

Open Industrial User Guide



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Chapter 1

Introduction

This document provides a complete description of Open Industrial Linux (OpenIL) features, getting started on OpenIL using NXP supported OpenIL platforms, and the various software settings and compilation steps involved. It describes in detail the industrial features such as NETCONF/YANG, TSN, Xenomai, Preempt-RT, IEEE 1588, and SELinux. It also includes detailed steps for running the demos for example: Selinux demo, 1-board TSN Demo, 3-board TSN demo, 4G-LTE demo, OTA implementation, BLE Click Board, and BEE Click Board.

1.1 Acronyms and abbreviations

The following table lists the acronyms used in this document.

Table 1. Acronyms and abbreviations

| Term | Description |
|----------|---|
| AVB | Audio Video Bridging |
| BC | Boundary clock |
| BLE | Bluetooth low energy |
| BMC | Best master clock |
| CA | Client application |
| CAN | Controller area network |
| DEI | Drop eligibility indication |
| DP | Display port |
| EtherCAT | Ethernet for control automation technology |
| ECU | Electronic Control Units |
| FMan | Frame manager |
| GPU | General Processor Unit |
| ICMP | Internet control message protocol |
| IEEE | Institute of electrical and electronics engineers |
| IETF | Internet engineering task force |
| IPC | Inter process communication |
| KM | Key management |
| LBT | Latency and bandwidth tester |
| MAC | Medium access control |
| NFC | Near field communication |
| NCI | NFC controller interface |
| NMT | Network management |
| OC | Ordinary clock |

Table continues on the next page...

Table 1. Acronyms and abbreviations (continued)

| Term | Description |
|--------|---|
| OpenIL | Open industry Linux |
| OPC | Open platform communications |
| OP-TEE | Open portable trusted execution environment |
| OS | Operating system |
| OTA | Over-the-air |
| OTPMK | One-time programmable master key |
| PCP | Priority code point |
| PDO | Process data object |
| PHC | PTP hardware clock |
| PIT | Packet inter-arrival times |
| PLC | programmable logic controller |
| PTP | Precision time protocol |
| QSPI | Queued serial peripheral interface |
| RCW | Reset configuration word |
| REE | Rich execution environment |
| RPC | Remote procedure call |
| RTT | Round-trip times |
| SABRE | Smart application blueprint for rapid engineering |
| SDO | Service data object |
| SPI | Serial periphery interface |
| SRK | Single root key |
| TA | Trusted application |
| TAS | Time-aware scheduler |
| TCP | Transmission control protocol |
| TEE | Trusted execution environment |
| TFTP | Trivial file transfer protocol |
| TSN | Time sensitive networking |
| TZASC | Trust zone address space controller |
| UDP | User datagram protocol |
| VLAN | Virtual local area network |

1.2 Reference documentation

1. Refer to the following documents for detailed instructions on booting up the NXP hardware boards supported by Open IL:
 - [LS1012ARDB Getting Started Guide](#).

- [LS1021AIoT Getting Started Guide](#).
 - [LS1021ATSN Getting Started Guide](#)
 - [LS1021ATWR Getting Started Guide](#)
 - [LS1043ARDB Getting Started Guide](#).
 - [LS1046ARDB Getting Started Guide](#).
 - [LS1046AFRWY Getting Started Guide](#)
 - [i.MX6 SabreSD Board Quick Start Guide](#)
 - [LS1028ARDB Quick Start Guide](#)
 - [LX2160A/LX2160A-Rev2 RDB Quick Start Guide](#)
 - [i.MX8MM-EVK Quick Start Guide](#)
2. For booting up LS1021A-TSN board, refer to the Section [Booting the board](#) of this document.
 3. For the complete description of the industrial IoT baremetal framework, refer to the latest available version of [Industrial IoT Baremetal Framework Developer Guide](#).

1.3 About OpenIL

The OpenIL project (“Open Industry Linux”) is designed for embedded industrial usage. It is an integrated Linux distribution for industry.

OpenIL is built on buildroot project and provides packages for the industrial market.

- **Focus on industry:** OpenIL provides key components for industry usage, for example, Time sensitive network (TSN), Netconf, IEEE 1588, and Xenomai or Preempt-RT.
- **Ease of use:** OpenIL is a tool that simplifies and automates the process of building a complete Linux system for an embedded system, using cross-compilation. It follows the buildroot project rules. For more buildroot information, refer to the page: <https://buildroot.org/>
- **Extensibility:** OpenIL provides capabilities of industry usage and standardized Linux system packages. And user can also easily replicate the same setup on customized packages and devices.
- **Lightweight:** OpenIL only includes necessary Linux packages and industry packages in order to make the system more lightweight to adapt to industry usage. Users can customize the package via a configuration file.
- **Open Source:** OpenIL is an open project. Anyone can participate in the OpenIL development through the Open Source community.

1.3.1 OpenIL Organization

OpenIL follows the Buildroot directory structure depicted in the following figure. The second and third levels of the directory are generated during compilation.

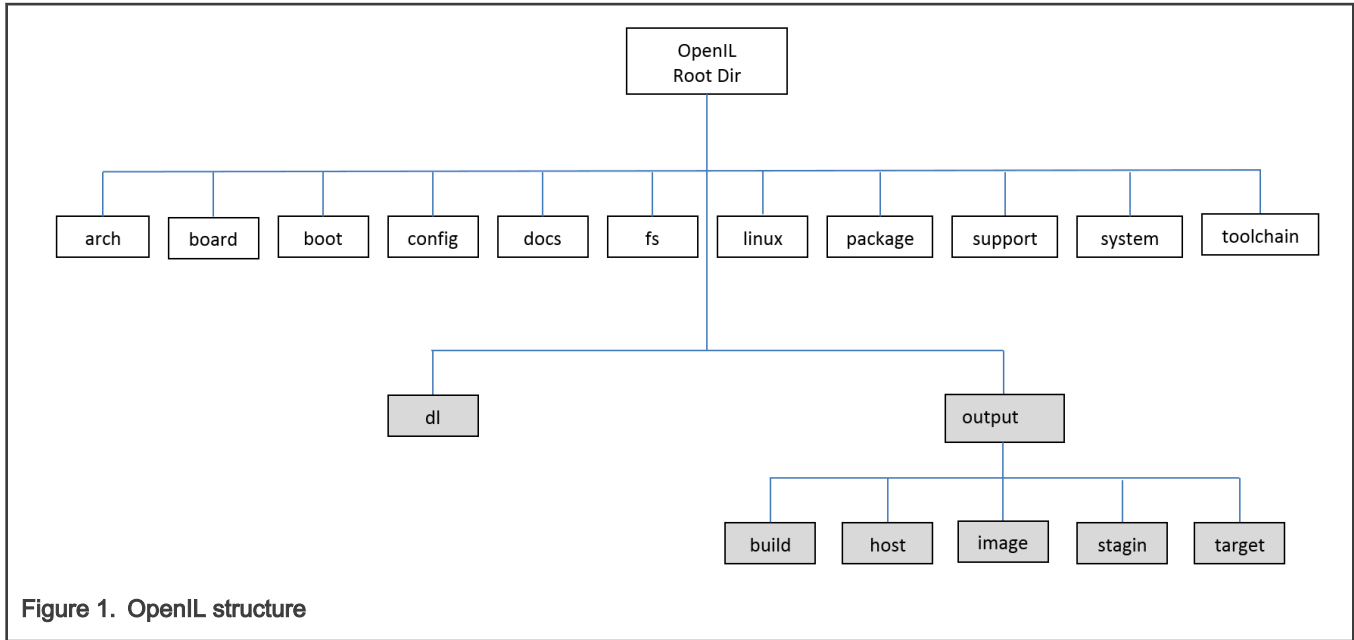


Table 2. Source directories

| Directory name | Description |
|----------------|--|
| arch | Files defining the architecture variants (processor type, ABI, floating point, etc.) |
| toolchain | Packages for generating or using tool-chains |
| system | Contains the rootfs skeleton and options for system-wide features |
| linux | The linux kernel package. |
| package | All the user space packages (1800+) |
| fs | Logic to generate file system images in various formats |
| boot | Boot-loader packages |
| configs | Default configuration files for various platforms |
| board | Board-specific files (kernel configurations, patches, image flashing scripts, etc.) |
| support | Miscellaneous utilities (kconfig code, libtool patches, download helpers, and more) |
| docs | Documentation |

Table 3. Build directories

| Directory name | Description |
|----------------|---|
| dl | Path where all the source tarballs are downloaded |
| output | Global output directory |
| output/build | Path where all source tarballs are extracted and the build of each package takes place. |
| output/host | Contains both the tools built for the host and the sysroot of the toolchain |
| output/staging | A symbolic link to the sysroot, that is, to host/<tuple>/sysroot/ for convenience |
| output/target | The target Linux root filesystem, used to generate the final root filesystem images |

Table continues on the next page...

Table 3. Build directories (continued)

| Directory name | Description |
|----------------|--|
| output/images | Contains all the final images: kernel, bootloader, root file system, and so on |

1.4 Supported NXP platforms and configurations

The following table lists the NXP platforms and configurations supported by OpenIL.

Table 4. Supported NXP platforms

| Platform | Architecture | Configuration file in OpenIL | Boot |
|------------------------------|--------------|--|------|
| LS1021ATSN (default) | ARM v7 | configs/nxp_ls1021atsn_defconfig | SD |
| LS1021ATSN (Ubuntu) | ARM v7 | configs/nxp_ls1021atsn_ubuntu_defconfig | SD |
| LS1021AIOT (default) | ARM v7 | configs/nxp_ls1021aiot_defconfig | SD |
| LS1021AIOT (Baremetal) | ARM v7 | configs/nxp_ls1021aiot_baremetal_defconfig | SD |
| LS1021AIOT (Ubuntu) | ARM v7 | configs/nxp_ls1021aiot_ubuntu_defconfig | SD |
| LS1021ATWR (default, QSPI) | ARM v7 | configs/nxp_ls1021atwr_defconfig | SD |
| LS1021ATWR (IFC) | ARM v7 | configs/nxp_ls1021atwr_sdboot_ifc_defconfig | SD |
| LS1043ARDB (64bit, default) | ARM v8 | configs/nxp_ls1043ardb-64b_defconfig | SD |
| LS1043ARDB (Baremetal) | ARM v8 | configs/nxp_ls1043ardb_baremetal-64b_defconfig | SD |
| LS1043ARDB (Ubuntu) | ARM v8 | configs/nxp_ls1043ardb-64b_ubuntu_defconfig | SD |
| LS1046ARDB (64bit, default) | ARM v8 | configs/nxp_ls1046ardb-64b_defconfig | SD |
| LS1046ARDB (EMMC) | ARM v8 | configs/nxp_ls1046ardb-64b-emmcboot_defconfig | EMMC |
| LS1046ARDB (QSPI) | ARM v8 | configs/nxp_ls1046ardb-64b_qspi_defconfig | QSPI |
| LS1046ARDB (QSPI-SB) | ARM v8 | configs/nxp_ls1046ardb-64b_qspi-sb_defconfig | QSPI |
| LS1046ARDB (Baremetal) | ARM v8 | configs/nxp_ls1046ardb_baremetal-64b_defconfig | SD |
| LS1046ARDB (Ubuntu) | ARM v8 | configs/nxp_ls1046ardb-64b_ubuntu_defconfig | SD |
| LS1046AFRWY (64bit, default) | ARM v8 | configs/nxp_ls1046afwy-64b_defconfig | SD |
| LS1046AFRWY (QSPI) | ARM v8 | configs/nxp_ls1046afwy-64b_qspi_defconfig | QSPI |
| LS1046AFRWY (Ubuntu) | ARM v8 | configs/nxp_ls1046afwy-64b_ubuntu_defconfig | SD |
| LS1012ARDB (64bit) | ARM v8 | configs/nxp_ls1012ardb-64b_defconfig | QSPI |
| i.MX6Q SabreSD (default) | ARM v7 | configs/imx6q-sabresd_defconfig | SD |
| i.MX6Q SabreSD (Baremetal) | ARM v7 | configs/imx6q-sabresd_baremetal_defconfig | SD |
| i.MX6Q SabreSD (Ubuntu) | ARM v7 | configs/imx6q-sabresd_ubuntu_defconfig | SD |
| i.MX8MM EVK (64bit default) | ARM v8 | configs/imx8mmevk_defconfig | SD |
| i.MX8MM EVK (64bit default) | ARM v8 | configs/imx8mmevk_revb_defconfig | SD |
| i.MX8MM EVK (Baremetal) | ARM v8 | configs/imx8mmevk_baremetal_defconfig | SD |

Table continues on the next page...

Table 4. Supported NXP platforms (continued)

| Platform | Architecture | Configuration file in OpenIL | Boot |
|-------------------------------|--------------|---|------|
| i.MX8MM EVK (Baremetal) | ARM v8 | configs/imx8mmevk_revb_baremetal_defconfig | SD |
| i.MX8MM EVK (Ubuntu) | ARM v8 | configs/imx8mmevk_ubuntu_defconfig | SD |
| i.MX8MM EVK (Ubuntu) | ARM v8 | configs/imx8mmevk_revb_ubuntu_defconfig | SD |
| i.MX8MP EVK (64bit, default) | ARM v8 | configs/imx8mpevk_defconfig | SD |
| i.MX8MP EVK (Ubuntu) | ARM v8 | configs/imx8mpevk_ubuntu_defconfig | SD |
| LS1028ARDB (64bit, default) | ARM v8 | configs/nxp_ls1028ardb-64b_defconfig | SD |
| LS1028ARDB (EMMC) | ARM v8 | configs/nxp_ls1028ardb-64b-emmc_defconfig | EMMC |
| LS1028ARDB (XSPI) | ARM v8 | configs/nxp_ls1028ardb-64b-xspi_defconfig | XSPI |
| LS1028ARDB (Baremetal) | ARM v8 | configs/nxp_ls1028ardb_baremetal-64b_defconfig | SD |
| LS1028ARDB (Ubuntu) | ARM v8 | configs/nxp_ls1028ardb-64b_ubuntu_defconfig | SD |
| LS1028ATSN(64bit, default) | ARM v8 | configs/fii_ls1028atsn-64b_defconfig | SD |
| LS1028ATSN(Ubuntu) | ARM v8 | configs/fii_ls1028atsn-64b_ubuntu_defconfig | SD |
| LX2160ARDB (64bit, default) | ARM v8 | configs/nxp_lx2160ardb-64b_defconfig | SD |
| LX2160ARDB (XSPI) | ARM v8 | configs/nxp_lx2160ardb-64b-xspi_defconfig | XSPI |
| LX2160ARDB (Baremetal) | ARM v8 | configs/nxp_lx2160ardb_baremetal-64b_defconfig | SD |
| LX2160ARDB (Ubuntu) | ARM v8 | configs/nxp_lx2160ardb-64b_ubuntu_defconfig | SD |
| LX2160A Rev2 (64bit, default) | ARM v8 | configs/nxp_lx2160ardb_rev2-64b_defconfig | SD |
| LX2160A Rev2 (XSPI) | ARM v8 | configs/nxp_lx2160ardb_rev2-64b-xspi_defconfig | XSPI |
| LX2160A Rev2 (Baremetal) | ARM v8 | configs/nxp_lx2160ardb_rev2_baremetal-64b_defconfig | SD |
| LX2160A Rev2 (Ubuntu) | ARM v8 | configs/nxp_lx2160ardb_rev2-64b_ubuntu_defconfig | SD |

1.4.1 Default compilation settings for NXP platforms

The following table provides the default compilation settings for each OpenIL NXP platform.

Table 5. Default compilation settings

| Platform | Toolchain | libc | Init system | Filesystem |
|---------------------|-----------|------------|-------------|---------------------------|
| LS1021ATSN | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL default |
| LS1021ATSN (Ubuntu) | gcc 7.5.0 | glibc 2.25 | Systemd | ubuntu-base-18.04.5-arm |
| LS1021AIOT | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL default |
| LS1021AIOT (Ubuntu) | gcc 7.5.0 | glibc 2.25 | Systemd | ubuntu-base-18.04.5-arm |
| LS1021ATWR | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL default |
| LS1043ARDB (64-bit) | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL default |
| LS1043ARDB (Ubuntu) | gcc 9.2.0 | glibc 2.31 | Systemd | ubuntu-base-18.04.5-arm64 |

Table continues on the next page...

Table 5. Default compilation settings (continued)

| Platform | Toolchain | libc | Init system | Filesystem |
|---------------------------|-----------|------------|-------------|---------------------------|
| LS1046ARDB (64-bit) | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL default |
| LS1046ARB (Ubuntu) | gcc 9.2.0 | glibc 2.31 | Systemd | ubuntu-base-18.04.5-arm64 |
| LS1046AFRWY (64-bit) | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL default |
| LS1046AFRWY (Ubuntu) | gcc 9.2.0 | glibc 2.31 | Systemd | ubuntu-base-18.04.5-arm64 |
| LS1012ARDB (64-bit) | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL default |
| i.MX6Q SabreSD | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL default |
| i.MX6Q SabreSD (Ubuntu) | gcc 7.5.0 | glibc 2.25 | Systemd | ubuntu-base-18.04.5-arm |
| i.MX8MM EVK (64bit) | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL default |
| i.MX8MM EVK (Ubuntu) | gcc 9.2.0 | glibc 2.31 | Systemd | ubuntu-base-18.04.5-arm64 |
| i.MX8MP EVK (64bit) | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL default |
| i.MX8MP EVK (Ubuntu) | gcc 9.2.0 | glibc 2.31 | Systemd | ubuntu-base-18.04.5-arm64 |
| LS1028ARDB (64-bit) | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL default |
| LS1028ARDB (Ubuntu) | gcc 9.2.0 | glibc 2.31 | Systemd | ubuntu-base-18.04.5-arm64 |
| LS1028ATSN (64-bit) | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL default |
| LS1028ATSN (Ubuntu) | gcc 9.2.0 | glibc 2.31 | Systemd | ubuntu-base-18.04.5-arm64 |
| LX2160ARDB (64-bit) | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL default |
| LX2160ARDB (Ubuntu) | gcc 9.2.0 | glibc 2.31 | Systemd | ubuntu-base-18.04.5-arm64 |
| LX2160A Rev2 RDB (64bit) | gcc 9.2.0 | glibc 2.31 | BusyBox | OpenIL-default |
| LX2160A Rev2 RDB (Ubuntu) | gcc 9.2.0 | glibc 2.31 | Systemd | ubuntu-base-18.04.5-arm64 |

Chapter 2

Release Notes

2.1 What's New

The following section describe the new features for each release.

2.1.1 What's new in OpenIL v1.11

What's New:

- **TSN**
 - — 802.1AS-2020
 - Initial support for multi-domain on i.MX8MP and LS1028A
- **Hardware**
 - i. MX8MP silicon A1
- **Linux Kernel**
 - LTS 5.4.70 for i.MX8
- **U-boot**
 - v2020.04 for i.MX8
- **Baremetal**
 - v2020.04 for Layerscape and i.MX8
 - i.MX8MP EVK

2.1.2 What's new in OpenIL v1.10

What's New:

- **TSN**
 - — VCAP chain mode
 - GenAVB/TSN stack
- **Real-time**
 - PREEMPT-RT 5.4 on i.MX8MM
 - Ethernet
 - PCIe
 - GPIO
 - DSI
- **Baremetal**
 - i.MX8MM (A core to A core)
 - ICC
 - Ethernet
 - GPIO

- **OpenIL framework**
 - Board
 - i.MX8MM platform
 - GPU: OpenGL ES
 - Display: OpenGL ES, Weston, DSI-MIPI, CSI-MIPI

2.1.3 What's new in OpenIL v1.9

What's New:

- **TSN**
 - tc flower support for Qbu and Qci
 - 802.1 QinQ
 - Multi-ports TSN switch solution
 - MX8MP TSN
- **Real-time**
 - PREEMPT-RT 5.4 on i.MX8MP
- **Baremetal**
 - LX2160ARDB rev2 support and ICC
- **OpenIL framework**
 - linuxptp uprev to 3.0
 - Board
 - MX8MP
 - TSN: Qbv, Qbu, Qav
 - GPU: OpenGL ES, OpenCL
 - Display: OpenGL ES, Weston
 - LS1028ARDB
 - Display: OpenGL ES, Weston
 - GPU: OpenGL ES, OpenCL
 - LX2160ARDB rev2

2.1.4 What's new in OpenIL v1.8

What's New:

- **TSN**
 - tc VCAP support for VLAN-retagging
 - tc VCAP support for police
 - tc support for Qav and Qbv
 - SJA1105 DSA Support and clock synchronization
 - YANG modules for network config (IP, MAC and VLAN)
- **Real time**
 - PREEMPT-RT 5.4

- Baremetal
 - LX2160A rev1 ICC
- OpenIL framework
 - buildroot uprev to 2020.02
 - Kernel/U-Boot
 - Linux upgraded to LSDK20.04 - Linux-5.4.3
 - U-Boot upgraded to LSDK20.04 - U-Boot 2019.10
 - Board
 - i.MX8MM
 - Foxconn LS1028ATSN board with SJA1105

2.1.5 What's new in OpenIL v1.7

What's New:

- TSN
 - BC based 802.1AS bridge mode
 - Netopper2 support based on sysrepo. Support Qbv, Qbu, Qci configuration
 - VLAN based tc flower policer
 - Web based TSN configuration tool - available for Qbv, Qbu and Qci configuration
- Real time
 - Xenomai
 - Xenomai I-pipe uprev to 4.19
 - Baremetal
 - SAI support on LS1028
 - i.MX6Q baremetal ICC
- Industrial protocols
 - CANopen over EtherCAT
- OpenIL framework
 - Kernel/U-Boot
 - Linux upgraded to LSDK1909 - 4.19
 - U-Boot upgraded to U-Boot-2019.04
 - Boards
 - LX2160ARDB SD boot
 - LX2160ARDB XSPI boot
 - LS1028ARDB XSPI boot
 - LS1046ARDB eMMC boot

2.1.6 What's new in OpenIL v1.6

What's New:

- TSN

- Web based TSN configuration tool - available for Qbv and Qbu configuration
- TSN driver enhancement
- Real time
 - Baremetal
 - i.MX6Q-sabresd baremetal support
- NETCONF/YANG
 - NETCONF/YANG model for Qbu and Qci protocol
- Industrial protocols
 - LS1028A - BEE click board

2.1.7 What's new in OpenIL v1.5

What's New:

- TSN
 - Web based TSN configuration tool - available for Qbv and Qbu configuration
 - 802.1AS endpoint mode for LS1028A TSN switch
- Real time
 - Xenomai
 - LS1028 ENETC Xenomai RTNET support
 - Baremetal
 - LS1028 Baremetal ENETC support
- NETCONF/YANG
 - NETCONF/YANG model for Qbv protocol
- Industrial protocols
 - LS1028A - BLE click board

2.1.8 What's new in OpenIL v1.4

What's New:

- TSN
 - ENETC TSN driver: Qbv, Qbu, Qci, Qav
 - ENETC 1588 two steps timestamping support
 - SWITCH TSN driver: Qbv, Qci, Qbu, Qav, 802.1CB support
- Real time
 - Xenomai
 - LS1028ARDB
 - Baremetal
 - LS1021AIoT, LS1043ARDB, LS1046ARDB
 - LS1028 Baremetal basic baremetal support
- Industrial protocols
 - LS1028A - NFC click board

— QT5.11

- OpenIL framework

— boards: LS1028ARDB

2.2 Feature support matrix

The following tables show the features that are supported in this release.

Table 6. Key features

| Feature | | LS10 21A TSN | LS10 21A IOT | LS10 21A TWR | LS10 43A RDB | LS10 46A RDB | LS10 46A FRW Y | LS10 12A RDB | i.MX6 Q Sabr eSD | i.MX8 MM EVK | i.MX8 MP EVK | LS10 28A RDB | LS10 28A TSN | LX216 0A RDB |
|-----------------|----------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------------|--------------------|---------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| Boot mode | SD | y | y | y | y | y | y | | y | y | y | y | y | y |
| | XSPI | | | | | | | | | | | y | | y |
| | QSPI | | | | | y | | y | | | | | | |
| | eMMC | | | | | y | | | | | | y | | |
| Uboot Baremetal | ICC | | y | | y | y | | | y | y | y | y | y | y |
| | PCIe | | y | | y | y | | | | | | y | | |
| | Ethernet | | | | y | y | | | | y | y | y | | |
| | GPIO | | y | | | | | | | y | y | | | |
| | IPI | | y | | y | y | | | y | y | y | y | | y |
| | UART | | y | | y | y | | | y | y | y | y | | y |
| | USB | | y | | y | y | | | | | | | | |
| | SAI | | | | | | | | | | | | y | |
| | CAN | | y | | | | | | | | | | | |
| | I2C | | y | | y | y | | | | | | | y | |
| | QSPI | | | | | | y | | | | | | | |
| IFC | | | | | | y | | | | | | | | |
| Linux Baremetal | ICC | | y | | y | y | | | y | y | y | y | y | y |
| | IPI | | y | | y | y | | | y | y | y | y | y | y |
| Preempt-RT | | y | y | y | y | y | y | y | y | y | y | y | y | y |
| TSN | Qbv | | | | | | | | | | | y | y | y |
| | Qbu | | | | | | | | | | | y | y | |
| | Qci | | | | | | | | | | | n/a | y | y |
| | Qav | | | | | | | | | | | y | y | y |
| | 802.1AS | | | | | | | | | | | y | y | y |

Table continues on the next page...

Table 6. Key features (continued)

| Feature | | LS10 21A TSN | LS10 21A IOT | LS10 21A TWR | LS10 43A RDB | LS10 46A RDB | LS10 46A FRW Y | LS10 12A RDB | i.MX6 Q Sabr eSD | i.MX8 MM EVK | i.MX8 MP EVK | LS10 28A RDB | LS10 28A TSN | LX216 0A RDB |
|-----------------------------------|---------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------------|--------------------|---------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| | 802.1C B | | | | | | | | | | n/a | y | y | |
| | VCAP chain mode | | | | | | | | | | n/a | y | | |
| | 802.1 Q-in-Q | | | | | | | | | | | y | | |
| NETCON F/YANG | Qbv | | | | | | | | | | y | y | y | |
| | Qbu | | | | | | | | | | y | y | | |
| | Qci | | | | | | | | | | n/a | y | y | |
| | IP | | | | | | | | | | y | y | y | |
| | MAC | | | | | | | | | | y | y | y | |
| | VLAN config | | | | | | | | | | y | y | y | |
| Web based configura tion | Qbv | | | | | | | | | | y | y | y | |
| | Qbu | | | | | | | | | | y | y | | |
| | Qci | | | | | | | | | | n/a | y | y | |
| Industrial Protocol | EtherC AT master (IGH) | y | y | y | y | y | y | y | y | y | y | y | y | y |
| | CoE | y | y | y | y | y | y | y | y | y | y | y | y | y |
| | OPC- UA | y | y | y | y | y | y | y | y | y | y | y | y | y |
| | BEE | | | | | | | | | | | y | | |
| | BLE | | | | | | | | | | | y | | |
| | NFC | | | | | | | | | | | y | | |
| | FlexCA N | | | | | | | | | | | y | | |
| | CANop en | | y | | | | | | | | | | | |

Chapter 3

Getting started

After reading this section, user should be able to get the OpenIL source code, build and program the NXP platform images, and run the OpenIL system on the supported NXP platforms.

3.1 Getting OpenIL

OpenIL releases are available every few months. The Release Number follows the format 'YYYYMM', for example, 201708. Release tarballs are available at: <https://github.com/openil/openil>.

To follow development, make a clone of the Git repository. Use the below command:

```
$ git clone https://github.com/openil/openil.git
$ cd openil
# checkout to the 2021.04 v1.11 release
$ git checkout OpenIL-v1.11-202104 -b OpenIL-v1.11-202104
```

3.2 OpenIL quick start

The steps below help the user to build the NXP platform images with OpenIL quickly. Ensure to follow the important notes provided in the following section.

3.2.1 Host system requirements

OpenIL is designed to build in Linux systems. The following host environments have been verified to build the OpenIL.

- Ubuntu 20.04 (Recommended)
- Ubuntu 18.04
- Ubuntu 16.04

While OpenIL itself builds most host packages it needs for the compilation, certain standard Linux utilities are expected to be already installed on the host system. The following tables provide an overview of the mandatory and optional packages.

User also can run following script to make sure all packages required have been installed into HOST machine.

```
$ cd openil
# Run below command to check and install these packages required automatically.
$ ./env_setup.sh
```

NOTE

Package names listed in the following tables might vary between distributions.

NOTE

When Building i.MX8MMEVK and i.MX8MPEVK images, the Host machine requires Ubuntu-20.04 or later because gstreamer1.0-1.16.1 needs GLIB 2.29 or later (Ubuntu-18.04 is 2.27). If the host machine is not Ubuntu-20.04, please refer to chapter 25 "Camera" to disable gstreamer .

Table 7. Host system mandatory packages

| Mandatory packages | Remarks |
|--------------------|---------|
| which | |

Table continues on the next page...

Table 7. Host system mandatory packages (continued)

| Mandatory packages | Remarks |
|---|----------------------------------|
| sed | |
| make | Version 3.81 or later |
| binutils | |
| build-essential | Only for Debian based systems |
| gcc | Version 2.95 or later |
| g++ | Version 2.95 or later |
| bash | |
| patch | |
| gzip | |
| bzip2 | |
| perl | Version 5.8.7 or later |
| tar | |
| cpio | |
| python | Version 2.6 or later |
| unzip | |
| rsync | |
| file | Must be in /usr/bin/file |
| bc | |
| wget | |
| autoconf, dh-autoreconf | |
| openssl, libssl-dev | |
| libmagickwand-dev (Debian, Ubuntu) imageMagick-devel (CentOS) | |
| autogen autoconf libtool | |
| pkg-config | |
| python3-pyelftools | |
| python-pyelftools | |
| python3-pycryptodome | |
| python-pycryptodome | |
| binfmt-support | used when building ubuntu-rootfs |
| qemu-system-common | used when building ubuntu-rootfs |
| qemu-user-static | used when building ubuntu-rootfs |

Table continues on the next page...

Table 7. Host system mandatory packages (continued)

| Mandatory packages | Remarks |
|--------------------|----------------------------------|
| debootstrap | used when building ubuntu-rootfs |

Table 8. Host system optional packages

| Optional packages | Remarks |
|---------------------------------|--|
| ncurses5 | To use the menuconfig interface |
| qt4 | To use the xconfig interface |
| glib2, gtk2 and glade2 | To use the gconfig interface |
| bazaar | Source fetching tools. |
| cvs | If user enable packages using any of these methods, user need to install the corresponding tool on the host system |
| git | |
| mercurial | |
| scp | |
| javac compiler | Java-related packages, if the Java Classpath needs to be built for the target system |
| jar tool | |
| asciidoc | Documentation generation tools |
| w3m | |
| python with the argparse module | |
| dblatex | |
| graphviz | To use graph-dependends and <pkg>-graph-dependends |
| python-matplotlib | To use graph-build |

3.2.2 Creating RAMDISK file system

OpenIL support to generate RAMDISK file system.

- **Create Ramdisk root filesystem** by using the `make menuconfig` command.

```
Filesystem images --->
[*] cpio the root filesystem (for use as an initial RAM filesystem)
[*] Create U-Boot image of the root filesystem
```

This configuration will generate Ramdisk root filesystem based on CPIO, some files created: `rootfs.cpio.uboot`, `rootfs.cpio.gz`, `rootfs.cpio`.

3.2.3 Resizing second partition

Resizing the second partition, which is root filesystem.

- **Specify partition size** of the storage for the filesystem by using the `make menuconfig` command.

```
System configuration --->
  (3G) Partition size of the storage for the rootfs
  [*] Install rootfs_resize service
```

This configuration specifies the size of the storage device partition for the building rootfs and currently used by NXP platforms and SD card device. The default size is 3GB, user can set the size of the partition with 512M, 2G or other values, the target system can get the specific size of partition space for the using filesystem.

- Another way to modify the space size of second partition: using tool "fdisk" to resize the partition on HOST machine, below are the example steps.

```
# First flash sdcard.img to SD card on host machine wiht dd command
~$ sudo dd if=./sdcard.img of=/dev/sdc

# Then list the partitions
~$ sudo fdisk -l /dev/sdc
Disk /dev/sdc: 7.4 GiB, 7948206080 bytes, 15523840 sectors
Units: sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
Disklabel type: dos
Disk identifier: 0x00000000

Device      Boot  Start      End  Sectors  Size Id Type
/dev/sdc1   *    131072   655359   524288   256M c W95 FAT32 (LBA)
/dev/sdc2                655360 1703935 1048576   512M 83 Linux
# Notice: we need this start sectors "655360" of second partition when create new partition.#

# Then, Re-create the second partition and expand to full SD capability
~$ sudo fdisk /dev/sdc

Welcome to fdisk (util-linux 2.31.1).
Changes will remain in memory only, until you decide to write them.
Be careful before using the write command.

Command (m for help): d
Partition number (1,2, default 2):

Partition 2 has been deleted.

Command (m for help): n
Partition type
   p   primary (1 primary, 0 extended, 3 free)
   e   extended (container for logical partitions)
Select (default p):

Using default response p.
Partition number (2-4, default 2):
First sector (2048-15523839, default 2048): 655360
Last sector, +sectors or +size{K,M,G,T,P} (655360-15523839, default 15523839):

Created a new partition 2 of type 'Linux' and of size 7.1 GiB.
Partition #2 contains a ext4 signature.

Do you want to remove the signature? [Y]es/[N]o: n

Command (m for help): w
```



```

The partition table has been altered.
Calling ioctl() to re-read partition table.
Syncing disks.

# Finally, check the second partiton and resize to full SD capability
~$ sudo fsck.ext4 /dev/sdc2
e2fsck 1.44.1 (24-Mar-2018)
/dev/sdc2: clean, 3493/32768 files, 26617/131072 blocks
~$ sudo resize2fs /dev/sdc2
resize2fs 1.44.1 (24-Mar-2018)
Resizing the filesystem on /dev/sdc2 to 1858560 (4k) blocks.
The filesystem on /dev/sdc2 is now 1858560 (4k) blocks long.
~$ sudo fdisk -l /dev/sdc
Disk /dev/sdc: 7.4 GiB, 7948206080 bytes, 15523840 sectors
Units: sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
Disklabel type: dos
Disk identifier: 0x00000000

Device      Boot  Start        End  Sectors  Size Id Type
/dev/sdc1   *    131072     655359    524288  256M  c W95 FAT32 (LBA)
/dev/sdc2             655360 15523839 14868480   7.1G  83 Linux

```

3.2.4 Customing Ubuntu file system

OpenIL supports custom Ubuntu as the target **root file system**. This section describes the steps for customing the Ubuntu root file system.

Users can download OpenIL and build the target system with an Ubuntu file system. The specific filesystem can be set conveniently by using the `make menuconfig` command as shown below.

NOTE

The "sudo" permission is required when building ubuntu root file system.

```

System configuration --->
  Root FS skeleton (custom target skeleton) --->
    Custom skeleton via network --->

```

Currently, there are ten NXP platforms that can support Ubuntu file system:

- configs/nxp_ls1043ardb-64b_ubuntu_defconfig
- configs/nxp_ls1043ardb-64b_ubuntu_full_defconfig
- configs/nxp_ls1046ardb-64b_ubuntu_defconfig
- configs/nxp_ls1046ardb-64b_ubuntu_full_defconfig
- configs/nxp_ls1046afrawy-64b_ubuntu_defconfig
- configs/nxp_ls1046afrawy-64b_ubuntu_full_defconfig
- configs/fii_ls1028atsn-64b_ubuntu_defconfig
- configs/fii_ls1028atsn-64b_ubuntu_full_defconfig
- configs/nxp_ls1028ardb-64b_ubuntu_defconfig
- configs/nxp_ls1028ardb-64b_ubuntu_full_defconfig
- configs/nxp_ls1021aiot_ubuntu_defconfig
- configs/nxp_ls1021aiot_ubuntu_full_defconfig

- configs/nxp_ls1021atsn_ubuntu_defconfig
- configs/nxp_ls1021atsn_ubuntu_full_defconfig
- configs/imx6q-sabresd_ubuntu_defconfig
- configs/imx6q-sabresd_ubuntu_full_defconfig
- configs/nxp_lx2160ardb-64b_ubuntu_defconfig
- configs/nxp_lx2160ardb-64b_ubuntu_full_defconfig
- configs/nxp_lx2160ardb_rev2-64b_ubuntu_defconfig
- configs/nxp_lx2160ardb_rev2-64b_ubuntu_full_defconfig
- configs/imx8mmevk_revb_ubuntu_defconfig
- configs/imx8mmevk_ubuntu_defconfig
- configs/imx8mpevk_ubuntu_defconfig

NOTE

In the package list specified above:

- ****_ubuntu_default:** supports basic packages to boot the system.
 - ****_ubuntu_full_default:** supports all packages in ****_ubuntu_default** and other necessary packages required by all features.
-

3.2.5 Building the images

For the NXP platforms supported by OpenIL, the default configuration files can be found in the `configs` directory. The following table describes the default configuration files for the NXP-supported OpenIL platforms.

Table 9. Default configuration

| Platform | Configuration file in OpenIL |
|------------------------------|---|
| i.MX6Q SabreSD | configs/imx6q-sabresd_defconfig |
| i.MX6Q SabreSD (Baremetal) | configs/imx6q-sabresd_baremetal_defconfig |
| i.MX6Q SabreSD (Ubuntu) | configs/imx6q-sabresd_ubuntu_defconfig |
| i.MX6Q SabreSD (Full ubuntu) | configs/imx6q-sabresd_ubuntu_full_defconfig |
| i.MX8MM EVK (64bit) | configs/imx8mmevk_revb_defconfig |
| i.MX8MM EVK (64bit) | configs/imx8mmevk_defconfig |
| i.MX8MM EVK (Baremetal) | configs/imx8mmevk_baremetal_defconfig |
| i.MX8MM EVK (Baremetal) | configs/imx8mmevk_revb_baremetal_defconfig |
| i.MX8MM EVK (Ubuntu) | configs/imx8mmevk_ubuntu_defconfig |
| i.MX8MM EVK (Ubuntu) | configs/imx8mmevk_revb_ubuntu_defconfig |
| i.MX8MP EVK (64bit) | configs/imx8mpevk_defconfig |
| i.MX8MP EVK (Ubuntu) | configs/imx8mpevk_ubuntu_defconfig |

Table continues on the next page...

Table 9. Default configuration (continued)

| Platform | Configuration file in OpenIL |
|--------------------------|--|
| LS1012ARDB (64bit) | configs/nxp_ls1012ardb-64b_defconfig |
| LS1021AIOT | configs/nxp_ls1021aiot_defconfig |
| LS1021AIOT (Baremetal) | configs/nxp_ls1021aiot_baremetal_defconfig |
| LS1021AIOT (Ubuntu) | configs/nxp_ls1021aiot_ubuntu_defconfig |
| LS1021AIOT (Full ubuntu) | configs/nxp_ls1021aiot_ubuntu_full_defconfig |
| LS1021ATSN | configs/nxp_ls1021atsn_defconfig |
| LS1021ATSN (Ubuntu) | configs/nxp_ls1021atsn_ubuntu_defconfig |
| LS1021ATSN (Full ubuntu) | configs/nxp_ls1021atsn_ubuntu_full_defconfig |
| LS1021ATWR (QSPI) | configs/nxp_ls1021atwr_defconfig |
| LS1021ATWR (IFC) | configs/nxp_ls1021atwr_sdboot_ifc_defconfig |
| LS1028ARDB (EMMC) | configs/nxp_ls1028ardb-64b-emmc_defconfig |
| LS1028ARDB (XSPI) | configs/nxp_ls1028ardb-64b-xspi_defconfig |
| LS1028ARDB (Baremetal) | configs/nxp_ls1028ardb_baremetal-64b_defconfig |
| LS1028ARDB (64bit) | configs/nxp_ls1028ardb-64b_defconfig |
| LS1028ARDB (Ubuntu) | configs/nxp_ls1028ardb-64b_ubuntu_defconfig |
| LS1028ARDB (Full ubuntu) | configs/nxp_ls1028ardb-64b_ubuntu_full_defconfig |
| LS1028ATSN (64bit) | configs/fii_ls1028atsn-64b_defconfig |
| LS1028ATSN (Ubuntu) | configs/fii_ls1028atsn-64b_ubuntu_defconfig |
| LS1028ATSN (Full ubuntu) | configs/fii_ls1028atsn-64b_ubuntu_full_defconfig |
| LS1043ARDB (64bit) | configs/nxp_ls1043ardb-64b_defconfig |
| LS1043ARDB (Baremetal) | configs/nxp_ls1043ardb_baremetal-64b_defconfig |
| LS1043ARDB (Ubuntu) | configs/nxp_ls1043ardb-64b_ubuntu_defconfig |
| LS1043ARDB (Full ubuntu) | configs/nxp_ls1043ardb-64b_ubuntu_full_defconfig |
| LS1046ARDB (64-bit) | configs/nxp_ls1046ardb-64b_defconfig |
| LS1046ARDB (EMMC) | configs/nxp_ls1046ardb-64b-emmcboot_defconfig |
| LS1046ARDB (QSPI) | configs/nxp_ls1046ardb-64b_qspi_defconfig |
| LS1046ARDB (QSPI-SB) | configs/nxp_ls1046ardb-64b_qspi-sb_defconfig |
| LS1046ARDB (QSPI4EMMC) | configs/nxp_ls1046ardb-64b-emmc_qspiboot_defconfig |
| LS1046ARDB (Baremetal) | configs/nxp_ls1046ardb_baremetal-64b_defconfig |
| LS1046ARDB (Ubuntu) | configs/nxp_ls1046ardb-64b_ubuntu_defconfig |
| LS1046ARDB (Full ubuntu) | configs/nxp_ls1046ardb-64b_ubuntu_full_defconfig |
| LS1046AFRWY (64bit) | configs/nxp_ls1046afrawy-64b_defconfig |

Table continues on the next page...

Table 9. Default configuration (continued)

| Platform | Configuration file in OpenIL |
|--------------------------------|---|
| LS1046AFRWY (QSPI) | configs/nxp_ls1046afrawy-64b_qspi_defconfig |
| LS1046AFRWY (Ubuntu) | configs/nxp_ls1046afrawy-64b_ubuntu_defconfig |
| LS1046AFRWY (Full ubuntu) | configs/nxp_ls1046afrawy-64b_ubuntu_full_defconfig |
| LX2160ARDB (64bit) | configs/nxp_lx2160ardb-64b_defconfig |
| LX2160ARDB (XSPI) | configs/nxp_lx2160ardb-64b-xspi_defconfig |
| LX2160ARDB (Baremetal) | configs/nxp_lx2160ardb_baremetal-64b_defconfig |
| LX2160ARDB (Ubuntu) | configs/nxp_lx2160ardb-64b_ubuntu_defconfig |
| LX2160ARDB (Full ubuntu) | configs/nxp_lx2160ardb-64b_ubuntu_full_defconfig |
| LX2160A Rev2 RDB (64bit) | configs/nxp_lx2160ardb_rev2-64b_defconfig |
| LX2160A Rev2 RDB (XSPI) | configs/nxp_lx2160ardb_rev2-64b-xspi_defconfig |
| LX2160A Rev2 RDB (Baremetal) | configs/nxp_lx2160ardb_rev2_baremetal-64b_defconfig |
| LX2160A Rev2 RDB (Ubuntu) | configs/nxp_lx2160ardb_rev2-64b_ubuntu_defconfig |
| LX2160A Rev2 RDB (Full ubuntu) | configs/nxp_lx2160ardb_rev2-64b_ubuntu_full_defconfig |

The “configs/nxp_xxxx_defconfig” files listed in the preceding table include all the necessary U-Boot, kernel configurations, and application packages for the filesystem. Based on the files without any changes, user can build a complete Linux environment for the target platforms.

To build the images for an NXP platform (for example, LS1046ARDB), run the following commands:

```
$ cd openil
$ make nxp_ls1046ardb-64b_defconfig
$ make
# or make with a log
$ make 2>&1 | tee build.log
```

NOTE

The `make clean` command should be implemented before any other new compilation.

The `make` command generally performs the following steps:

- Downloads source files (as required and at the first instance);
- Configures, builds, and installs the cross-compilation toolchain;
- Configures, builds, and installs selected target packages;
- Builds a kernel image, if selected;
- Builds a bootloader image, if selected;
- Creates the BL2, BL31, BL33 binary from ATF;
- Creates a root filesystem in selected formats.
- Generates the Image file for booting;

After the correct compilation, all the images for the platform can be found at `output/images`.

```
images/
├─ b12_sd.pbl          --- BL2 + RCW
```

```

├─ fip.bin          --- BL31 + BL33 (uboot)
├─ rcw_1800_sdboot.bin  --- RCW binary
├─ boot.vfat
├─ fmucode.bin
├─ fsl-ls1046a-rdb-sdk.dtb  --- dtb file for ls1046ardb
├─ rootfs.ext2
├─ rootfs.ext4
├─ rootfs.tar
├─ sdcard.img      --- entire image can be programmed into the SD
├─ uboot-env.bin
├─ u-boot-dtb.bin  --- uboot image for ls1046ardb
└─ Image          --- kernel image for ls1046ardb

```

NOTE

The image file name used for each configuration are as described below:

- `xspi.cpio.img`: the image file used for FlexNor flash boot, built by the `*xspi_defconfig` file.
- `sdcard.img`: the image file used for SD or eMMC boot, built by default and `*emmc_defconfig` file.
- `qspi.cpio.img`: the image file used for QSPI flash boot, built by `*qspi_defconfig` file.

3.2.6 Troubleshooting

- Users can login all platforms through SSH. However, for LS1028ARDB, i.MX8MMEVK and i.MX8MPEVK, Linux-PAM is enabled, which is required by weston. Hence, if users don't want to follow Linux-PAM policy to login through SSH, the below steps are necessary:

```

1> Open file /etc/ssh/sshd_config and comment out the below line:
# UsePAM yes
2> Then, restart SSHD using the command:
$ /etc/init.d/S50sshd restart

```

- All configurations are built by the normal user. But, "sudo" permission is required when building ubuntu root file system on HOST machine. User can enter below line to file `/etc/sudoers` to avoid entering sudo password during building ("username" should be changed to the true user name):

```
username ALL=(ALL:ALL) NOPASSWD:ALL
```

- The `PERL_MM_OPT` issue: Users might encounter an error message for the `PERL_MM_OPT` parameter when using the `make` command in some host Linux environments as shown below:

```

You have PERL_MM_OPT defined because Perl local::lib is installed on your system.
Please unset this variable before starting Buildroot, otherwise the compilation of Perl
related packages will fail.
make[1]: *** [core-dependencies] Error 1
make: *** [_all] Error 2

```

To resolve this issue, just unset the `PERL_MM_OPT` parameter.

```
$ unset PERL_MM_OPT
```

3.3 Booting the board


Before proceeding further with the instructions in this section, refer to the *Getting Started Guide* of the respective board for detailed instructions regarding board boot-up. See [Reference documentation](#).

NOTE

- Before booting up the board, user need to install mbed Windows serial port driver in order to obtain the board console. This is a one time activity. Please ignore this step if user have already installed the mbed driver on user system (PC or laptop). User can download the mbed Windows serial port driver from the link below: <https://developer.mbed.org/handbook/Windows-serial-configuration>.
- Download and install Tera Term on the host computer from the Internet. After installation, a shortcut to the tool is created on the desktop of the host computer.
- If user is using a Windows 10 machine as a host computer and encountering a serial port unstable issue, then, disable the *Volume Storage* service of the Windows machine.

All the NXP platforms can be booted up from the SD card or QSPI flash. After the compilation for one platform, the image files (*sdcard.img* or *qspi.img*) are generated in the folder `output/images`. The following table describes the software settings to be used while booting up the NXP platforms with the images built from OpenIL.

Table 10. Switch settings for the NXP boards

| Platform | Boot mode | Image name | Board SWITCH Setting (ON = 1) |
|-----------------|-----------|---|---|
| i.MX6Q SabreSD | SD card | sdcard.img | SW6 = 0b'01000010 |
| i.MX8MMEVK-RevB | SD card | Sdcard.img | SW1101 = 0b'01000110, SW1102 = 0b'00110100 |
| i.MX8MMEVK-RevC | SD card | Sdcard.img | SW1101 = 0b'0110110010, SW1102 = 0b'0001101000 |
| i.MX8MP EVK | SD card | sdcard.img | SW4[1-4] = 0b'0011 |
| LS1012ARDB | QSPI | qspi.cpio  | SW1 = 0b'10100110 SW2 = 0b'00000000 |
| LS1021AIOT | SD card | sdcard.img | SW2[1] = 0b'0 |
| LS1021ATSN | SD card | sdcard.img | SW2 = 0b'111111 |
| LS1021ATWR | SD card | sdcard.img | QSPI enabled: SW2[1-8] = 0b'00101000, SW3[1-8] = 0b'01100001 IFC enabled: SW2[1-8] = 0b'00100000, SW3[1-8] = 0b'01100001 |
| LS1028ARDB | SD card | sdcard.img | SW2[1-8] = 0b'10001000 |
| LS1043ARDB | SD card | sdcard.img | SW4[1-8] +SW5[1] = 0b'00100000_0 |
| LS1046ARDB | SD card | sdcard.img | SW5[1-8] +SW4[1] = 0b'00100000_0 |
| LS1046AFRWW | SD card | sdcard.img | SW1[1-9] = 0b'0_01000000 |
| LX2160ARDB/Rev2 | SD card | sdcard.img | SW1[1-4] = 0b'1000 |

The flash image (*sdcard.img* or *qspi.img*) includes all the information: RCW, DTB, U-Boot, kernel, rootfs, and necessary applications.

NOTE

Make sure the board is set to boot up from SD card or QSPI using software configuration. Refer to the preceding table for the switch settings for the respective platform.

3.3.1 SD card bootup

For platforms that can be booted up from an SD card, following are the steps to program the *sdcard.img* into an SD card:

1. Insert one SD card (at least 4G size) into any Linux host machine.

2. Run the below commands:

```
$ sudo dd if=./sdcard.img of=/dev/sdx
# or in some other host machine:
$ sudo dd if=./sdcard.img of=/dev/mmcblkx

# find the right SD Card device name in user host machine and replace the "sdx" or "mmcblkx".
```

3. Now, insert the SD card into the target board (switch the board boot from SD card first) and power on.

3.3.2 QSPI/FlexSPI bootup

For platforms that can be booted up from QSPI (for example, LS1012ARDB), following are the steps to program the qspi.img into QSPI flash.

Set the board boot from QSPI, then power on, and enter the U-Boot command environment.

FlexSPI (XSPI, image name is xspi.cpio.img) boot has the same commands to make the flash.

```
# In order to void damage the default bank which will cause the board can NOT bootup, we need to
write the image to altbank for ls1012ardb
# First, select the altbank with below command
=>i2c mw 0x24 0x7 0xfc; i2c mw 0x24 0x3 0xf5
# Then, download the image qspi.cpio.img
=>tftp 0x80000000 qspi.cpio.img
# Last, erase the flash and write the image to flash
=>sf probe 0:0
=>sf erase 0x0 +$filesize
=>sf write 0x80000000 0x0 $filesize
=>reset
```

3.3.3 eMMC bootup

For platforms that can be booted up from eMMC (for example, ls1028ardb, ls1046ardb), use the following steps to program the sdcard image into eMMC:

LS1028ARDB eMMC bootup

1. Bootup the ls1028ardb into U-Bootprompt with XSPI or SD boot.
2. Download the image from server.

eMMC boot image is built with `nxp_ls1028ardb-64b-emmc_defconfig`.

Make sure that the network in U-Boot can access the TFTP server and the eMMC bootup image is ready in this server using the command:

```
> tftpboot 0xa0000000 sdcard.img
```

3. Select eMMC as shown in the steps below:

```
=> mmc dev 1
=> mmcinfo
Device: FSL_SDHC
Manufacturer ID: 13
OEM: 14e
Name: Q2J55
Bus Speed: 52000000
Mode: MMC High Speed (52MHz)
Rd Block Len: 512
MMC version 5.0
```

```
High Capacity: Yes
Capacity: 7.1 GiB
Bus Width: 4-bit
Erase Group Size: 512 KiB
HC WP Group Size: 8 MiB
User Capacity: 7.1 GiB WRREL
Boot Capacity: 2 MiB ENH
RPMB Capacity: 4 MiB ENH
```

4. Flash sdcard.img to eMMC:

First, erase eMMC, the block number is calculated by image-bytes/block-size (usually, the block size is 512).

For example, image bytes is 725191680, the block number is: $725191680 / 512 = 0x159CC6$.

In the below example, the image size is assumed to be 725191680 and block number is 0x159CC6, hence parameter greater than 0x159CC6 can be used, for example 0x160000. Users should change this parameter according to the true size of the sdcard.img.

```
=> mmc erase 0 0x160000
-> mmc write 0xa0000000 0 0x160000
```

5. Reset the board to eMMC boot:

```
=> qixis_reset emmc
```

Or, power off the ls1028ardb board, change the switch setting SW2[1-4] = 0b'1001, then power on ls1028ardb, the board can be booted up from eMMC directly.

LS1046ARDB eMMC bootup

- Build two images with `nxp_ls1046ardb-64b-emmc_qspiboot_defconfig` and `nxp_ls1046ardb-64b-emmcboot_defconfig`:
 - `qspi.cpio.img`: built with `nxp_ls1046ardb-64b-emmc_qspiboot_defconfig`
 - `sdcard.img`: built with `nxp_ls1046ardb-64b-emmcboot_defconfig`
- Bootup the ls1046ardb board to uboot prompt with QSPI or SD boot Make sure the U-Boot network can access TFTP server and these two images are ready in this server.
- Flash `qspi.cpio.img` to QSPI to enable eMMC:

```
=> tftpboot 0xa0000000 qspi.cpio.img
=> sf probe 0:0
=> sf erase 0x0 +$filesize
=> sf write 0xa0000000 0x0 $filesize
```

- Remove SD card from SD slot, and reset the board with qspi boot.

```
=> cpld reset qspi
```

- Now the eMMC can be accessed as shown in the console log below:

```
=> mmcinfo
Device: FSL_SDHC
Manufacturer ID: fe
OEM: 14e
Name: PLXXX
Bus Speed: 52000000
Mode : MMC High Speed (52MHz)
Rd Block Len: 512
MMC version 4.5
```



```
High Capacity: Yes
Capacity: 3.6 GiB
Bus Width: 4-bit
Erase Group Size: 512 KiB
HC WP Group Size: 4 MiB
User Capacity: 3.6 GiB
Boot Capacity: 2 MiB ENH
RPMB Capacity: 128 KiB ENH
```

6. Download eMMC bootup image:

```
=> tftpboot 0xa0000000 sdcard.img
```

7. Flash this image to eMMC

First, erase eMMC, the block number is calculated by image-bytes/block-size (usually, the block size is 512).

For example, if image bytes is 738197504, the block number is: $738197504 / 512 = 0x160000$.

The below steps assume that for the image size of 738197504 and the block number $0x160000$, the parameter greater than $0x160000$ can be used, for example $0x170000$.

NOTE

Users should change this parameter according to the actual size of the sdcard image.

```
=> mmc erase 0 0x170000
-> mmc write 0xa0000000 0 0x170000
```

8. Reset the board to use eMMC boot:

```
=> cpld reset sd
```

Or, power off the ls1046ardb board, set the switch to SD boot, and power on the board.

NOTE

Make sure there is not SD card in the SD card slot if the user wants to perform eMMC boot.

