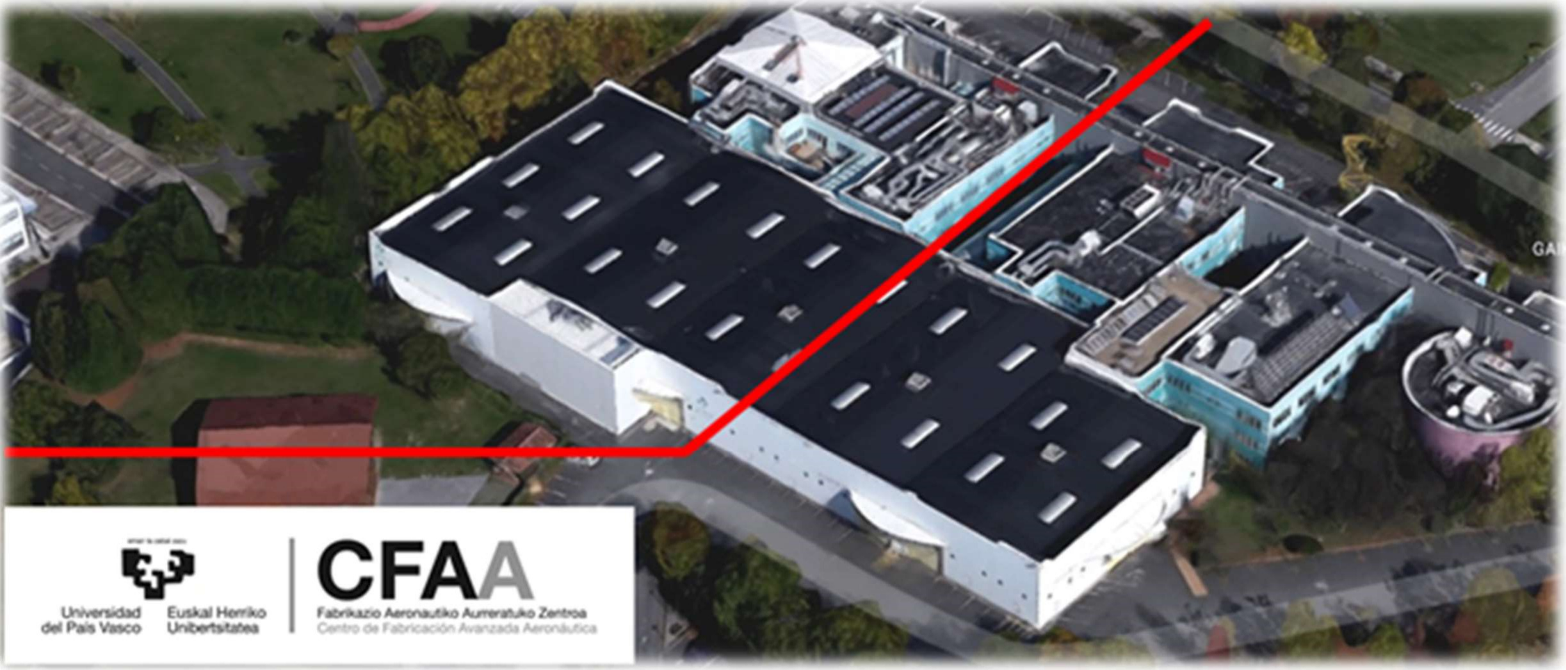
SoCe

System-on-Chip *engineering*



Redundant Interoperable TSN implementation for CNC Milling Machines Networking in the Aeronautics Advanced Manufacturing Center

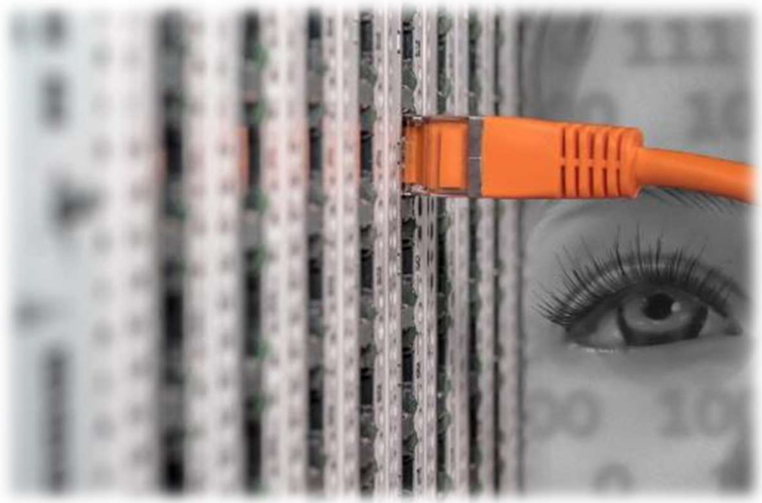
Presenters: Alicia Alonso (SoC-e)
Michael Zapke (Xilinx)

SoCe XILINX

TSN Technology & Applications ®

Index

- **Why?**
  - » **Critical Systems demand High-Availability networking**
- **What?**
  - » **TSN aims to support Seamless redundancy via CB**
- **How?**
  - » **TSN CB Pilot interoperable & *brownfield***



SoCe XILINX

SoCe

Why?

Critical Systems: Where "availability" is a must

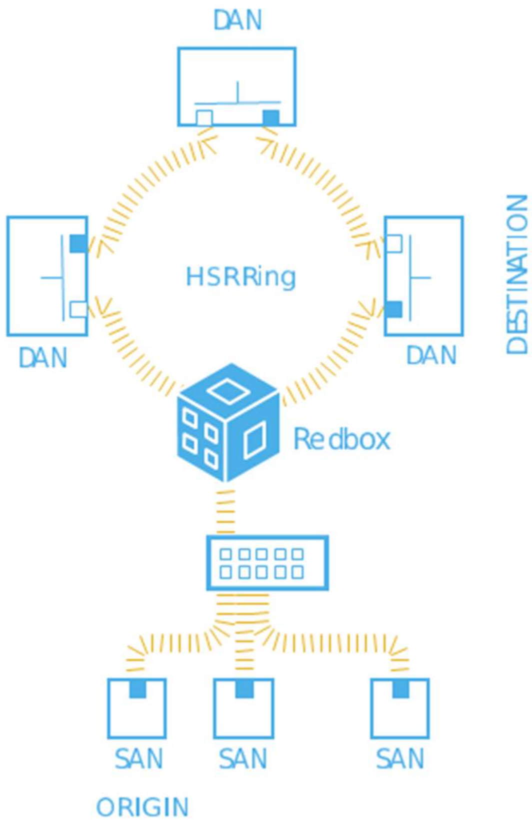
- No-frame lost
- Zero-delay recovery time

SoCe XILINX

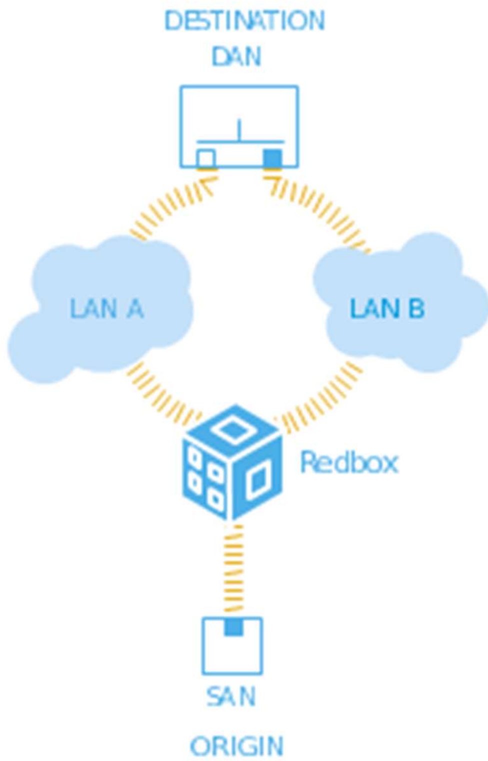
Current State-of-the-Art: HSR/PRP

- IEC 62349
- Widely extended in the Electric Sector: IEC 61850
- Industry, Military and Broadcasting

HSR



PRP



SoCe XILINX

Current State-of-the-Art: HSR/PRP

- Pros:
  1. Robust Layer-2 operation (hardware)
  2. No configuration required
  3. PRP operated in standard Ethernet networks (x2)
  4. IEEE 1588v2 supported
- Cons:
  1. HSR needs HSR-capable devices in the ring
  2. Limited applicability for real-time operation:
     - HSR supports the calculation of the Worst-case delivery time

SoCe

What?

