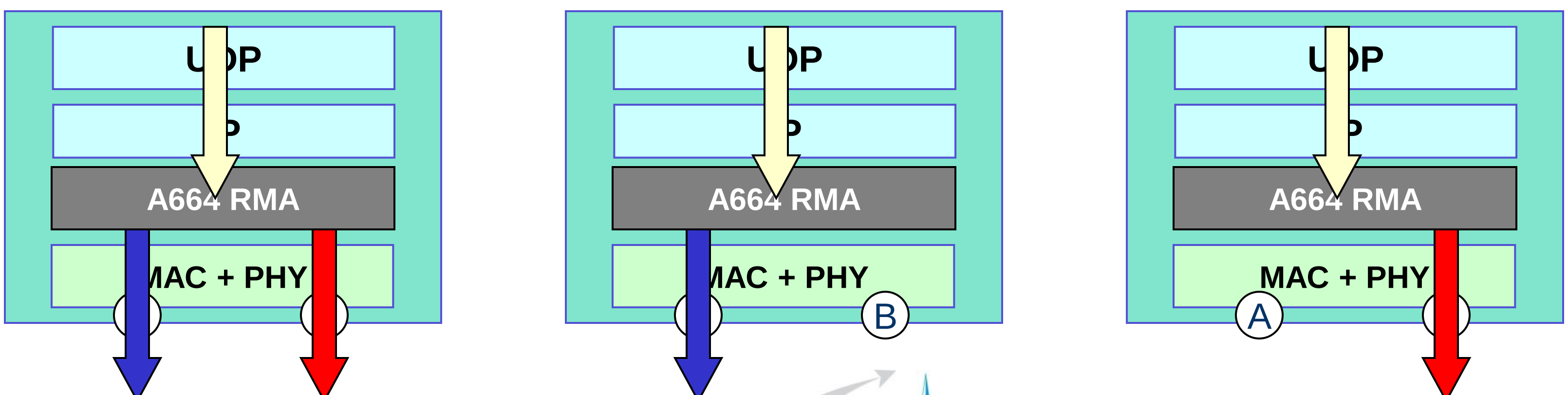
Authorized logical communication : Rx side (ES Part)

- In Rx, there is a one to one mapping between Application port (API) and A664 port
  - **Rx data flow demultiplexing**
  - **Sampling port can be multicasted**



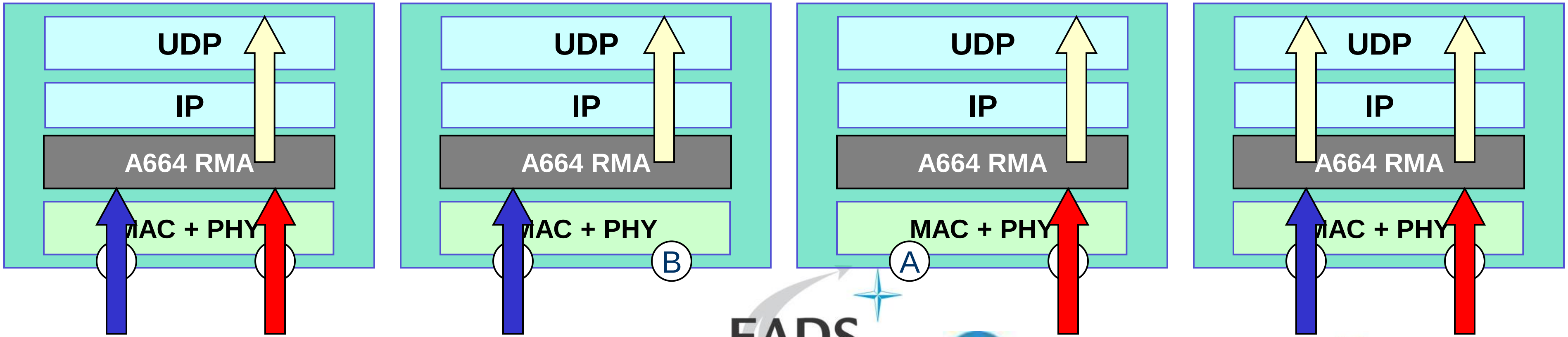
Redundancy types : Tx side (ES Part)

- At Tx side, redundancy is a parameter attached to VL
- A VL can be configured to be
  - Redundant
    - the frame is sent simultaneously to both A and B attachments
  - Non redundant
    - the frame is sent only on one attachment A or B



Redundancy types : Rx side (ES Part)

- At Rx side, redundancy is a parameter attached to a port
- A port can be configured to receive message
  - from a Redundant VL
    - only the first received frame is stored in the port whatever its origin A or B
  - from a given attachment A or B
    - only the frame received from A (resp. B) is stored in the port
    - Note:
      - when the transmitting VL is redundant, this allows to process the two frames at application level
      - when the transmitting VL is not redundant, it is expected that the attachments are the same in Tx and Rx