3.3.4 Starting up the board

After programming the sdcard or qspi image, startup the board. Users should see the following information on the console.

```

Starting logging: OK
Initializing random number generator... [ 6.120727] random: dd urandom read with 13 bits of entropy available
done.
Mounting cgroupfs hierarchy: OK
Starting system message bus: done
Starting network: OK
ssh-keygen: generating new host keys: RSA DSA ECDSA ED25519
Starting sshd: OK
resize2fs 1.43.3 (04-Sep-2016)
Filesystem at /d[ 7.560413] EXT4-fs (mmcblk0p2): resizing filesystem from 212800 to 2097152 blocks
ev/mmcblk0p2 is [ 7.568527] EXT4-fs (mmcblk0p2): Converting file system to meta_bg
mounted on /; on-line resizing required
old_desc_blocks = 1, new_desc_blocks = 8
[ 7.611678] EXT4-fs (mmcblk0p2): resized filesystem to 2097152
[ 7.825614] random: nonblocking pool is initialized
The filesystem on /dev/mmcblk0p2 is now 2097152 (1k) blocks long.

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                                           openil.org

[root@OpenIL:~]#

```

Figure 2. OpenIL system startup

The system will be logged in automatically.

3.4 Basic OpenIL operations

This section describes the commands that can be used for performing basic OpenIL operations.

In OpenIL, all packages used are in directory `./package/`, and the package name is the sub-directory name. Linux kernel and uboot are also packages, the package name for Linux kernel is `linux`, and package name for u-boot is `uboot`. Packages "linux" and "uboot" is not in directory `./package/`, the path of package "linux" is `./linux`, the path of package "uboot" is `./boot/uboot`.

NOTE

Packages `linux` and `uboot` are not in directory `./package/`.

- The path of package `linux` is `./linux`, and
- The path of package `uboot` is `./boot/uboot`.

Sample usages of the 'make' command:

- Displays all commands executed by using the make command:

```
$ make V=1 <target>
```

- Displays the list of boards with a defconfig:

```
$ make list-defconfigs
```

- Displays all available targets:

```
$ make help
```

- Sets Linux configurations:

```
$ make linux-menuconfig
```

- Deletes all build products (including build directories, host, staging and target trees, images, and the toolchain):

```
$ make clean
```

- Resets OpenIL for a new target.

- Deletes all build products as well as the configuration (including `d1` directory):

```
$ make distclean
```

NOTE

Explicit cleaning is required when any of the architecture or toolchain configuration options are changed.

- **Downloading, building, modifying, and rebuilding a package**

Run the below command to build and install a particular package and its dependencies:

```
$ make <pkg>
```

For packages relying on the OpenIL infrastructure, there are numerous special `make` targets that can be called independently such as the below command:

```
$ make <pkg>-<target>
```

The package build targets are listed in the following table.

Table 11. Package build targets

| Package Target | Description |
|----------------------|---|
| <pkg> | Builds and installs a package and all its dependencies |
| <pkg>-source | Downloads only the source files for the package |
| <pkg>-extract | Extracts package sources |
| <pkg>-patch | Applies patches to the package |
| <pkg>-depends | Builds package dependencies |
| <pkg>-configure | Builds a package up to the configure step |
| <pkg>-build | Builds a package up to the build step |
| <pkg>-show-depends | Lists packages on which the package depends |
| <pkg>-show-rdepends | Lists packages which have the package as a dependency |
| <pkg>-graph-depends | Generates a graph of the package dependencies |
| <pkg>-graph-rdepends | Generates a graph of the package's reverse dependencies |
| <pkg>-dirclean | Removes the package's build directory |
| <pkg>-reconfigure | Restarts the build from the configure step |
| <pkg>-rebuild | Restarts the build from the build step |

Thus, a package can be downloaded in the directory `d1/`, extracted to the directory `output/build/<pkg>`, and then built in the directory `output/build/<pkg>`. User need to modify the code in the `output/build/<pkg>`, and then run the command, `$make <pkg>-rebuild` to rebuild the package.

For more details about OpenIL operations, refer to the Buildroot document available at the URL: <https://buildroot.org/downloads/manual/manual.html#getting-buildroot>.

3.4.1 Building Linux kernel

OpenIL is a tool for building the final flash/SD image, including Linux kernel.

If users want to build the Linux kernel separately, they can follow the below methods:

1. Build Linux kernel in OpenIL without code modified

This is the simple method to build the Linux kernel, using the following command:

```
# enter openil directory
$ cd openil
# make one default configuration file, for example nxp_ls1028ardb-64b_defconfig
$ make nxp_ls1028ardb-64b_defconfig
# build the Linux kernel image, which will be stored in directory output/images/
$ make linux
```

2. Build Linux kernel in OpenIL with code modified: If users want to modify the Linux code and build it, follow the below steps:

a. Clone the Linux repos from github.com/openil/linux

```
$ git clone https://github.com/openil/linux.git
```

b. Enter "linux" repos and checkout to current release tag or any tag user want, for example OpenIL-v1.11-linux-ls-imx6-202104 for layerscape (OpenIL-v1.11-linux-imx-202104 is for IMX).

```
$ git checkout -b OpenIL-v1.11-linux-ls-imx6-202104 OpenIL-v1.11-linux-ls-imx6-202104
```

c. Modify the code and generate the patch following "git" usage.

d. Copy these patches just generated from "linux" directory to openil linux directory with 0001-xx, 0002-xx, ... order

e. Build the Linux image with command "make linux":

```
$ make linux
```

3. Build Linux kernel in separate directory with code modified:

There is another way to build the Linux image with code modified. The following steps explain how to do it bu using ls1028ardb board as an example.

a. Setup cross-compile environment.

```
# downloading toolchain armv8-64bit (ls1028ardb is armv8 and 64bit)
$ wget https://developer.arm.com/-/media/Files/downloads/gnu-a/9.2-2019.12/binrel/gcc-arm-9.2-2019.12-x86_64-aarch64-none-linux-gnu.tar.xz
# extracting the toolchain tarball to /opt
$ tar xvf gcc-arm-9.2-2019.12-x86_64-aarch64-none-linux-gnu.tar.xz -C /opt/
# setting environment variables
$ export PATH=$PATH:/opt/gcc-arm-9.2-2019.12-x86_64-aarch64-none-linux-gnu/bin/
$ export ARCH=arm64
$ export CROSS_COMPILE=aarch64-none-linux-gnu-
```

b. Clone the Linux repos from github.com/openil/linux.

```
$ git clone https://github.com/openil/linux.git
```

- c. Enter "linux" repository and checkout to the current release tag or the desired tag, for example OpenIL-v1.11-linux-ls-imx6-202104 for layerscape (OpenIL-v1.11-linux-imx-202104 is for IMX).

```
$ git checkout -b OpenIL-v1.11-linux-ls-imx6-202104 OpenIL-v1.11-linux-ls-imx6-202104
```

- d. Modify the code.
- e. Build the Linux image using the below command:

```
$ make defconfig lsdk.config
$ make
```

- f. Replace the Linux image : "Image" file built just is in "arch/arm64/boot/", DTB file "fsl-ls1028a-rdb.dtb" is in "arch/arm64/boot/dts/freescale/".

- g. Copy them to openil directory output/images/, and rebuild the flash image with bellow comamnd:

```
# in OpenIL directory
$ make
```

3.4.2 Building U-Boot

OpenIL is a tool for building the final flash/SD image, including U-Boot.

If users want to build the U-Boot separately, they can follow below methods.

1. Build U-Boot in OpenIL without code modified

This is the simple method to build the U-Boot, using the following command below:

```
# enter openil directory
$ cd openil
# make one default configuration file, for example nxp_ls1028ardb-64b_defconfig
$ make nxp_ls1028ardb-64b_defconfig
# build the U-Boot image, which will be stored in directory output/images/
$ make uboot
```

2. Build U-Boot in OpenIL with code modified

- a. If users want to modify the U-Boot code and build it, user can follow below steps.

Clone the U-Boot repository from github.com/openil/u-boot

```
$ git clone https://github.com/openil/u-boot.git
```

- b. Enter "u-boot" repos and checkout to current release tag or any tag user want, for example OpenIL-v1.11-u-boot-ls-imx6-202104:

```
$ git checkout -b OpenIL-v1.11-u-boot-ls-imx6-202104 OpenIL-v1.11-u-boot-ls-imx6-202104
```

- c. Modify the code and generate the patch following "git" usage.
- d. Copy these patches just generated from "u-boot" directory to openil uboot directory "boot/uboot/" with 0001-xx, 0002-xx, ... order.
- e. build the U-Boot image with command "make uboot"

3. **Build U-Boot in separate directory with code modified** There is another way to build the U-Boot image with code modified. The following steps explain how to perform this by using ls1028ardb board as an example.

- a. Setup cross-compile environment as shown below:

```
# downloading toolchain armv8-64bit (ls1028ardb is armv8 and 64bit)
$ wget https://developer.arm.com/-/media/Files/downloads/gnu-a/9.2-2019.12/binrel/gcc-arm-9.2-2019.12-x86_64-aarch64-none-linux-gnu.tar.xz
# extracting the toolchain tarball to /opt
$ tar xvf gcc-arm-9.2-2019.12-x86_64-aarch64-none-linux-gnu.tar.xz -C /opt/
# setting environment variables
$ export PATH=$PATH:/opt/gcc-arm-9.2-2019.12-x86_64-aarch64-none-linux-gnu/bin/
$ export ARCH=arm64
$ export CROSS_COMPILE=aarch64-none-linux-gnu-
```

- b. Clone the U-Boot repository from github.com/openil/u-boot

```
$ git clone https://github.com/openil/u-boot.git
```

- c. Enter "u-boot" repository and checkout to current release tag or any tag user want, for example `OpenIL-v1.11-u-boot-ls-imx6-202104` for layerscape (`OpenIL-v1.11-u-boot-imx-202104` is for IMX):

```
$ git checkout -b OpenIL-v1.11-u-boot-ls-imx6-202104 OpenIL-v1.11-u-boot-ls-imx6-202104
```

- d. Modify the code.

- e. Build the U-Boot image using the below command:

```
$ make ls1028ardb_tfa_defconfig
$ make
```

- f. Replace the U-Boot image. All images just built are in the current u-boot root directory.

- g. Copy `u-boot-dtb.bin` to `openil` directory "`output/images/`", and rebuild the flash image using the bellow comamnd:

```
# in OpenIL directory, build arm-trusted-firmware again, because U-Boot image is used to
generate fip.bin and bl2 image
$ make arm-trusted-firmware
$ make
```

Chapter 4

NXP OpenIL platforms

OpenIL supports the following NXP Layerscape ARM® platforms: LS1012ARDB, LS1021A-TSN, LS1021-IoT, LS1021A-TWR, LS1043ARDB, LS1046ARDB, LS1046AFRWY, LS1028ARDB, LS1028ATSN, LX2160ARDB/Rev2, i.MX6QSabreSD and i.MX8MPEVK. For more information about those platforms, refer to the following URLs:

- <http://www.nxp.com/products/microcontrollers-and-processors/arm-processors/qorIQ-layerscape-arm-processors:QORIQ-ARM>.
- https://www.nxp.com/products/processors-and-microcontrollers/arm-based-processors-and-mcus/i.mx-applications-processors:IMX_HOME

4.1 Introduction

This chapter provides instructions on booting up the boards with a complete SD card or QSPI image. It also describes the process for deploying the U-Boot, Linux kernel, and root file system on the board. The instructions start with generic host and target board pre-requisites. These are followed by the board-specific configurations listed below:

- Switch settings
- U-Boot environment variables
- Device microcodes or firmware
- Reset configuration word (RCW)
- Flash bank usage

NOTE

This chapter is meant for those who want to perform more sub-system debugs, such as U-Boot, kernel, and so on. At the beginning, the board should be booted up and run in U-Boot command environment.

4.2 LS1021A-TSN

The LS1021A Time-Sensitive Networking (TSN) reference design is a platform that allows developers to design solutions with the new IEEE Time-Sensitive Networking (TSN) standard. The board includes the QorIQ Layerscape LS1021A industrial applications processor and the SJA1105T TSN switch. The LS1021A-TSN is supported by an industrial Linux SDK with Xenomai real time Linux, which also provides utilities for configuring TSN on the SJA1105T switch.

With virtualization support, trust architecture, secure platform, Gigabit Ethernet, SATA interface, and an Arduino Shield connector for multiple wireless modules, the LS1021A-TSN platform readily supports industrial IoT requirements.

4.2.1 Switch settings

The following table lists and describes the switch configuration for LS1021ATSN board.

NOTE

OpenIL supports only the SD card boot for LS1021ATSN platform.

Table 12. LS1021ATSN SD boot software setting

| Platform | Boot source | Software setting |
|------------|-------------|------------------|
| LS1021ATSN | SD card | SW2 = 0b'111111 |

4.2.2 Updating target images

Use the following commands to build the images for LS1021A-TSN platform:

- **Building images**

```
$ cd openil
$ make nxp_ls1021atsn_defconfig
$ make
# or make with a log
$ make 2>&1 | tee build.log
```

- **Programming U-Boot in SD card**

Power on the LS1021A-TSN board to the U-Boot command environment, then use the following commands:

```
=>tftp 81000000 u-boot-with-spl-pbl.bin
=>mmc erase 8 0x500
=>mmc write 0x81000000 8 0x500
#then reset the board
```

- **Deploying kernel and Ramdisk from TFTP**

1. Set the U-Boot environment.

```
=>setenv bootargs 'root=/dev/ram0 rw ramdisk_size=50000000 console=ttyS0,115200'
=>saveenv
```

2. Boot up the system.

```
=>tftp 83000000 uImage
=>tftp 88000000 rootfs.cpio.uboot
=>tftp 8f000000 ls1021a-tsn.dtb
=>bootm 83000000 88000000 8f000000
```

4.3 LS1021A-TWR

The NXP® TWR-LS1021A module is a development system based on the QorIQ® LS1021A processor.

This feature-rich, high-performance processor module can be used standalone or as part of an assembled Tower® System development platform.

Incorporating dual Arm® Cortex®-A7 cores running up to 1 GHz, the TWR-LS1021A delivers an outstanding level of performance.

The TWR-LS1021A offers HDMI, SATA3 and USB3 connectors as well as a complete Linux software developer's package.

The module provides a comprehensive level of security that includes support for secure boot, Trust Architecture and tamper detection in both standby and active power modes, safeguarding the device from manufacture to deployment.

4.3.1 Switch settings

The following table lists and describes the switch configuration for LS1021ATWR board.

| Platform | Boot source | SW setting |
|------------|-------------|--|
| LS1021ATWR | SD | IFC enabled: SW2[1~8] = 0b'00101000; SW3[1-8] = 0b'01100001 |
| | | QSPI enabled: SW2[1-8] = 0b'00100000; SW3[1-8] = 0b'01100001 |

4.3.2 Updating target images

Use the following commands to build the images for LS1021A-TWR platform:

- **Building images**

```
$ cd openil
$ make nxp_ls1021atwr_defconfig
$ make
# or make with a log
$ make 2>&1 | tee build.log
```

- **Programming U-Boot in SD card**

Power on the LS1021A-TWR board to the U-Boot command environment, then use the following commands:

```
=>tftp 81000000 u-boot-with-spl-pbl.bin
=>mmc erase 8 0x500
=>mmc write 0x81000000 8 0x500
#then reset the board
```

- **Deploying kernel and Ramdisk from TFTP**

1. Set the U-Boot environment.

```
=>setenv bootargs `root=/dev/ram0 rw ramdisk_size=50000000 console=ttyS0,115200`
=>saveenv
```

2. Boot up the system.

```
=>tftp 83000000 uImage
=>tftp 88000000 rootfs.cpio.uboot
=>tftp 8f000000 ls1021a-twr.dtb
=>bootm 83000000 88000000 8f000000
```

4.4 LS1021A-IoT

The LS1021A-IoT gateway reference design is a purpose-built, small footprint hardware platform equipped with a wide array of both high-speed connectivity and low speed serial interfaces. It is engineered to support the secure delivery of IoT services to end-users at their home, business, or other commercial locations. The LS1021A-IoT gateway reference design offers an affordable, ready-made platform for rapidly deploying a secure, standardized, and open infrastructure gateway platform for deployment of IoT services.

4.4.1 Switch settings

The following table lists and describes the switch configuration for LS1021A-IoT board.

NOTE

OpenIL supports only the SD card boot for the LS1021A-IoT platform.

Table 13. LS1021A-IoT SD boot software setting

| Platform | Boot source | software setting |
|-------------|-------------|------------------|
| LS1021A-IoT | SD card | SW2[1] = 0b'0 |

4.4.2 Updating target images

Use the following commands to build the images for LS1021A-IoT platform:

- **Building images**

```
$ cd openil
$ make nxp_ls1021aiot_defconfig
$ make
# or make with a log
$ make 2>&1 | tee build.log
```

- **Programming U-Boot on the SD card**

Power on the LS1021A-IoT board to U-Boot command environment. Then, use the commands below:

```
=>tftp 81000000 u-boot-with-spl-pbl.bin
=>mmc erase 8 0x500
=>mmc write 0x81000000 8 0x500
#then reset the board
```

- **Deploying kernel and Ramdisk from TFTP**

1. Set the U-Boot environment.

```
=>setenv bootargs 'root=/dev/ram0 rw ramdisk_size=50000000 console=ttyS0,115200'
=>saveenv
```

2. Boot up the system.

```
=>tftp 83000000 uImage
=>tftp 88000000 rootfs.cpio.uboot
=>tftp 8f000000 ls1021a-iot.dtb
=>bootm 83000000 88000000 8f000000
```

4.5 LS1043ARDB, LS1046ARDB and LS1046AFRWY

The QorIQ LS1043A and LS1046A reference design boards are designed to exercise most capabilities of the LS1043A and LS1046A devices. These are NXP's first quad-core, 64-bit ARM®-based processors for embedded networking and industrial infrastructure.

4.5.1 Switch settings

OpenIL supports only the SD card boot mode for LS1043ARDB and the LS1046ARDB platforms.

Table 14. LS1043ARDB/LS1046ARDB SD boot software settings

| Platform | Boot source | Software setting |
|-------------|-------------|----------------------------------|
| LS1043ARDB | SD card | SW4[1-8] +SW5[1] = 0b'00100000_0 |
| LS1046ARDB | SD card | SW5[1-8] +SW4[1] = 0b'00100000_0 |
| LS1046AFRWY | SD card | SW1[1-10] = 0b'0010000000 |

NOTE

In order to identify the LS1043A silicon correctly, users should ensure that the SW5[7-8] is = 0b'11.

4.5.2 Updating target images

For LS1043ARDB, LS1046AFRWY and LS1046ARDB platforms, the OpenIL can support 64-bit systems. Use the following commands to build the images for the LS1043ARDB, LS1046AFRWY or LS1046ARDB platforms:

- **Building images**

```
$ cd openil
$ make nxp_ls1043ardb-64b_defconfig
# or
$ make nxp_ls1046ardb-64b_defconfig
# or
$ make nxp_ls1046afrawy-64b_defconfig
$ make
# or make with a log
$ make 2>&1 | tee build.log
```

- **Programming BL2, RCW, BL31, U-Boot and FMan ucode in SD card**

Power on the LS1043ARDB / LS1046ARDB/LS1046AFRWY board to U-Boot command environment, then use the following commands:

```
# programming BL2 and RCW (for example: boot from SD card)
=> tftpboot 82000000 bl2_sd.pbl
=> mmc erase 8 800
=> mmc write 82000000 8 800
# programming the FMan ucode
=> tftpboot 82000000 fmucode.bin
=> mmc erase 0x4800 0x200
=> mmc write 82000000 0x4800 0x200
# programming the BL31 and U-Boot firmware
=> mmc erase 0x800 0x2000
=> tftpboot 82000000 fip.bin
=> mmc write 82000000 0x800 0x2000
#then reset the board
```

- **Deploying kernel and Ramdisk from TFTP**

1. Set the U-Boot environment.

```
=>setenv bootargs "root=/dev/ram0 earlycon=uart8250,mmio,0x21c0500 console=ttyS0,115200"
=>saveenv
```

2. Boot up the system.

```
# for ls1046ardb
=>tftp 83000000 Image
=>tftp 88000000 rootfs.cpio.uboot
=>tftp 8f000000 fsl-ls1046a-rdb-sdk.dtb
# or for ls1046afrawy
=>tftp 8f000000 fsl-ls1046a-frwy-sdk.dtb
# or for ls1043ardb
=>tftp 8f000000 fsl-ls1043a-rdb-sdk.dtb

=>booti 83000000 88000000 8f000000
```

4.6 LS1012ARDB

The QorIQ [LS1012A](#) processor delivers enterprise-class performance and security capabilities to consumer and networking applications in a package size normally associated with microcontrollers. Combining a 64-bit ARM®v8-based processor with network packet acceleration and QorIQ trust architecture security capabilities, the [LS1012A](#) features line-rate networking performance at 1 W typical power in a 9.6 mm x 9.6 mm package.

The QorIQ LS1012A reference design board (LS1012A-RDB) is a compact form-factor tool for evaluating LS1012A application solutions. The LS1012A-RDB provides an Arduino shield expansion connector for easy prototyping of additional components such as an NXP NFC Reader module.

4.6.1 Switch settings

The LS1012ARDB platform can be booted up only using the QSPI Flash.

The table below lists the default switch settings and the description of these settings.

Table 15. LS1012ARDB QSPI boot software settings

| Platform | Boot source | SW setting |
|------------|--------------|--|
| LS1012ARDB | QSPI Flash 1 | SW1 = 0b'10100110 SW2 = 0b'00000000 |
| | QSPI Flash 2 | SW1 = 0b'10100110 SW2 = 0b'00000010 |

4.6.2 Updating target images

For LS1012ARDB platform, the OpenIL supports 32-bit and 64-bit systems. Use the following commands to build the images for the LS1012ARDB platform:

- **Building images**

```
$ cd openil
$ make nxp_ls1012ardb-64b_defconfig
$ make
# or make with a log
$ make 2>&1 | tee build.log
```

- **Programming BL2, BL31, U-Boot, RCW and pfe firmware in QSPI**

Power on the LS1012ARDB board to U-Boot command environment. Then, use the commands below:

```
# programming BL31 and U-Boot
=>i2c mw 0x24 0x7 0xfc; i2c mw 0x24 0x3 0xf5
=>tftp 0x80000000 fip.bin
=>sf probe 0:0
=>sf erase 0x100000 +$filesize
=>sf write 0x80000000 0x100000 $filesize
# programming BL2 and RCW
=>i2c mw 0x24 0x7 0xfc; i2c mw 0x24 0x3 0xf5
=>tftp 0x80000000 bl2_qspi.pbl
=>sf probe 0:0
=>sf erase 0x0 +$filesize
=>sf write 0x80000000 0x0 $filesize
# programming pfe firmware
=> tftp 0x80000000 pfe_fw_sbl.itb
=> sf probe 0:0
=> sf erase 0xa00000 +$filesize
=> sf write 0x80000000 0xa00000 $filesize
# then reset the board
```

- **Deploying kernel and RAMdisk from TFTP**

1. Set the U-Boot environment.

```
=>setenv bootargs `ttyS0,115200 root=/dev/ram0 earlycon=uart8250,mmio,0x21c0500`
=>saveenv
```

2. Boot up the system.

```
=>tftp a0000000 kernel-ls1012a-rdb.itb
=>bootm a0000000
```

4.7 i.MX6Q SabreSD

The i.MX 6Dual/6Quad processors feature NXP's advanced implementation of the quad ARM® Cortex®-A9 core, which operates at speeds up to 1 GHz. These processors include 2D and 3D graphics processors, 3D 1080p video processing, and integrated power management. Each processor provides a 64-bit DDR3/LVDDR3/LPDDR2-1066 memory interface and a number of other interfaces for connecting peripherals, such as WLAN, Bluetooth®, GPS, hard drive, displays, and camera sensors.

The Smart Application Blueprint for Rapid Engineering (SABRE) board for smart devices introduces developers to the i.MX 6 series of applications processors. Designed for ultimate scalability, this entry level development system ships with the i.MX 6Quad applications processor but is schematically compatible with i.MX6 Dual, i.MX6 DualLite, and i.MX6 Solo application processors. This helps to reduce time to market by providing a foundational product design and serves as a launching point for more complex designs.

4.7.1 Switch settings for the i.MX6Q SabreSD

The following table lists and describes the switch configuration for i.MX6Q SabreSD board:

NOTE

OpenIL supports only the SD card boot for the i.MX6Q SabreSD platform.

Table 16. Switch configuration for the i.MX6Q SabreSD board

| Platform | Boot source | Software setting |
|----------------|-------------------|----------------------|
| i.MX6Q SabreSD | SD card on slot 3 | SW2[1] = 0b'01000010 |

4.7.2 Updating target images

Use the following commands to build the images for i.MX6Q SabreSD platform:

Building images

```
$ cd openil
$ make imx6q-sabresd_defconfig
$ make
# or make with a log
$ make 2>&1 | tee build.log

# See built images as follows:
$ ls output/images/
boot.vfat imx6q-sabresd.dtb rootfs.ext2 rootfs.ext2.gz rootfs.ext4.gz rootfs.tar sdcad.img
SPL u-boot.bin u-boot.img zImage
```

Programming U-Boot on the SD card

Power on the board to U-Boot command environment. Then, use the commands below:

```
$ dd if=SPL of=/dev/sdX bs=1K seek=1
$ dd if=u-boot.imx of=/dev/sdX bs=1K seek=69; sync
```

NOTE

Replace `sdX` with user own SD card 'node name' detected by the system.

Deploying kernel and device tree image

Kernel and device tree image are stored in the first partition (vfat) of SD card.

```
$ cp -avf imx6q-sabresd.dtb /mnt
$ cp -avf zImage /mnt
$ umount /mnt
```

NOTE

`/mnt` is the mount point of the vfat partition.

4.8 LS1028ARDB and LS1028ATSN

The QorIQ® LS1028A reference design board (LS1028ARDB) is a computing, evaluation, development, and test platform supporting the QorIQ LS1028A processor, which is a dual-core Arm® Cortex®-v8 A72 processor with frequency up to 1.3 GHz. The LS1028ARDB is optimized to support SGMII (1 Gbit/s), QSGMII (5 Gbit/s), PCIe x1 (8 Gbit/s), and SATA (6 Gbit/s) over high-speed SerDes ports, USB 3.0, DisplayPort, and also a high-bandwidth DDR4 memory. The LS1028ARDB can be used to develop and demonstrate human machine interface systems, industrial control systems such as robotics controllers and motion controllers, and PLCs. The reference design also provides the functionality needed for Industrial IoT gateways, edge computing, industrial PCs, and wireless or wired networking gateways.

LS1028ATSN board integrates three SJA1105 TSN switches, which will extend the TSN switch to 12 ports.

4.8.1 Switch settings

The following table lists and describes the switch configuration for LS1028ARDB board.

| Platform | Boot source | SW setting |
|------------|-------------|------------------|
| LS1028ARDB | SD | sw2: 0b'10001000 |

4.8.2 Interface naming

The following section describes the association between physical interfaces and networking interfaces as presented by the software.

4.8.2.1 Interface naming in U-Boot

The following figure shows the Ethernet ports as presented in U-Boot:

Note: In U-Boot running on RDB, only `enet#0` is functional.

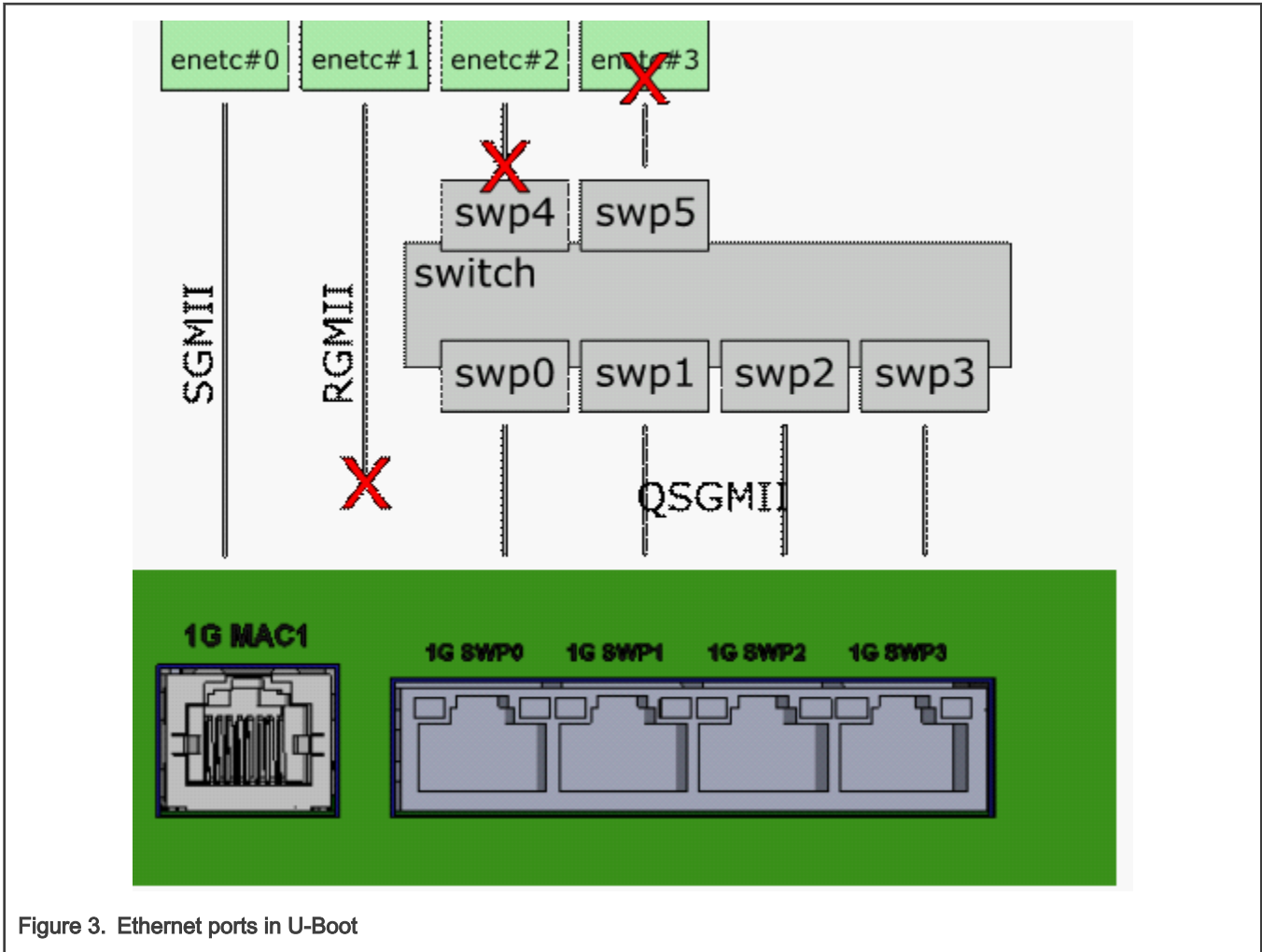


Figure 3. Ethernet ports in U-Boot

Table 17. Interface naming in U-Boot

| RDB port | U-Boot interface | PCI function | Comments |
|--------------------|------------------|--------------|---|
| 1G MAC1 | <i>enetc#0</i> | 0000:00:00.0 | <i>enetc#0</i> is 1G SGMII port of ENETC. |
| N/A | <i>enetc#1</i> | 0000:00:00.1 | <i>enetc#1</i> is presented in U-Boot on all boards. This interface is not functional on RDB. |
| Internal | <i>enetc#2</i> | 0000:00:00.2 | Connected internally (MAC to MAC) to the Ethernet switch. Note that the switch is not initialized in U-Boot; therefore, this interface is not functional. |
| Internal | <i>enetc#3</i> | 0000:00:00.6 | Connected internally (MAC to MAC) to the Ethernet switch. This interface is presented if bit 851 is set in RCW. Note that the switch is not initialized in u-boot; therefore, this interface is not functional. |
| 1G SWP0 to 1G SWP3 | N/A | 0000:00:00.5 | The switch is currently not initialized by U-Boot; therefore, these interfaces are not functional. |

4.8.2.2 Interface naming in Linux

The following figure shows how Ethernet ports are presented in Linux for LS1028ARDB.

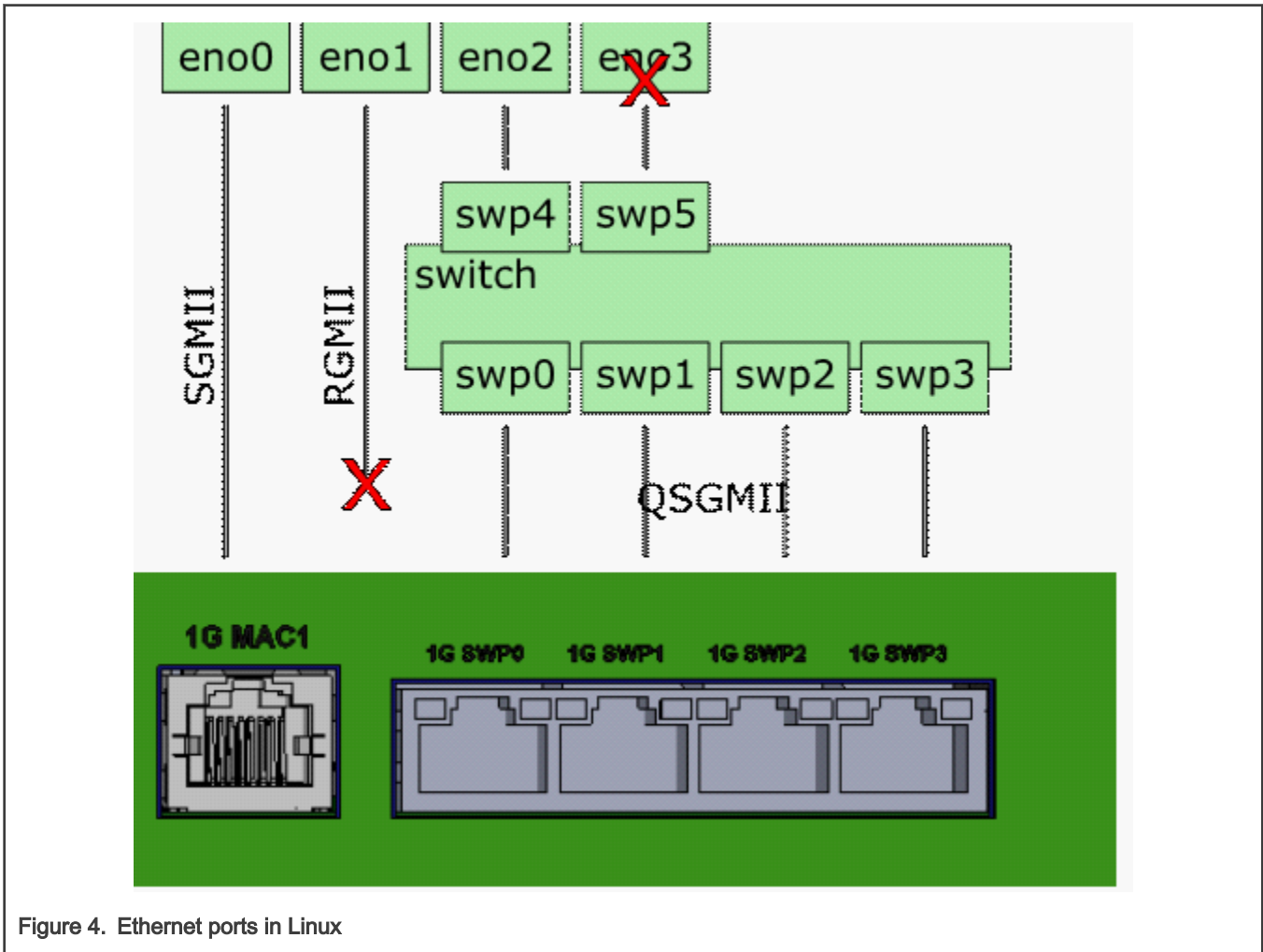


Figure 4. Ethernet ports in Linux

Table 18. Interface naming in Linux

| RDB port | Linux netdev | PCI function | Comments |
|----------|--------------|--------------|---|
| 1G MAC1 | <i>eno0</i> | 0000:00:00.0 | |
| N/A | <i>eno1</i> | 0000:00:00.1 | RGMII interface is not present on RDB board and the associated ENETC interface is disabled in device tree: <pre> &enetc_port1 { status = "disabled"; } </pre> |
| Internal | <i>eno2</i> | 0000:00:00.2 | Connected internally (MAC to MAC) to <i>swp4</i> . This is used to carry traffic between the switch and software running on ARM cores. |

Table continues on the next page...

Table 18. Interface naming in Linux (continued)

| | | | |
|-------------------------------|----------------------------|--------------|---|
| Internal | <i>eno3</i> | 0000:00:00.6 | Connected internally (MAC to MAC) to <i>swp5</i> . This is intended to be used by user- space data-path applications and is disabled by default. It can be enabled by setting bit 851 in RCW. |
| 1G SWP0 to 1G SWP3 | <i>swp0</i> to <i>swp3</i> | 0000:00:00.5 | By default, switching is not enabled on these ports. |
| Internal | <i>swp4</i> | | Connected internally (MAC to MAC) to <i>eno2</i> . |
| Internal | <i>swp5</i> | | Last switch port (connected to <i>eno3</i>) is currently not presented in Linux. |

4.8.2.3 Interface naming for LS1028ATSN

The following figure shows how Ethernet ports are presented both in uboot and Linux.

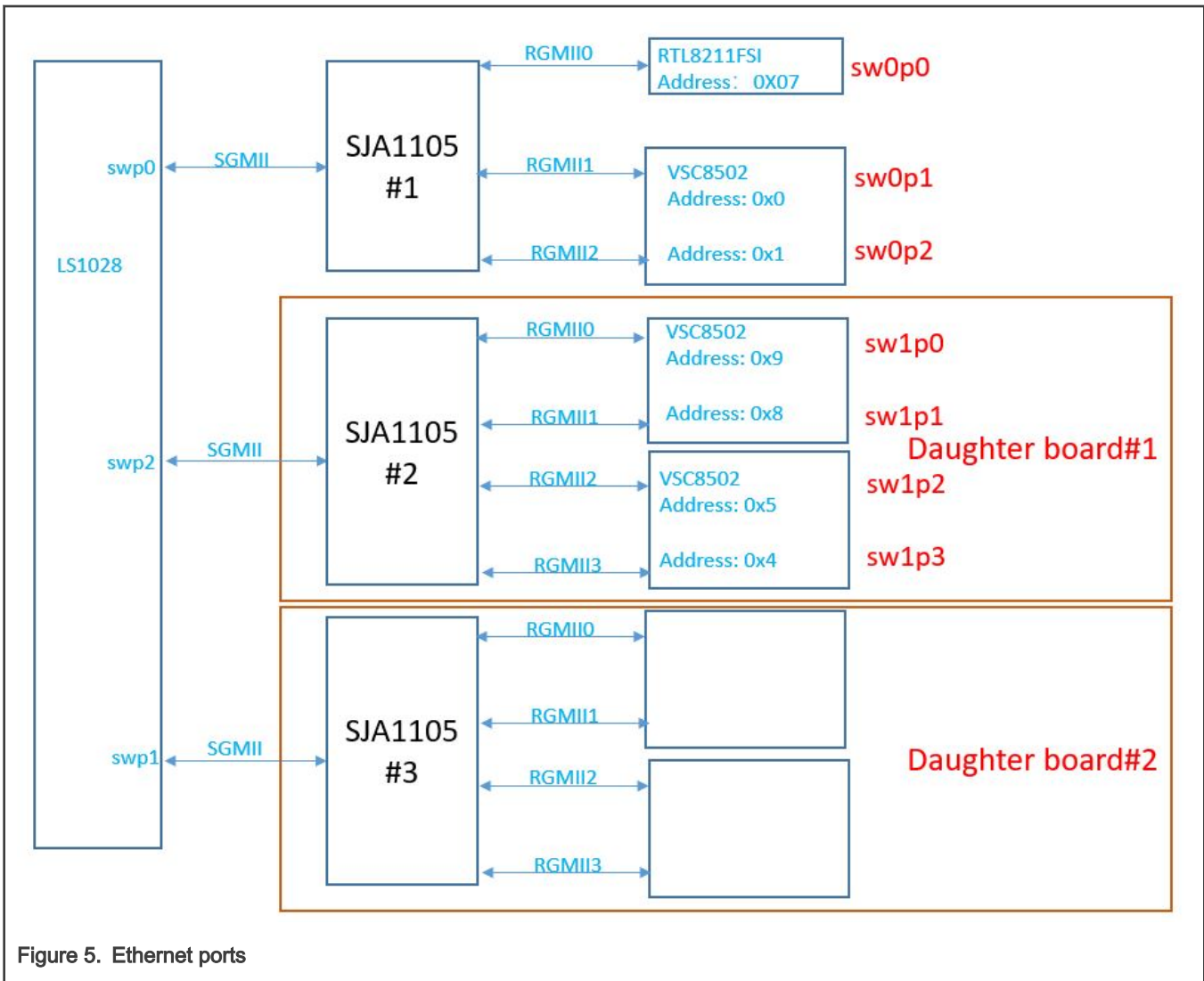


Figure 5. Ethernet ports

Table 19. Interface naming both in uboot and Linux

| LS1028ATSN port | Linux netdev | PCI function | Comments |
|---------------------|----------------------------|--------------|---|
| 1G MAC1 | <i>eno0</i> | 0000:00:00.0 | |
| N/A | <i>eno1</i> | 0000:00:00.1 | |
| Internal | <i>eno2</i> | 0000:00:00.2 | Connected internally (MAC to MAC) to <i>swp4</i> . This is used to carry traffic between the switch and software running on ARM cores. |
| Internal | <i>eno3</i> | 0000:00:00.6 | Connected internally (MAC to MAC) to <i>swp5</i> . This is intended to be used by user- space data-path applications and is disabled by default. It can be enabled by setting bit 851 in RCW. |
| Internal | <i>swp0</i> to <i>swp3</i> | 0000:00:00.5 | By default, switching is not enabled on these ports. |
| Internal | <i>swp4</i> | | Connected internally (MAC to MAC) to <i>eno2</i> . |
| Internal | <i>swp5</i> | | Last switch port (connected to <i>eno3</i>) is currently not presented in Linux. |
| 1G sw0p0 ~ 1G sw0p2 | sw0p0~ sw0p2 | | Connected internal swp0 |
| 1G sw1p0 ~ 1G sw1p3 | sw1p0 ~ sw1p3 | | Connected internal swp2 |

4.8.3 Updating target images

This section describes how to update the target images for NXP's LS1028ARDB/LS1028ATSN platforms. For this platform, OpenIL can support 64-bit systems. Use the following commands to build the images for the LS1028ARDB/LS1028ATSN platforms:

1. Building images

```
$ cd openil
$ make nxp_ls1028ardb-64b_defconfig
# or
$ make fii_ls1028atsn-64b_defconfig
$ make # or make with a log
$ make 2>&1 | tee build.log
```

2. Programming BL2, RCW, BL31, U-Boot in SD card:

Power on the LS1028ARDB/LS1028ATSN board to U-Boot command environment, then use the following commands:

```
# programming the BL2 and RCW (for example: boot from SD card) binary
=> tftpboot 82000000 bl2_sd.pbl
=> mmc erase 8 0x800
=> mmc write 0x82000000 8 0x800
# programming BL31 and U-Boot
=> tftpboot 82000000 fip.bin
=> mmc erase 0x800 0x800
=> mmc write 82000000 0x800 0x2000
# programming the u-boot environment
=> tftpboot 82000000 uboot-env.bin
=> mmc erase 0x2800 0x800
```

```
=> mmc write 82000000 0x2800 0x800
#then reset the board
```

3. Deploying kernel and Ramdisk from TFTP

- Set the U-Boot environment using the commands below:

```
=> setenv bootargs
"root=/dev/ram0 earlycon=uart8250,mmio,0x21c0500 console=ttyS0,115200"
=> saveenv
```

- Boot up the system

```
=> tftp 83000000 Image
=> tftp 88000000 rootfs.cpio.uboot
=> tftp 8f000000 fsl-ls1028a-rdb.dtb
# or
=> tftp 8f000000 fii-ls1028a-tsn.dtb
=> booti 83000000 88000000 8f000000
```

4.8.4 LCD controller and DisplayPort/eDP

The LCD controller is a system master that fetches graphics stored in internal or external memory and displays them on a TFT LCD panel, with resolution up to 4k (3840x2160).

The display PHY controller offers multi-protocol support of standards, such as eDP and DisplayPort with one of these standards supported at a time.

Following will describe how to setup one lightweight desktop on LS1028ARDB.

1. Building image

```
$ cd openil
$ make nxp_ls1028ardb-64b_ubuntu_full_defconfig
$ make -j8
# Flash image sdcard.img to SD card and extend the second partition to full space of the card as
previous chapter describes.
```

2. Connect the displayer to LS1028ARDB:

The default resolution for LS1028ARDB in OpenIL is 1080P (video=1920x1080-32@60), so one displayer support 1080P is required. If other resolution is wanted, the environment variable "bootargs" in u-boot should be modified according to the required resolution.

LS1028ARDB has one DP for display, connect LS1028ARDB to displayer with DP cable.

3. Install lightweight desktop:

Xubuntu desktop is one example.

Xubuntu is an elegant and easy to use operating system. Xubuntu comes with Xfce, which is a stable, light and configurable desktop environment. Xubuntu is perfect for those who want the most out of their desktops, laptops and netbooks with a modern look and enough features for efficient, daily usage.

```
# Get the IP address (make sure ubuntu can get the IP address automatically or set it manually)
root@LS1028ARDB-Ubuntu:~# dhclient
# Update source list (make sure LS1028ARDB can access internet, setup the proxy if necessary)
root@LS1028ARDB-Ubuntu:~# apt update
# Install Xubuntu desktop (More than 2GB space is needed and it will take some time to finish this
job)
root@LS1028ARDB-Ubuntu:~# apt install xubuntu-desktop
# Add new user and enter the password
```

```
# Reboot LS1028ARDB board
root@LS1028ARDB-Ubuntu:~# reboot
# After rebooting, login dialog will be appeared on displayer, select the user and enter the password
to login.
```

4.9 LX2160ARDB/Rev2

The QorIQ LX2160A/Rev2 processor is built on NXP's software-aware, core-agnostic DPAA2 architecture, which delivers scalable acceleration elements sized for application needs, unprecedented efficiency, and smarter, more capable networks. When coupled with ease-of-use facilities such as real-time monitoring and debug, virtualization, and software management utilities, the available toolkits allow for both hardware and software engineers to bring a complete solution to market faster than ever.

The LX2160A integrated multicore processor combines sixteen Arm® Cortex®-A72 processor cores with 24 lanes of the latest 25 GHz SerDes technology supporting high-performance Ethernet speeds (10 Gbps, 25 Gbps, 40 Gbps, 50 Gbps, and 100 Gbps) and PCI express to Gen4 (16 Gbps). With the low power of FinFET process technology and common network and peripheral bus interfaces, the LX2160A is well suited for networking, telecom/datacom, wireless infrastructure, storage and military/aerospace applications.

The LX2160A processor is supported by a consistent API that provides both basic and complex manipulation of the hardware peripherals in the device, releasing the developer from the classic programming challenges of interfacing with new peripherals at the hardware level.

The QorIQ LX2160A reference design board is a 1U form-factor tool for evaluation and design of value-added networking applications such as 5G packet processing, network-function virtualization (NFV) solutions, edge computing, white box switching, industrial applications, and storage controllers.

4.9.1 Switch settings

The following table lists and describes the switch configuration for LX2160ARDB board.

| Platform | Boot source | SW setting |
|------------|-------------|-------------------|
| LX2160ARDB | SD | sw1[1~4]: 0b'1000 |

4.9.2 Updating target images

Use the following commands to build the images for LX2160ARDB platform:

- **Building images**

```
$ cd openil
$ make nxp_lx2160ardb-64b_defconfig
$ make
# or make with a log
$ make 2>&1 | tee build.log
```

- **Programming BL2 and RCW , BL31 and U-Boot on the SD card**

Power on the LX2160ARDB board to U-Boot command environment. Then, use the commands below:

```
# flash BL2 and RCW (for example: boot from SD card) binary
=>tftp 81000000 bl2_sd.pbl
=>mmc erase 8 0x500
=>mmc write 0x81000000 8 0x500
# flash BL31 and U-Boot binary
=>tftp 81000000 fip.bin
=>mmc erase 0x800 0x2000
=>mmc write 0x81000000 0x800 0x2000
# flash DDR firmware
```

```

=>tftp 81000000 fip_dds.bin
=>mmc erase 0x4000 0x400
=>mmc write 0x81000000 0x4000 0x400
# flash phy-ucode firmware
=>tftp 81000000 phy-ucode.txt
=>mmc erase 0x4C00 0x200
=>mmc write 0x81000000 0x4C00 0x200
# flash MC firmware
=>tftp 81000000 mc.itb
=>mmc erase 0x5000 0x1800
=>mmc write 0x81000000 0x5000 0x1800
# flash dpl-eth firmware
=>tftp 81000000 dpl-eth.19.dtb
=>mmc erase 0x6800 0x800
=>mmc write 0x81000000 0x6800 0x800
# flash dpc-usxgmii firmware
=>tftp 81000000 dpc-usxgmii.dtb
=>mmc erase 0x7000 0x800
=>mmc write 0x81000000 0x7000 0x800
#then reset the board

```

• Deploying kernel and Ramdisk from TFTP

1. Set the U-Boot environment.

```

=>setenv bootargs 'console=ttyAMA0,115200 root=/dev/ram0 rw
rootwait earlycon=pl011,mmio32,0x21c0000'
=>saveenv

```

2. Boot up the system.

```

=>mmcinfo;mmc read $mc_fw_addr 0x05000 0x1800;mmc read $dpc_addr 0x07000 0x800;mmc read
$dpl_addr 0x06800 0x800;fsl_mc start mc $mc_fw_addr $dpc_addr;fsl_mc apply dpl $dpl_addr;
=>tftp 83000000 Image
=>tftp 88000000 rootfs.cpio.uboot
=>tftp 8f000000 fsl-lx2160a-rdb.dtb
=>booti 83000000 88000000 8f000000

```

4.10 i.MX8M Plus EVK

The i.MX 8M Plus family is a set of NXP products focused on machine learning applications, combining state-of-art multimedia features with high-performance processing optimized for low-power consumption. The i.MX 8M Plus Media Applications Processor is built to achieve both high performance and low power consumption and relies on a powerful, fully coherent core complex based on a quad Cortex-A53 cluster and Cortex-M7 low-power coprocessor, audio digital signal processor, machine learning, and graphics accelerators.

The i.MX 8M family provides additional computing resources and peripherals:

- Advanced security modules for secure boot, cipher acceleration and DRM support
- A wide range of audio interfaces including I2S, AC97, and TDM
- Large set of peripherals that are commonly used in consumer/industrial markets including USB, PCIe, and Ethernet.

The i.MX 8M Plus Media Applications Processor targets applications on:

- Smart homes, buildings and cities
- Machine learning and industrial automation
- Consumer and pro-audio/voice systems

4.10.1 Switch settings for the i.MX8MPEVK

The following table lists and describes the switch configuration for i.MX8MPEVK board:

NOTE

Open IL supports only the SD card boot for the i.MX8MPEVK platform.

Table 20. Switch configuration for the i.MX8MPEVK board

| Platform | Boot source | Software setting |
|------------|---------------|--------------------|
| i.MX8MPEVK | MicroSD/SDHC2 | SW4[1-4] = 0b'0011 |

4.10.2 Updating target images

Use the following commands to build the images for i.MX8MPEVK platform:

- **Building images**

```
$ cd openil
$ make imx8mpevk_defconfig
$ make
# or make with a log
$ make 2>&1 | tee build.log
```

- **Programming U-Boot in SD card**

Power on the i.MX8MPEVK board to the U-Boot command environment, then use the following commands:

```
=>tftp 81000000 imx8-boot-sd.bin
=>mmc erase 64 0xD00
=>mmc write 0x81000000 64 0xD00
#then reset the board
```

- **Deploying kernel and Ramdisk from TFTP**

1. Boot up the system.

```
=>tftp 83000000 Image
=>tftp 88000000 rootfs.cpio.uboot
=>tftp 8f000000 imx8mp-evk
=>booti 83000000 88000000 8f000000
```

4.11 i.MX8M Mini EVK

The i.MX 8M Mini applications processor is a member of the i.MX 8M family of products focused on delivering an excellent video and audio experience, combining media-specific features with high-performance processing optimized for low-power consumption.

The i.MX 8M Mini provides additional computing resources and peripherals:

- 4x Arm® Cortex®-A53
- 1x Arm Cortex-M4
- Mini-SAS MIPI-DSI connector for display
- Mini-SAS MIPI-CSI connector for camera
- M.2 connector for Wi-Fi/BT (PCIe, I2 C, etc.)

4.11.1 Switch settings for the i.MX8MMEVK

The following table lists and describes the switch configuration for i.MX8MMEVK board: NOTE:

OpenIL supports only the SD card boot for the i.MX8MMEVK platform.

Table 20. Switch configuration for the i.MX8MMEVK board

Table 21.

| Platform | Boot source | Switch setting |
|---------------------------|----------------|--|
| i.MX8MMEVK RevB | MicroSD/uSDHC2 | SW1101 = 0b'01000110 SW1102 = 0b'00110100 |
| i.MX8MMEVK RevC (default) | MicroSD/uSDHC2 | SW1101 = 0b' 0110110010 SW1102 = 0b' 0001101000 |

4.11.2 Updating target images

Use the following commands to build the images for i.MX8MPEVK platform:

- Building images

```
$ cd openil
```

```
$ make imx8mmevk_defconfig
```

```
$ make
```

```
# or make with a log
```

```
$ make 2>&1 | tee build.log
```

- Programming U-Boot in SD card

Power on the i.MX8MMEVK board to the U-Boot command environment, then use the following commands:

```
=>tftp 81000000 imx8-boot-sd.bin
```

```
=>mmc erase 66 0xD00
```

```
=>mmc write 0x81000000 66 0xD00
```

```
#then reset the board
```

- Deploying kernel and Ramdisk from TFTP

1. Boot up the system.

```
=>tftp 83000000 Image
```

```
=>tftp 88000000 rootfs.cpio.uboot
```

```
=>tftp 8f000000 imx8mm-evk
```

```
=>booti 83000000 88000000 8f000000
```

Chapter 5

Industrial features

This section provides a description of the following industrial features: NETCONF/YANG, TSN, Xenomai, IEEE 1588 and SELinux.

NOTE

For the Industrial IoT baremetal framework, refer to the document, *Industrial_IoT_Baremetal_Framework_Developer_Guide* available at https://www.nxp.com/support/developer-resources/nxp-designs/time-sensitive-networking-solution-for-industrial-iot:LS1021A-TSN-RD?tab=Documentation_Tab.

5.1 Deterministic Network

Deterministic network includes Time Sensitive Networking (TSN) and IEEE 1588 (Precise Time Protocol)/802.1AS.

5.1.1 IEEE 1588/802.1AS

IEEE 1588 is the IEEE standard for a precision clock synchronization protocol for networked measurement and control systems.

IEEE 802.1AS is the IEEE standard for local and metropolitan area networks – timing and synchronization for time-sensitive applications in bridged local area networks. It specifies the use of IEEE 1588 specifications where applicable in the context of IEEE Std 802.1D-2004 and IEEE Std 802.1Q-2005.

