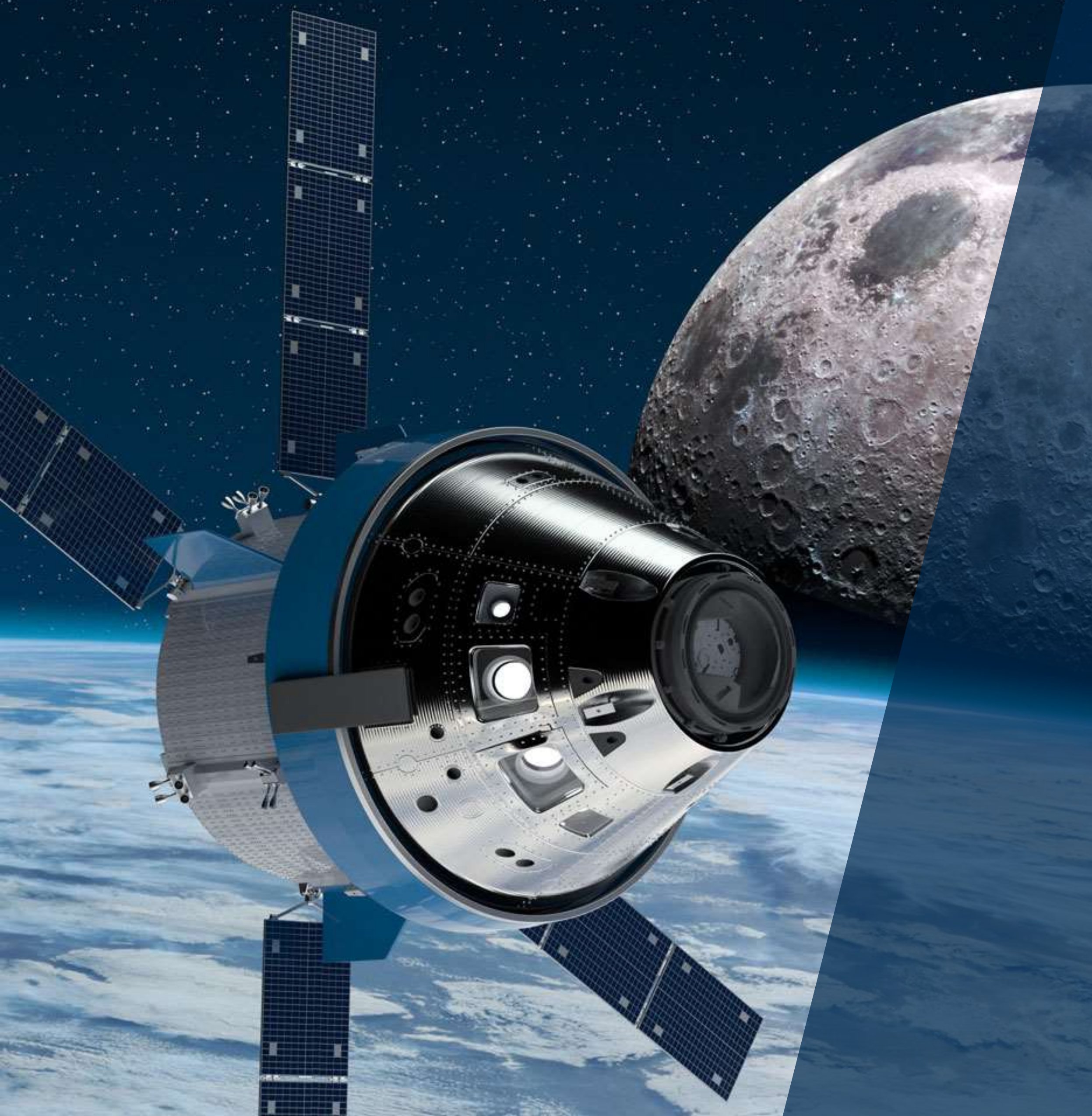

TTTech

Building a deterministic real-time systems with GR740 and TTEthernet

GR740 User‘s Day
13.12.2022

Stefan Mödlhamer
Ivan Masar

TTTech Computertechnik AG

Our vision

Advancing safe technologies, improving human lives

TTTech Group
Key facts

Founded in **1998**, headquartered in Vienna, Austria, with **21** offices in **15** countries worldwide

Products in **1173** production programs

Connected companies: TTTech Auto, TTTech Industrial, TTControl, RT-RK

2,300
Employees/ subcontractors

60
Nations represented in our workforce

380
R&D/ENG/ADMIN

50
TTTech Industrial

490
RT-RK

100
TTControl

1,170
TTTech Auto

90
TTTech Aerospace

TTTech

Connecting markets to solutions

TTTech Group

Group Company Services

Group Research & Development

Long-term oriented investors as partners

TTTechAuto

Digital platforms for highly automated vehicles

TTControl
HYDAC INTERNATIONAL

Automating safe environments for mobile machinery

TTTech industrial

Real-time communication & edge computing platforms for the Internet of Things (IoT)

TTTech Aerospace

Safety control platforms & real-time networks for aerospace & space applications

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Simplifying Spacecraft System and SW Design, Integration and Verification using TTEthernet

TTTech is a Leading Provider of TTEthernet

TTEthernet becoming a standard for high-reliable deterministic Ethernet for safety-critical space systems

- Launcher vehicles
  - Ariane 6
  - US customers
- Human-Space Flight
  - Gateway / Artemis missions
- Exploration
  - Commercial projects

Ariane6, ArianeGroup.

Gateway/Artemis, NASA/ESA/CSA/Jaxa

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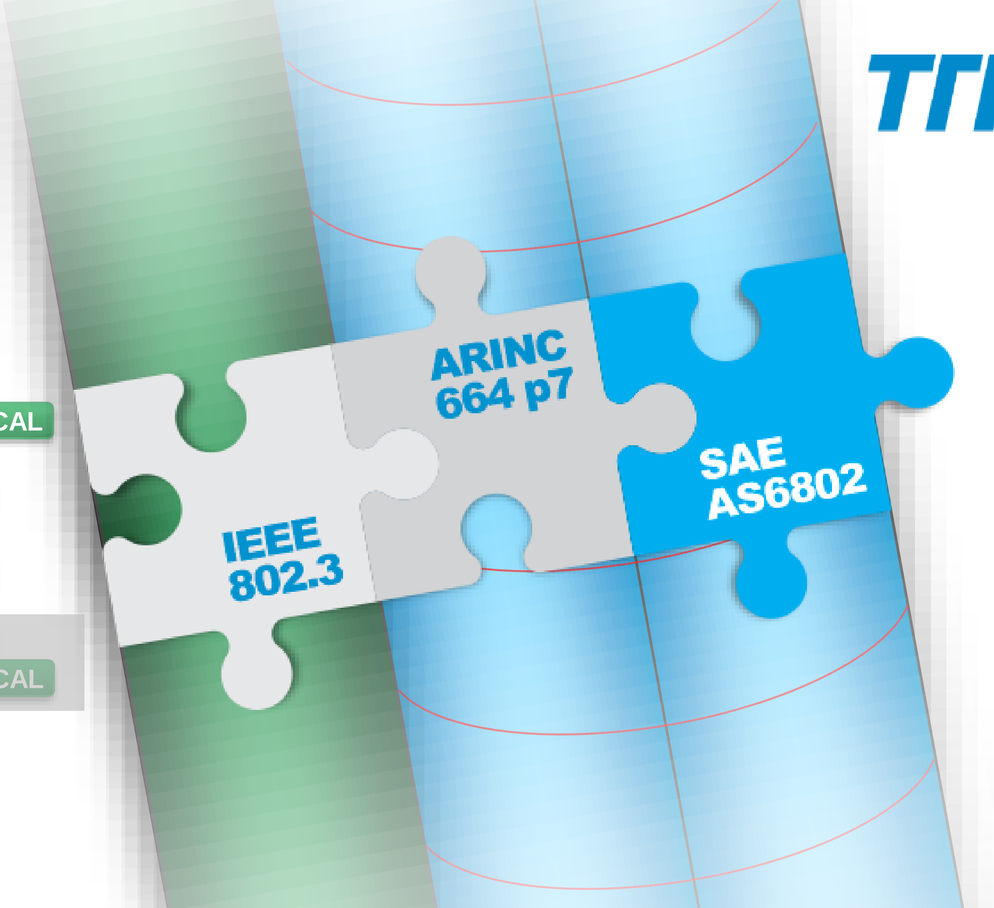
What is TTEthernet?

