Combine Operational Technology (OT) Traffic and Best Effort (IT) Traffic on a Single Network with TSN 802.1Qbv

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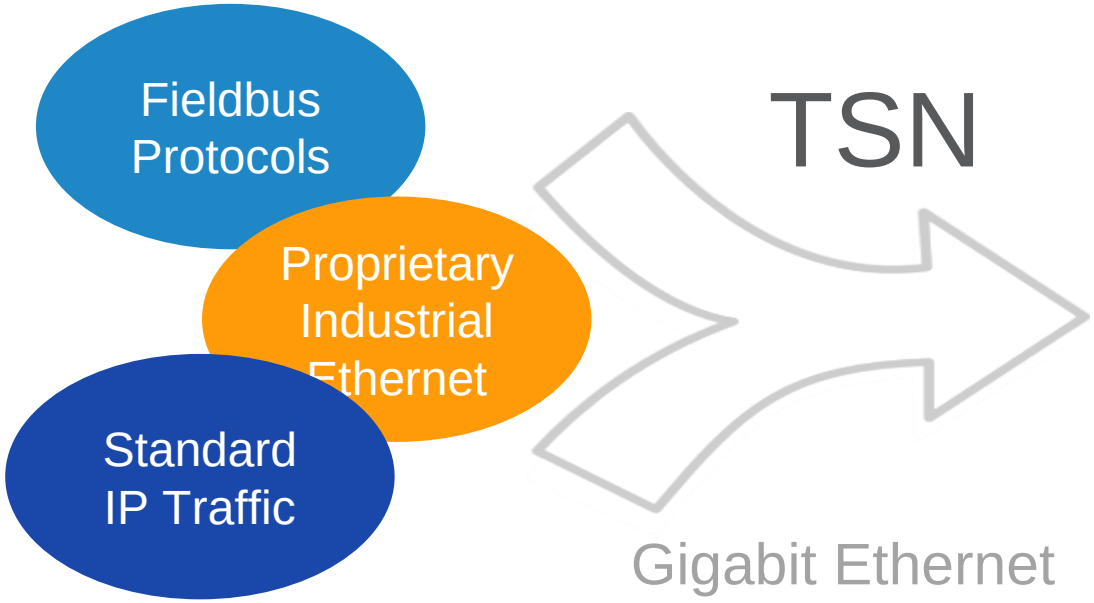
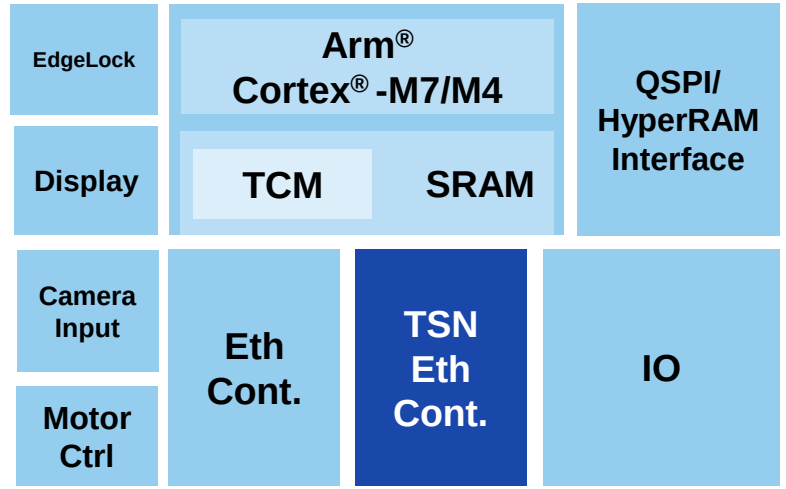
SECURE CONNECTIONS FOR A SMARTER WORLD

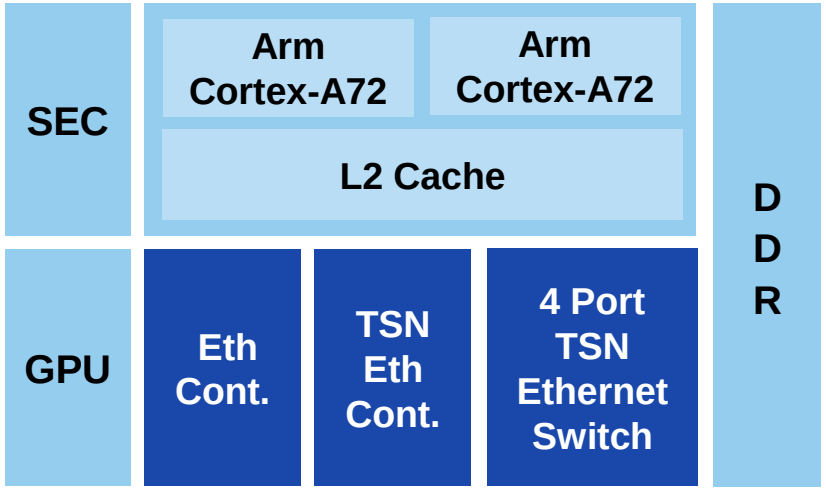
EXTERNAL

EMBEDDED TIME-SENSITIVE NETWORKING (TSN)