NXP's QorIQ platform provides hardware assist for 1588 compliant time stamping with the 1588 timer module to support applications of IEEE 1588/802.1AS.

5.1.2 TSN

On the LS1021A-TSN platform, TSN features are implemented as part of the **SJA1105TEL** Automotive Ethernet L2 switch. These are:

- MII, RMII, RGMII, 10/100/1000 Mbps
- IEEE 802.1Q: VLAN frames and L2 QoS
- IEEE 1588v2: Hardware forwarding for one-step sync messages
- IEEE 802.1Qci: Ingress rate limiting (per-stream policing)
- IEEE 802.1Qbv: Time-aware traffic shaping
- Statistics for transmitted, received, dropped frames, buffer load
- TTEthernet (SAE AS6802)

5.2 Real Time

OpenIL support three real time world, Xenomai, Preempt-RT and Baremetal.

5.2.1 PREEMPT-RT

This option turns the kernel into a real-time kernel by replacing various locking primitives (spinlocks, rwlocks, etc.) with preemptible priority-inheritance aware variants, enforcing interrupt threading and introducing mechanisms to break up long non-preemptible sections. This makes the kernel, except for very low level and critical code pathes (entry code, scheduler, low level interrupt handling) fully preemptible and brings most execution contexts under scheduler control.

5.2.2 Xenomai

NOTE

Xenomai is not yet supported in the current OpenIL release.

Xenomai is a free software framework adding real-time capabilities to the mainline Linux kernel. Xenomai also provides emulators of traditional RTOS APIs, such as VxWorks® and pSOS®. Xenomai has a strong focus on embedded systems, although it runs over mainline desktop and server architectures as well.

Xenomai 3 is the new architecture of the Xenomai real-time framework, which can run seamlessly side-by-side Linux as a co-kernel system, or natively over mainline Linux kernels. In the latter case, the mainline kernel can be supplemented by the [PREEMPT-RT patch](#) to meet stricter response time requirements than standard kernel preemption would bring.

One of the two available real-time cores is selected at build time.

Xenomai can help user in:

- Designing, developing, and running a real-time application on Linux.
- Migrating an application from a proprietary RTOS to Linux.
- Optimally running real-time applications alongside regular Linux applications.

Xenomai features are supported for LS1021A-TSN, LS1043ARDB, LS1046ARDB, LS1028ARDB, and i.MX6Q SabreSD. More information can be found at the Xenomai official website: <http://xenomai.org/>.

5.2.3 Baremetal

Baremetal is another real time mode, please refer to **Industrial IoT Baremetal Framework Developer Guide** for detail.

5.3 Industrial Protocols

Many industrial protocols have been supported.

5.3.1 EtherCAT

OpenIL supports the use of EtherCAT ((Ethernet for Control Automation Technology) and integrates the IGH EtherCAT master stack. EtherCAT support is verified on NXP's LS1021-IoT, LS1043ARDB, LS1046ARDB, and LS1028ARDB platforms.

5.3.2 OPC-UA

OPC (originally known as “OLE for Process Control”, now “Open Platform Communications”) is a collection of multiple specifications, most common of which is OPC Data Access (OPC DA).

OPC Unified Architecture (OPC UA) was released in 2010 by the OPC Foundation as a backward incompatible standard to OPC Classic, under the name of IEC 62541.

5.3.3 FlexCAN

Both the LS1021A and LS1028A boards have the FlexCAN module. The FlexCAN module is a communication controller implementing the CAN protocol according to the CAN 2.0 B protocol specification. The main sub-blocks implemented in the FlexCAN module include an associated memory for storing message buffers, Receive (Rx) Global Mask registers, Receive Individual Mask registers, Receive FIFO filters, and Receive FIFO ID filters.

5.3.4 NFC

The NXP's PN7120 NFC IC integrates an ARM™ Cortex-M0 MCU, which enables easier integration into designs, because it requires fewer resources from the host MCU. The integrated firmware provides all NFC protocols for performing the contactless communication in charge of the modulation, data processing and error detection.

5.3.5 BLE

LS1028ARDB support BLE click board, BLE P click carries the nRF8001 IC that allows user to add Bluetooth 4.0 to the device.

5.3.6 BEE/ZigBEE

LS1028ARDB support BEE click board, which can implement the MRF24J40MA 2.4 GHz IEEE 802.15.4 radio transceiver module from Microchip.

5.3.7 4G-LTE

LTE is an abbreviation for Long Term Evolution. LTE is a 4G wireless communications standard developed by the 3rd Generation Partnership Project (3GPP) that's designed to provide up to 10x the speeds of 3G networks for mobile devices such as smartphones, tablets, netbooks, notebooks and wireless hotspots.

5.4 Security

OpenIL support SELinux for security.

5.4.1 SELinux

SELinux is a security enhancement to Linux that allows users and administrators better access control.

Access can be constrained on variables so as to enable specific users and applications to access specific resources. These resources may take the form of files. Standard Linux access controls, such as file modes (-rwxr-xr-x) are modifiable by the user and the applications which the user runs. Conversely, SELinux access controls are determined by a policy loaded on the system, which are not changed by careless users or misbehaving applications.

SELinux also adds finer granularity to access controls. Instead of only being able to specify who can read, write or execute a file, for example, SELinux lets user specify who can unlink, append only, move a file, and so on. SELinux allows user to specify access to many resources other than files as well, such as network resources and interprocess communication (IPC).

More information can be found at official Security Enhanced Linux (SELinux) project page: <https://selinuxproject.org>.

5.5 Remote Management

NXP OpenIL remote management includes some important features, for example NETCONF/YANG and NXP servo (EtherCAT configuration).

5.5.1 NETCONF/YANG

- NETCONF v1.0 and v1.1 compliant ([RFC 6241](#))
- NETCONF over SSH ([RFC 6242](#)) including Chunked Framing Mechanism
- DNSSEC SSH Key Fingerprints ([RFC 4255](#))
- NETCONF over TLS ([RFC 5539bis](#))
- NETCONF Writable-running capability ([RFC 6241](#))
- NETCONF Candidate configuration capability ([RFC 6241](#))
- NETCONF Validate capability ([RFC 6241](#))
- NETCONF Distinct startup capability ([RFC 6241](#))
- NETCONF URL capability ([RFC 6241](#))
- NETCONF Event Notifications ([RFC 5277](#) and [RFC 6470](#))
- NETCONF With-defaults capability ([RFC 6243](#))
- NETCONF Access Control ([RFC 6536](#))

- NETCONF Call Home ([Reverse SSH draft, RFC 5539bis](#))
- NETCONF Server Configuration ([IETF Draft](#))

5.6 Display

Some NXP platforms have integrated display and GPU module.

This section describes the high-level details of the peripherals that comprise the display on NXP chip (for example i.MX8MPEVK, LS1028ATSN and LS1028ARDB). This peripheral is interconnected through the chip to support several application specific solutions that include the use of ML / AI accelerator and vision.

Following display support:

- LCDIF Display Controllers
- LVDS interfaces
- HDMI interface
- DP interface

5.6.1 GPU

Both LS1028A and i.MX8MP have integrated this GPU, the chip incorporates the following Graphics Processing Unit (GPU) features:

- 2D/3D acceleration
- 2 shader
- Supports OpenGL ES 1.1, 2.0, 3.0
- Supports OpenCL 1.2
- Supports Vulkan
- Supports multi-source composition
- Supports one-pass filter
- Supports tile format

5.6.2 Weston

Weston is the reference implementation of a Wayland compositor, and a useful compositor in its own right. Weston has various backends that lets it run on Linux kernel modesetting and evdev input as well as under X11.

LS1028A and i.MX8MP has the display interface, and OpenIL enable weston desktop for these two platforms.

5.6.3 QT

Qt is a full development framework with tools designed to streamline the creation of applications and user interfaces for desktop, embedded, and mobile platforms. LS1028ARDB enables QT5 support.

5.6.4 Camera

i.MX8MM supports two 4-lane MIPI CSI2 camera input. The key features of the MIPI CSI2 (controller and PHY) include:

- Compliant to MIPI-CSI2 standard
- Support up to 4 data lanes
- When one ISP is used, MIPI CSI interface 1 supports:
- Pixel clock up to 400MHz at nominal voltage and 500MHz at overdrive Voltage
- 80Mbps - 1.5Gbps per lane data rate in high speed operation

- When two ISPs are used, both MIPI CSI interfaces supports:
- Pixel clock up to 266MHz at nominal and overdrive voltage
- 80Mbps - 1.5Gbps per lane data rate in high speed operation maximum speed of 1.5Gbps per lane is only supported when 2 data lanes are used)
- When used in conjunction with output to the ISP, the RAW8, RAW10, RAW12, and RAW14 image formats are supported
- When used in conjunction with output to the ISI, the YUV420 (8-bit and 10-bit), YUV422 (8-bit and 10-bit), RGB565, RGB666, RGB888 image formats (and user defined packets such as JPEG) are supported
- Support 10Mbps data rate in low power operation

Chapter 6

IEEE 1588/802.1AS

IEEE 1588 is the IEEE standard for a precision clock synchronization protocol for networked measurement and control systems.

IEEE 802.1AS is the IEEE standard for local and metropolitan area networks – timing and synchronization for time-sensitive applications in bridged local area networks. It specifies the use of IEEE 1588 specifications where applicable in the context of IEEE Std 802.1D-2004 and IEEE Std 802.1Q-2005.

NXP's QorIQ platform provides hardware assist for 1588 compliant time stamping with the 1588 timer module to support applications of IEEE 1588/802.1AS.

6.1 Introduction

NXP's QorIQ platform provides hardware assist for 1588 compliant time stamping with the 1588 timer module. The software components required to run IEEE 1588/802.1AS protocol utilizing the hardware feature are listed below:

1. Linux PTP Hardware Clock (PHC) driver
2. Linux Ethernet controller driver with hardware timestamping support
3. A software stack application for IEEE 1588/802.1AS

NOTE

In this document, IEEE 1588 mentioned is IEEE 1588-2008, and IEEE 802.1AS mentioned is IEEE 802.1AS-2011.

6.2 IEEE 1588 device types

There are five basic types of PTP devices in IEEE 1588.

- **Ordinary clock**

A clock that has a single Precision Time Protocol (PTP) port in a domain and maintains the timescale used in the domain. It may serve as a source of time (be a master clock) or may synchronize to another clock (be a slave clock).

- **Boundary clock**

A clock that has multiple Precision Time Protocol (PTP) ports in a domain and maintains the timescale used in the domain. It may serve as a source of time (be a master clock) or may synchronize to another clock (be a slave clock).

- **End-to-end transparent clock**

A transparent clock that supports the use of the end-to-end delay measurement mechanism between slave clocks and the master clock.

- **Peer-to-peer transparent clock**

A transparent clock that, in addition to providing Precision Time Protocol (PTP) event transit time information, also provides corrections for the propagation delay of the link connected to the port receiving the PTP event message. In the presence of peer-to-peer transparent clocks, delay measurements between slave clocks and the master clock are performed using the peer-to-peer delay measurement mechanism.

- **Management node**

A device that configures and monitors clocks.

NOTE

Transparent clock, is a device that measures the time taken for a Precision Time Protocol (PTP) event message to transit the device and provides this information to clocks receiving this PTP event message.

6.3 IEEE 802.1AS time-aware systems

In gPTP, there are only two types of time-aware systems: end stations and Bridges, while IEEE 1588 has ordinary clocks, boundary clocks, end-to-end transparent clocks, and P2P transparent clocks. A time-aware end station corresponds to an IEEE 1588 ordinary clock, and a time-aware Bridge is a type of IEEE 1588 boundary clock where its operation is very tightly defined, so much so that a time-aware Bridge with Ethernet ports can be shown to be mathematically equivalent to a P2P transparent clock in terms of how synchronization is performed.

1. Time-aware end station

An end station that is capable of acting as the source of synchronized time on the network, or destination of synchronized time using the IEEE 802.1AS protocol, or both.

2. Time-aware bridge

A Bridge that is capable of communicating synchronized time received on one port to other ports, using the IEEE 802.1AS protocol.

6.4 Software stacks

6.4.1 linuxptp stack

Features of open source linuxptp

- Supports hardware and software time stamping via the Linux SO_TIMESTAMPING socket option.
- Supports the Linux PTP Hardware Clock (PHC) subsystem by using the clock_gettime family of calls, including the clock_adjtimex system call.
- Implements Boundary Clock (BC), Ordinary Clock (OC) and Transparent Clock (TC).
- Transport over UDP/IPv4, UDP/IPv6, and raw Ethernet (Layer 2).
- Supports IEEE 802.1AS-2011 in the role of end station.
- Modular design allowing painless addition of new transports and clock servos.
- Implements unicast operation.
- Supports a number of profiles, including:
 - The automotive profile.
 - The default 1588 profile.
 - The enterprise profile.
 - The telecom profiles G.8265.1, G.8275.1, and G.8275.2.
 - Supports the NetSync Monitor protocol.
- Implements Peer to peer one-step.
- Supports bonded, IPoIB, and vlan interfaces.

Note: the features listed are from linuxptp website. It does not mean all these features work on release boards. The hardware 1588 capability, driver support and ptp4l version needs to be considered. Refer to following user manual of this chapter for what had been verified.

Features added by OpenIL

- Supports IEEE 802.1AS-2011 in the role of time-aware bridge.
- Support dynamic direction in ts2phc to cooperate with ptp4l.

6.4.2 NXP GenAVB/TSN gPTP stack

Following are the features of the NXP GenAVB/TSN gPTP stack:

- Implements gPTP IEEE 802.1AS-2020, for both time-aware Endpoint and Bridge systems
- Implements gPTP BMCA
- Supports GrandMaster, Master, and Slave capabilities
- Supports multiple gPTP domains
- Supports Avnu Alliance Automotive profile
- Supports configuration profiles for the stack
- Supports hardware and software time stamping via the Linux `SO_TIMESTAMPING` socket option
- Supports the Linux PTP Hardware Clock (PHC) subsystem by using the `clock_gettime` family of calls, including the `clock_adjtimex` system call.

6.5 Quick Start for IEEE 1588

6.5.1 Ordinary clock verification

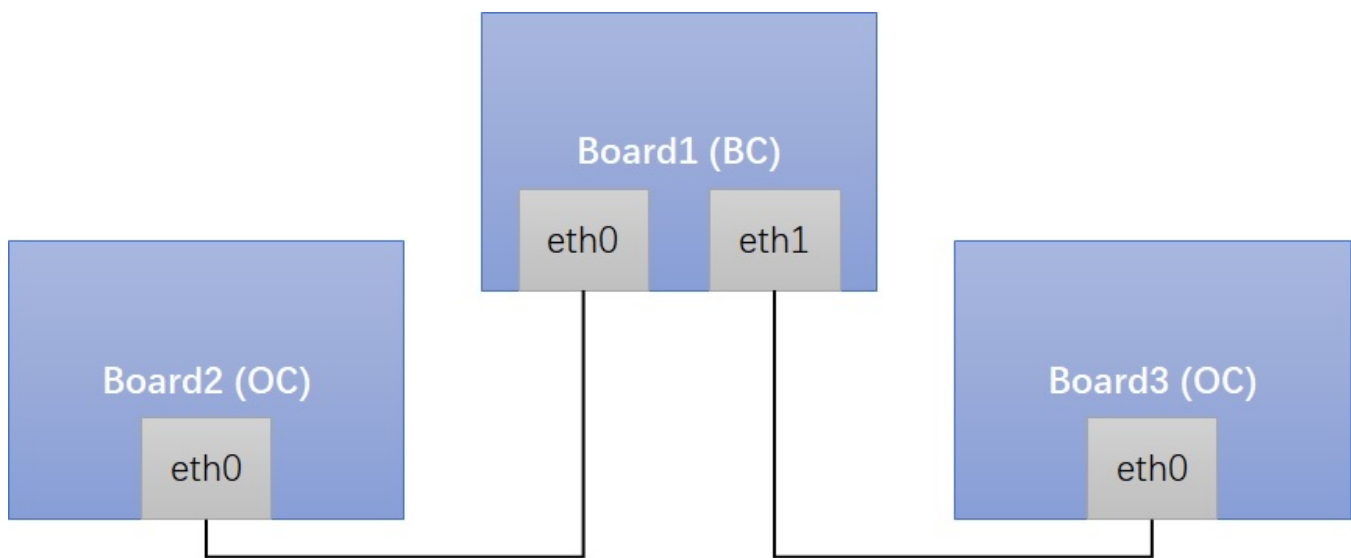
Connect two network interfaces in back-to-back manner for two boards. Make sure there is no MAC address conflict on the boards, the IP addresses are set properly and ping the test network. Run `linuxptp` on each board. For example, `eth0` is used on each board.

```
$ ptp4l -i eth0 -m
```

On running the above command time synchronization will start, and the slave `linuxptp` selected automatically will synchronize to master with synchronization messages displayed, such as time offset, path delay and so on.

6.5.2 Boundary clock verification

At least three boards are needed. Below is an example for three boards network connection. Make sure there is no MAC address conflict on the boards, the IP addresses are set properly and ping the test network.



Run `linuxptp` on Board1 (boundary clock).

```
$ ptp4l -i eth0 -i eth1 -m
```

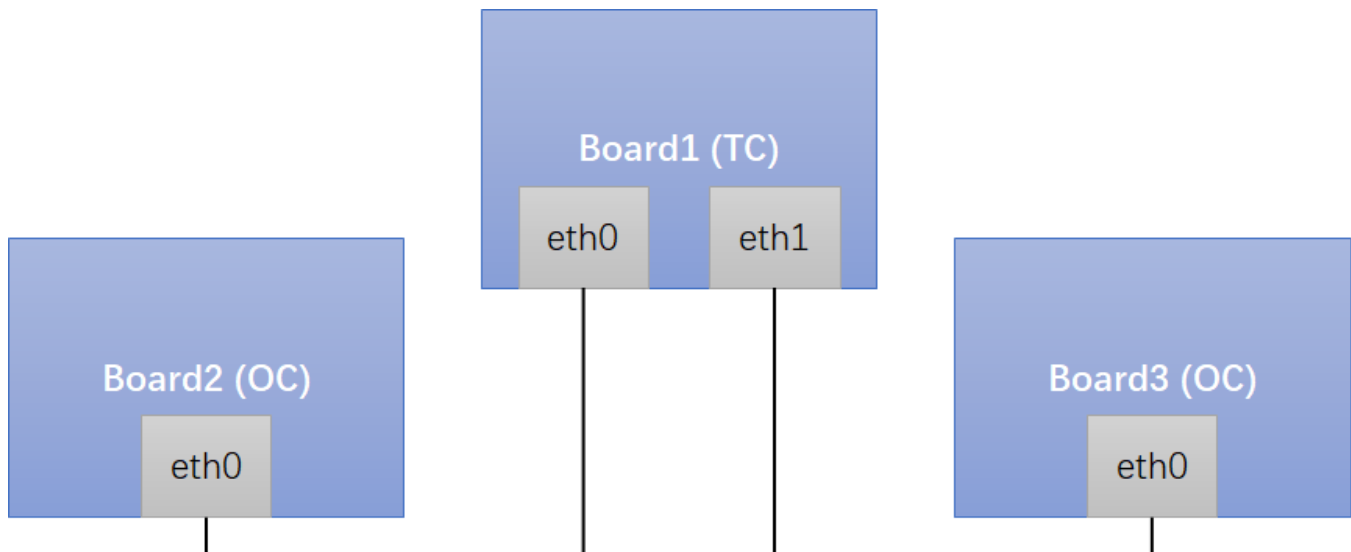
Run `linuxptp` on Board2/Board3 (ordinary clock).

```
$ ptp4l -i eth0 -m
```

On running the above command, time synchronization will start, and the slaves `linuxptp` selected automatically will synchronize to the unique master with synchronization messages displayed such as time offset, path delay and so on.

6.5.3 Transparent clock verification

At least three boards are needed. Below is an example for three boards network connection. Make sure there is no MAC address conflict on the boards, the IP addresses are set properly, and ping the test network.



Run `linuxptp` on Board1 (transparent clock). If want Board1 works as E2E TC, use `E2E-TC.cfg`. If want Board1 works as P2P TC, use `P2P-TC.cfg`.

```
$ ptp4l -i eth0 -i eth1 -f /etc/ptp4l_cfg/E2E-TC.cfg -m
```

Run `linuxptp` on Board2/Board3 (ordinary clock).

```
$ ptp4l -i eth0 -m
```

On running the above commands, time synchronization will start between ordinary clocks, and the slave `linuxptp` selected automatically will synchronize to the master with synchronization messages displayed such as time offset, path delay and so on.

6.6 Quick Start for IEEE 802.1AS

The following sections describe the steps for implementing IEEE 802.1AS on NXP boards. The following steps make use of `linuxptp` stack but similar commands can be executed with NXP GenAVB/TSN `gPTP` stack on supported boards, as described [here](#).

6.6.1 Time-aware end station verification

Connect two network interfaces in back-to-back way for two boards. Make sure no MAC address conflict on the boards, IP address set properly and ping test work.

Remove below option in `/etc/ptp4l_cfg/gPTP.cfg` to use default larger value, because estimate path delay including PHY delay may exceed 800ns since hardware is using MAC timestamping.

```
neighborPropDelayThresh 800
```

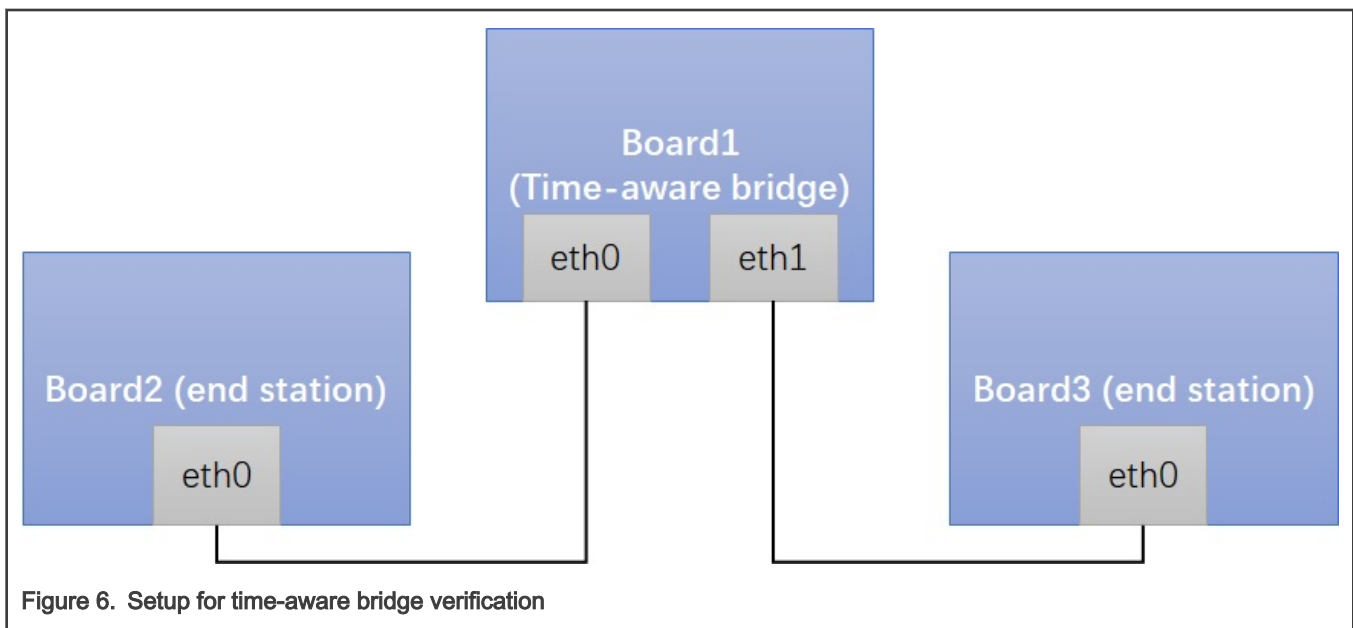
Run `linuxptp` on each board. For example, `eth0` is used on each board.

```
$ ptp4l -i eth0 -f /etc/ptp4l_cfg/gPTP.cfg -m
```

Time synchronization will start, and the slave `linuxptp` selected automatically will synchronize to master with synchronization messages printed, like time offset, path delay and so on.

6.6.2 Time-aware bridge verification

At least three boards are needed for the time-aware bridge verification. Below is an example of the network connection amongst the three boards. Make sure there is no MAC address conflict on the boards.



Remove the below option in `/etc/ptp4l_cfg/gPTP.cfg` file to use the default larger value, because estimated path delay including PHY delay may exceed 800 ns since hardware is using MAC timestamping.

```
neighborPropDelayThresh 800
```

Run `linuxptp` on Board1 (time-aware bridge) using the command below:

```
$ ptp4l -i eth0 -i eth1 -f /etc/ptp4l_cfg/gPTP.cfg -m
```

Run linuxptp on Board2/Board3 (time-aware end station) using the command:

```
$ ptp4l -i eth0 -f /etc/ptp4l_cfg/gPTP.cfg -m
```

Time synchronization will start between the three boards, and the linuxptp slaves selected will automatically synchronize to the unique master with synchronization messages displayed (such as time offset, path delay and so on).

6.7 Boundary clock jbod mode on LS1028ATSN

There are several PTP devices on LS1028ATSN providing timestamping to their networking interfaces. The board was designed to emit PPS signal from LS1028A TSN switch to three SJA1105 for PTP devices synchronization.

In order to run ptp4l on all networking interfaces with different PTP devices, the boundary_clock_jbod config is used. This option allows ptp4l to work as a boundary clock using "just a bunch of devices" that are not synchronized to each other.

For this mode, the collection of clocks must be synchronized by an external program. The ts2phc is used here.

Configuration files for running

ts2phc.cfg:

```
[global]
first_step_threshold    0.00002
step_threshold          0.00002
ts2phc.pulsewidth      500000000
ts2phc.perout_phase    0

# Felix
[/dev/ptp1]
ts2phc.master          1

# SJA1105 switch 1
[/dev/ptp2]
ts2phc.channel         0
ts2phc.extts_polarity both

# SJA1105 switch 2
[/dev/ptp3]
ts2phc.channel         0
ts2phc.extts_polarity both
```

gPTP.cfg:

```
#
# 802.1AS example configuration containing those attributes which
# differ from the defaults. See the file, default.cfg, for the
# complete list of available options.
#
[global]
gmCapable              1
priority1              248
priority2              248
logAnnounceInterval   0
logSyncInterval       -3
syncReceiptTimeout    3
neighborPropDelayThresh 800
min_neighbor_prop_delay -20000000
assume_two_step       1
path_trace_enabled    1
follow_up_info        1
```

```

transportSpecific      0x1
ptp_dst_mac           01:80:C2:00:00:0E
network_transport     L2
delay_mechanism       P2P
step_threshold        0.00002
tx_timestamp_timeout  20
boundary_clock_jbod   1

```

```

[sw0p0]
[sw0p1]
[sw0p2]
[sw1p0]
[sw1p1]
[sw1p2]
[sw1p3]

```

Run boundary clock jbod mode

```

$ phc_ctl /dev/ptp1 freq 0
$ phc_ctl /dev/ptp2 freq 0
$ phc_ctl /dev/ptp3 freq 0
$ ptp4l -f gPTP.cfg -m &
$ ts2phc -f ts2phc.cfg -m -a --transportSpecific 0x1

```

See long term test results “Boundary clock jbod mode on LS1028ATSN”.

NOTE

1. OpenIL supports an addition '-a' option on the standard ts2phc program, which makes the program subscribe to port state events from ptp4l, and automatically detect and synchronize the PHC devices that are not synchronized directly by ptp4l (which are the ones that are not directly connected to the GM).
2. If '-a' is used, then the transportSpecific option of ts2phc must match the one from ptp4l (similarly to phc2sys). If gPTP is used, then transportSpecific must be 1, else it must be 0.

6.8 Long term test

This section describes the long term test results for Linux PTP stack implementation.

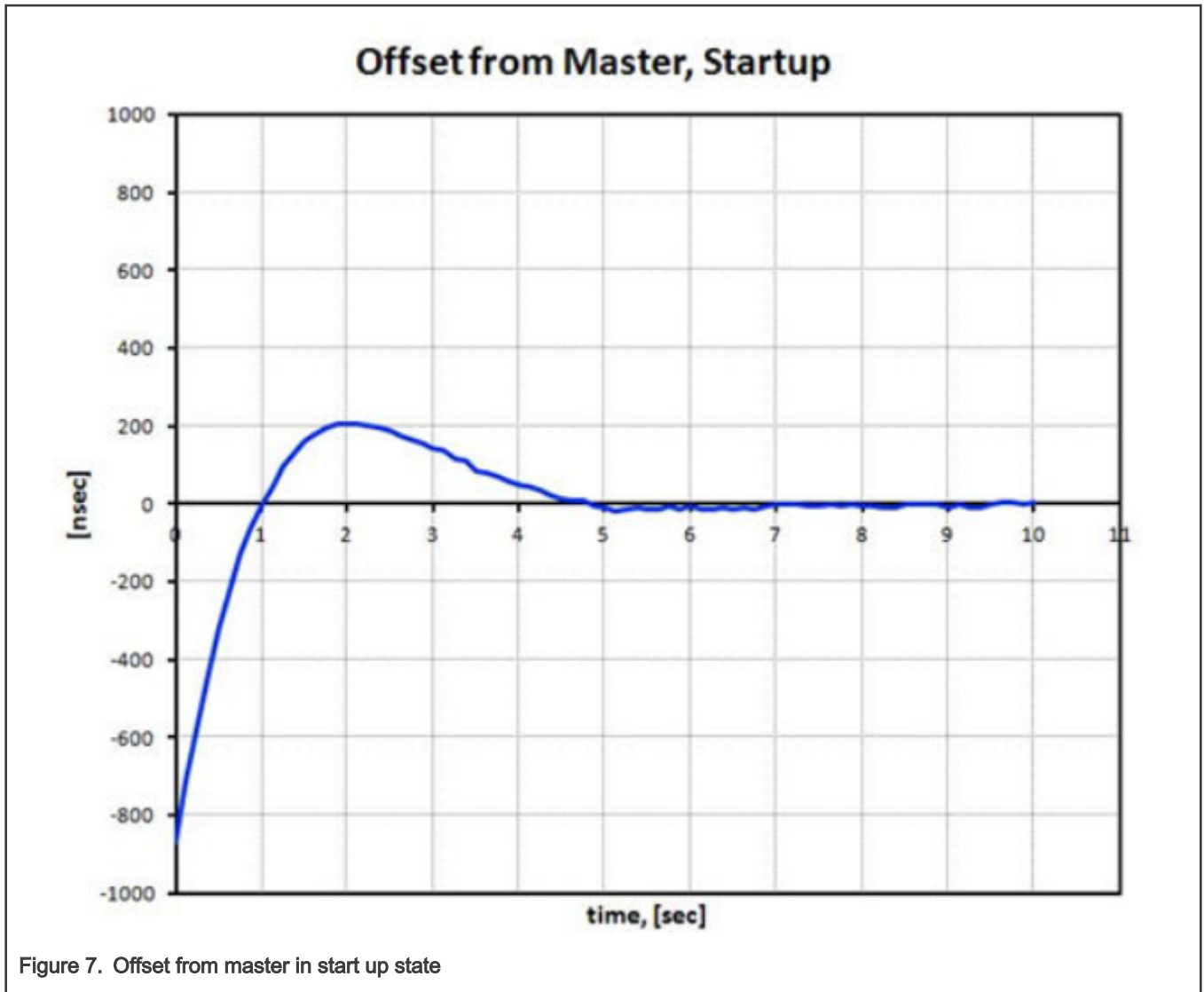
6.8.1 linuxptp basic synchronization

Linux PTP

Connection: back-to-back master to slave

Configuration: Sync internal is -3

Test boards: two LS1021ATSN boards, one as master and another one as slave.



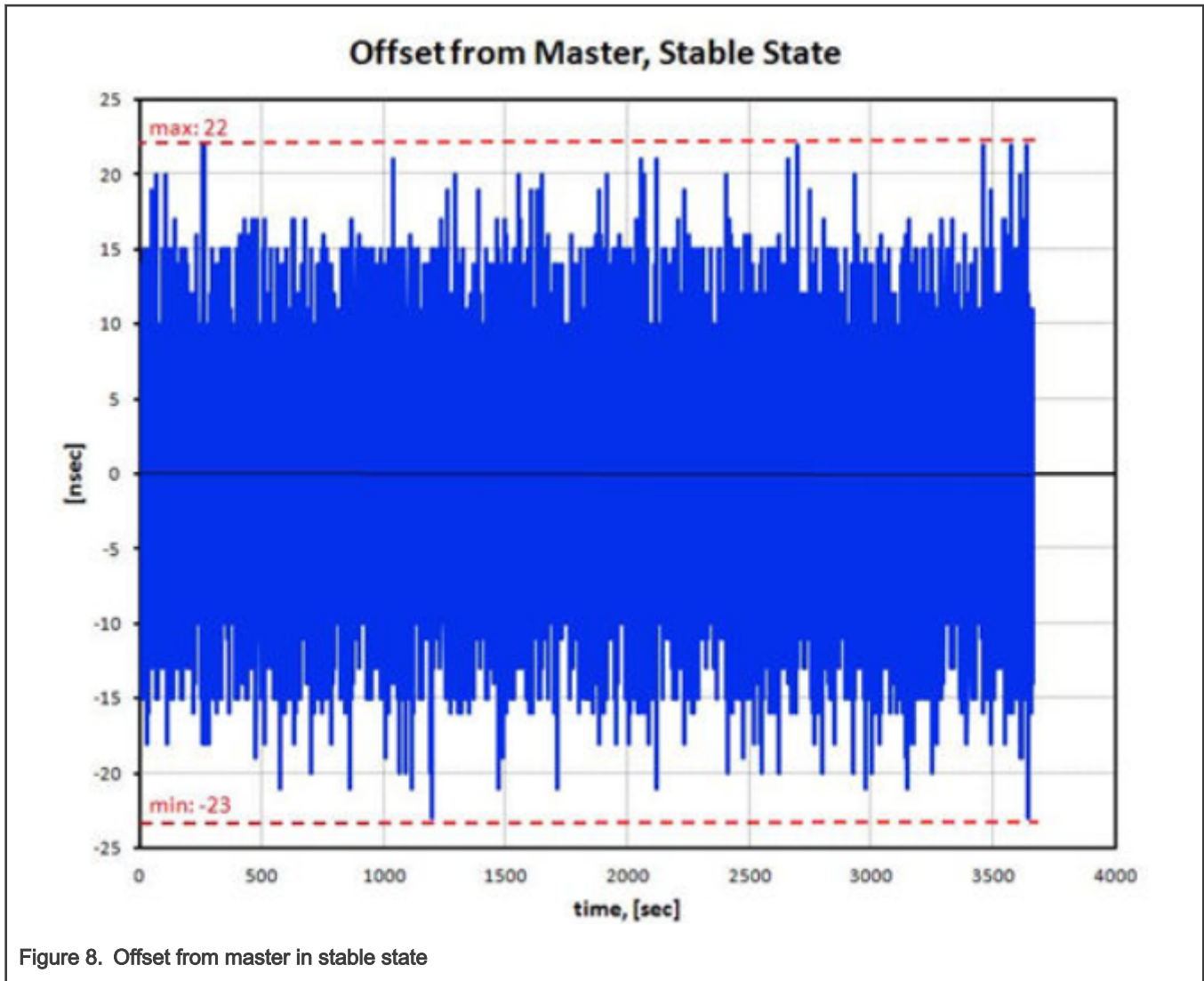


Figure 8. Offset from master in stable state

6.8.2 Boundary clock jbod mode on LS1028ATSN

Connection: LS1021A-TSN swp2 (GM) <-> LS1028A-TSN sw1p3 (slave)

Configuration: see "Boundary clock jbod mode on LS1028ATSN"

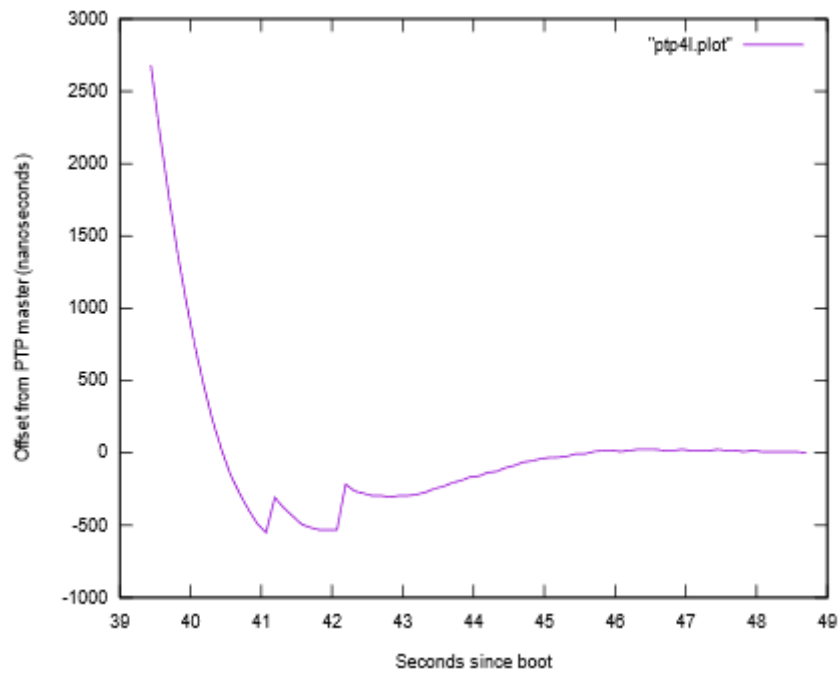


Figure 9. ptp4l offset from master in start up state

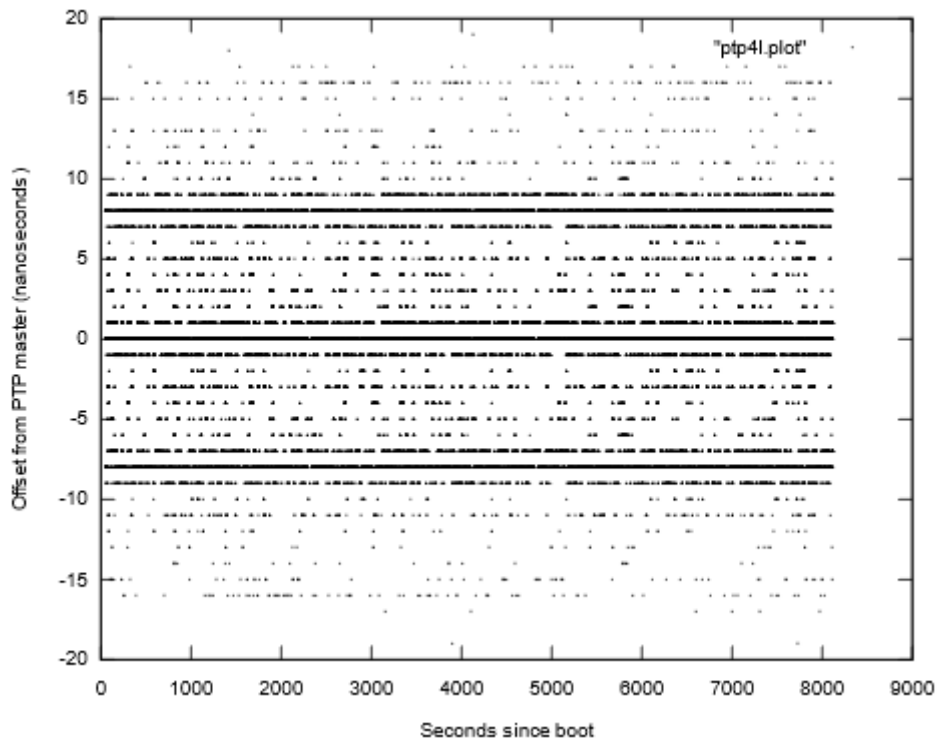


Figure 10. ptp4l offset from master in stable state

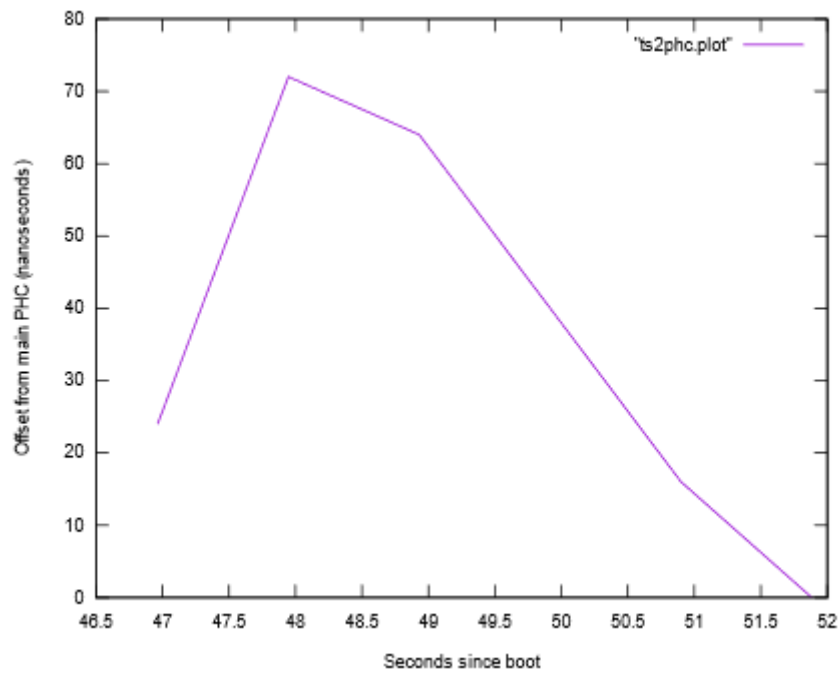


Figure 11. ts2phc offset from master in start up state

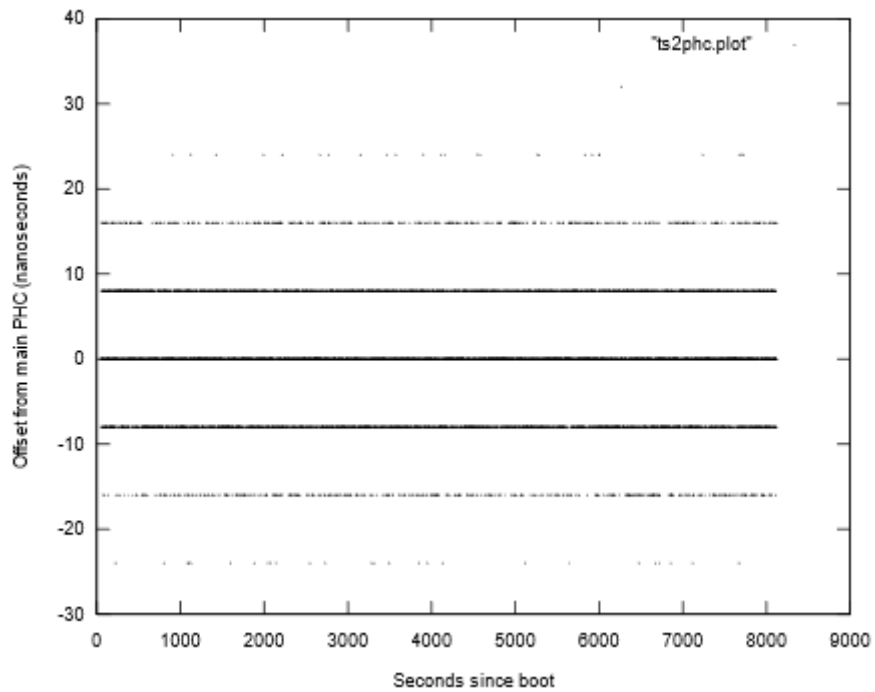


Figure 12. ts2phc offset from master in stable state

Since the sja1105 PTP clock resolution is 8 ns, the ts2phc offset is always a multiple of that (0, 8, 24 ns).

6.9 Known issues and limitations

1. When LS1028A TSN switch in Linux is configured as L2 switch, the interfaces should not be configured with IP addresses. Running linuxptp on these interfaces must use Ethernet protocol instead of UDP/IP. The method is to add an option "-2" executing ptp4l command. For example,

```
$ ptp4l -i eth0 -2 -m
```

2. i.MX8MP current dwmac driver (eth1) initializes some hardware functions during opening net device, including PTP initialization. Before that, the operations on it may not work, like ethtool queries, and PTP operations. So, the workaround is, do operations on the eth1 and PTP of dwmac only after "ifconfig eth1 up".

3. If below error is reported during ptp4l running, just try to increase tx_timestamp_timeout. User space may need to wait longer for TX timestamp. For example, use option --tx_timestamp_timeout=20 when run ptp4l.

```
ptp4l[1560.726]: timed out while polling for tx timestamp  
ptp4l[1560.726]: increasing tx_timestamp_timeout may correct this issue, but it is likely caused by a  
driver bug
```


Chapter 7

Time Sensitive Network (TSN)

Time Sensitive Networking (TSN) is an extension to traditional Ethernet networks, providing a set of standards compatible with IEEE 802.1 and 802.3. These extensions are intended to address the limitations of standard Ethernet in sectors ranging from industrial and automotive applications to live audio and video systems. Applications running over traditional Ethernet must be designed very robust in order to withstand corner cases such as packet loss, delay or even reordering. TSN aims to provide guarantees for deterministic latency and packet loss under congestion, allowing critical and non-critical traffic to be converged in the same network.

This chapter describes the process and use cases for implementing TSN features on the LS1021ATSN and the LS1028ARDB boards.

7.1 TSN hardware capability

Table 22. TSN hardware capability on different platforms

| Platform | 802.1Qbv(Enhancements for Scheduled Traffic) | 802.1Qbu and 802.3br(Frame Preemption) | 802.1Qav(Credit Based Shaper) | 802.1AS(Precision Time Protocol) | 802.1CB(Frame Replication and Elimination for Reliability) | 802.1Qci(Per Stream Filtering and Policing) |
|------------------------|--|--|-------------------------------|----------------------------------|--|---|
| ENETC(LS1028a) | Y | Y | Y | Y | N | Y |
| Felix switch(L S1028a) | Y | Y | Y | Y | Y | Y |
| SJA110 5(LS102 1a-TSN) | Y | N | Y | Y | N | Pre-standard |
| Stmac(i. mx8mp) | Y | Y | Y | Y | N | N |

7.2 TSN configuration

The table below describes the TSN configuration tools support on different platforms

Table 23. TSN configuration tools support on different platforms

| Platform | 802.1Qbv (Enhancements for Scheduled Traffic) | 802.1Qbu and 802.3br (Frame Preemption) | 802.1Qav (Credit Based Shaper) | 802.1AS (Precision Time Protocol) | 802.1CB (Frame Replication and Elimination for Reliability) | 802.1Qci (Per Stream Filtering and Policing) |
|-----------------|---|---|--------------------------------|-----------------------------------|---|--|
| ENETC (LS1028A) | tc-taprio tsntool | ethtool tsntool | tc-cbs tsntool | ptp4l | N/A | tc-flower tsntool |

Table continues on the next page...

Table 23. TSN configuration tools support on different platforms (continued)

| Platform | 802.1Qbv (Enhancements for Scheduled Traffic) | 802.1Qbu and 802.3br (Frame Preemption) | 802.1Qav (Credit Based Shaper) | 802.1AS (Precision Time Protocol) | 802.1CB (Frame Replication and Elimination for Reliability) | 802.1Qci (Per Stream Filtering and Policing) |
|------------------------|---|---|--------------------------------|-----------------------------------|---|--|
| Felix switch (LS1028A) | tc-taprio tsntool | ethtool tsntool | tc-cbs tsntool | ptp4l, GenAVB/TSN stack | tsntool | tc-flower tsntool |
| SJA1105 (LS1021A-TSN) | tc-taprio | N/A | tc-cbs | ptp4l | N/A | tc-flower |
| Stmac (i.mx8mp) | tc-taprio | ethtool | tc-cbs | ptp4l, GenAVB/TSN stack | N/A | N/A |

7.2.1 Using Linux traffic control (tc)

Enable following configs in kernel when using Linux traffic control (tc):

```
Symbol: NET_SCH_MQPRIO [=y] && NET_SCH_CBS [=y] && NET_SCH_TAPRIO [=y]
[*] Networking support --->
  Networking options --->
    [*] QoS and/or fair queueing --->
      <*> Credit Based Shaper (CBS)
      <*> Time Aware Priority (taprio) Scheduler
      <*> Multi-queue priority scheduler (MQPRIO)
    [*] Actions --->
      <*> Traffic Policing
      <*> Generic actions
      <*> Redirecting and Mirroring
      <*> SKB Editing
      <*> Vlan manipulation
      <*> Frame gate entry list control tc action
```

On ls1028a platform, ENETC Qos driver need to be set to support tc configuration.

```
Symbol: FSL_ENETC_QOS [=y]
Device Drivers--->
  [*] Network device support --->
    [*] Ethernet driver support --->
      [*] Freescale devices
      [*] ENETC hardware Time-sensitive Network support
```

1. Using tc-taprio to set Qbv, detail introduce is here:

<https://man7.org/linux/man-pages/man8/tc-taprio.8.html>

2. Using tc-cbs to set Qav, detail introduce is here:

<https://man7.org/linux/man-pages/man8/tc-cbs.8.html>

3. Using tc-flower to set Qci and ACL, detail introduce is here:

<https://man7.org/linux/man-pages/man8/tc-flower.8.html>

7.2.2 Using tsntool

Tsntool is a tool to set the TSN capability of the Ethernet ports of TSN Endpoint and TSN switch. It's used on LS1028a platform, so enable TSN, ENETC_TSN, and MSCC_FELIX_SWITCH_TSN to support tsntool configuration on LS1028a.

```
Symbol: TSN [=y]
[*] Networking support --->
  Networking options --->
    [*] 802.1 Time-Sensitive Networking support

Symbol: ENETC_TSN [=y] && FSL_ENETC_PTP_CLOCK [=y] && FSL_ENETC_HW_TIMESTAMPING [=y]
Device Drivers --->
  [*] Network device support --->
    [*] Ethernet driver support --->
      [*] Freescale devices
      <*> ENETC PF driver
      <*> ENETC VF driver
      -* ENETC MDIO driver
      <*> ENETC PTP clock driver
      [*] ENETC hardware timestamping support
      [*] TSN Support for NXP ENETC driver

Symbol: MSCC_FELIX_SWITCH_TSN [=y]
Device Drivers --->
  [*] Network device support --->
    Distributed Switch Architecture drivers --->
      <*> Ocelot / Felix Ethernet switch support --->
      <*> TSN on FELIX switch driver
```

Enable PKTGEN in Kernel to use pktgen for testing,

```
Symbol: NET_PKTGEN [=y]
[*] Networking support --->
  Networking options --->
    Network testing --->
      <*> Packet Generator (USE WITH CAUTION)
```

See "Tsntool User Manual" to get detail information.

7.2.3 Remote configuration using NETCONF/YANG

1. Overview

The NETCONF protocol defines a mechanism for device management and configuration retrieval and modification. It uses a remote procedure call (RPC) paradigm and a system of exposing device (server) capabilities, which enables a client to adjust to the specific features of any network equipment.

YANG is a standards-based, extensible, hierarchical data modeling language that is used to model the configuration and state data used by NETCONF operations, remote procedure calls (RPCs), and server event notifications.

2. Support for different platforms in OpenIL

| TSN offload | OpenIL | | | |
|---|--------|----|---------|---------|
| | LS1028 | | SJA1105 | i.MX8MP |
| | libtsn | tc | tc | tc |
| 802.1Qbv (Time Aware Shaper) | Y | Y | Y | Y |
| 802.1Qbu/802.3br (Frame Preemption) | Y | Y | N/A | Y |
| 802.1Qav (Credit Based Shaper) | - | - | - | - |
| 802.1CB (Frame Replication and Elimination for Reliability) | - | - | N/A | N/A |
| 802.1Qci (Per-Stream Filtering and Policing) | Y | Y | Y | N/A |
| IP config | Y | Y | Y | Y |
| MAC config | Y | Y | Y | Y |
| VLAN config | Y | Y | Y | Y |

3. Installation and Configuration

Netopeer is a set of NETCONF tools built on the libnetconf library. [sysrepo-tsn](https://github.com/openil/sysrepo-tsn) (https://github.com/openil/sysrepo-tsn) helps to configure TSN features, including Qbv, Qbu, Qci, and stream identification via network, without logging in to device. For details of configuring TSN features via Netopeer, please refer to [NETCONF/YANG](#). Some application scenarios for tsn refer to [Application scenarios](#).

7.2.4 Remote configuration using Web UI

1. Overview

The Web UI allows the remote control of the YANG model. The user can connect http server, and input TSN parameter on web UI, and click "Yes, confirm" button to send them to the board.

2. User Interface

2.1 Qbv Configuration

ADD TSN SETTING +

qbv v

*device: swp2 v

enable disable

basetime: example: s.ns

*gate control list:

| GATE | PERIOD |
|------|---|
| 3 | 4000 + |

Yes, confirm

cancel

STATUS Get Config

console output

```

getconfig operation: true
-----0-----
getconfig operation: true
-----1-----
getconfig operation: true
-----2-----
editconfig operation: true
{
  "interfaces":{
    "@xmlns":"urn:ietf:params:xml:ns:yang:ietf-interfaces",
    "interface":{
      "name":"swp2",
      "enabled":"true",
      "type":{
        "@xmlns:ianaift":"urn:ietf:params:xml:ns:yang:iana-if-type",
        "#text":"ianaift:ethernetCsmacd"
      }
    },
    "gate-parameters":{
      "@xmlns":"urn:ieee:std:802.1Q:yang:ieee802-dot1q-sched",
      "gate-enabled":"true",
      "config-change":"true",
      "admin-control-list-length":"1",
      "admin-control-list":{
        "index":"0",
        "operation-name":"set-gate-states",
        "sgs-params":{
          "gate-states-value":"3",
          "time-interval-value":"4000"
        }
      }
    }
  }
}
                    
```

2.2 Qbu Configuration

ADD TSN SETTING +

qbu v

*device: swp2 v

enable disable

TC0 preemptable express

TC1 preemptable express

TC2 preemptable express

TC3 preemptable express

TC4 preemptable express

TC5 preemptable express

TC6 preemptable express

TC7 preemptable express

Yes, confirm

cancel

STATUS Get Config

```

      "gate-states-value":"3",
      "time-interval-value":"4000"
    }
  },
  "admin-base-time":{
    "seconds":"0",
    "fractional-seconds":"0"
  }
},
"frame-preemption-parameters":{
  "@xmlns":"urn:ieee:std:802.1Q:yang:ieee802-dot1q-preemption",
  "frame-preemption-status-table":{
    {
      "traffic-class":"0",
      "frame-preemption-status":"express"
    },
    {
      "traffic-class":"1",
      "frame-preemption-status":"express"
    },
    {
      "traffic-class":"2",
      "frame-preemption-status":"express"
    },
    {
      "traffic-class":"3",
      "frame-preemption-status":"preemptable"
    },
    {
      "traffic-class":"4",
      "frame-preemption-status":"express"
    },
    {
      "traffic-class":"5",
      "frame-preemption-status":"express"
    },
    {
      "traffic-class":"6"
                    
```

2.3 Qci Configuration



In this interface, user can choose configuration for "stream identify", "stream filter", "stream gate" and "flow metering".

3. Installation and Configuration

For details introduction of web UI, please refer to [Web UI demo](#).