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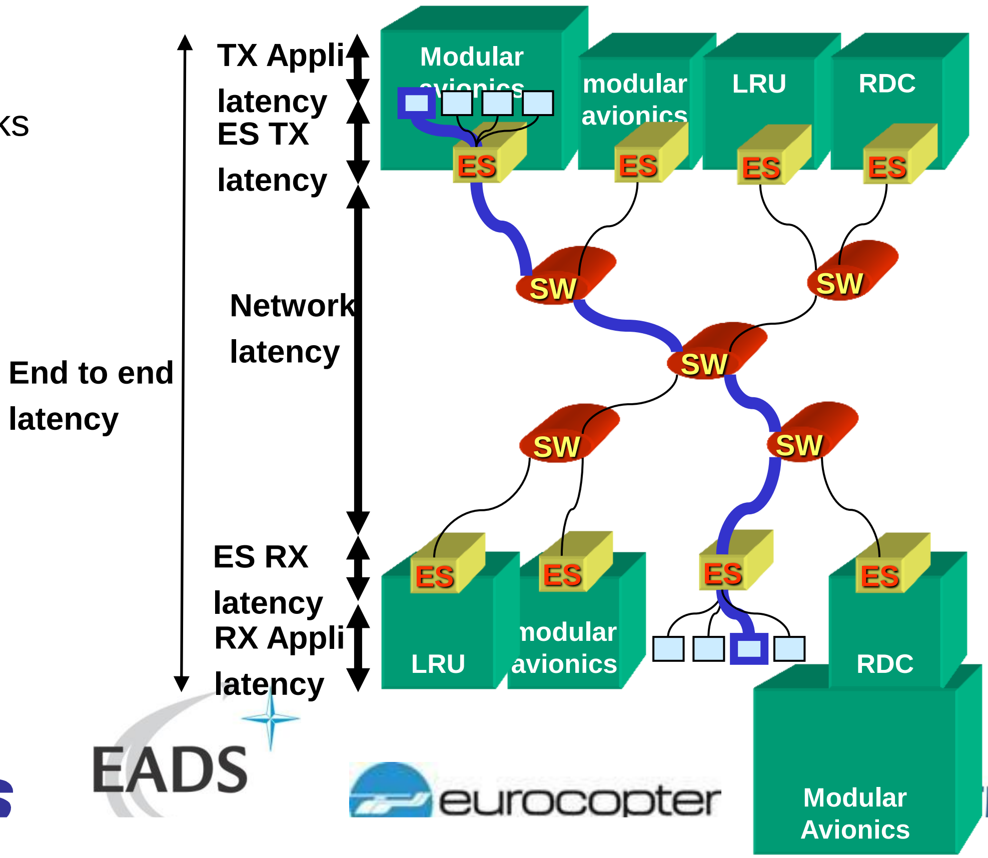
Performance aspects and Determinism…

