Next-Generation Wi-Fi Networks for Time-Critical Applications

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Outline

Industrial applications and requirements

Industrial control networks

IEEE 802.1 TSN (Time Sensitive Networking)

Wireless TSN Capabilities and Challenges

Testbeds and Research Directions

Conclusions

Un-wiring the factory

Increasing demand for automation requires **adaptability and flexibility** of industrial control and communication systems.

"In a wired system, the **cost of each additional instrument requires extra wiring and the associated labor, equipment, and maintenance**. Wireless can save 20 to 30% in simple configurations. Cost reductions can be even more compelling in scaled installations. "

Source: ISA In-Tech magazine Nov-Dec 2014

Industrial Applications and Classes of Service

Monitoring & Diagnostics Services	Connected Workers & HMI	Closed-loop Control Systems	Autonomous & Human-Guided Systems

Applications

Monitoring & Diagnostics Services
- Predictive maintenance (analytics)
- Diagnostics and tele-maintenance
- Asset tracking and monitoring

Connected Workers & HMI
- Worker's safety (body and environment monitoring)
- Portables/Wearables
- Augmented Reality

Closed-loop Control Systems
- Control of manufacturing process (PLCs, Sensors, Actuators)
- Re-configurable manufacturing cells

Autonomous & Human-Guided Systems
- Autonomous robots/drones
- Remote controlled robots/vehicles/drones

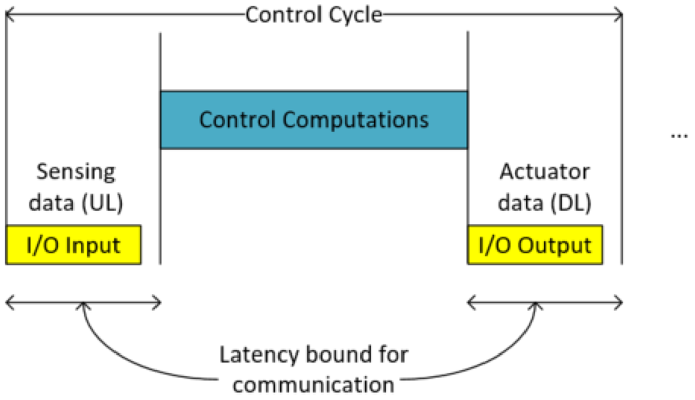
Class of Service

Delay-Tolerant	Real-Time	Time-Critical

Wireless enables flexibility, re-configurability, easy deployment, and mobility

Basic model of an industrial control system

Time synchronized operation



Latency/jitter may cause instability of the system

IEEE 802.1 Time Sensitive Networking (TSN) Components

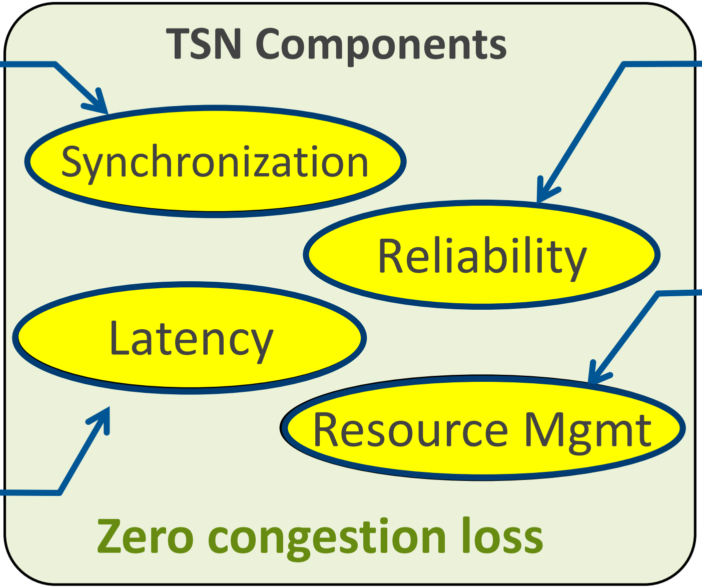
Standard Ethernet with synchronization, small and/or fixed latency, and extremely low packet loss