Practical Reason for FRER with 802.1CB

Factory Floor Example – simplified

- 1000 connected nodes
- 1 Ethernet frame per millisecond in average from each node
  - » 1000 nodes x 1000 frames/(s x node) x 10^5 s/day = 10^{10} frames/day

- Assume a probability for a frame that it's lost/damaged of $5x10^{-5}$
- Change into safe state after two consecutive damaged packets with $(5x10^{-5)})^2$ = 2.5 $x10^{-11}$
  - » **1 product line stop per month** (=10^{10} x 2.5 10^{-11})

Factory Automation for Production require
availability enhancements through Redundancy

SoCe XILINX

802.1CB and TSN Network Elements

- TSN 802.1CB distinguishes
  - Talker End System / Listener End System: Two MAC Interfaces without no switching between them. Typically one port is active, the other is passive to react on media (cable) failures.
  - Relay system: Bridge or router. Placed in ring or chain topologies

Devices Under Test (DUT) in this presentation are
End Systems with built-in Relay Systems (2 external ports)

Redundancy (802.1CB)

Principle

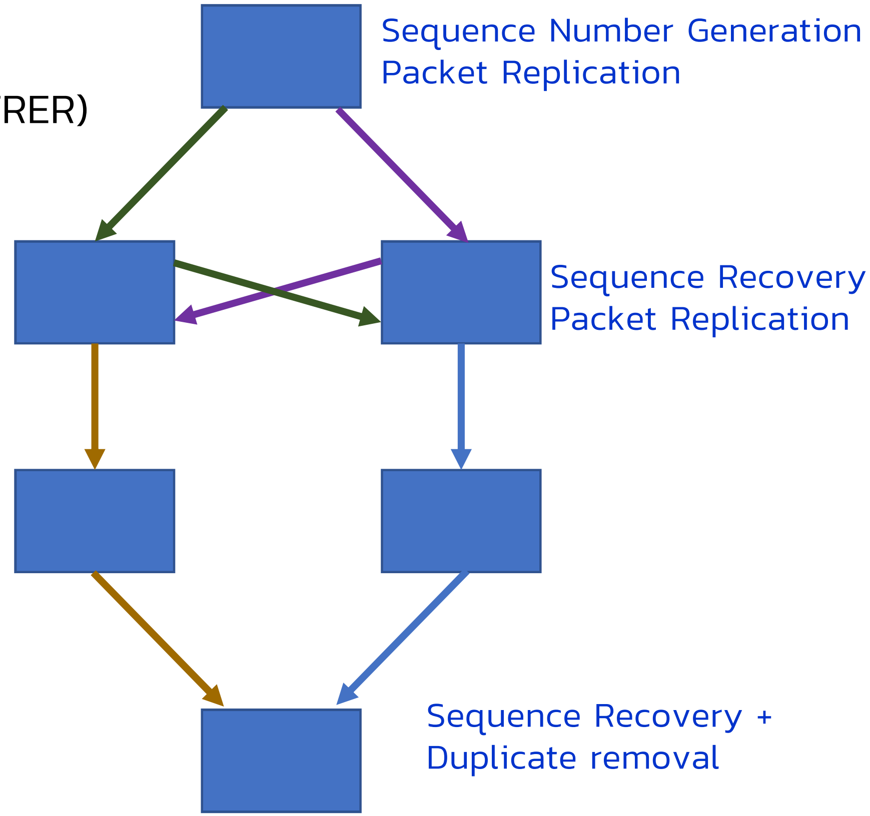
- Frame Replication and Elimination for Reliability (FRER)

Targets

- Higher availability
- Robustness against equipment failures

Functions

1. Stream Identification
2. Replication of Frames
3. Redundancy Tag generation with Frame Sequence Number
4. Identification and removal of Duplicates
5. Sequence Recovery



SoCe XILINX

The Redundancy TAG

Sequence Encode/Decode Function in 802.1CB, are needed to identify the sequence in a split stream and compund stream

» Mandatory feature: Redundancy Tag (or R-TAG) in frames with EtherType "F1C1"

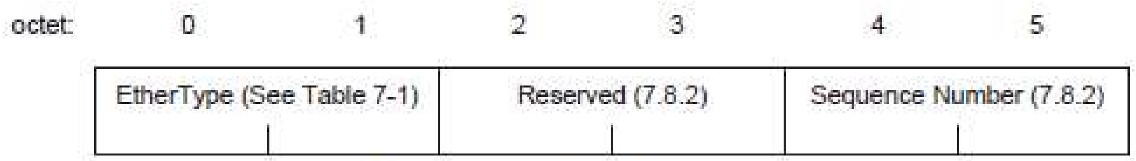


Figure 7-4—R-TAG format

» Optional feature in CB: HSR Sequence Tags and PRP Sequence Trailers

- 802.1CB-compliant coding of HSR and PRP tags not supported yet by test equipment

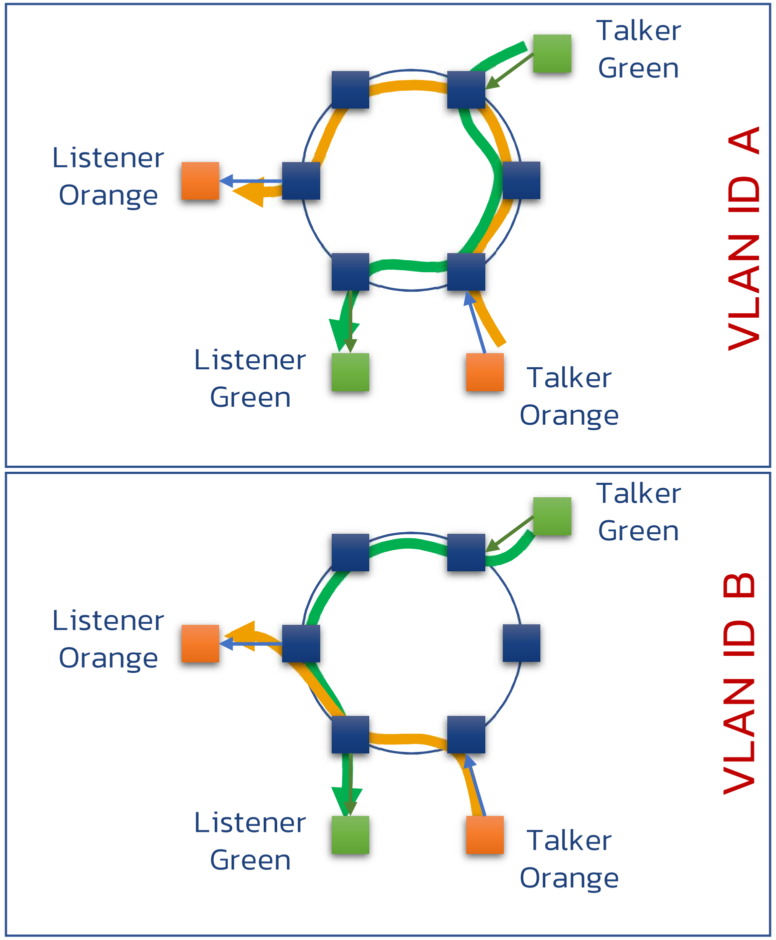
SoCe XILINX

FRER: Frame Replication and Elimination for Reliability

Specification Overview	Implementation

Two split streams form a compound stream

- Same DMAC Address for a Listener
- Different VLAN ID for redundant flows
- Individual forwarding rules for each split stream
- The Redundancy Tag (R-TAG) defines the sequence of frames