Supports **three** configurable traffic classes:

- Best-effort traffic / VLANs (**IEEE 802.3**) NON-CRITICAL
- Rate-constrained traffic (full **ARINC 664 part 7**) CRITICAL
- Time-triggered traffic (**SAE AS 6802**) CRITICAL
- Time-sensitive traffic (IEEE TSN, **802.1 DP**) CRITICAL / NON-CRITICAL

and processes non-critical and critical traffic

in parallel on one physical infrastructure.



“Safe hard real-time data communication over standard Ethernet infrastructure.”

Lunar Gateway Programm

TTTech

Habitation and Logistic Outpost Module (HALO)

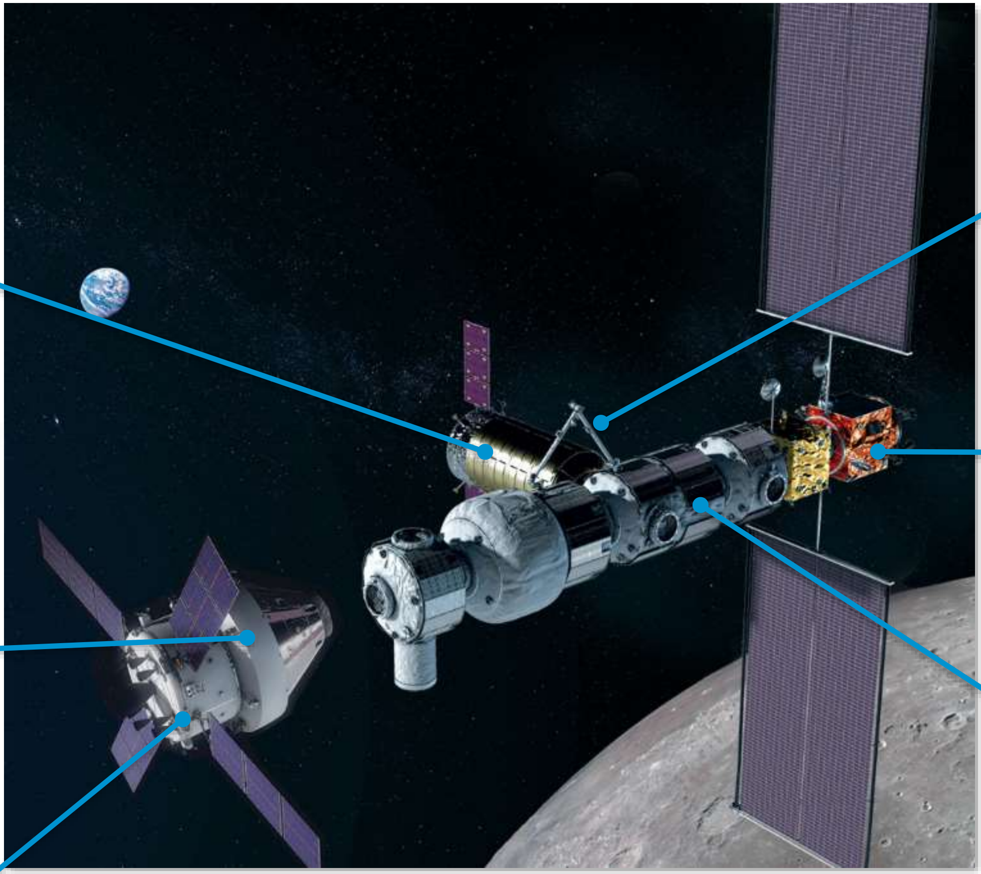
- Agency: NASA
- Prime: Northrop Grumman Space Systems
- Avionics modules:
  - Flight Computer
  - TTEthernet Switching Unit
  - Power Management and Distribution (PMAD) – by Airbus/Crisa
  - VxWorks drivers + integration with cFS
  - Firmware

Orion Capsule

- Agency: NASA
- Prime: Lockheed Martin Space Systems
- TTTech products:
  - TTEthernet IP (with Honeywell)

European Service Module (ESM)

- Agency. ESA
- Prime: Airbus
- TTTech products:
  - TTEthernet IP (with Honeywell)



TTEthernet specified as International Avionics System Interoperability Standards

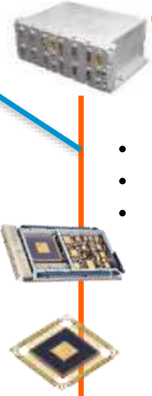
Planned to use GR740 with TTEthernet

Robotic Arm (CANADARM)

- Prime: MDA
- TTTech products (currently in definition):
  - TTEthernet End Systems + Switches
  - SW integration
  - TTE-Tools

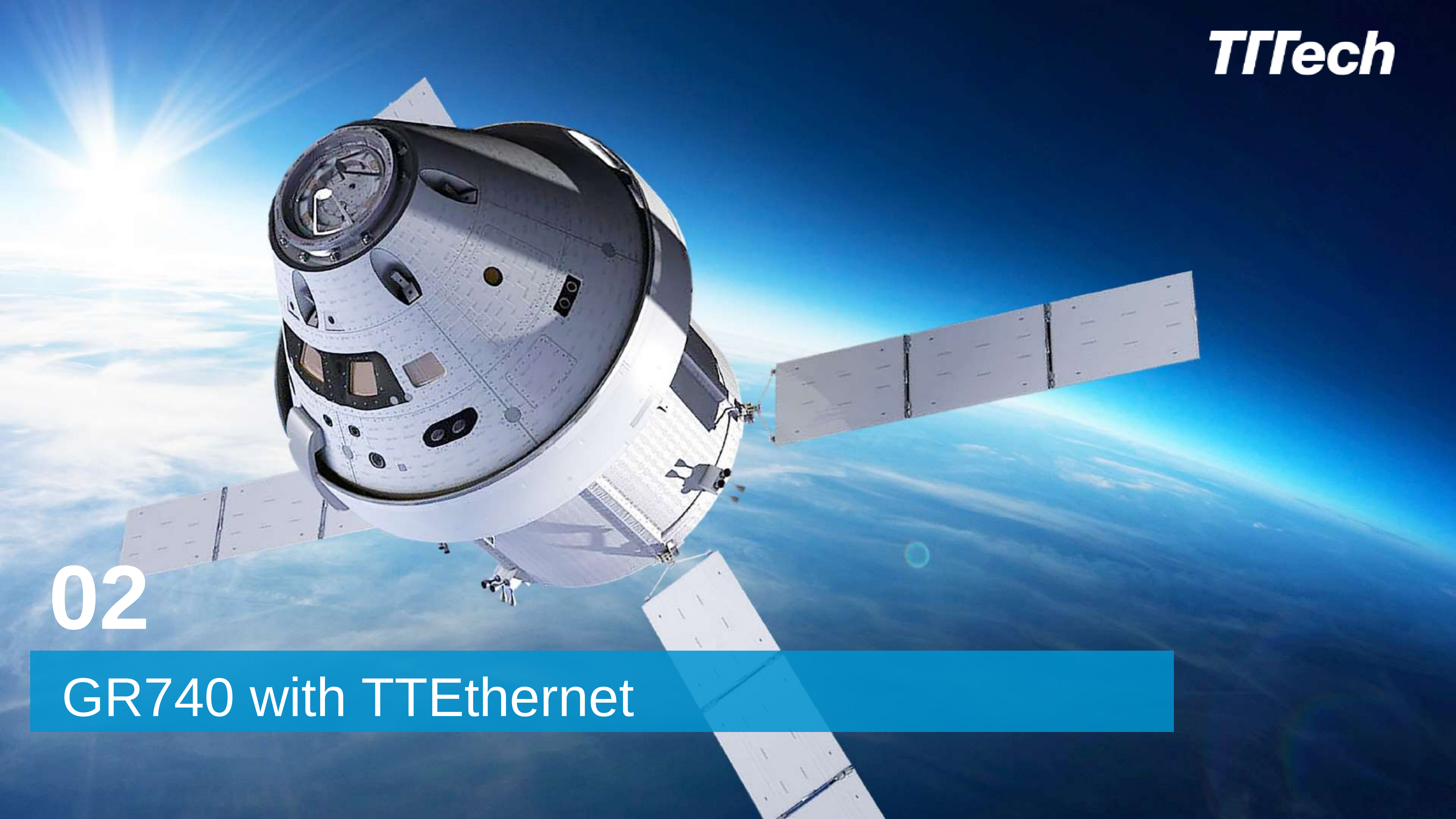
Power and Propulsion Element (PPE)