Time synchronization

Timing accuracy is 1usec or better

Bounded low latency:

Latency is 1msec for a single wireless link*



Credit: János Farkas, Ericsson TSNA Conference 2017

Ultra reliability

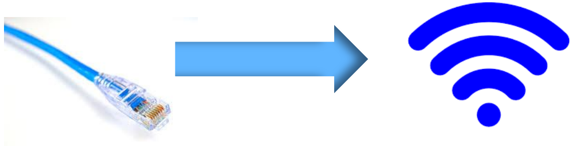
99.999% or better delivery guaranteed

Dedicated resources

Provisioning, data streams reservation and TNS configuration

These TSN Capabilities are being enabled over Wireless (e.g. 802.11/Wi-Fi, 5G NR)

Is Wireless TSN feasible?



Core challenge: *Determinism*

Predictable Low Latency + Extremely Low Packet loss

(e.g. 1 msec) (e.g. 10^{-5} error rate)

(Network Congestion) (Media/hardware failures)

Wired Links

Constant/high capacity
~ 0 media/channel errors

√ Can be provisioned for **determinism with high confidence**

Wireless Links

Variable capacity
10% error rate (typical)

- Stochastic in nature
- Time/frequency/space varying (shadowing, multipath, …)
- Harsh environment (obstructions, noise, interference)

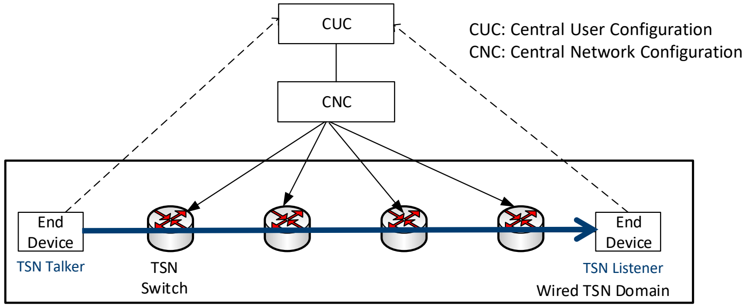
Not designed (so far) for determinism:

- **optimized average performance**
- **reliability vs latency tradeoffs**

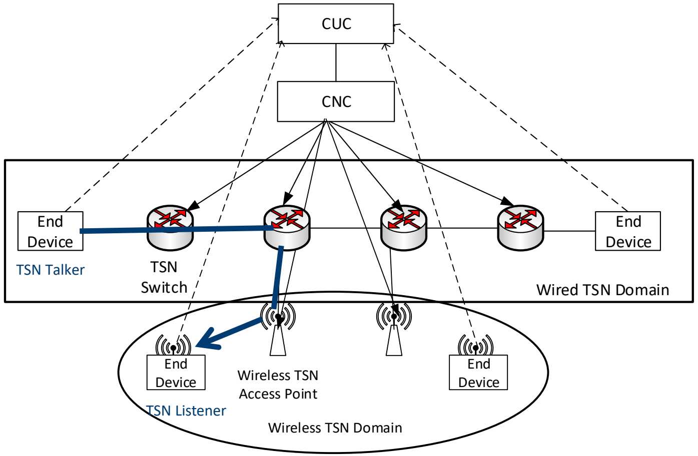
From Wired (Ethernet) to Wireless TSN

Most TSN capabilities and standards have been restricted to Ethernet

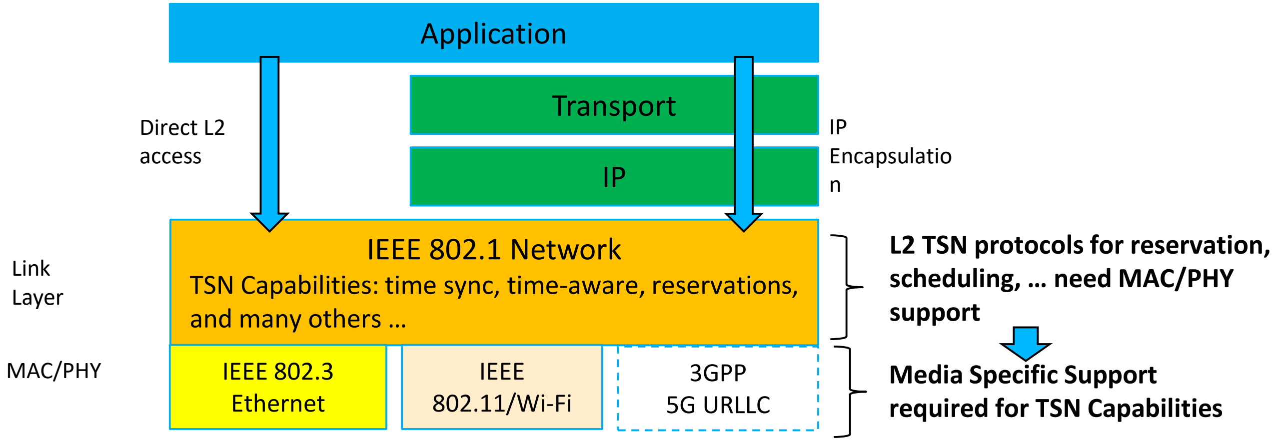
- Ethernet (802.3 MAC/PHY) provides **stable links with predictable capacity**
  - The network is provisioned to serve end-to-end TSN streams using the TSN capabilities at each TSN Switch
  - The CUC/CNC are responsible for user and network configuration (defined by the 802.1Qcc model)



Wireless TSN will extend the TSN capabilities to a "Wireless TSN Domain"



802.1 TSN and Wireless Support Required



802.11 support for TSN:

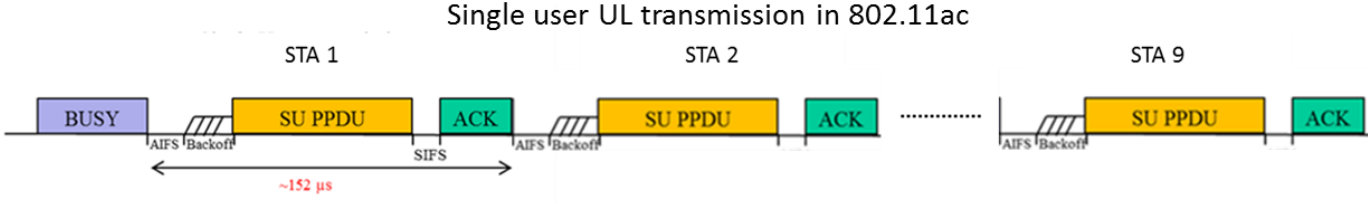
✓Integration with 802.1 TSN
✓Time synchronization: 802.1AS over 802.11
• Timeliness (bounded latency, reliability)

5G NR ongoing TSN activities:

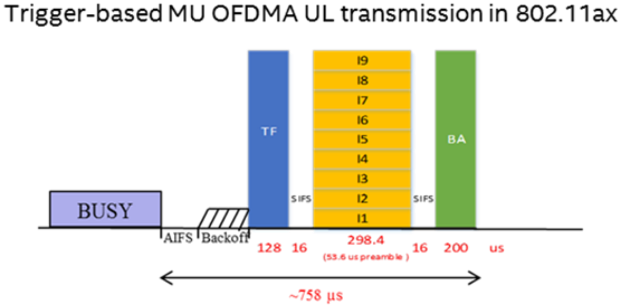
- TSN support is part of Vertical_LAN Work Item (Rel.16 ongoing work):
  - Time synchronization across a 5G System
  - Integration with TSN (802.1Qbv, 802.1Qcc, …)

Improvement with 802.11ax: Trigger-based/OFDMA Access

- OFDMA reduces latency by avoiding multi-user contentions
- Scheduled access allows better control of channel access and link adaptation