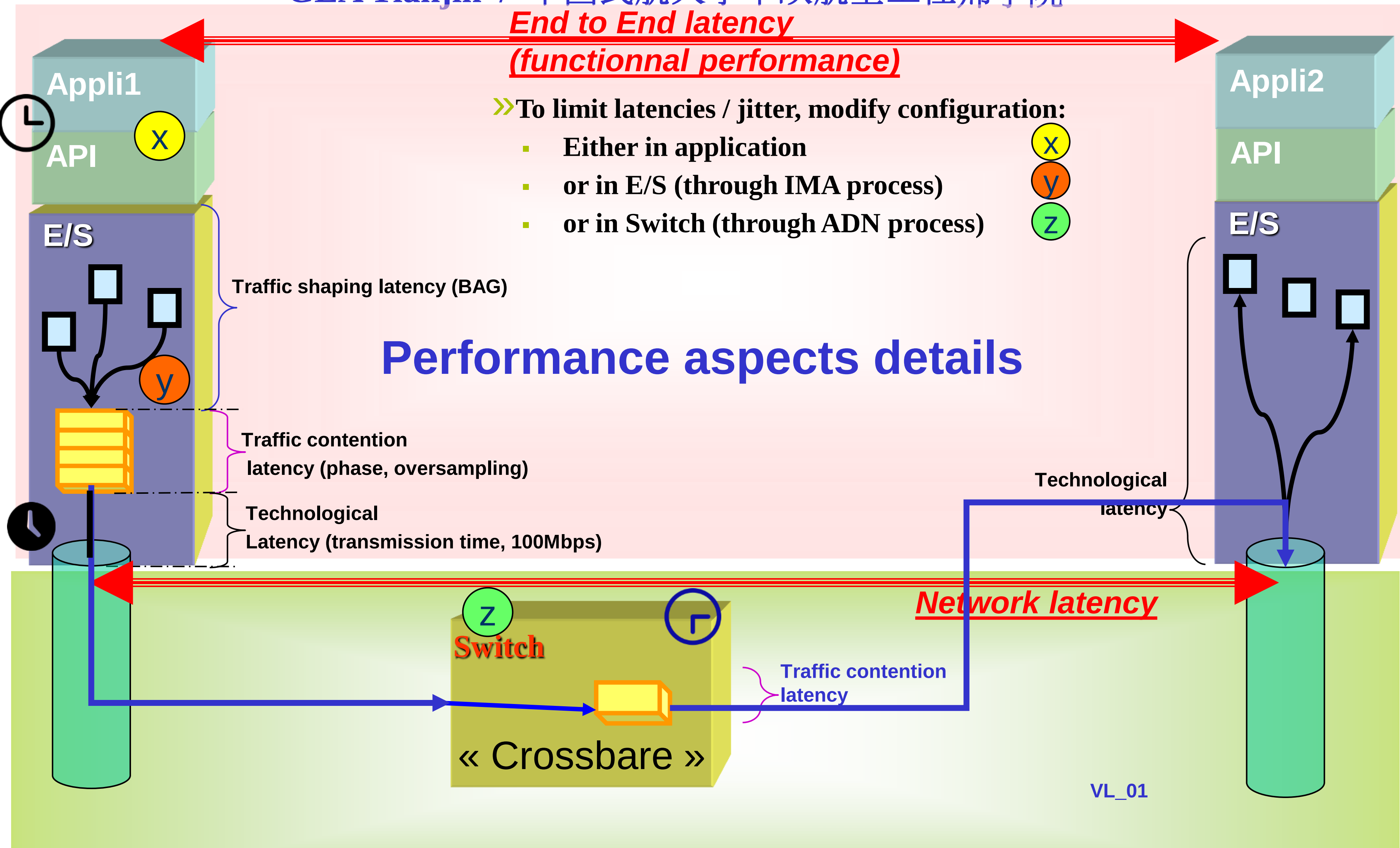
- The major performance parameter in A664 network is the latency.
  - Latency is defined as the delay for a message to be received.
  - Jitter is defined as the variation of this latency
- End to end latency is the addition of several successive latencies:
  - TX Applicative latency
  - latency in the Tx ES
  - cumulated latency along the links
  - latency in the Rx ES
  - RX Applicative latency



Performance aspects details

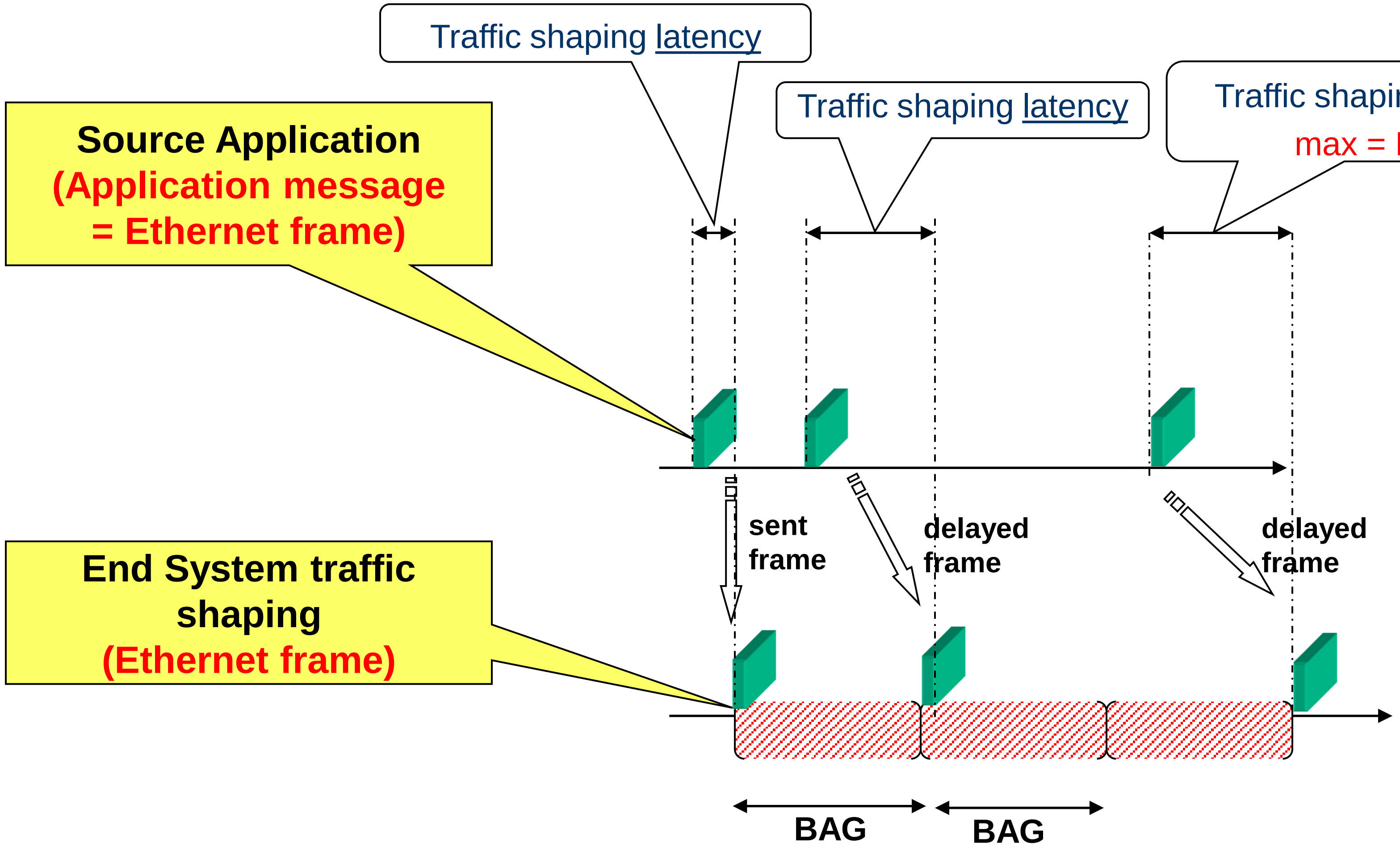
To limit latencies / jitter, modify configuration:

- Either in application x
- or in E/S (through IMA process) y
- or in Switch (through ADN process) z

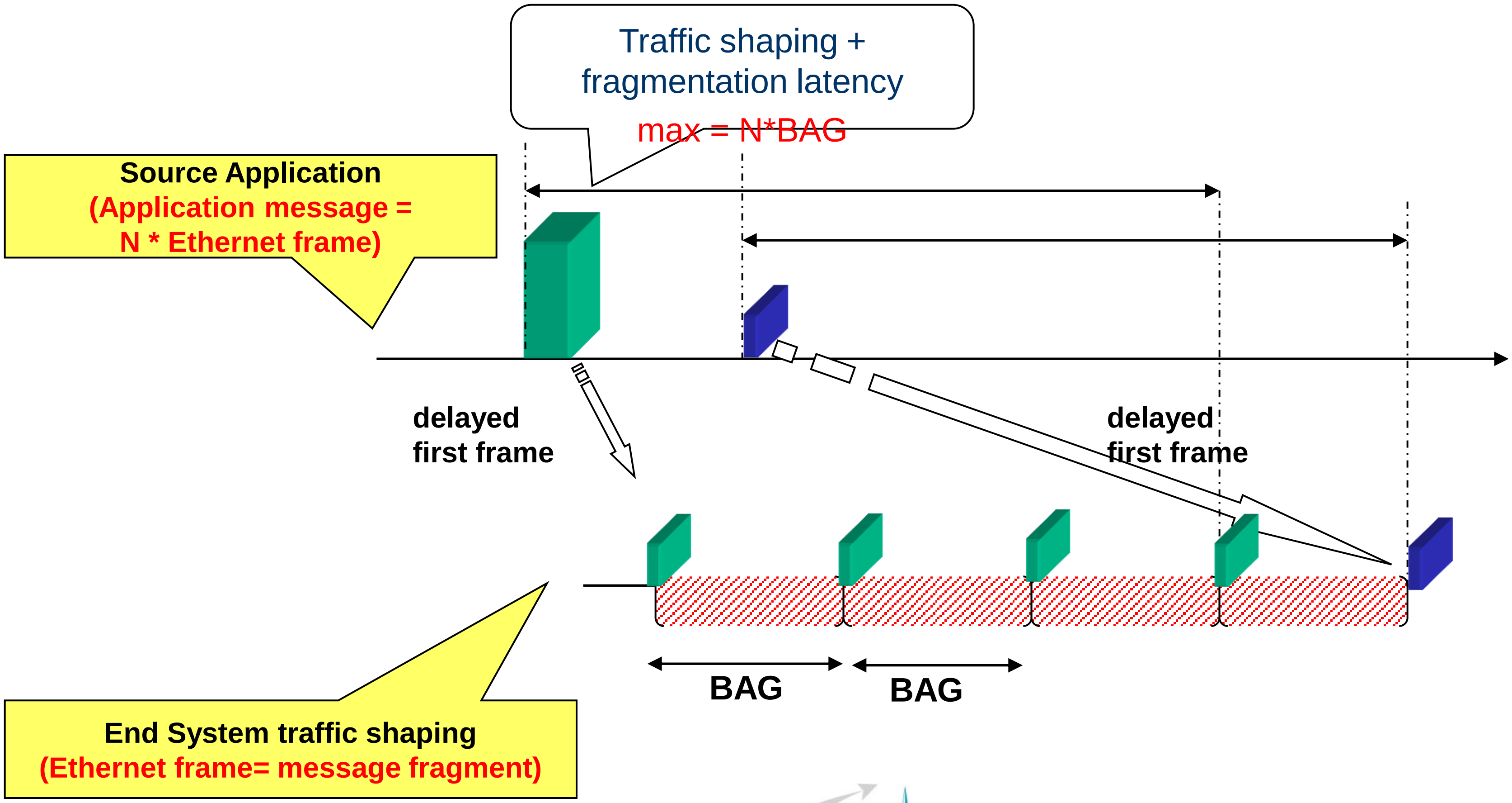


Network Integrator: Configures switch, calculates, qualifies Network latency

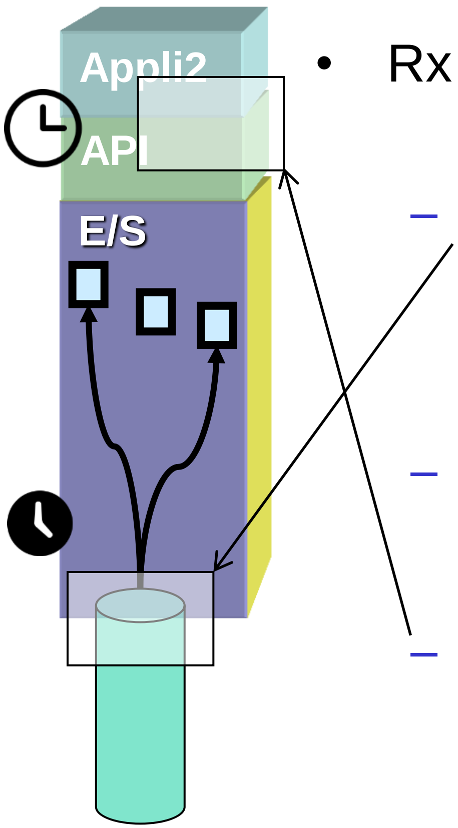
Tx ES: Traffic shaping latency / sampling