7.3 Verifying TSN features on LS1028ARDB board

The **tsntool** is an application configuration tool to configure the TSN capability on LS1028ARDB. The files **/usr/bin/tsntool** and **/usr/lib/libtsn.so** are located in the rootfs. Run **tsntool** to start the setting shell.

7.3.1 Tsntool User Manual

Tsntool is a tool to set the TSN capability of the Ethernet ports of TSN Endpoint and TSN switch. This document describes how to use tsntool for NXP's LS1028ARDB hardware platform.

NOTE

- Tsntool supports only the LS1028ARDB platform. Other hardware platforms might be supported in future.
- Current tsntool binary and lib are default for kernel version v4.19. If you want to use kernel v4.13, you need to clone the tsntool source code, and compile the tag point v0.2 source code.

7.3.1.1 Getting the source code

Github of the tsntool code is:

<https://github.com/openil/tsntool.git>

7.3.1.2 Tsn tool commands

The following table lists the TSN tool commands and their description.

Table 24. TSN tool commands and their description

| Command | Description |
|------------------------|---|
| help | Lists commands support |
| version | Shows software version |
| verbose | Debugs on/off for tsntool |
| quit | Quits prompt mode |
| qbvset | Sets time gate scheduling config for <ifname> |
| qbvget | Gets time scheduling entries for <ifname> |
| cbstreamidset | Sets stream identification table |
| cbstreamidget | Gets stream identification table and counters |
| qcisfiset | Sets stream filter instance |
| qcisfiget | Gets stream filter instance |
| qcisgiset | Sets stream gate instance |
| qcisgiget | Gets stream gate instance |
| qcisfcounterget | Gets stream filter counters |
| qcifmiset | Sets flow metering instance |
| qcifmiget | Gets flow metering instance |
| cbssset | Sets TCs credit-based shaper configure |
| cbssget | Gets TCs credit-based shaper status |
| qbuset | Sets one 8-bits vector showing the preemptable traffic class |
| qbudgetstatus | Not supported |
| tsdset | Not supported |
| tsdget | Not supported |
| ctset | Sets cut through queue status (specific for Is1028 switch) |
| cbgen | Sets sequence generate configure (specific for Is1028 switch) |
| cbrec | Sets sequence recover configure (specific for Is1028 switch) |
| dscpset | Sets queues map to DSCP of Qos tag (specific for Is1028 switch) |
| sendpkt | Not supported |

Table continues on the next page...

Table 24. TSN tool commands and their description (continued)

| Command | Description |
|------------------|---|
| regtool | Register read/write of bar0 of PFs (specific for ls1028 enetc) |
| ptptool | ptptool get/set ptp timestamp. Useful commands: <pre>#get ptp0 clock time ptptool -g</pre> <pre>#get ptp1 clock time ptptool -g -d /dev/ptp1</pre> |
| dscpset | Set queues map to DSCP of QoS tag (specific for ls1028 switch) |
| qicapget | Gets qci instance's max capability |
| tsncapget | Gets device's tsn capability |

7.3.1.3 Tsntool commands and parameters

This section lists the tsntool commands along with the parameters and arguments, with which they can be used.

Table 25. qbvset

| Parameter <argument> | Description |
|-------------------------------------|---|
| --device <ifname> | An interface such as eno0/swp0 |
| --entryfile <filename> | A file script to input gatelist format. It has the following arguments: <pre># 'NUMBER' 'GATE_VALUE' 'TIME_LONG'</pre> <ul style="list-style-type: none"> NUMBER: # 't' or 'T' head. Plus entry number. Duplicate entry number will result in an error. GATE_VALUE: # format: xxxxxxxb . # The MSB corresponds to traffic class 7. The LSB corresponds to traffic class 0. # A bit value of 0 indicates closed, whereas, a bit value of 1 indicates open. TIME_LONG: # nanoseconds. Do not input 0 time long. t0 11101111b 1000 t1 11011111b 1000 <p style="text-align: center;">NOTE</p> <p style="text-align: center;">Entryfile parameter must be set. If not set, there will be a vi text editor prompt, "require to input the gate list".</p> |
| --basetime <value> | AdminBaseTime A 64-bit hex value means nano second until now. OR a value input format as: Seconds.decimalSecond Example: 115.000125means 115seconds and 125us. |
| --cycletime <value> | AdminCycleTime |
| --cycleextend <value> | AdminCycleTimeExtension |

Table continues on the next page...

Table 25. qbvset (continued)

| Parameter <argument> | Description |
|----------------------------|--|
| --enable --disable | <ul style="list-style-type: none"> enable: enables the qbv for this port disable: disables the qbv for this port Default is set to enable, if no enable or disable input |
| --maxsdu <value> | queueMaxSDU |
| --initgate <value> | AdminGateStates |
| --configchange | ConfigChange. Default set to 1. |
| --configchangetime <value> | ConfigChangeTime |

Table 26. qbvget

| Parameter <argument> | Description |
|----------------------|--------------------------------|
| --device <ifname> | An interface such as eno0/swp0 |

Table 27. cbstreamidset

| Parameter <argument> | Description |
|---|--|
| --enable --disable | <ul style="list-style-type: none"> enable: Enables the entry for this index. disable: Disables the entry for this index. Default is set to enable if no enable or disable input |
| --index <value> | Index entry number in this controller. Mandatory parameter. This value corresponds to tsnStreamIdHandle on switch configuration. |
| --device <string> | An interface such as eno0/swp0 |
| --streamhandle <value> | tsnStreamIdHandle |
| --infacoutport <value> | tsnStreamIdInFacOutputPortList |
| --outfacoutport <value> | tsnStreamIdOutFacOutputPortList |
| --infacinport <value> | tsnStreamIdInFacInputPortList |
| --outfacinport <value> | tsnStreamIdOutFacInputPortList |
| --nullstreamid --sourcemacvid --destmacvid --ipstreamid | tsnStreamIdIdentificationType: <ul style="list-style-type: none"> -nullstreamid: Null Stream identification -sourcemacvid: Source MAC and VLAN Stream identification -destmacvid: not supported |

Table continues on the next page...

Table 27. cbstreamidset (continued)

| Parameter <argument> | Description |
|------------------------|--|
| | <ul style="list-style-type: none"> -ipstreamid: not supported |
| --nulldmac <value> | tsnCpeNullDownDestMac |
| --nulltagged <value> | tsnCpeNullDownTagged |
| --nullvid <value> | tsnCpeNullDownVlan |
| --sourcemac <value> | tsnCpeSmacVlanDownSrcMac |
| --sourcetagged <value> | tsnCpeSmacVlanDownTagged |
| --sourcevid <value> | tsnCpeSmacVlanDownVlan |

Table 28. cbstreamidset

| Parameter <argument> | Description |
|----------------------|---|
| --device <ifname> | An interface such as <code>eno0/swp0</code> |
| --index <value> | Index entry number in this controller. Mandatory to have. |

Table 29. qcisfiset

| Parameter <argument> | Description |
|------------------------|--|
| --device <ifname> | An interface such as <code>eno0/swp0</code> |
| --enable --disable | <ul style="list-style-type: none"> enable: enable the entry for this index disable: disable the entry for this index default to set <code>enable</code> if no enable or disable input |
| --maxsdu <value> | Maximum SDU size. |
| --flowmeterid <value> | Flow meter instance identifier index number. |
| --index <value> | StreamFilterInstance. index entry number in this controller. This value corresponds to <code>tsnStreamIdHandle</code> of <code>cbstreamidset</code> command on switch configuration. |
| --streamhandle <value> | StreamHandleSpec This value corresponds to <code>tsnStreamIdHandle</code> of <code>cbstreamidset</code> command. |
| --priority <value> | PrioritySpec |
| --gateid <value> | StreamGateInstanceID |

Table continues on the next page...

Table 29. qcisfiset (continued)

| Parameter <argument> | Description |
|----------------------|---------------------------------------|
| --oversizeenable | StreamBlockedDueToOversizeFrameEnable |
| --oversize | StreamBlockedDueToOversizeFrame |

Table 30. qcisfiget

| parameter <argument> | Description |
|----------------------|---|
| --device <ifname> | An interface such as eno0/swp0 |
| --index <value> | Index entry number in this controller. Mandatory to have. |

Table 31. qcisgiset

| Parameter <argument> | Description |
|----------------------|--|
| --device <ifname> | An interface such as eno0/swp0 |
| --index <value> | Index entry number in this controller. Mandatory to have. |
| --enable --disable | <ul style="list-style-type: none"> • enable: enable the entry for this index. PSFPGateEnabled • disable: disable the entry for this index • default to set enable if no enable or disable input |
| --configchange | configchange |
| --enblkinvrx | PSFPGateClosedDueToInvalidRxEnable |
| --blkinvrx | PSFPGateClosedDueToInvalidRx |
| --initgate | PSFPAdminGateStates |
| --initipv | AdminIPV |
| --cycletime | Default not set. Get by gatelistfile. |
| --cycletimeext | PSFPAdminCycleTimeExtension |
| --basetime | PSFPAdminBaseTime A 64-bit hex value means nano second until now. OR a value input format as: Seconds.decimalSecond Example: 115.000125means 115seconds and 125us. |
| --gatelistfile | PSFPAdminControlList. A file input the gate list: 'NUMBER' 'GATE_VALUE' 'IPV' 'TIME_LONG' 'OCTET_MAX' |

Table continues on the next page...

Table 31. qcisgiset (continued)

| Parameter <argument> | Description |
|----------------------|---|
| | <ul style="list-style-type: none"> • NUMBER: # 't' or 'T' head. Plus entry number. Duplicate entry number will result in an error. • GATE_VALUE: format: xb: The MSB corresponds to traffic class 7. The LSB corresponds to traffic class 0. A bit value of 0 indicates closed, A bit value of 1 indicates open. • IPV: # 0~7 • TIME_LONG: in nanoseconds. Do not input time long as 0. • OCTET_MAX: The maximum number of octets that are permitted to pass the gate. If zero, there is no maximum. t0 1b -1 50000 10 |

Table 32. qcisgiget

| Parameter <argument> | Description |
|----------------------|---|
| --device <ifname> | An interface such as eno0/swp0 |
| --index <value> | Index entry number in this controller. Mandatory to have. |

Table 33. qcifmiset

| Parameter <argument> | Description |
|----------------------|---|
| --device <ifname> | An interface such as eno0/swp0 |
| --index <value> | Index entry number in this controller. Mandatory to have. |
| --disable | If not set disable, then to be set enable. |
| --cir <value> | cir. kbit/s. |
| --cbs <value> | cbs. octets. |
| --eir <value> | eir.kbit/s. |
| --ebs <value> | ebs.octets. |
| --cf | cf. couple flag. |
| --cm | cm. color mode. |
| --dropyellow | drop yellow. |
| --markred_enable | mark red enable. |
| --markred | mark red. |

Table 34. qcifmiget parameter

| Parameter <argument> | Description |
|----------------------|---|
| --device <ifname> | An interface such as <code>eno0/swp0</code> |
| --index <value> | Index entry number in this controller. Mandatory to have. |

Table 35. qbuset parameter

| Parameter <argument> | Description |
|-----------------------|---|
| --device <ifname> | An interface such as <code>eno0/swp0</code> |
| --preemptable <value> | 8-bit hex value. Example: <code>0xfe</code> The MS bit corresponds to traffic class 7. The LS bit to traffic class 0. A bit value of 0 indicates express. A bit value of 1 indicates preemptable. |

Table 36. cbsset command

| Parameter <argument> | Description |
|----------------------------------|---|
| --device <ifname> | An interface such as <code>eno0/swp0</code> |
| --tc <value> | Traffic class number. |
| --percentage <value> | Set percentage of tc limitation. |
| --all <tc-percent:tc-percent...> | Not supported. |

Table 37. cbsget

| Parameter <argument> | Description |
|----------------------|---|
| --device <ifname> | An interface such as <code>eno0/swp0</code> |
| --tc <value> | Traffic class number. |

Table 38. regtool

| Parameter <argument> | Description |
|---|---|
| Usage: <code>regtool { pf number } { offset } [data]</code> | pf number: pf number for the pci resource to act on |
| | offset: offset into pci memory region to act upon |
| | data: data to be written |

Table 39. ctset

| Parameter <argument> | Description |
|----------------------|--|
| --device <ifname> | An interface such as swp0 |
| --queue_stat <value> | Specifies which priority queues have to be processed in cut-through mode of operation. Bit 0 corresponds to priority 0, Bit 1 corresponds to priority 1 so-on. |

Table 40. cbgen

| Parameter <argument> | Description |
|----------------------|---|
| --device <ifname> | An interface such as swp0 |
| --index <value> | Index entry number in this controller. Mandatory to have. This value corresponds to tsnStreamIdHandle of cbstreamidset command. |
| --iport_mask <value> | INPUT_PORT_MASK: If the packet is from input port belonging to this port mask, then it's a known stream and Sequence generation parameters can be applied |
| --split_mask <value> | SPLIT_MASK: Port mask used to add redundant paths (or ports). If split is enabled (STREAM_SPLIT) for a stream. This is OR'ed with the final port mask determined by the forwarding engine. |
| --seq_len <value> | SEQ_SPACE_LOG2: Minimum value is 1 and maximum value is 28. $tsnSeqGenSpace = 2^{**}SEQ_SPACE_LOG2$ For example, if this value is 12, then valid sequence numbers are from 0x0 to 0xFFFF. |
| --seq_num <value> | GEN_REC_SEQ_NUM: The sequence number to be used for outgoing packet passed to SEQ_GEN function. Note: Only lower 16-bits are sent in RED_TAG. |

Table 41. cbrec

| Parameter <argument> | Description |
|----------------------|--|
| --device <ifname> | An interface such as swp0 |
| --index <value> | Index entry number in this controller. Mandatory to have. This value corresponds to tsnStreamIdHandle of cbstreamidset command. |
| --seq_len <value> | SEQ_SPACE_LOG2:Min value is 1 and maximum value is 28. $tsnSeqRecSeqSpace = 2^{**}SEQ_REC_SPACE_LOG2$ For example, if this value is 12, then valid sequence numbers are from 0x0 to 0xFFFF. |
| --his_len <value> | SEQ_HISTORY_LEN: Refer to SEQ_HISTORY, Min 1 and Max 32. |
| --rtag_pop_en | REDTAG_POP: If True, then the redundancy tag is popped by rewriter. |

Table 42. dscpset

| Parameter <argument> | Description |
|----------------------|---|
| --device <ifname> | An interface such as swp0 |
| --disable | Disable DSCP to traffic class for frames. |
| --index | DSCP value |
| --cos | Priority number of queue which is mapped to |
| --dpl | Drop level which is mapped to |

Table 43. qcicapget

| Parameter <argument> | Description |
|----------------------|---------------------------|
| --device <ifname> | An interface such as swp0 |

Table 44. tsncapget

| Parameter <argument> | Description |
|----------------------|---------------------------|
| --device <ifname> | An interface such as swp0 |

7.3.1.4 Input tips

While providing the command input, user can use the following shortcut keys to make the input faster:

- When user input a command, use the **TAB** key to help list the related commands.

For example:

```
tsntool> qbv
```

Then press **TAB** key, to get all related `qbv*` start commands.

If there is only one choice, it is filled as the whole command automatically.

- When user input parameters, if user does not remember the parameter name. User can just input "--" then press **TAB** key. It displays all the parameters.

If user input half the parameter's name, pressing the **TAB** key lists all the related names.

- History: press the up arrow "↑". User will get the command history and can re-use the command.

7.3.1.5 Non-interactive mode

Tsntool also supports non-interactive mode.

For example:

In the interactive mode:

```
tsntool> qbuset --device eno0 --preemptable 0xfe
```

In non-interactive mode:

```
tsntool qbuset --device eno0 --preemptable 0xfe
```

7.3.2 TSN configuration on ENETC

The `tsntool` is an application configuration tool to configure the TSN capability. User can find the file, `/usr/bin/tsntool` and `/usr/lib/libtsn.so` in the rootfs. Run `tsntool` to start the setting shell. The following sections describe the TSN configuration examples on the ENETC ethernet driver interfaces.

Before testing the ENETC TSN test cases, user need to enable `mcprio` by using the command:

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

7.3.2.1 Clock synchronization

To test 1588 synchronization on ENETC interfaces, use the following procedure:

1. Connect ENETC interfaces on two boards in a back-to-back manner. (For example, eno0 to eno0.)

The linux booting log is as follows:

```
...
pps pps0: new PPS source ptp0
...
```

2. Check PTP clock and timestamping capability:

```
# ethtool -T eno0
Time stamping parameters for eno0:
Capabilities:
  hardware-transmit      (SOF_TIMESTAMPING_TX_HARDWARE)
  hardware-receive      (SOF_TIMESTAMPING_RX_HARDWARE)
  hardware-raw-clock    (SOF_TIMESTAMPING_RAW_HARDWARE)
PTP Hardware Clock: 0
Hardware Transmit Timestamp Modes:
  off      (HWTSTAMP_TX_OFF)
  on       (HWTSTAMP_TX_ON)
Hardware Receive Filter Modes:
  none     (HWTSTAMP_FILTER_NONE)
  all      (HWTSTAMP_FILTER_ALL)
```

3. Configure the IP address and run `ptp4l` on two boards:

```
# ifconfig eno0 <ip_addr>
# ptp4l -i eno0 -p /dev/ptp0 -m
```

4. After running, one board would be automatically selected as the master, and the slave board would print synchronization messages.
5. For 802.1AS testing, just use the configuration file `gPTP.cfg` in `linuxptp` source. Run the below command on the boards, instead:

```
# ptp4l -i eno0 -p /dev/ptp0 -f gPTP.cfg -m
```

7.3.2.2 Qbv

This test includes the Basic gates closing test, Basetime test, and the Qbv performance test. These are described in the following sections.

7.3.2.2.1 Basic gates closing

The commands below describe the steps for closing the basic gates:

```
cat > qbv0.txt << EOF
t0      00000000b      20000
EOF
```

```
#Explanation:
# 'NUMBER'      :      t0
# 'GATE_VALUE'  :      00000000b
# 'TIME_LONG'   :      20000 ns
```

```
cp libtsn.so /lib
./tsntool
tsntool> verbose
tsntool> qbvset --device eno0 --entryfile ./qbv0.txt

ethtool -S eno0
ping 192.168.0.2 -c 1 #Should not pass any frame since gates are all off.
```

7.3.2.2.2 Basetime test

Base on case 1 qbv1.txt gate list.

```
#create 1s gate
cat > qbv1.txt << EOF
t0  11111111b      10000
t1  00000000b      99990000
EOF

#ENETC Qbv basetime can be set any past time or future time.
#For the past time, hardware calculate by:
#   effective-base-time = base-time + N x cycle-time
#where N is the smallest integer number of cycles such that effective-base-time >= now.
#If you want a future time, you can get current time by:

tsntool> ptptool -g

#Below example shows basetime start at 260.666 s (start of 1 January 1970):

tsntool> qbvset --device eno0 --entryfile qbv1.txt --basetime 260.666
tsntool> qbvget --device eno0 #User can check configchange time
tsntool> regtool 0 0x11a10 #Check pending status, 0x1 means time gate is working

#Waiting to change state, ping remote computer
ping 192.168.0.2 -A -s 1000

#The reply time will be about 100 ms
```

Since 10000 ns is the maximum limit for package size 1250 B.

```
ping 192.168.0.2 -c 1 -s 1300 #frame should not pass
```

7.3.2.2.3 Qbv performance test

Use the setup described in the figure below for testing ENETC port0 (MAC0).

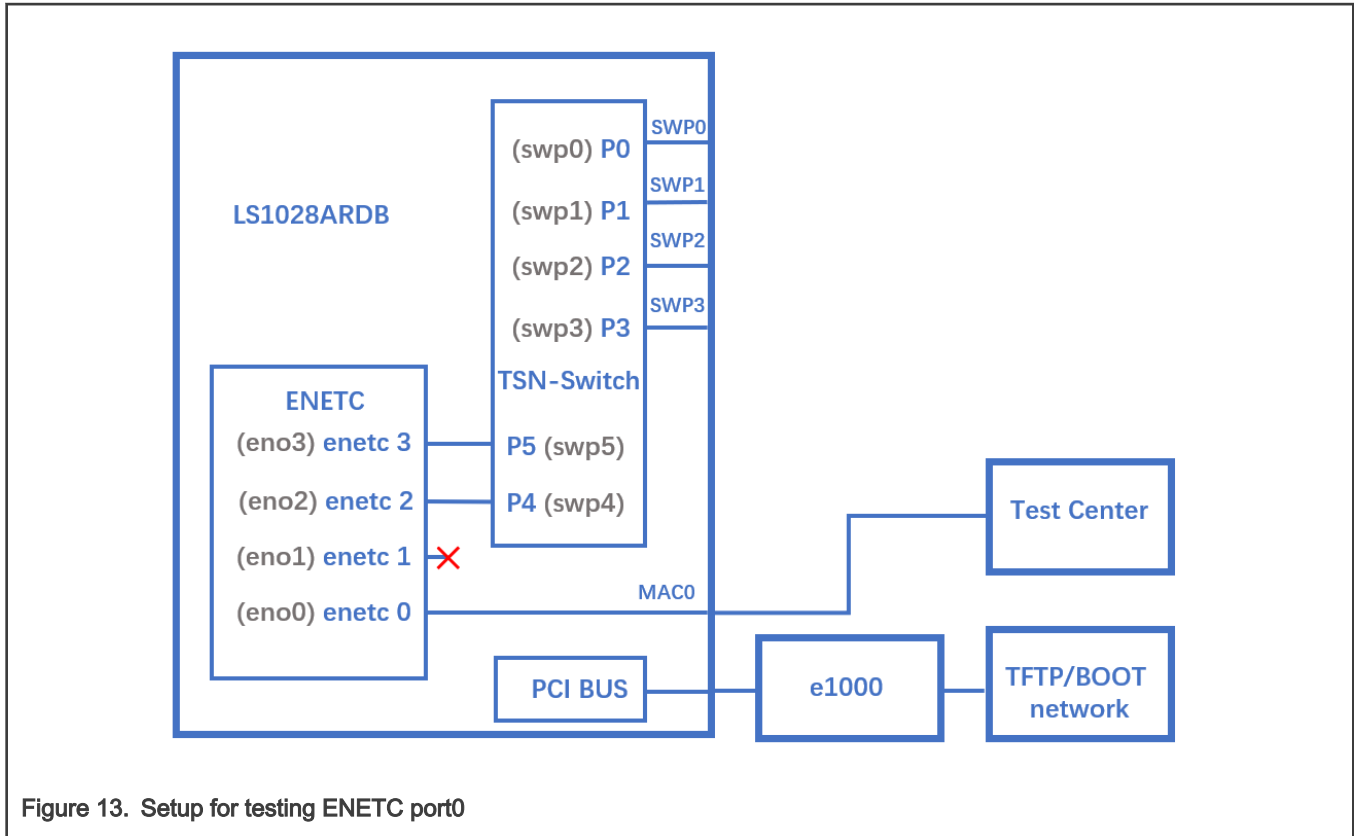


Figure 13. Setup for testing ENETC port0

```
cat > qbv5.txt << EOF
t0 11111111b      1000000
t1 00000000b      1000000
EOF

qbvset --device eno0 --entryfile qbv5.txt
./pktgen/pktgen_twoqueue.sh -i eno0 -q 3 -n 0

#The stream would get about half line rate
```

7.3.2.2.4 Using taprio Qdisc Setup Qbv

LS1028ardb support the taprio qdisc to setup Qbv either. Below is an example Setup.

```
#Qbv test do not require the mqprio setting.
# If mqprio is enabled, try to disable it by below command:
tc qdisc del dev eno0 root handle 1: mqprio

# Enable the Qbv for ENETC eno0 port
# Below command set eno0 with gate 0x01, means queue 0 open, the other queues gate close.
tc qdisc replace dev eno0 parent root handle 100 taprio num_tc 8 map 0 1 2 3 4 5 6 7 queues 1@0 1@1
1@2 1@3 1@4 1@5 1@6 1@7 base-time 0 sched-entry S 01 300000 flags 0x2
# Ping through eno0 port should be ok

# Then close the gate queue 0. Open gate queue 1. The other queues gate close.
tc qdisc replace dev eno0 parent root handle 100 taprio num_tc 8 map 0 1 2 3 4 5 6 7 queues 1@0 1@1
1@2 1@3 1@4 1@5 1@6 1@7 base-time 0 sched-entry S 02 300000 flags 0x2
# Ping through eno0 port should be dropped
```

```
#Disable the Qbv for ENETC eno0 port as below
tc qdisc del dev eno0 parent root handle 100 taprio
```

7.3.2.3 Qci

Use the following as the background setting:

- Set eno0 MAC address

```
ip link set eno0 address 10:00:80:00:00:00
```

Opposite port MAC address **99:aa:bb:cc:dd:ee** as frame provider as example.

- Use the figure below as the hardware setup.

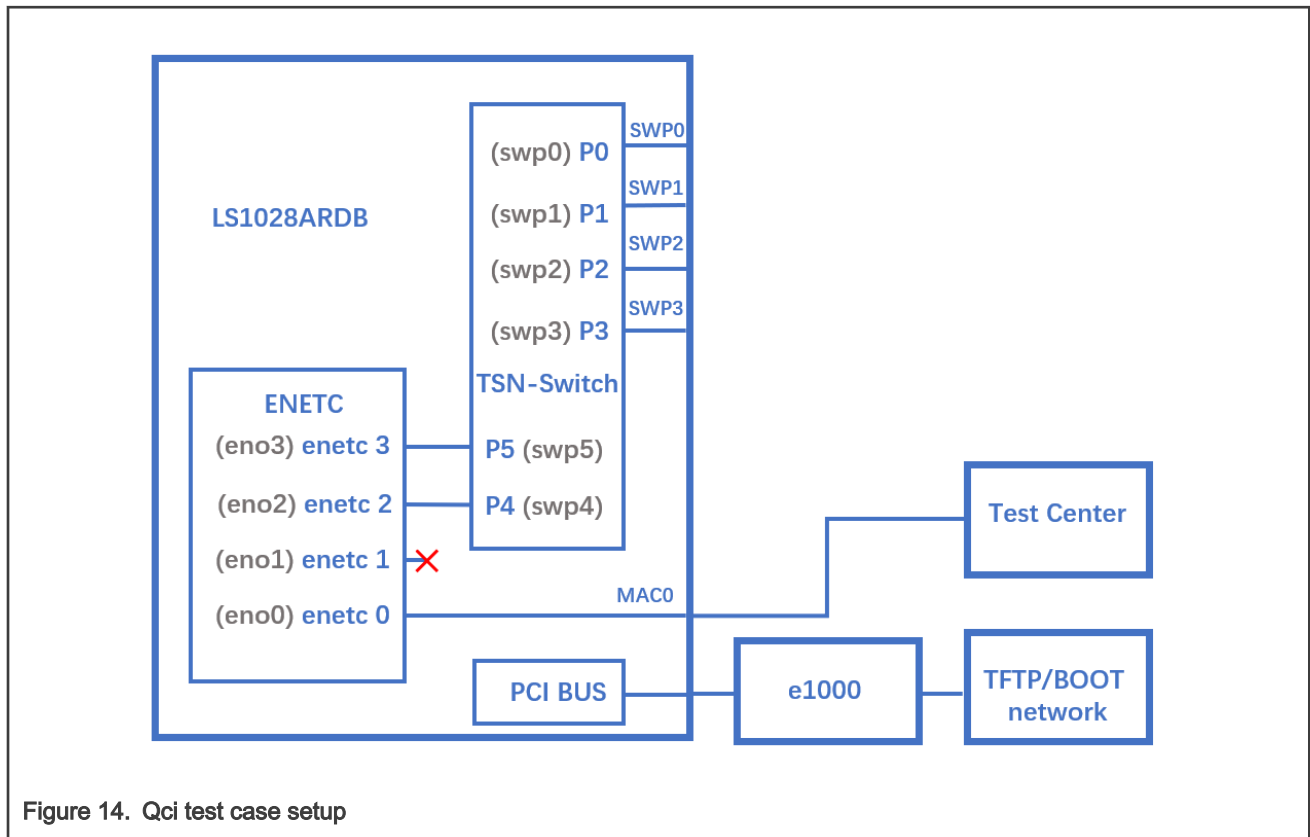


Figure 14. Qci test case setup

7.3.2.3.1 Test SFI No Streamhandle

Qci PSFP can work for the streams without stream identify module which means streams without mac address and vid filter. Such kind of filter setting always set larger index number stream filter entry. Those frames won't be filtered then flow into this stream filter entry.

Below example test no streamhandle in a stream filter, set on stream filter entry index 2 with a gate stream entry id 2. Then none stream identifies frames would flow into the stream filter entry index 2 then pass the gate entry index 2, as shown in the following example:

```
tsntool> qcisfiset --device eno0 --index 2 --gateid 2
```

- Streams no streamhandle should pass this filter.

```
tsntool> qcisfiget --device eno0 --index 2
```

- Send a frame from the opposite device port (ping for example).

```
tsntool> qcisfiget --device eno0 --index 2
```

- Set Stream Gate entry 2

```
tsntool> qcisgiset --device eno0 --index 2 --initgate 1
```

- Send a frame from the opposite device port.

```
tsntool> qcisfiget --device eno0 --index 2
```

- Set Stream Gate entry 2, gate closes permanently.

```
tsntool> qcisgiset --device eno0 --index 2 --initgate 0
```

- Send a frame from the opposite device port.

```
tsntool> qcisfiget --device eno0 --index 2

#The result should look like below:
match pass gate_drop sdu_pass sdu_drop red
  1   0   1       1       0       0
```

7.3.2.3.2 Testing null stream identify entry

Null stream identify in stream identify module means try to filter as destination mac address and vlan id.

Following steps shows stream identify entry index 1 set with filtering destination mac address is 10:00:80:00:00:00, vlan id ignored(with or without vlan id). Then stream filter set on the entry index 1 with stream gate index entry id 1.

1. Set main stream by close gate.
2. Set Stream identify Null stream identify entry 1.

```
tsntool> cbstreamidset --device eno0 --index 1 --nullstreamid --nullldmac
0x000000800010 --nulltagged 3 --nullvid 10 --streamhandle 100
```

3. Get stream identify entry index 1.

```
tsntool> cbstreamidget --device eno0 --index 1
```

4. Set Stream filter entry 1 with stream gate entry id 1.

```
tsntool> qcisfiset --device eno0 --streamhandle 100 --index 1 --gateid 1
```

5. Set Stream Gate entry 1, keep gate state close (all frames dropped. return directly if ask user for editing gate list).

```
tsntool> qcisgiset --device eno0 --index 1 --initgate 0
```

6. Send one frame from the opposite device port should pass to the close gate entry id 1.

```
tsntool> qcisfiget --device eno0 --index 1
```

7. The result should look like the output below:

```
match pass gate_drop sdu_pass sdu_drop red
  1  0  1  1  0  0
```

7.3.2.3.3 Testing source stream identify entry

Source stream identify means stream identify the frames by the source mac address and vlan id.

Use the following steps for this test:

1. Keep Stream Filter entry 1 and Stream gate entry 1.
2. Add stream2 in opposite device port: SMAC is 66:55:44:33:22:11 DMAC:20:00:80:00:00:00 (Not with destination mac address 10:00:80:00:00:00 which stream identify entry index 1 is filtering that dmac address)
3. Set Stream identify Source stream identify entry 3

```
tsntool> cbstreamidset --device eno0 --index 3 --sourcemacvid --sourcemac 0x112233445566 --
source tagged 3 --sourcevid 20 --streamhandle 100
```

4. Send frame from opposite device port. The frame passes to stream filter index 1.

```
tsntool> qcisfiget --device eno0 --index 1
```

7.3.2.3.4 SGI stream gate list

Use the command below for this test:

```
cat > sgi1.txt << EOF
t0 0b -1 100000000 0
t1 1b -1 100000000 0
EOF
tsntool> qcisfiset --device eno0 --index 2 --gateid 2
tsntool> qcisgiset --device eno0 --index 2 --initgate 1 --gatelistfile sgi1.txt

#flooding frame size 64bytes from opposite device port.(iperf or netperf as example)
tsntool> qcisfiget --device eno0 --index 2
```

Check the frames dropped and passed, they should be the same since stream gate list is setting 100ms open and 100ms close periodically.

7.3.2.3.5 FMI test

Only send green color frames(Normally it is the TCI bit value in 802.1Q tag). Flooding the stream against the eno0 port speed to 10000kbps/s:

```
tsntool> qcisfiset --device eno0 --index 2 --gateid 2 --flowmeterid 2
tsntool> qcifmisset --device eno0 --index 2 --cm --cf --cbs 1500 --cir 5000 --ebs 1500 --eir 5000
```

'cm' parameter set color mode enable means frames separate green frames and yellow frames judged by the TCI bit in frame. Or else, any frames are green frames.

'cf' parameter set the coupling flag enable. When CF is set to 0, the frames that are declared yellow is bounded by EIR. When CF is set to 1, the frames that are declared Yellow is bounded by CIR + EIR depending on volume of the offered frames that are declared Green.

After upper commands setup, since green frames not larger than EIR + CIR 10Mbit/s. So the green frame would not be dropped.

The below setting shows the dropped frames:

```
tsntool> qcifmisset --device eno0 --index 2 --cm --cf --cbs 1500 --cir 5000 --ebs 1500 --eir 2000
```

This case makes the green frames pass 5Mbit/s in CIR, then it pass to the EIR space, but EIR is 2Mbit/s, so total EIR + CIR 7Mbit/s still not qualify the total 10Mbit/s bandwidth. So green frame would be dropped part.

To get information of color frame counters showing at application layer, use the code as in the below example:

```

tsntool> qcifmiget --device eno0 --index 2
=====
bytecount drop dr0_green dr1_green dr2_yellow remark_yellow dr3_red remark_red
1c89 0 4c 0 0 0 0 0
=====
index = 2
cir = c34c
cbs = 5dc
eir = 4c4b3c
ebs = 5dc
couple flag
color mode
    
```

7.3.2.4 Qbu

If user has two ls1028ardb boards, and link the two eno0 back to back, the test would not need to setup the switch and omit the step 1,2,3, then just perform step 0,4,5.

If user has only one board, user can set the frame path from eno0 to switch by linking enetc ports MAC0 - SWP0. The setup enable the switch SWP0 port merging capability, then enetc eno0 could show the preemption capability. Use the setup as shown in the following figure for the Qbu test.

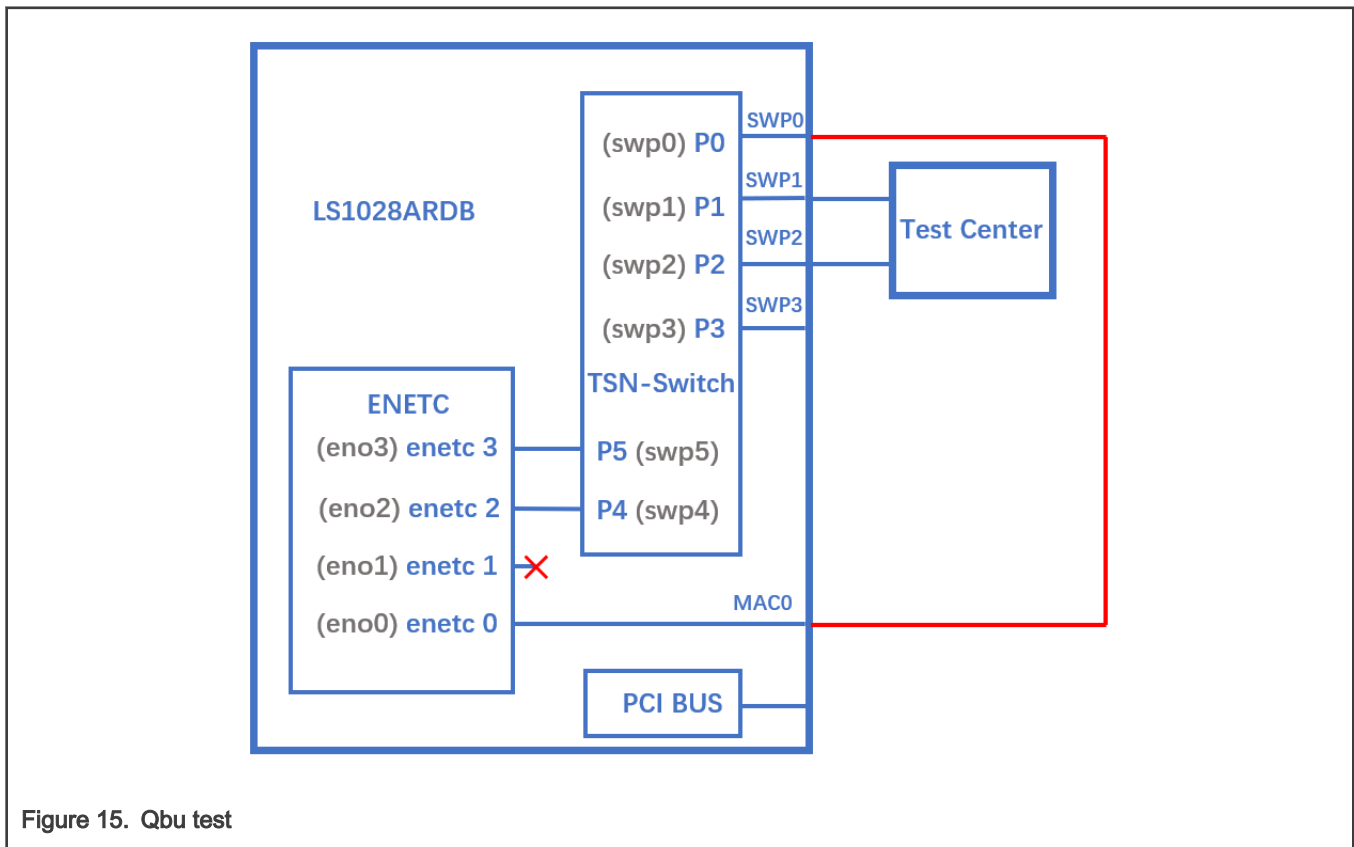


Figure 15. Qbu test

Before link the cable between ENETC port0 to SWP0, set up the switch up(refer the [Switch configuration](#)) and set IP for ENETC port0. To make sure linking the ENETC port0 to SWP0, use the steps below:

0. Don't forget to enabling the priority for each traffic class:

```

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

1. Make sure link speed is 1 Gbps by using the command:

```
ethtool eno0
```

2. If it is not 1Gbps, set it to 1 Gbps by using the command:

```
ethtool -s swp0 speed 1000 duplex full autoneg on
```

3. Set the switch to enable merge(or user can link to another merge capability port in another board):

```
devmem 0x1fc10048 32 0x111 #DEV_GMII:MM_CONFIG:ENABLE_CONFIG
```

4. ENETC port setting set and frame preemption test

```
ip link set eno0 address 90:e2:ba:ff:ff:ff
tsntool qbuset --device eno0 --preemptable 0xfe
./pktgen/pktgen_twoqueue.sh -i eno0 -q 0 -s 100 -n 20000 -m 90:e2:ba:ff:ff:ff
```

pktgen would fluding frames on TC0 and TC1.

5. Check the tx merge counter, if it has a non-zero value, it indicates that the Qbu is working.

```
tsntool regtool 0 0x11f18
```

NOTE

0x11f18 counting the merge frame count:

```
0x11f18 Port MAC Merge Fragment Count TX Register (MAC_MERGE_MMFCTXR)
```

LS1028 also support ethtool setup the preemption as example:

```
ethtool --set-frame-preemption eno0 preemptible-queues-mask 0xfe
```

Which means got same result TC0 to pass express MAC and TC1~TC7 to pass preemptable MAC.

7.3.2.5 Qav

7.3.2.5.1 Using tsntool

The following figure illustrates the hardware setup diagram for the Qav test.

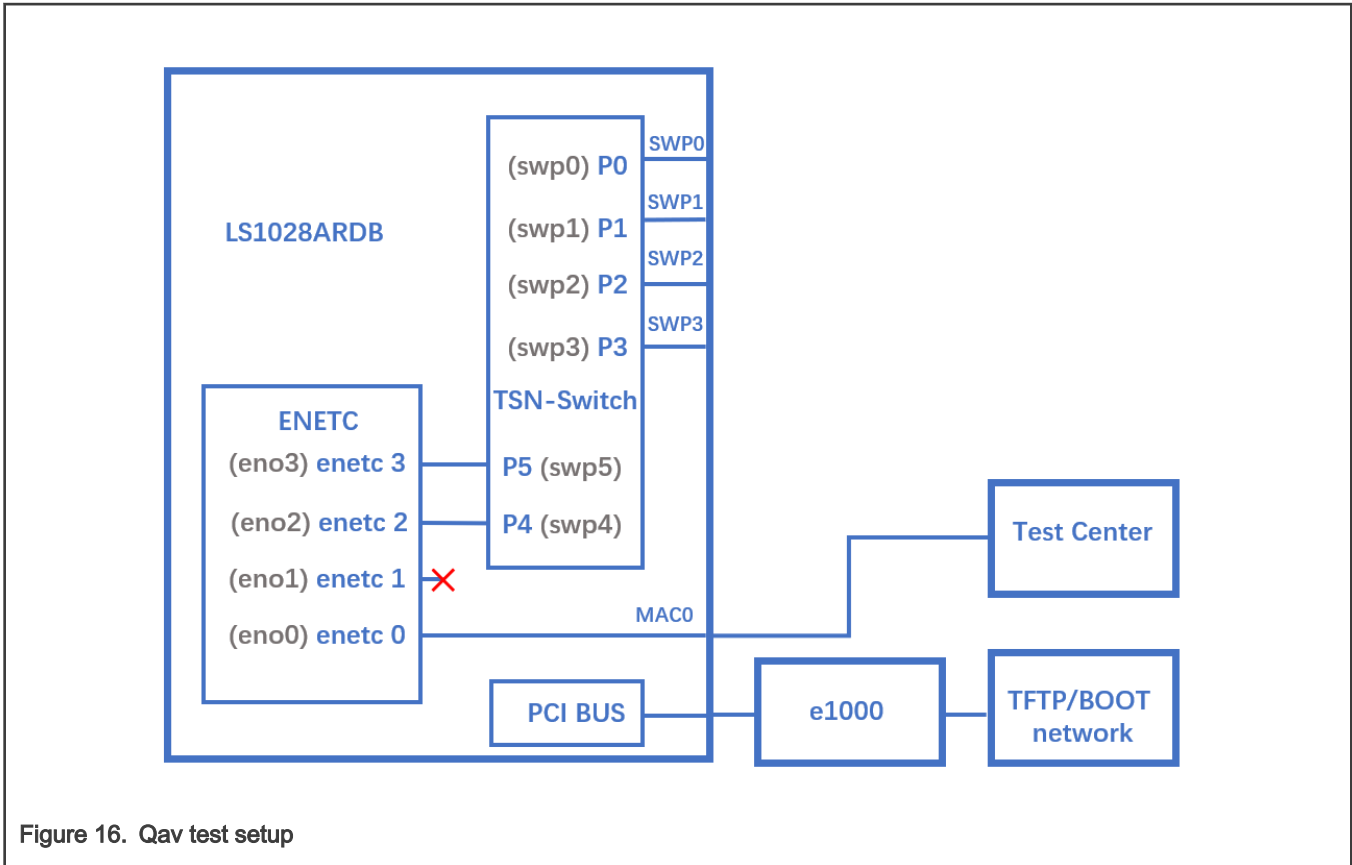


Figure 16. Qav test setup

0. Don't forget to enabling the priority for each traffic class:

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

1. Run the following commands:

```
cbsset --device eno0 --tc 7 --percentage 60
cbsset --device eno0 --tc 6 --percentage 20
```

2. Check each queue bandwidth (pktgen require enabling NET_PKTGEN in kernel)

```
./pktgen/pktgen_sample01_simple.sh -i eno0 -q 7 -s 500 -n 30000
```

wait seconds later to check result. It should get about 60% percentage line rate.

```
./pktgen/pktgen_sample01_simple.sh -i eno0 -q 6 -s 500 -n 30000
```

Wait seconds later to check result. It should get about 20% percentage line rate.

7.3.2.5.2 Using CBS Qdisc Setup Qav

LS1028a support the CBS qdisc to setup Credit-based Shaper. Below commands set CBS with 100Mbit/s for queue 7 and 300Mbit/s for queue 6.

```
tc qdisc add dev eno0 root handle 1: mqprio num_tc 8 map 0 1 2 3 4 5 6 7 hw 1
tc qdisc replace dev eno0 parent 1:8 cbs locredit -1470 hicredit 30 sendslope -900000 idleslope 100000 offload 1
tc qdisc replace dev eno0 parent 1:7 cbs locredit -1470 hicredit 30 sendslope -700000 idleslope 300000 offload 1
```



```
# Try to flood stream here (require kernel enable NET_PKTGEN)
./pktgen/pktgen_sample01_simple.sh -i eno0 -q 7 -s 500 -n 20000
./pktgen/pktgen_sample01_simple.sh -i eno0 -q 6 -s 500 -n 20000
tc qdisc del dev eno0 parent 1:7 cbs
tc qdisc del dev eno0 parent 1:8 cbs
```

7.3.3 TSN configuration on Felix switch

The following sections describe examples for the basic configuration of TSN switch.

7.3.3.1 Linux switch configuration

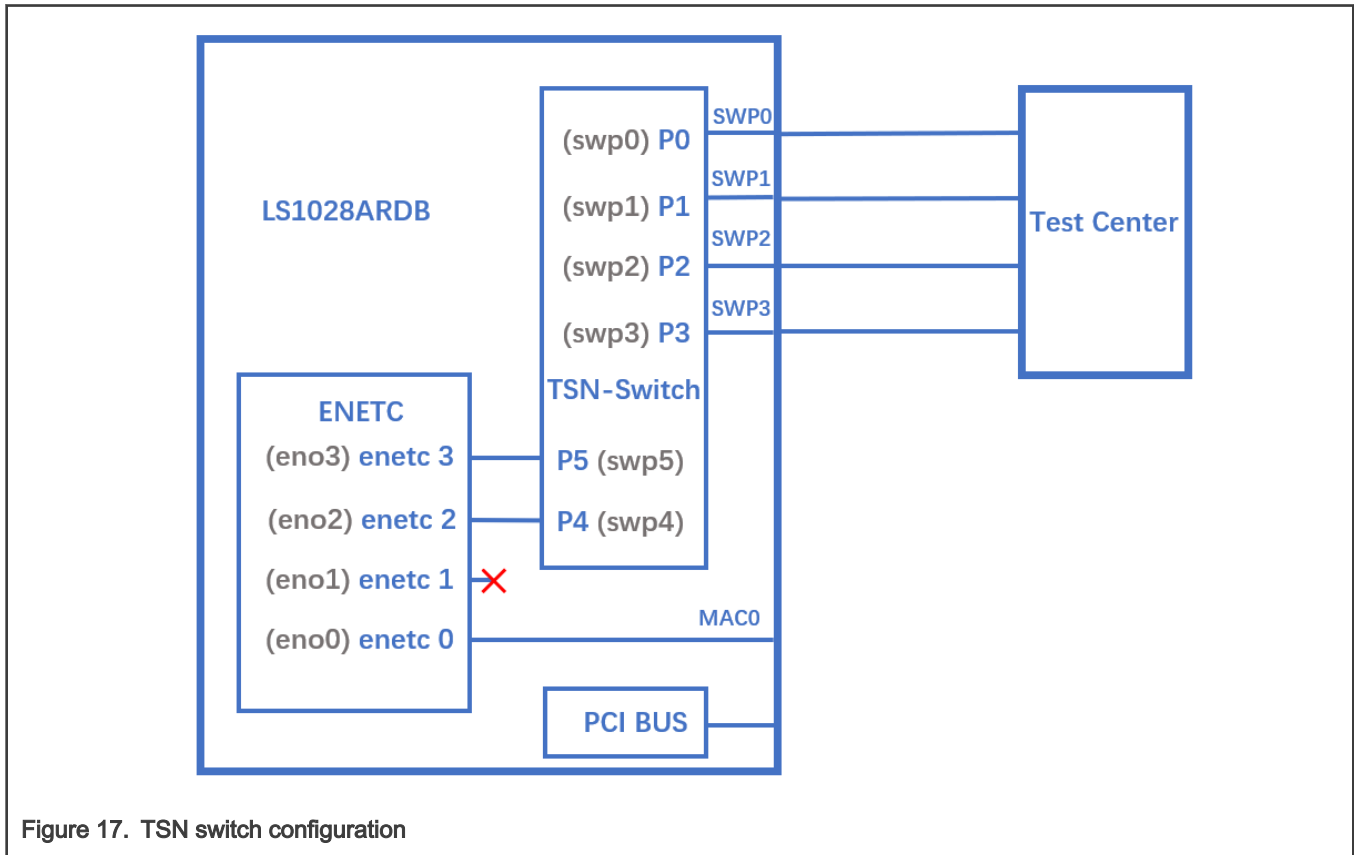


Figure 17. TSN switch configuration

Use the following commands for configuring the switch on LS1028ARDB:

```
ls /sys/bus/pci/devices/0000:00:00.5/net/
```

Get switch device interfaces: swp0 swp1 swp2 swp3>

```
ifconfig eno2 up
ip link add name switch type bridge
ip link set switch up
ip link set swp0 master switch && ip link set swp0 up
ip link set swp1 master switch && ip link set swp1 up
ip link set swp2 master switch && ip link set swp2 up
ip link set swp3 master switch && ip link set swp3 up
```

7.3.3.2 Clock synchronization

To test 1588 synchronization on felix-switch interfaces, use the following procedure:

1. Connect two boards back-to-back with switch interfaces. For example, swp0 to swp0.

The Linux booting log is displayed below:

```
...
pps pps0: new PPS source ptp1
...
```

2. Check PTP clock and time stamping capability using the commands below:

```
$ ethtool -T swp0
Time stamping parameters for swp0:
Capabilities:
  hardware-transmit  (SOF_TIMESTAMPING_TX_HARDWARE)
  hardware-receive  (SOF_TIMESTAMPING_RX_HARDWARE)
  hardware-raw-clock (SOF_TIMESTAMPING_RAW_HARDWARE)
PTP Hardware Clock: 1
Hardware Transmit Timestamp Modes:
  off  (HWTSTAMP_TX_OFF)
  on   (HWTSTAMP_TX_ON)
Hardware Receive Filter Modes:
  none (HWTSTAMP_FILTER_NONE)
  all  (HWTSTAMP_FILTER_ALL)
```

3. Set switch ip on two board, and ping each other.

```
$ ifconfig switch 192.168.1.2 /* On board A */
$ ifconfig switch 192.168.1.3 /* On board B */
$ ping 192.168.1.3 /* On board A */
```

4. For 802.1AS testing, use the configuration file `gPTP.cfg` in `linuxptp` source. Run the below commands on the two boards instead.

```
$ ptp4l -i swp0 -p /dev/ptp1 -f gPTP.cfg -2 -m
```

Or use GenAVB/TSN Stack with the following command: `'avb.sh start'`. Note that the configuration file `/etc/genavb/fgptp-br.cfg` is automatically used.

NOTE

Install `ptp4l` (`linuxptp`), if not installed already in ubuntu rootfs. Also, stop and disable `ptp4l.service` in case of failure; as used needs to write it as per the requirement. `ptp4l v1.8` is used for LSDK verification.

```
# apt update
# apt install linuxptp
# systemctl stop ptp4l.service
# systemctl disable ptp4l.service
```

7.3.3.3 Qbv

The following figure describes the setup for Qbv test on LS1028ARDB.

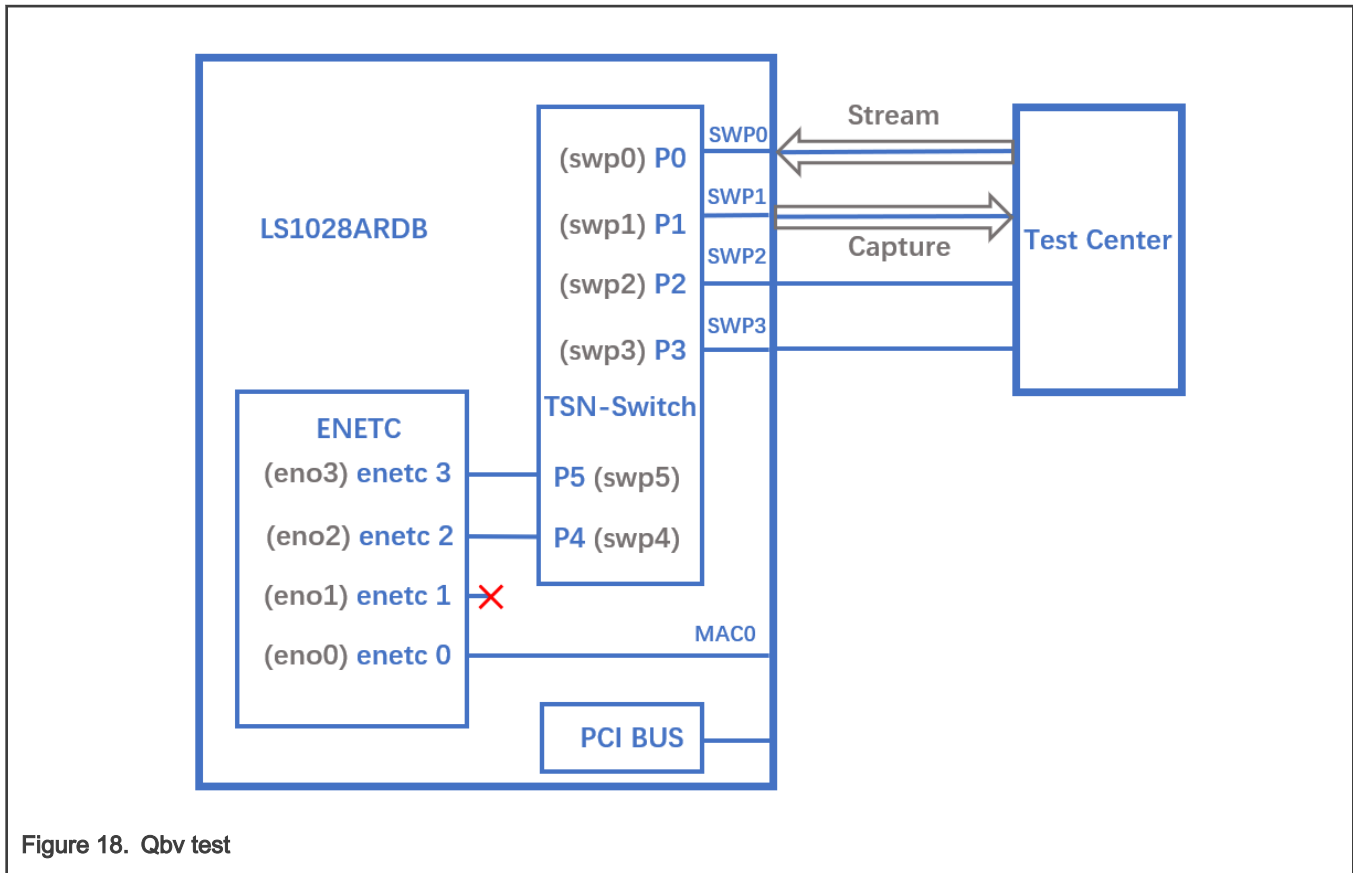


Figure 18. Qbv test

7.3.3.3.1 Tsntool usage

7.3.3.3.1.1 Closing basic gates

Use the set of commands below for basic gate closing.