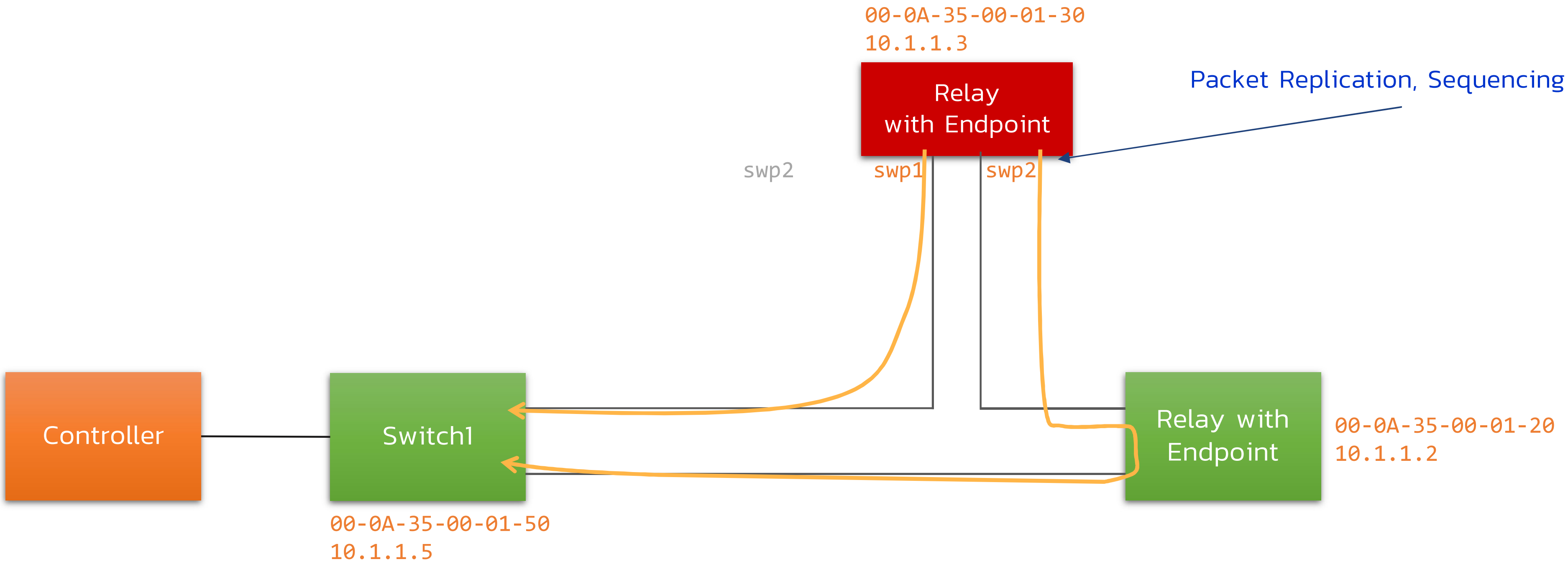
Stream Identification in each node

FRER Member Memory

- Identifies which split stream belong to a compound stream
- Specifys physical port over which a split stream is accepted
- Configures sequence recovery behavior

SoCe XILINX

Data Flow in SoC-e + Xilinx test application



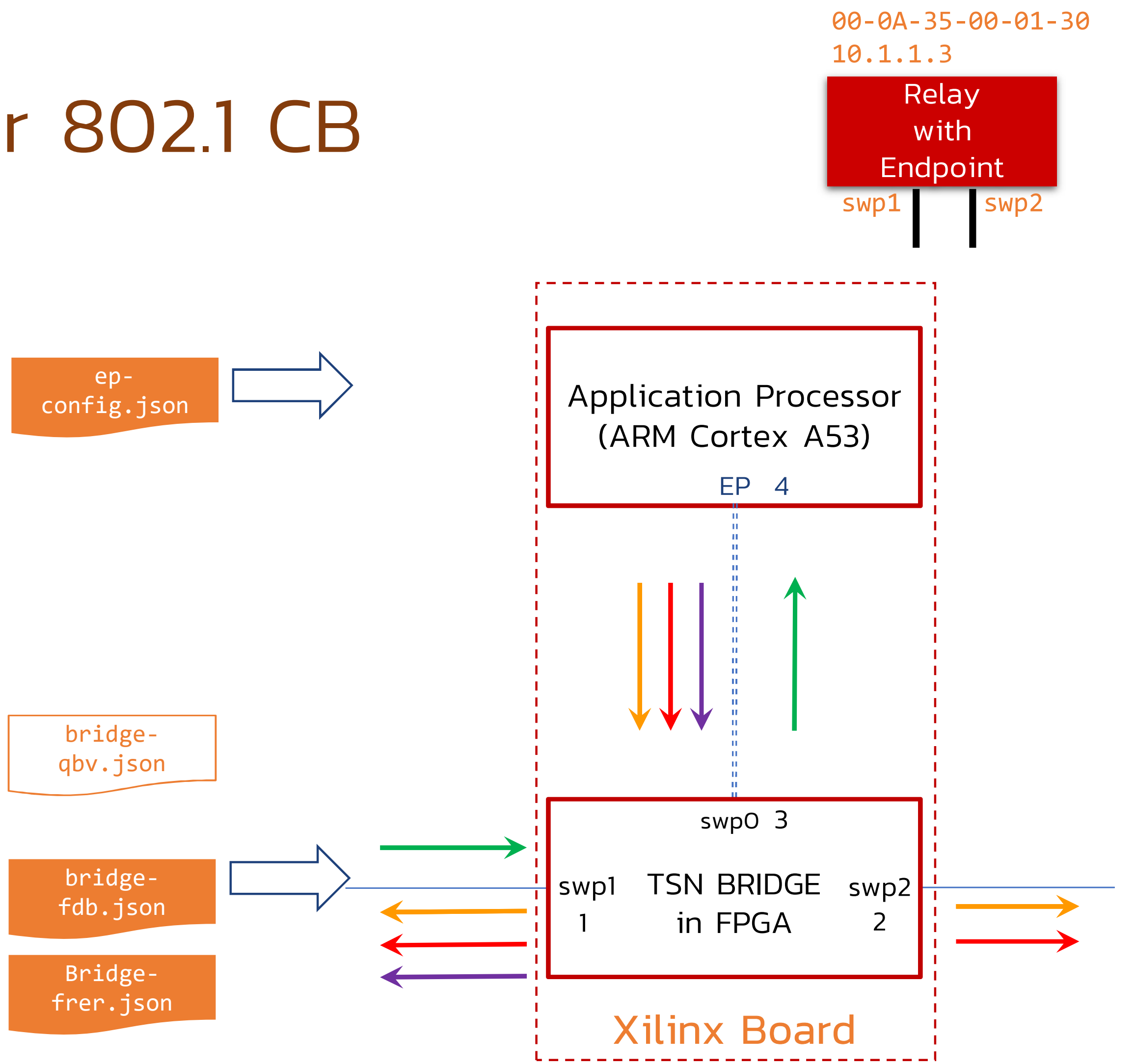
Relay configuration for 802.1 CB

Stream Identification with IP Interception
DMA configuration
Scheduler configuration

Qbv gate states for all flows and all ports

Forwarding table entries for all flows

CB/redundancy configuration for all flows



SoCe XILINX

Endpoint configuration for 802.1 CB

MAC and VLAN Assignment

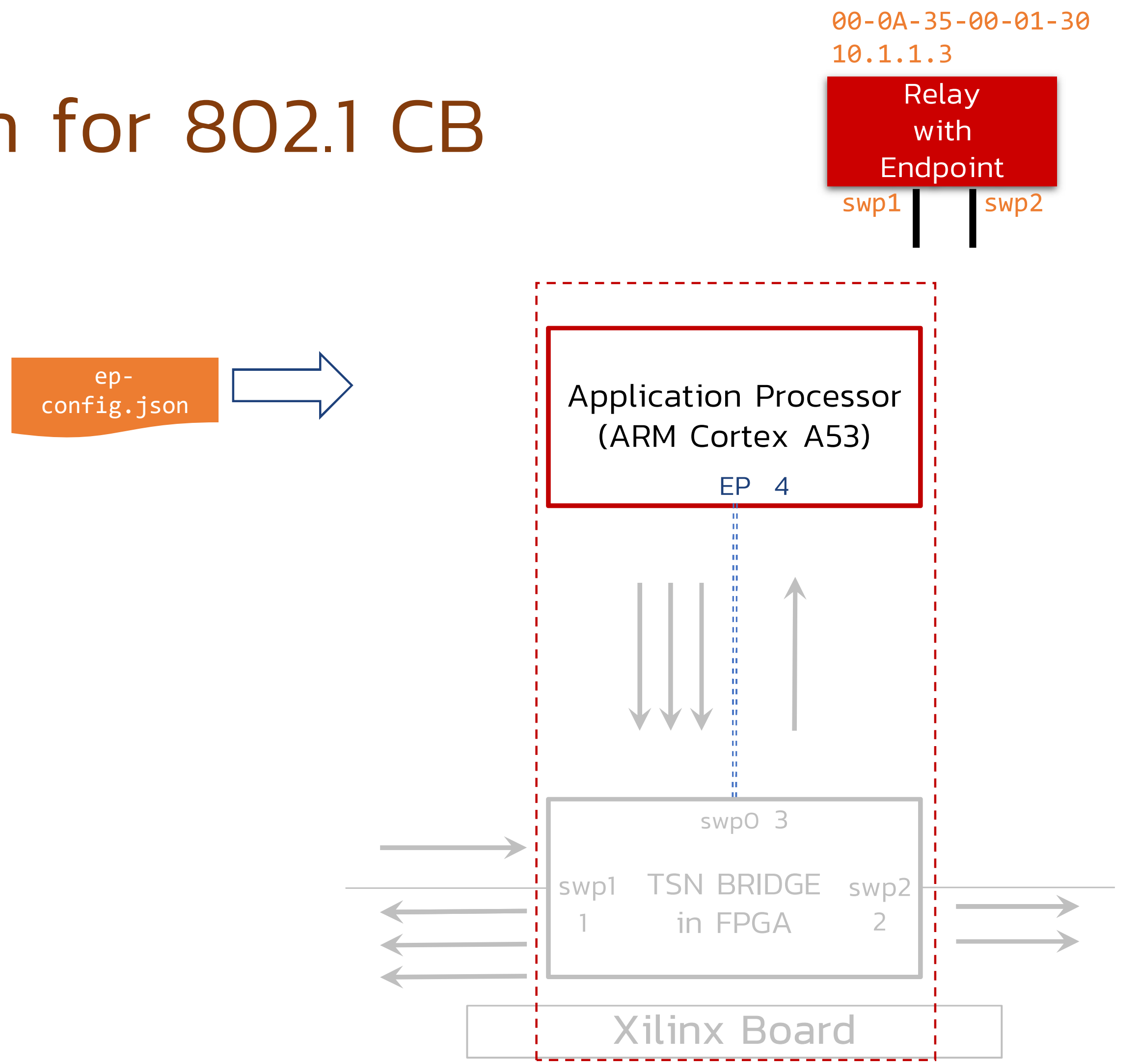
```
"ieee802-mac-addresses": {
   "source-mac-address": "00-0A-35-00-01-30",
   "destination-mac-address": "00-0A-35-00-01-50"
                         }
"ieee802-vlan-tag": {
   "priority-code-point": 4,
   "vlan-id": 4
                    }
```