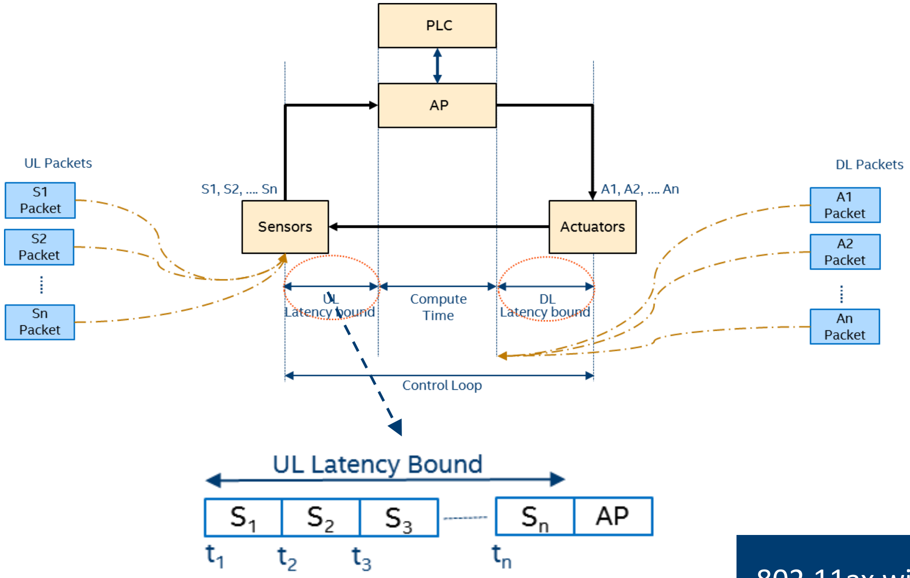
≈ 1300 µs



≈ 758 µs

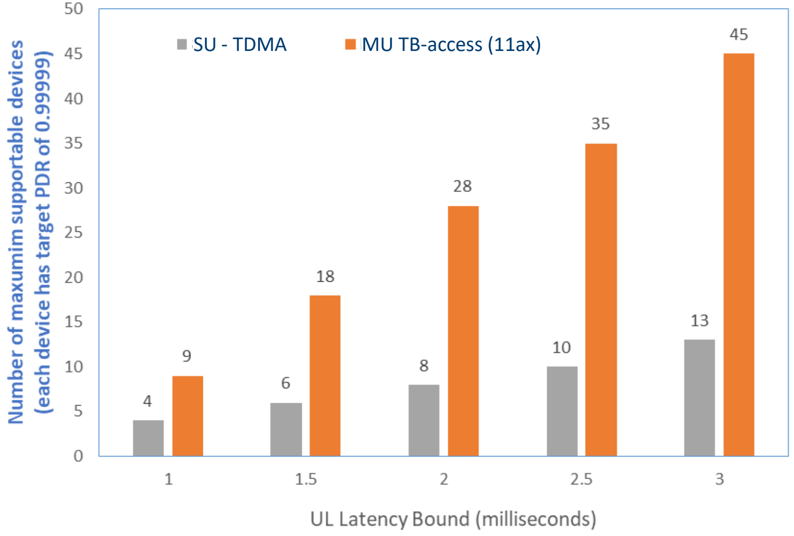
Industrial control enabled by 802.11ax optimized scheduling

Wireless Control Loop (WCL) model



Single-user Schedule (TDMA)

Reliability requirement: 0.99999 (five nines) PDR

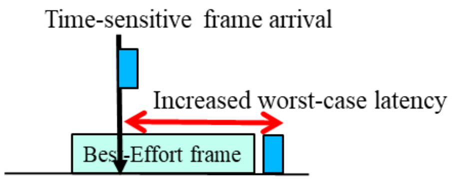


802.11ax with time-sensitive scheduling can support ~**3x** capacity for a given latency bound compared to the Single User TDMA baseline