```
echo "t0 0000000b 20000" > qbv0.txt
#Explanation:
# 'NUMBER'      : t0
# 'GATE_VALUE'  : 0000000b
# 'TIME_LONG'   : 20000 ns

./tsntool
tsntool> verbose
tsntool> qbvset --device swp1 --entryfile ./qbv0.txt

#Send one broadcast frame to swp0 from TestCenter.
ethtool -S swp1
#Should not get any frame from swp1 on TestCenter.

echo "t0 1111111b 20000" > qbv0.txt
tsntool> qbvset --device swp1 --entryfile ./qbv0.txt

#Send one broadcast frame to swp0 on TestCenter.
ethtool -S swp1
#Should get one frame from swp1 on TestCenter.
```

7.3.3.3.1.2 Basetime test

For the basetime test, first get the current second time:

```
#Get current time:
tsntool> ptptool -g -d /dev/ptp1

#add some seconds, for example user gets 200.666 time clock, then set 260.666 as result
tsntool> qbvset --device swp1 --entryfile ./qbv0.txt --basetime 260.666

#Send one broadcast frame to swp0 on the Test Center.
#Frame could not pass swp1 until time offset.
```

7.3.3.3.1.3 Qbv performance test

Use the following commands for the QBv performance test:

```
cat > qbv5.txt << EOF
t0 11111111b 1000000
t1 00000000b 1000000
EOF
qbvset --device swp1 --entryfile qbv5.txt
```

#Send 1G rate stream to swp0 on TestCenter.

#The stream would get about half line rate from swp1.

7.3.3.3.2 Tc-taprio usage

LS1028ardb support the taprio qdisc to setup Qbv either. Below is an example Setup.

1. Enable the Qbv for swp1 port, set queue 1 gate open, set circle time to be 300um.

```
tc qdisc replace dev swp1 parent root handle 100 taprio num_tc 8 map 0 1 2 3 4 5 6 7 \
    queues 1@0 1@1 1@2 1@3 1@4 1@5 1@6 1@7 base-time 0 sched-entry S 02 300000 flags 0x2
```

NOTE

Since the hardware can only use PCP, DSCP or other methods to classify Qos, it cannot map Qos to different hardware queues. mqprio is not implemented in the felix driver, so "map 0 1 2 3 4 5 6 7" in the tc-taprio command is invalid.

2. Send one frame with PCP=1 in vlan tag to swp0 from TestCenter, we will capture the frame from swp1.

3. Send one frame with PCP=2 in vlan tag to swp0 from TestCenter, gate is closed and we couldn't capture the frame from swp1.

4. Disable the Qbv for swp1 port as below

```
tc qdisc del dev swp1 parent root handle 100 taprio
```

7.3.3.4 Qbu

The figure below illustrates the setup for performing the Qbu test using the TSN switch.

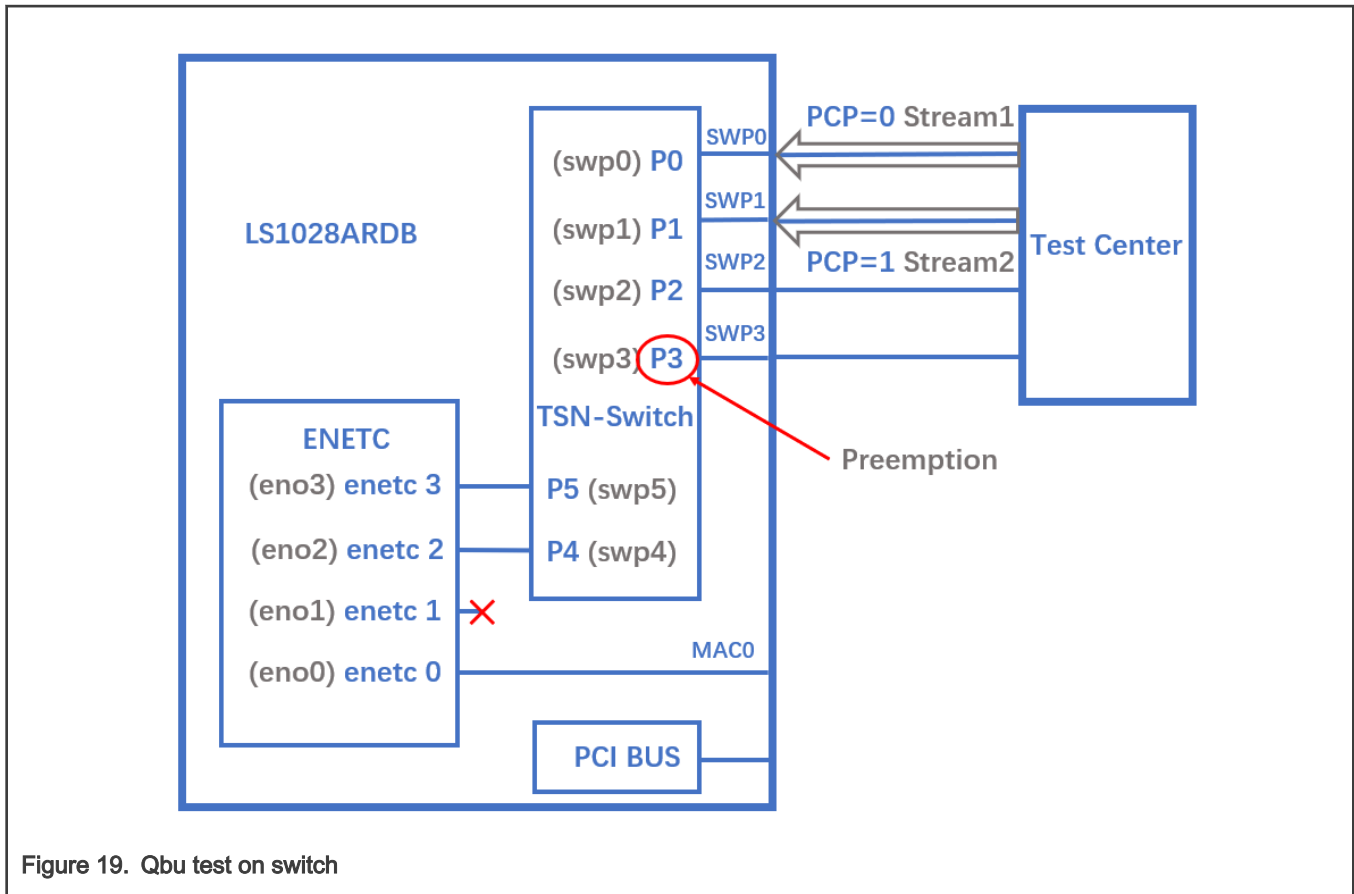


Figure 19. Qbu test on switch

7.3.3.4.1 Tsntool usage

1. Set queue 1 to be preemptable. There are two ways to set preemptable queues, users can choose tsntool or ethtool to set it.

```
#tsntool command to set preemptable queues:
tsntool> qbuset --device swp3 --preemptable 0x02
```

2. Send two streams from TestCenter, set packet size to be 1500Byte and bandwidth to be 1G, then check the number of additional mPackets transmitted by PMAC:

```
devmem 0x1fc010e48 32 0x3 && devmem 0x1fc010280
```

3. Qbu combined with Qbv test.

Set queue 0 gate open 20us, queue 1 gate open 20us.

```
cat > qbv0.txt << EOF
t0 00000001b 200000
t1 00000010b 200000
EOF
qbvset --device swp3 --entryfile qbv0.txt
```

Send two streams from TestCenter, packets in queue 1 will be preempted when gate 1 closed

7.3.3.4.2 Ethtool usage

1. Set queue 1 to be preemptable. There are two ways to set preemptable queues, users can choose tsntool or ethtool to set it.

```
#ethtool command to set preemptable queues:
ethtool --set-frame-preemption swp3 preemptible-queues-mask 0x02 min-frag-size 124
```

Explanation:

- `preemptible-queues-mask`: A 8-bit vector which specifies preemptable queues within the 8 priorities (with bit-0 for priority-0 and bit-7 for priority-7).
 - `min-frag-size`: at least frame bytes have been transmitted in fragment, the minimum non-final fragment size is 64, 128, 192, or 256 octets (include 4 Bytes fragment header).
2. Send two streams from TestCenter, set packet size to be 1500Byte and bandwidth to be 1G, then check the number of additional mPackets transmitted by PMAC:

```
devmem 0x1fc010e48 32 0x3 && devmem 0x1fc010280
```

3. Qbu combined with Qbv test.

Set queue 0 gate open 20us, queue 1 gate open 20us.

```
tc qdisc replace dev swp3 parent root handle 100 taprio num_tc 8 map 0 1 2 3 4 5 6 7 \
  queues 1@0 1@1 1@2 1@3 1@4 1@5 1@6 1@7 base-time 0 \
    sched-entry S 01 200000 \
    sched-entry S 02 200000 flags 0x2
```

Send two streams from TestCenter, packets in queue 1 will be preempted when gate 1 closed

7.3.3.5 Qav

The below figure illustrates the Qav test case setup.

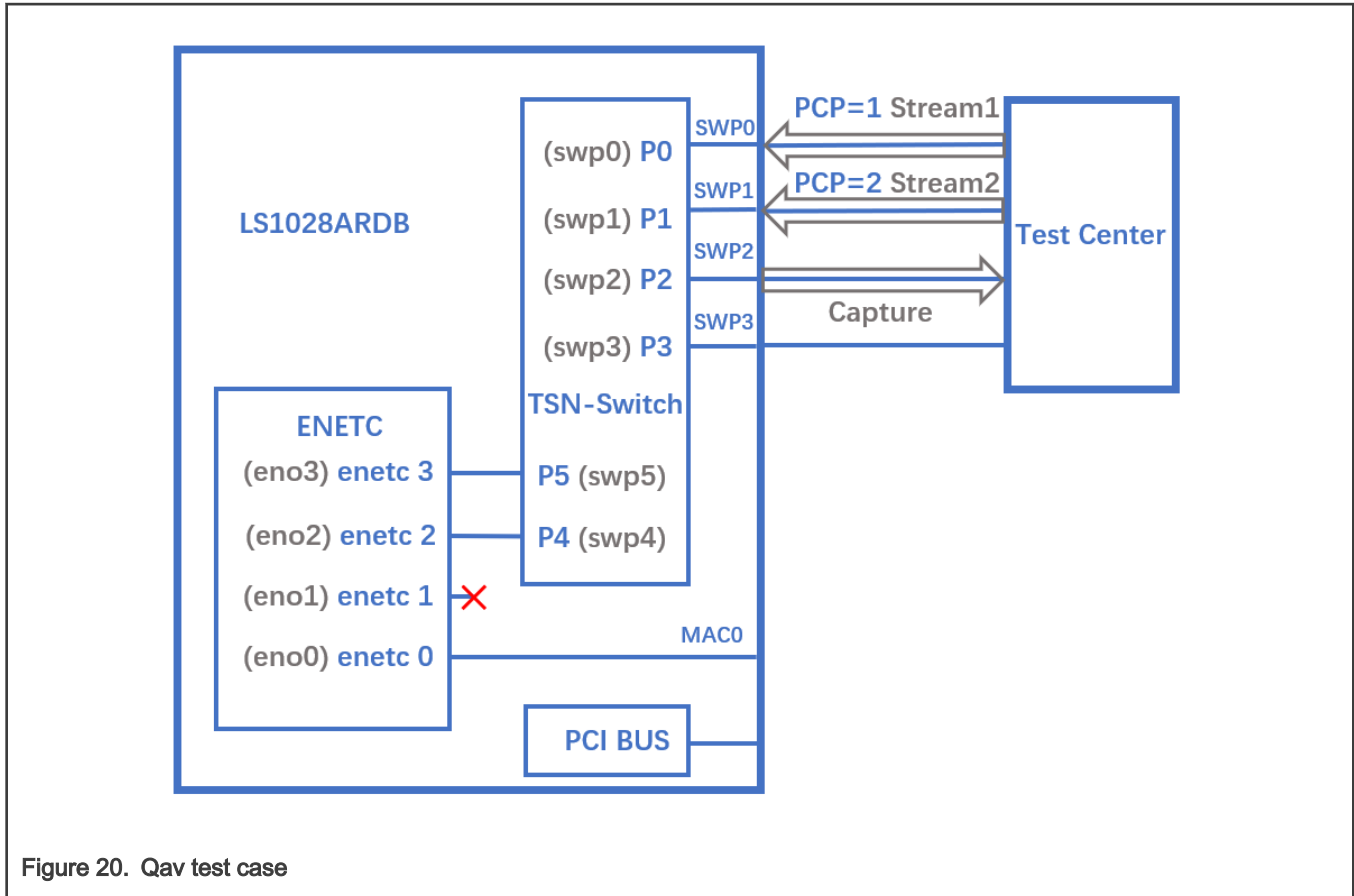


Figure 20. Qav test case

7.3.3.5.1 Tsntool usage

1. Set the percentage of two traffic classes:

```
tsntool> cbsset --device swp2 --tc 1 --percentage 20
tsntool> cbsset --device swp2 --tc 2 --percentage 40
```

2. Send two streams from Test center, then check the frames count.

```
ethtool -S swp2
```

Note that the frame count of queue1 is half of queue2.

NOTE

Stream rate must larger than bandwidth limited of queue.

3. Capture frames on swp2 on TestCenter.

The Get Frame sequence is: (PCP=1), (PCP=2), (PCP=2), (PCP=1), (PCP=2), (PCP=2),...

7.3.3.5.2 Tc-cbs usage

LS1028a support the CBS qdisc to setup Credit-based Shaper. Below commands set CBS with 20Mbit/s for queue 1 and 40Mbit/s for queue 2.

1. Set the cbs of two traffic classes:

```
tc qdisc add dev swp2 root handle 1: mqprio num_tc 8 map 0 1 2 3 4 5 6 7 \
  queues 1@0 1@1 1@2 1@3 1@4 1@5 1@6 1@7 hw 0
tc qdisc replace dev swp2 parent 1:2 cbs locredit -1470 hicredit 30 \
  sendslope -980000 idleslope 20000 offload 1
tc qdisc replace dev swp2 parent 1:3 cbs locredit -1440 hicredit 60 \
  sendslope -960000 idleslope 40000 offload 1
```

2. Send one stream with PCP=1 from TestCenter, we can get the stream bandwidth is 20Mbps from swp2.

3. Send two streams from Test center, then check the frames count.

```
ethtool -S swp2
```

Note that the frame count of queue1 is half of queue2.

4. delete the cbs rules.

```
tc qdisc del dev swp2 parent 1:2 cbs
tc qdisc del dev swp2 parent 1:3 cbs
```

7.3.3.6 Qci

The figure below illustrates the Qci test case setup.

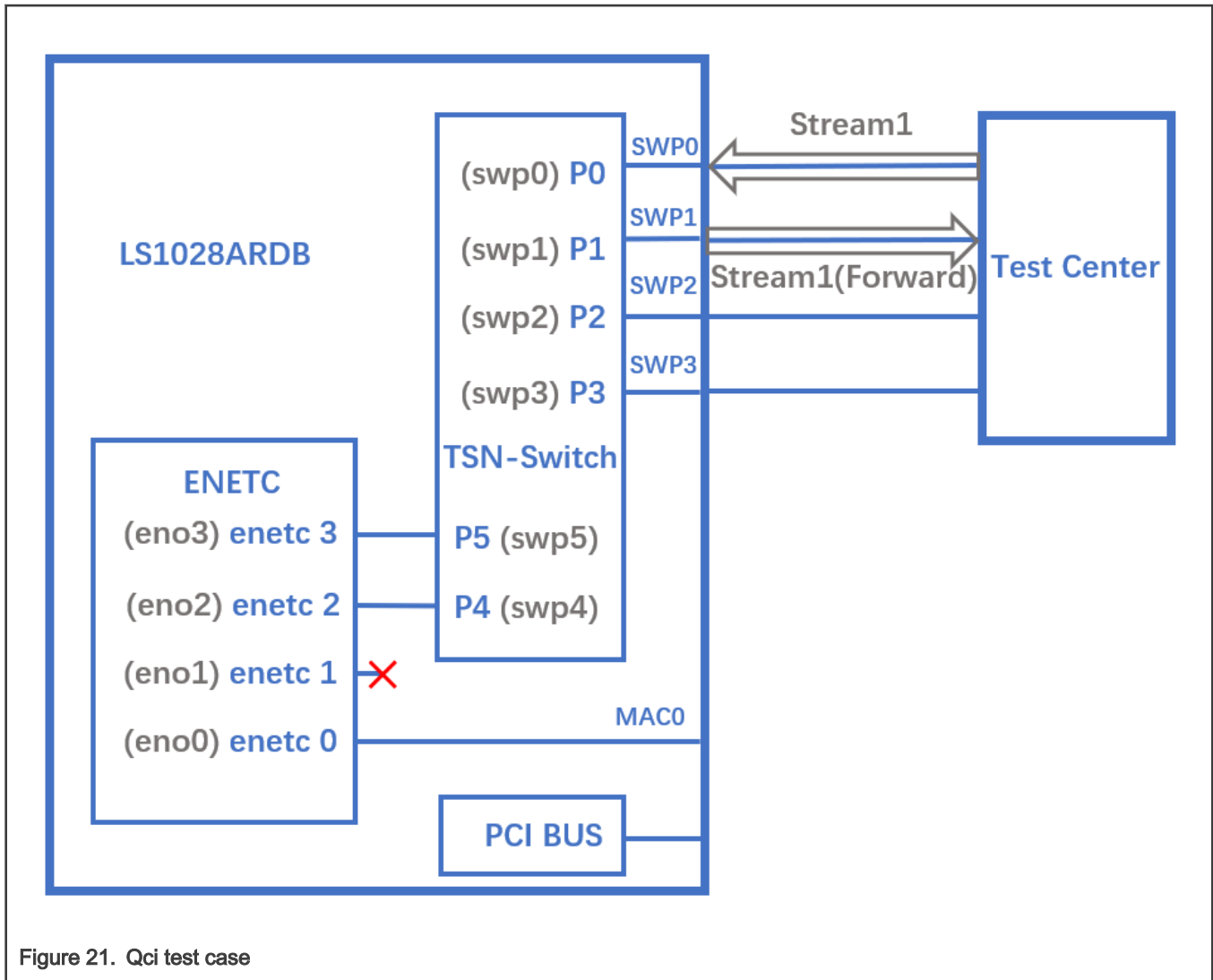


Figure 21. Qci test case

7.3.3.6.1 Tsntool usage

7.3.3.6.1.1 Stream identification

Use the following commands for stream identification:

1. Set a stream to `swp0` on TestCenter.
2. Edit the stream, set the destination MAC as: `00:01:83:fe:12:01`, Vlan ID : 1

```
tsntool> cbstreamidset --device swp1 --nullstreamid --index 1 --nulldmac 0x000183fe1201 --
nullvid 1 --streamhandle 1
```

Explanation:

- `device`: set the device port which is the stream forwarded to. If the {`destmac`, `VID`} is already learned by switch, switch will not care device port.
- `nulltagged`: switch only support `nulltagged=1` mode, so there is no need to set it.

- `nullvid`: Use "bridge vlan show" to see the ingress VID of switch port.

```
tsntool> qcisfiset --device swp0 --index 1 --streamhandle 1 --gateid 1 --priority 0 --
flowmeterid 68
```

Explanation:

- `device`: can be any one of switch ports.
- `index`: value is the same as streamhandle of `cbstreamidset`.
- `streamhandle`: value is the same as streamhandle of `cbstreamidset`.
- `flowmeterid`: PSFP Policer id, ranges from 63 to 383.

3. Send one frame, then check the frames.

```
ethtool -S swp1
ethtool -S swp2
```

Only `swp1` can get the frame.

4. Use the following command to check and debug the stream identification status.

```
qcisfiget --device swp0 --index 1
```

NOTE

The parameter `streamhandle` is the same as `index` in stream filter set, we use `streamhandle` as SFID to identify the stream, and use `index` to set stream filter table entry.

7.3.3.6.1.2 Stream gate control

1. Use the following commands for stream gate control:

```
echo "t0 1b 3 50000 200" > sgi.txt
tsntool> qcisgiset --device swp0 --enable --index 1 --initgate 1 --initipv 0 --gatelistfile
sgi.txt --basetime 0x0
```

Explanation:

- `'device'`: can be any one of switch ports.
- `'index'`: gateid
- `'basetime'`: It is the same as `Qbv` set.

2. Send one frame on TestCenter.

```
ethtool -S swp1
```

Note that the frame could pass, and `green_prio_3` has increased.

3. Now run the following commands:

```
echo "t0 0b 3 50000 200" > sgi.txtx
tsntool> qcisgiset --device swp0 --enable --index 1 --initgate 1 --initipv 0 --gatelistfile
sgi.txt --basetime 0x0
```

4. Next, send one frame on TestCenter.

```
ethtool -S swp1
```

Note that the frame could not pass.

7.3.3.6.1.3 SFI maxSDU test

Use the following command to run this test:

```
tsntool> qcisfiset --device swp0 --index 1 --gateid 1 --priority 0 --flowmeterid 68 --maxsdu 200
```

Now, send one frame (frame size > 200) on TestCenter.

```
ethtool -S swp1
```

User can observe that the frame could not pass.

7.3.3.6.1.4 FMI test

Use the following set of commands for the FMI test.

1. Run the command:

```
tsntool> qcifmiset --device swp0 --index 68 --cir 100000 --cbs 4000 --ebs 4000 --eir 100000
```

NOTE

- The 'device' in above command can be any one of the switch ports.
- The index of `qcifmiset` must be the same as `flowmeterid` of `qcisfiset`.

2. Now, send one stream (rate = 100M) on TestCenter.

```
ethtool -S swp0
```

Note that all frames pass and get all green frames.

3. Now, send one stream (rate = 200M) on TestCenter.

```
ethtool -S swp0
```

Observe that all frames pass and get green and yellow frames.

4. Send one stream (rate = 300M) on TestCenter.

```
ethtool -S swp0
```

Note that not all frames could pass and get green, yellow, and red frames.

5. Send one yellow stream (rate = 100M) on TestCenter.

```
ethtool -S swp0
```

All frames pass and get all yellow frames.

6. Send one yellow stream (rate = 200M) on TestCenter.

```
ethtool -S swp0
```

Note that not all frames could pass and get yellow and red frames.

7. Test of mode.

```
tsntool> qcifmiset --device swp0 --index 68 --cir 100000 --cbs 4000 --ebs 4000 --eir 100000 --cf
```

8. Send one yellow stream (rate = 200M) on TestCenter.

```
ethtool -S swp0
```

All frames pass and get all yellow frames (use CIR as well as EIR).

9. Send one yellow stream (rate = 300M) on TestCenter.

```
ethtool -S swp0
```

Note that not all frames could pass and get yellow and red frames.

7.3.3.6.1.5 Port based SFI set

LS1028a switch can work on port based PSFP set, which means when a null identified stream is received on ingress port, switch will use the port default SFI.

Below example test no streamhandle in qcisfiset to set a port default SFI.

1. Using SFID 2 to set as swp0 port default SFI.

```
tsntool> qcisfiset --device swp0 --index 2 --gateid 1 --flowmeterid 68
```

After the port default SFI set, any stream send from swp0 port will do the gate 1 and flowmeter 68 policy.

2. Set stream gate control.

```
echo "t0 1b 4 50000 200" > sgi.txt  
tsntool> qcisgiset --device swp0 --enable --index 1 --initgate 1 --initipv 0 --gatelistfile sgi.txt
```

3. Send any stream to swp0.

```
ethtool -S swp1
```

Note that the frame could pass, and green_prio_4 has increased.

7.3.3.6.2 Tc-flower usage

The figure below illustrates the tc-flower based Qci test case setup.

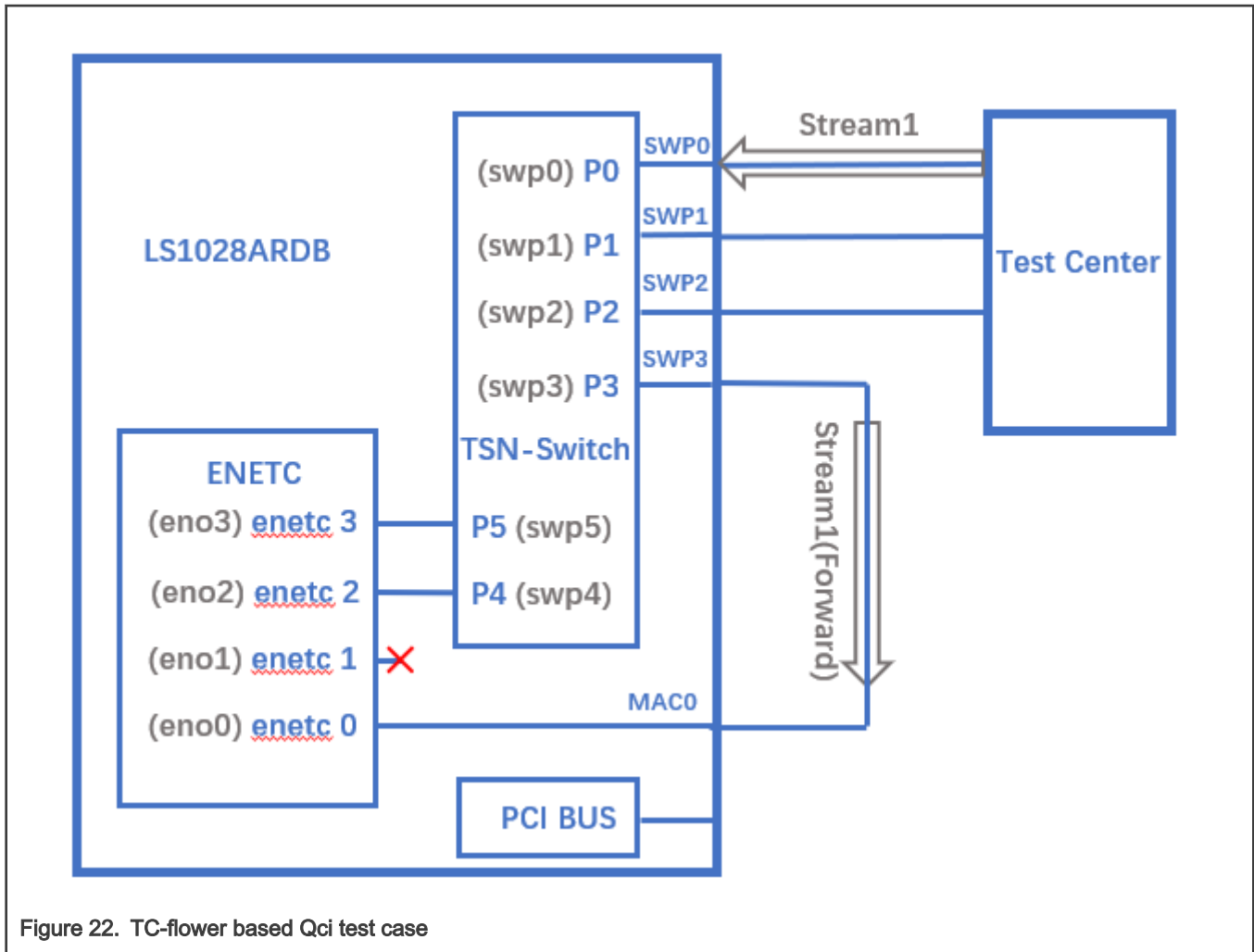


Figure 22. TC-flower based Qci test case

1. Get destination MAC on LS1028ARDB board, then use "dst_mac CA:9C:00:BC:6D:68" as shown in the following commands.

```
ifconfig eno0
Link encap:Ethernet HWaddr CA:9C:00:BC:6D:68
  inet addr:169.254.88.50 Bcast:169.254.255.255 Mask:255.255.0.0
  inet6 addr: fe80::ed36:c4ce:bb04:863d/64 Scope:Link
  UP BROADCAST RUNNING MULTICAST MTU:1500 Metric:1
  RX packets:2 errors:0 dropped:0 overruns:0 frame:0
  TX packets:1529 errors:0 dropped:0 overruns:0 carrier:0
  collisions:0 txqueuelen:1000
  RX bytes:152 (152.0 B) TX bytes:118456 (115.6 KiB)
```

2. Set Qci on ingress port swp0.

a) Use the following commands to set Qci gate.

```
tc qdisc add dev swp0 ingress
tc filter add dev swp0 chain 30000 protocol 802.1Q parent ffff: flower skip_sw dst_mac
CA:9C:00:BC:6D:68 vlan_id 1 action gate index 1 base-time 0 sched-entry CLOSE 6000 -1 -1
```

b). Use the following commands to set Qci flow meter.

```
tc qdisc add dev swp0 ingress
tc filter add dev swp0 chain 30000 protocol 802.1Q parent ffff: flower skip_sw dst_mac
CA:9C:00:BC:6D:68 vlan_id 1 action police index 1 rate 10Mbit burst 10000
```

c). Use the following commands to set Qci SFI priority.

```
tc qdisc add dev swp0 ingress
tc filter add dev swp0 chain 30000 protocol 802.1Q parent ffff: flower skip_sw dst_mac
CA:9C:00:BC:6D:68 vlan_id 1 vlan_prio 1 action gate index 1 base-time 0 sched-entry CLOSE 6000 -1
-1
```

d). Use the following commands to set both gate and flow meter.

```
tc qdisc add dev swp0 ingress
tc filter add dev swp0 chain 30000 protocol 802.1Q parent ffff: flower skip_sw dst_mac
CA:9C:00:BC:6D:68 vlan_id 1 action gate index 1 base-time 0 sched-entry OPEN 6000 2 -1 action police
index 1 rate 10Mbit burst 10000
```

3. Send a stream from testcenter, set the stream destination mac as CA:9C:00:BC:6D:68, set vid=1 and vlan_prio=1 in the vlan tag.

4. Using "tcpdump -i eno0 -w eno0.pcap" to receive the stream on eno0, check if packets are received.

5. Use the following commands to delete a stream rule.

```
tc -s filter show dev swp0 ingress chain 30000
tc filter del dev swp0 ingress chain 30000 pref 49152
```

NOTE

- Each stream can only be added only once. If a user wants to update it, delete the rule and add a new one.
- MAC and VID of stream must have been learned in switch MAC table if the stream is required to be added.
- Qci gate cycle time is expected to be more than 5 μ s.
- Qci flow meter can only set `cir` and `cbs` now, and the policers are shared with ACL VCAPs.

7.3.3.7 802.1CB

The following figure describes the test setup for the seamless redundancy test case.

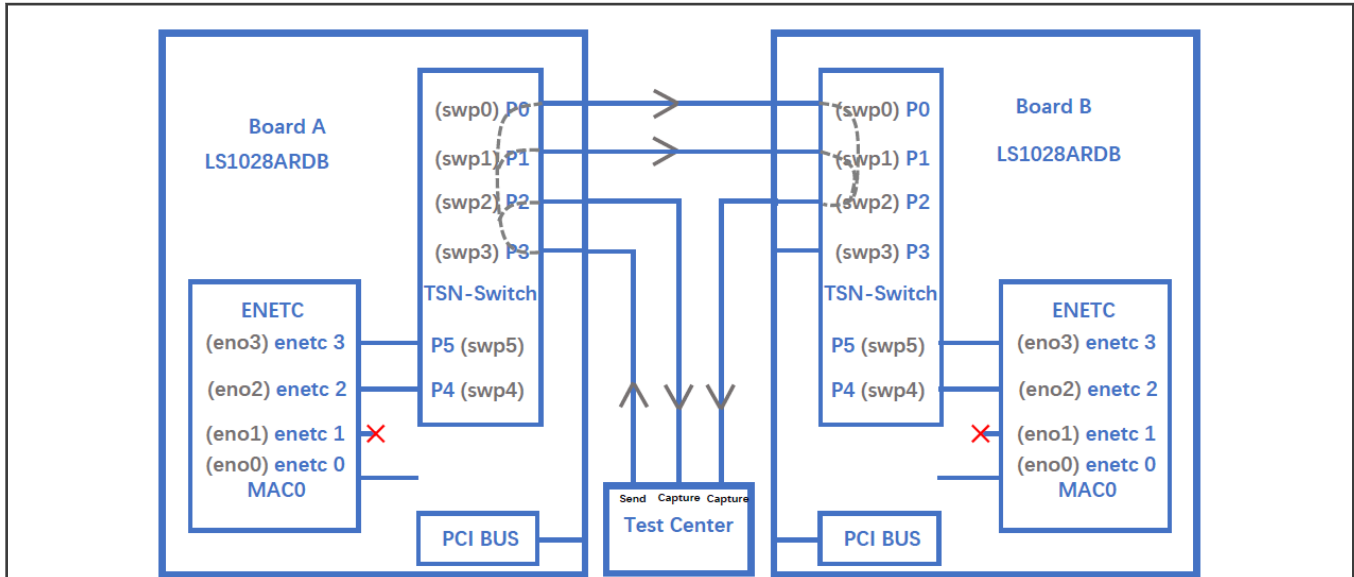


Figure 23. Seamless redundancy test

7.3.3.7.1 Sequence Generator test

Use the following set of commands for the 'Sequence Generator' test.

1. Configure switch ports to be forward mode.

On board A:

```
ip link add name switch type bridge vlan_filtering 1
ip link set switch up
ip link set swp0 master switch && ip link set swp0 up
ip link set swp1 up
ip link set swp2 master switch && ip link set swp2 up
ip link set swp3 master switch && ip link set swp3 up
bridge vlan add dev swp0 vid 1 pvid
bridge vlan add dev swp2 vid 1 pvid
bridge vlan add dev swp3 vid 1 pvid
```

On board B

```
ip link add name switch type bridge vlan_filtering 1
ip link set switch up
ip link set swp0 master switch && ip link set swp0 up
ip link set swp1 master switch && ip link set swp1 up
ip link set swp2 master switch && ip link set swp2 up
ip link set swp3 master switch && ip link set swp3 up
bridge vlan add dev swp0 vid 1 pvid
bridge vlan add dev swp1 vid 1 pvid
bridge vlan add dev swp2 vid 1 pvid
bridge vlan add dev swp3 vid 1 pvid
```

2. On board A, run the commands:

```
tsntool> cbstreamidset --device swp0 --index 1 --nullstreamid --nullldmac 0x7EA88C9B41DD --
nullvid 1 --streamhandle 1
tsntool> cbgen --device swp0 --index 1 --iport_mask 0x08 --split_mask 0x07 --seq_len 16 --
seq_num 2048
```

In the command above,

- `device`: can be any one of switch ports.
 - `index`: value is the same as streamhandle of `cbstreamidset`.
3. Send a stream from TestCenter to swp3 of board A, set destination mac as 7E:A8:8C:9B:41:DD.
 4. Capture frames on swp2 on TestCenter.

We can get frames from swp2 on TestCenter, each frame adds the sequence number: 23450801, 23450802, 23450803...

5. Capture frames from swp2 of board B on TestCenter, we can get the same frames.

7.3.3.7.2 Sequence Recover test

Use the following steps for the **Sequence Recover** test:

1. On board B, run the following commands:

```
tsntool> cbstreamidset --device swp2 --index 1 --nullstreamid --nulldmac 0x7EA88C9B41DD --
nullvid 1 --streamhandle 1
tsntool> cbrec --device swp0 --index 1 --seq_len 16 --his_len 31 --rtag_pop_en
```

In the `cbrec` command mentioned above:

- `device`: can be any one of switch ports.
 - `index`: value is the same as `streamhandle` of `cbstreamidset`.
2. Send a frame from TestCenter to swp3 of board A, set dest mac to be 7E:A8:8C:9B:41:DD.
 3. Capture frames from swp2 of board B on TestCenter, we can get only one frame without sequence tag.

7.3.3.8 TSN stream identification

TSN module uses QoS class to identify and control streams. There are three ways to identify the stream to different QoS class. These are explained in the following sections.

7.3.3.8.1 Stream identification based on PCP value of Vlan tag

The default QoS class is based on PCP of Vlan tag for a frame. If there is no Vlan tag for a frame, the default QoS class is 0. Set the PCP value on TestCenter.

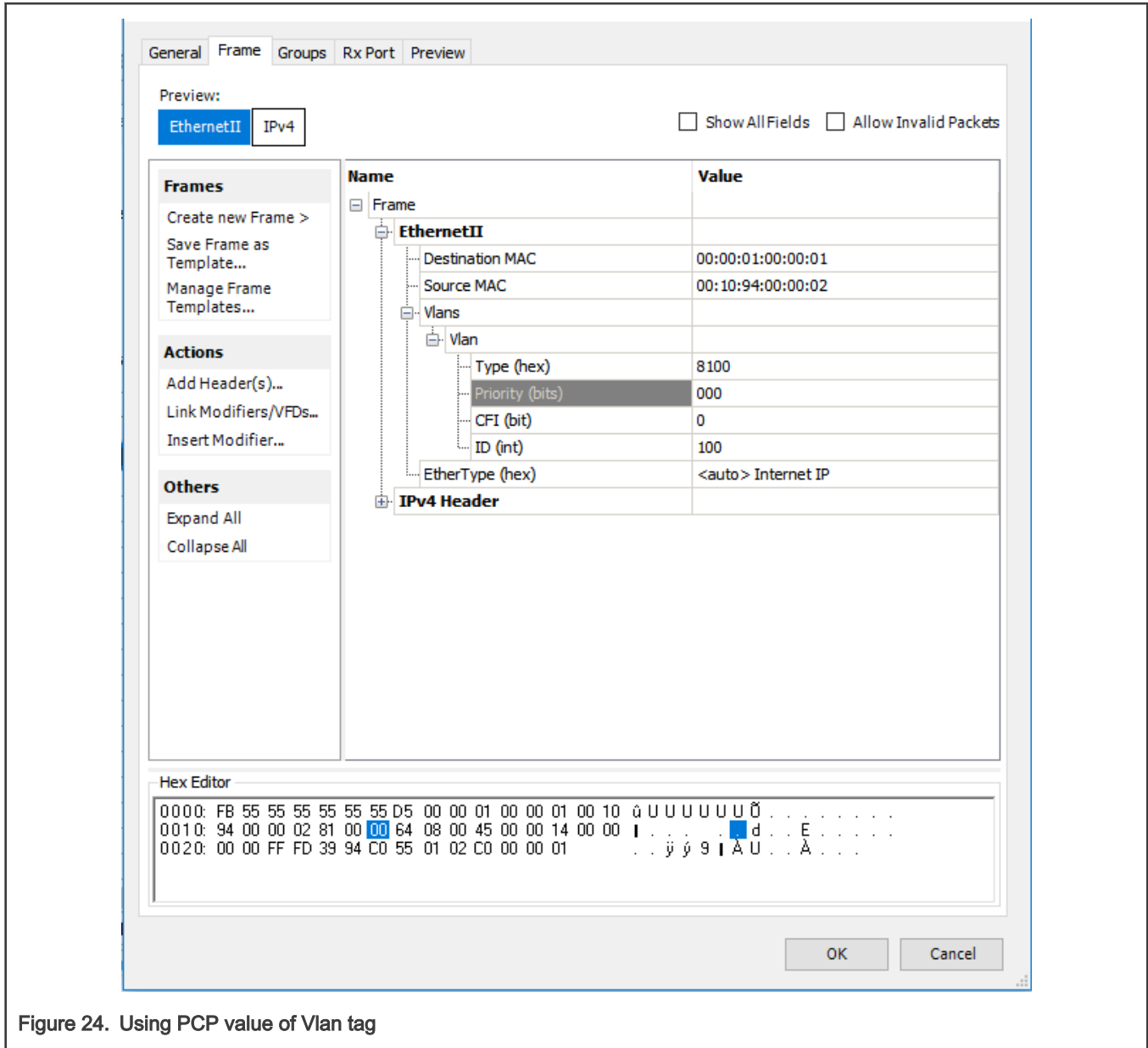


Figure 24. Using PCP value of Vlan tag

7.3.3.8.2 Based on DSCP of ToS tag

Use the below steps to identify stream based on DSCP value of ToS tag.

1. Map the DSCP value to a specific QoS class using the command below:

```
tsntool> dscpset --device swp0 --index 1 --cos 1 --dpl 0
```

Explanation:

- `index`: DSCP value of stream, 0-63.
 - `cos`: QoS class which is mapped to.
 - `dpl`: Drop level which is mapped to.
2. Set the DSCP value on TestCenter. DSCP value is the upper six bits of ToS in IP header, set the DSCP value on TestCenter as shown in the following figure.

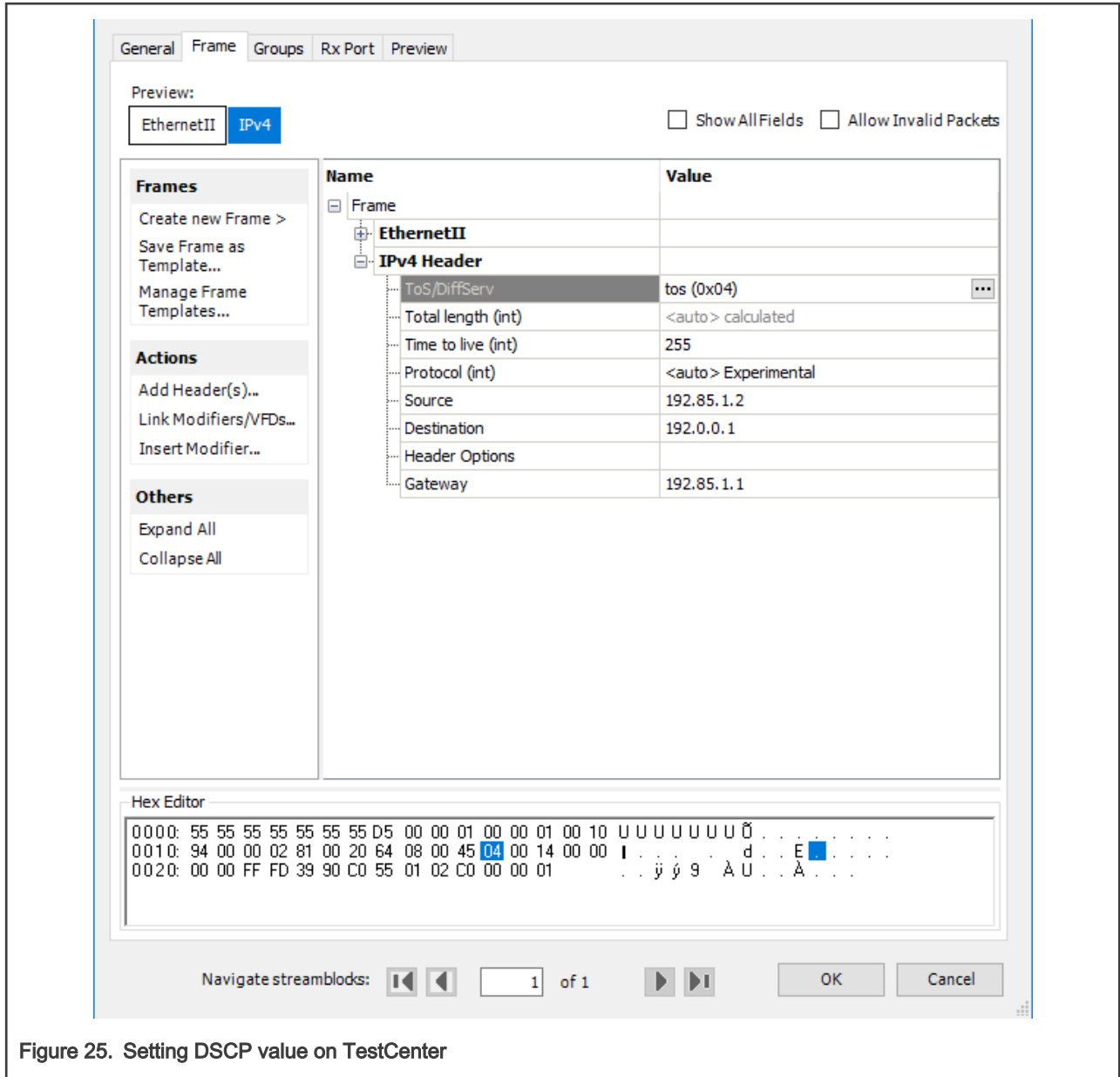


Figure 25. Setting DSCP value on TestCenter

7.3.3.8.3 Based on qci stream identification

The following steps describe how to use qci to identify the stream and set it to a QoS class.

1. Identify a stream.

```

tsntool> cbstreamidset --device swp1 --nullstreamid --nullldmac 0x000183fel201 --nullvid 1 --
streamhandle 1
tsntool> qcisfiset --device swp0 --index 1 --gateid 1 --flowmeterid 68
    
```

2. Set to Qos class 3 by using stream gate control.

```

echo "t0 1b 3 50000 200" > sgi.txt
tsntool> qcisgiset --device swp0 --enable --index 1 --initgate 1 --initipv 0 --
gatelistfile sgi.txt
    
```

NOTE

The Qci-based identity stream can only be used on both the ingress and egress are bridge ports. The flow injected or extracted through the CPU port cannot be configured for Qci.

7.3.3.9 VCAP

The VCAP is a content-aware packet processor for wire-speed packet inspection. it is using “tc flower” command to set the filter and actions. Following keys and actions are supported on LS1028a:

keys:

- vlan_id
- vlan_prio
- dst_mac/src_mac for non IP frames
- dst_ip/src_ip
- dst_port/src_port

actions:

- trap
- drop
- police
- vlan modify
- vlan push(Egress)

Using following commands to set, get and delete VCAP rules:

```
tc qdisc add dev swp0 clsact
tc filter add dev swp0 ingress chain [chain-id] protocol [ip/802.1Q] flower skip_sw [keys]
action [actions]
tc -s filter show dev swp0 ingress chain [chain-id]
tc filter del dev swp0 ingress chain [chain-id] pref [pref_id]

tc qdisc add dev swp1 clsact
tc filter add dev swp1 egress protocol 802.1Q flower skip_sw [keys] action vlan push id [value]
priority [value]
tc filter show dev swp1 egress
tc filter del dev swp1 egress pref [pref_id]
```

There are two ingress VCAPs and one egress VCAPs. tc-flower Chains are used on LS1028a ingress ports, each action has a fixed chain, following is chain allocation:

Table 46. chain allocation

| chain ID | actions | Hardware module | keys |
|----------|-----------------------|-----------------|---|
| 10000 | skbedit priority | IS1 lookup 0 | Source MAC address, source IP address (32 bits) outer VLAN, IP protocol, source TCP/UDP ports. |
| 11000 | vlan pop; vlan modify | IS1 lookup 1 | Inner and outer VLAN, source and destination IP addresses (32 bits), IP protocol, |

Table continues on the next page...

Table 46. chain allocation (continued)

| chain ID | actions | Hardware module | keys |
|-------------|----------------------|-----------------|---|
| | | | source and destination TCP/UDP ports. |
| 12000 | goto chain [PAG] | IS1 lookup 2 | Source MAC address, source IP address (32 bits) outer VLAN, IP protocol, source TCP/UDP ports. |
| 20000-20255 | police | IS2 lookup 0 | Source and destination MAC address, source and destination IP addresses (32 bits), IP protocol, source and destination TCP/UDP ports. |
| 21000-21255 | drop; trap; redirect | IS2 lookup 1 | Source and destination MAC address, source and destination IP addresses (32 bits), IP protocol, source and destination TCP/UDP ports. |
| 30000 | gate; police | PSFP | destination MAC address and Vlan ID |

Before using chains, need register each chain and set chain pipeline order for a packet, the hardware ingress order is : IS1->IS2->PSFP.

```
tc qdisc add dev swp0 clsact
tc filter add dev swp0 ingress chain 0 pref 49152 flower skip_sw action goto chain 10000
tc filter add dev swp0 ingress chain 10000 pref 49152 flower skip_sw action goto chain 11000
tc filter add dev swp0 ingress chain 11000 pref 49152 flower skip_sw action goto chain 12000
tc filter add dev swp0 ingress chain 12000 pref 49152 flower skip_sw action goto chain 20000
tc filter add dev swp0 ingress chain 20000 pref 49152 flower skip_sw action goto chain 21000
tc filter add dev swp0 ingress chain 21000 pref 49152 flower skip_sw action goto chain 30000
```

After registering the chain, add rules to the corresponding chain. following are use cases for testing:

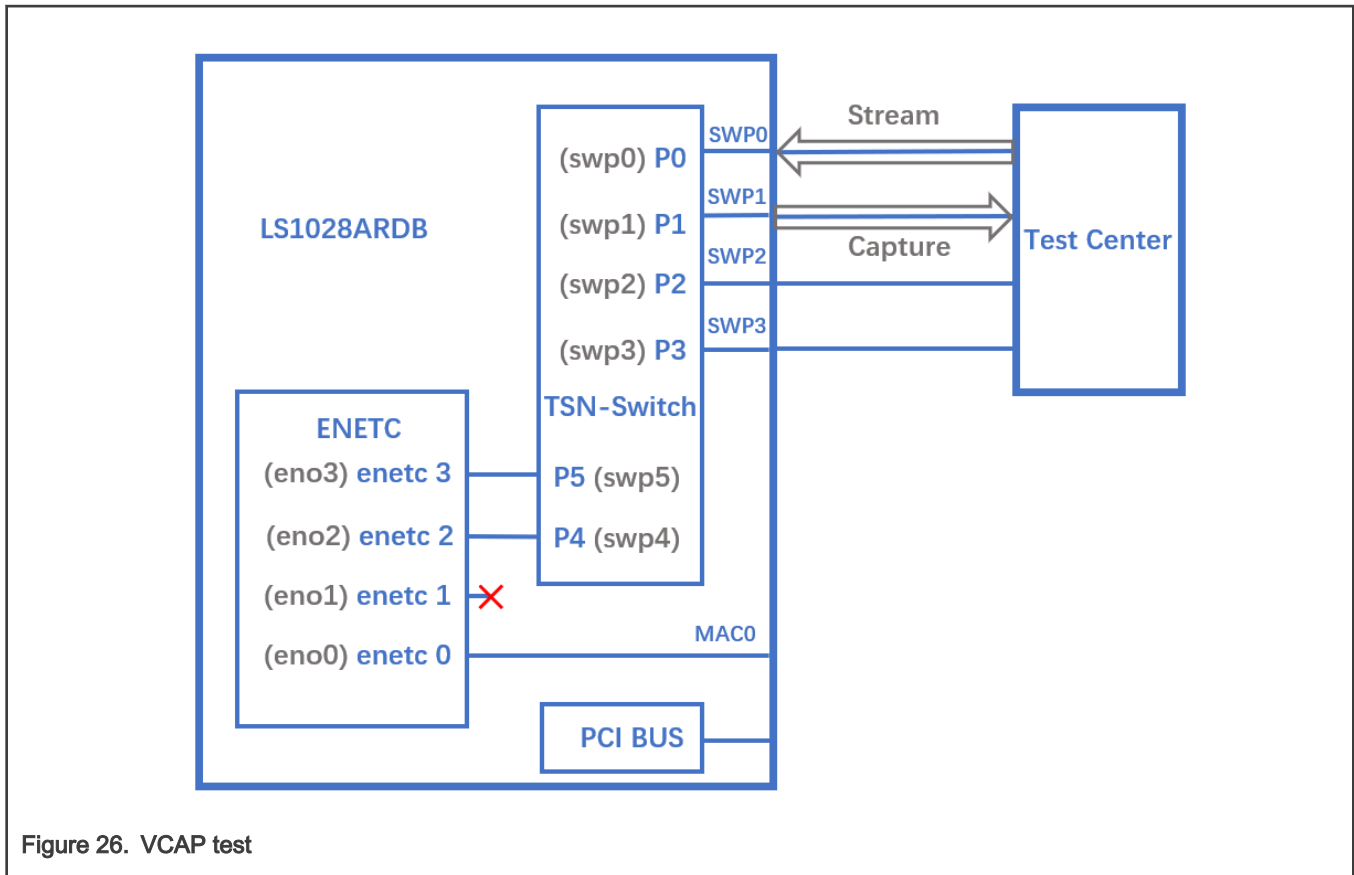


Figure 26. VCAP test

1. Drop all frames from source IP 192.168.2.1.

```
tc filter add dev swp0 ingress chain 21000 protocol ip flower skip_sw src_ip 192.168.2.1
action drop
```

Set source IP as 192.168.2.1 and send ip package from testcenter, package will be dropped on swp0.

2. Limit bandwidth of HTTP streams to 10Mbps.

```
tc filter add dev swp0 ingress chain 20000 protocol ip flower skip_sw ip_proto tcp dst_port 80
action police rate 10Mbit burst 10000 action goto chain 21000
```

Send TCP package and set destination port as 80 on testcenter, set the stream bandwidth to 1Gbps, we can get a 10Mbps stream rate.

3. Filter frames which have a specific vlan tag(VID=1 and PCP=1), then modify the vlan tag(VID=2, PCP=2) and classified to Qos traffic class 2.

```
ip link set switch type bridge vlan_filtering 1
tc filter add dev swp0 ingress chain 11000 protocol 802.1Q flower skip_sw vlan_id 1 vlan_prio 1
action vlan modify id 2 priority 2 action goto chain 12000
bridge vlan add dev swp0 vid 2
bridge vlan add dev swp1 vid 2
```

Set vid=1 and pcp=1 in vlan tag, then send ip package from testcenter, we can get a package with vid=2, pcp=2 from swp1 on TestCenter.

4. Push a specific vlan tag(vid=3, pcp=3) into frames(classified vid=2, pcp=2 in switch) egress from swp1.

```
tc qdisc add dev swp1 clsact
tc filter add dev swp1 egress protocol 802.1Q flower skip_sw vlan_id 2 vlan_prio 2 action vlan
push id 3 priority 3
```

Set vid=1 and pcp=1 in vlan tag, then send ip package from testcenter, the frame will hit rule in usecase 3 and retag the vlan(vid=2, pcp=2). we can get a frame with vid=3, pcp=3 from swp1 on TestCenter.

5. Push double vlan tag(Q-in-Q) into frames egress to swp1.

```
ip link add dev br0 type bridge
ip link set dev swp0 master br0
ip link set dev swp1 master br0
ip link set br0 type bridge vlan_filtering 1
bridge vlan add dev swp0 vid 222
bridge vlan add dev swp1 vid 222
tc qdisc add dev swp1 clsact
tc filter add dev swp1 egress protocol 802.1Q flower skip_sw \
    vlan_id 222 vlan_prio 2 \
    action vlan push id 200 priority 1 protocol 802.1AD \
    action vlan push id 300 priority 3
```

Result: TX(tpid:8100 vid:222 pri:2) -> swp0 -> swp1 -> RX(S-TAG tpid:88A8 vid:200 pri:1, C-TAG tpid:8100 vid:300 pri:3)

6. Pop single or double vlan tag(Q-in-Q) from frames ingress from swp0.