Tx ES: Traffic shaping latency / queuing

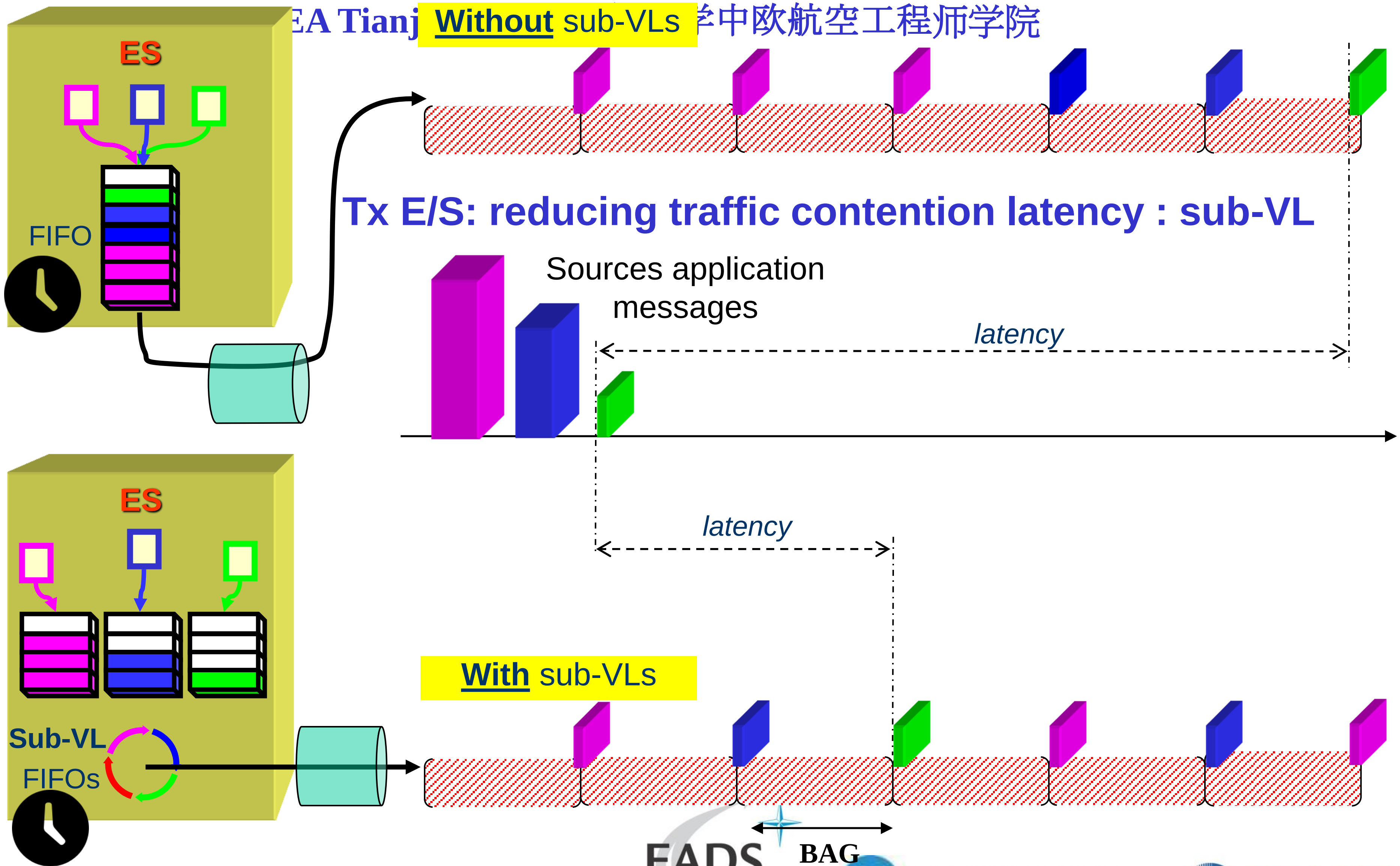


Rx ES latency



- Rx ES latency includes
  - **Technological latency**
    - The "floor" delay needed to process the message when no other message is processed (typical max value = 150 µs)
    - This latency includes Traffic filtering and message reassembly
  - **Traffic contention latency**
    - There is **NO** contention in Rx
  - **Application asynchronism latency**
    - The destination application is (often in avionics) periodic
    - There can be one period delay before the application receive actually its message

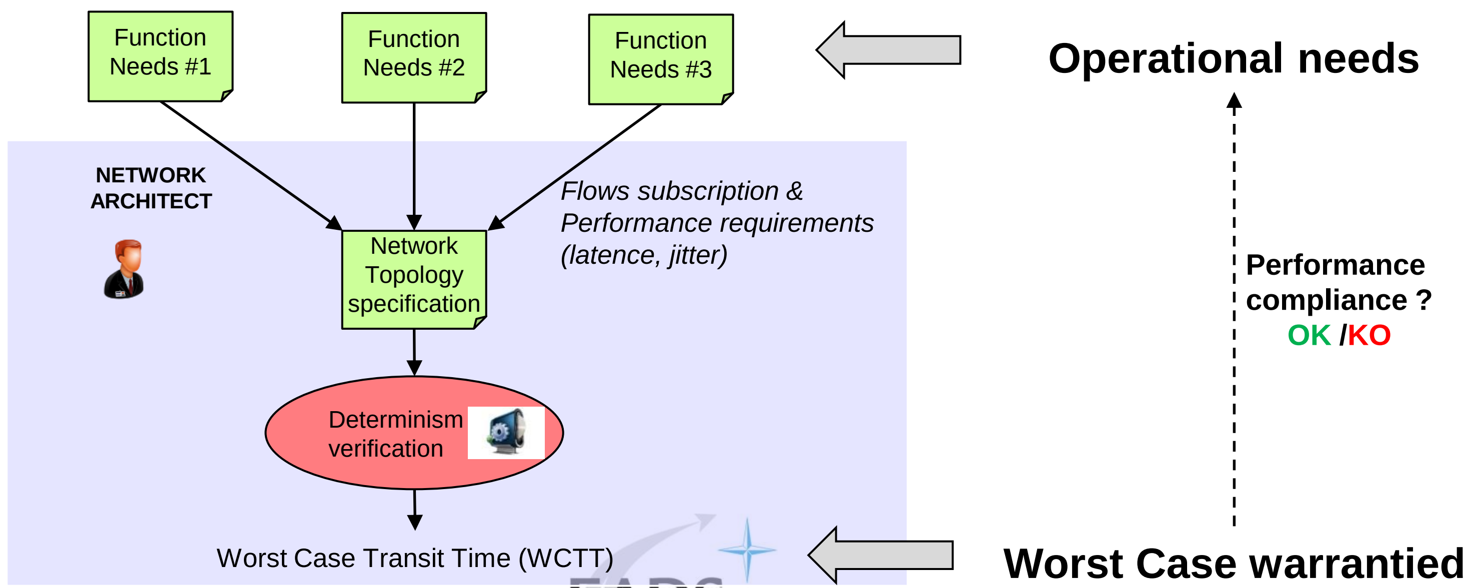
Tx E/S: reducing traffic contention latency : sub-VL