- Converge OT and IT traffic in a single network
- Determinist Ethernet at gigabit speeds
- Reduce network delays, improve robustness
- Embedded in Multi-processor and Crossover SoCs



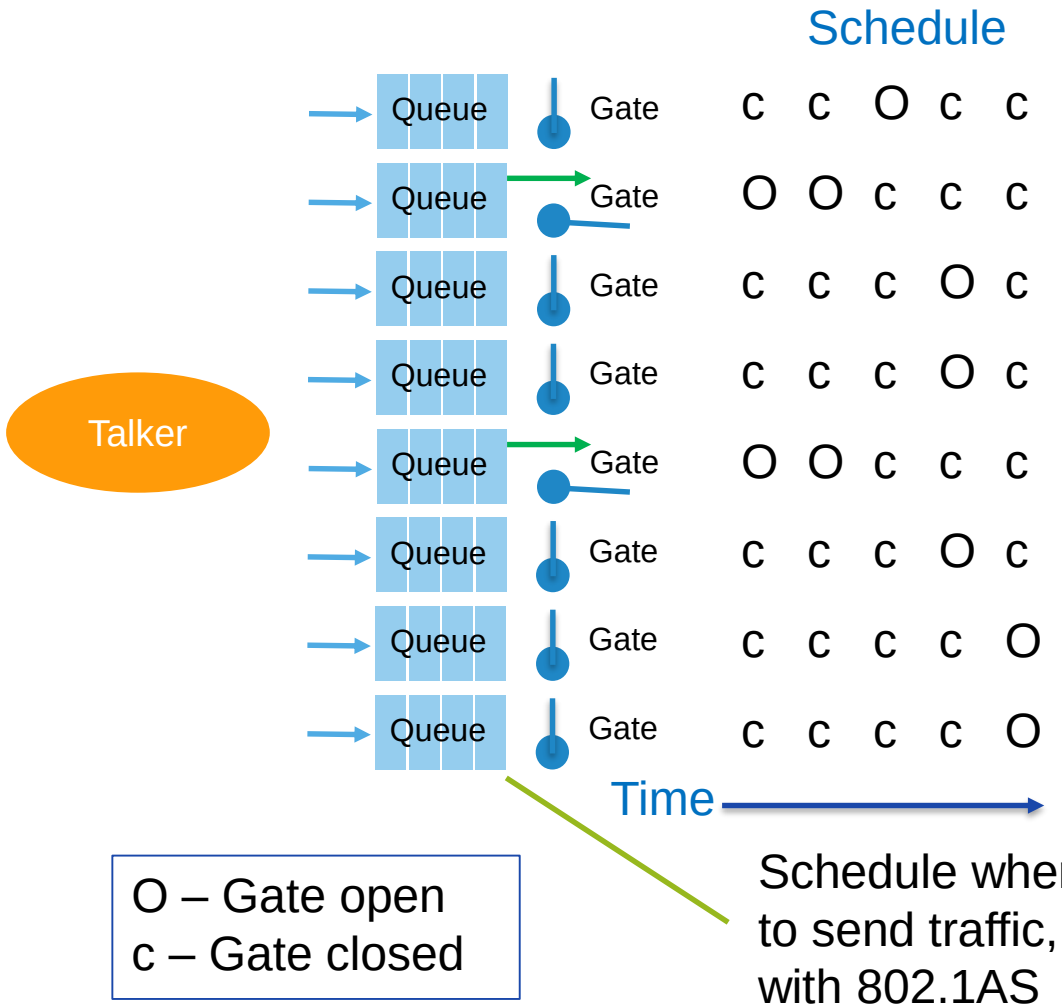




TSN STANDARDS FOR INDUSTRY

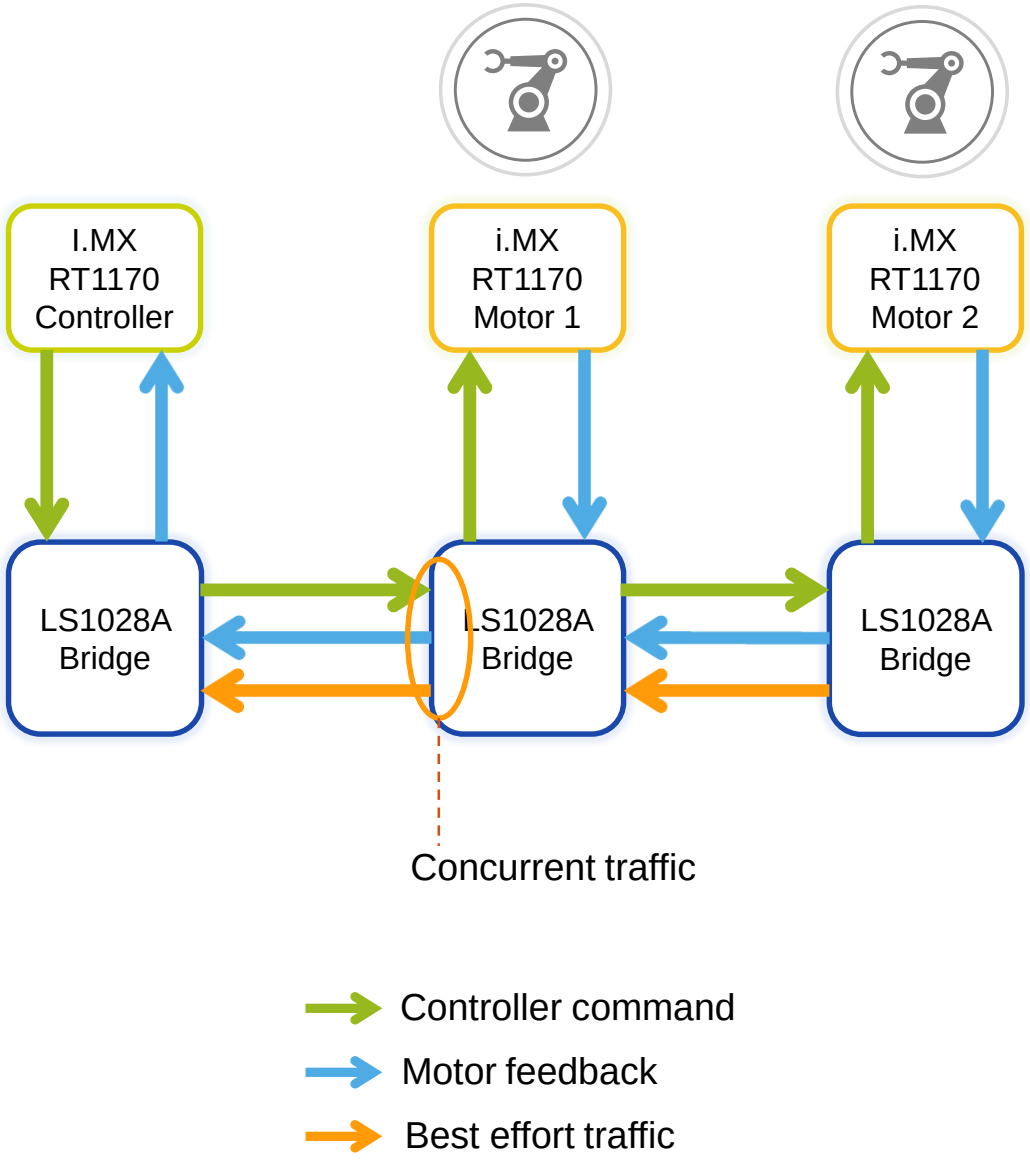
Standard	Description
802.1Qbv	Scheduled Traffic
802.1Qav	Forwarding and Queuing Enhancements