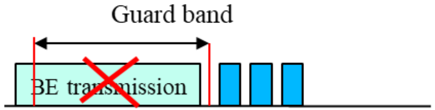
PDR: Packet Delivery Ratio (Fraction of packets successfully delivered within the latency bound)

Frame Preemption (802.1Qbu/802.3br)

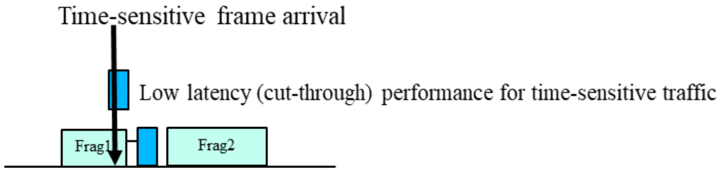
Large frame transmissions increase worst-case latency for time-sensitive frames



A guard band (GB) of the size of the largest (BE) fame is needed before the scheduled period starts → less efficient/reduced capacity



Preemption reduces worst-case latency for time-sensitive frames and increases efficiency (smaller guard band for scheduled traffic)

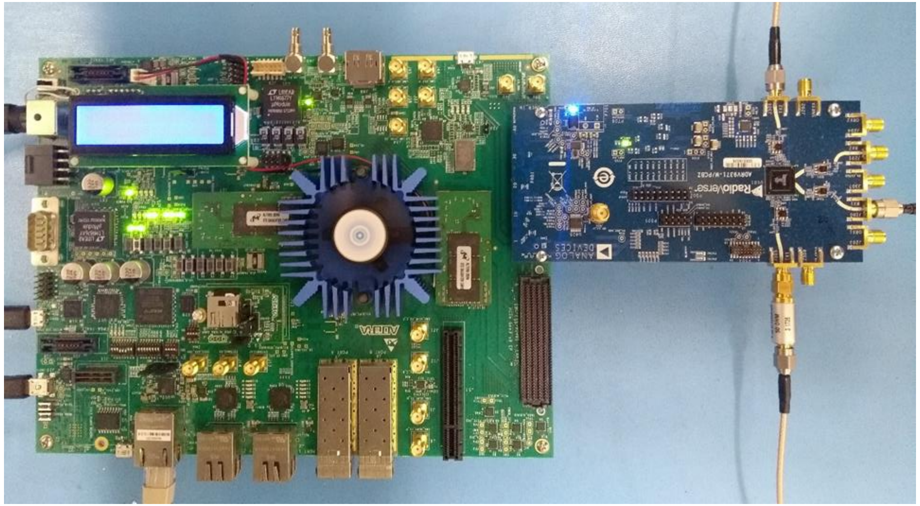


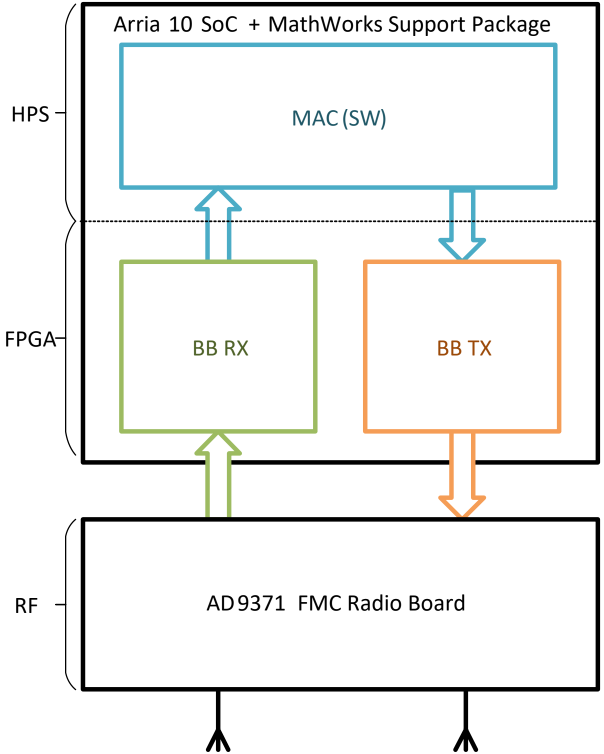
802.3br defines MAC enhancements to support preemption in Ethernet