IP Interception

```
"ipv4-tuple": {
   "source-ip-address": "10.1.1.3",
   "destination-ip-address": "10.1.1.5",
   "dscp": 0,
   "protocol": 17,
   "source-port": 0,
   "destination-port": 10351
               }
```

Schedule

```
"time-aware-parameters": {
   "duration": 4288,
   "max-frames-per-interval": 1,
   "admin-cycle-time": 10000000
                          }
```



SoCe XILINX

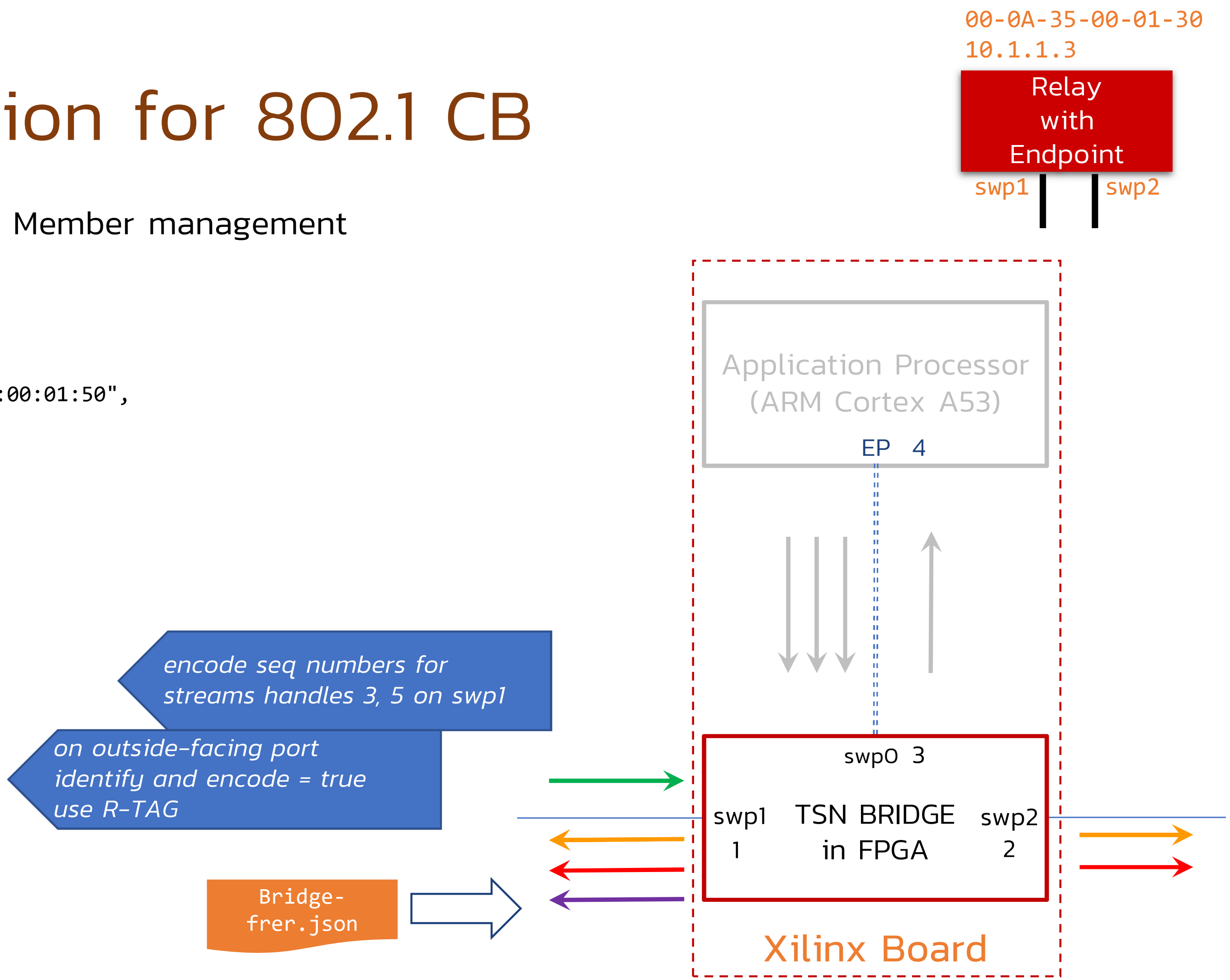
Relay configuration for 802.1 CB

Define compound streams for FRER Member management

```
"stream-identity-table": {
  "tsn-stream-id-entry": {
     "tsn-stream-id-handle": 3,
     (...)                  },
  "tsn-stream-id-parameters": {
     "tsn-cpe-null-down-dest-mac": "00:0a:35:00:01:50",
     "tsn-cpe-null-down-vlan": 4
                                 }
                          },
```

Sequence Identification

```
"sequence-identification-table": {
  "frer-seq-enc-entry": {
     "frer-seq-enc-index": 1,
     "frer-seq-enc-stream-list": [ 3, 5 ],
     "frer-seq-enc-port": 1,
     "frer-seq-enc-direction": true,
     "frer-seq-enc-active": true,
     "frer-seq-enc-encaps-type": 1
                         },
     {
     "frer-seq-enc-index": 2,
     "frer-seq-enc-stream-list": [ 3, 5 ],
     "frer-seq-enc-port": 2,
     (...)
     }
                                  },
```



