



# 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



- 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

Delay-Tolerant

Real-Time

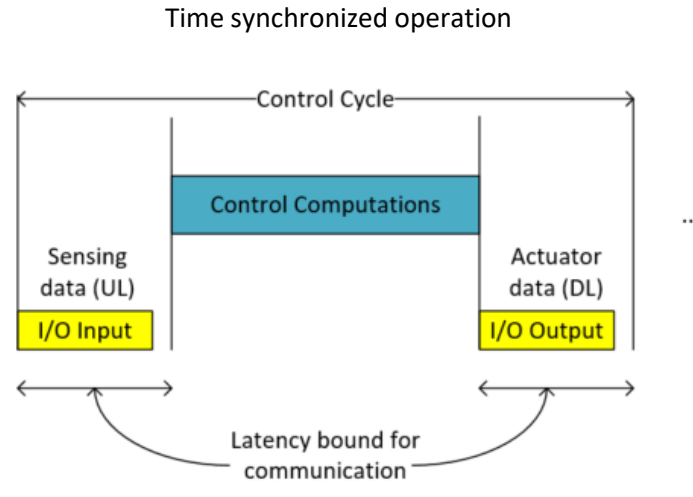
Time-Critical

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

Applications

Class of Service

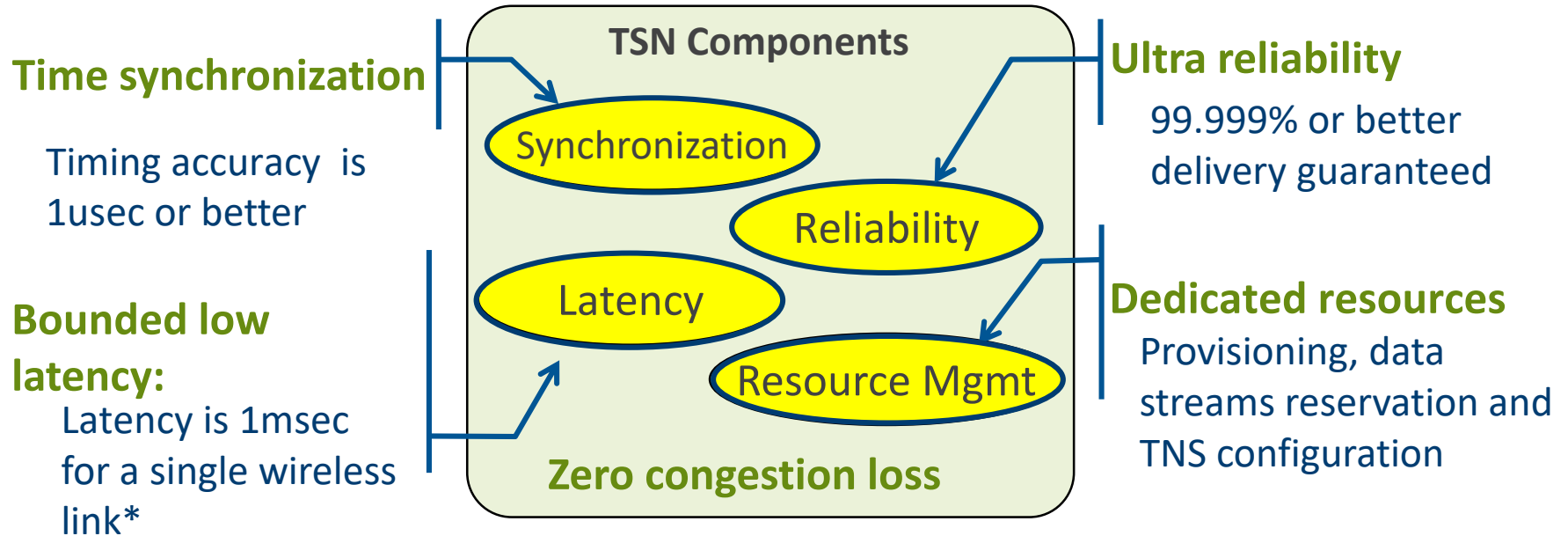
# Basic model of an industrial control system