- Prime: MAXAR
- TTTech products:
  - Avionics Hosting Unit
  - VxWorks drivers + integration with cFS
  - TTE-Tools



International Habitation Module (iHAB)

- Agency: ESA | JAXA
- Prime: TAS
- Avionics modules:
  - Flight Computer Unit (FCU)
  - TTEthernet Switching Unit (TSU)
  - Power Distribution Unit (PDU)
  - VxWorks drivers + integration with cFS
  - Firmware
  - TTE-Tools



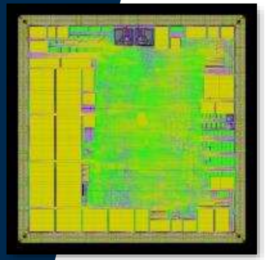
02

GR740 with TTEthernet

TTEController Space

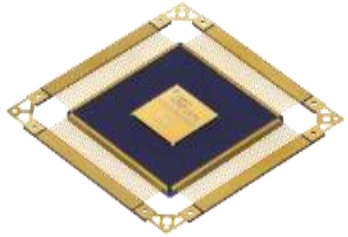
TTEController provides functionality of both TTEEnd System and TTESwitch and thereby is a fundamental building block for TTEthernet

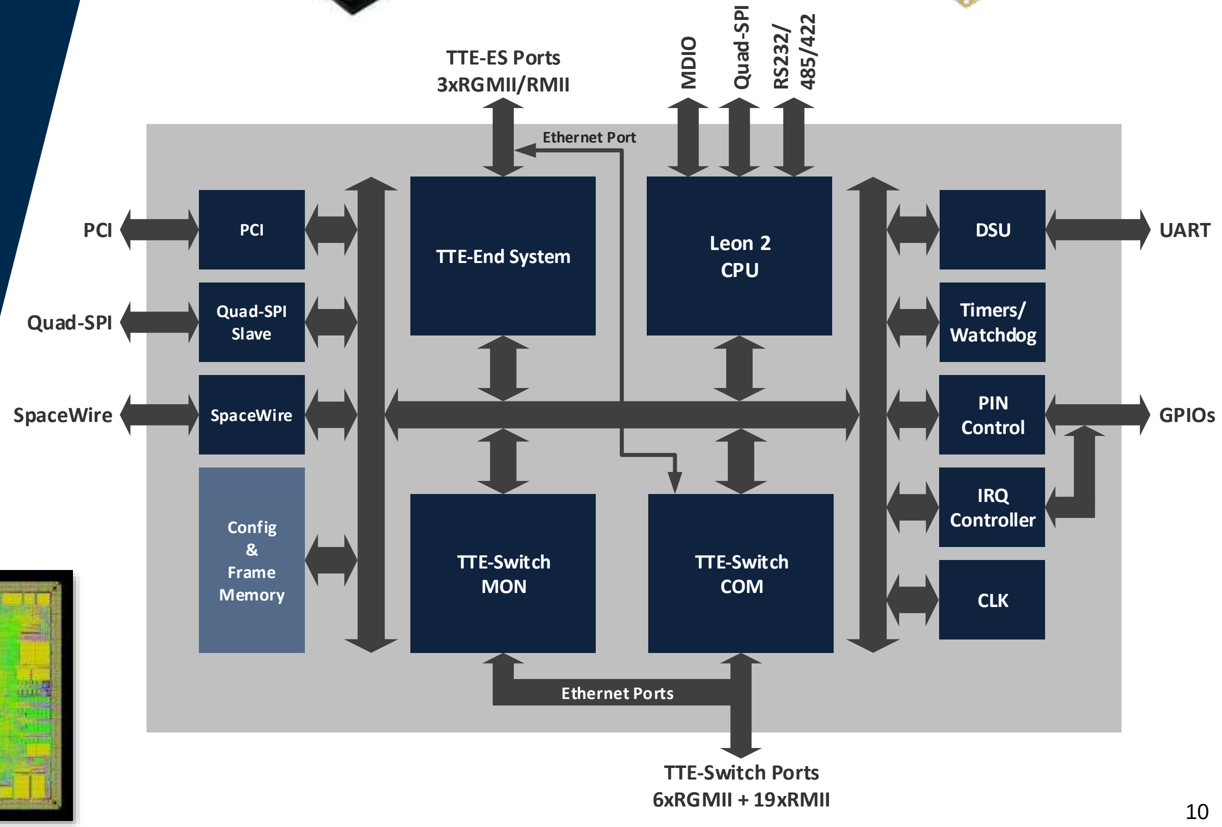
- Rad-hard by design ASIC, based on 65nm CMOS space technology by STMicroelectronics
- TTEEnd System IP and COM/MON TTESwitch IP to ensure fail-silent behavior in case of a fault within the silicon
- System on a Chip (SoC) with LEON2FT CPU
- Manufactured in PBGA 400 and CQFP 352
- AEC-Q100 (PBGA400) qualification for launchers and cost-sensitive LEO applications
- QML-V (CQFP352) qualification ongoing



PBGA400

CQFP352





Equipment qualified for Gateway based on TTE-Controller

Scalable hardware - a **crucial building block for the design of the various modules for the Gateway**

International cooperation
NASA, ESA, JAXA, and CSA

^{TTE}Switch Space 3U cPCI

- 12 Ethernet ports (6x 1000BASE-T/ 100BASE-TX + 6x 100BASE-TX/ 10BASE-TX)
- Self-managed switch via Leon2 firmware
- 600 g, < 14 W

^{TTE}End System Space 3U cPCI

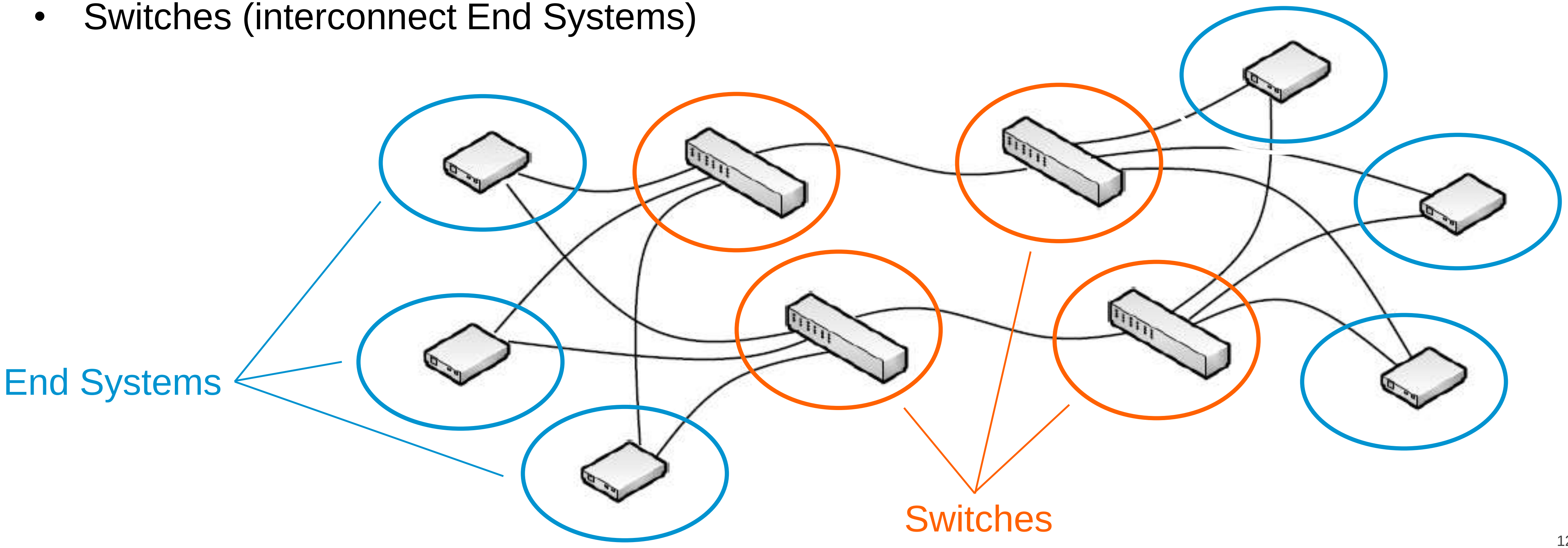
- 3 Ethernet ports (3x 1000BASE-T/ 100BASE-TX)
- PCI, QSPI, SpaceWire host
- Handling of redundant traffic in hardware by ES IP
- 400 g, < 6 W

