

# PCIe-over-TCP-over-TSN-over-10/25GigE

Dr. Endric Schubert, CTO

Presentation at  
“Programmable Processing for the Autonomous / Connected Vehicle” Sep-24 2020

<https://innosued.de/workshop-programmable-processing-for-the-autonomous-connected-vehicle/>

# Outline

## WHY

- Automotive needs 10 Gig networking, or more! Electric vehicles and ADAS / Automated Driving push the migration from Domain-based over to Zone-based Architectures, which again pushes for more bandwidth and real-time capabilities in the Automotive Network.

## WHAT

- Out patent pending technology integrates IEEE Standards for Time-Sensitive Networking with Heterogeneous Packet Tunneling for PCIe, 100Base-T1, MIPI CSI-2, CAN-FD, and others. Utilizing Protocol Acceleration in hardware we can scale to 10 Gbps linerates, and beyond.

## HOW

- A Software and Semiconductor IP core subsystem which integrates 3rd party IP from German Fraunhofer with technology from MLE and can be licensed for FPGA and ASIC implementations.

# Backgrounder Missing Link Electronics

Our Mission is to

- Apply FPGA technology for Domain-Specific Architectures
- Offer pre-validate FPGA subsystems of FPGA IP blocks and open-source software
- Support customer projects with deep expertise and hands-on design services

Head-quartered in Silicon Valley with Design Offices in Germany

- Founded 2010, employee owned
- 15+ Certified FPGA Designers
- 50+ Presentations at Technology Conferences, 4 Patents

Technology Partnerships



# Our Technology Achievements

- Patented technology in the fields of networking, mixed-signal, functional safety
  - US Patent 9,209,828 - Configurable Mixed-Signal Systems
  - US Patent 10,140,049 - Partitioning Systems Operation in Multiple Domains
  - US Patent 10,509,880 - Automation for Configurable Mixed-Signal Systems
  - US Patent 10,708,199 - Heterogeneous Packet-Based Transport
- 50+ Presentations at Technology Conferences and in Technology Journals
  - Embedded World Conferences
  - PCI-SIG Developers Conferences
  - IBM Open Power Summit
  - SNIA Storage Developers Conferences
  - Flash Memory Summits
  - Xilinx XCELL Magazines
  - XILINX Developer Forum and Security Workshops

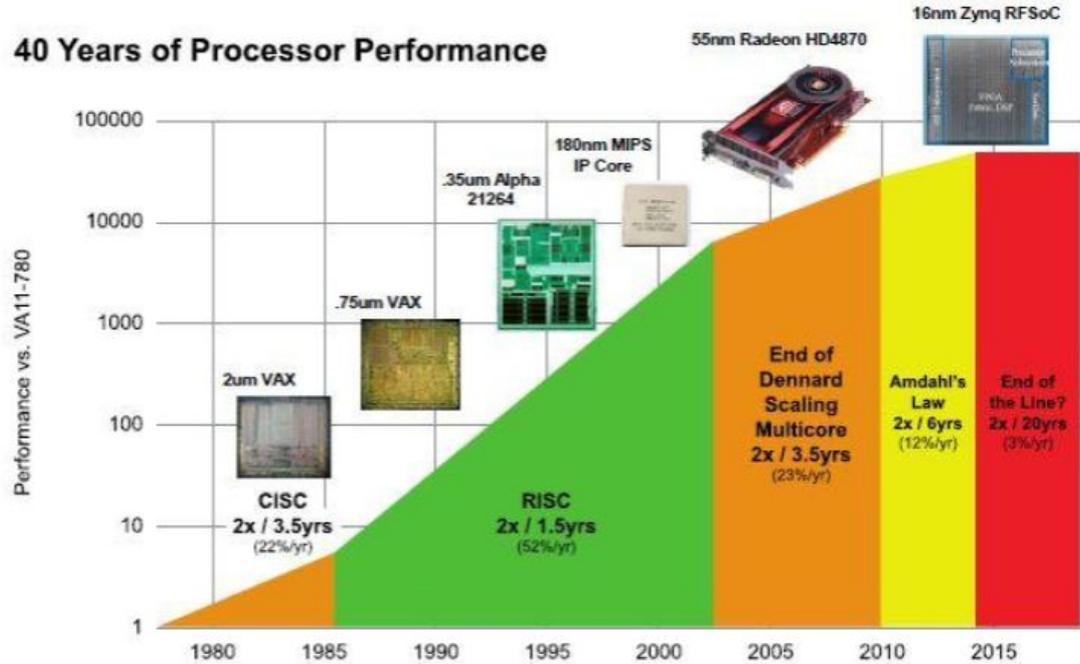


# Domain-Specific Architectures

FPGAs as a very powerful processor that executes “dataflow software”

Apply HPC/HA Datacenter technology to other verticals - “Proudly borrowed elsewhere!”

## Challenges: The End of Moore’s Law and Scaling



Source: John Hennessy and David Patterson, Computer Architecture: A Quantitative Approach, 6e 2018

# Our FPGA Design Expertise

- Mentor, Cadence, Xilinx Toolflows
- Zynq-7000 SoC in designs since Q1/2012
- Zynq Ultrascale+ MPSoC in designs since Q4/2015
- Zynq UltraScale+ RFSoc in designs since Q2/2018
- PetaLinux / Vanilla Linux and Yocto-based SW development
- Multigigabit transceiver configurations
  - PCIe Gen2/3/4, SATA 3/6G, SAS 6/12G, NVMe,
  - CAPI, JESD204B, DP/HDMI, MIPI CSI-2 D-PHY
  - 10/25/4050/100G Ethernet, Low Latency Ethernet
- Radar, civil, mil/aero, automotive
- camera, Lidar, data recording
- Functional Safety Design Flows ISO 26262 (ASIL), IEC 61508 (SIL)
- Security & Trust
  - PUF, Crypto, Trusted Execution Environment, OP-TEE

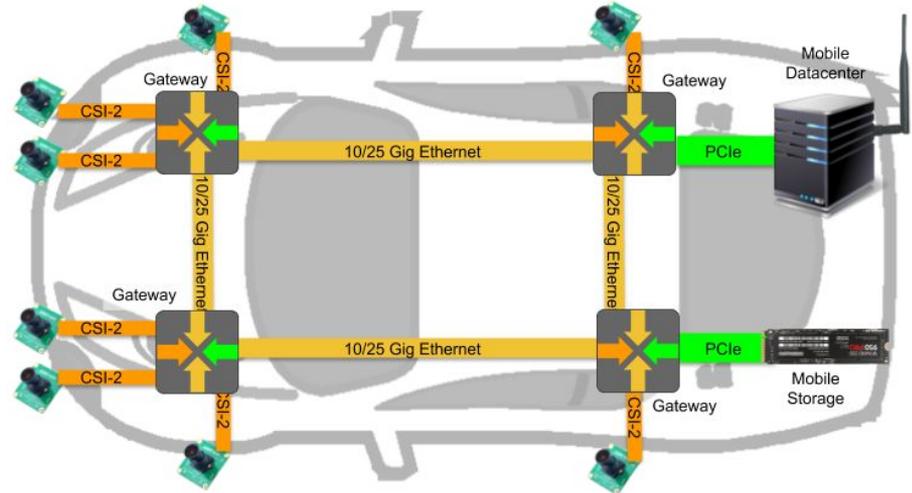


# Zone-Based 10 GigE Automotive Backbone

Do you ...