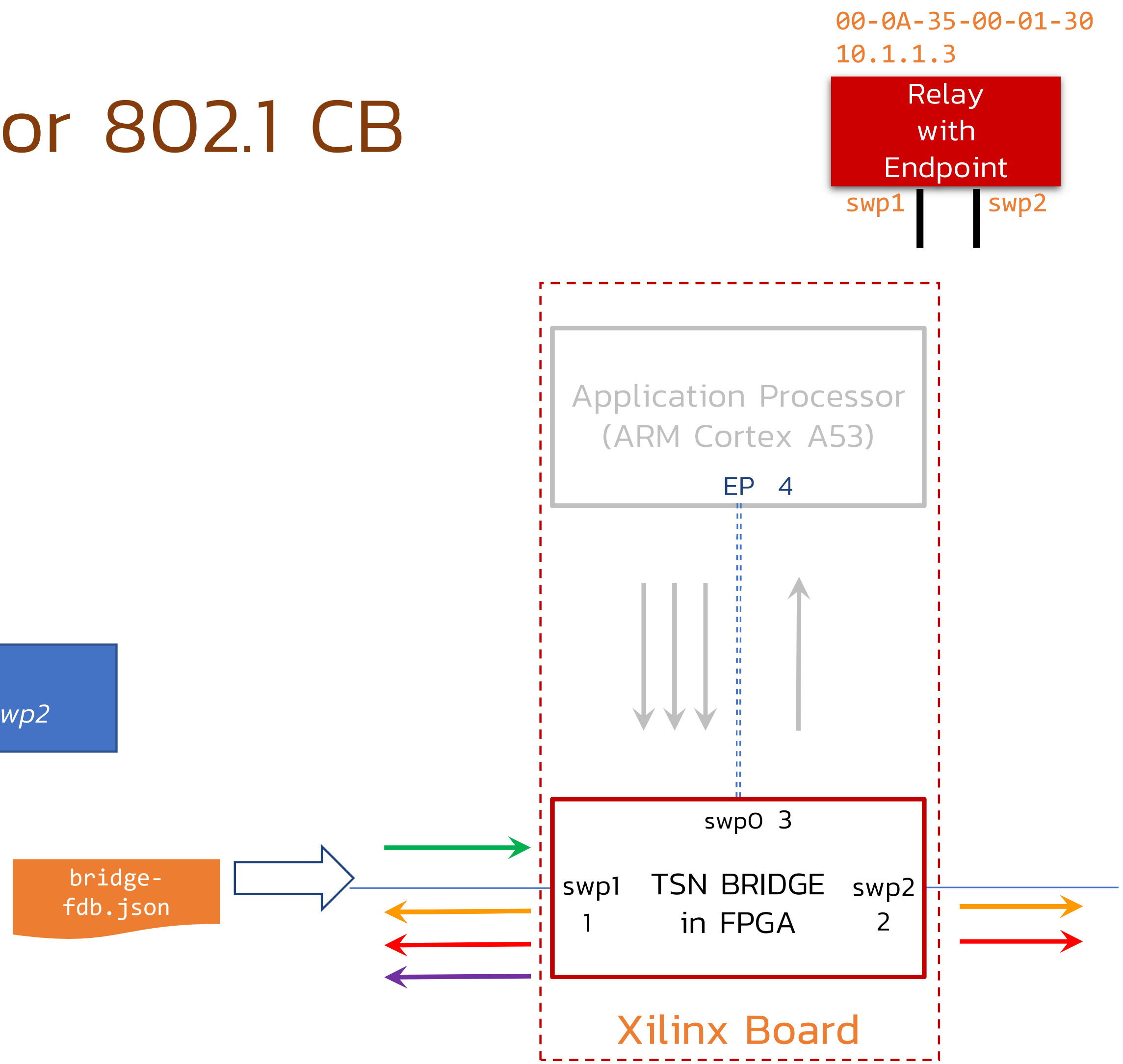
SoCe XILINX

Switch configuration for 802.1 CB

Forwarding and Replication

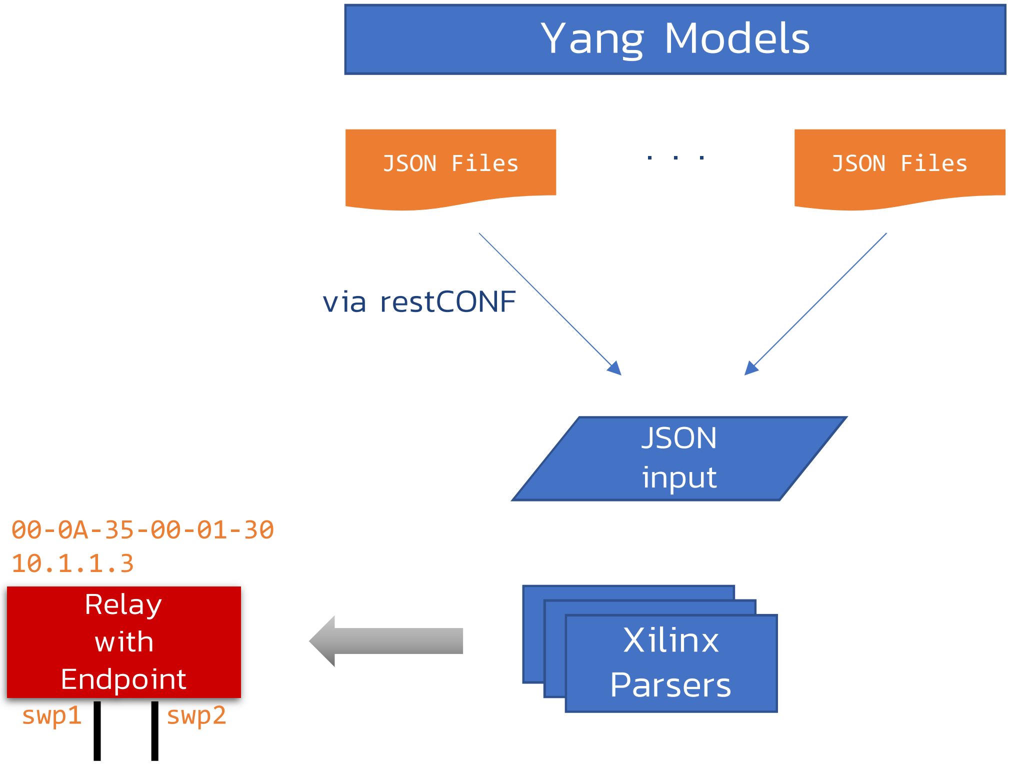
```
"forwarding-entry": [
 {
  "stream-id": "00-0A-35-00-01-30:EC-C1",
  "destination-mac-address": "00:0a:35:00:01:50",
  "vids": "4",
  "port-map": [
    {
     "port-ref": 3,
     "port-dest": [1, 2]
    }
              ]
  },
```

swp0 is source port
forward it to swp1 and swp2



SoCe XILINX

YANG Models for CB



- YANG Models for IEEE 801.2CB are taken from General Electric Global Research Center in Niskayuna, NY
  - ep-config@2019-03-04.yang
  - ge-fdb@2019-03-04.yang
  - ge-frer-simplified@2019-03-06.yang
  - ge-qbv.yang
  - ieee802-dot1q-bridge.yang
  - ieee802-dot1q-tsn-types.yang
  - ieee802-dot1q-types.yang
  - ietf-inet-types@2013-07-15.yang
  - ietf-interfaces.yang
  - ietf-yang-types@2013-07-15.yang
- Models are supported by GE's CNC
- Parsers on Python developed by Xilinx to automate configuration of relay
  - bridge-qbv.py
  - ep-qbv.py
  - fdb-parser.py
  - frer-parser.py
  - ipic-parser.py

SoCe XILINX

SoCe

How?