^{TTE}Avionics Hosting Unit

- Allows the integration of several TTESwitch & End System Space 3U cPCI cards
- 4 cPCI card slots
- Modular backplane & connectors
- < 4 kg, up to 75 W for host cards

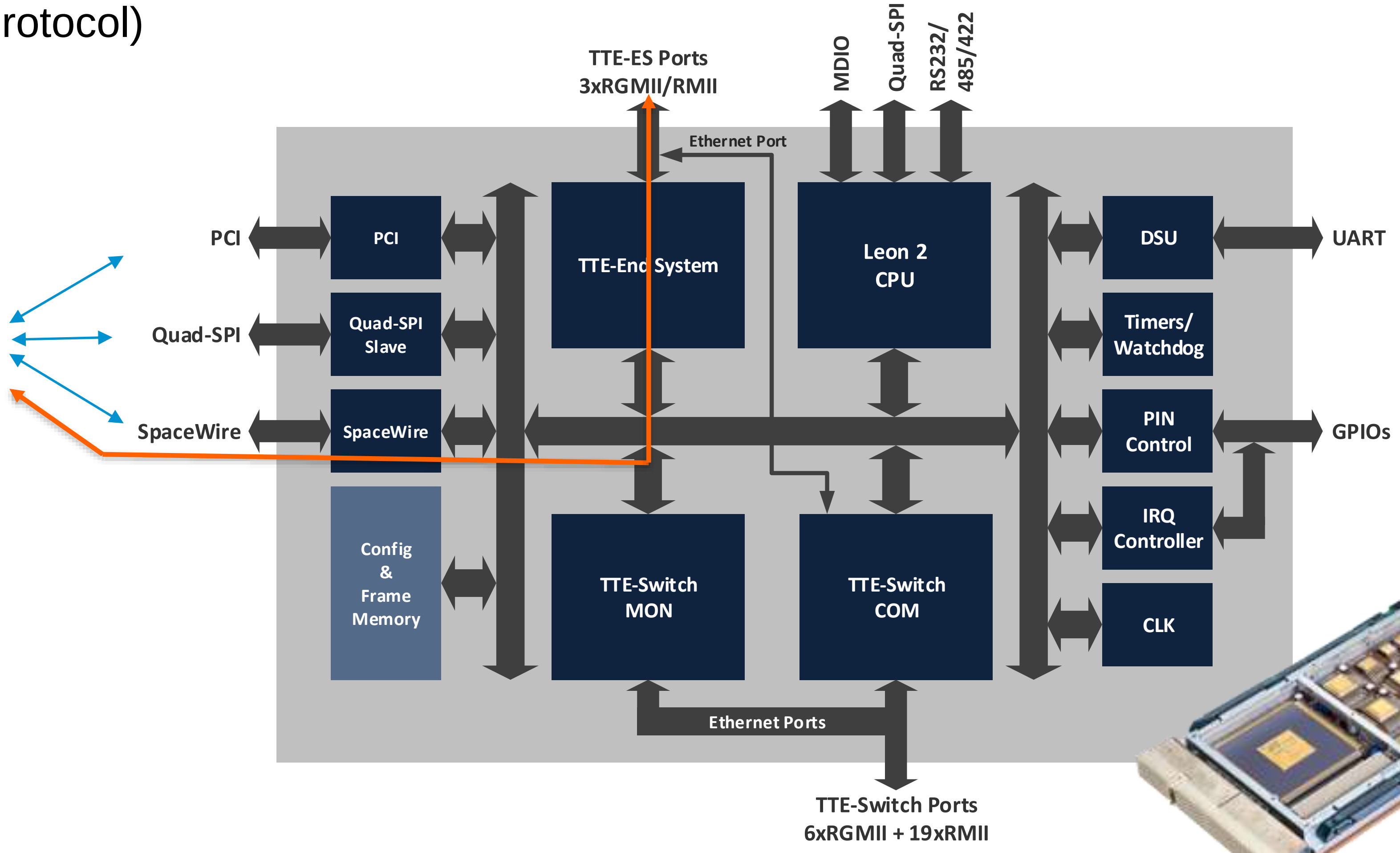
Using TTE-HW in Network Architecture

- Switched communication network based on industry-standard Ethernet
- Consists of two device types
  - End Systems (exchange data over the network)
  - Switches (interconnect End Systems)



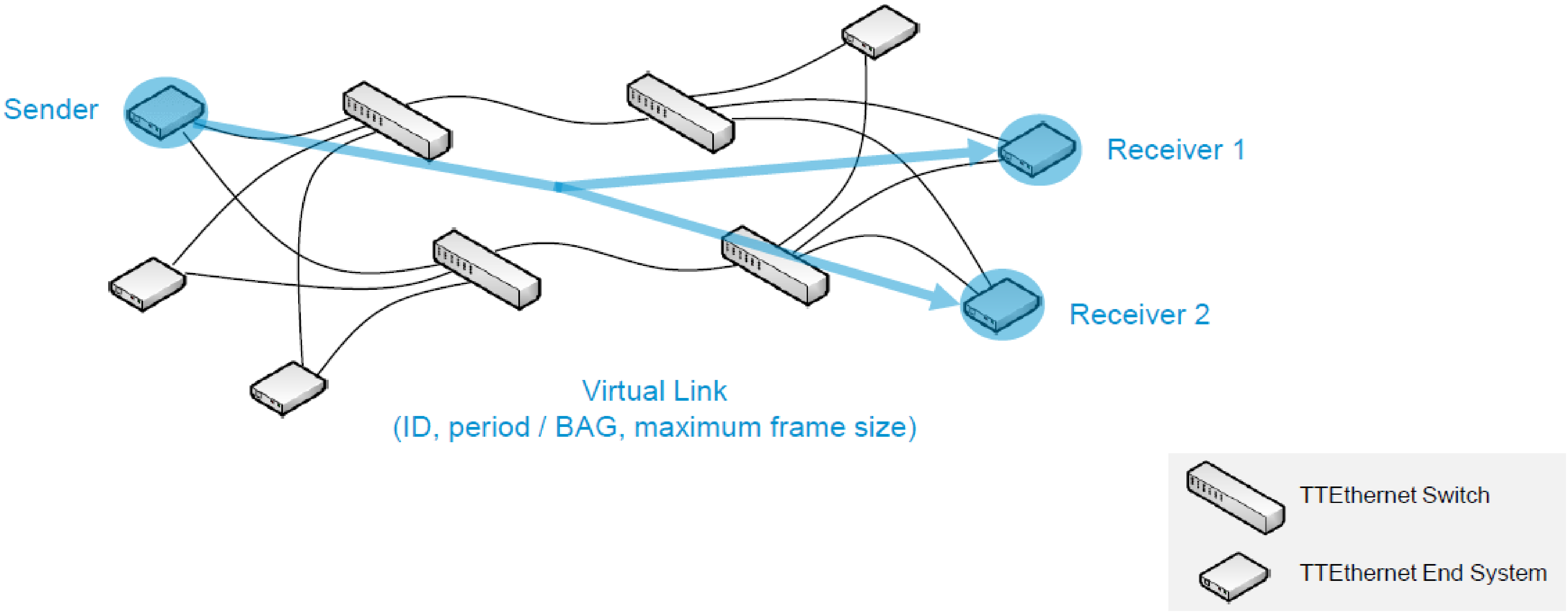
Interconnection with GR740

- Host interface used to send/receive data between GR740 and TTE-End System
  - PCI
  - SpaceWire (RMAP protocol)
  - SPI