Latency/jitter may cause instability of the system

# IEEE 802.1 Time Sensitive Networking (TSN) Components

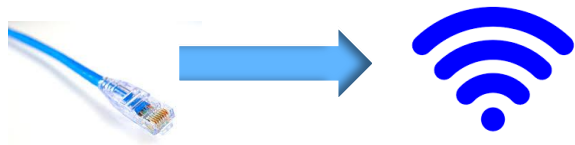
Standard Ethernet with synchronization, small and/or fixed latency, and extremely low packet loss



Credit: János Farkas, Ericsson TSNA Conference 2017

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

(e.g. 1 msec)

+

Extremely Low  
Packet loss

(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)

**Not designed (so far) for determinism:**

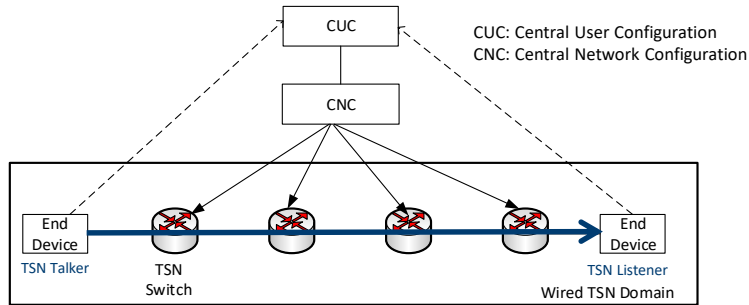
- Stochastic in nature
- Time/frequency/space varying (shadowing, multipath, ...)
- Harsh environment (obstructions, noise, interference)

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

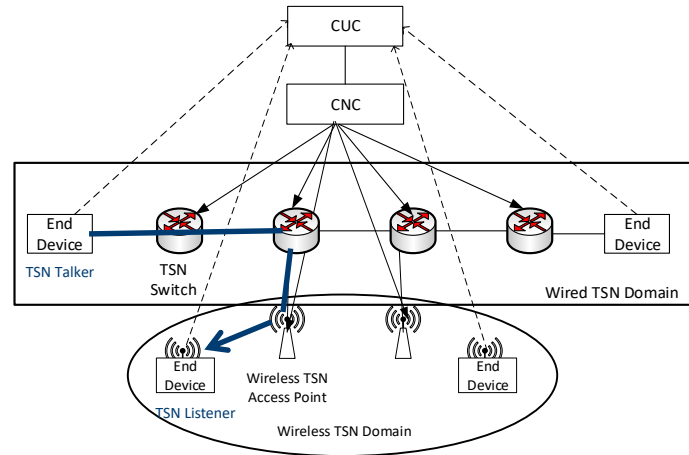
# From Wired (Ethernet) to Wireless TSN

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)