802.1Qbu, 802.3BR	Frame Preemption
802.1CB	Frame Replication and Elimination for Reliability
802.1Qci	Per-stream filtering and policing
802.1AS	Timing and synchronization for Time-Sensitive Applications

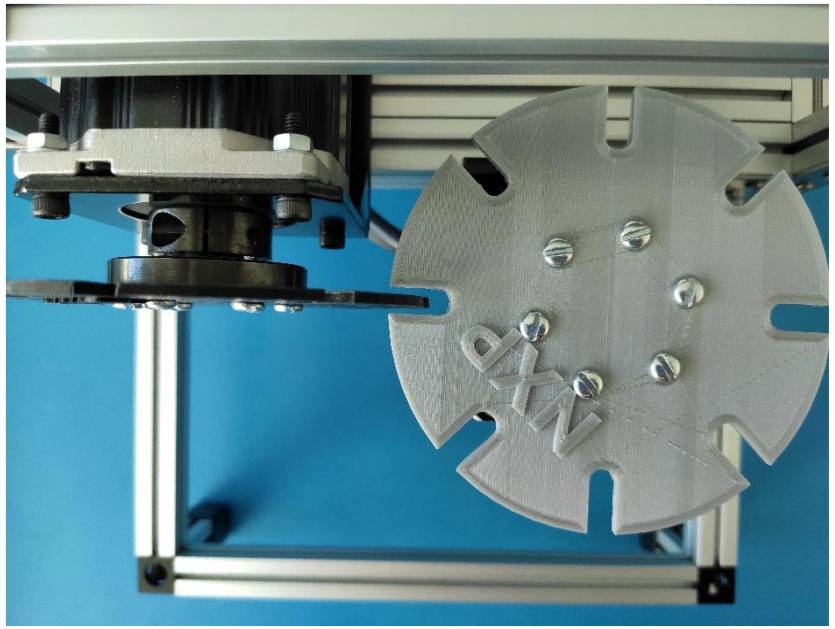
802.1.QBV – TIME AWARE SHAPING



- Different priority traffic allocated to each queue
- Queue gate schedule synchronized to global time
- 8 Queues available