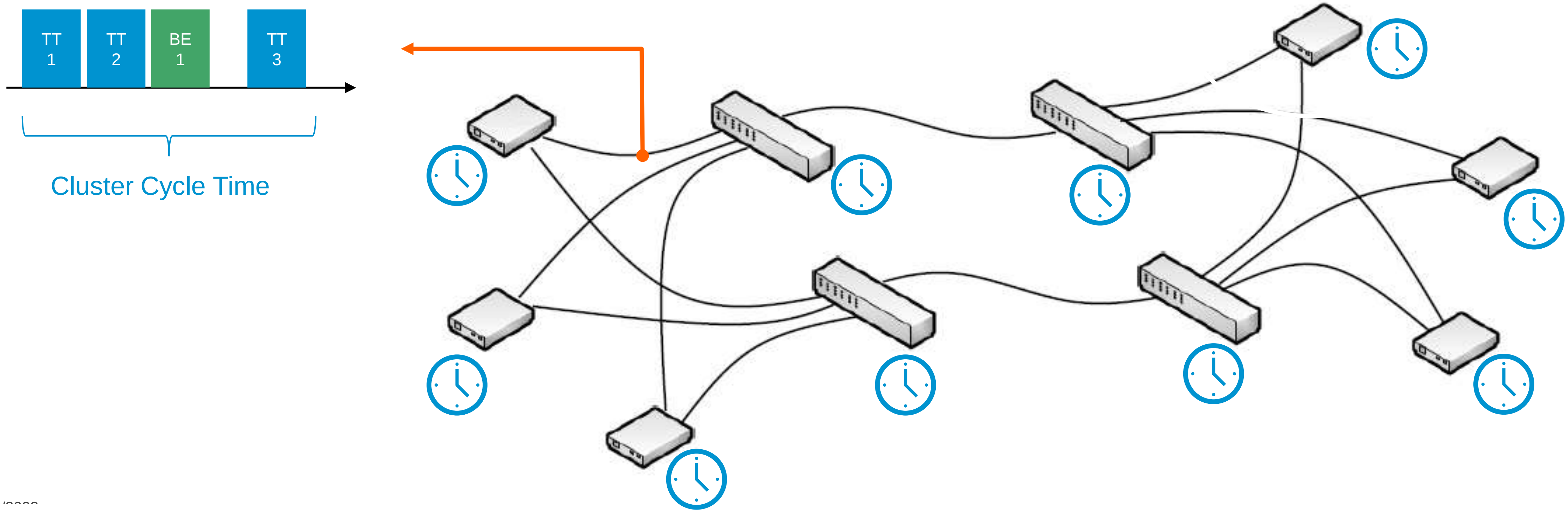
Logical Network Topology

Logical topology defines which source is connected to which targets by a virtual link. A virtual link is a path between one sender and one or more receivers with a unique identifier, realized by time-triggered or rate-constrained traffic (a virtual link is not a physical connection, see the ARINC 664 Part 7 and TTEthernet specifications)



Synchronized Systems and Scheduled Traffic

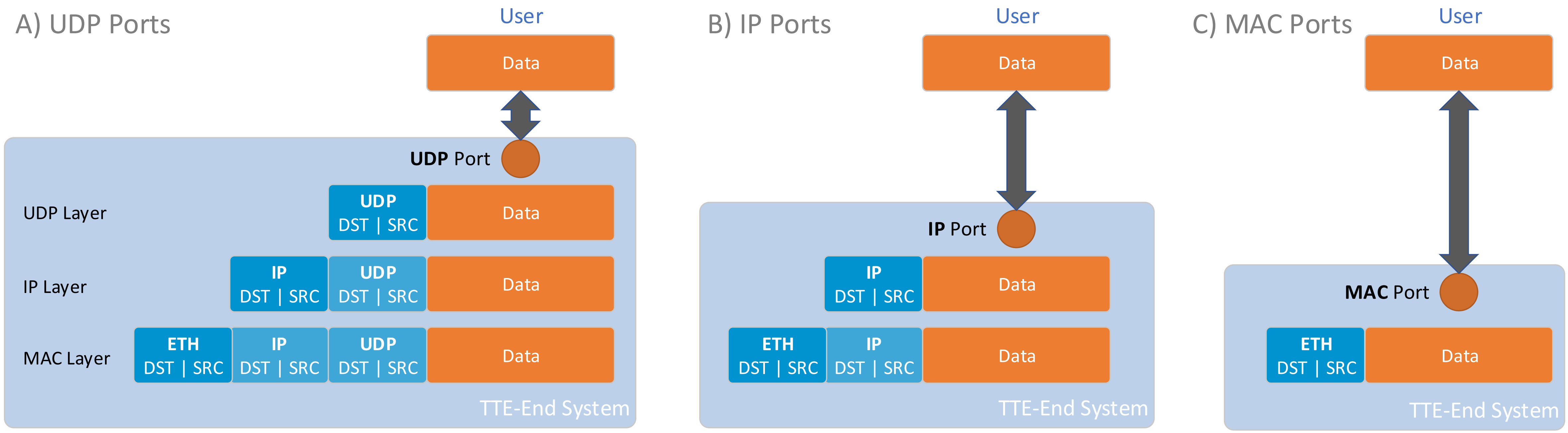
- All systems in the network are synchronized (same notion of time)
- Data transfers on every link according to the schedule (repeating within Cluster Cycle Time)
- Application synchronization to the network time – optimized execution on available data



TTE-End System Space – Protocol Support

User operates on data encapsulated (and de-encapsulated) in protocol headers by the End System

Different types of ports provide interface on different level of protocol – simplification of access to the TTE-ES



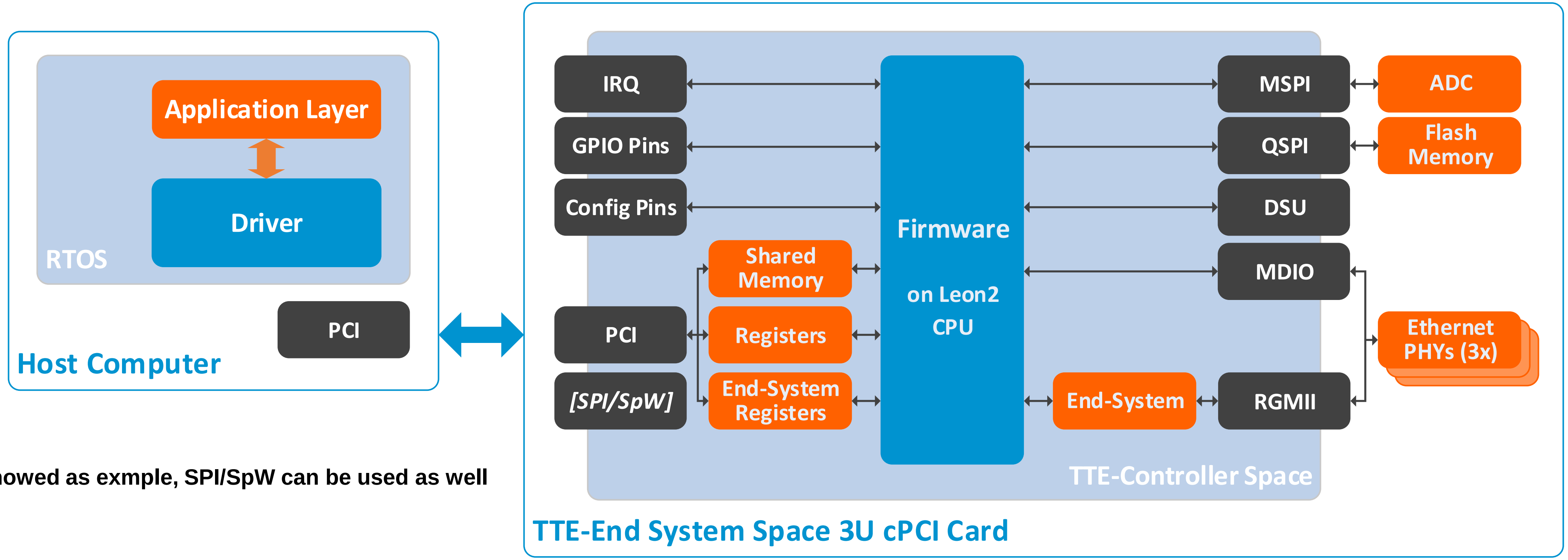
End System Software Components

1 End System Driver

- Device driver and communication middleware
- Integrated in RTOS on host computer
- Provides End System functions to Application