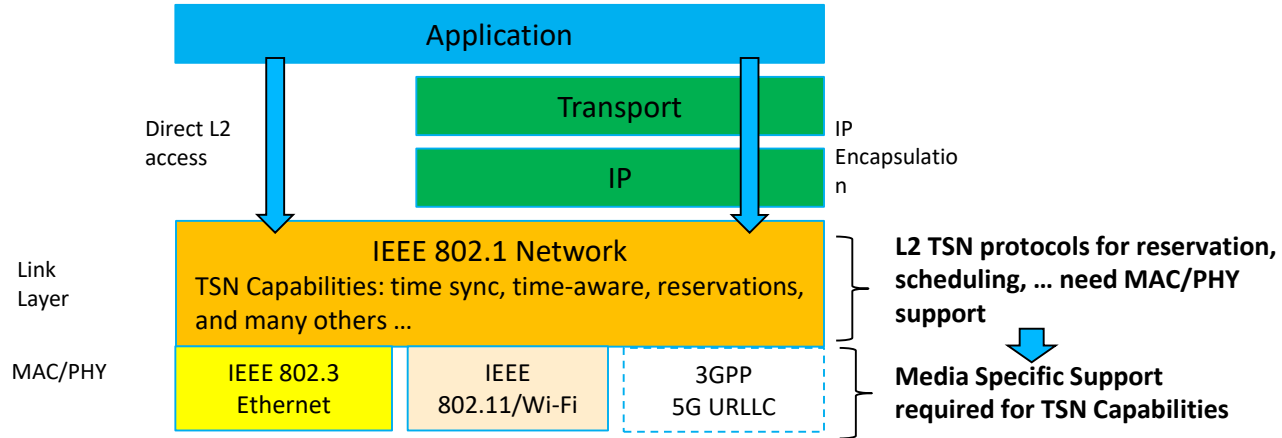


Wireless TSN will extend the TSN capabilities to a “Wireless TSN Domain”





# 802.1 TSN and Wireless Support Required



## 802.11 support for TSN:

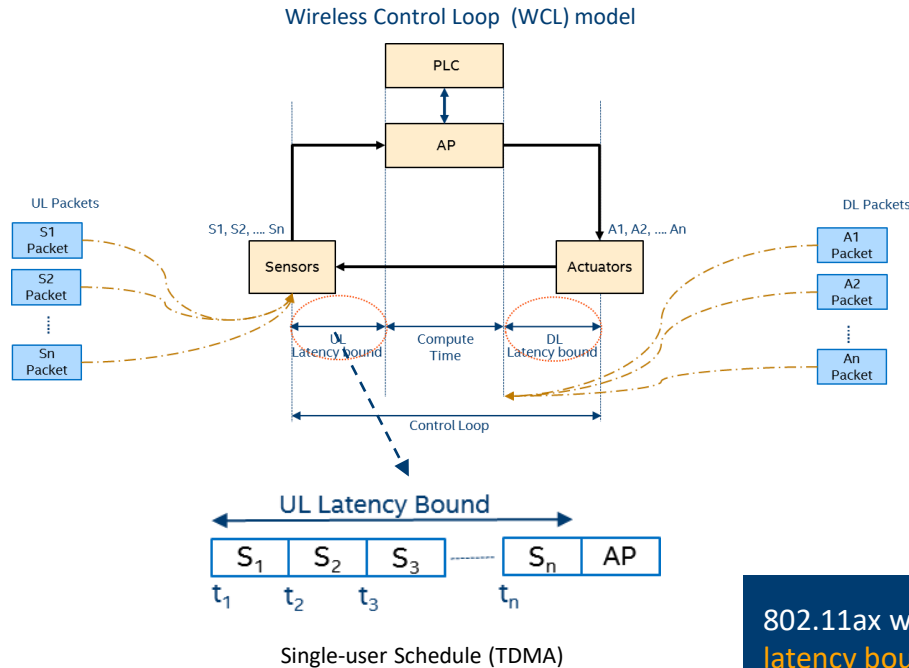
- ✓ Integration with 802.1 TSN
- ✓ Time synchronization: 802.1AS over 802.11
- Timeliness (bounded latency, reliability)