- Define and handle express and preemptable frames
- Arbitrate between express (time-sensitive) and preemptable frames
- Preserve frame integrity (fragmentation/reassembly)

802.11 support for preemption could be considered

Software Defined Radio as WTSN Testbed





Intel Based SDR (Software Defined Radio) for rapid prototyping.
Intel FPGA Arria10SoC+AD9371.

Intel-based SDR Platform: Components

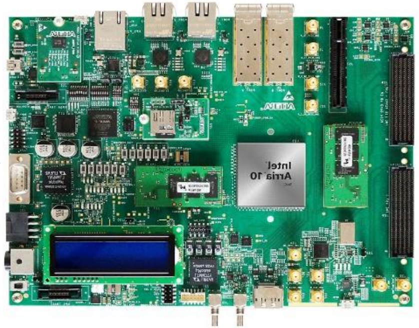
FPGA & SoC Development Tools

Design Model

Intel-based SDR support package

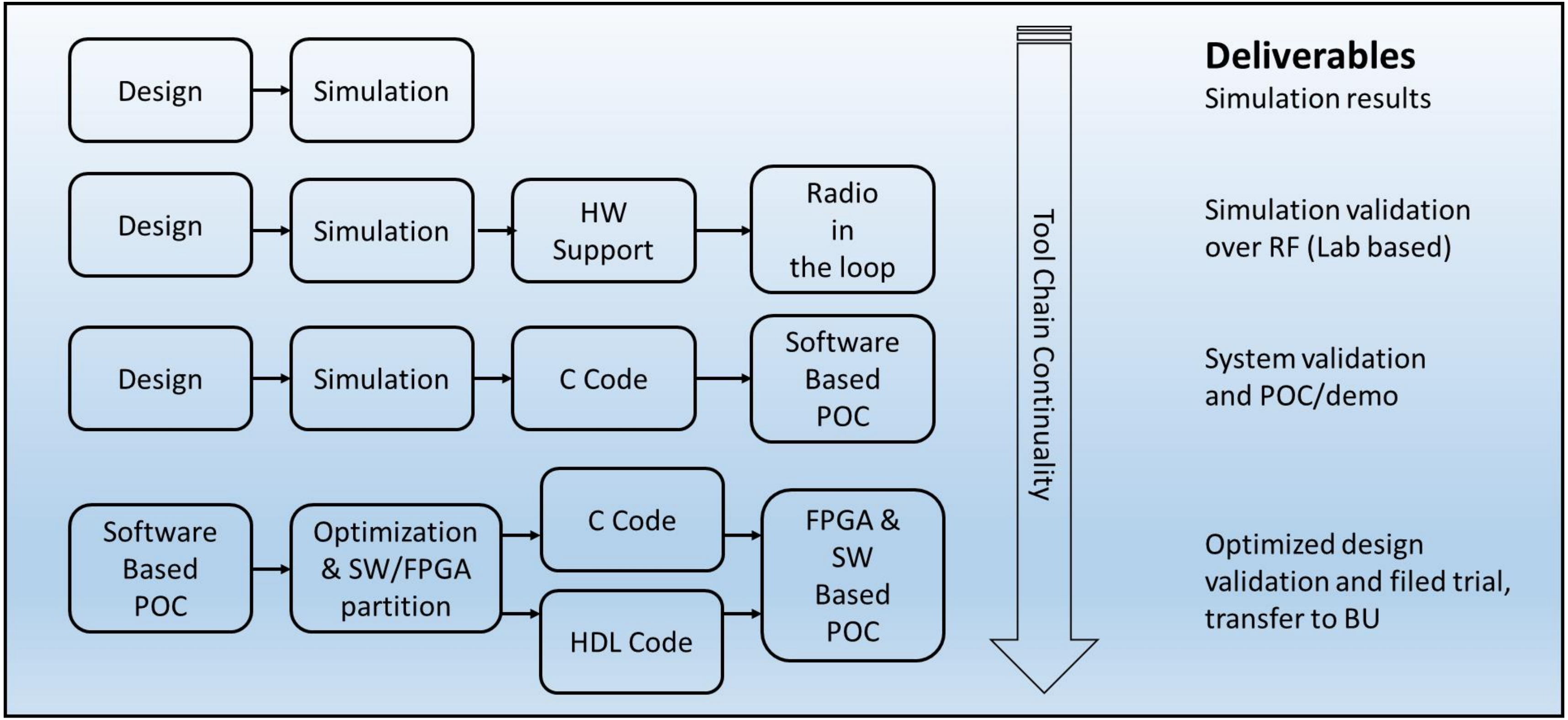
LibIIO Linux Library

Intel’s Arria 10 FPGA SoC