2 End System Firmware

- Application and support code (drivers, stacks)
- Bare-metal firmware on Leon 2FT processor
- Init and Config of TTE-Controller, Monitoring, Commanding



The PCI interface showed as exmple, SPI/SpW can be used as well

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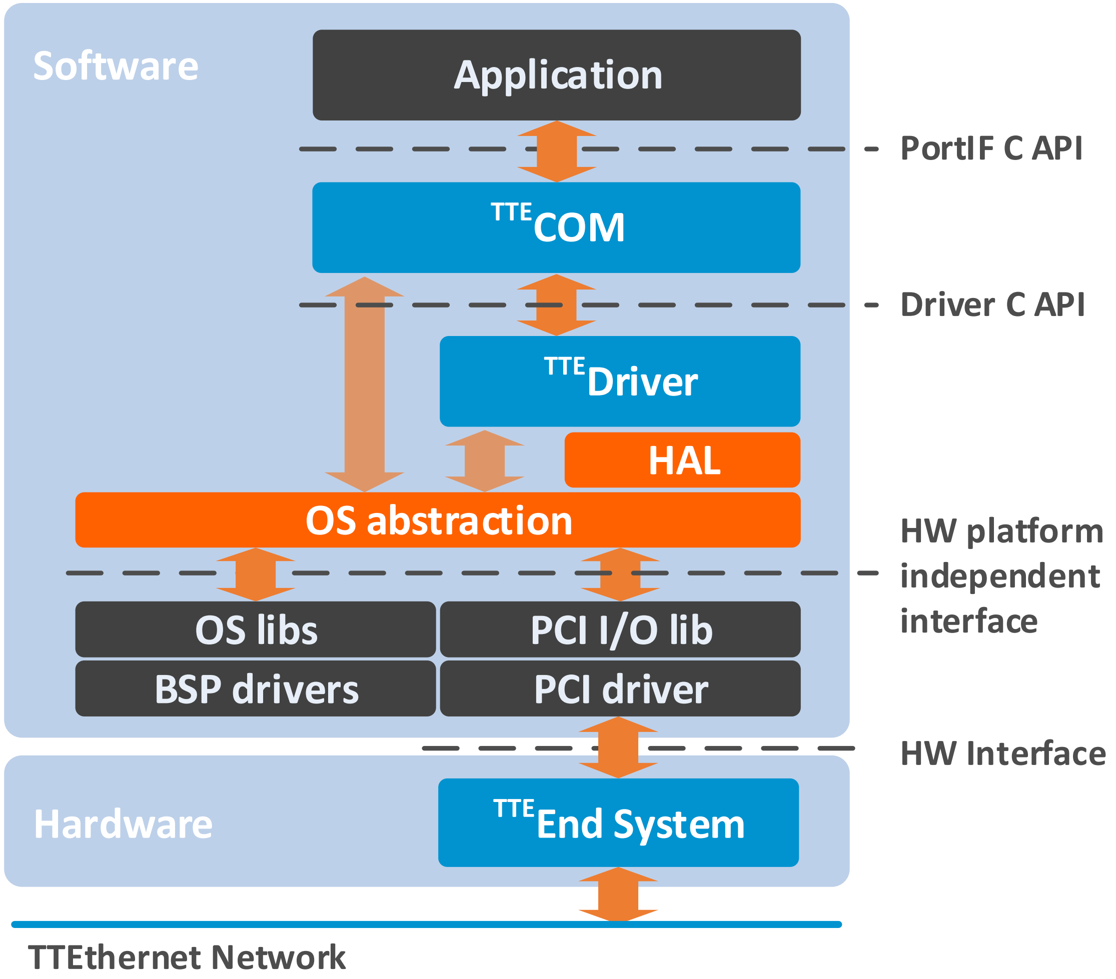
Integration of the Driver

Main Functions

- **Initialization** and power-on built-in tests (PBIT) for the End System
- **Download** of the **Network Configuration** into the End System
- Data **transmission** to the TTEthernet network
- Data **reception** from the TTEthernet network
- Status and health **monitoring** of the End System
- **Interface to Firmware** that is embedded in the ASIC, e.g. to start and evaluate IBIT, local status monitoring

OS/HW Abstraction Layers

- Target platform and host interface specific
- Mapping/implementation of memory management, I/O, timers, logging, etc.



Application Synchronization for Real-Time Systems

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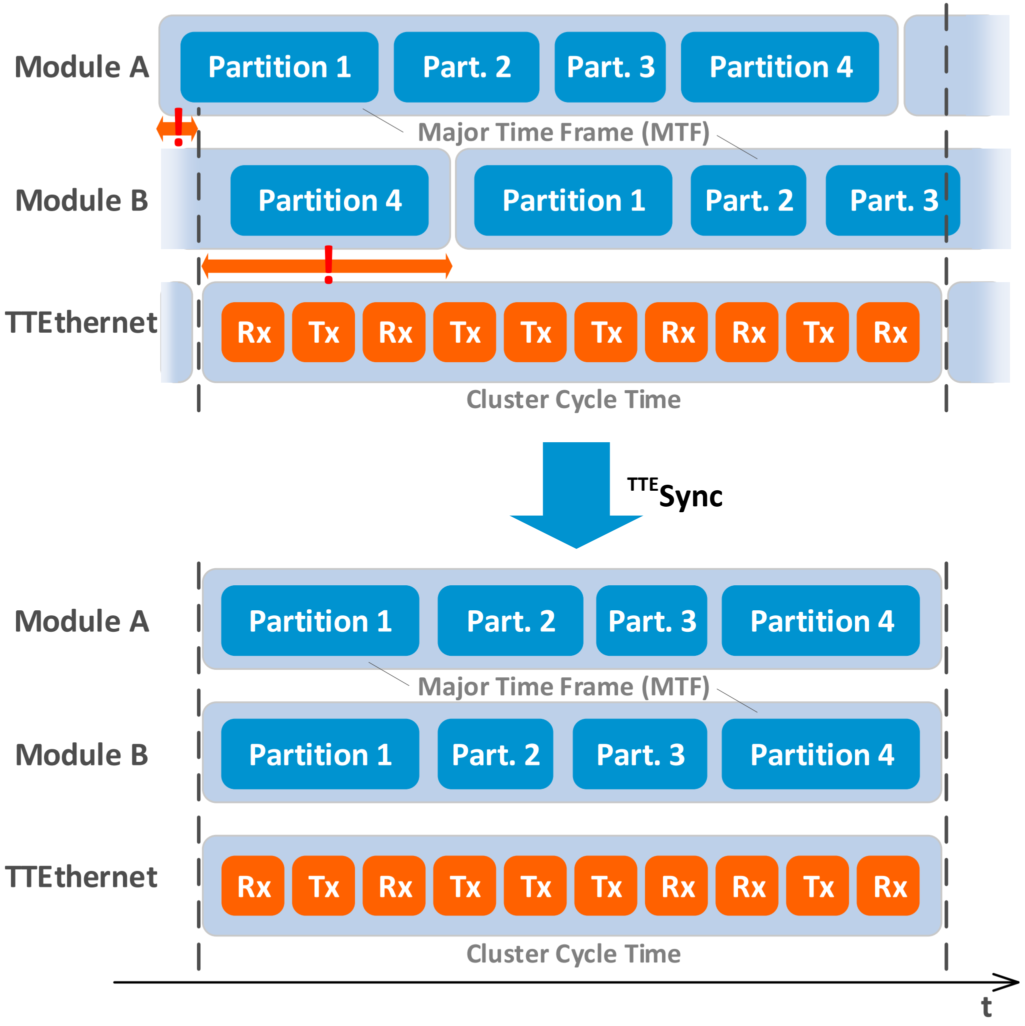
- **TTESync for ARINC 653**
- Works with time-driven, repetitive OS task scheduler according to ARINC 653
- Enables synchronized execution of time partitions on multiple distributed modules
- Nodes in network are synchronized based on TTEthernet fault tolerant clock distribution
- OS partitions will get aligned to network time
- *Major Time Frame* of the OS is synchronized to *Cluster Cycle Time* of TTEthernet
- “soft” sync – OS gives pace for MTF, but clocks are corrected to match