## 5G NR ongoing TSN activities:

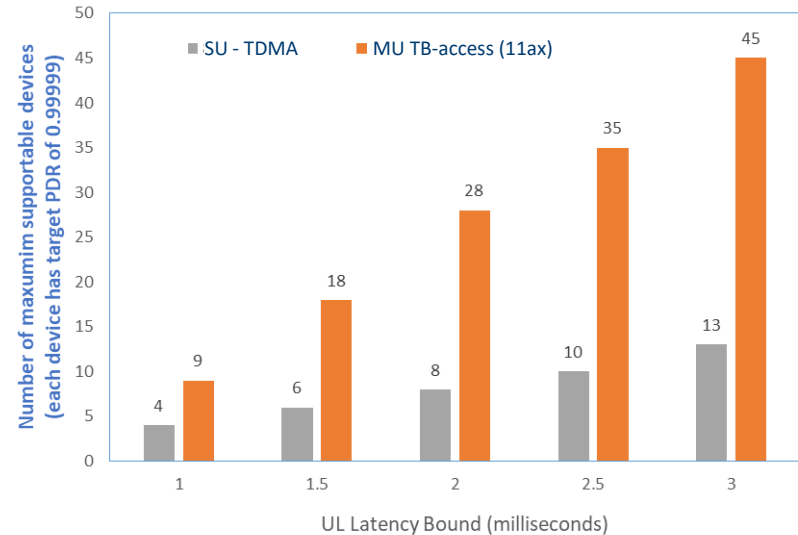
- TSN support is part of Vertical\_LAN Work Item (Rel.16 ongoing work):
  - Time synchronization across a 5G System
  - Integration with TSN (802.1Qbv, 802.1Qcc, ...)



# Industrial control enabled by 802.11ax optimized scheduling



Reliability requirement: 0.99999 (five nines) PDR

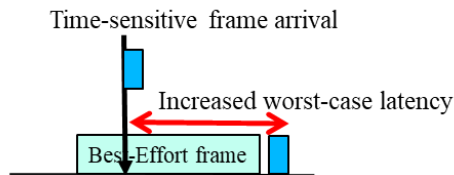


802.11ax with time-sensitive scheduling can support **~3x capacity** for a given **latency bound** compared to the Single User TDMA baseline

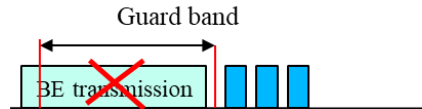
PDR: Packet Delivery Ratio (Fraction of packets successfully delivered within the latency bound)

# Frame Preemption (802.1Qbu/802.3br)

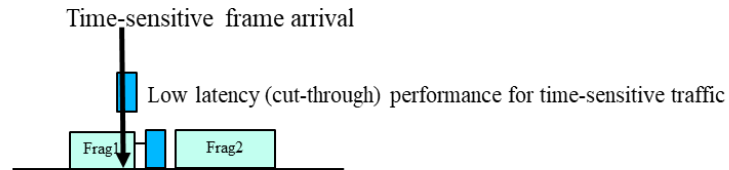
Large frame transmissions increase worst-case latency for time-sensitive frames



A guard band (GB) of the size of the largest (BE) frame 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)