Bandwidth is distributed fairly between **sub-VLs**

Network latency : Formal Proof

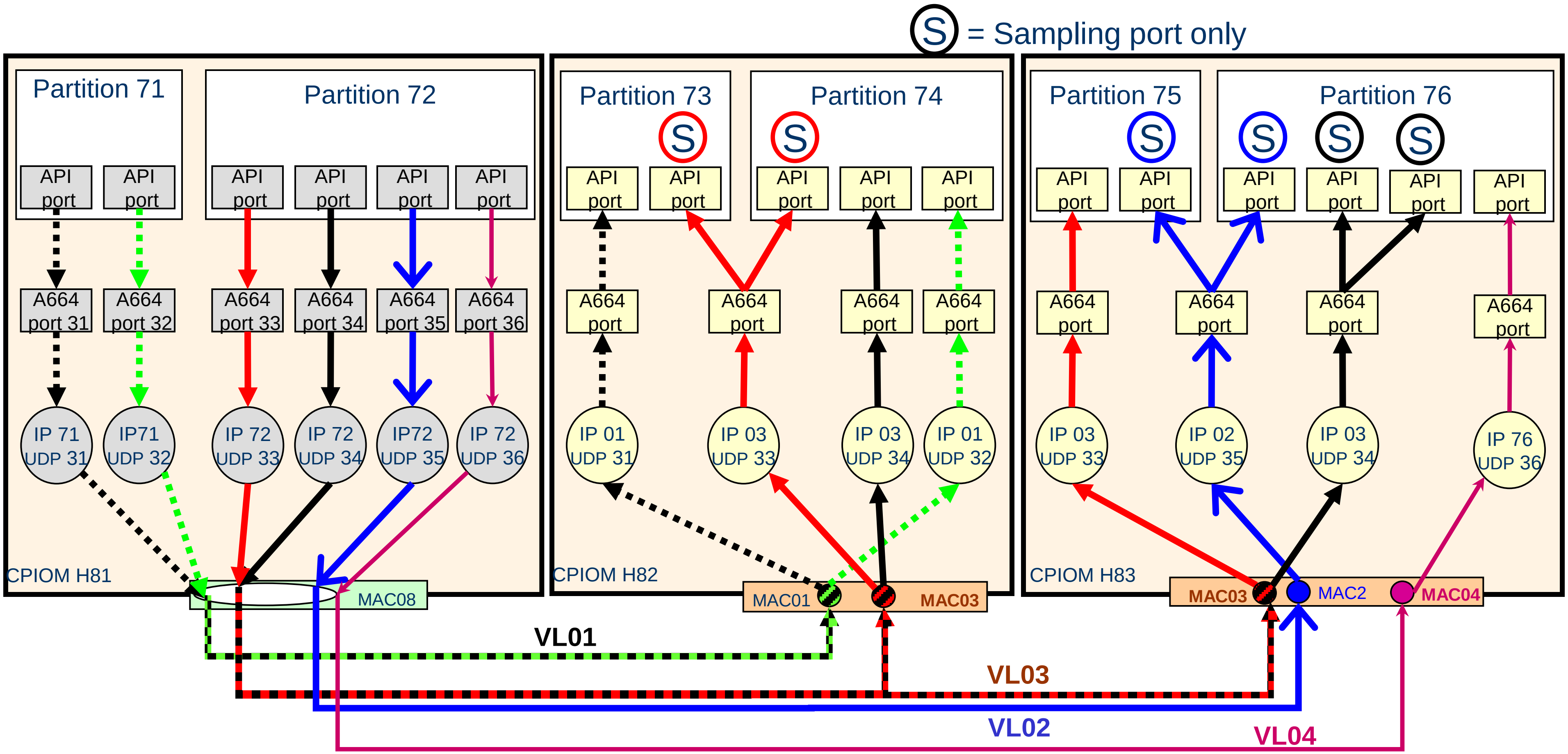
- **Principle**
  - **All functions which need to use the network specify their needs**
  - **Network architect build a topology (physical and logical) to satisfy them**
  - **Determinism is formally proved running a dedicated algorithm (software tool) which :**
    - **computes the Worst Case transit Time (WCTT) for any paths**
    - **checks if any need is satisfied in the Worst Case**



Outlines

- The A664 Standard
  - Short reminder : Communication Principles
  - The aircraft communication context and constraints
  - The origin of the standard
  - Products
- Key Features
  - Open Standard
  - Virtual Link concept
  - “Firewalling” (Traffic Shaping / Policing /Filtering)
  - Redundancy
  - Latency / Determinism
- Network Architecture
  - Physical architecture design
    - Main drivers for physical architecture design
    - Safety constraints
  - Logical Architecture design
    - Logical architecture principles
    - ES Part / The different types of application port
    - ES Part / Different logical communications
    - SWM Part
- Performances optimisation and determinism
  - Several sources of latency
  - ES Latencies
    - descriptions / optimisation
  - SWM Latencies
    - descriptions / optimisation
- A664 addressing features
- Networks optimization & Field Bus technologies overview