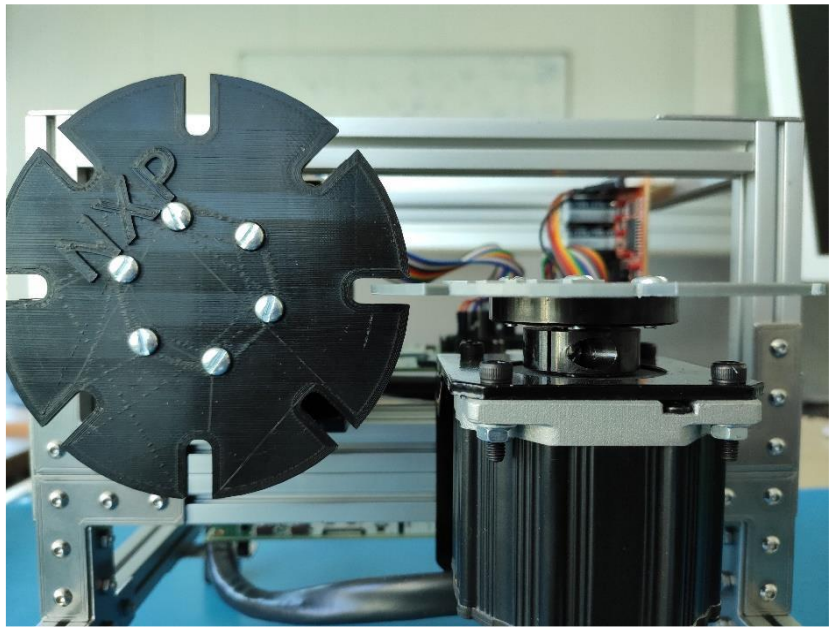
WHY DO WE NEED TIME-AWARE SHAPING?