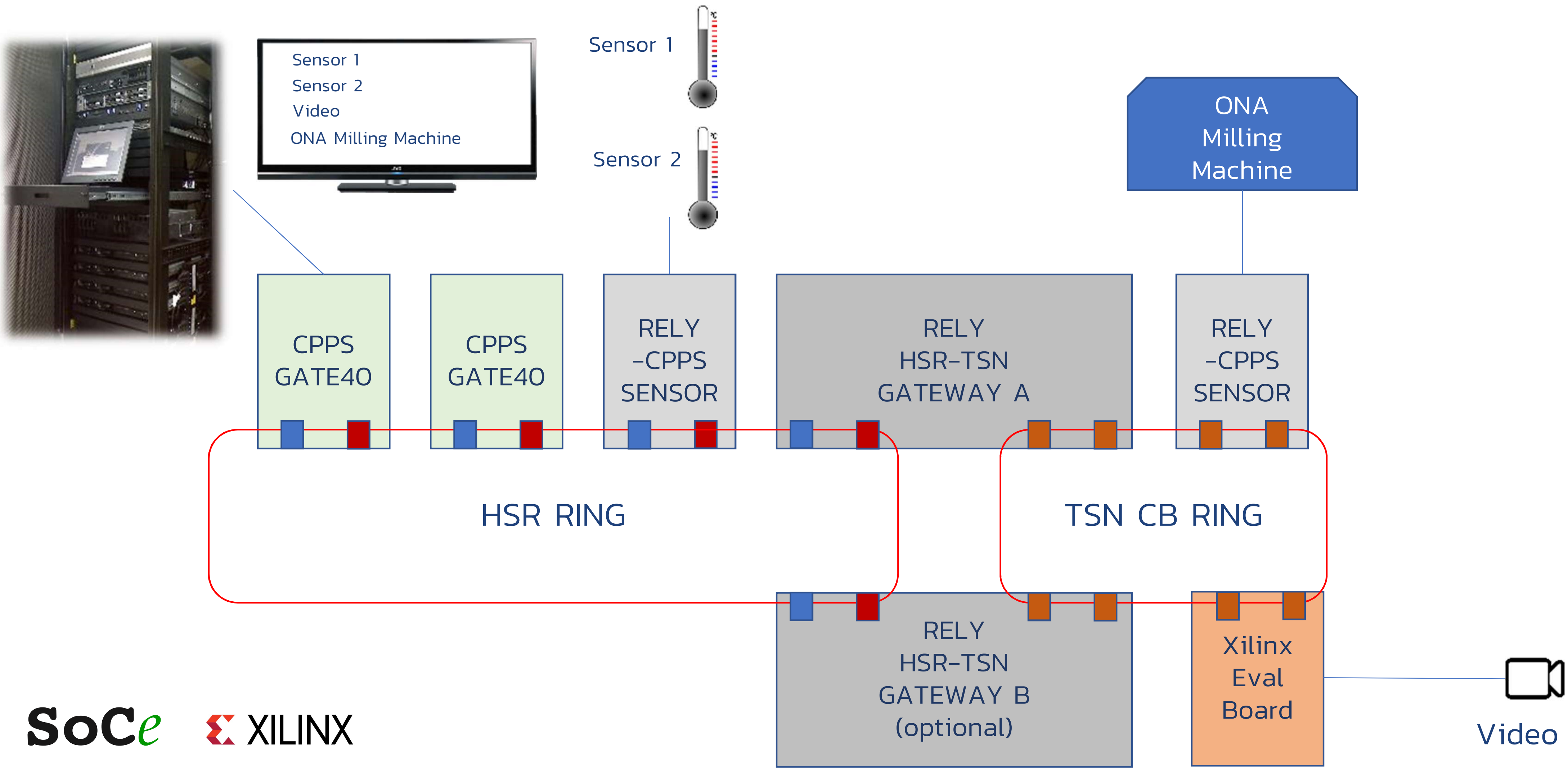
SoCe XILINX

Center for the Aeronautics Advanced Manufacturing

'Manufacturing Readiness Levels' 6-7

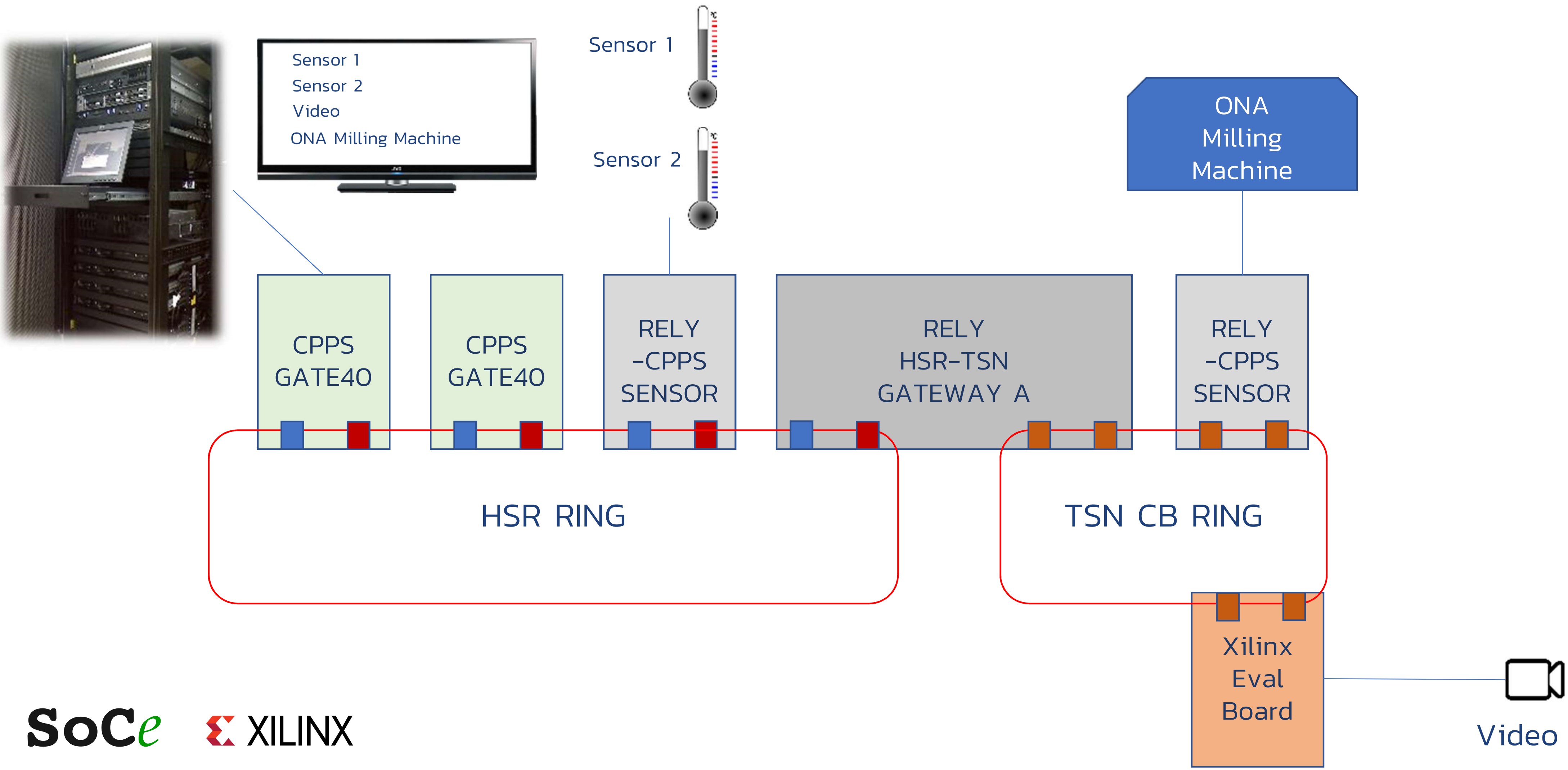
Cutting-Edge machinery: CNC, Robotics, additive printing, etc.