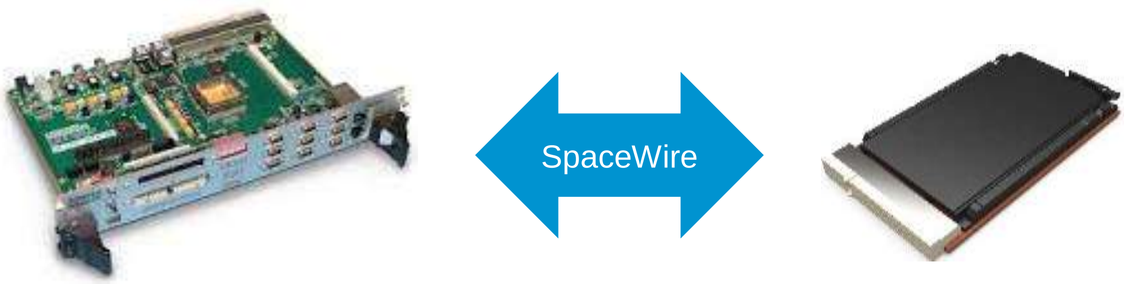
Application Synchronization for Real-Time Systems

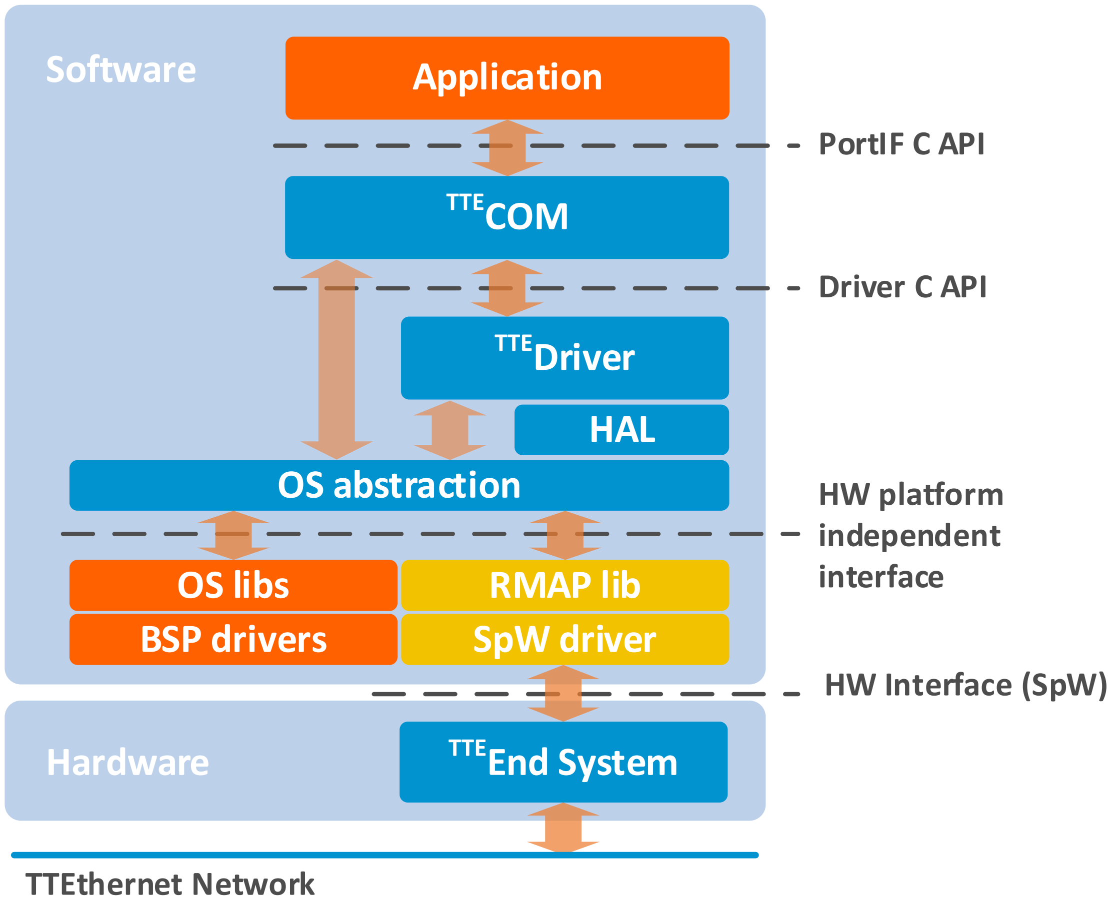
- **Time Synchronization in non-A653 OS**
- Works with interrupt-enabled OS
- Interrupt from ES hardware, based on network time, creates pace for tasks
- Can use cluster cycle start, or integration cycle or “rx/tx ready” IRQ
- Nodes in network are synchronized based on TTEthernet fault tolerant clock distribution
- Tasks in OS will get aligned to network by triggering their execution at due time