- Prefer open IEEE standards over closed proprietary ones?
- Need 10+ Gbps bandwidth?
- Need deterministic, low-latency real-time network behavior, namely TSN?
- Need heterogeneous connectivity with PCIe, 100Base-T1, MIPI CSI-2, CAN-FD, etc?
- Need Functional Safety and Security / Hardware Root-of-Trust?

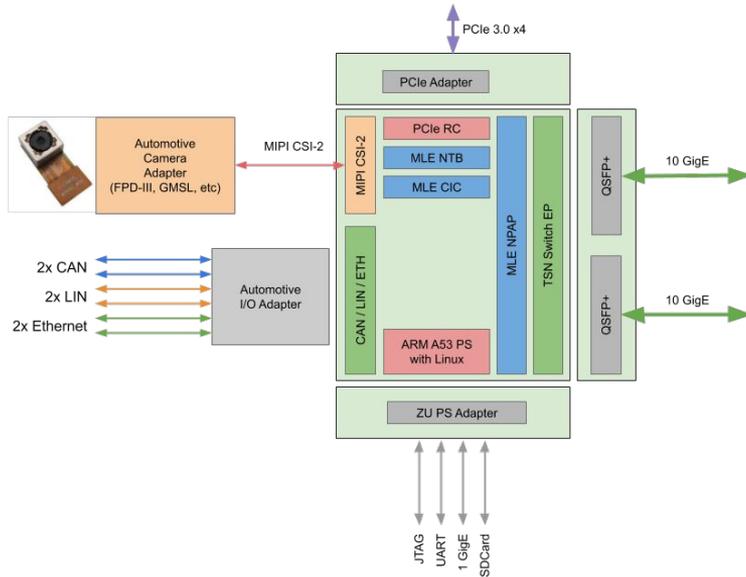
⇒ Use time-to-market solutions from MLE  
100% "Made-in-Germany"



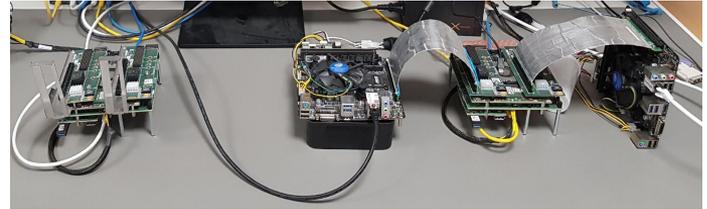
# MLE LabCar for “Tunneling” PCIe (and else)

FPGA-based Prototyping System for  
Architecture Exploration and Development

- Example of Zone Gateway Node



- Commercial Product License for FPGA or ASIC implementation
- Sign-once License for complete subsystem including 3rd party IP
- Customization NRE fee

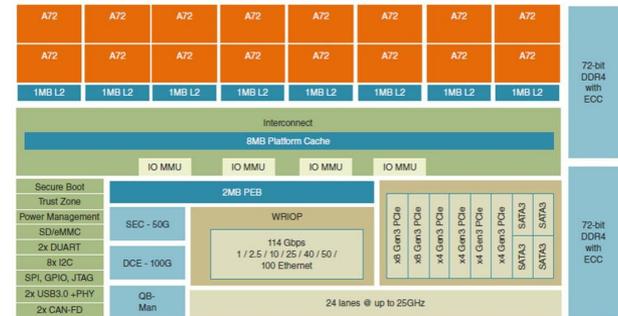
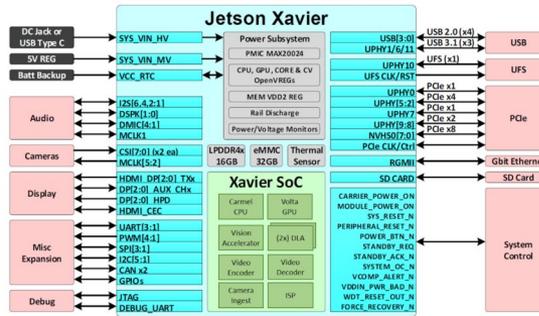
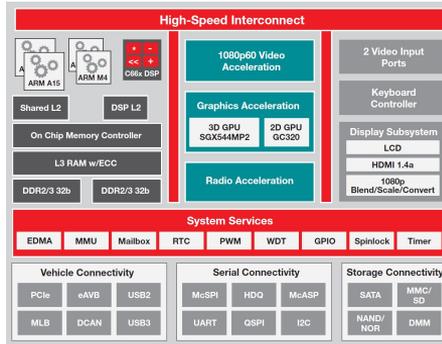


- Prototyping example:  
4-node “Lab Car”, incl. Hardware, Software, Firmware and licenses for in-house evaluation and FPGA development

⇒ Use time-to-market solutions from MLE  
100% “Made-in-Germany”

# Why PCIe?

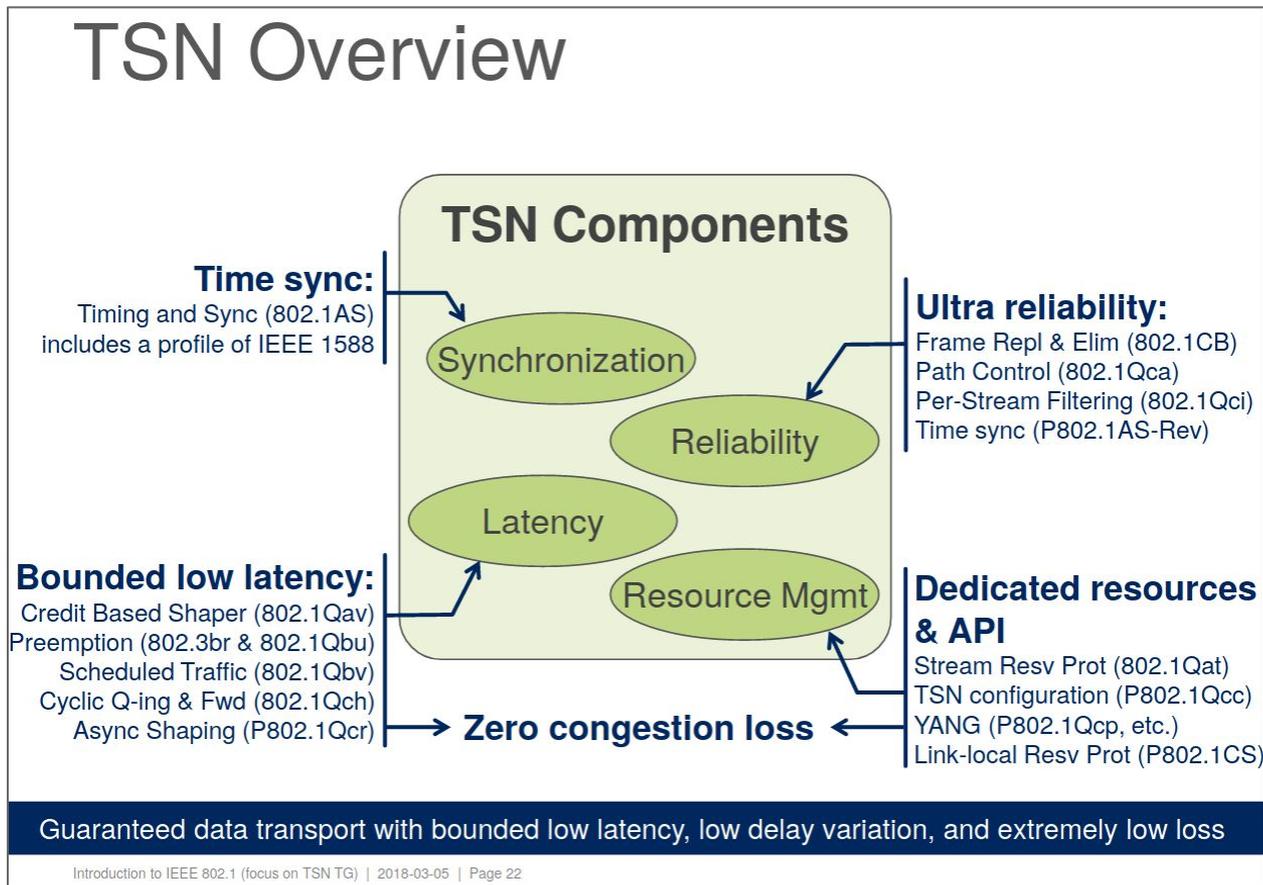
- Future-proof road-map, driven by PCI-SIG
- PC, Cloud Computing, Embedded Systems drive this roadmap
- Best-in-class price (\$) per performance (Gbps) ratio
- Modern automotive SoCs all support PCIe