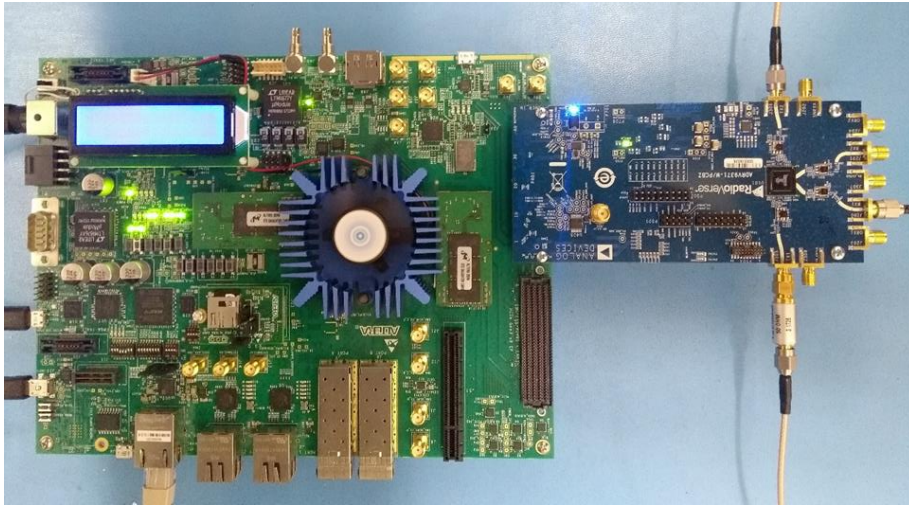


## 802.3br defines MAC enhancements to support preemption in Ethernet

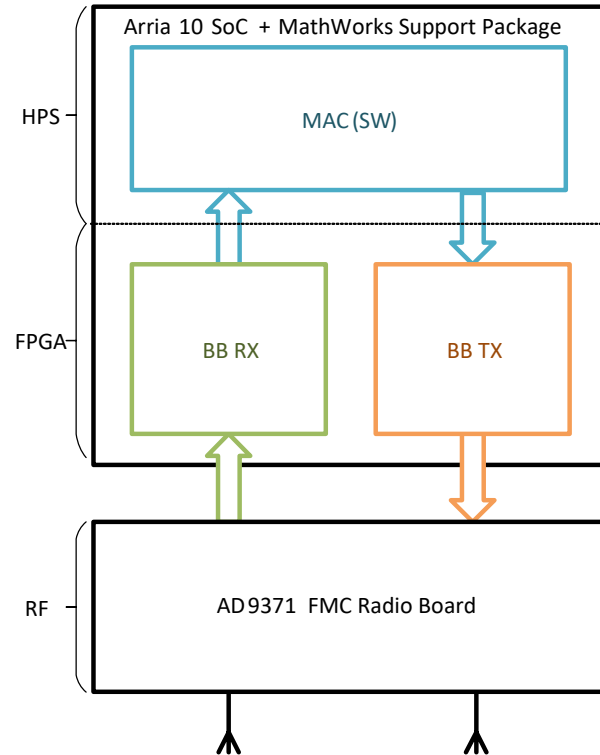
- Define and handle express and preemptable frames
- Arbitrate between express (time-sensitive) and preemptable frames
- Preserve frame integrity (fragmentation/reassembly)

802.11 support for preemption could be considered

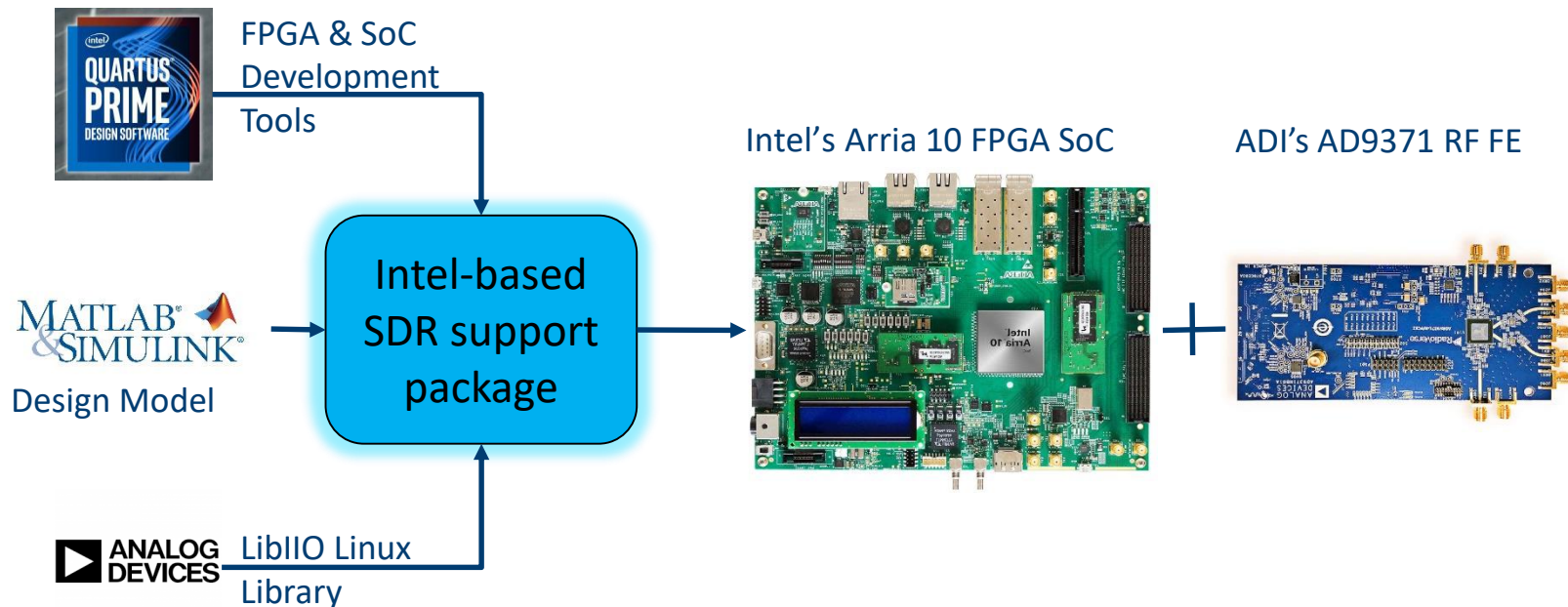
# Software Defined Radio as WTSN Testbed