```
ip link add dev br0 type bridge
ip link set dev swp0 master br0
ip link set dev swp1 master br0
tc filter add dev swp0 ingress chain 11000 \
    protocol 802.1ad flower \
    vlan_id 111 vlan_prio 1 vlan_ethertype 802.1q \
    cvlan_id 222 cvlan_prio 2 cvlan_ethertype ipv4 \
    action vlan pop action goto chain 12000
```

Result: TX(S-TAG tpid:88A8 vid:111 pri:1, C-TAG tpid:8100 vid:222 pri:2) -> swp0 -> swp1 -> RX(TAG tpid:8100 vid:222 pri:2)

```
tc filter add dev swp0 ingress chain 11000 \
    protocol 802.1ad flower \
    vlan_id 111 vlan_prio 1 vlan_ethertype 802.1q \
    cvlan_id 223 cvlan_prio 2 cvlan_ethertype ipv4 \
    action vlan pop \
    action vlan pop action goto chain 12000
```

Result: TX(S-TAG tpid:88A8 vid:111 pri:1, C-TAG tpid:8100 vid:223 pri:2) -> swp0 -> swp1 -> RX(received packets without VLAN tag)

7.3.4 Q-in-Q configuration on Felix switch

1. Q-in-Q feature

Q-in-Q feature allow service providers to create a Layer 2 Ethernet connection between two user sites. Providers can segregate different user's VLAN traffic on a link or bundle different user VLANs. When using Q-in-Q, the user's 802.1Q VLAN tags(C-TAG:0x8100) are prepended by the service VLAN tag(S-TAG: 0x88A8).

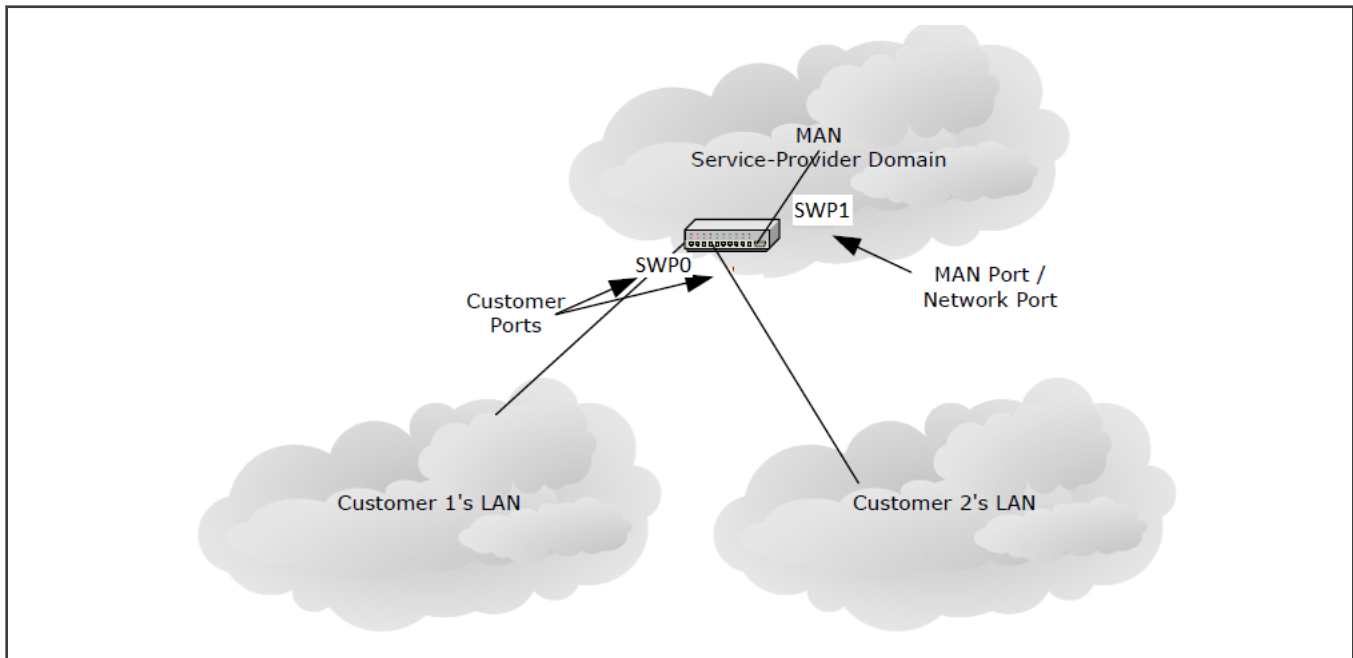
2. Q-in-Q application scenario

In the following scenario, switch's port swp0 connects with Customer 1's LAN, swp1 connects with ISP's MAN,

The traffic with VLAN tag is like this:

uplink: Customer LAN(only C-TAG) -> swp0 -> swp1(add S-TAG) -> ISP MAN(S-TAG + C-TAG)

downlink: ISP MAN(S-TAG + C-TAG) -> swp1(pop S-TAG)-> swp0(only C-TAG) -> Customer LAN



3. Q-in-Q configuration example

3.1 Enable swp1 Q-in-Q mode

```
devlink dev param set pci/0000:00:00.5 name qinq_port_bitmap value 2 cmode runtime
```

Note:

- 0000:00:00.5 is pcie bus and device number of ocelot switch.
- value 2 is bitmap for port 1, if port n is linked to ISP MAN, the related bit n should be set to 1.

3.2 Create bridge and add ports

```
ip link add dev br0 type bridge vlan_protocol 802.1ad
ip link set dev swp0 master br0
ip link set dev swp1 master br0
ip link set dev br0 type bridge vlan_filtering 1
```

3.3 Set swp0 pvid and untagged for egress traffic

```
bridge vlan del dev swp0 vid 1 pvid
bridge vlan add dev swp0 vid 100 pvid untagged
bridge vlan add dev swp1 vid 100
```

3.4 Result

Customer(tpid:8100 vid:111) -> swp0 -> swp1 -> ISP(STAG tpid:88A8 vid:100, CTAG tpid:8100 vid:111)

ISP(tpid:88A8 vid:100 tpid:8100 vid:222) -> swp1 -> swp0 -> Customer(tpid:8100 vid:222)

7.4 Verifying TSN features on LS1021A-TSN board

On the LS1021A-TSN platform, TSN features are provided by the SJA1105TEL Automotive Ethernet switch. These hardware features comply to pre-standard (draft) versions of the following IEEE specifications:

- 802.1Qbv - Time Aware Shaping
- 802.1Qci - Per-Stream Filtering and Policing
- 1588v2 - Precision Time Protocol

The following demonstration illustrates the SJA1105 hardware features listed below:

- Ingress rate limiting via the L2 (best-effort) policers
- Time-aware shaping
- 802.1AS gPTP synchronization

7.4.1 Topology

For demonstrating the SJA1105 TSN features, the following topology is required:

- 1 LS1021A-TSN board, acting as a TSN switch
- 1 generic host (can be a PC or another board) capable of PTP hardware timestamping, acting as a sender of latency-sensitive traffic
- 1 generic host (can be a PC or another board), acting as a sender of high-bandwidth traffic
- 1 generic host (can be a PC or another board) capable of PTP hardware timestamping, acting as receiver for the latency-sensitive and for the high-bandwidth traffic

The required software packages for the generic hosts are:

- ptp4l, phc2sys and phc_ctl from the linuxptp package: <https://github.com/openil/linuxptp>
- iperf3
- isochron from the tsn-scripts package: <https://github.com/vladimiroltean/tsn-scripts/tree/isochron>

The generic hosts are assumed to be connected to the LS1021A-TSN board through an interface called eth0.

This topology is depicted in the following figure.

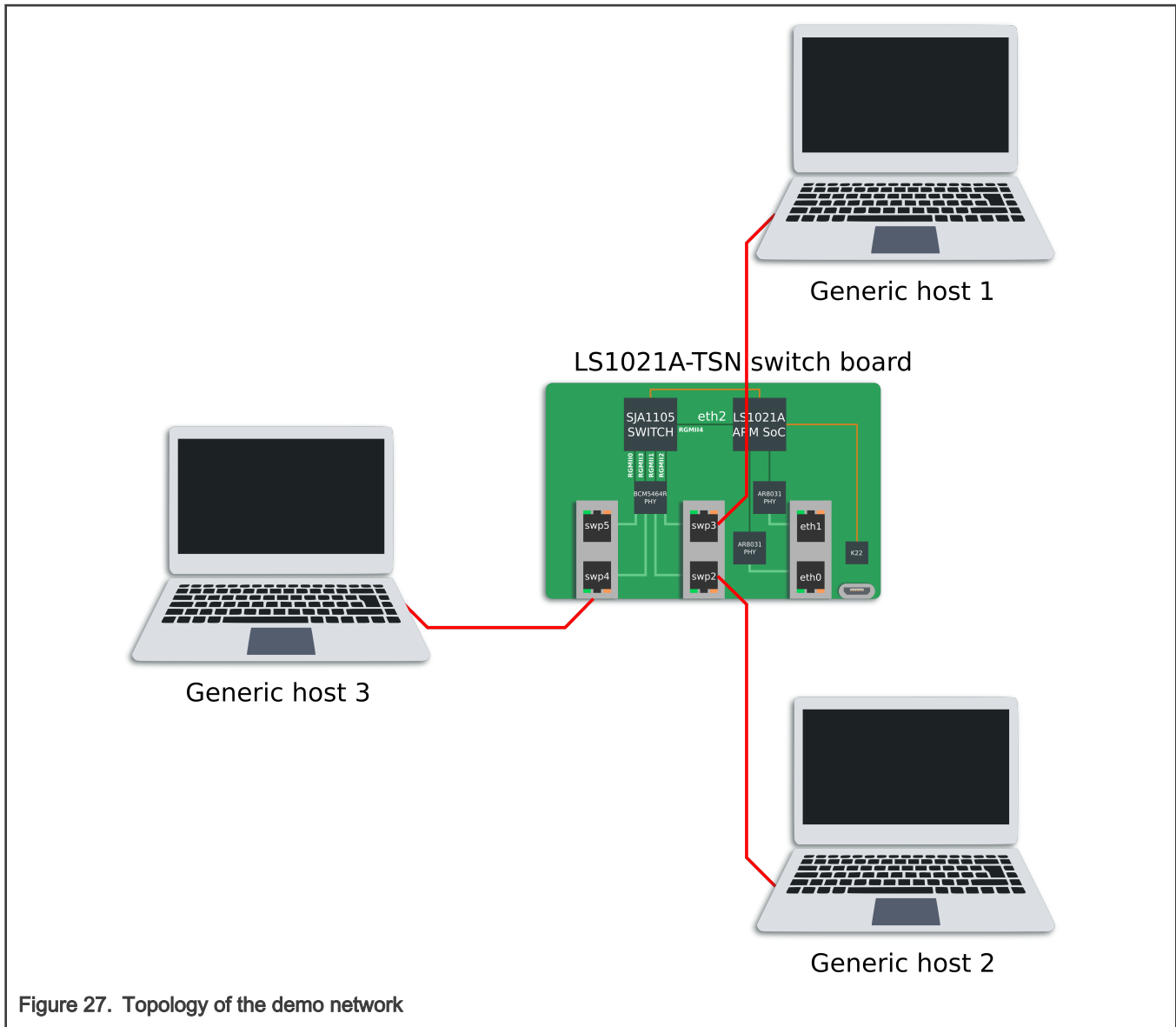


Figure 27. Topology of the demo network

7.4.2 SJA1105 Linux support

The SJA1105 switch is supported in the OpenIL Linux kernel using the Distributed Switch Architecture (DSA) framework (an overview of which can be found at <https://netdevconf.info/2.1/papers/distributed-switch-architecture.pdf>).

The following kernel configuration options are available for controlling its features:

- `CONFIG_NET_DSA_SJA1105`: enables base support for probing the SJA1105 ports as 4 standalone net devices capable of sending and receiving traffic
- `CONFIG_NET_DSA_SJA1105_PTP`: enables additional support for the PTP Hardware Clock (PHC), visible in `/dev/ptp1` on the LS1021A-TSN board, and for PTP timestamping on the SJA1105 ports
- `CONFIG_NET_DSA_SJA1105_TAS`: enables additional support for the Time-Aware Scheduler (TAS), which is configured via the `tc-taprio qdisc` offload

The documentation for this kernel driver is available at <https://www.kernel.org/doc/html/latest/networking/dsa/sja1105.html>. Below is a listing of several driver features.

The LS1021A-TSN device tree (`arch/arm/boot/dts/ls1021a-tsn.dts`) defines the sja1105 port names as `swp2`, `swp3`, `swp4` and `swp5`. The numbers have a direct correspondence with the chassis labels ETH2, ETH3, ETH4 and ETH5. The ETH2 chassis label (represented in Linux by the `swp2` net device) should not be confused with the `eth2` net device, which represents the LS1021A host port for this switch (called DSA master).

On the LS1021A-TSN board, network management is done by the `systemd-networkd` daemon, whose configuration files are located in `/etc/systemd/network/`. On this board, the following configuration files for `systemd-networkd` are present by default:

- `br0.netdev`: Creates a bridge net device with VLAN filtering disabled, STP disabled and MVRP disabled
- `br0.network`: Configures the net devices enslaved to `br0` to request an IPv4 address via DHCP
- `eth0.network`, `eth1.network`, `swp.network`: Configures all 6 ports of the LS1021A-TSN board to be part of the same `br0` bridge (4 ports are bridged in hardware, 2 ports are bridged in software)
- `eth2.network`: Configures the DSA master port to come up automatically, and assigns it a dummy link-local IP address. Having the DSA master interface up is a requirement for using the switch net devices.

Although all ports are configured for L2 forwarding by default (and therefore the only IP address for this board should be assigned to `br0`), this can be changed by removing the "Bridge=br0" line from the files in `/etc/systemd/network/` and then running "systemctl restart systemd-networkd".

In standalone mode, each SJA1105 port is able of acquiring an IP address and transferring general purpose packets to/from the kernel. This is internally supported by the kernel driver by repurposing the VLAN tagging functionality for switch port separation and identification. Therefore the ability to support general purpose traffic I/O only works as long as the user does not request VLAN tagging, via the bridge `vlan_filtering` option. When this happens, the switch driver goes to a reduced functionality mode, where the `swpN` net devices are no longer capable of sending and receiving general packets to/from the kernel. This is a hardware limitation which can be somewhat mitigated by enabling the `best_effort_vlan_filtering` devlink parameter (by following the steps in the kernel documentation).

Actually there is a second mechanism of frame tagging, which works for STP and PTP traffic and does not rely on VLAN tagging. Therefore, the STP and PTP protocols remain operational on the sja1105 driver even when the ports are enslaved to a bridge with `vlan_filtering=1`.

When VLAN awareness is disabled, the sja1105 ports perform no checks on VLAN port membership or PCP, and performs no alteration to the VLAN tags. For these operations, the following command is necessary:

```
ip link set dev br0 type bridge vlan_filtering 1
```

Once VLAN filtering is enabled, the VLAN table of each switch port can be inspected and modified using the "bridge vlan" commands from the `iproute2` package.

The STP state machine can be started on the bridge using the following command:

```
ip link set dev br0 type bridge stp_state 1
ip link set dev br0 down
ip link set dev br0 up
```

The switch L2 address forwarding database (FDB) can be inspected and modified using the "bridge fdb" set of commands.

Port statistics counters can be inspected using the `ethtool -S swpN` command.

The sja1105 port MTU can be configured up to a maximum of 2021 using the following command:

```
ip link set dev swp2 mtu 2000
```

Port mirroring on a sja1105 port (mirroring of ingress and/or egress packets) can be configured via the following set of commands:

```
tc qdisc add dev swp2 clsact
tc filter add dev swp2 ingress matchall skip_sw \
    action mirred egress mirror dev swp3
```

```
tc filter show dev swp2 ingress
tc filter del dev swp2 ingress pref 49152
```

There are 3 types of policers currently supported by the sja1105 driver:

- **Port policers:** These affect all traffic that is incoming on a port, except traffic that hits a more specific rule (see below). These are configured as follows:

```
tc qdisc add dev swp2 clsact
tc filter add dev swp2 ingress matchall skip_sw \
    action police rate 10mbit burst 64k
```

- **Traffic class policers:** These affect only traffic having a specific VLAN PCP. To limit traffic with VLAN PCP 0 (also includes untagged traffic) to 100 Mbit/s on port swp2 only:

```
tc qdisc add dev swp2 clsact
tc filter add dev swp2 ingress protocol 802.1Q flower skip_sw \
    vlan_prio 0 action police rate 100mbit burst 64k
```

- **Broadcast policers:** These affect only broadcast traffic (destination MAC ff:ff:ff:ff:ff:ff) received on an ingress port.

```
tc qdisc add dev swp2 clsact
tc filter add dev swp2 ingress flower skip_sw dst_mac ff:ff:ff:ff:ff:ff \
    action police rate 10mbit burst 64k
```

In absence of a specific policer allocated to a traffic class or to broadcast traffic, these packets will consume from the bandwidth budget of the port policer.

It is also possible to combine the bandwidth allocation of a traffic class, or of broadcast traffic on multiple ports, and assign them to a single policer. This functionality is called "shared filter blocks" and can be configured as follows (the example below limits broadcast traffic coming from all switch ports to a total of 10 Mbit/s):

```
tc qdisc add dev swp2 ingress_block 1 clsact
tc qdisc add dev swp3 ingress_block 1 clsact
tc qdisc add dev swp4 ingress_block 1 clsact
tc qdisc add dev swp5 ingress_block 1 clsact
tc filter add block 1 flower skip_sw dst_mac ff:ff:ff:ff:ff:ff \
    action police rate 10mbit burst 64k
```

For PTP, the sja1105 driver implements the kernel primitives required for interoperating with the linuxptp and other open source application stacks. OpenIL on the LS1021A-TSN is configured to start linuxptp by default in 802.1AS bridge mode on ports swp2, swp3, swp4 and swp5. The following system components are involved:

- **ptp4l:** Daemon that implements the IEEE 1588/802.1AS state machines. Configured via the /etc/linuxptp.cfg file and controlled via the linuxptp.service systemctl service.
- **phc2sys:** Daemon that synchronizes the system time (CLOCK_REALTIME) to the active PHC (/dev/ptp1) or viceversa, depending on the board role in the network (PTP master or slave). Configured via the /etc/linuxptp-system-clock.cfg file and controlled via the phc2sys.service systemctl service.

To inspect the PTP synchronization status of the board, the following commands can be used:

```
systemctl start --now ptp4l
systemctl start --now phc2sys
journalctl -b -u ptp4l -f
journalctl -b -u phc2sys -f
```

Under steady state, the switch ports are expected to maintain a synchronization offset of +/- 100 ns offset to the PTP master.

During normal operation, the static configuration of the sja1105 needs to be changed by the driver. In turn, this requires a switch reset, which temporarily disrupts Ethernet traffic and PTP synchronization. After a switch reset, the PTP synchronization offset may jump to a higher momentary range of +/- 2 500 000 ns. The list of reset reasons in the sja1105 kernel driver is:

- Enabling or disabling VLAN filtering, via the "ip link" command.
- Enabling or disabling PTP timestamping.
- Configuring the ageing time (which is done automatically by the kernel STP state machine when STP is active).
- Configuring the Time-Aware Scheduler via the tc-taprio command.
- Configuring the L2 policers (for MTU or for policing).

7.4.3 Synchronized 802.1Qbv demo

The objectives of this demonstration are the following:

- Synchronize the SJA1105 PTP clock using IEEE 802.1AS.
- Run the SJA1105 Time-Aware Scheduler (802.1Qbv engine) based on the PTP clock.
- Create a small switched TSN network with a flow requiring deterministic latency. Prove the latency is not affected by interfering traffic.

In the topology described earlier in this chapter, the boards which need to be synchronized by PTP are hosts 1, 2 and the LS1021A-TSN board. Host 3 only generates iperf traffic, which is not time-sensitive.

The following commands are required to start PTP synchronization using the 802.1AS profile on host 1 and 2:

```
ptp4l -i eth0 -f /etc/ptp4l_cfg/gPTP.cfg -m
phc2sys -a -rr --transportSpecific 0x1 --step_threshold 0.0002 --first_step_threshold 0.0002
```

Different output is expected on the two hosts. One will become PTP grandmaster and show the following logs:

- ptp4l:

```
Apr 07 17:20:24 OpenIL ptp4l[3267]: [13.067] port 1: link up
Apr 07 17:20:24 OpenIL ptp4l[3267]: [13.104] port 1: FAULTY to LISTENING on INIT_COMPLETE
Apr 07 17:20:27 OpenIL ptp4l[3267]: [16.113] port 1: LISTENING to MASTER
on ANNOUNCE_RECEIPT_TIMEOUT_EXPIRES
Apr 07 17:20:27 OpenIL ptp4l[3267]: [16.113] selected local clock 00049f.ffff.05de06 as
best master
Apr 07 17:20:27 OpenIL ptp4l[3267]: [16.113] port 1: assuming the grand master role
Apr 07 17:20:27 OpenIL ptp4l[3267]: [16.692] port 1: new foreign master 001f7b.ffff.630248-1
Apr 07 17:20:27 OpenIL ptp4l[3267]: [16.692] selected best master clock 00049f.ffff.05f627
Apr 07 17:20:27 OpenIL ptp4l[3267]: [16.692] port 1: assuming the grand master role
```

- phc2sys:

```
Apr 07 17:21:24 OpenIL phc2sys[3268]: [73.382] eno0 sys offset      12 s2 freq  +2009
delay  1560
Apr 07 17:21:25 OpenIL phc2sys[3268]: [74.382] eno0 sys offset       2 s2 freq  +2003
delay  1560
Apr 07 17:21:26 OpenIL phc2sys[3268]: [75.382] eno0 sys offset     -18 s2 freq  +1983
delay  1600
Apr 07 17:21:27 OpenIL phc2sys[3268]: [76.383] eno0 sys offset      27 s2 freq  +2023
delay  1600
Apr 07 17:21:28 OpenIL phc2sys[3268]: [77.383] eno0 sys offset       7 s2 freq  +2011
delay  1600
Apr 07 17:21:29 OpenIL phc2sys[3268]: [78.383] eno0 sys offset     -18 s2 freq  +1988
delay  1560
```

```
Apr 07 17:21:30 OpenIL phc2sys[3268]: [79.383] eno0 sys offset      -8 s2 freq  +1993
delay 1560
```

While the other board will become a PTP slave, as seen by the following logs:

- ptp4l:

```
Apr 07 17:23:14 OpenIL ptp4l[3778]: [68484.668] rms 17 max 36 freq +1613 +/- 15 delay 737
+/-
0
Apr 07 17:23:15 OpenIL ptp4l[3778]: [68485.668] rms 8 max 15 freq +1622 +/- 11 delay 737
+/-
0
Apr 07 17:23:16 OpenIL ptp4l[3778]: [68486.669] rms 14 max 28 freq +1643 +/- 13 delay 737
+/-
0
Apr 07 17:23:17 OpenIL ptp4l[3778]: [68487.670] rms 11 max 17 freq +1650 +/- 10 delay 738
+/-
0
Apr 07 17:23:18 OpenIL ptp4l[3778]: [68488.671] rms 11 max 20 freq +1633 +/- 15 delay 738
+/-
0
Apr 07 17:23:19 OpenIL ptp4l[3778]: [68489.672] rms 8 max 16 freq +1640 +/- 11 delay 737
+/-
0
Apr 07 17:23:20 OpenIL ptp4l[3778]: [68490.673] rms 16 max 32 freq +1640 +/- 23 delay 737
+/-
0
Apr 07 17:23:21 OpenIL ptp4l[3778]: [68491.674] rms 12 max 21 freq +1622 +/- 13 delay 737
+/-
0
Apr 07 17:23:22 OpenIL ptp4l[3778]: [68492.675] rms 13 max 19 freq +1648 +/- 13 delay 738
+/- 0
Apr 07 17:23:23 OpenIL ptp4l[3778]: [68493.676] rms 18 max 34 freq +1668 +/- 15 delay 737
+/- 0
```

- phc2sys:

```
Apr 07 17:23:38 OpenIL phc2sys[3774]: [68508.790] CLOCK_REALTIME phc offset      10 s2 freq
-342 delay 1600
Apr 07 17:23:39 OpenIL phc2sys[3774]: [68509.791] CLOCK_REALTIME phc offset      2 s2 freq
-347 delay 1560
Apr 07 17:23:40 OpenIL phc2sys[3774]: [68510.791] CLOCK_REALTIME phc offset      9 s2 freq
-339 delay 1600
Apr 07 17:23:41 OpenIL phc2sys[3774]: [68511.791] CLOCK_REALTIME phc offset     -22 s2 freq
-368 delay 1560
Apr 07 17:23:42 OpenIL phc2sys[3774]: [68512.791] CLOCK_REALTIME phc offset     -19 s2 freq
-371 delay 1560
Apr 07 17:23:43 OpenIL phc2sys[3774]: [68513.791] CLOCK_REALTIME phc offset     -13 s2 freq
-371 delay 1560
Apr 07 17:23:44 OpenIL phc2sys[3774]: [68514.791] CLOCK_REALTIME phc offset      48 s2 freq
-314 delay 1560
Apr 07 17:23:45 OpenIL phc2sys[3774]: [68515.792] CLOCK_REALTIME phc offset      22 s2 freq
-325 delay 1560
Apr 07 17:23:46 OpenIL phc2sys[3774]: [68516.792] CLOCK_REALTIME phc offset      17 s2 freq
-324 delay 1560
Apr 07 17:23:47 OpenIL phc2sys[3774]: [68517.792] CLOCK_REALTIME phc offset     -29 s2 freq
-365 delay 1560
```

The role of the LS1021A-TSN board is to relay the PTP time from the 802.1AS grandmaster to the slave. It acts as a slave on the port connected to the GM and as a master on the port connected to the other host.

```
[root@OpenIL ~] # journalctl -b -u ptp41 -f
-- Logs begin at Tue 2020-04-07 14:02:11 UTC. --
Apr 07 17:24:34 OpenIL ptp41[291]: [86640.528] rms 10 max 23 freq -19731 +/- 11 delay 737
+/- 0
Apr 07 17:24:35 OpenIL ptp41[291]: [86641.528] rms 9 max 15 freq -19740 +/- 13 delay 736
+/- 0
Apr 07 17:24:36 OpenIL ptp41[291]: [86642.529] rms 12 max 19 freq -19757 +/- 10 delay 737
+/- 0
Apr 07 17:24:37 OpenIL ptp41[291]: [86643.530] rms 9 max 14 freq -19747 +/- 13 delay 737
+/- 0
Apr 07 17:24:38 OpenIL ptp41[291]: [86644.530] rms 13 max 22 freq -19733 +/- 15 delay 736
+/- 0
Apr 07 17:24:39 OpenIL ptp41[291]: [86645.531] rms 7 max 14 freq -19735 +/- 9 delay 737
+/- 0
Apr 07 17:24:40 OpenIL ptp41[291]: [86646.532] rms 7 max 13 freq -19735 +/- 9 delay 737
+/- 0
Apr 07 17:24:41 OpenIL ptp41[291]: [86647.532] rms 11 max 19 freq -19750 +/- 12 delay 737
+/- 0
Apr 07 17:24:42 OpenIL ptp41[291]: [86648.533] rms 6 max 14 freq -19745 +/- 8 delay 737
+/- 0
Apr 07 17:24:43 OpenIL ptp41[291]: [86649.534] rms 9 max 15 freq -19750 +/- 12 delay 736
+/- 0
```

The above information can be interpreted as follows (only the last line is interpreted here):

- Because the default (implicit) `summary_interval` in `/etc/linuxptp.cfg` is 0 (print stats once per second) and the `logSyncInterval` required by 802.1AS is -3 (the sync messages are sent at an interval of 1/8 seconds - 125 ms), this means that synchronization stats cannot be printed in full (for each packet) and are printed in an abbreviated form (there is no "offset" in the logs).
- The offset to the master has a root mean square value of 9 ms, with a maximum of 15 ns in the past 1 second.
- The frequency correction required to synchronize to the GM was on average -19750 parts per billion (ppb). If the frequency adjustment exceeds a certain sanity threshold (depending on kernel driver), `ptp41` may print "clockcheck" warnings and stop synchronization. This can be sometimes remedied manually by running the following command to reset the PTP clock frequency adjustment to zero:

```
phc_ctl /dev/ptp0 freq 0
```

- The measured path delay (MAC to MAC propagation delay for ~70 bytes frames at 1Gbps) between its device and its link partner is exactly 736 ns.

The clock distribution tree in this network is as follows: the system clock of the PTP GM (e.g. Host 1) disciplines its PTP hardware clock (`/dev/ptp0`), using `phc2sys`. Over Ethernet, the PTP GM disciplines the SJA1105 PHC, which disciplines the PTP slave (e.g. Host 2). On the slave host, the `phc2sys` process runs in the reverse direction, disciplining the system clock (`CLOCK_REALTIME`) to the PTP hardware clock (`/dev/ptp0`).

A note on using the LS1021A-TSN board as a gPTP GM for this scenario (in place of Host 1). On this board there is no battery-backed RTC, so there is no persistent source of time onboard. One has to rely on the NTP service (`ntpd.service`) to provide time, otherwise a time in 1970 will be relayed into the PTP network.

A note on using `phc2sys` on the slave host. Since `phc2sys` attempts to discipline `CLOCK_REALTIME`, one must manually ensure that other daemons in the system do not attempt to do the same thing, such as `ntpd`. Otherwise there will be access conflicts between `phc2sys` and the other daemon, and `phc2sys` will keep printing clockcheck warning messages.

Install the following schedule into the `sja1105` port egressing towards Host 2:

```
tc qdisc add dev swp2 parent root taprio \
    num_tc 8 \
```

```
map 0 1 2 3 4 5 6 7 \
queues 1@0 1@1 1@2 1@3 1@4 1@5 1@6 1@7 \
base-time 0 \
sched-entry S 80 50000 \
sched-entry S 40 50000 \
sched-entry S 3f 300000 \
flags 2
```

The base-time of 0 indicates the phase offset of the network schedule. This time corresponds to Jan 1st 1970, but it is automatically advanced into an equivalent time into the immediate PTP future (it is advanced by an integer number of cycle-time nanoseconds).

The cycle-time in this example is not provided explicitly, but it is calculated as the sum of the durations of all gate events: 400 microseconds (us).

The schedule at the egress of swp2 is divided as follows:

- 50 us for PTP traffic (S 80). The traffic class assignment of 7 for link-local management traffic (STP, PTP, etc) is fixed to 7 at driver level and is not user configurable at this time.
- 50 us for traffic class 6 (S 40). The latency-sensitive traffic generator will be injecting into this window.
- 300 us for all other traffic classes 0-5 (S 3f).

Enabling QoS classification on the sja1105 switch based on VLAN PCP is done by running:

```
ip link set dev br0 type bridge vlan_filtering 1
```

First the receiver for latency-sensitive traffic needs to be started on Host 2. This process waits for connections from the sender and then transmits its statistics to it.

```
ip addr add 192.168.1.2/24 dev eth0
isochron rcv --interface eth0 --quiet
```

The sender is started on Host 1 as follows:

```
ip addr add 192.168.1.1/24 dev eth0
isochron send --interface eth0 --dmac 00:04:9f:05:de:06 --priority 6 --vid 0 \
--base-time 0 --cycle-time 400000 --shift-time 50000 --advance-time 90000 \
--num-frames 10000 --frame-size 64 --client 192.168.1.2 --quiet
```

The log should look as follows:

```
Base time 0.000040000 is in the past, winding it into the future
Now: 1586282691.751150218
Base time: 1586282691.751160000
Cycle time: 0.000400000
Collecting receiver stats
Summary:
Path delay: min 4329 max 4444 mean 4387.987 stddev 24.508
HW TX deadline delta: min -65238 max -18938 mean -59707.395 stddev 1371.995
SW TX deadline delta: min -33528 max 25058 mean -28221.001 stddev 1844.235
HW RX deadline delta: min -60874 max -14529 mean -55319.408 stddev 1372.222
SW RX deadline delta: min -43398 max 130659 mean -38212.966 stddev 2514.592
HW TX deadline misses: 0 (0.000%)
SW TX deadline misses: 1 (0.010%)
```

The following clarifications are necessary:

- The destination MAC is that of Host 2's interface eth0
- The sent packets have a VLAN tag with VID 0 and PCP 6. Because they are priority-tagged (802.1p) the sja1105 switch ports will accept these packets without any "bridge vlan add vid 0 dev swp3" command.

- The isochron program sends a number of 10000 frames, at an interval of 400 us. The base-time is the same as on the sja1105 egress port swp2, but it is shifted with 50 us to the right, in order to align with the beginning of traffic class 6's window (which is the second timeslot in the schedule). The packet transmission deadlines are therefore at (base-time + shift-time + N * cycle-time).
- Packets must in fact be transmitted earlier than the TX deadline, in order to compensate for scheduling latencies in the Linux kernel and the actual propagation delay of the packet. So the isochron program sleeps until 90 us in advance of the next deadline.
- By "winding the base time into the future", one understands the process by which the original base time (0) is incremented by the smallest number N of cycles such that it becomes greater than the current PTP time (1586282691.751150218). In this case, the new base-time is 1586282691.751160000.
- For each packet, the sender collects 2 TX timestamps: one hardware and one software. The receiver also collects two timestamps. These timestamps are not printed to the console because the --quiet option was specified.
- Correlation between timestamps at the sender and at the receiver is done through a secondary socket. The receiver waits for connections on TCP port 5000, and transmits its log to the sender, which correlates with its own log by using a key formed out of {sequence number, scheduled TX time (deadline)}. Both these values are embedded into the packet payload. If the --client option is omitted, the statistics correlation is not performed. This TCP socket is the only reason for which IP communication is necessary in this network.
- The path delay is calculated as the delta between the RX hardware timestamp at the receiver and the TX hardware timestamp at the sender.
- Each "deadline delta" is calculated as the difference between the timestamp and the scheduled TX time of this packet. The HW TX deadline delta should always be negative, as that indicates the packets were sent before the scheduled TX time has expired. The SW TX timestamps are taken after the HW TX timestamps in this case, so their meaning is less relevant for this driver. The RX deadline deltas will become relevant once the 802.1Qbv schedule is installed on the sja1105 switch port.

The above log was taken with no 802.1Qbv schedule active on the sja1105 port and no background traffic. After starting background traffic:

```
# Host 2
iperf3 -s > /dev/null &
sysctl -w kernel.sched_rt_runtime_us=-1
chrt --fifo 90 isochron rcv -i eth0 --quiet
# Host 3
ip addr add 192.168.1.3/24 dev eth0
iperf3 -c 192.168.1.2 -t 48600
Connecting to host 10.0.0.112, port 5201
[ 5] local 10.0.0.113 port 60360 connected to 10.0.0.112 port 5201
[ ID] Interval      Transfer       Bitrate        Retr  Cwnd
[ 5]  0.00-1.00    sec    105 MBytes    878 Mbits/sec    0   489 KBytes
[ 5]  1.00-2.00    sec    102 MBytes    859 Mbits/sec    0   513 KBytes
[ 5]  2.00-3.00    sec    102 MBytes    858 Mbits/sec    0   513 KBytes
[ 5]  3.00-4.00    sec    101 MBytes    851 Mbits/sec    0   513 KBytes
[ 5]  4.00-5.00    sec    102 MBytes    860 Mbits/sec    0   539 KBytes
```

a re-run of the isochron traffic generated by Host 1 looks as follows:

```
chrt --fifo 90 isochron send -i eno0 -d 00:04:9f:05:de:06 -p 6 -v 0 -b 0 -S 50000 -c 400000 -a 90000
-n 10000 -s 64 -C 10.0.0.112 -q
Base time 0.000040000 is in the past, winding it into the future
Now: 1586286409.635121693
Base time: 1586286409.635160000
Cycle time: 0.000400000
Collecting receiver stats
Summary:
Path delay: min 4314 max 16774 mean 9725.688 stddev 3919.150
HW TX deadline delta: min -64273 max -8538 mean -59894.931 stddev 1467.284
```



```

SW TX deadline delta: min -33286 max 37575 mean -28498.114 stddev 2006.546
HW RX deadline delta: min -58924 max -904 mean -50169.243 stddev 4183.042
SW RX deadline delta: min -52757 max 1109472 mean -29436.032 stddev 23537.847
HW TX deadline misses: 0 (0.000%)
SW TX deadline misses: 4 (0.040%)

```

It can be seen that the path delay variance has increased due to the prolonged wait of packets until MTU-sized packets generated by iperf3 have finished transmission.

Finally, installing the 802.1Qbv schedule on the switch has effects upon all statistics calculated by isochron:

```

chrt --fifo 90 isochron send -i eno0 -d 00:04:9f:05:de:06 -p 6 -v 0 -b 0 -S 50000 -c 400000 -a 90000
-n 10000 -s 64 -C 10.0.0.112 -q
Base time 0.000040000 is in the past, winding it into the future
    Now: 1586286689.223100936
    Base time: 1586286689.223160000
Cycle time: 0.000400000
Collecting receiver stats
Summary:
Path delay: min 14199 max 65684 mean 61357.368 stddev 1494.831
HW TX deadline delta: min -64128 max -12643 mean -59822.445 stddev 1494.557
SW TX deadline delta: min -33616 max 25621 mean -28448.709 stddev 1974.185
HW RX deadline delta: min 1476 max 2041 mean 1534.924 stddev 24.822
SW RX deadline delta: min 5243 max 1122800 mean 21040.814 stddev 16752.155
HW TX deadline misses: 0 (0.000%)
SW TX deadline misses: 5 (0.050%)

```

The path delay has increased, but that is because now it contains the time spent by the packets blocked on the switch waiting for gate 6 to open.

The HW RX deadline delta now has a new meaning, since in the last example (with 802.1Qbv enabled on the switch), the gate acts as a barrier and eliminates the jitter in HW TX timestamps, which is induced by scheduling latencies in the sender's operating system. Generally speaking, the jitter of the sender is eliminated by the first switch upon packet admission into the TSN network. The effect is that the receiver sees a packet stream with low jitter.

The path delay can be reduced by decreasing the advance time. It is configured in such a way that the packets arrive on the switch prior to the gate opening, which depends on the jitter of the sender. Minimizing the TX jitter is outside the scope of this demonstration.

7.5 Verifying TSN features on i.MX8MP board

On i.MX8MP platform, TSN features are provided by dwmac510 ethernet endpoint. The following are hardware features supported:

- IEEE 802.1Qbv - Time Aware Shaper
- IEEE 802.1Qav - Credit-based Shaper
- IEEE802.1Qbu/802.3br, Frame preemption and Interspersing Express Traffic
- IEEE 1588v2 - Precision Time Protocol
- Multiple queues (up to 5) on the Transmit path with a common memory for all Tx queues

7.5.1 Verifying TSN features on i.MX8MP board

7.5.1.1 Test environment

On i.mx8mp platform, there is only eth1 has TSN features, connect eth1 to Test center to test TSN features.

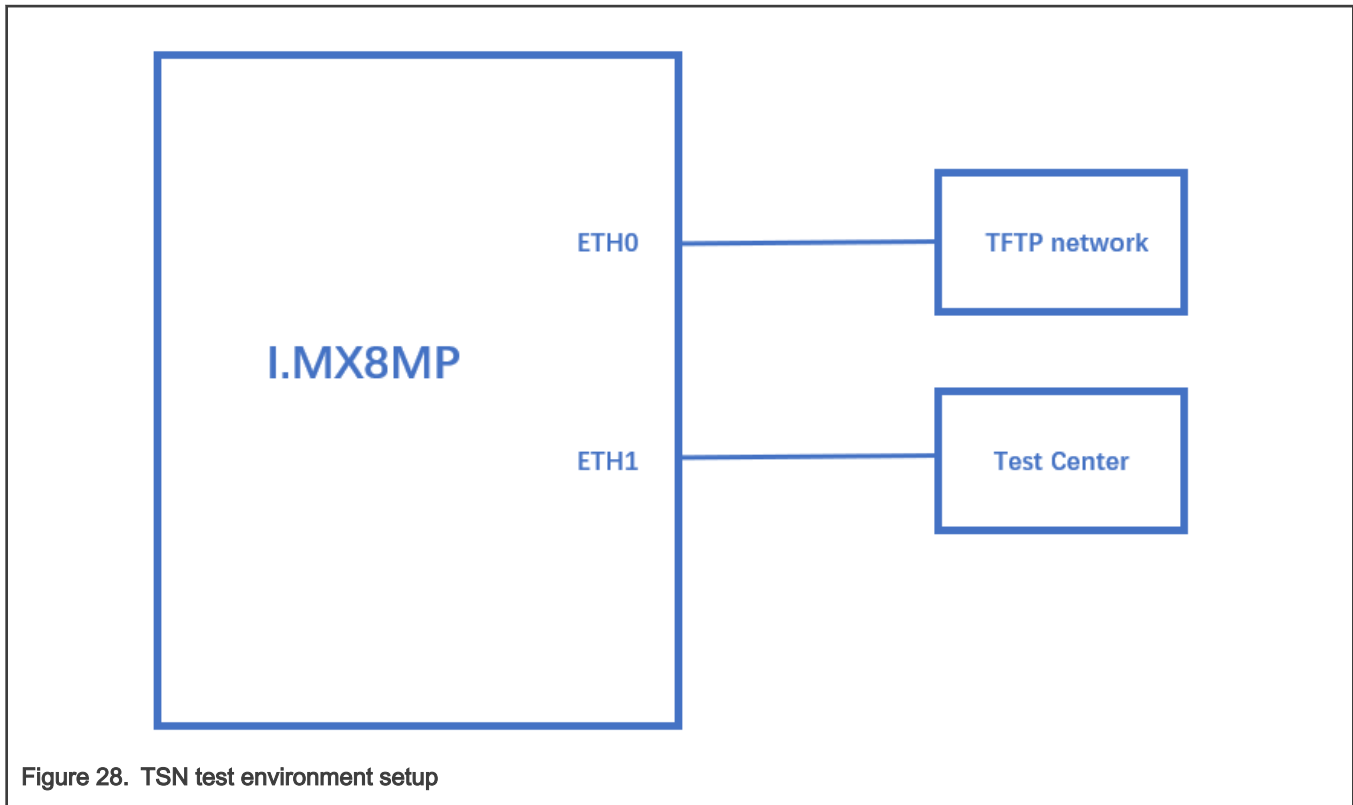


Figure 28. TSN test environment setup

7.5.1.1.2 Clock synchronization

To test 1588 synchronization on dwcmac interfaces, use the following procedure:

1. Connect eth1 interfaces on two boards in a back-to-back manner.

The linux booting log is as follows:

```
...
pps pps0: new PPS source ptp0
...
```

2. Configure the IP address

```
ifconfig eth1 192.168.3.1
```

3. Check PTP clock and timestamping capability:

```
# ethtool -T eth1
Time stamping parameters for eth1:
Capabilities:
    hardware-transmit      (SOF_TIMESTAMPING_TX_HARDWARE)
    software-transmit     (SOF_TIMESTAMPING_TX_SOFTWARE)
    hardware-receive      (SOF_TIMESTAMPING_RX_HARDWARE)
    software-receive      (SOF_TIMESTAMPING_RX_SOFTWARE)
    software-system-clock (SOF_TIMESTAMPING_SOFTWARE)
    hardware-raw-clock    (SOF_TIMESTAMPING_RAW_HARDWARE)
PTP Hardware Clock: 1
Hardware Transmit Timestamp Modes:
    off      (HWTSTAMP_TX_OFF)
    on       (HWTSTAMP_TX_ON)
Hardware Receive Filter Modes:
```

| | |
|--------------------|---------------------------------------|
| none | (HWTSTAMP_FILTER_NONE) |
| all | (HWTSTAMP_FILTER_ALL) |
| ptpv1-l4-event | (HWTSTAMP_FILTER_PTP_V1_L4_EVENT) |
| ptpv1-l4-sync | (HWTSTAMP_FILTER_PTP_V1_L4_SYNC) |
| ptpv1-l4-delay-req | (HWTSTAMP_FILTER_PTP_V1_L4_DELAY_REQ) |
| ptpv2-l4-event | (HWTSTAMP_FILTER_PTP_V2_L4_EVENT) |
| ptpv2-l4-sync | (HWTSTAMP_FILTER_PTP_V2_L4_SYNC) |
| ptpv2-l4-delay-req | (HWTSTAMP_FILTER_PTP_V2_L4_DELAY_REQ) |
| ptpv2-event | (HWTSTAMP_FILTER_PTP_V2_EVENT) |
| ptpv2-sync | (HWTSTAMP_FILTER_PTP_V2_SYNC) |
| ptpv2-delay-req | (HWTSTAMP_FILTER_PTP_V2_DELAY_REQ) |

4. Run ptp4l on two boards:

```
ptp4l -i eth1 -p /dev/ptp1 -m -2
```

5. After running, one board would be automatically selected as the master, and the slave board would print synchronization messages.

6. For 802.1AS testing, just use the configuration file `gPTP.cfg` in `linuxptp` source. Run the below command on the boards, instead:

```
ptp4l -i eth1 -p /dev/ptp1 -f gPTP.cfg -m
```

Or use GenAVB/TSN Stack with the following command: `'avb.sh start'`. Note that the configuration file `/etc/genavb/fgptp.cfg` is automatically used.

NOTE

i.MX8MP current `dwmac` driver (`eth1`) initializes few hardware functions while opening net device, including PTP initialization. Before that, the operations such as `ethtool` queries, and PTP operations might not work. So, the workaround is to do operations on the `eth1` and PTP of `dwmac` only after `"ifconfig eth1 up"`.

7.5.1.1.3 Qbv

1. Enable ptp device, and get current ptp time.

```
ptp4l -i eth1 -p /dev/ptp1 -m

#Get current time(seconds)
devmem 0x30bf0b08
0x5E01F9B2
```

2. Get the basetime to be 2 minute later

```
#Basetime = (currenttime + 120) * 1000000000 = 1577187882000000000
```

3. Set time schedule, open queue 1 in 100us and open queue 2 in 100us

```
tc qdisc replace dev eth1 parent root handle 100 taprio \
  num_tc 5 map 0 1 2 3 4 queues 1@0 1@1 1@2 1@3 1@4 base-time 1577187882000000000 \
  sched-entry S 2 100000 \
  sched-entry S 4 100000 flags 2
```

4. Send two streams into queue 1 and queue 2.

```
./pktgen/pktgen_twoqueue.sh -i eth1 -q 1 -s 1000 -n 0 -m 90:e2:ba:ff:ff:ff
```

5. Capture the streams on TestCenter, 100us queue 1 frames(length=1004) and 100us queue 2 frames(length=1504) will be got.

Note:

- Qbv basetime only can set a time after current time.
- More than one entry need to be set on each tc taprio command.
- Using “devmem 0x30bf0c58” to get Qbv status to see if qbv status is active. Please refer to "MTL_EST_Status" register.

7.5.1.1.4 Qbu

1. Using ethtool to enable Qbu on eth1, set queue 1 to be preemptable.

```
ethtool --set-frame-preemption eth1 preemptible-queues-mask 0x02 min-frag-size 60
```

Note: Once Qbu enabled, queue 0 is always preemptable queue.

2. Send two streams into queue 1 and queue 2

```
./pktgen/pktgen_twoqueue.sh -i eth1 -q 1 -s 1000 -n 0 -m 90:e2:ba:ff:ff:ff
```

3. Capture the streams on TestCenter, We can see that Q1 frames were preempted into fragments.

4. Qbu combined with Qbv test

Once a queue is set to preemptable queue, gate open/close is invalid in Qbv gate control list, the queue is considered as always "Open". Using Hold/Release to control all preemptable queues. When the GCL entry set from Hold to Release, preemptable queues will be transmitting, when GCL entry set from Release to Hold, preemptable queues will be holding.

```
tc qdisc replace dev eth1 parent root handle 100 taprio \
  num_tc 5 map 0 1 2 3 4 queues 1@0 1@1 1@2 1@3 1@4 base-time 1577187882000000000 \
  sched-entry H 2 100000 \
  sched-entry R 4 100000 flags 2
```

7.5.1.1.5 Qav

1. Set a queue map handle.

```
tc qdisc add dev eth1 root handle 1: mqprio num_tc 5 map 0 1 2 3 4
```

2. Set bandwidth of queue 3 to be 20Mbps

```
tc qdisc replace dev eth1 parent 1:4 cbs locredit -1470 hicredit 30 sendslope -980000 idleslope 20000
offload 1
```

3. Send a stream into queue 3

```
./pktgen/pktgen_sample01_simple.sh -i eth1 -q 3 -s 500 -n 3000
```

4. Get the result, bandwidth is 19Mbps.

```
WARN : Missing destination MAC address
WARN : Missing destination IP address
Running... ctrl^C to stop
Done
Result device: eth1
Params: count 3000 min_pkt_size: 500 max_pkt_size: 500
  frags: 0 delay: 0 clone_skb: 0 ifname: eth1
  flows: 0 flowlen: 0
  queue_map_min: 3 queue_map_max: 3
```

```

dst_min: 198.18.0.42 dst_max:
src_min: src_max:
src_mac: a6:85:82:fc:89:bf dst_mac: 02:5d:ae:ba:e0:00
udp_src_min: 9 udp_src_max: 109 udp_dst_min: 9 udp_dst_max: 9
src_mac_count: 0 dst_mac_count: 0
Flags: UDPSRC_RND NO_TIMESTAMP QUEUE_MAP_RND
Current:
pkts-sofar: 3000 errors: 0
started: 5631940023us stopped: 5632560030us idle: 79984us
seq_num: 3001 cur_dst_mac_offset: 0 cur_src_mac_offset: 0
cur_saddr: 0.0.0.0 cur_daddr: 198.18.0.42
cur_udp_dst: 9 cur_udp_src: 41
cur_queue_map: 3
flows: 0
Result: OK: 620007(c540023+d79984) usec, 3000 (500byte,0frags)
4838pps 19Mb/sec (19352000bps) errors: 0

```

5. Set bandwidth of queue 4 to be 40Mbps

```

tc qdisc replace dev eth1 parent 1:5 cbs locredit -1440 hicredit 60 sendslope -960000 idleslope 40000
offload 1

```

6. Send a stream into queue 4 and get the result.

```

./pktgen/pktgen_sample01_simple.sh -i eth1 -q 4 -s 500 -n 3000
WARN : Missing destination MAC address
WARN : Missing destination IP address
Running... ctrl^C to stop
Done
Result device: eth1
Params: count 3000 min_pkt_size: 500 max_pkt_size: 500
frags: 0 delay: 0 clone_skb: 0 ifname: eth1
flows: 0 flowlen: 0
queue_map_min: 4 queue_map_max: 4
dst_min: 198.18.0.42 dst_max:
src_min: src_max:
src_mac: a6:85:82:fc:89:bf dst_mac: 02:5d:ae:ba:e0:00
udp_src_min: 9 udp_src_max: 109 udp_dst_min: 9 udp_dst_max: 9
src_mac_count: 0 dst_mac_count: 0
Flags: UDPSRC_RND NO_TIMESTAMP QUEUE_MAP_RND
Current:
pkts-sofar: 3000 errors: 0
started: 6113136017us stopped: 6113443758us idle: 38457us
seq_num: 3001 cur_dst_mac_offset: 0 cur_src_mac_offset: 0
cur_saddr: 0.0.0.0 cur_daddr: 198.18.0.42
cur_udp_dst: 9 cur_udp_src: 17
cur_queue_map: 4
flows: 0
Result: OK: 307741(c269283+d38457) usec, 3000 (500byte,0frags)
9748pps 38Mb/sec (38992000bps) errors: 0

```

7. Send two streams into queue 3 and queue 4

```

./pktgen/pktgen_twoqueue.sh -i eth1 -q 3 -s 1500 -n 0

```

8. Capture the streams on test center, the frames sort by one Q3 frame and two Q4 frames

Chapter 8

Preempt-RT

8.1 System RT Latency Tests

The basic measurement tool for RT Linux is `cyclicttest`.

8.1.1 Running Cyclicttest

Cyclicttest accurately and repeatedly measures the difference between a thread's intended wake-up time and the time at which it actually wakes up in order to provide statistics about the system's latencies. It can measure latencies in real-time systems caused by the hardware, the firmware, and the operating system.

The original test was written by Thomas Gleixner (tgx), but several people have subsequently contributed modifications. Cyclicttest is currently maintained by Clark Williams and John Kacur and is part of the test suite [rt-tests](#).

`cyclicttest` :

- Use the below command to Latency Test:

```
$ cyclicttest -p90 -h50 -D30m
```

NOTE

For detailed parameters of Cyclicttest, please refer to <https://wiki.linuxfoundation.org/realtime/documentation/howto/tools/cyclicttest/start?s%5b%5d=cyclicttest>.

8.2 RT application development

This section describes the steps for developing the RT (real time) application.

RT Application: API, Basic Structure, Background:

- Basic Linux application rules are the same; Use the POSIX API.
- There is still a division of Kernel Space and User Space.
- Linux applications run in User Space
- For details, please refer to: http://rt.wiki.kernel.org/index.php/RT_PREEMPT_HOWTO

RT Application: Users can build it using the steps below:

- **Using the cross compiler example:**

```
$ arm-linux-gnueabi-gcc <filename>.c -o <filename>.out -lrt -Wall
```

- **Using the native compiler on a target example:**

```
$ gcc <filename>.c -o <filename>.out -lrt -Wall
```

Scheduling policies have two classes:

Completely Fair Scheduling (CFS)

- SCHED_NORMAL
- SCHED_BATCH
- SCHED_IDLE

RT policies:

- SCHED_FIFO
- SCHED_RR
- SCHED_DEADLINE

Chapter 9

Xenomai

Note: Xenomai is not supported in the current OpenIL release.

9.1 Xenomai running mode

The dual kernel core is codenamed Cobalt, whereas the native Linux implementation is called Mercury. Both Mercury and Cobalt are supported.

9.1.1 Running Xenomai Mercury

Xenomai Mercury provides the following API references:

1. Test programs:

- latency: The user manual for Xenomai timer latency benchmark can be found at:
<http://www.xenomai.org/documentation/xenomai-3/html/man1/latency/index.html>.
- cyclictst: The user manual for Xenomai high resolution timer test can be found at:
<http://www.xenomai.org/documentation/xenomai-2.6/html/cyclictst/index.html>.

2. Utilities:

- xeno: The user manual for Wrapper for Xenomai executables can be found at:
<http://www.xenomai.org/documentation/xenomai-2.6/html/xeno/index.html>.
- xeno-config: The user manual for displaying Xenomai libraries configuration can be found at:
<http://www.xenomai.org/documentation/xenomai-2.6/html/xeno-config/index.html>.

9.1.2 Running Cobalt mode

Xenomai Cobalt provides many APIs to perform testing.

1. Clocktest : The test program `clocktest` provided by Xenomai can be used to test timer APIs. There are three kinds of timer sources: `CLOCK_REALTIME`, `CLOCK_MONOTONIC`, and `CLOCK_HOST_REALTIME`.

- Use the below command to check a timer with clock name `CLOCK_REALTIME`:

```
$ clocktest -C 0
```

- Use the below command to check a timer with clock name `CLOCK_MONOTONIC`:

```
$ clocktest -C 1
```

- Use the below command to check a timer with clock name `CLOCK_HOST_REALTIME` (Just for Arm V7 SoC):

```
$ clocktest -C 32
```

2. The interrupts handled by Cobalt : IFC and e1000e interrupts are handled by the Cobalt kernel.