# Why TSN?

- IEEE open standard for real-time networking
- Telco and Datacenter drive the roadmap



# Unique Technology Combination

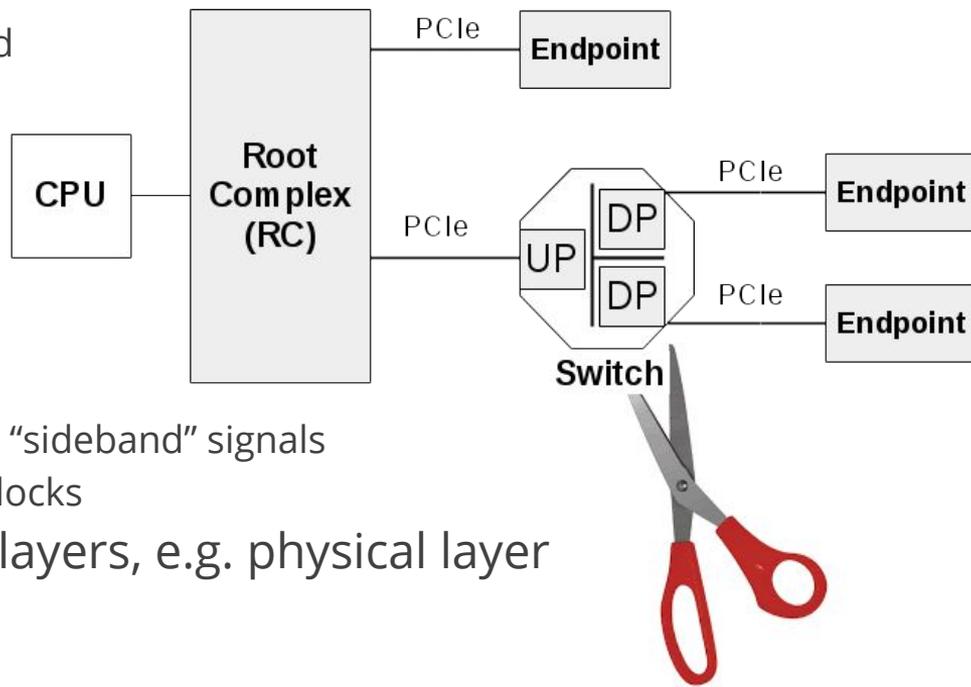
1. PCIe Range Extension via Robust, Long-Range Protocol Tunnels
2. PCIe Non-Transparent Bridging (NTB)
3. PCIe / NVMe Full Acceleration
4. TCP/UDP/IP Full Acceleration (Fraunhofer HHI)
5. Time-Sensitive Network IP (Fraunhofer IPMS)

⇒ Real-Time Multi-Protocol Heterogeneous Packet-Based Transport

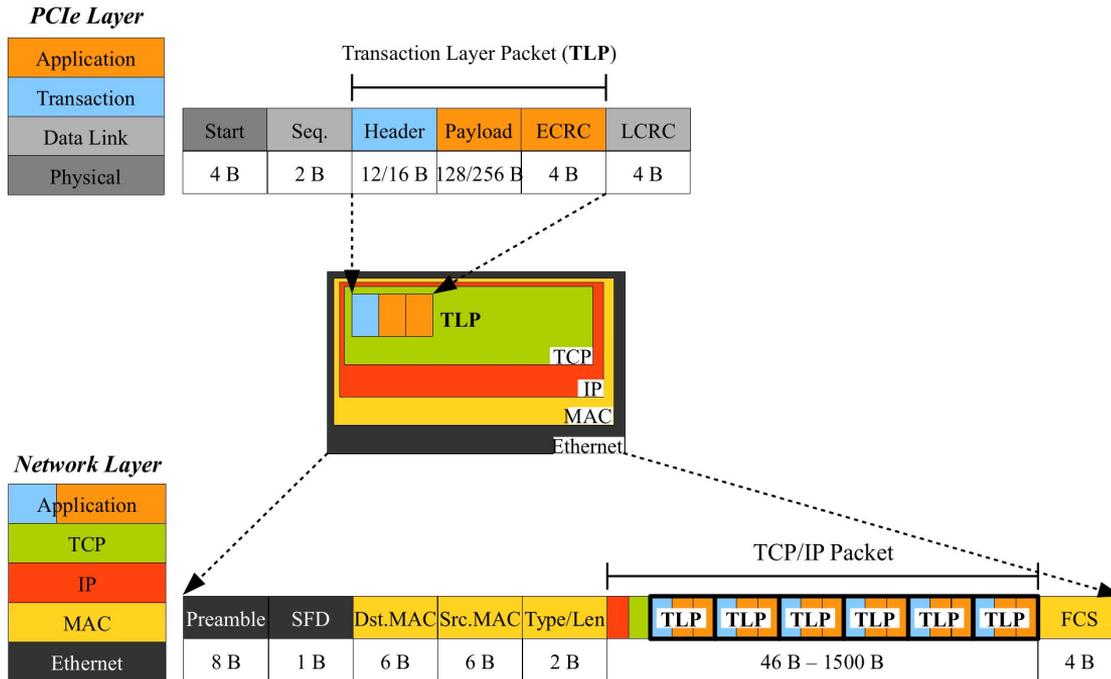
Licensed by other Xilinx customers as Platform Subsystem