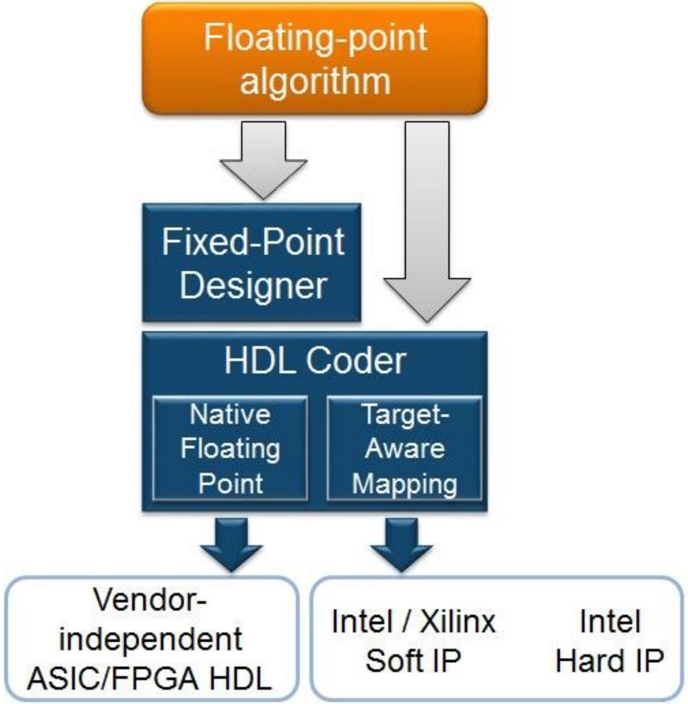


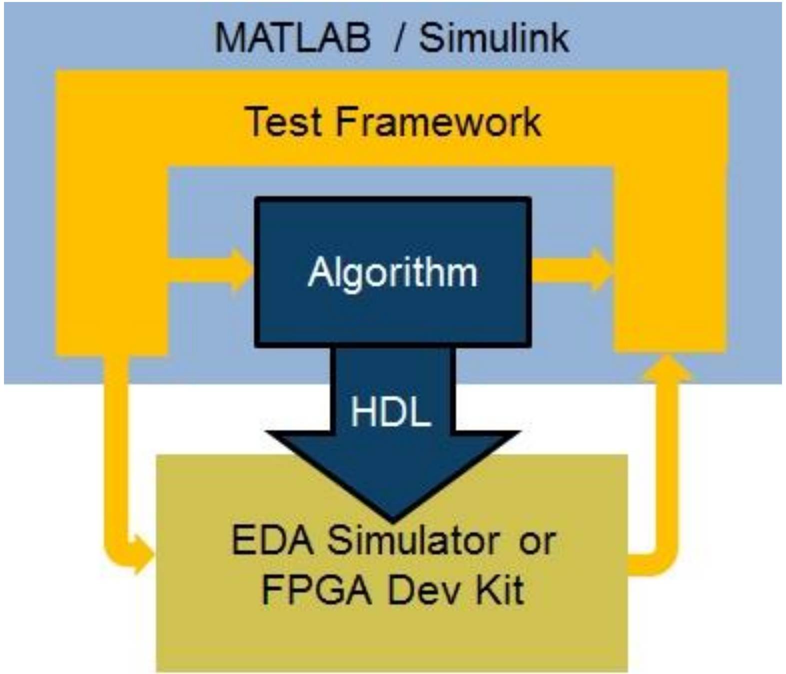
ADI’s AD9371 RF FE

Comm System Design Flow with MATLAB/SL

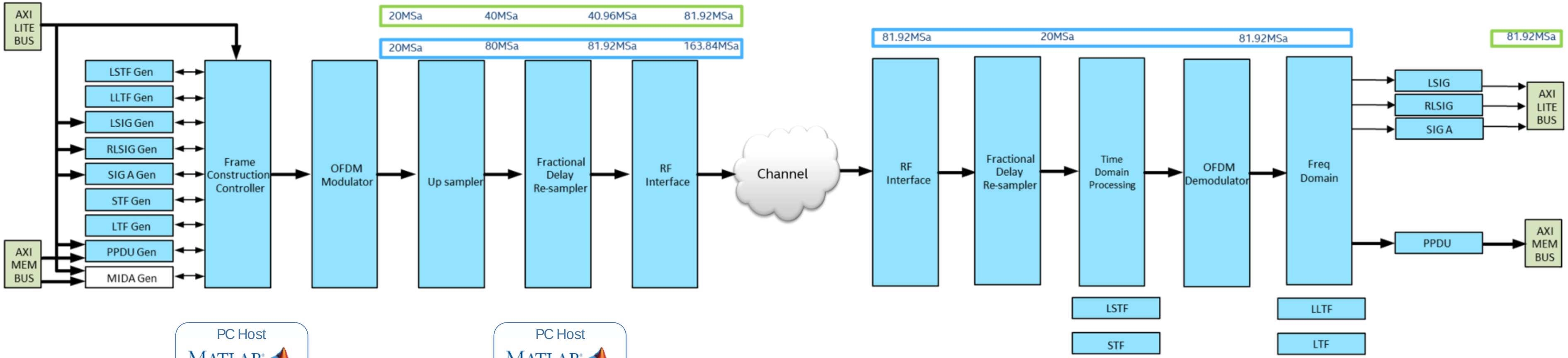


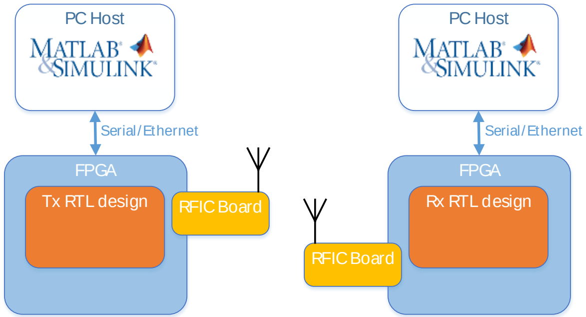
HDL Coder Methodology





Digital Baseband Transceiver





PoC 802.11ax digital baseband for WTSN research

Digital baseband RTL development for Transceiver in **FPGA** and its integration into SDR platform with HPS Linux SW and off-the-shelf RFIC FMC daughter board Analog Devices 9371 (2.4GHz/5GHz bands).

Conclusions

Future industrial communication networks are converging around Ethernet and 802.1 TSN standards

Extending TSN to Wireless can enable flexibility, mobility, and reduce wiring costs

Emerging wireless technologies (e.g. 802.11ax/be, 5G) are introducing new capabilities to enable Wireless TSN

- Time synchronization
- Time-aware and latency optimized scheduling

Testbeds are key to test the feasibility of WTSN capabilities in the PHY Layer (e.g., frame preemption in 802.11

- Intel-based FPGA SoC SDR for flexible PHY layer implementation
- MATLAB/Simulink model-based implementation

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