Routing example (ES part) – Back-up slide



Addressing example (ES part) – Back-up slide

IP dest unicast : one partition (10.yy.zz.tt)

IP dest multicast: address based on VL (224.224.VLid)

One API port

= one A664 port

= one UDP source address

MAC dest. :

one MAC destination address per VL

MAC source :
Two MAC addresses per CPIOM
(A & B channels)

One IP source address

= one partition

Source port ID

= source UDP

= dest. UDP

	MAC dest.	MAC source	IP dest.	IP source	UDP dest.	UDP source
VL01	03.00.00.00.**00.01**	02.00.xx.**PP.PP.20**	224.224.**00.01**	10.yy.**00.71**	32	32
VL04	03.00.00.00.**00.04**	02.00.xx.**PP.PP.20**	10.yy.**00.76**	10.yy.**00.72**	36	36

VL

A or B

Partition

Pin-prog

VL if multicast,
Partition if unicast

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Network Optimisation (1/2)

Optimisation can be performed on :

- The topology of the network :
  - Objective = to meet safety constraints with a limited number of switches
- The choice of MFS and BAG values for a given VL bandwidth
  - Objective = to minimize the impact of a VL on the neighbouring VLs within a switch
  - Stakes = a true realization of incremental certification
- The WCTT (Worst Case Transfer Time)
  - Objective = to use the network at its maximum capability

Network Optimisation (2/2)

Topology optimisation

- A problem of Graph Theory and linear optimisation when safety constaints are applied on the choice of the effective path

MFS / BAG

- A compromise to be found
  - The minimum MFS, the minimum the impact on latency
  - The maximum MFS,the maximum the efficiency of the frame overhead

WCTT

- WCTT computation gives over pessimistic values that drive to "under" usage of the network
- State of the art of WCTT computation:
  - Network Calculus (Airbus, Rockwell-Collins approach)
  - "Model based" (Thales approach)
- Both give about the same result, some direction of improvement are under experimentation

Market New demands…Recurrent needs

- NG Communication for safety-critical controls shall fulfill:
  - Cost optimization/reduction
  - Increase of performances
    - Operational
    - Flight safety
    - System reliability & aircraft availability
    - Modular design with incremental certification features (DO297)
    - Maintenance, repair & overhaul
    - Obsolescence management
  - Enhancement of functionality
  - Seamless design tool integration

Field Bus Communication Technologies I

- Traditional event-driven
  (network activity is triggered by application activity)
  - CAN, ARINC429, …

- Time-Triggered
  (network activity is triggered by schedule executed on flow of time)
  - TTP, FlexRay, …

- Time-Triggered Ethernet Approach
  (Can cover standard Ethernet, rate constrained and time-triggered data traffic requirements)

Field Bus Communication Technologies II

- Technical Overview about Field-bus Protocol Features:

technical	Determinism/Testability	Fault-Tolerance built-in	Data-rate / Bandwidth	DC-free coding
CAN	-	-	1Mbit/s	-
MIL1553B	medium	-	1Mbit/s	●
ARINC429	-	-	100kbit/s	●
ARINC629	low	-	2Mbit/s	●
TTP	high	●	2x5Mbit/s	●
FlexRay	high	-	2x10Mbit/s	-

Field Bus Data Communication Technologies III

- Commercial Overview about Field-bus Protocols:

commercial	Technology cost	second source (S) multi source (M)	Physical Layer specified	certification acc. aerospace standards	Aerospace proven
CAN	low	M	●	●	●
MIL1553B	high	M	●	●	●
ARINC429	high	M	●	●	●
ARINC629	high	-	●	●	●
TTP	medium	(S) under design	in progress (AS6003)	●	●
FlexRay	low	M	●	-	-

Field Bus Selection Outline (back-up)

- Advantages/benefits for Time-Triggered Protocols (TTP/FxR)
  - CAN, MIL1553B, ARINC429, ARINC629:
    - Bandwidth at it upper limit for aerospace use
    - Insufficient determinism
    - Lack of fault tolerance mechanisms / services built-in
    - Not sufficiently suited for modular/platform based design
- Difference TTP – FxR, trade-off
  - FxR disadvantages:
    - Certification acc. to aerospace standards
    - Start-up (CAS babbler)
    - Suitability for safety-critical applications (FxR: withdrawn)
    - DC free physical layer (TTP: Manchester versus FxR: NRZ)
    - Aerospace production project history
    - Limitation to automotive use
  - TTP disadvantages:
    - Second source controller not finished (under design)
    - TTTech is single supply of Tools & origin of controllers (VHDL model)
    - Strict design rules require update of all nodes (in case of change of frame sending pattern) if no future extensions were foreseen in the design
    - Market share (good success in production programs but limited number)