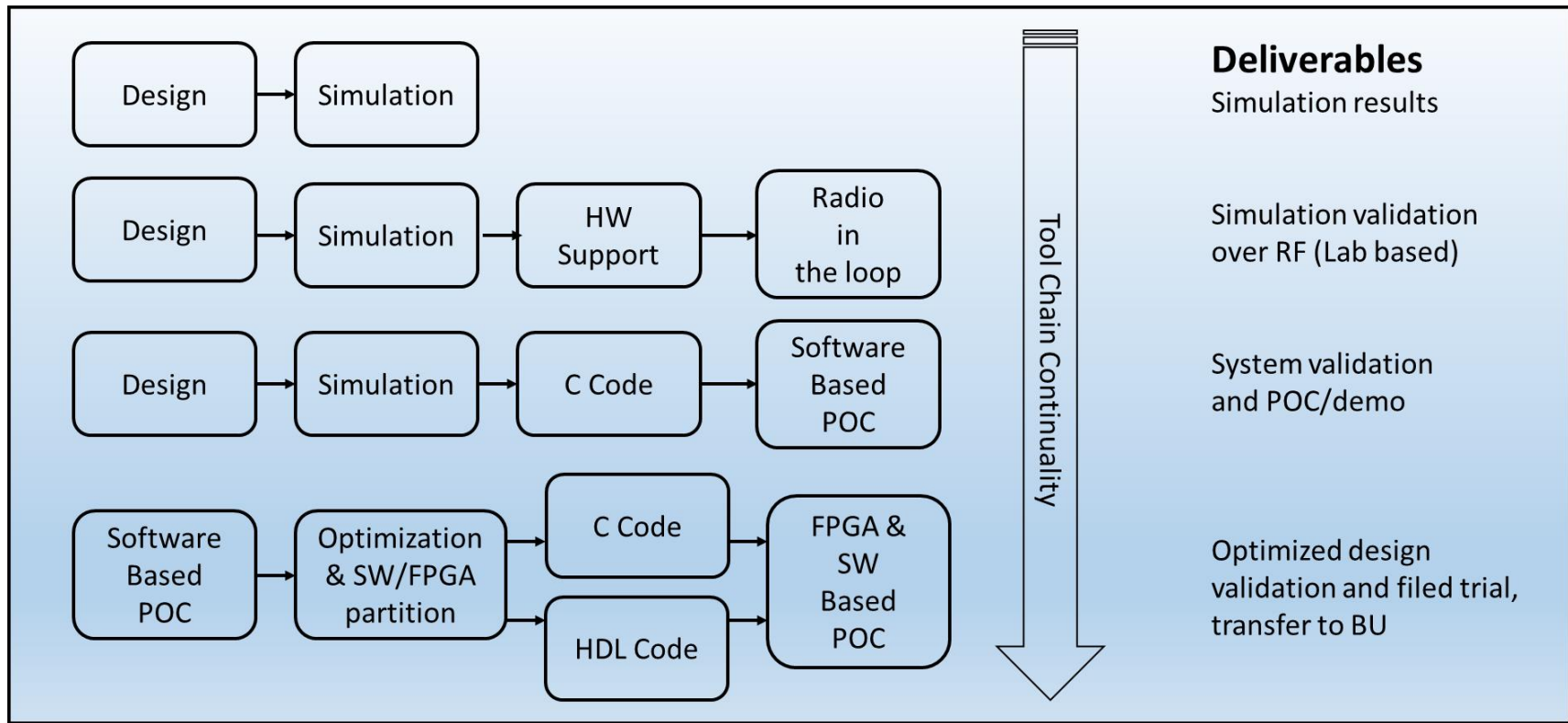
Intel Based SDR (Software Defined Radio) for rapid prototyping.  
Intel FPGA Arria10SoC+AD9371.