CFAA TSB CB Pilot – Block Diagram



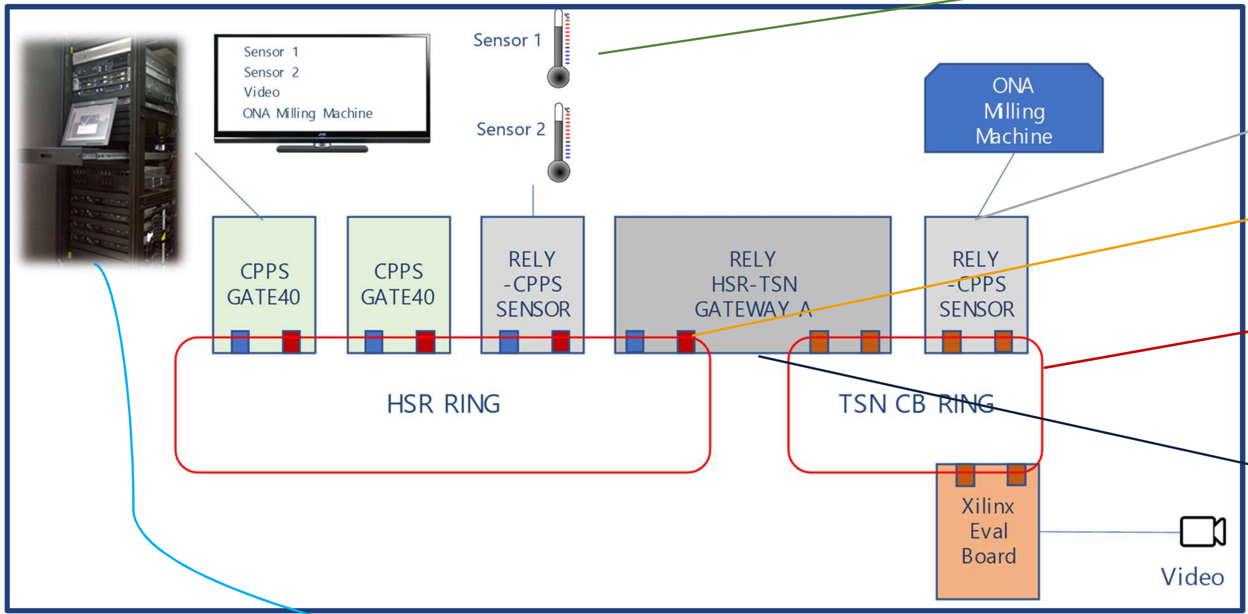
SoCe XILINX

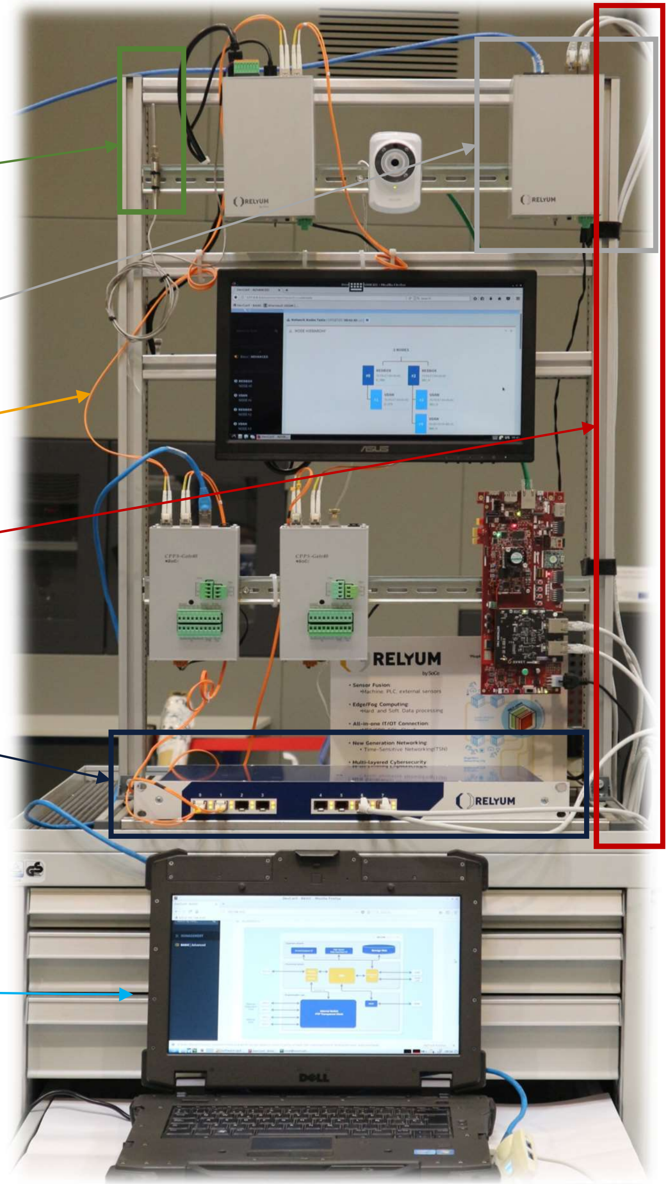
CFAA TSB CB Pilot – Block Diagram



SoCe XILINX

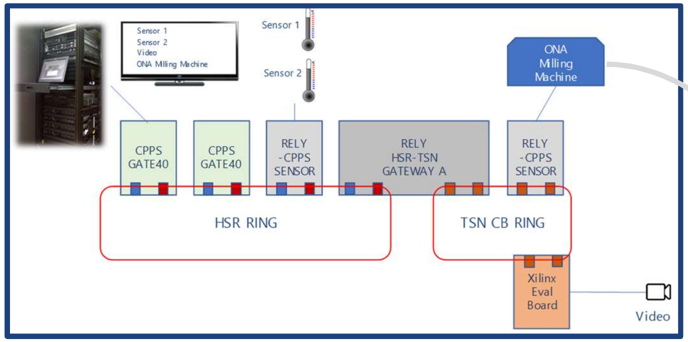
CFAA TSB CB Pilot - Elements





SoCe XILINX

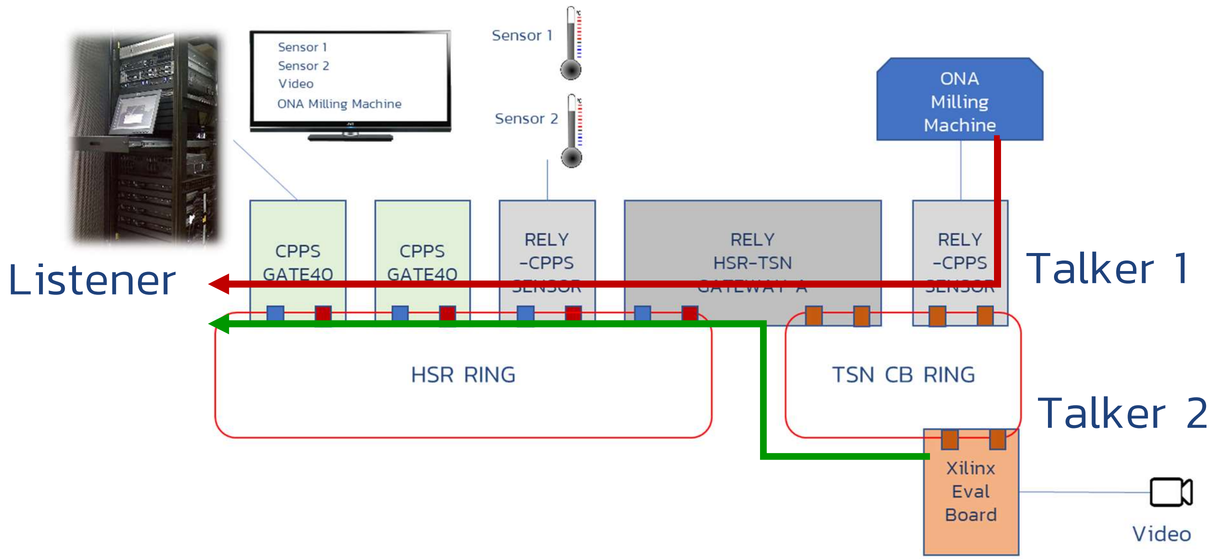
CFAA TSB CB Pilot – Elements



SoCe XILINX

CFAA TSB CB Pilot – Starting considerations

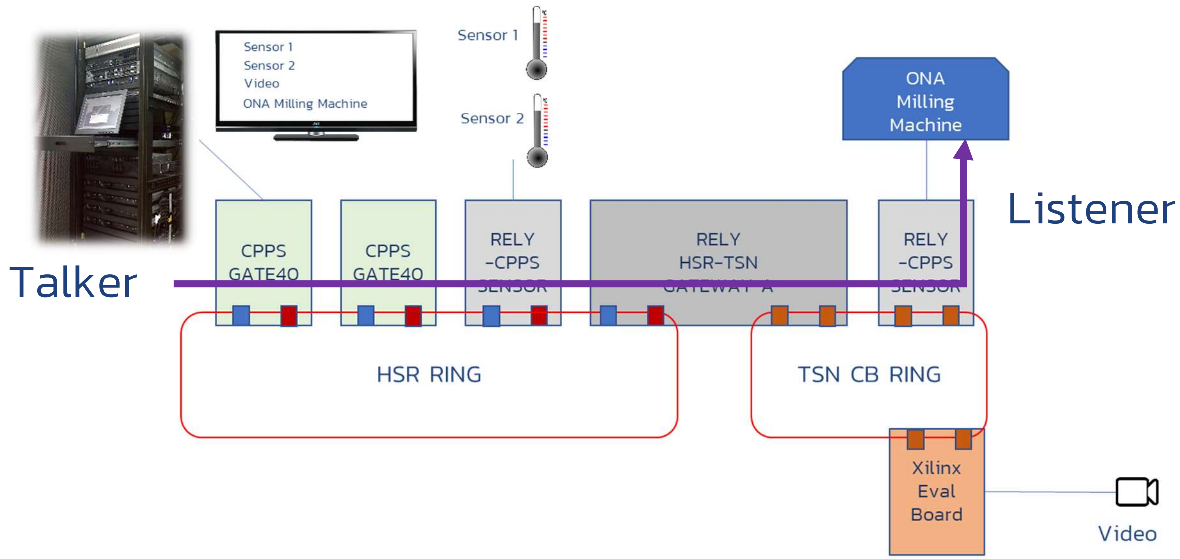
- Functional description:
  - Talkers:
    - RELY-CPPS sensor connected to ONA Milling Machine
    - Xilinx Eval Board connected to video camera
  - Listener:
    - GATE40 connected to control PC



SoCe XILINX

CFAA TSB CB Pilot – Starting considerations

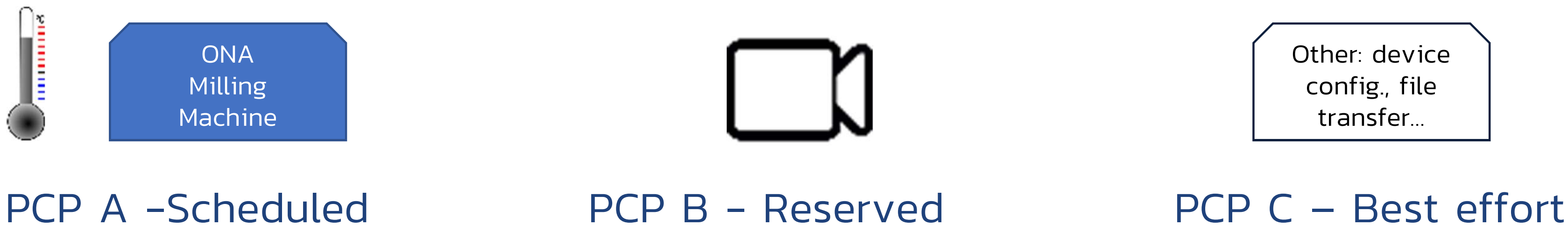
- Functional description:
  - Talkers:
    - GATE40 connected to control PC
  - Listener:
    - RELY-CPPS sensor connected to ONA Milling Machine



SoCe XILINX

CFAA TSB CB Pilot – Starting considerations

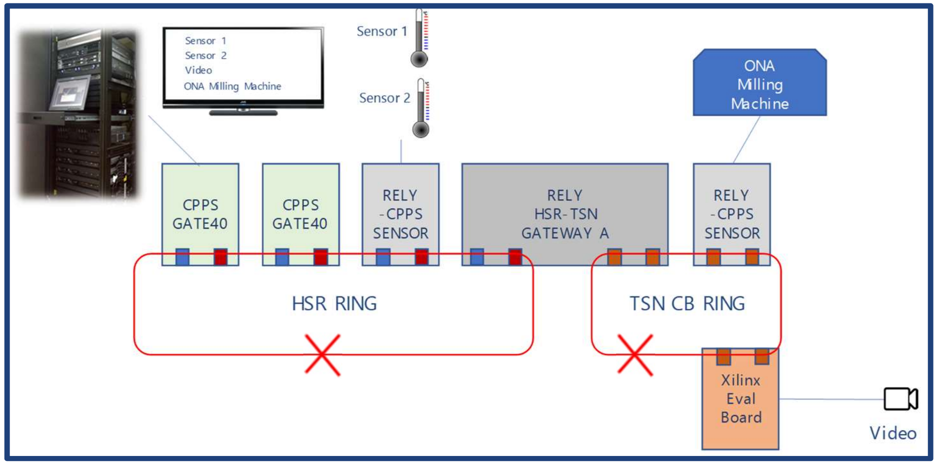
- Traffic classification
  - Sensor/CNC information: **Scheduled traffic**. VLAN A, PCP A.
  - Real-time video stream: **Reserved traffic**. VLAN B, PCP B.
  - Injected traffic and general traffic: **Best-effort traffic**. VLAN C, PCP C.