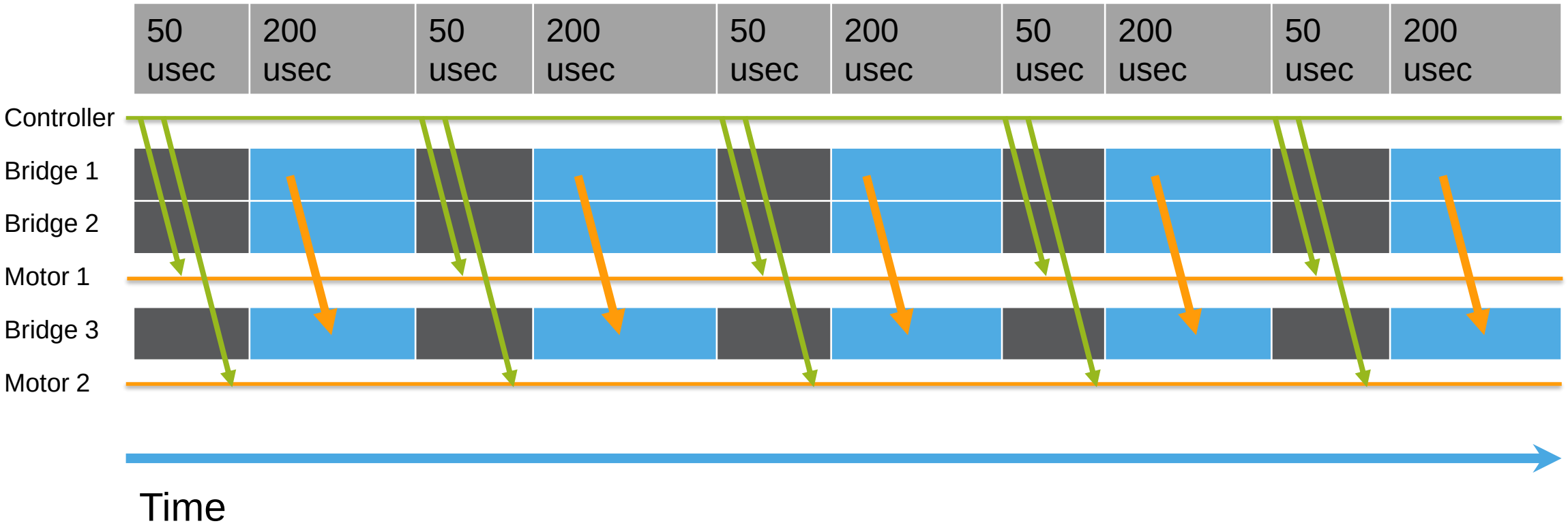


Motor 2

Motor 1



TIME-BASED SCHEDULING OF ETHERNET TRAFFIC

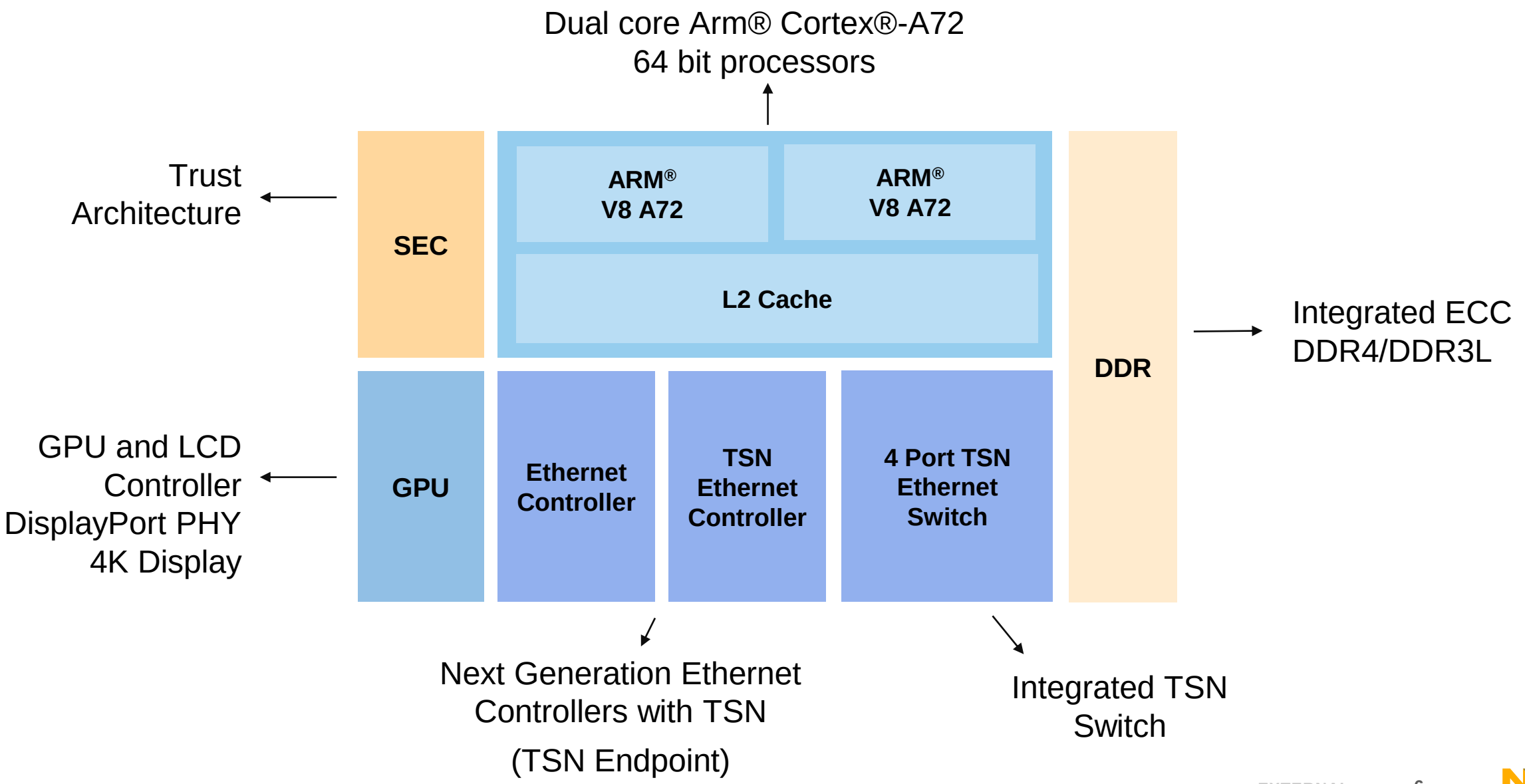


Simple example with 2 traffic classes

Critical Control Traffic

Best Effort Traffic

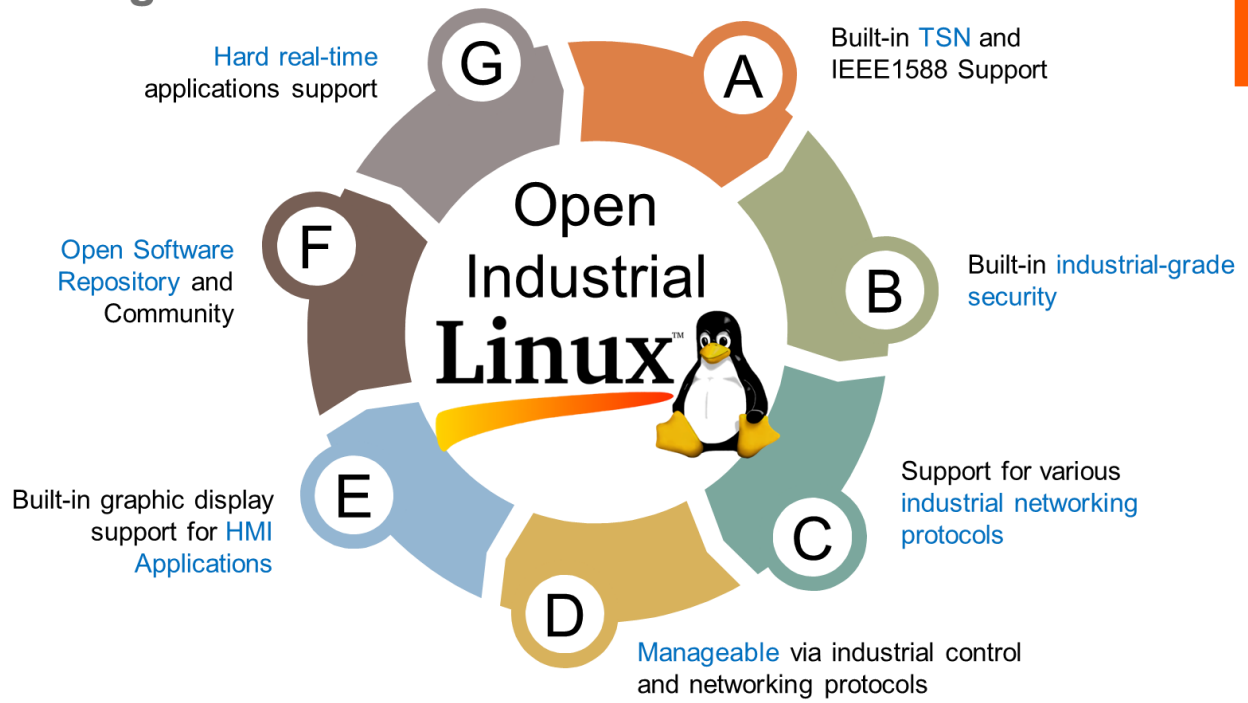
LAYERSCAPE LS1028A – INDUSTRY READY



OPENIL

OPEN INDUSTRIAL LINUX

OpenIL.org



LS1028A

- Deterministic Computing
  - Xenomai Linux
  - Bare Metal Framework
- Open Source support for TSN
- Open source support for timing synchronization (PTP, gPTP)

ETHERNET CONTROLLER TRANSMIT QUEUE SELECTION

- The ENETC driver probes the hardware capability of each ENETC port in order to determine the number of available transmit and receive rings.
- For the eno0 interface, where 16 rings are available, the driver reserves only 8 for use, and 8 for the Virtual Station Interface (VSI).
- To view on which transmit ring a frame is steered to, the ethtool counters may be consulted:

```
$ ethtool -S eno0 | grep 'Tx ring'
Tx ring 0 frames: 0
Tx ring 1 frames: 6
Tx ring 2 frames: 28
Tx ring 3 frames: 1
Tx ring 4 frames: 0
Tx ring 5 frames: 1
Tx ring 6 frames: 70
Tx ring 7 frames: 2
```

ETHERNET CONTROLLER TRANSMIT QUEUE SELECTION

- By default all transmit rings are of equal priority (0).
- The TSN features use the hardware priority, not the Tx ring number.
- In order to assign a priority to each transmit ring, install a root qdisc with a configurable priority mapping, such as tc-mqprio:

```
$ tc qdisc del dev eno0 root
$ tc qdisc add dev eno0 root handle 1: mqprio num_tc 8 map 0 1 2 3 4 5 6 7 hw 1
```

- Above is a one-to-one mapping between Tx ring index and hardware priority.