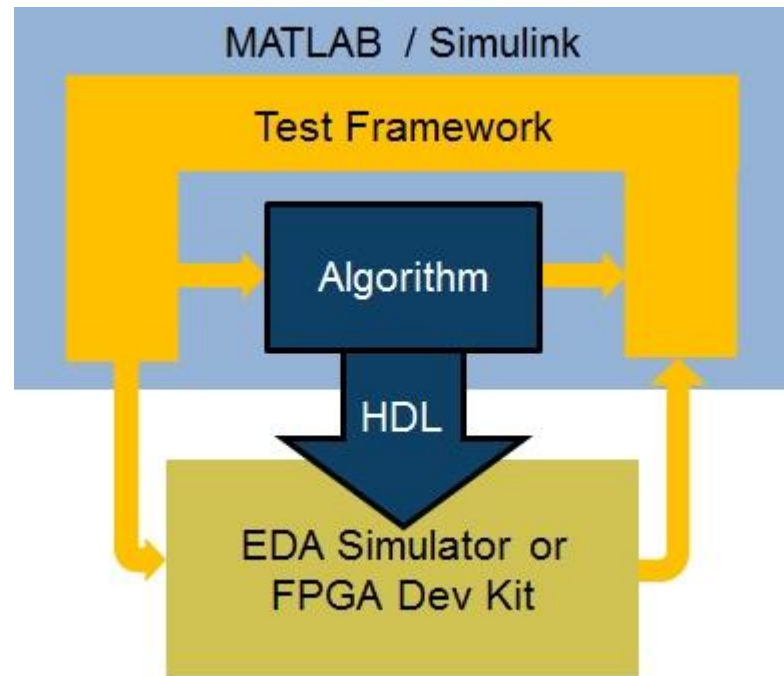
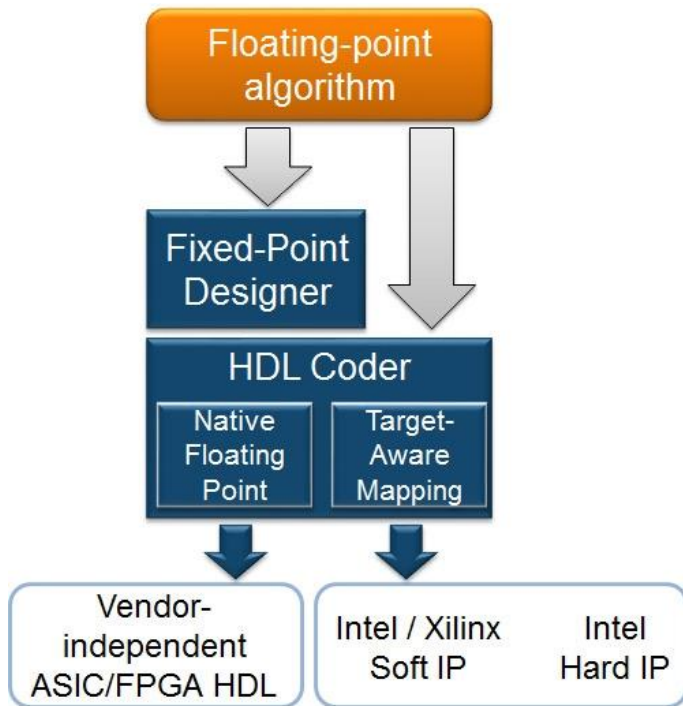
# Intel-based SDR Platform: Components