# PCIe Range Extension via TCP/IP

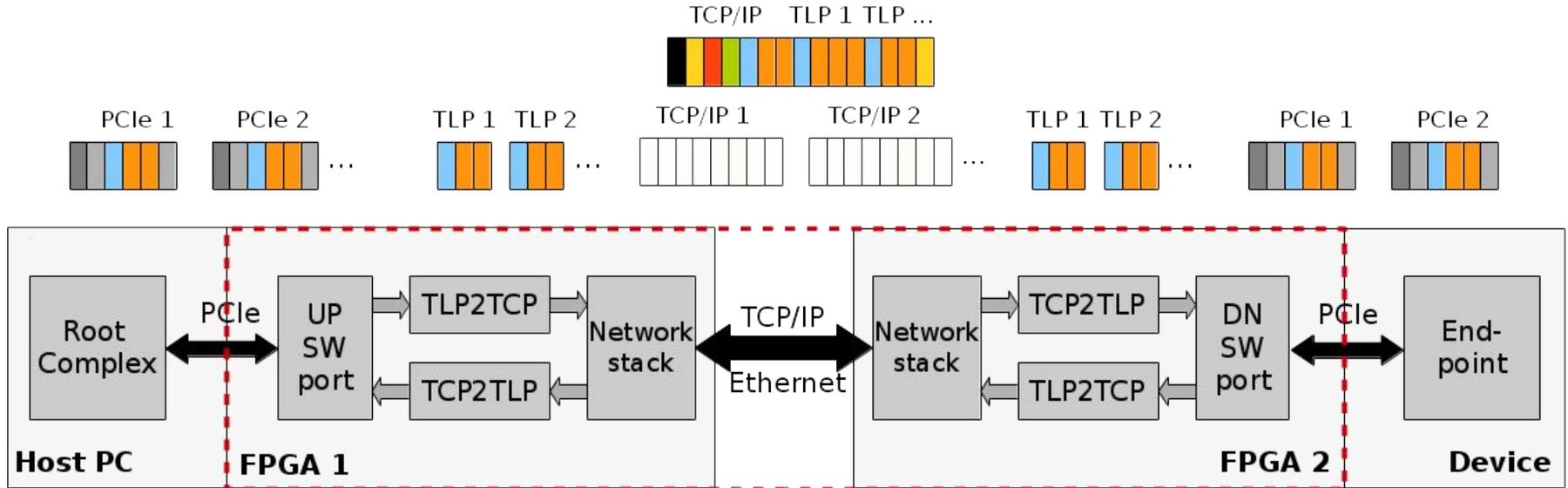
- Fully transparent to network equipment
  - Just a bunch of TCP sessions
  - No special traffic handling required
- Fully transparent to PCIe
  - Reliable transport via TCP
  - Congestion control via TCP
- A “distributed” PCIe Switch
  - In accordance to PCIe Spec
  - Scalable via TCP session count
  - Supports latency requirements for “sideband” signals
  - Special care needed to avoid deadlocks
- Independent of lower network layers, e.g. physical layer



# Concept of PCIe-over-TCP (1)



# Concept of PCIe-over-TCP (2)



----- Distributed PCIe Switch

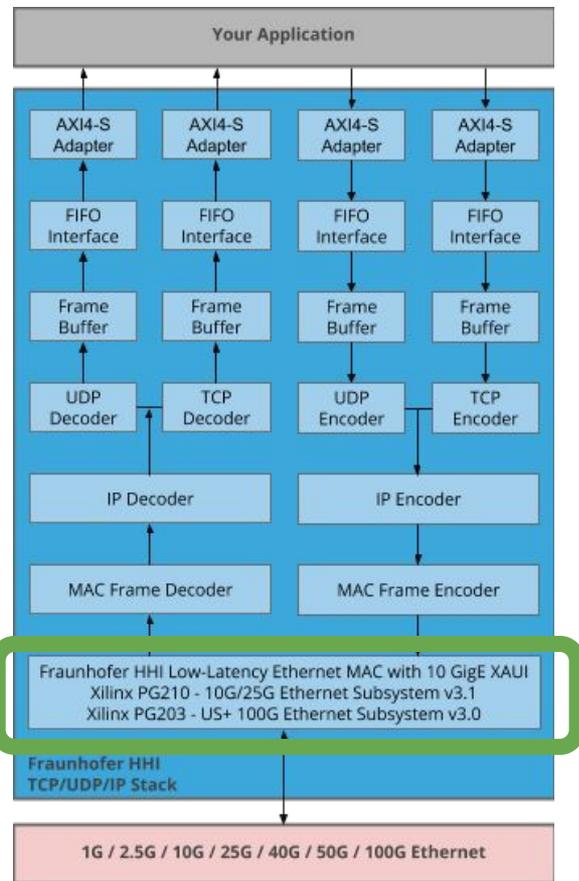
# TCP/UDP/IP Full Accelerator

- “Packet Processing” in hardware (FPGA/ASIC)
  - Low latency in microseconds
  - Deterministic (no CPU, no cache misses)
  - Performance scales to 100 Gbps
- In accordance to IETF RFC 1122

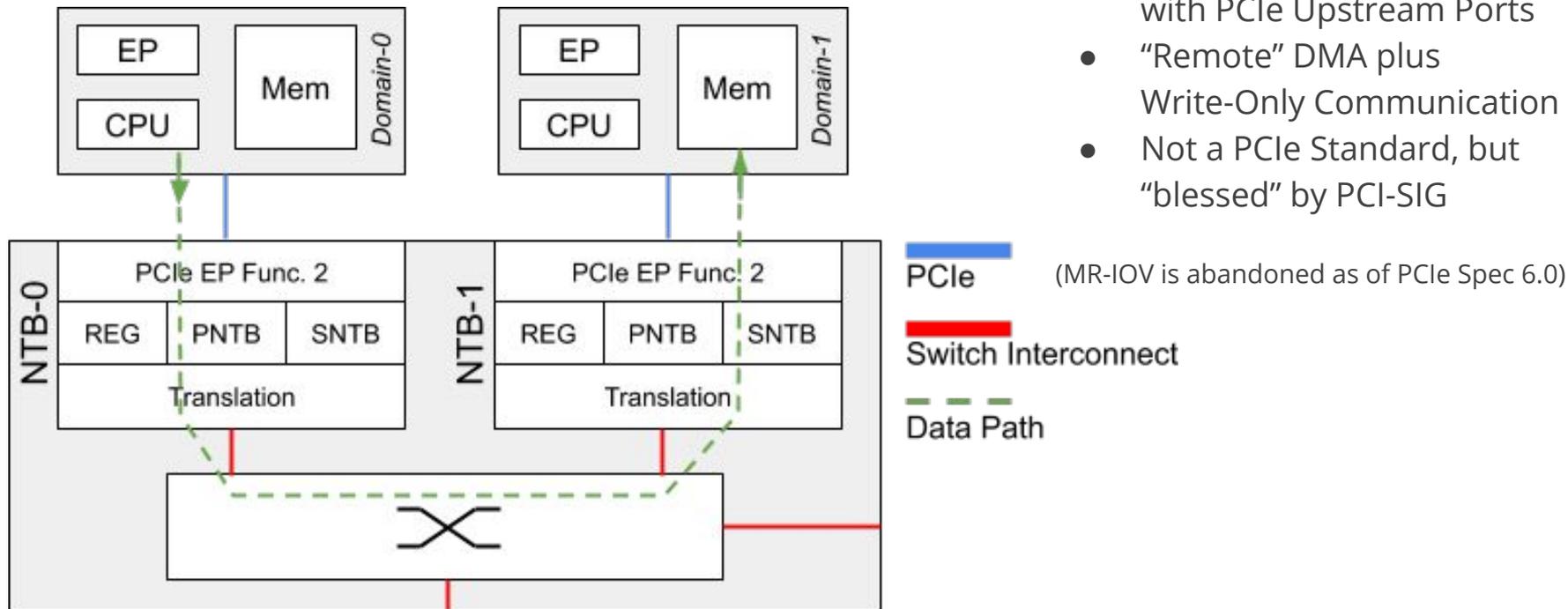
Mature technology licensed from Fraunhofer HHI