  - The Tx ring is selected based on skb (Linux packet) priority (configured by applications via the SO_PRIORITY socket ioctl API).
  - Any other priority mappings are possible.

ETHERNET CONTROLLER TRANSMIT QUEUE SELECTION

- If applications do not use the SO_PRIORITY API, it is possible to attach tc filters on the root qdisc and edit their skb priority such that they exit the system on the correct transmit ring.

```
# https://www.tldp.org/HOWTO/Adv-Routing-HOWTO/lartc.qdisc.filters.html

$ tc qdisc add dev eno0 clsact

# ICMP is protocol 1 according to /etc/protocols, and 0xff is the matching mask
$ tc filter add dev eno0 egress prio 1 u32 match ip protocol 1 0xff action skbedit priority 5

# This matches iperf3 traffic sent to default port 5201
$ tc filter add dev eno0 egress prio 1 u32 match ip dport 5201 0xffff action skbedit priority 2

# This matches L4 PTP
$ tc filter add dev eno0 egress prio 1 u32 match ip dst 224.0.1.129/32 action skbedit priority 7
```

ETHERNET CONTROLLER TIME AWARE SCHEDULING (IEEE 802.1QBV)

- A typical Qbv configuration is applied on an ENETC port using the following workflow:

```
$ cat > qbv0.txt << EOF
t0 00000001 50000
t1 00000010 200000
EOF
$ tsntool qbvset --device eno0 --entryfile qbv0.txt --
enable
```

- Create a GCL with two entries (t0 and t1). These names do not bear any significance.
- The t0 GCL entry opens gate 0 and closes gates 1, 2, 3, 4, 5, 6, 7. It is active for 50,000 nanoseconds.
- Then the t1 GCL gets invoked, which closes gate 0 and opens gate 1. The other gates are still closed. The active time for t1 is 200,000 nanoseconds, then t0 is executed again by the ENETC port.