```
$ cat /proc/xenomai/irq
```


NOTE

For e1000e test case, the Linux kernel standard network stack is used instead of rtnet stack.

3. Cobalt IPIPE tracer: The following options are available while configuring the kernel settings:
 - a. CONFIG_IPIPE_TRACE_ENABLE (Enable tracing on boot): Defines if the tracer is active by default when booting the system or shall be later enabled via `/proc/ipipe/trace/enable`. Specifically if function tracing is enabled, deferring to switch on the tracer reduces the boot time on low-end systems.
 - b. CONFIG_IPIPE_TRACE_MCOUNT (Instrument function entries): Traces each entry of a kernel function. Note that this instrumentation, though it is the most valuable one, has a significant performance impact on low-end systems (~50% larger worst-case latencies on a Pentium-I 133 MHz).
 - c. CONFIG_IPIPE_TRACE_IRQSOFF (Trace IRQs-off times): Instruments each disable and re-enable of hardware IRQs. This allows to identify the longest path in a system with IRQs disabled.
 - d. CONFIG_IPIPE_TRACE_SHIFT (Depth of trace log): Controls the number of trace points. The I-pipe tracer maintains four ring buffers per CPU of the given capacity in order to switch traces in a lock-less fashion with respect to potentially pending output requests on those buffers. If user run short on memory, try reducing the trace log depth which is set to 16000 trace points by default.
 - e. CONFIG_IPIPE_TRACE_VMALLOC (Use vmalloc'ed trace buffer): Instead of reserving static kernel data, the required buffer is allocated via `vmalloc` during boot-up when this option is enabled. This can help to start systems that are low on memory, but it slightly degrades overall performance. Try this option when a traced kernel hangs unexpectedly at boot time.

4. Latency of timer IRQ

```
$ latency -t 2 -T 60
```

NOTE

The location of 'latency' might differ from version to version. Currently it is located in `/usr/bin`.

5. Latency of task in Linux kernel

```
$ latency -t 1 -T 60
```

6. Latency of task in user space

```
$ latency -t 0 -T 60
```

7. Smokey to check feature enabled

```
$ smokey --run
```

8. Thread context switch

```
$ switchtest -T 30
```

9. xeno-test: By default, the load command is `dohell 900`, which generates load during 15 minutes.

Step #1: Prepare one storage disk and ethernet port connected server, for example:

```
$ fdisk /dev/sda
$ mkfs.ext2 /dev/sda1
$ mount /dev/sda1 /mnt
$ ifconfig <nw port> <ip addr>
```

```

Step #2:
$ cd /usr/xenomai/bin

Step #3:
$ sudo ./xeno-test -l "dohell -s <server ip> -m /mnt"

```

9.2 RTnet

RTnet is a protocol stack that runs between the Ethernet layer and the application layer (or IP layer). It aims to provide deterministic communication, by disabling the collision detection CSMA/CD, and preventing buffering packets in the network, through the use of time intervals (time-slots).

RTnet is a software developed to run on Linux kernel with RTAI or Xenomai real-time extension. It exploits the real time kernel extension to ensure the determinism on the communication stack. To accomplish this goal, all the instructions related to this protocol make use of real time kernel functions rather than those of Linux. This binds the latencies to the execution times and latencies of interruptions, which provides deterministic communication.

The following sections describe how to enable the RTnet feature in Xenomai and enable data path acceleration architecture (DPAA) for Xenomai RTnet.

9.2.1 Hardware requirements

Following are the hardware requirements for implementing the RTnet protocol in user's design:

- For LS1043A, two LS1043ARDB boards (one used as a master and one as a slave board).
- For LS1046A, two LS1046ARDB boards (one used as a master and one as a slave board).
- For LS1028A, two LS1028ARDB boards (one used as a master and one as a slave board).
- In case three or more boards are used, a switch is required for connecting all boards into a subnet.
- If user use an e1000e NIC, insert the e1000e NIC into the P4 slot of the LS1043ARDB or LS1046ARDB board.

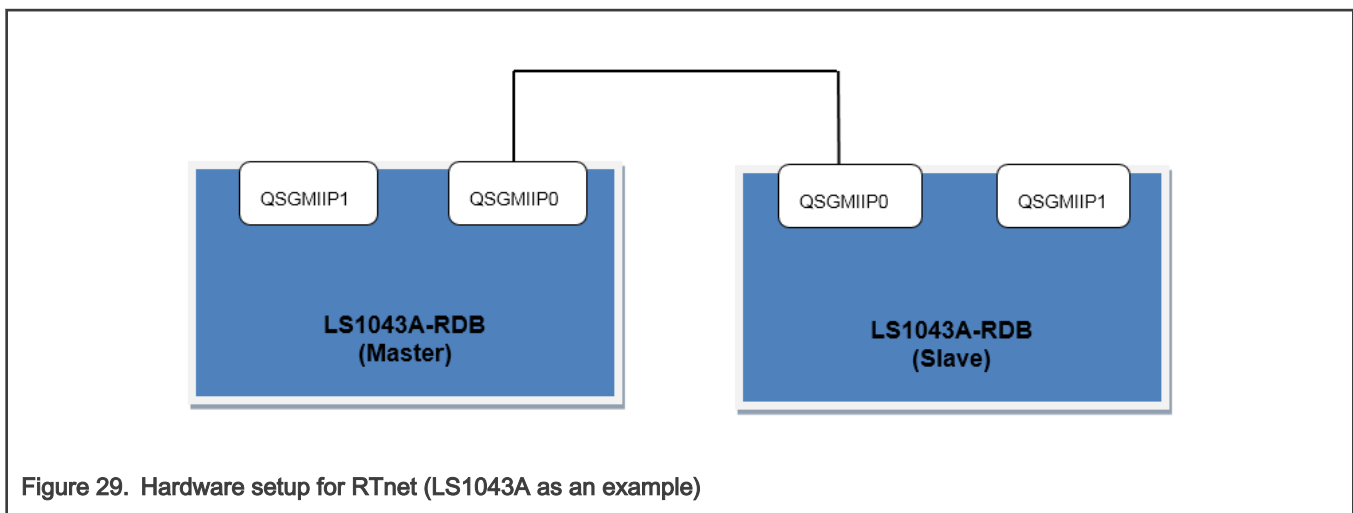


Figure 29. Hardware setup for RTnet (LS1043A as an example)

9.2.2 Software requirements

Use the following steps for enabling the RTnet functionality on a Xenomai supported network.

1. Run the command below to configure LS1043ARDB in the `openil` directory:

```
make nxp_ls1043ardb-64b_defconfig
```

2. Alternatively, for configuring LS1046ARDB in the `openil` directory, use the command below:

```
make nxp_ls1046ardb-64b_defconfig
```

3. Or, for configuring LS1028ARDB in the `openil` directory, use the command below:

```
make nxp_ls1028ardb-64b_defconfig
```

4. Then, configure the Linux kernel according to the steps listed below.

For DPAA devices:

- Disable the Linux DPAA driver using the settings below:

```
$make linux-menuconfig
Device Drivers --->
  [*] Staging drivers --->
    [ ] Freescale Datapath Queue and Buffer management
```

- Add the Xenomai RTnet driver and protocol stack using the commands below:

```
$make linux-menuconfig
[*] Xenomai/cobalt --->
  Drivers --->
    RTnet --->
      <M> RTnet, TCP/IP socket interface
      Protocol Stack --->
        <M> RTmac Layer --->
          < > TDMA discipline for RTmac
          < M > NoMAC discipline for RTmac
      Drivers --->
        <M> FMAN independent mode
```

For e1000e devices:

- Disable the Linux e1000e driver using the settings below:

```
$make linux-menuconfig
Drivers --->
  [*] Network device support --->
    [*] Ethernet driver support --->
      < > Intel(R) PRO/1000 PCI-Express Gigabit Ethernet support
```

- Add the Xenomai RTnet driver and protocol stack using the commands below:

```
$make linux-menuconfig
[*] Xenomai/cobalt ---> Drivers --->
  RTnet --->
    <M> RTnet, TCP/IP socket interface Protocol Stack --->
      <M> RTmac Layer --->
        < > TDMA discipline for RTmac
        <M> NoMAC discipline for RTmac Drivers --->
        <M> New Intel(R) PRO/1000 PCIe (Gigabit)
```

For ENETC devices

- Disable the Linux ENETC driver using the settings below:

```
$make linux-menuconfig
Device Drivers --->
  Network device support --->
```

```

        Ethernet driver support --->
        < > ENETC PF driver
        < > FELIX switch driver
Add the Xenomai RTnet driver and protocol stack using the commands below:
$make linux-menuconfig
[*] Xenomai/cobalt --->
    Drivers --->
        RTnet --->
            <M> RTnet, TCP/IP socket interface Protocol Stack --->
            <M> RTmac Layer --->
                < > TDMA discipline for RTmac
                < M > NoMAC discipline for RTmac
    Drivers --->
        <M> ENETC

```

5. Now, run the `make` command to build all images.
6. After flashing images to the SD card, boot LS1043ARDB or LS1046ARDB from the SD card and enter the Linux prompt.
7. Edit the configuration file, located by default, in the `/etc/rtnet.conf` directory using the settings below:

a. **DPAA devices**

• **Master board**

- `RT_DRIVER="rt_fman_im"` - The driver used (currently, it is 'rt_fman_im').
- `IPADDR="192.168.100.101"` - IP address of the master board.
- `NETMASK="255.255.255.0"` - The other slave board will have the IP 192.168.100.XXX.
- `TDMA_MODE="master"`
- `TDMA_SLAVES="192.168.100.102"` – If there are two slave boards, this will be "192.168.100.102 192.168.100.103".

• **Slave board**

- `RT_DRIVER="rt_fman_im"` - The driver used (currently, it is 'rt_fman_im').
- `IPADDR="192.168.100.102"` - IP address of the slave board.
- `NETMASK="255.255.255.0"` - net mask
- `TDMA_MODE="slave"`
- `TDMA_SLAVES="192.168.100.102"` – If there are two slave boards, this will be "192.168.100.102 192.168.100.103".

b. **e1000e devices:**

• **Master board**

- `RT_DRIVER="rt_e1000e"` - The driver used (currently, it is 'rt_e1000e').
- `IPADDR="192.168.100.101"` - IP address of the master board.
- `NETMASK="255.255.255.0"` - The other slave board will have the IP 192.168.100.XXX.
- `TDMA_MODE="master"`
- `TDMA_SLAVES="192.168.100.102"` – If there are two slave boards, this will be "192.168.100.102 192.168.100.103".

• **Slave board**

- `RT_DRIVER="rt_e1000e"` - The driver used (currently, it is 'rt_e1000e').

- IPADDR="192.168.100.102" - IP address of the slave board.
- NETMASK="255.255.255.0" - net mask
- TDMA_MODE="slave"
- TDMA_SLAVES="192.168.100.102" – If there are two slave boards, this will be "192.168.100.102 192.168.100.103".

c. ENETC devices

• Master board

- RT_DRIVER= "rt_enetc" - The driver used (currently, it is 'rt_enetc').
- IPADDR="192.168.100.101" - IP address of the master board.
- NETMASK="255.255.255.0" - The other slave board will have the IP 192.168.100.XXX.
- TDMA_MODE="master"
- TDMA_SLAVES="192.168.100.102" – If there are two slave boards, this will be "192.168.100.102 192.168.100.103".

• Slave board

- RT_DRIVER= "rt_enetc" - The driver used (currently, it is 'rt_enetc').
- IPADDR="192.168.100.102" - IP address of the slave board.
- NETMASK="255.255.255.0" - net mask
- TDMA_MODE="slave"
- TDMA_SLAVES="192.168.100.102" – If there are two slave boards, this will be "192.168.100.102 192.168.100.103".

9.2.3 Verifying RTnet

Use the following steps to verify the RTnet connection:

- Step1: Load all modules related with Xenomai RTnet and analyze the configuration file **both** on master and slave sides.

```
$ rtnet start
```

- Use **CTRL+ C** key combination to exit after using the preceding command, if it does not exit on its own.
- Use the below command to display all ethernet ports. Currently, it should display four Ethernet ports (QSGMII Port 0 to Port 3) on master and slave:

```
$ rtifconfig -a
```

- Configure the network on the master side using the commands below:

```
$ rtifconfig rteth0 up 192.208.100.101
$ rtroute solicit 192.208.100.102 dev rteth0
```

- Configure the network on the slave side using the command below:

```
$ rtifconfig rteth0 up 192.208.100.102
```

NOTE

If there are more than one slave boards, user should redo this step using the IP address of the used boards.

- Verify the network connection using the command below:

```
$ rtping 192.208.100.102
```

Chapter 10

EtherCAT

OpenIL supports the use of EtherCAT ((Ethernet for Control Automation Technology) and integrates the IGH EtherCAT master stack. EtherCAT support is verified on NXP's LS1021-IoT, LS1043ARDB, LS1046ARDB, and LS1028ARDB platforms.

10.1 Introduction

EtherCAT is an Ethernet-based fieldbus system, invented by BECKHOFF Automation. The protocol is standardized in IEC 61158 and is suitable for both hard and soft real-time computing requirements in automation technology. The goal during development of EtherCAT was to apply Ethernet for automation applications requiring short data update times (also called cycle times; $\leq 100 \mu\text{s}$) with low communication jitter (for precise synchronization purposes; $\leq 1 \mu\text{s}$) and reduced hardware costs.

- EtherCAT is Fast: 1000 dig. I/O: $30 \mu\text{s}$, 100 slaves: $100 \mu\text{s}$.
- EtherCAT is Ethernet: Standard Ethernet at I/O level.
- EtherCAT is Flexible: Star, line, drop, with or without switch.
- EtherCAT is Inexpensive: ethernet is mainstream technology, therefore inexpensive.
- EtherCAT is Easy: everybody knows Ethernet, it is simple to use.

At present, the EtherCAT master supports the common open source code for SOEM of RT - LAB development (Simple Open Source EtherCAT Master) and EtherLab, the IGH EtherCAT master. To use SOEM is simpler than to use the IGH EtherCAT Master, but IGH for the realization of the EtherCAT is more complete. For example, IGH supports more NIC. For more information, see <https://rt-labs.com/ethercat/> and <http://www.etherlab.org>. The integration in OpenIL is IGH EtherCAT master.

10.2 IGH EtherCAT architecture

The components of the master environment are described below:

- **Master module:** This is the kernel module containing one or more EtherCAT master instances, the 'Device Interface' and the 'Application Interface'.
- **Device modules:** These are EtherCAT-capable Ethernet device driver modules that offer their devices to the EtherCAT master via the device interface. These modified network drivers can handle network devices used for EtherCAT operation and 'normal' Ethernet devices in parallel. A master can accept a certain device and then, is able to send and receive EtherCAT frames. Ethernet devices declined by the master module are connected to the kernel's network stack, as usual.
- **Application:** A program that uses the EtherCAT master (usually for cyclic exchange of process data with EtherCAT slaves). These programs are not part of the EtherCAT master code, but need to be generated or written by the user. An application can request a master through the application interface. If this succeeds, it has the control over the master: It can provide a bus configuration and exchange process data. Applications can be kernel modules (that use the kernel application interface directly) or user space programs, that use the application interface via the EtherCAT library, or the RTDM library.

The following figure shows that IGH EtherCAT master architecture.

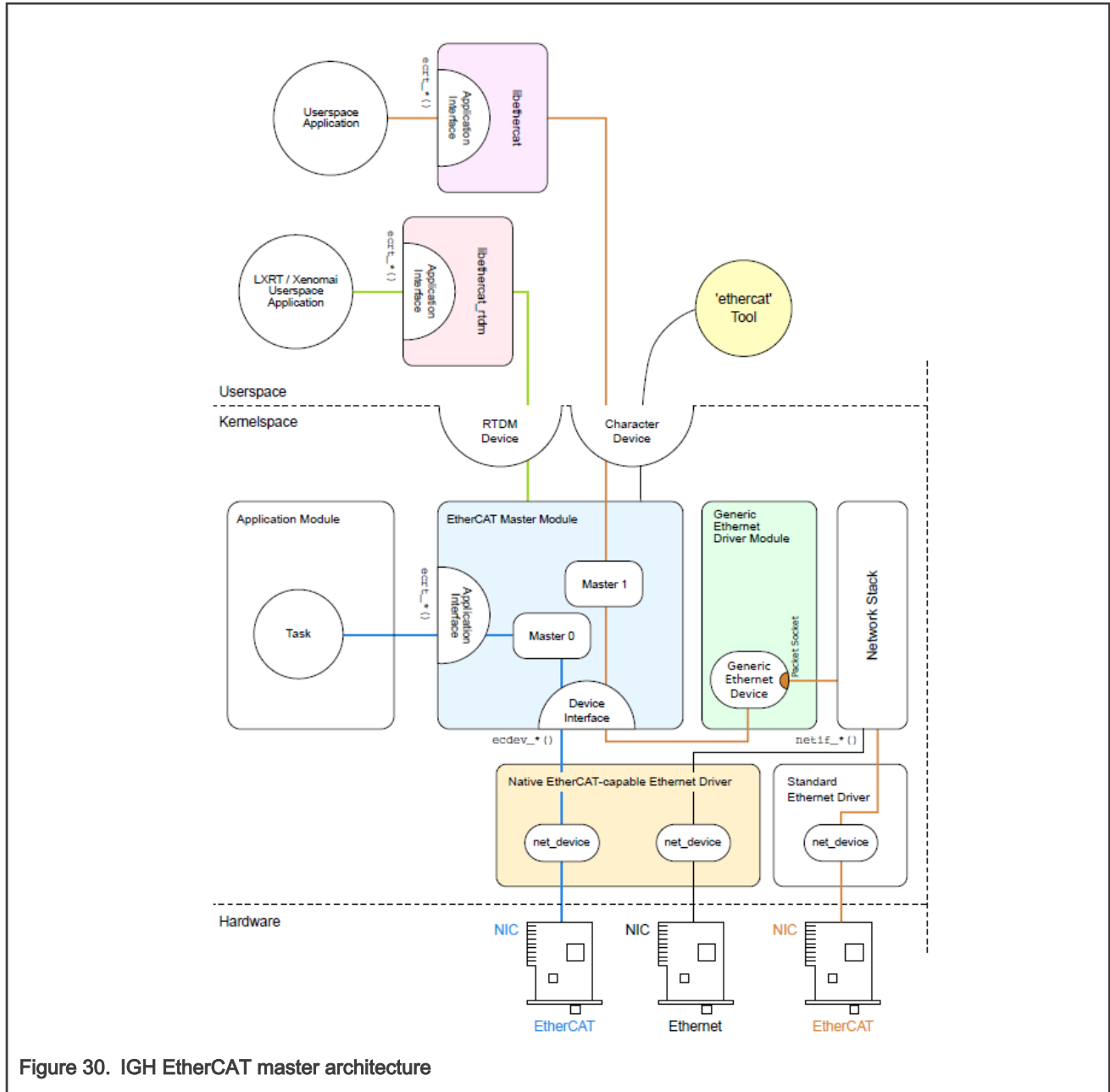


Figure 30. IGH EtherCAT master architecture

10.3 EtherCAT protocol

Following are the characteristics of the EtherCAT protocol:

- The EtherCAT protocol is optimized for process data and is transported directly within the standard IEEE 802.3 Ethernet frame using Ethertype 0x88a4.
- The data sequence is independent of the physical order of the nodes in the network; addressing can be in any order.
- Broadcast, multicast, and communication between slaves is possible, but must be initiated by the master device.
- If IP routing is required, the EtherCAT protocol can be inserted into UDP/IP datagrams. This also enables any control with Ethernet protocol stack to address EtherCAT systems.
- It does not support shortened frames.

The following figure shows the EtherCAT frame structure.

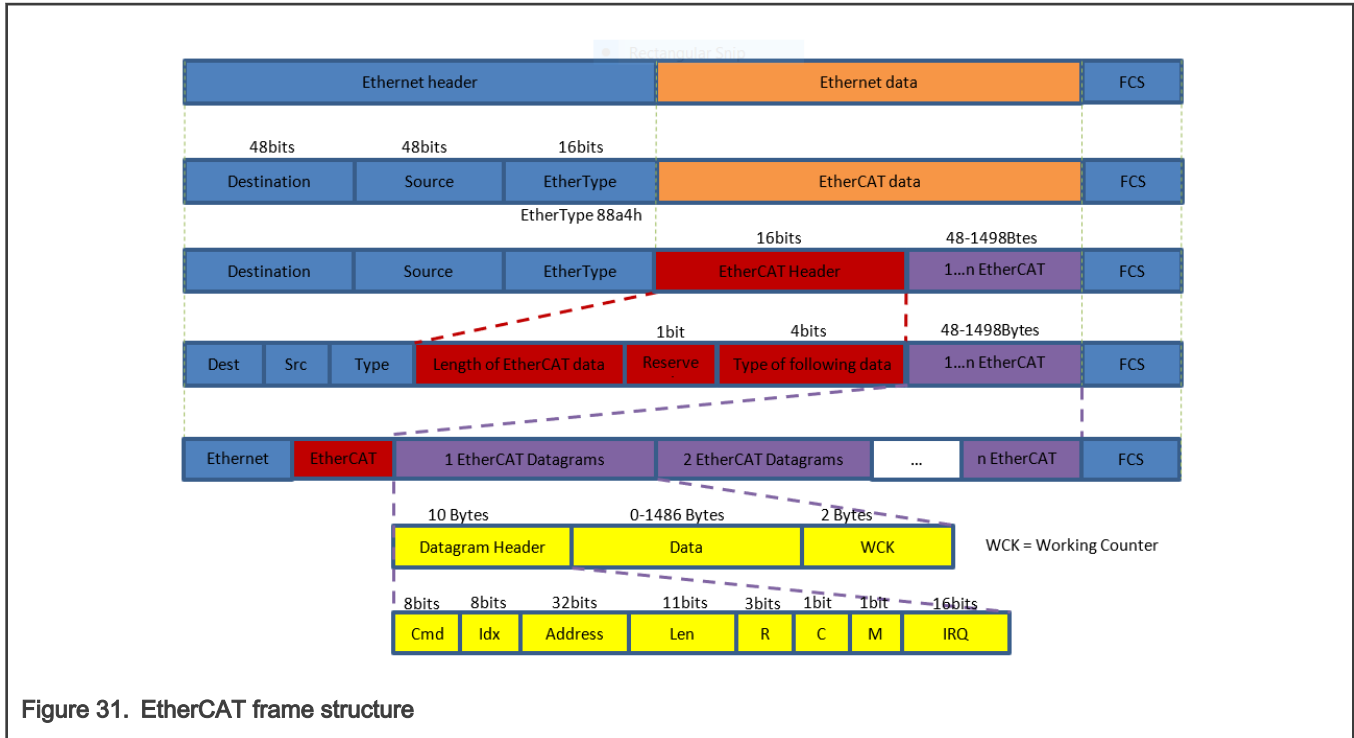


Figure 31. EtherCAT frame structure

10.4 EtherCAT system integration and example

This section describes how to integrate EtherCAT with the OpenIL system and provides an example of running the BECKHOFF application.

10.4.1 Building kernel images for EtherCAT

For **LS1021A-IoT**, EtherCAT supports the following configuration files:

- nxp_ls1021aiot_baremetal_defconfig
- nxp_ls1021aiot_baremetal_ubuntu_defconfig
- nxp_ls1021aiot_defconfig
- nxp_ls1021aiot_ubuntu_defconfig.

For **LS1043ARDB**, EtherCAT supports the following configurations:

- nxp_ls1043ardb-64b_defconfig
- nxp_ls1043ardb-64b_ubuntu_defconfig
- nxp_ls1043ardb_baremetal-64b_defconfig.

For **LS1046ARDB**, EtherCAT supports the following configurations:

- nxp_ls1046ardb-64b_defconfig
- nxp_ls1046ardb-64b_qspi_defconfig
- nxp_ls1046ardb-64b_qspi-sb_defconfig
- nxp_ls1046ardb-64b_ubuntu_defconfig
- nxp_ls1046ardb_baremetal-64b_defconfig.

Use the command below to build image supporting EtherCAT (example: nxp_ls1046ardb-64b_defconfig):

```
$ make nxp_ls1046ardb-64b_defconfig
$ make
```

Then, flash the image to SD card and reboot the board with this card and SD boot.

10.4.2 Command-line tool

Each master instance gets a character device as a userspace interface. The devices are named `/dev/EtherCATx`, where `x` is the index of the master.

Device node creation The character device nodes are automatically created, if the startup script is executed. The following example illustrates the command-line tools:

Table 47. Command line tools for EtherCAT

| Command | Description | Arguments | Output |
|------------------------------|---|---|--|
| ethercat config [OPTIONS] | Shows slave configurations. | Options: <ul style="list-style-type: none"> • <code>--alias -a <alias ></code> Configuration alias (see above) • <code>--position -p <pos ></code> > Relative position (see above). • <code>--verbose -v</code> Show detailed configurations. | Without the <code>--verbose</code> option, slave configurations are output one -per - line. For example, the output for <code>1001:0 0 x0000003b /0 x02010000 3</code> would be displayed as follows: <ul style="list-style-type: none"> • 1001:0 -> Alias address and relative position (both decimal). • 0 x0000003b /0 x02010000 -> Expected vendor ID and product code (both hexadecimal). • 3 -> Absolute decimal ring position of the attached slave, or '-' if none attached. • OP -> Application – layer state of the attached slave, or '-', if no slave is attached. |
| ethercat master [OPTIONS] | Shows master and Ethernet device information. | Options: <ul style="list-style-type: none"> • <code>--master -m <indices ></code> Master indices. A comma - separated list with ranges is supported. Example: <code>1 ,4 ,5 ,7 -9</code> . Default: <code>- (all)</code> . | <pre>Master0 Phase: Idle Active: no Slaves: 8 Ethernet devices: Main: 00:00:08:44: ab :66 (attached) Link: UP Tx frames: 18846 Tx bytes: 1169192 Rx frames: 18845 Rx bytes: 1169132 Tx errors: 0 Tx frame rate [1/s]: 125 395 241 Tx rate</pre> |

Table continues on the next page...

Table 47. Command line tools for EtherCAT (continued)

| | | | |
|--|--|--|---|
| | | | <pre> [KByte/s]: 7.3 24.0 14.6 Rx frame rate [1/s]: 125 395 241 Rx rate [KByte/s]: 7.3 24.0 14.6 Common: Tx frames: 18846 Tx bytes: 1169192 Rx frames: 18845 Rx bytes: 1169132 Lost frames: 0 Tx frame rate [1/s]: 125 395 241 Tx rate [KByte/s]: 7.3 24.0 14.6 Rx frame rate [1/s]: 125 583 241 Rx rate [KByte/s]: 7.3 210.4 14.6 Loss rate [1/s]: 0 -0 0 Frame loss [%]: 0.0 -0.0 0.0 Distributed clocks: Reference clock: Slave 0 Application time: 0 </pre> |
| <p><code>ethercat states</code> <code>[OPTIONS] <STATE ></code></p> | <p>Requests application - layer states</p> | <p>STATE can be 'INIT', 'PREOP', 'BOOT', 'SAFEOP', or 'OP'.</p> <p>Options:</p> <ul style="list-style-type: none"> • <code>--alias -a <alias ></code> • <code>-- position -p <pos ></code> Slave selection. See the help of the 'slaves' command. | <p>None</p> |

NOTE

- Numerical values can be specified either with decimal (no prefix), octal (prefix '0') or hexadecimal (prefix '0x') base.
- More command-line information can be obtained by using the command **ethercat --help**.

10.4.3 System integration

An `init` script and a `sysconfig` file are provided to integrate the EtherCAT master as a service into a running system. These are described below.

- **Init Script**

The EtherCAT master `init` script conforms to the requirements of the 'Linux Standard Base' (LSB). The script is installed to `etc/init.d/EtherCAT`, before the master can be inserted as a service. Please note, that the `init` script depends on the `sysconfig` file described below.

LSB defines a special comment block to provide service dependencies (that is, which services should be started before others) inside the `init` script code. System tools can extract this information to insert the EtherCAT `init` script at the correct place in the startup sequence:

```
# Required - Start: $local_fs $syslog $network
# Should - Start: $time ntp
# Required - Stop: $local_fs $syslog $network
# Should - Stop: $time ntp
# Default - Start: 3 5
# Default - Stop: 0 1 2 6
# Short - Description: EtherCAT master
# Description: EtherCAT master 1.5.2
### END INIT INFO
```

- **Sysconfig file**

For persistent configuration, the `init` script uses a `sysconfig` file installed to `etc/sysconfig/EtherCAT`, that is mandatory for the `init` script. The `sysconfig` file contains all configuration variables needed to operate one or more masters. The documentation is inside the file and included below:

```
#-----
## Main Ethernet devices.
#
# The MASTER <X> _DEVICE variable specifies the Ethernet device for a master
# with index 'X '.
#
# Specify the MAC address (hexadecimal with colons) of the Ethernet device to
# use. Example: "00:00:08:44: ab :66"
#
# The broadcast address "ff:ff:ff:ff:ff:ff" has a special meaning : It tells
# the master to accept the first device offered by any Ethernet driver.
#
# The MASTER <X> _DEVICE variables also determine, how many masters will be
# created: A non - empty variable MASTER0_DEVICE will create one master, adding a
# non - empty variable MASTER1_DEVICE will create a second master, and so on.
#
MASTER0_DEVICE =""
# MASTER1_DEVICE =""
#
# Backup Ethernet devices
#
# The MASTER <X> _BACKUP variables specify the devices used for redundancy. They
# behaves nearly the same as the MASTER <X> _DEVICE variable, except that it
# does not interpret the ff:ff:ff:ff:ff:ff address .
#
# MASTER0_BACKUP =""
#
# Ethernet driver modules to use for EtherCAT operation.
#
# Specify a non - empty list of Ethernet drivers, that shall be used for
# EtherCAT operation.
#
# Except for the generic Ethernet driver module, the init script will try to
```

```

# unload the usual Ethernet driver modules in the list and replace them with
# the EtherCAT - capable ones. If a certain (EtherCAT - capable) driver is not
# found, a warning will appear.
#
# Possible values: 8139 too, e100, e1000, e1000e, r8169, generic, ccat, igb.
# Separate multiple drivers with spaces.
#
# Note: The e100, e1000, e1000e, r8169, ccat and igb drivers are not built by
# default. Enable them with the --enable -<driver > configure switches.
#
# Attention: When using the generic driver, the corresponding Ethernet device
# has to be activated (with OS methods, for example 'ip link set ethX up '),
# before the master is started, otherwise all frames will time out.
#
DEVICE_MODULES=""
#
# Flags for loading kernel modules.
#
# This can usually be left empty. Adjust this variable, if you have problems
# with module loading.
#
# MODPROBE_FLAGS="-b"
#-----

```

Starting the Master as a service: After the `init` script and the `sysconfig` file are placed into the right location, the EtherCAT master can be inserted as a service. The `init` script can also be used for manually starting and stopping the EtherCAT master. It should be executed with one of the parameters: `start`, `stop`, `restart` or `status`. For example:

```

$/etc/init.d/EtherCAT restart
    Shutting down EtherCAT master done
    Starting EtherCAT master done

```

10.4.4 Running a sample application

This section describes how to run a sample application.

List of materials

Following is the list of materials needed for running the Igh EtherCAT application:

- OpenIL board (LS1021-IoT, LS1043ARDB, and LS1046ARDB)
- BECKHOFF EK1100 and EL2008
- 24V Power Supply

The figures below show the required materials:

- The figure below shows the board and BECKHOFF connected by a Ethernet cable.



Figure 32. Board connects with BECKHOFF

- The figure below shows the BECKHOFF's EK1100 and EL2008.

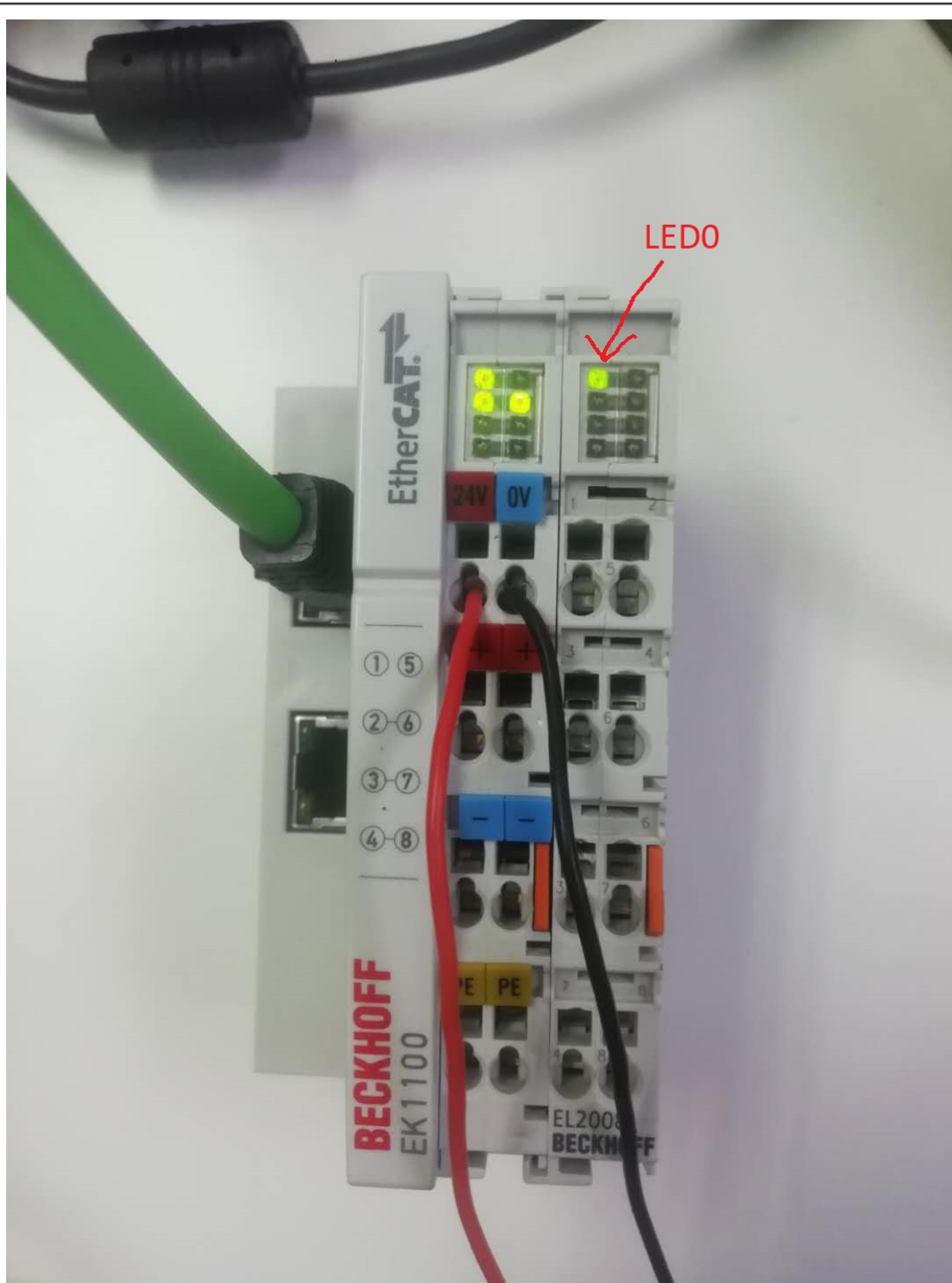


Figure 33. BECKHOFF EK1100 and EL2008

For more information about EL2008, see <https://www.beckhoff.com/english.asp?ethercat/el2008.htm>.

Follow the steps below to run a sample application:

1. Update the `sysconfig` file `etc/sysconfig/EtherCAT` for the persistent configuration. Variables `MASTER0_DEVICE` and `DEVICE_MODULES` need to be changed to the specified MAC and driver type. The MAC address is the one that is connected to BECKHOFF.

For example, the MAC used is `00:00:08:44: ab :66` and the drivers used are `generic`:

```
MASTER0_DEVICE ="00:00:08:44: ab :66"
DEVICE_MODULES ="generic"
```

- Execute the initialization script and specify the parameter start.

```
$ /etc/init.d/ethercat restart
```

- Run the example application.

```
$ ec_user_example
```

- If the `init` script fails to start EtherCAT master, the command `insmod` or `modprobe` can be used to load the module directly: `ec_master.ko` and `ec_generic.ko` are found in the path `/lib/modules/4.9.35-ipipe/extra/`

```
$ insmod ec_master.ko main_devices= MAC address
$ insmod ec_generic.ko
```

- Run the example application.

```
$ ec_user_example
```

- Check whether the LED0 on EL2008 is blinking with 1Hz.

ATTENTION

If the console prompts `Failed to open /dev/EtherCAT0`, the module fails to load, please check it.

10.5 NXP servo stack

nxp-servo is a CiA402 (also referred to as DS402) profile framework based on Igh CoE interface (An EtherCAT Master stack, see [EtherCAT](#) section for details). It abstracts the CiA 402 profile and provides an easily-usable API for the Application developer.

The *nxp-servo* project consists of a basic library *libnservo* and several auxiliary tools.

The application developed with *libnservo* is flexible enough to adapt to the changing of CoE network by modifying the *xm/config* file, which is loaded when the application starts. The *xm/config* file describes the necessary information, including EtherCAT network topology, slaves configurations, masters configurations and all axes definitions.

10.5.1 CoE network

A typical CoE network is shown in the figure below:

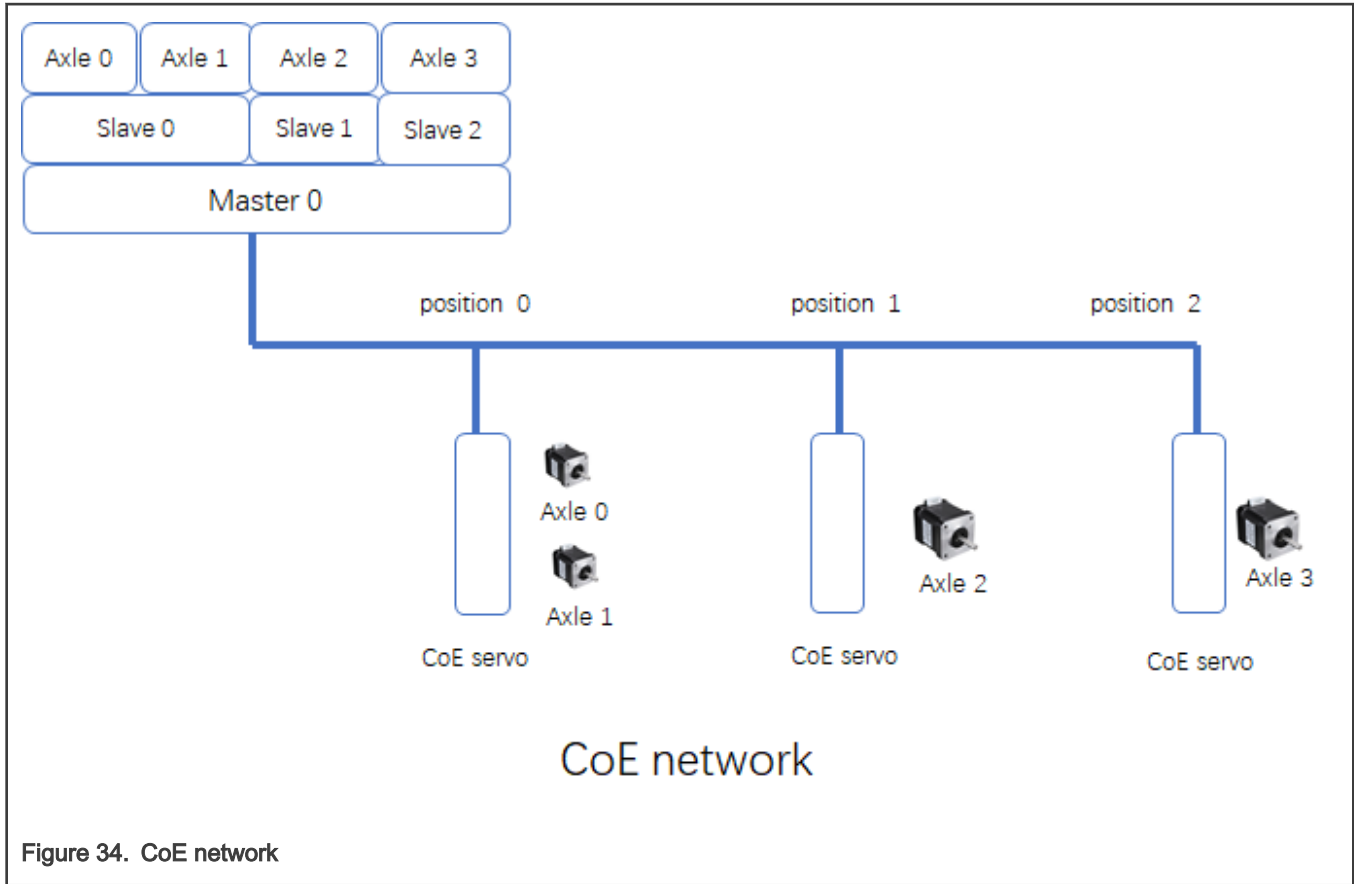


Figure 34. CoE network

There are three CoE servos on this network and we name them slave *x* as the position they are. Each CoE servo could have more than one axle. The libnservo then initiates the CoE network and encapsulates the detail of network topology into axle nodes. So the developer could focus on the each axle operation without taking care of the network topology.

10.5.2 Libnservo Architecture

nxp-servo is running on top of *lgh* EtherCAT stack. And the *lgh* stack provides CoE communication mechanisms - Mailbox and Process Data. Using these mechanisms, *nxp-servo* could access the CiA Object Dictionary located on CoE servo.

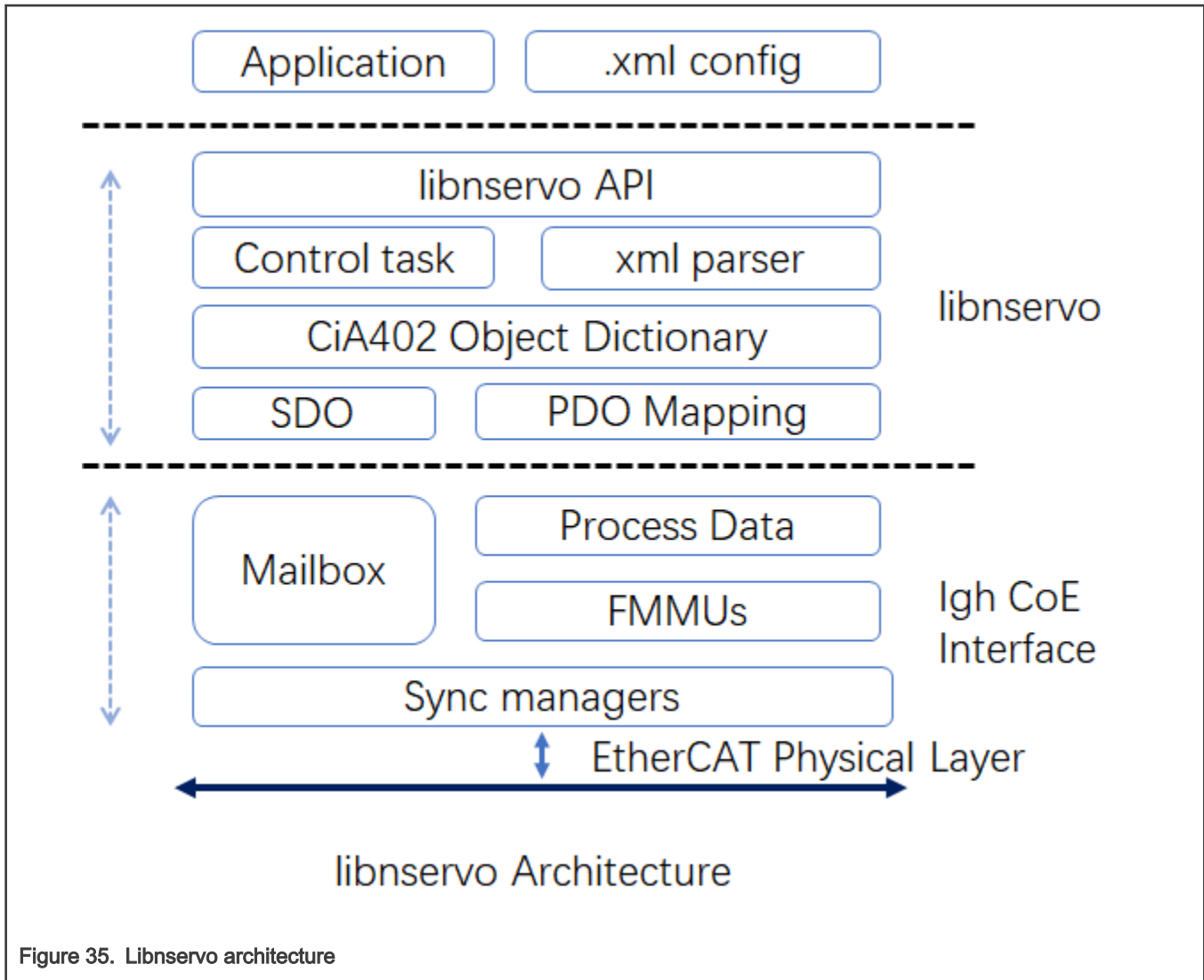


Figure 35. Libnservo architecture

Control task initiates the master, all slaves on the CoE network and registers all PDOs to Igh stack, then constructs a data structure to describe each axle. Finally, the control task creates a task to run the user task periodically.

10.5.3 Xml Configuration

This section focuses on how the xml config file describes a CoE network.

The skeleton of XML config is shown as in figure below:

```
<?xml version="1.0" encoding="utf-8"?>
<Config Version="1.2">
  <PeriodTime>#10000000</PeriodTime>
  <MaxSafeStack>#8192</MaxSafeStack>
  <master_status_update_freq>#1</master_status_update_freq>
  <slave_status_update_freq>#1</slave_status_update_freq>
  <axle_status_update_freq>#1</axle_status_update_freq>
  <sync_ref_update_freq>#2</sync_ref_update_freq>
  <is_xenomai>#1</is_xenomai>
  <sched_priority>#82</sched_priority>
  <Masters>
    <Master>
      ...
    
```

```

    <\Master>
    <Master>
        ...
    <\Master>
<\Master>

<Axles>
    <Axle>
        ...
    <\Axle>
    <Axle>
        ...
    <\Axle>
<\Axles>
</Config>

```

- All config elements must be inside the <Config> element.
- All config elements shown above are mandatory.
- The numerical value started with # means that it is a decimal value.
- The numerical value started with #x means that it is a hexadecimal value.
- <PeriodTime> element means that the period of control task is 10ms.
- <MaxSafeStack> means the stack size, and it is an estimated value. 8K is enough to satisfy most application.
- <master_status_update_freq> element means the frequency of masters status update. the value #x means update the masters status every task period.
- <slave_status_update_freq> element means the frequency of slaves status update. the value #1 means update the slaves status every task period.
- <axle_status_update_freq> element means the frequency of axles status update. the value #1 means update the axles status every task period.
- <sync_ref_update_freq> element means the frequency of reference clock update. the value #2 means update the axles status every two task period.
- <is_xenomai> element means whether Xenomai is supported. the value #1 means that Xenomai is supported on this host, and #0 means not.
- <sched_priority> element means the priority of the user task.
- <Masters> element could contain more then one Master element . For most cases, there is only one master on a host.
- <Axles> element could contain more then one Axle element, which is the developer really care about.

10.5.3.1 Master Element

As *CoE network* section shown, the Master could has many slaves, so the Master element will consist of some *Slave* elements.

```

<Master>
    <Master_index>#0</Master_index>
    <Reference_clock>#0</Reference_clock>
    <Slave alias="#0" slave_position="#0">
        ....
    </Slave>
    <Slave alias="#1" slave_position="#1">
        ....
    </Slave>
</Master>

```

- <Master_index> element means the index of the master. as mentioned above, for many cases, there is only one master, so the value of this element is always #0.
- <Reference_clock> element is used to indicate which slave will be used the reference clock.
- <Slave> element means there is a slave on this master.

10.5.3.1.1 Slave Element

```

<Slave alias="#0" slave_position="#0">
  <VendorId>#x66668888</VendorId>
  <ProductCode>#x20181302</ProductCode>
  <Name>2HSS458-EC</Name>
  <Emerg_size>#x08</Emerg_size>
  <WatchDog>
    <Divider>#x0</Divider>
    <Intervals>#4000</Intervals>
  </WatchDog>
  <DC>
    <SYNC SubIndex='#0'>
      <Shift>#0</Shift>
    </SYNC>
  </DC>
  <SyncManagers force_pdo_assign="#1">
    <SyncManager SubIndex="#0">
      ...
    </SyncManager>
    <SyncManager SubIndex="#1">
      ...
    </SyncManager>
  </SyncManagers>
  <Sdos>
    <Sdo>
      ...
    </Sdo>
    <Sdo>
      ...
    </Sdo>
  </Sdos>
</Slave>

```

- *alias* attribute means the alias name of this slave.
- *slave_position* attribute means which position of the slave is on this network.
- <Name>element is the name of the slave.
- <Emerg_size> element is always 8 for all CoE device.
- <WatchDog> element is used to set the watch dog of this slave.
- <DC> element is used to set the sync info.
- <SyncManagers> element should contain all syncManager channels.
- <Sdos> element contains the default value we want to initiate by SDO channel.

10.5.3.1.1.1 SyncManagers Element

For a CoE device, there are generally four syncManager channels.

- SM0: Mailbox output
- SM1: Mailbox input

- SM2: Process data outputs
- SM3: process data inputs

```

<SyncManager SubIndex="#2">
  <Index>#x1c12</Index>
  <Name>Sync Manager 2</Name>
  <Dir>OUTPUT</Dir>
  <Watchdog>ENABLE</Watchdog>
  <PdoNum>#1</PdoNum>
  <Pdo SubIndex="#1">
    <Index>#x1600</Index>
    <Name>RxPdo 1</Name>
    <Entry SubIndex="#1">
      ...
    </Entry>
    <Entry SubIndex="#2">
      ...
    </Entry>
  </Pdo>
</SyncManager>

```

- <Index> element is the object address.
- <Name> is a name of this syncmanager channel.
- <Dir> element is the direction of this syncmanager channel.
- <Watchdog> is used to set watchdog of this syncmanager channel.
- <PdoNum> element means how many PDO we want to set.
- <Pdo SubIndex="#1"> element contains the object dictionary entry we want to mapped.
 - <Index> PDO address.
 - <Name> PDO name
 - <Entry> the object dictionary we want to mapped.

The Entry element is used to describe a object dictionary we want to mapped.

```

<Entry SubIndex="#1">
  <Index>#x6041</Index>
  <SubIndex>#x0</SubIndex>
  <DataType>UINT</DataType>
  <BitLen>#16</BitLen>
  <Name>statusword</Name>
</Entry>

```

10.5.3.1.1.2 Sdo Element

The Sdo element is used to set the default value of a object dictionary.

```

<Sdo>
  <Index>#x6085</Index>
  <Subindex>#x0</Subindex>
  <value>#x1000</value>
  <BitLen>#32</BitLen>
  <DataType>DINT</DataType>
  <Name>Quick_stop_deceleration</Name>
</Sdo>

```

The element shown in figure above means set the Object Dictionary "6085" to 0x1000.

10.5.3.2 Axle Element

```
<Axle master_index='#0' slave_position="#0" AxleIndex="#0" AxleOffset="#0">
  <Mode>pp</Mode>
  <Name>x-axle</Name>
  <reg_pdo>
    ...
  </reg_pdo>
  <reg_pdo>
    ...
  </reg_pdo>
</Axle>
```

- *master_index* attribute indicates which *master* this *axle* belong to.
- *slave_position* attribute indicates which *slave* this *axle* belong to.
- *AxleOffset* attribute indicates which *axle* this *axle* is on the slave. As mentioned above, a CoE slave could have more than one *axle* . If this axle is the second axle on the slave, set *AxleOffset="#1"* .
- <Mode> means which mode this axle will work on.
- <Name> is the name of this axle.
- <reg_pdo> is the PDO entry we want to register.

reg_pdo element

```
<reg_pdo>
  <Index>#x606c</Index>
  <Subindex>#x0</Subindex>
  <Name></Name>
</reg_pdo>
```

10.5.4 Test

10.5.4.1 Hardware Preparation

- A CoE servo system
A CoE servo system includes a CoE servo and a motor. In this test, '2HSS458-EC' servo system shown as in figure below will be used.
- A board supported on OpenIL
In this test, LS1046ARDB will be used.



2HSS458-EC Servo System

10.5.4.2 Software Preparation

Make sure the below config options is selected when configuring OpenIL.

- BR2_PACKAGE_IGH_ETHERCAT=y
- BR2_PACKAGE_LIBXML2=y
- BR2_PACKAGE_QORIQ_SERVO=y

10.5.4.3 CoE Network Detection

- Igh configuration
 - Configure the MASTER0_DEVICE field of the */etc/ethercat.conf*
Set MASTER0_DEVICE to the MAC address to indicate which port the Igh uses .
 - Configure DEVICE_MODULES="generic" of the */etc/ethercat.conf*

- Using the command

```
[root@OpenIL:~]#ethercatctl start
```

to start Igh service.

- Check CoE servo using below command.

```
[root@OpenIL:~]#ethercat slaves
0 0:0 PREOP + 2HSS458-EC
```

10.5.4.4 Start Test

Note: The *Position encoder resolution* and *Velocity encoder resolution* of "2HSS458-EC" servo system are both 4000 . It means the ratio of encoder increments per motor revolution.

- *Profile Position* mode test

- Start the test service as below.

```
[root@OpenIL:~]# nservo_run -f /root/nservo_example/hss248_ec_config_pp.xml &
```

- Check whether the status of the slave has been transferred from "PREOP" to "OP".

```
[root@OpenIL:~]# ethercat slaves
0 0:0 OP + 2HSS458-EC
```

- Check whether the phase of the master has been transferred from "Idle" to "Operation".

```
[root@OpenIL:~]# ethercat master | grep Phase
Phase: Operation
```

- Run below commands to test whether the motor works.

- Get current mode of axle 0.

```
[root@OpenIL:~]# nservo_client -a 0 -c get_mode
get_mode of the axle 0 : Profile Position Mode
```

- Get current position of axle 0.

```
[root@OpenIL:~]# nservo_client -a 0 -c get_position
get_current_position of the axle 0 : 0
```

- Get the profile speed of axle 0.

```
[root@OpenIL:~]# nservo_client -a 0 -c get_profile_speed
get_profile_speed of the axle 0 : 800000
```

The value 800000 means 200 revolutions per second.

- Set profile speed of axle 0.

```
[root@OpenIL:~]# nservo_client -a 0 -c set_profile_speed:20000
set_profile_speed of the axle 0 : 20000
```

Set profile speed to 5 revolutions per second.

- Set target position of axle 0

```
[root@OpenIL:~]# nservo_client -c set_position:400000
set_position of the axle 0 : 400000
```

The value 400000 means that the motor will turn 100 rounds.

(target_position:400000 - current_position:0) / 4000 = 100

- Get current speed of axle 0

```
[root@OpenIL:~]# nservo_client -a 0 -c get_speed
get_speed of the axle 0 : 19999
```


- Get target position of axle 0

```
[root@OpenIL:~]# nservo_client -a 0 -c get_target_position
get_target_position of the axle 0 : 400000
```

— Exit

```
[root@OpenIL:~]# nservo_client -c exit
```

- *Profile Velocity* mode test

— Start the test service as below.

```
[root@OpenIL:~]# nservo_run -f /root/nservo_example/hss248_ec_config_pv.xml &
```

— Check whether the status of the slave has been transferred from "PREOP" to "OP".

```
[root@OpenIL:~]# ethercat slaves
0 0:0 OP + 2HSS458-EC
```

— Check whether the phase of the master has been transferred from "Idle" to "Operation".

```
[root@OpenIL:~]# ethercat master | grep Phase
Phase: Operation
```

— Run below commands to test whether the motor works.

- Get current mode of axle 0.

```
[root@OpenIL:~]# nservo_client -a 0 -c get_mode
get_mode of the axle 0 : Profile Velocity Mode
```

- Set target speed of axle 0.

```
[root@OpenIL:~]# nservo_client -a 0 -c set_speed:40000
set_speed of the axle 0 : 40000
```

The value 40000 means that the motor will turn with 10 revolutions per second.

- Get current speed of axle 0.

```
[root@OpenIL:~]# nservo_client -a 0 -c get_speed
get_speed of the axle 0 : 32000
```

- Get target speed of axle 0.