Extensible Real-Time Behavior via TSN MAC



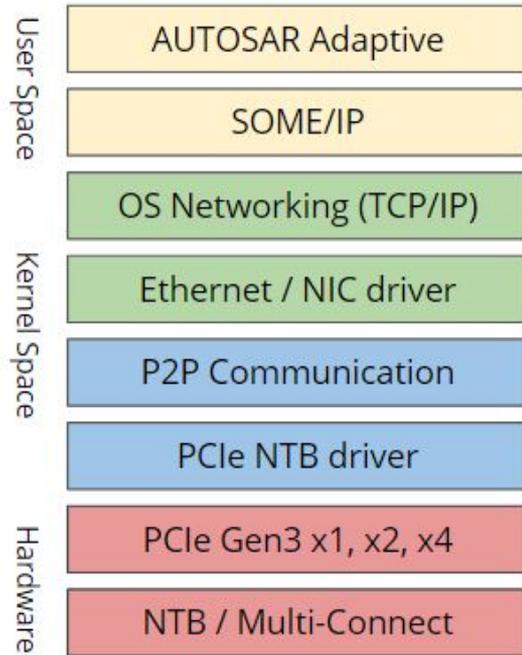
# PCIe NTB - enables CPU-to-CPU Direct Comm



- Combines Network-on-Chip with PCIe Upstream Ports
- “Remote” DMA plus Write-Only Communication
- Not a PCIe Standard, but “blessed” by PCI-SIG

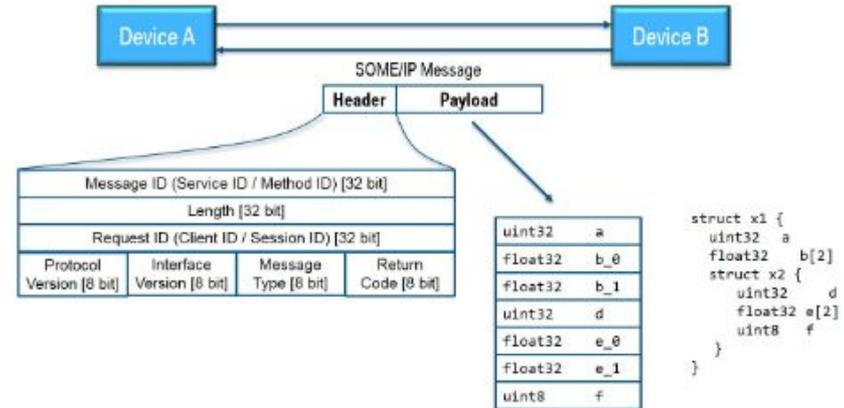
# PCIe NTB - Via Well Known Network API

Software Stack on Compute Node  
(Linux, QNX, Adaptive AUTOSAR, ...)



Application Programmer's View

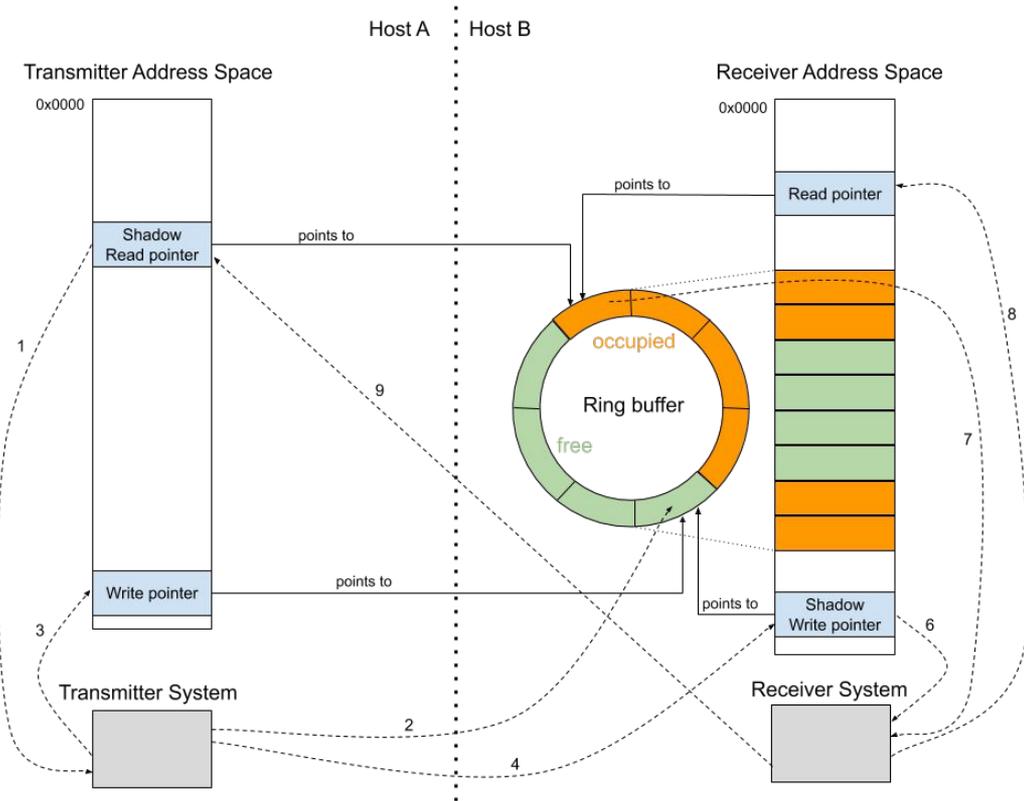
- Fully transparent comm. via PCIe NTB
  - Local (within one ECU)
  - Remote (between multiple ECUs)
- IP address for each Compute Node
- Gateway does routing, fail-over re-routing
- Send/receive TCP/IP, UDP/IP, SOME/IP messages