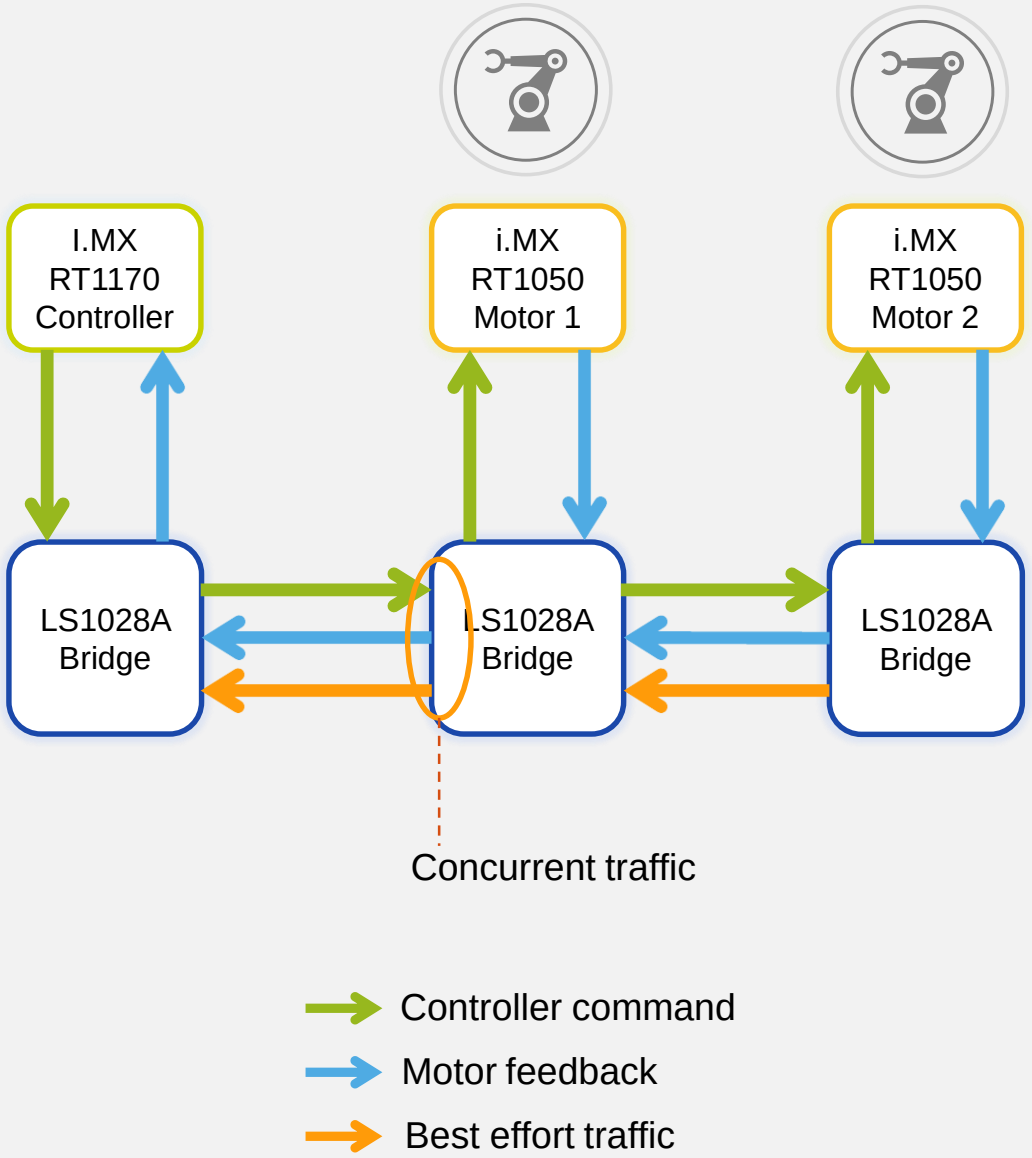
802.1QBV SWITCH CONFIGURATION – PORT BASED PRIORITY

```
bash /etc/tsn/tsntool-switch-raw write 0xc0 --device port3 --
block ana --group port --reg qos_cfg
bash /etc/tsn/tsntool-switch-raw write 0xe0 --device port2 --
block ana --group port --reg qos_cfg
tsntool qbvset --device swp4 --entryfile /etc/tsn/qbv.txt


[qbv.txt]
t0 10000001b 50000
t1 01000001b 150000
```

Assign port 2 to QoS class 7, port 3 to QoS class 6
QoS class 7 opens for 50 usec every 150

Distributed Motor Control Over TSN Featuring i.MXRT1170 MCUs and LS1028A Applications Processor