SoCe XILINX

CFAA TSB CB Pilot – Target

- Network failure behaviour on different situations:
  1. HSR Ko, TSN Ok
  2. HSR Ok, TSN Ko
  3. HSR Ko, TSN Ko



Check no packet loss / Holdover recovery = 0

SoCe XILINX

CFAA TSB CB Pilot – Test constraints

- Traffic classification: use of VLANs in HSR
- Merge *non time-sensitive* network (HSR) and *time-sensitive* network (TSN)
  - » No time control in the transmission for transferring HSR to TSN (Qbv)
  - » Buffer overflow causes packet loss
- Decoupled IEEE 802.1CB testing required
  - » RESULTS: No packet loss

CFAA TSB CB Pilot – To Do

1. Latencies and data bandwidth measurements
2. Explore other mode-of-failure
3. Set-up extension to avoid Single-point-of-Failure

Summary

- Current high-availability Ethernet solutions lack full determinism support
- IEEE 802.1CB fulfils the technical requirements of critical sectors
- In the CFAA pilot, it has been tested:
  - The use of CB Yang models for configuration
  - The interoperability between two TSN technology providers
  - The simultaneous operation of HSR and TSN rings

SoCe XILINX

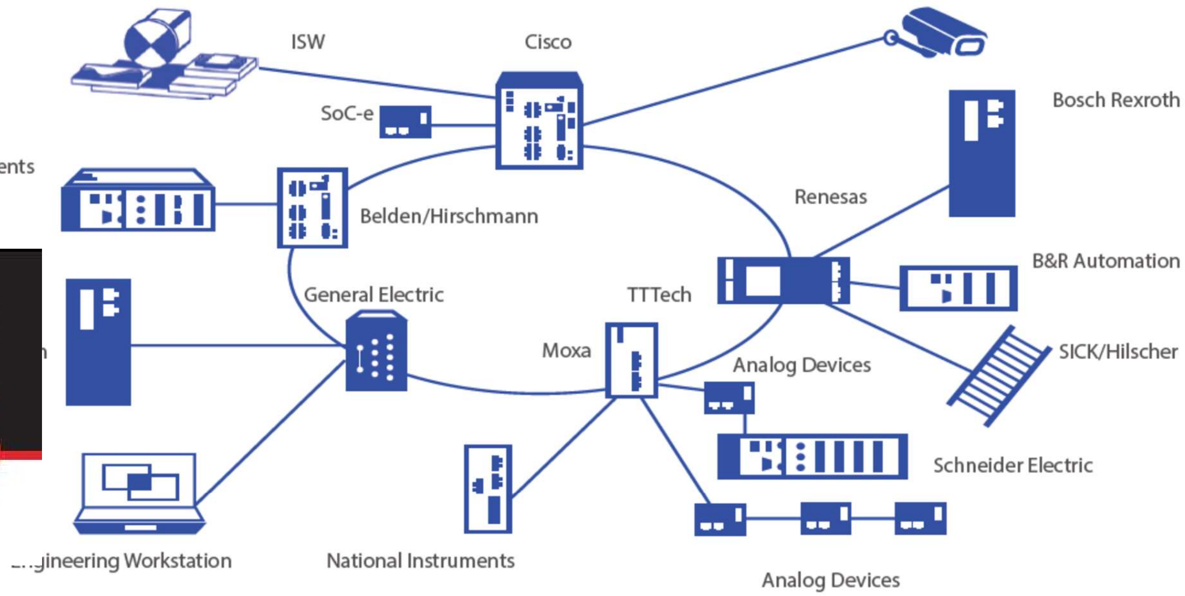
About SoC-e

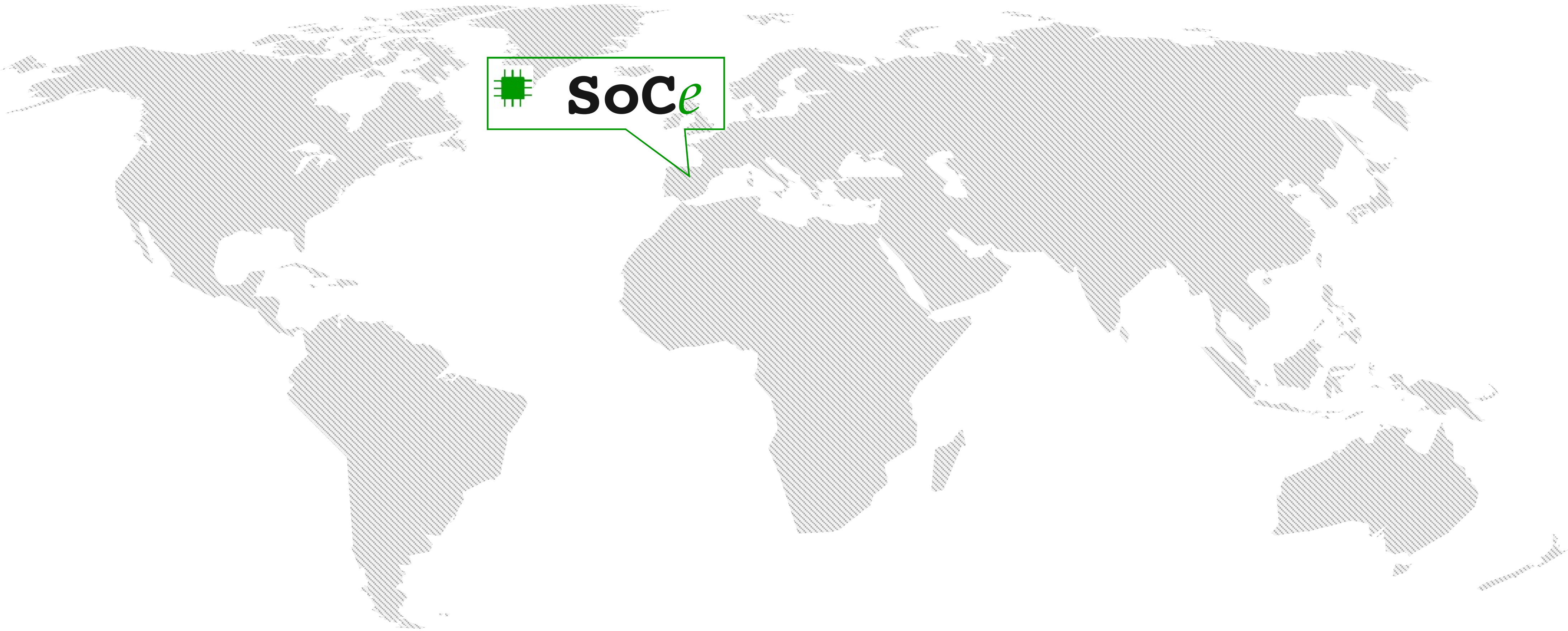
- Provides IP cores, modules and end-equipment for
  - Networking:
    - Deterministic Ethernet:
      - MTSN, D-HSR
    - High-availability Ethernet:
      - HSR/PRP, MRP, S-HSR
    - Time-aware Ethernet:
      - MES, UES, Field-buses
  - Synchronization:
    - IEEE1588, IRIG-B
  - Real-time Cyber-security

SoCe XILINX

About SoC-e

Time Sensitive Networking (TSN) is key for industrial applications such as process and machine control where low communication latency and minimal jitter are critical to meeting closed loop control requirements. TSN is the first fully open, standard and interoperable way to fulfill these requirements.





www.soc-e.com

info@soc-e.com

T.+34 944 420 700
info@soc-e.com

Edificio Udondo, 6° planta
Avd. Ribera de Axpe, 50
48950 Erandio · Bizkaia | SPAIN