# PCIe NTB High Performance Delivered

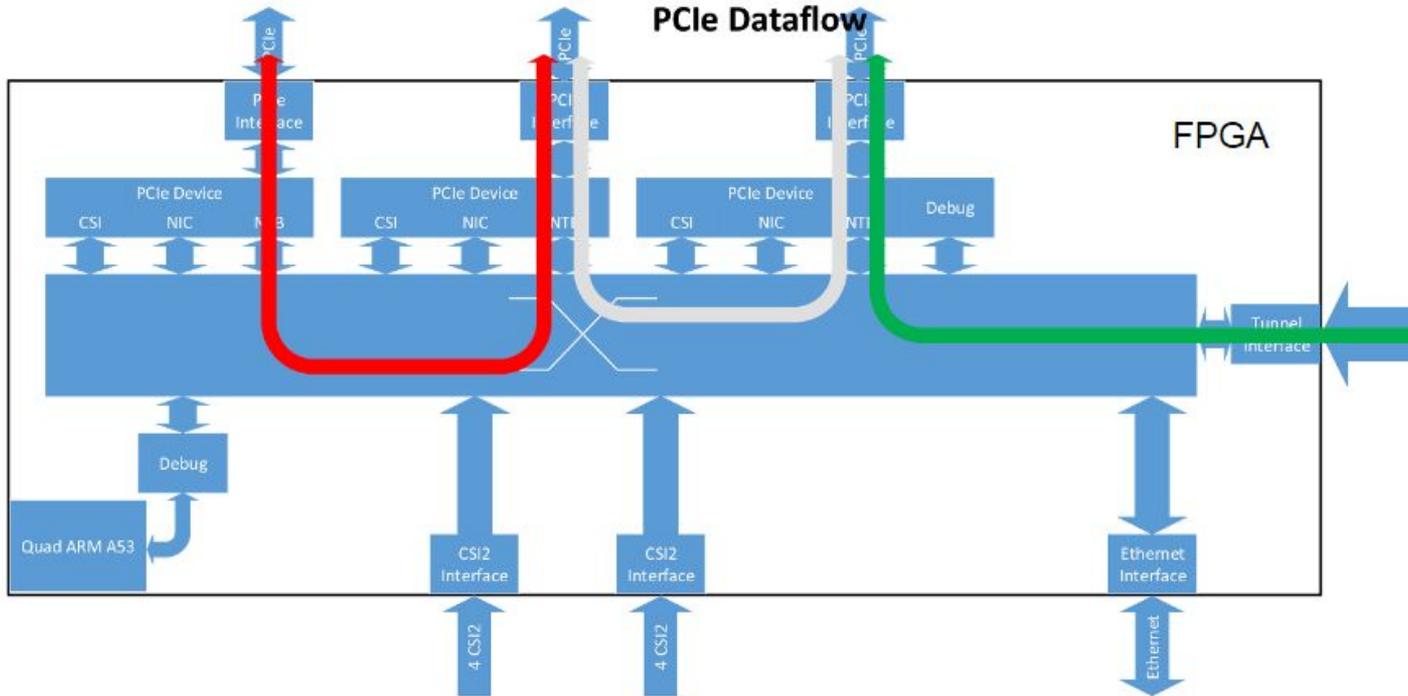
- Write-Only Comm via Doorbells and PCIe Posted Writes
- Avoids difficulties of PCIe multi-device
- Scales to > 32 PCIe RCs

“Borrowed” from NVMe Spec



# Network of PCIe - Onchip, Offchip, Backbone

## Custom Switch Based Design



# Platform Technology Example

Fully integrated system stack for automotive connectivity

- Available for ASIC and/or FPGA implementation

TSN Features:

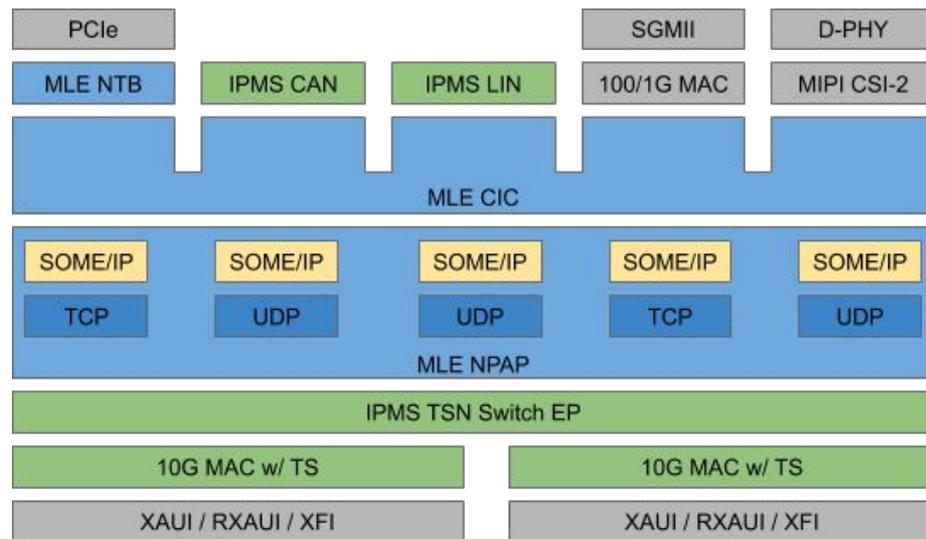
- IEEE 802.1AS, 802.1Qav, 802.1Qbv, 802.1Qci, 802.1Qcb
- Switch and Endpoint mode
- Scales to 10/25 Gbps

TCP/UDP/IP Features:

- IETF RFC 1122 Supported
- Autosar 4.x SOME/IP accelerated
- Scales to 10/25/50/100 Gbps

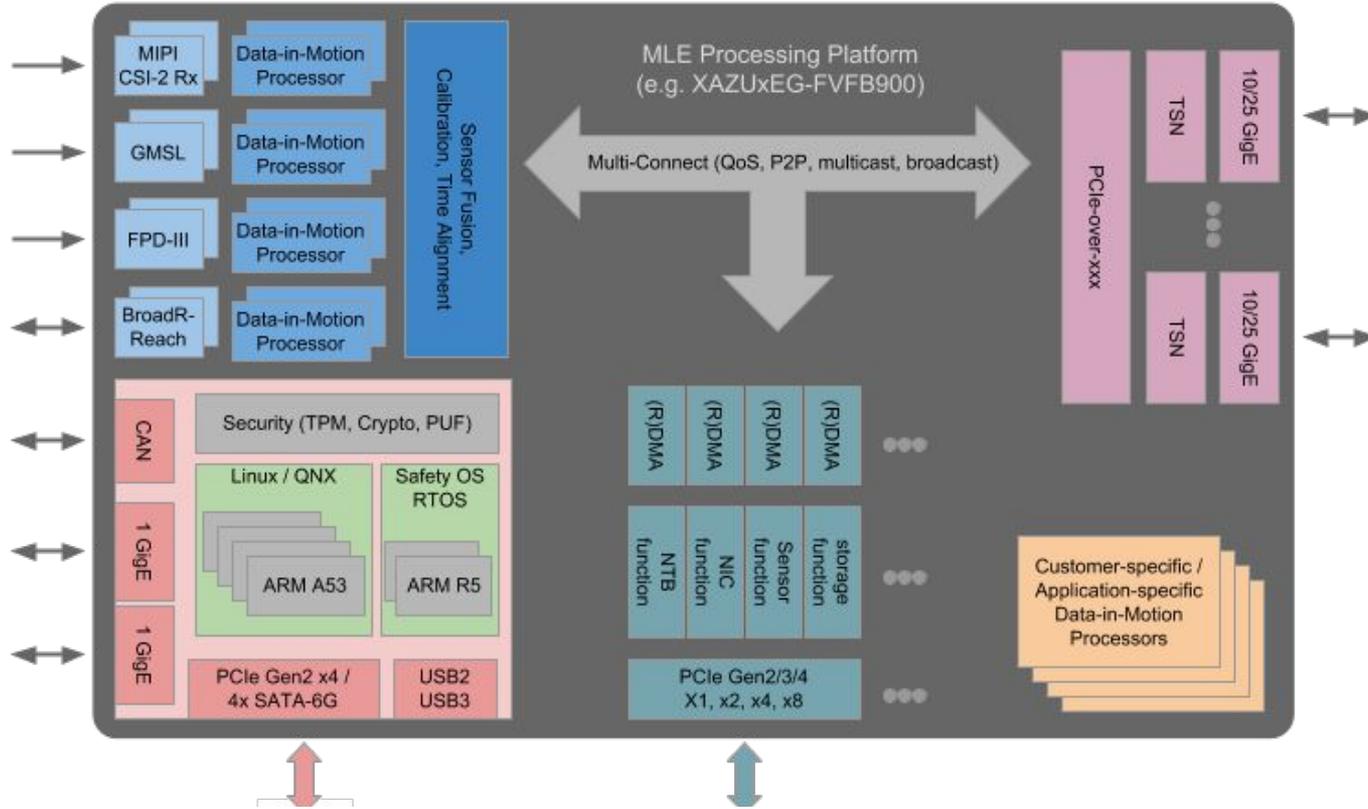
PCIe Features:

- PCI-SIG Base Spec 3.1 or 4.0 using x1, x4, x8
- Scales to 8/16/32/64/128 Gbps



System-level protocol stack example

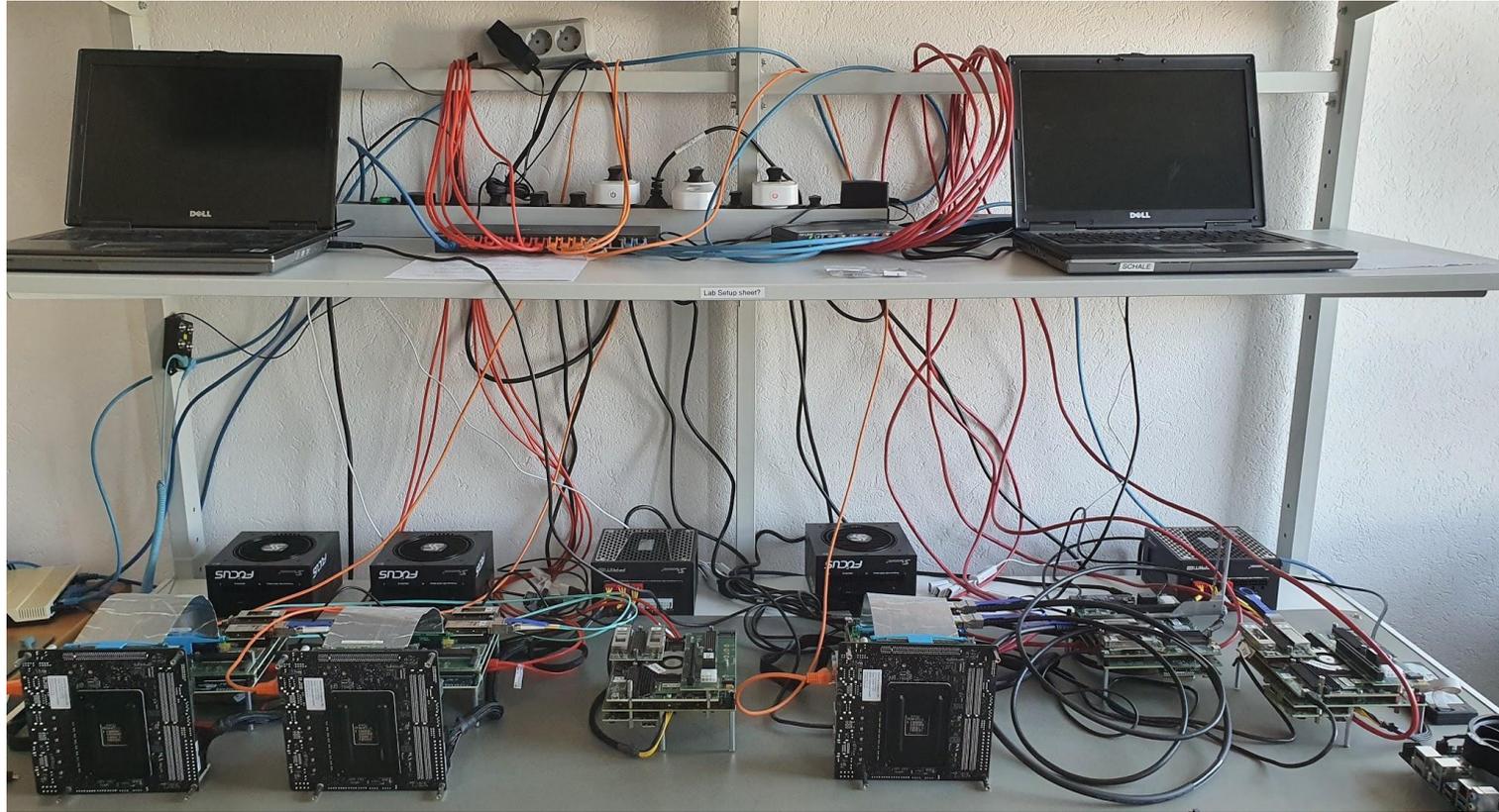
# Implementation with Xilinx FPGA



# Ongoing Research & Development w/ Partners

- Functional Safety (apply PCIe aspects for High-Availability)
  - Watchdog for PCIe AER (Advanced Error Reporting)
  - PCIe DPC (Downstream Port Containment)
  - IEEE 802.1CB (Frame Replication / Elimination)
- Security
  - PCIe RC/EP Authentication
  - ARM Secure OP-TEE
- Real-Time Behavior
  - IEEE 802.1AS and PCIe PTM