# Comm System Design Flow with MATLAB/SL

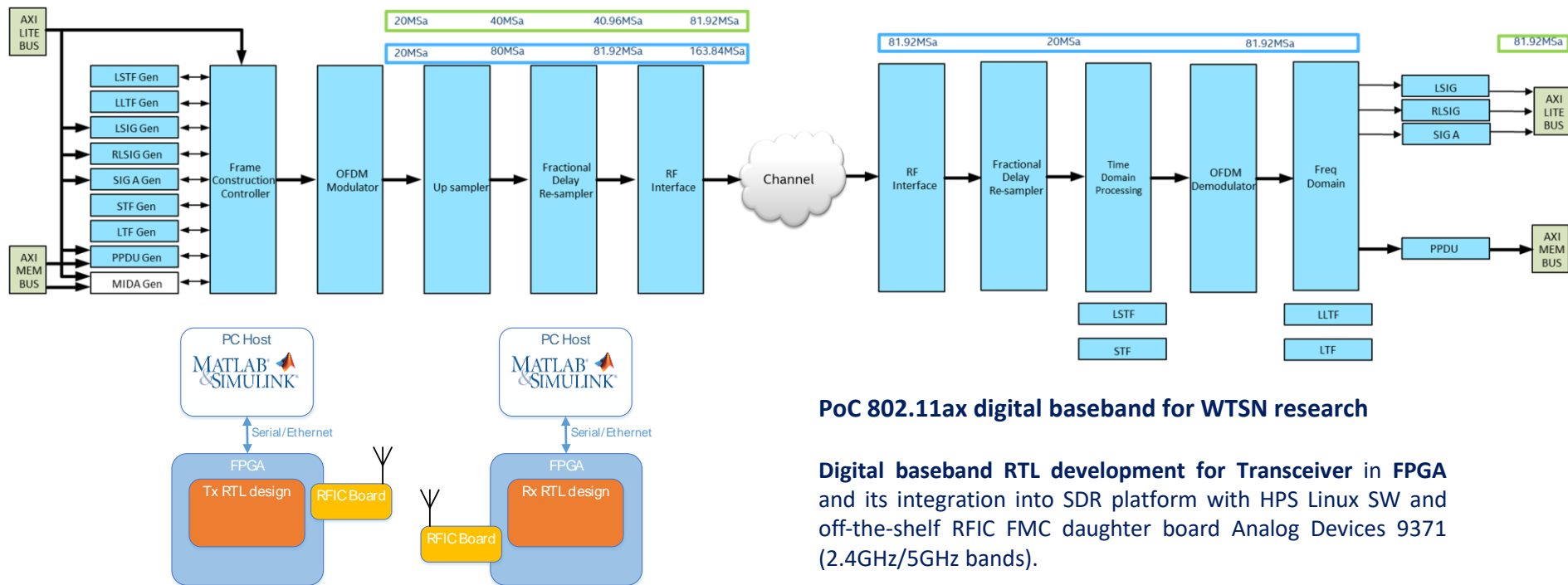


# HDL Coder Methodology





# 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