Gateway Example

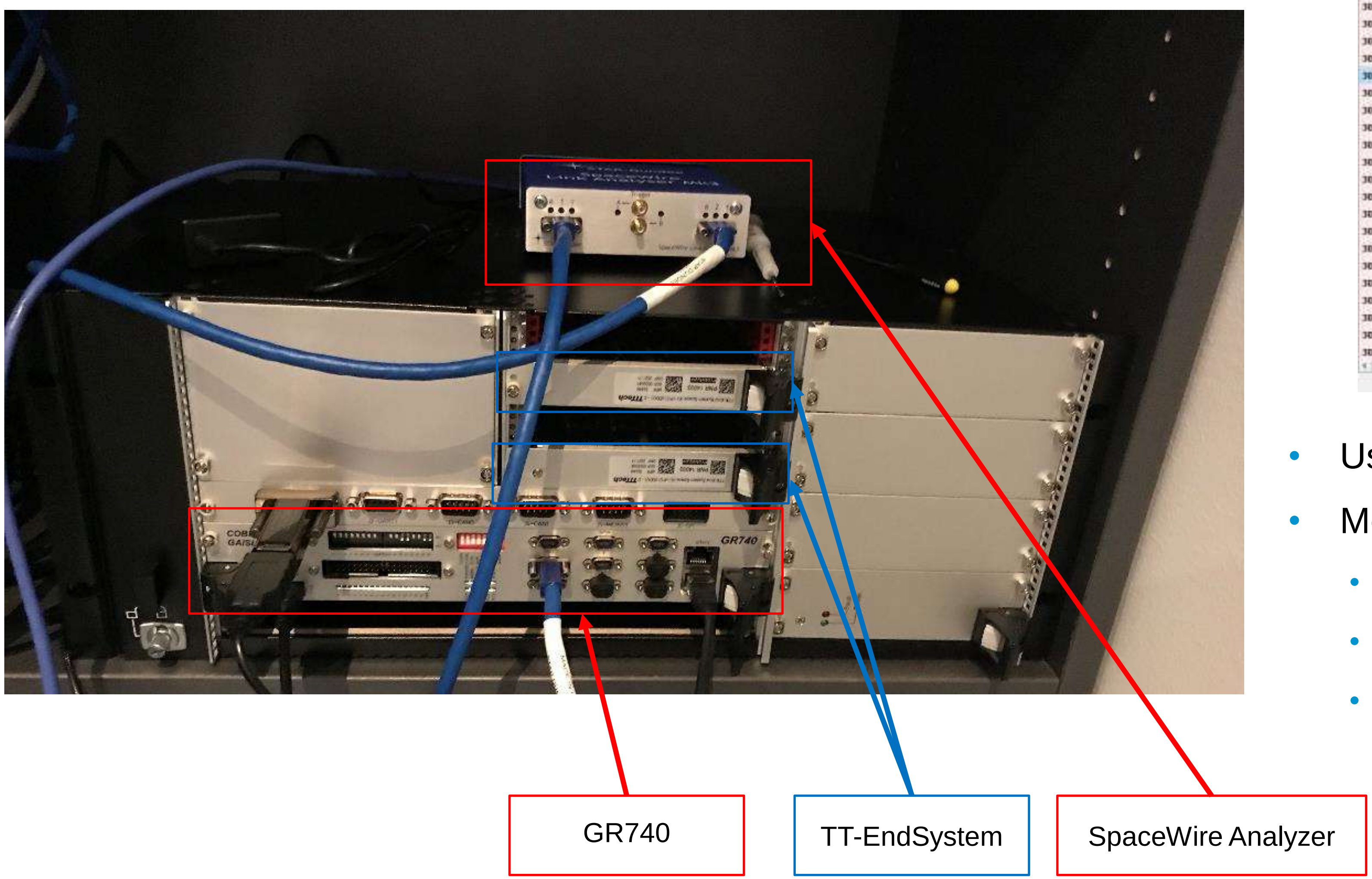
GR740 with SpaceWire Host Interface

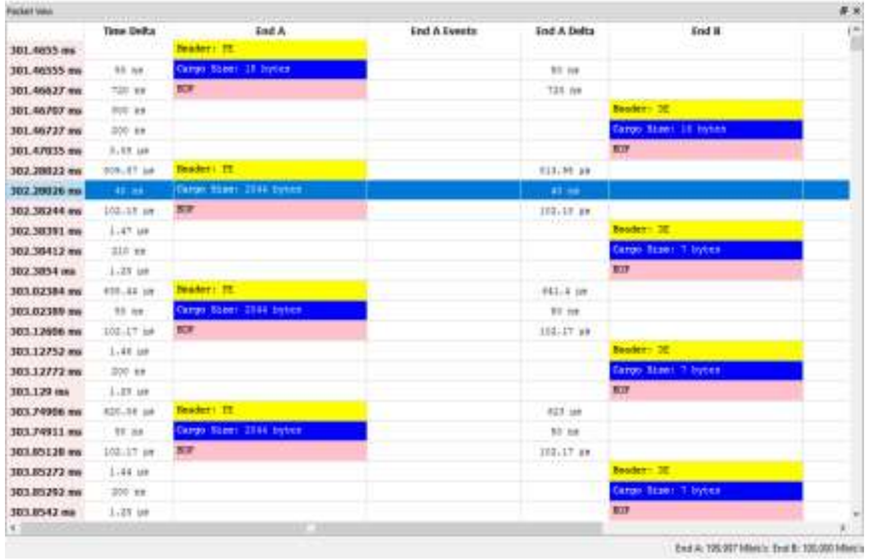
- TTE-COM-Driver for VxWorks 7
- SpaceWire HAL
- RMAP implementation for communication over SpW
- TTE-ES interrupt used to synchronize Application with cluster cycle start





SpW Test Setup



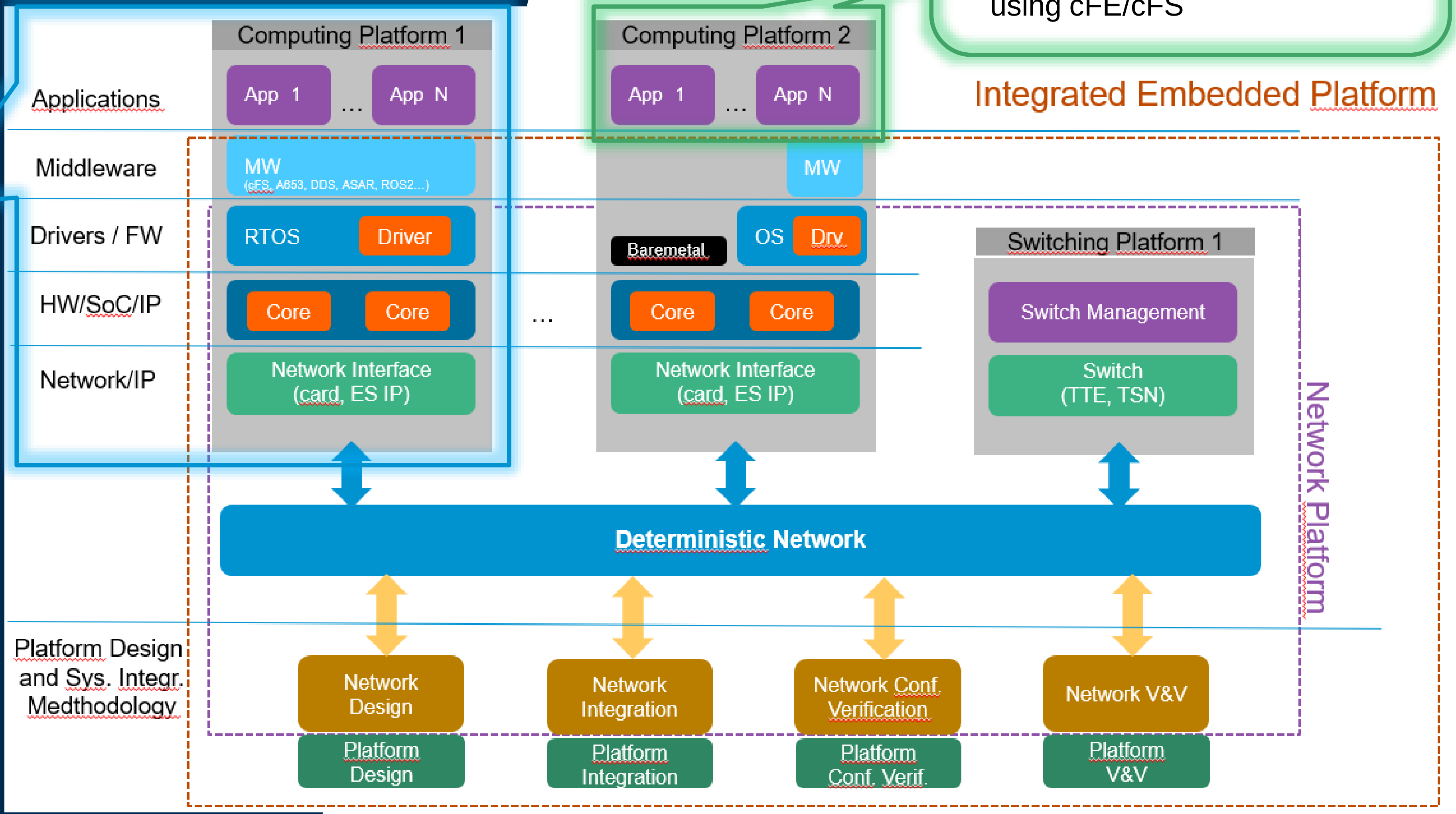


- Using GR740 development board
- Measured performance
  - Up to 26Mbit/s RX @ 1514 bytes frame size
  - Up to 49Mbit/s TX @ 1514 bytes frame size
  - Up to 34Mbit/s RX/TX (50%/50%) @ 1514 bytes frame size

From Data Network Towards Integrated Embedded Computing Platform

User Applications
- Spacecraft designer know-how
- Modular approach and application synchronization using cFE/cFS

Integrated Modular Avionics (IMA)
- Distributed processing capabilities & memories
- Requires careful planning and certification of the shared resources
- Latencies & timing guarantees become crucial



Deterministic Ethernet for Avionics Networks

- Network is key interface between functions
- Deterministic network allows to tightly control the interaction between subsystems
- Time partitioning prevents integration between subsystems where necessary
- TTE-Switches act as fault containment guardians (e.g. due to acceptance windows for messages)
- COM/MON can eliminate risk of bit-flips in configurations and therefore strengthen the fault containment

Conclusion & Outlook

- Application scheduling using TTEthernet
  - Easy synchronization of user application with the data
  - Efficient usage of system resources

- Faul-Tolerant Deterministic Computing Platform
  - Simplifies complex design
  - User can focus on spacecraft applications rather than communication technology needed to get the data on time
  - Features implemented by TTEthernet offers fault-tolerant architectures for various spacecraft types