# PCIe-over-TCP-over-TSN-over-10GE Lab Car

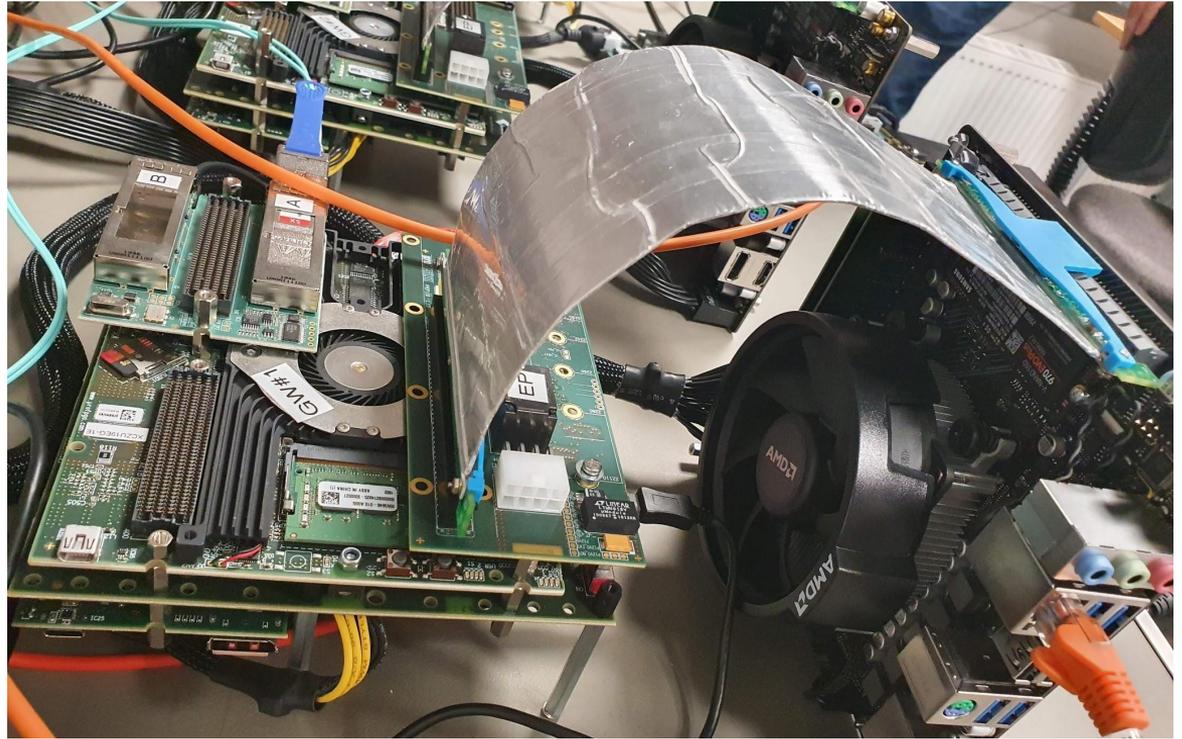


# PCIe-over-TCP-over-TSN-over-10GE Lab Car

Uses ASIC Emulators  
from ProDESIGN GmbH

“LEGO”-like interface  
boards for

- PCIe
- 10/25G Ethernet
- etc



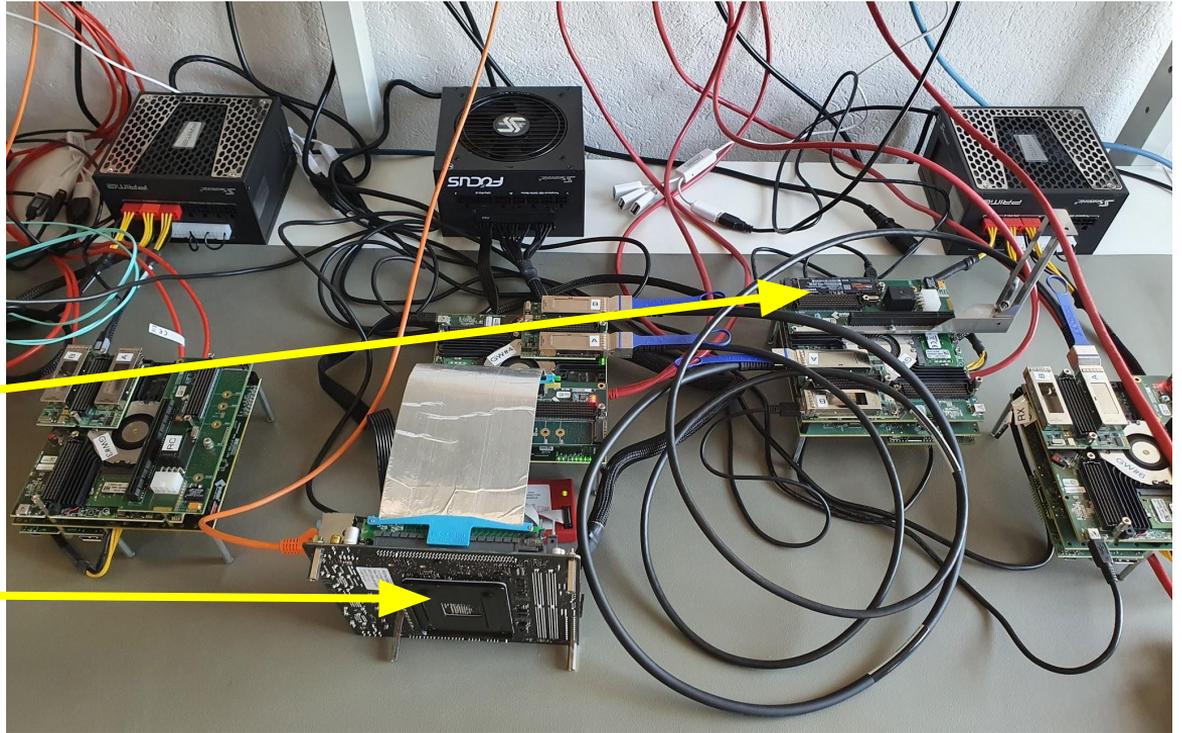
# PCIe-over-TCP-over-TSN-over-10GE Lab Car

Backbone with  
2 FPGA Gateways

for  
PCIe-over-...

to  
m.2 NVMe SSD

from  
mini-ITX PC

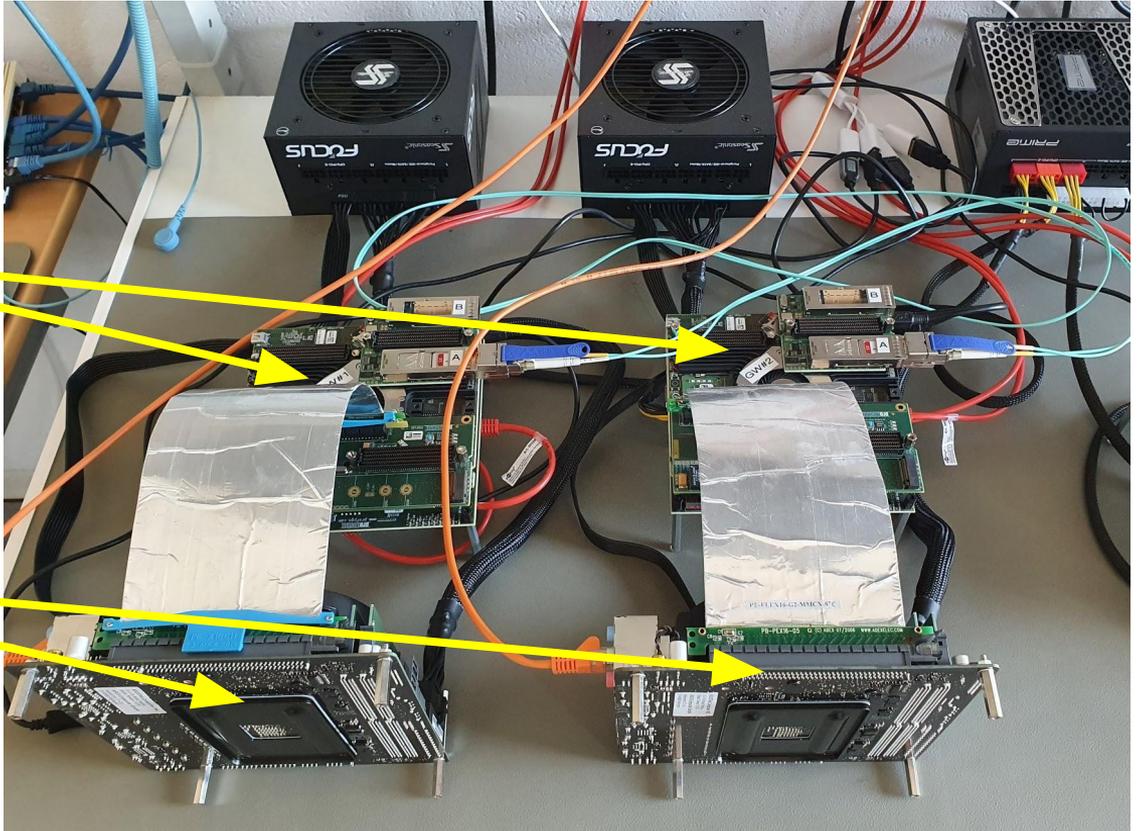


# PCIe-over-TCP-over-TSN-over-10GE Lab Car

Backbone with  
2 FPGA Gateways

for  
PCIe NTB

between  
2 mini-ITX PCs



# Our Contact Information

Missing Link Electronics, Inc.

+1 (408) 475-1490

2880 Zanker Road, Suite 203

San Jose, CA 95134

United States

Missing Link Electronics GmbH

+49 (731) 141149-0

Industriestrasse 10

89231 Neu-Ulm

Germany

Email contact: [sales-web@mlecorp.com](mailto:sales-web@mlecorp.com)