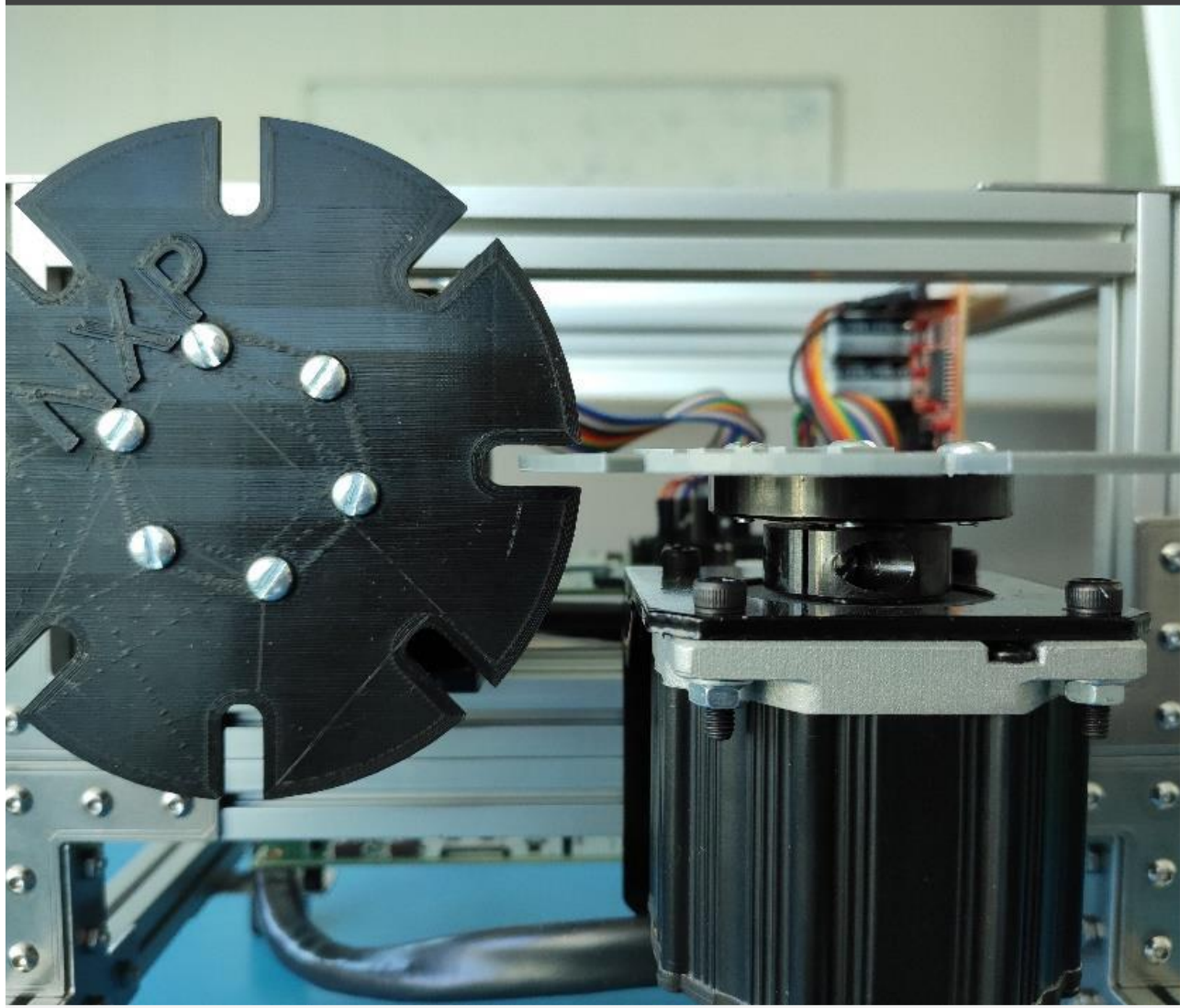
- 802.1AS for network time synchronization
- 802.1Qbv for low latency and low jitter transport
- i.MX RT1170 Slaves driving PMSM motors with100µs Field Oriented Control loop
- i.MX RT1170 Controller running position and velocity control loops with 250µs network cycle
- LS1028A acting as TSN bridges
- Isochronous scheduling shifted by 125µs between controller and slaves


TSN motor control with
i.MXRT1170/LS1028
Distributed motor control using Ethernet/TSN (Time Sensitive Networking)
802.1AS for network time synchronization
802.1Qbv for guaranteed transport latency and jitter
i.MXRT1170 Slaves driving PMSM motors using a 100µs Field Oriented Control loop
i.MXRT1170 Controller running position and velocity control loops with a 250µs network cycle
LS1028 acting as TSN bridges
TSN motor control with
i.MXRT1170/LS1028
M1
M2
C
B
B
B
Concurrent traffic
Controller command
Motor feedback
Best effort
www.nxp.com

BENEFITS FOR TIME-AWARE SHAPING 802.1QBV

- Provide low latency and low jitter transport for time-sensitive Ethernet traffic streams
- Reserve bandwidth for Ethernet traffic streams
- Share a single network between OT and IT devices
- Available on NXP Layerscape and i.MX applications processors, as well as i.MX RT crossover MCUs
- Open source and turnkey commercial software available

TSN AT NXP



ADDITIONAL RESOURCES

Product Pages

- LS1028A https://www.nxp.com/LS1028A
- i.MX RT1170 https://www.nxp.com/IMXRT1170
- i.MX RT1050 https://www.nxp.com/IMXRT1050

Commercial Software

- AVB Software https://www.nxp.com/design/software/embedded-software/audio-video-bridging-software:AVB-SOFTWARE

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