```
[root@OpenIL:~]# nservo_client -a 0 -c get_target_speed
get_target_speed of the axle 0 : 40000
```

— Exit

```
[root@OpenIL:~]# nservo_client -c exit
```

Chapter 11

OPC UA

OPC (originally known as “OLE for Process Control”, now “Open Platform Communications”) is a collection of multiple specifications, most common of which is OPC Data Access (OPC DA).

OPC Unified Architecture (OPC UA) was released in 2010 by the OPC Foundation as a backward incompatible standard to OPC Classic, under the name of IEC 62541.

OPC UA has turned away from the COM/DCOM (Microsoft proprietary technologies) communication model of OPC Classic, and switched to a TCP/IP based communication stack (asynchronous request/response), layered into the following:

- Raw connections
- Secure channels
- Sessions

11.1 OPC introduction

OPC UA defines:

- The transport protocol for communication (that can take place over HTTP, SOAP/XML or directly over TCP).
- A set of 37 'services' that run on the OPC server, and which clients call into, via an asynchronous request/response RPC mechanism.
- A basis for creating information models of data using object-oriented concepts and complex relationships.

The primary goal of OPC is to extract data from devices in the easiest way possible.

The *Information Model* provides a way for servers to not only provide data, but to do so in the most self-explanatory and intuitive way possible.

NOTE

Further references to 'OPC' in this document will imply OPC UA. OPC Classic is not discussed in this document.

Following are the typical scenarios for embedding an OPC-enabled device into a project:

- Manually investigate (“browse”) the server’s Address Space looking for the data user need using a generic, GUI client (such as UaExpert from Unified Automation, or the FreeOpcUa covered in this chapter).
- Using References and Attributes, understand the format it is in, and the steps that may be needed to convert the data.
- Have a custom OPC client (integrated into the application) subscribe directly to data changes of the node that contains the desired data.

In a typical use case:

- The OPC server runs near the source of information (in industrial contexts, this means near the physical process – for example, on a PLC on a plant floor).
- Clients consume the data at run time (for example, logging into a database, or feeding it into another industrial process).

OPC-enabled applications can be composed: an industrial device may run an OPC client and feed the collected data into another physical process, while also exposing the latter by running an OPC server.

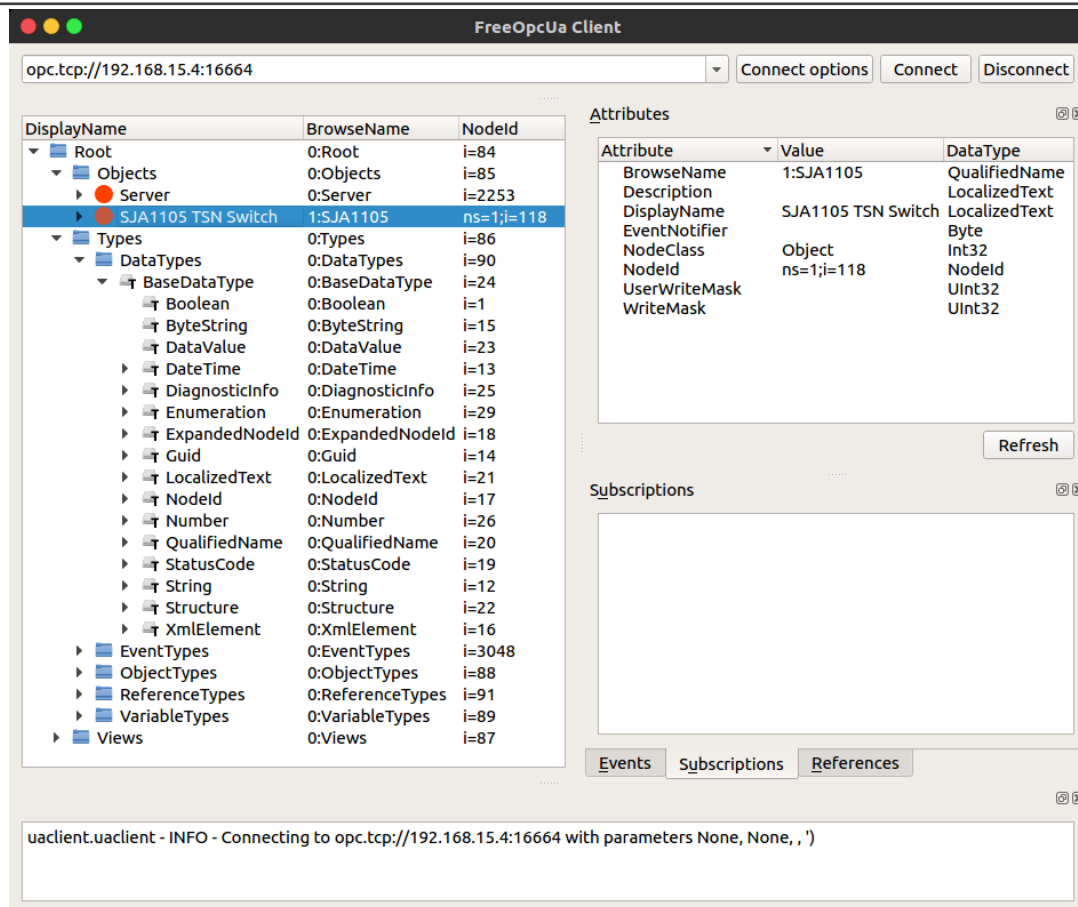
11.2 The node model

Data in an OPC server is structured in *Nodes*. The collection of all nodes that an OPC server exposes to its clients is known as an *Address Space*. Some nodes have a predefined meaning, while others have meaning that is unique to the *Information Model* of that specific OPC server.

Every Node has the following *Attributes*:

- an *ID* (unique)
- a *Class* (what type of node it is)
- a *BrowseName* (a string for machine use)
- a *DisplayName* (a string for human use)

Figure 36. OPC UA address space



Shown on the left-hand side of the figure is the *Address Space* (collection of information that the server makes available to clients) of the OPC server found at `opc.tcp://192.168.15.4:16664`.

Selected is a node with NodeID `ns=1;i=118`, BrowseName=`1:SJA1105` and of NodeClass `Object`.

The full path of the selected node is `0:Root,0:Objects,1:SJA1105`.

11.3 Node Namespaces

Namespaces are the means for separating multiple Information Models present in the same Address Space of a server.

- Nodes that do not have the `ns=` prefix as part of the NodeID have an implicit `ns=0;` prefix (are part of the namespace `zero`).
- Nodes in *namespace *0* have NodeID's pre-defined by the OPC UA standard. For example, the `0:Server` object, which holds self-describing information (capabilities, diagnostics, and vendor information), has a predefined NodeID of `ns=0;i=2253;`.

It is considered a good practice to not alter any of the nodes exposed in the *namespace *0*.

11.4 Node classes

OPC nodes have an inheritance model, based on their *NodeClass*.

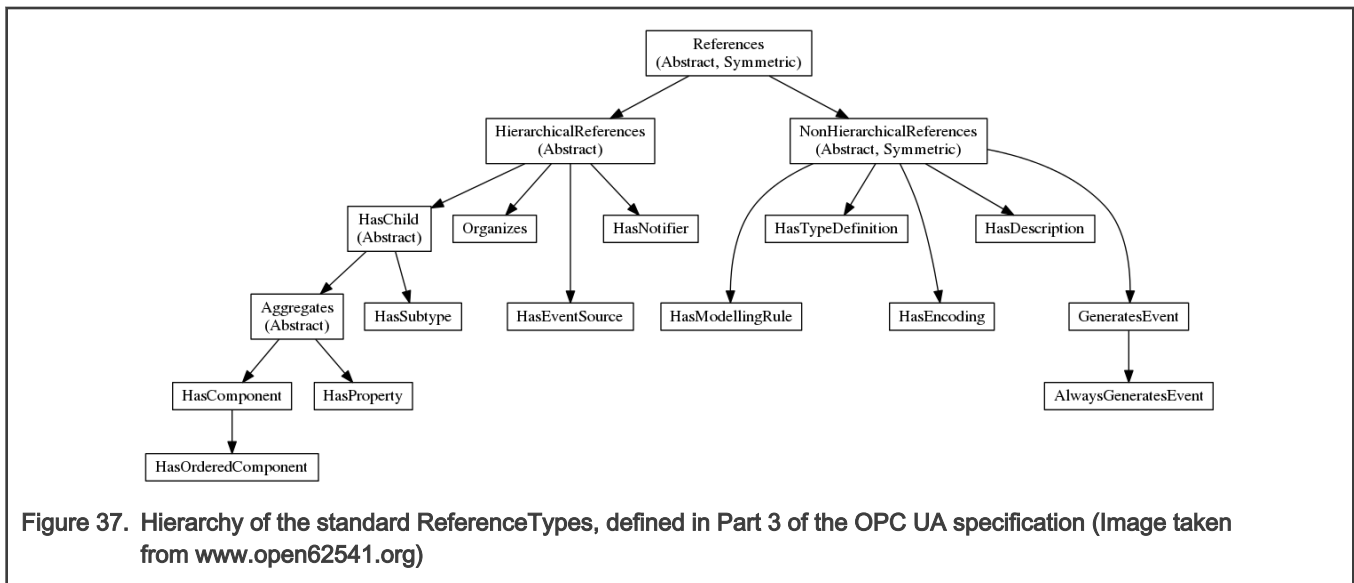
There are eight base node classes defined by the standard:

- Object
- Variable
- Method
- View
- ObjectType
- VariableType
- ReferenceType
- DataType

All nodes have the same base Attributes (inherited from the Node object), plus additional ones depending on their *NodeClass*.

11.5 Node graph and references

It may appear that nodes are only chained hierarchically, in a simple parent-child relationship. However, in reality nodes are chained in a complex directed graph, through *References* to other nodes.



In OPC, even ReferenceTypes are Nodes, and as such are structured hierarchically, as can be seen in the figure above.

The definitions of all OPC ReferenceTypes can be found under the `0:Root, 0:Types, 0:ReferenceTypes` path.

The semantics of OPC references can be enriched by creating custom ReferenceType nodes.

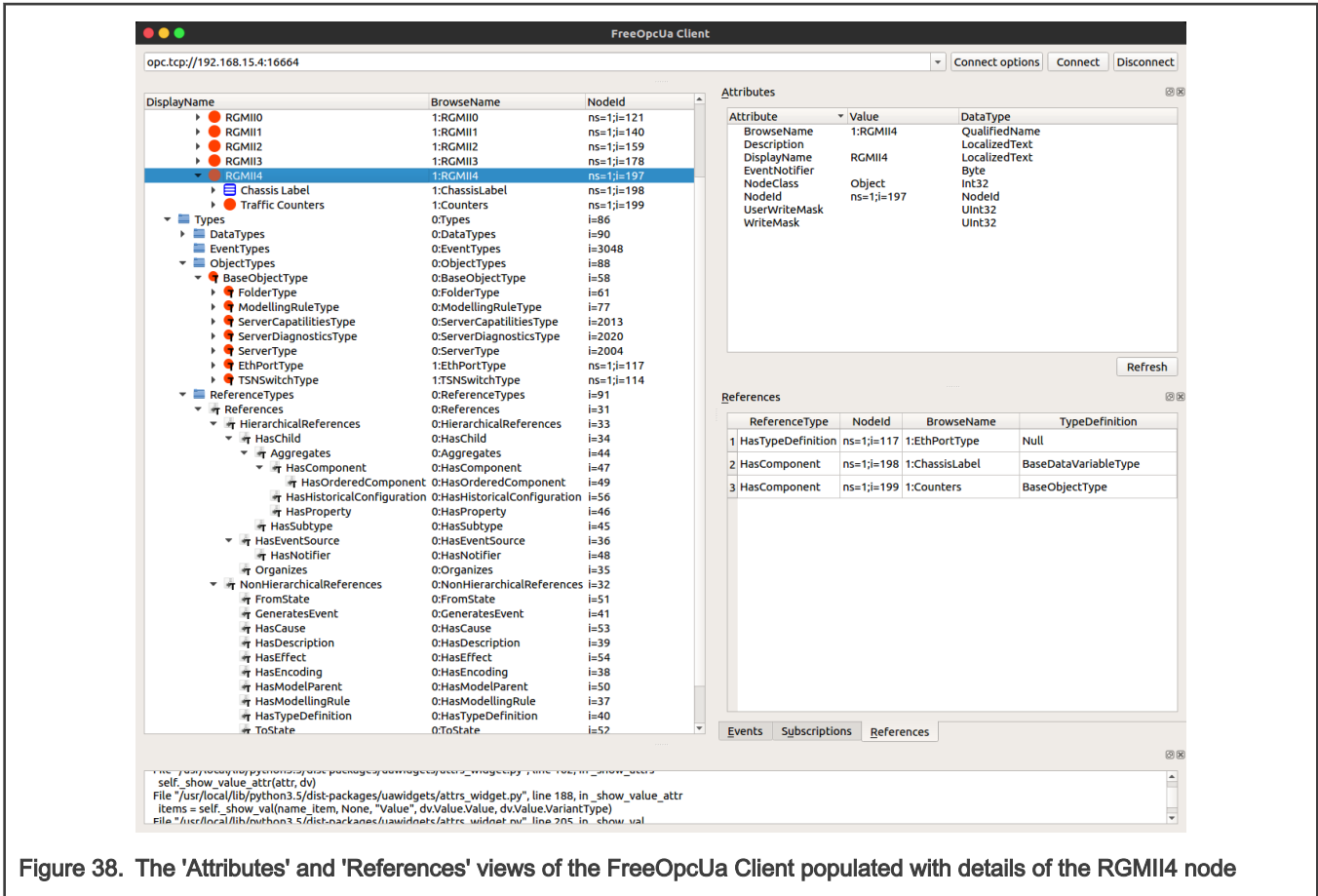


Figure 38. The 'Attributes' and 'References' views of the FreeOpcUa Client populated with details of the RGMII4 node

Selected in the Address Space is node ns=1;i=197. Conceptually, this represents one of the five Ethernet ports of the SJA1105 TSN switch.

Its NodeClass is Object, but it has a reference of type HasTypeDefinition to NodeId ns=1;i=117 which is 1:EthPortType. For this reason, the 1:RGMII4 node is of the custom ObjectType EthPortType.

11.6 Open62541

OpenIL integrates the Open62541 software stack (<https://open62541.org/>). This supports both server-side and client-side API for OPC UA applications. Only server-side capabilities of open62541 are being shown here.

Open62541 is distributed as a C-based dynamic library (libopen62541.so). The services run on pthreads, and the application code runs inside an event loop.

Enable open62541 in OpenIL with command "make menuconfig":

```
Target packages --->
  OPC UA tools --->
    [*] libopen62541
      Select build artefacts --->
        [*] Build example servers and clients
```

When building with the BR2_PACKAGE_LIBOPEN62541_BUILD_EXAMPLES flag, the following Open62541 example applications are included in the OpenIL target image:

- open62541_access_control_client
- open62541_access_control_server

- open62541_client
- open62541_client_async
- open62541_client_connect
- open62541_client_connectivitycheck_loop
- open62541_client_connect_loop
- open62541_client_subscription_loop
- open62541_custom_datatype_client
- open62541_custom_datatype_server
- open62541_server_ctt
- open62541_server_inheritance
- open62541_server_instantiation
- open62541_server_loglevel
- open62541_server_mainloop
- open62541_server_nodeset
- open62541_server_repeated_job
- open62541_tutorial_client_events
- open62541_tutorial_client_firststeps
- open62541_tutorial_datatypes
- open62541_tutorial_server_datasource
- open62541_tutorial_server_firststeps
- open62541_tutorial_server_method
- open62541_tutorial_server_monitoreditems
- open62541_tutorial_server_object
- open62541_tutorial_server_variable
- open62541_tutorial_server_variabletype

Chapter 12

FlexCAN

The following sections provide an introduction to the FlexCAN standard, details of the CAN bus, the Canopen communication system, details of how to integrate FlexCAN with OpenIL, and running a FlexCAN application.

12.1 Introduction

Both the LS1021A and LS1028A boards have the FlexCAN module. The FlexCAN module is a communication controller implementing the CAN protocol according to the CAN 2.0 B protocol specification. The main sub-blocks implemented in the FlexCAN module include an associated memory for storing message buffers, Receive (Rx) Global Mask registers, Receive Individual Mask registers, Receive FIFO filters, and Receive FIFO ID filters. A general block diagram is shown in the following figure. The functions of these submodules are described in subsequent sections.

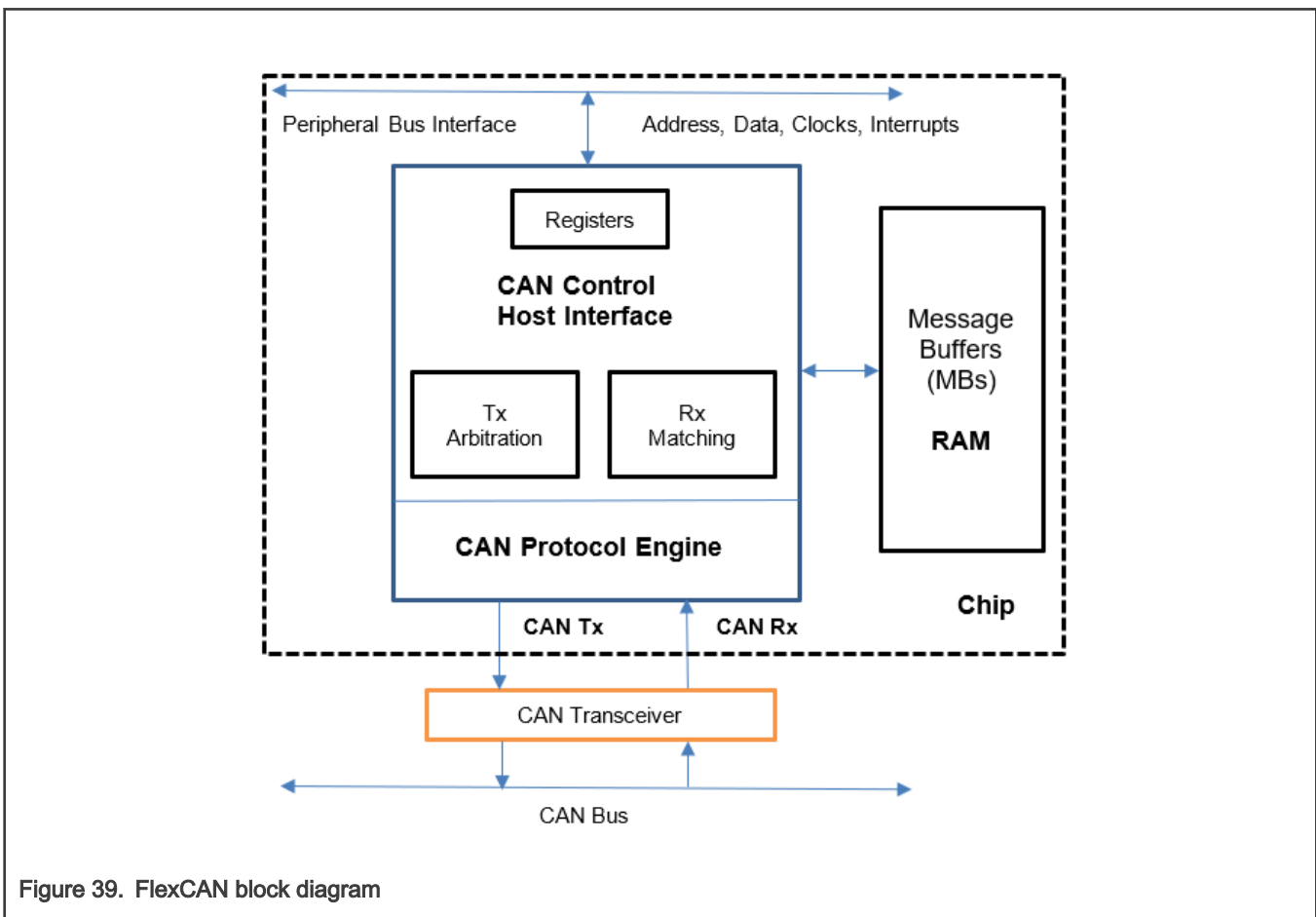


Figure 39. FlexCAN block diagram

12.1.1 CAN bus

CAN (Controller Area Network) is a serial bus system. A CAN bus is a robust [vehicle bus](#) standard designed to allow [microcontrollers](#) and devices to communicate with each other in applications without a [host computer](#). Bosch published several versions of the CAN specification and the latest is CAN 2.0 published in 1991. This specification has two parts; part A is for the standard format with an 11-bit identifier, and part B is for the extended format with a 29-bit identifier. A CAN device that uses 11-bit identifiers is commonly called CAN 2.0A and a CAN device that uses 29-bit identifiers is commonly called CAN 2.0B.

CAN is a [multi-master serial bus](#) standard for connecting Electronic Control Units [ECUs] also known as nodes. Two or more nodes are required on the CAN network to communicate. The complexity of the node can range from a simple I/O device up to

an embedded computer with a CAN interface and sophisticated software. The node may also be a gateway allowing a standard computer to communicate over a USB or Ethernet port to the devices on a CAN network. All nodes are connected to each other through a two wire bus. The wires are a twisted pair with a 120 Ω (nominal) characteristic impedance.

High speed CAN signaling drives the CAN high wire towards 5 V and the CAN low wire towards 0 V when transmitting a dominant (0), and does not drive either wire when transmitting a recessive (1). The dominant differential voltage is a nominal 2 V. The termination resistor passively returns the two wires to a nominal differential voltage of 0 V. The dominant common mode voltage must be within 1.5 to 3.5 V of common and the recessive common mode voltage must be within +/-12 of common.

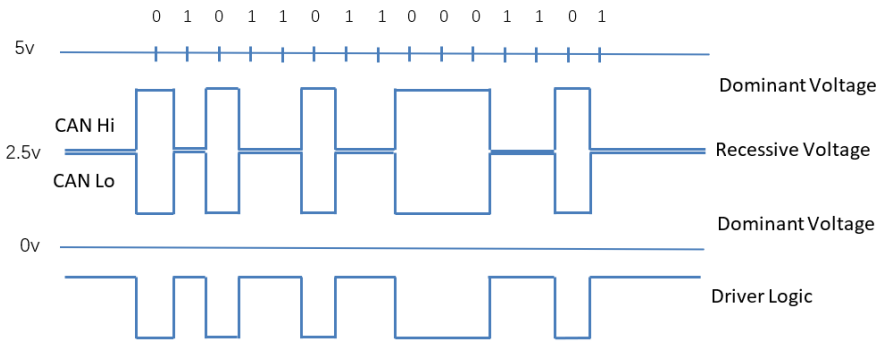


Figure 40. High speed CAN signaling

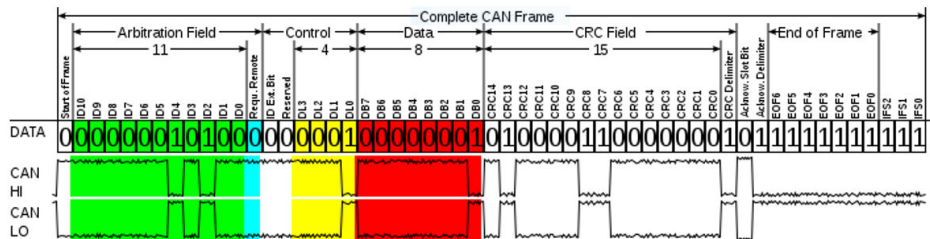


Figure 41. Base frame format

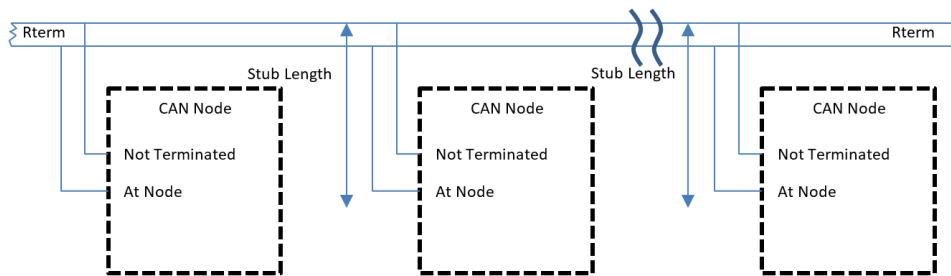


Figure 42. High speed CAN network

12.1.2 CANopen

CANopen is a CAN-based communication system. It comprises higher-layer protocols and profile specifications. CANopen has been developed as a standardized embedded network with highly flexible configuration capabilities. Today it is used in various application fields, such as medical equipment, off-road vehicles, maritime electronics, railway applications, or building automation.

CANopen provides several communication objects, which enable device designers to implement desired network behavior into a device. With these communication objects, device designers can offer devices that can communicate process data, indicate device-internal error conditions or influence and control the network behavior. As CANopen defines the internal device structure, the system designer knows exactly how to access a CANopen device and how to adjust the intended device behavior.

- **CANopen lower layers**

CANopen is based on a data link layer according to ISO 11898-1. The CANopen bit timing is specified in CiA 301 and allows the adjustment of data rates from 10 kbit/s to 1000 kbit/s. Although all specified CAN-ID addressing schemata are based on the 11-bit CAN-ID, CANopen supports the 29-bit CAN-ID as well. Nevertheless, CANopen does not exclude other physical layer options.

- **Internal device architecture**

A CANopen device consists of three logical parts. The CANopen protocol stack handles the communication via the CAN network. The application software provides the internal control functionality. The CANopen object dictionary interfaces the protocol as well as the application software. It contains indices for all used data types and stores all communication and application parameters. The CANopen object dictionary is most important for CANopen device configuration and diagnostics.

- **CANopen protocols**

- SDO protocol
- PDO protocol
- NMT protocol
- Special function protocols
- Error control protocols

The following figure shows the CANopen architecture.

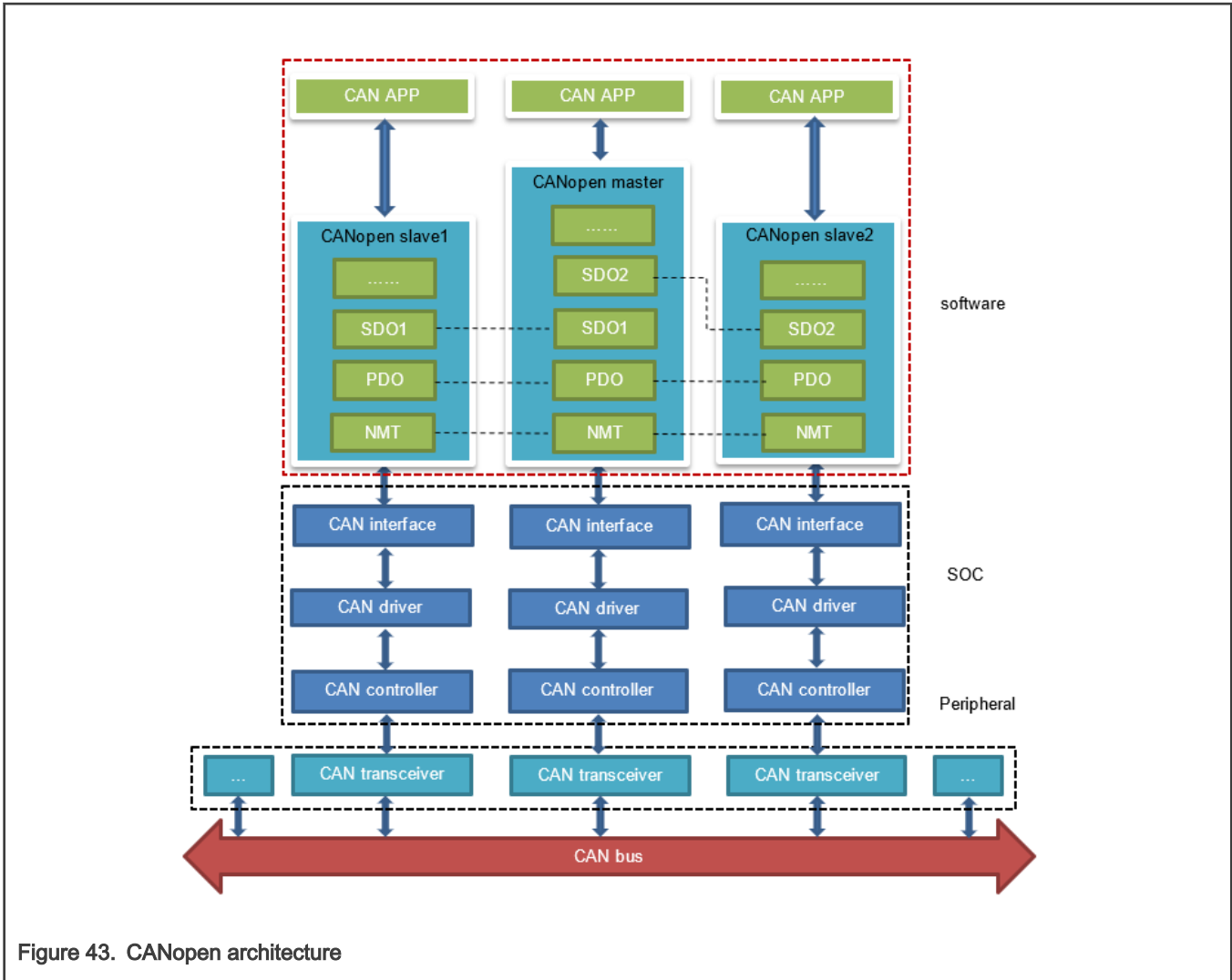


Figure 43. CANopen architecture

12.2 FlexCAN integration in OpenIL

For LS1021A, there are four CAN controllers. Two CAN controllers (CAN3 and CAN4) are used to communicate with each other. CAN4 is assigned to core0, which runs Linux and CANOpen as master node, whereas CAN3 is assigned to core1, which runs the baremetal and CANOpen as slave node. For LS1028A, there are two CAN controllers, CAN1 and CAN2, and both of them are used in LS1028ARDB board.

12.2.1 LS1021AIOT CAN resource allocation

This section describes steps for assigning CAN4 to Linux and CAN3 to baremetal core, and how to change or configure it. These examples assume that CAN1 and CAN2 are not enabled, and the pins of CAN1 and CAN2 are used by other IPs.

1. Assigning CAN4 to Linux

In Linux, the port is allocated through the DTS file. DTS file path is `industry-linux/arch/arm/boot/dts/ls1021a-iot.dts`. Content related to CAN ports is as follows:

```

/* CAN3 port */
&can2
{
    status = "disabled";
};
    
```

```

/* CAN4 port */
    &can3
    {
        status = "okay";
    };

```

2. Assigning CAN3 to Baremetal

In baremetal, the port is allocated through the `flexcan.c` file. The `flexcan.c` path is `industry-uboot/drivers/flexcan/flexcan.c`. In this file, user need to define the following variables:

- a. `struct can_bittiming_t flexcan3_bittiming = CAN_BITTIM_INIT(CAN_500K);`

NOTE

Set bit timing and baud rate (500K) of the CAN port.

- b. `struct can_ctrlmode_t flexcan3_ctrlmode`

```

struct can_ctrlmode_t flexcan3_ctrlmode =
{
    .loopmode = 0, /* Indicates whether the loop mode is enabled */
    .listenonly = 0, /* Indicates whether the only-listen mode is enabled */
    .samples = 0,
    .err_report = 1,
};

```

- c. `struct can_init_t flexcan3`

```

struct can_init_t flexcan3 =
{
    .canx = CAN3, /* Specify CAN port */
    .bt = &flexcan3_bittiming,
    .ctrlmode = &flexcan3_ctrlmode,
    .reg_ctrl_default = 0,
    .reg_esr = 0
};

```

- d. Optional parameters

- **CAN port**

```

#define CAN3 ((struct can_module *)CAN3_BASE)
#define CAN4 ((struct can_module *)CAN4_BASE)

```

- **Baud rate**

```

#define CAN_1000K 10
#define CAN_500K 20
#define CAN_250K 40
#define CAN_200K 50
#define CAN_125K 80
#define CAN_100K 100
#define CAN_50K 200
#define CAN_20K 500
#define CAN_10K 1000
#define CAN_5K 2000

```

12.2.2 Introducing the function of CAN example code

CAN example code supports the CANopen protocol. It mainly implements three parts of functions: network manage function (NMT protocol), service data transmission function (SDO protocol), and process data transmission function (PDO protocol). NMT protocol can manage and monitor slave nodes, include heart beat message. SDO protocol can transmit single or block data. The PDO protocol can transmit process data that requires real time.

CAN example calls the CANopen interfaces, described in the table below:

Table 48. CAN Net APIs and their description

| API name (type) | Description |
|--|---|
| UNS8 canReceive_driver (CAN_HANDLE fd0, Message * m) | Socketcan receive CAN messages <ul style="list-style-type: none"> fd0 – socketcan handle m – receive buffer |
| UNS8 canSend_driver (CAN_HANDLE fd0, Message const * m) | Socketcan send CAN messages <ul style="list-style-type: none"> fd0 – socketcan handle m – CAN message to be sent |
| void setNodeid(CO_Data* d, UNS8 nodeid) | Set this node id value. <ul style="list-style-type: none"> d – object dictionary nodeid – id value (up to 127) |
| UNS8 setState(CO_Data* d, e_nodeState newState) | Set node state <ul style="list-style-type: none"> d – object dictionary newState – The state that needs to be set Returns 0 if ok, > 0 on error |
| void canDispatch(CO_Data* d, Message *m) | CANopen handles data frames that CAN receive. <ul style="list-style-type: none"> d – object dictionary m – Received CAN message |
| void timerForCan(void) | CANopen virtual clock counter. |
| UNS8 sendPDOrequest (CO_Data * d, UNS16 RPDOIndex) | Master node requests slave node to feedback specified data. <ul style="list-style-type: none"> d – object dictionary RPDOIndex – index value of specified data |
| UNS8 readNetworkDictCallback (CO_Data* d, UNS8 nodeid, UNS16 index, UNS8 subIndex, UNS8 dataType, SDOCallback_t Callback, UNS8 useBlockMode) | The master node gets the specified data from the slave node. <ul style="list-style-type: none"> d – object dictionary nodeid – the id value of slave node index – the index value of the specified data subIndex – the subindex value of the specified data |

Table continues on the next page...

Table 48. CAN Net APIs and their description (continued)

| API name (type) | Description |
|--|--|
| | <ul style="list-style-type: none"> • dataType – the data type of the specified data • Callback – callback function • useBlockMode – specifies whether it is a block transmission |
| UNS8 writeNetworkDictCallback (CO_Data* d, UNS8 nodeId, UNS16 index, UNS8 subIndex, UNS32 count, UNS8 dataType, void *data, SDOCallback_t Callback, UNS8 useBlockMode) | The master node sets the specified data to the slave node. <ul style="list-style-type: none"> • d – object dictionary • nodeId – the id value of slave node • index – the index value of the specified data • subIndex – the subindex value of the specified data • count – the length of the specified data • dataType – the data type of the specified data • Callback – callback function • useBlockMode – specifies whether it is a block transmission |

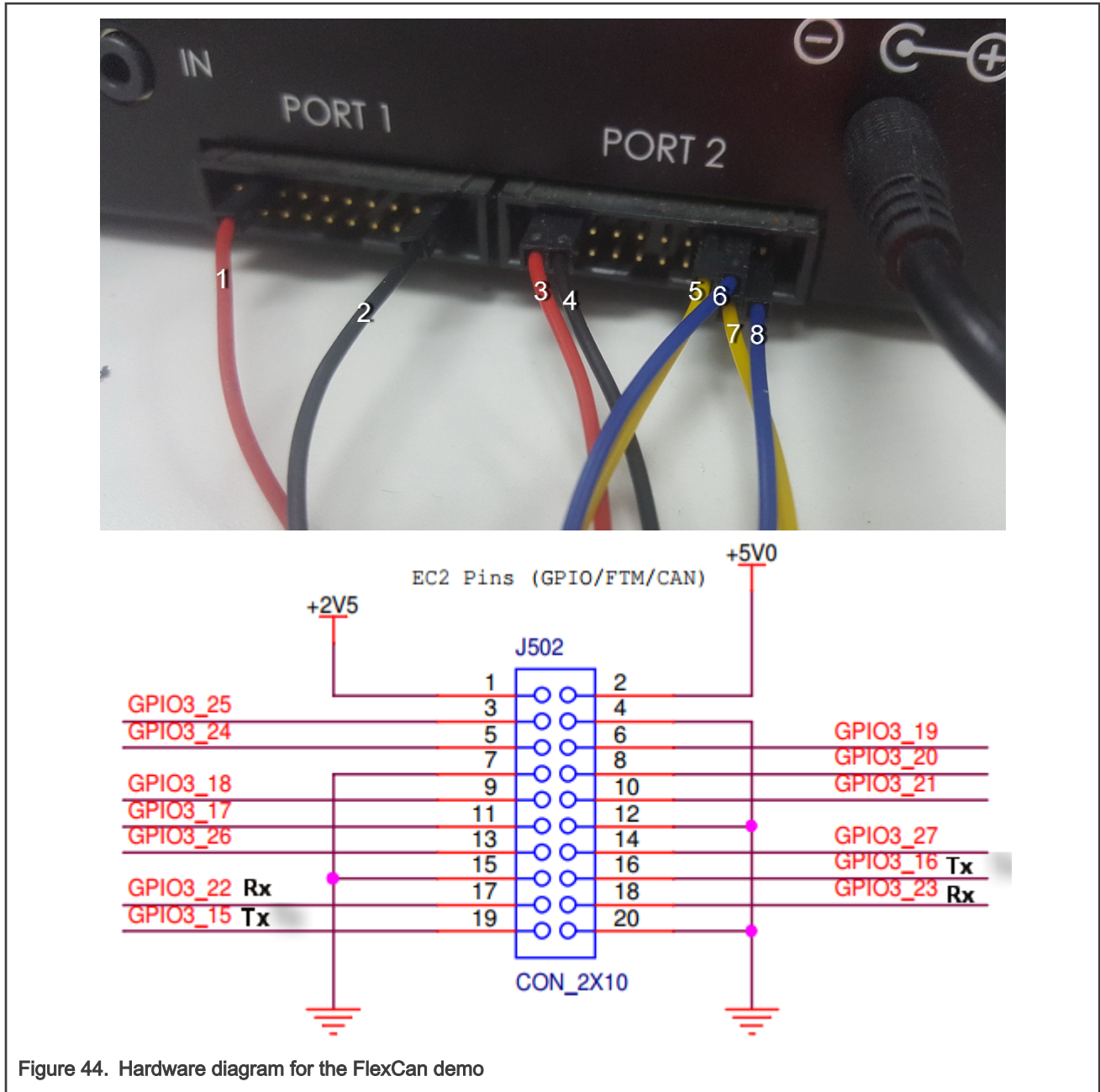
12.3 Running a CAN application

The following sections describe the hardware and software preparation steps for running a CAN application. The hardware preparation is described separately for the LS1021A-IoT and LS1028ARDB, but the sections [Compiling the CANopen-app binary for the master node](#), [Running the CANopen application](#), and [Running the Socketcan commands](#) are applicable to both LS1021A-IoT and LS1028A platforms.

12.3.1 Hardware preparation for LS1021-IoT

For LS1021-IoT, the list of hardware required for implementing the FlexCAN demo is as follows:

- LS1021A-IoT boards
- Two CAN hardware interfaces (for example, CAN3 and CAN4 for LS1021A-IoT)
- Two CAN transceivers (for example: TJA1050)



NOTE

- Line1 and line3 are 5.0 V.
- Line2 and line4 are GND.
- Line5 is CAN3 Tx.
- Line6 is CAN3 Rx.
- Line7 is CAN4 Rx.
- Line8 is CAN4 Tx.

12.3.2 Hardware preparation for LS1028ARDB

For LS1028ARDB, below hardware is required:

- LS1028ARDB board
- Two cables to connect CAN1 and CAN.

The hardware connection diagram is as shown in the following figure



Figure 45. Physical connection for CAN using LS1028ARDB

12.3.3 Compiling the CANopen-app binary for the master node

This section describes the procedure for compiling the CANopen-app binary for the master node, for both LS1021A and LS1028A platforms.

CANopen application's name is **CANopen-app**. Perform the steps listed below to compile Canopen-app as linux command to the `target/usr/bin` directory.

1. Configure cross-toolchain on user host environment.
2. Use the commands below:

```
$ git clone https://github.com/openil/openil.git
$ cd openil # checkout to OpenIL-201904
$ make nxp_ls1021aiot_baremetal_can_defconfig
# or
$ make nxp_ls1028ardb-64b_defconfig
$ make
```

3. The generated openil image file is in the `output/images/` directory.
4. Download the `sdcard.img` image file to the SD card:

In U-Boot mode, first run the `tftp` command for downloading `sdcard.img` to the buffer. Then, run the `mmc` command for downloading the `sdcard.img` to SD card.

NOTE

Make sure to enable the below options before building the image:

```
$ make menuconfig
Target packages --->
  Libraries --->
    Networking --->
      [*] canfestival
          driver (socket) --->
            (--SDO_MAX_LENGTH_TRANSFER=512 --SDO_BLOCK_SIZE=75
             --SDO_MAX_SIMULTANEOUS_TRANSFERS=1) additional
configure options
  [*] install examples
  [*] libsocketcan
Networking applications --->
  [*] can-utils
  [*] iproute2
```

NOTE

- The following options are displayed only when the `canfestival` option is set to Y.
- Linux uses the SocketCAN interface, so the `driver` option selects the socket.
- The following `additional configure options` can be configured in the `config.h` file of CANopen:

Parameter description:

- `--SDO_MAX_LENGTH_TRANSFER`: Sets buffer size of SDO protocol.
- `--SDO_BLOCK_SIZE`: Sets the maximum number of frames that can be sent by SDO block transport protocol.
- `--SDO_MAX_SIMULTANEOUS_TRANSFERS`: Sets the number of SDO modules.
- Install binary application to openil filesystem, if the `install examples` option is set to Y.

12.3.4 Running the CANopen application

This section describes the procedure for running the CANopen-app application. Only the LS1021A platforms support this application.

1. First, boot the LS1021A-IoT board.
2. Waiting for the baremetal core to output below information:

```
Note: the CANopen protocol starts to run!
=>
```

3. Then, run the `CANopen-app` command in any directory in Linux prompt. While executing this command, first run the test code.
4. After the test code is completed, user can implement the required instructions. The command `CANopen-app` execution process steps are described below:
 - a. First, indicate whether the CAN interface has opened successfully. All commands are dynamically registered. Then, indicate whether the command was registered successfully.

- **Command registration log**

```
Command Registration Log:
[root@OpenIL:~]# CANopen-app
[ 80.899975] IPv6: ADDRCONF(NETDEV_CHANGE): can0: link becomes ready
```



```
Note: open the CAN interface successfully!
"can_quit" command: register OK!
"setState" command: register OK!
"showPdo" command: register OK!
"requestPdo" command: register OK!
"sdo" command: register OK!
"" command: register OK!
"test_startM" command: register OK!
"test_sdoSingle" command: register OK!
"test_sdoSingleW" command: register OK!
"test_sdoBlock" command: register OK!
"test_showPdoCyc" command: register OK!
"test_showpdoreq" command: register OK!
"test_requestpdo" command: register OK!
```

b. There are nine test code in total, tests 1 to 9. Test code details are shown in the test log.

- **Test code log** “---test---” indicates that the test code begins.
- Firstly, the execution rights of the SDO and PDO protocol are explained.
- The **tests 1~4** are SDO protocol test code. After starting the CANopen master node, it automatically enters into initialization and pre-operation mode.
- The **test5** is a test code that master node enters the operation mode and starts all slave nodes.
- The **tests 6~9** are PDO protocol test code.

Test Code Log:

```
----- test -----
Note: Test code start execute...
      SDO protocol is valid in preoperation mode, but PDO protocol is invalid!
      SDO and PDO protocol are both valid in operation mode!
      Console is invalid when testing!
-----

Note: test1--Read slave node single data by SDO.
Note: master node initialization is complete!
Note: master node entry into the preOperation mode!
Note: Alarm timer is running!
Note: slave node "0x02" entry into "Initialisation" state!
-----

Note: test2--Write 0x2CD5 to slave node by SDO.
Note: Master write a data to 0x02 node successfully.
-----

Note: test3--Read slave node single data by SDO again.
Note: reveived data is 0x2CD5
-----

Note: test4--Read slave node block data by SDO.
----- text -----
Note: reveived string ==>
CANopen is a CAN-based communication system.
It comprises higher-layer protocols and profile specifications.
CANopen has been developed as a standardized embedded network with highly flexible
configuration capabilities.
It was designed originally for motion-oriented machine control systems, such as
handling systems.
Today it is used in various application fields, such as medical equipment, off-road
vehicles, maritime electronics, railway applications, or building automation.
-----

Note: test5--Master node entry operation mode, and start slave nodes!
```

```

Note: master node entry into the operation mode,and start all slave nodes!
-----
Note: test6--Master node show requested PDO data.
Note: Rpdo4 data is "      "
-----
Note: test7--Master node request PDO data.
-----
Note: test8--Master node show requested PDO data.
Note: Rpdo4 data is "require"
Note: slave node "0x02" entry into "Operational" state!
-----
Note: test9--Master node show received cycle PDO data.
Note: Rpdo2 data is "  cycle"
-----

```

NOTE

tests 1 to 9 are not commands.

- c. After the test code is executed, it automatically prints the list of commands. Num00~06 are normal commands. After executing these instructions without parameters, the instruction usage is displayed. Num08~14 are test commands. All test commands except num10 have no parameters. Argument of Num10 is a 16-bit integer.
 - Now the user can execute any command in the command list.

Command List

```

Command List:
-----
num  |      command      |      introduction
-----
00   |  ctrl_quit        |  console thread exit!
-----
01   |  help             |  command list
-----
02   |  can_quit         |  exit CANopen thread
-----
03   |  setState         |  set the CANopen node state
-----
04   |  showPdo          |  show the data of RPDO
-----
05   |  requestPdo       |  request the data of RPDO
-----
06   |  sdo              |  read/write one entry by SDO protocol
-----
07   |                  |
-----
08   |  test_startM      |  test -- Start master
-----
09   |  test_sdoSingle   |  test -- Read slave node single data
-----
10   |  test_sdoSingleW  |  test -- Write slave node single data
-----
11   |  test_sdoBlock    |  test -- Read slave node block data
-----
12   |  test_showPdoCyc |  test -- Show cycle PDO data
-----
13   |  test_showpdoreq |  test -- Show requested PDO data
-----
14   |  test_requestpdo  |  test -- Request PDO data
-----

```

```
Note: User can send command by console!
Note: Test code execution is complete!
```

Example: The following example shows the usage log after running the `sdo` command without any parameters.

```
SDO Command:
sdo
usage: sdo -type index subindex nodeid data
        type = "r"(read), "w"(write), "b"(block)
        index = 0~0xFFFF,unsigned short
        subindex = 0~0xFF,unsigned char
        nodeid = 1~127,unsigned char
        data = 0 ~ 0xFFFFFFFF
```

12.3.5 Running the Socketcan commands

This section describes the steps for running Socketcan commands that can be performed on either of the boards (LS1021A-IoT or LS1021ARDB). These commands are executed on Linux. The standard Socketcan commands are the following:

1. Open the can0 port.

```
$ ip link set can0 up
```

2. Close the can0 port.

```
$ ip link set can0 down
```

3. Set the baud rate to 500K for the can0 port

```
$ ip link set can0 type can bitrate 500000
```

4. Set can0 port to Loopback mode.

```
$ ip link set can0 type can loopback on
```

5. Send a message through can0. 002 (HEX) is node id, and this value must be 3 characters. 2288DD (HEX) is a message, and can take a value up to 8 bytes.

```
$ cansend can0 002#2288DD
```

6. Monitor can0 port and wait for receiving data.

```
$ candump can0
```

7. See can0 port details.

```
$ ip -details link show can0
```

NOTE

The third and fourth commands are valid when the state of can0 port is closed.

12.3.6 Testing CAN bus

Below is the sample code for testing the CAN bus on LS1028ARDB.

```
[root@OpenIL:~]# ip link set can0 down
[root@OpenIL:~]# ip link set can1 down
```

```
[root@OpenIL:~]# ip link set can0 type can loopback off
[root@OpenIL:~]# ip link set can1 type can loopback off
[root@OpenIL:~]# ip link set can0 type can bitrate 500000
[root@OpenIL:~]# ip link set can1 type can bitrate 500000
[root@OpenIL:~]# ip link set can0 up
[root@OpenIL:~]# ip link set can1 up
[root@OpenIL:~]# candump can0 &
[root@OpenIL:~]# candump can1 &
[root@OpenIL:~]# cansend can0 001#224466
  can0 001  [3] 22 44 66
[root@OpenIL:~]#   can1 001  [3] 22 44 66
[root@OpenIL:~]# cansend can1 001#224466
  can0 001  [3] 22 44 66
  can1 001  [3] 22 44 66
[root@OpenIL:~]# cansend can1 001#113355
  can0 001  [3] 11 33 55
  can1 001  [3] 11 33 55
[root@OpenIL:~]# cansend can0 000#224466
  can0 000  [3] 22 44 66
```

Chapter 13

NFC

NFC click board is a mikroBUS™ add-on board with a versatile near field communications controller from NXP — the [PN7120 IC](#). NFC devices are used in contactless payment systems, electronic ticketing, smartcards, but also in retail and advertising — inexpensive NFC tags can be embedded into packaging labels, flyers or posters.

This board is fully compliant with NFC Forum specifications. This implies that users can use the full potential of NFC and its three distinct operating modes listed below:

1. Card emulation
2. Read/Write
3. P2P

13.1 Introduction

The NXP's PN7120 IC integrates an ARM™ Cortex-M0 MCU, which enables easier integration into designs, because it requires fewer resources from the host MCU. The integrated firmware provides all NFC protocols for performing the contactless communication in charge of the modulation, data processing, and error detection.

The board communicates with the target board MCU through the mikroBUS™ I2C interface, in compliance with NCI (NFC controller interface) 1.0 host protocols. RST and INT pins provide additional functionality. The board uses a 3.3V power supply.

13.2 PN7120 features

PN7120 IC embeds a new generation RF contactless front-end, supporting various transmission modes according to NFCIP-1 and NFCIP-2, ISO/IEC14443, ISO/IEC 15693, ISO/IEC 18000-3, MIFARE, and FeliCa specifications. It embeds an ARM Cortex-M0 microcontroller core loaded with the integrated firmware supporting the NCI 1.0 host communication.

13.3 Hardware preparation

Use the following hardware items for the NFC clickboard demo setup:

1. LS1028ARDB
2. NFC click board
3. NFC sample card (tag)

NOTE

Users need to insert the NFC click board into the LS1028ARDB mikroBUS1 slot.

13.4 Software preparation

In order to support NFC click board, use the following steps:

1. In OpenIL environment, use the command `make menuconfig` to enable the below options:

```
$make menuconfig
Target packages --->
  Hardware handling --->
    NXP QorIQ libraries --->
      [*] qoriq-libnfc-nci
```

- In Linux kernel environment, make sure the below options are enabled:

```
$make linux-menuconfig
[*] Networking support --->
  <M>  NFC subsystem support  --->
      Near Field Communication (NFC) devices  --->
          <M> NXP PN5XX based driver
```

NOTE

The **NXP PN5XX based driver** only supports the Module mode.

- Use the `make` command to create the images.

13.5 Testing the NFC click board

Use the following steps for testing the NFC Clickboard:

- Install NFC driver module

```
[root@OpenIL:~]# modprobe pn5xx_i2c.ko
```

- The following log appears at the console after the above command is successful. The error information can be ignored in this case.

```
[root@OpenIL:~]# insmod /lib/modules/4.14.47-ipipe/kernel/[ 195.547601] random: crng init
done
[ 195.551016] random: 5 urandom warning(s) missed due to ratelimiting
[root@OpenIL:~]# insmod /lib/modules/4.14.47-ipipe/kernel/drivers/misc/nxp-pn5xx
/pn5xx_i2c.ko
[ 777.503246] pn54x_dev_init
[ 777.506048] pn54x_probe
[ 777.508523] pn544 7-0028: FIRM GPIO <OPTIONAL> error getting from OF node
[ 777.515344] pn544 7-0028: CLKREQ GPIO <OPTIONAL> error getting from OF node
[ 777.522347] pn544 7-0028: 7-0028 supply nxp,pn54x-pvdd not found, using dummy regulator
[ 777.530424] pn544 7-0028: 7-0028 supply nxp,pn54x-vbat not found, using dummy regulator
[ 777.538490] pn544 7-0028: 7-0028 supply nxp,pn54x-pmuvcc not found, using dummy regulato
r
[ 777.546723] pn544 7-0028: 7-0028 supply nxp,pn54x-sevdd not found, using dummy regulator
```

- Run the `nfcDemoApp` application:

```
[root@OpenIL:~]# nfcDemoApp poll
```

```
[root@OpenIL:~]# nfcDemoApp poll
#####
##                               NFC demo                               ##
#####
##                               Poll mode activated                       [ 1251.20807
1] pn54x_dev_open : 10,55
##
####[ 1251.212807] pn54x_dev_ioctl, cmd=1074063617, arg=1
#####[ 1251.219006] pn544_enable power on
#####
... press enter to quit ...

[ 1251.431597] pn54x_dev_ioctl, cmd=1074063617, arg=0
[ 1251.436416] pn544_disable power off
[ 1251.647586] pn54x_dev_ioctl, cmd=1074063617, arg=1
[ 1251.652401] pn544_enable power on
NfcHcpX:8103
NfcHcpR:8180
NfcHcpX:810103020304
NfcHcpR:8180
NfcHcpX:81010143da67663bda6766
NfcHcpR:8180
NfcHcpX:810204
NfcHcpR:818000
Waiting for a Tag/Device...
```

- Put the NFC Sample Card (tag) on top of the NFC click board:

```
Waiting for a Tag/Device...

NFC Tag Found

Type :          'Type A - Mifare UL'
NFCID1 :        '04 67 66 D2 9C 39 81 '
Record Found :
                NDEF Content Max size :   '868 bytes'
                NDEF Actual Content size :  '29 bytes'
                ReadOnly :                 'FALSE'
Read NDEF URL Error

                29 bytes of NDEF data received :
                D1 01 19 55 01 6E 78 70 2E 63 6F 6D 2F 64 65 6D 6F 62 6F 61 72 64 2F 4F 4D
35 35 37 38

NFC Tag Lost

Waiting for a Tag/Device...
```

Display of the above information indicates successful card reading.

Chapter 14

BLE

This chapter introduces the features of the BLE P click board and how to use it on NXP's LS1028A reference design board (RDB)

14.1 Introduction

BLE P click carries the nRF8001 IC that allows user to add Bluetooth 4.0 to user's device. The click communicates with the target board MCU through mikroBUS™ SPI (CS, SCK, MISO, MOSI), RDY and ACT lines, and runs on 3.3 V power supply.

BLE P click features a PCB trace antenna, designed for the 2400 MHz to 2483.5 MHz frequency band. The maximum device range is up to 40 meters in open space.

14.2 Features

Following are the features provided by BLE P clickboard:

- nRF8001 Bluetooth low energy RF transceiver
 - 16 MHz crystal oscillator
 - Ultra-low peak current consumption <14 mA
 - Low current for connection-oriented profiles, typically 2 µA
- PCB trace antenna (2400-2483.5 MHz, up to 40 meters)
- BLE Android app
- Interface: SPI (CS, SCK, MISO, MOSI), RDY and ACT lines
- 3.3 V power supply

14.3 Hardware preparation

Use the following hardware items for the BLE P click board demo setup:

1. LS1028ARDB
2. BLE P Click board
3. Android phone (option)

The figure below depicts the hardware setup required for the demo:

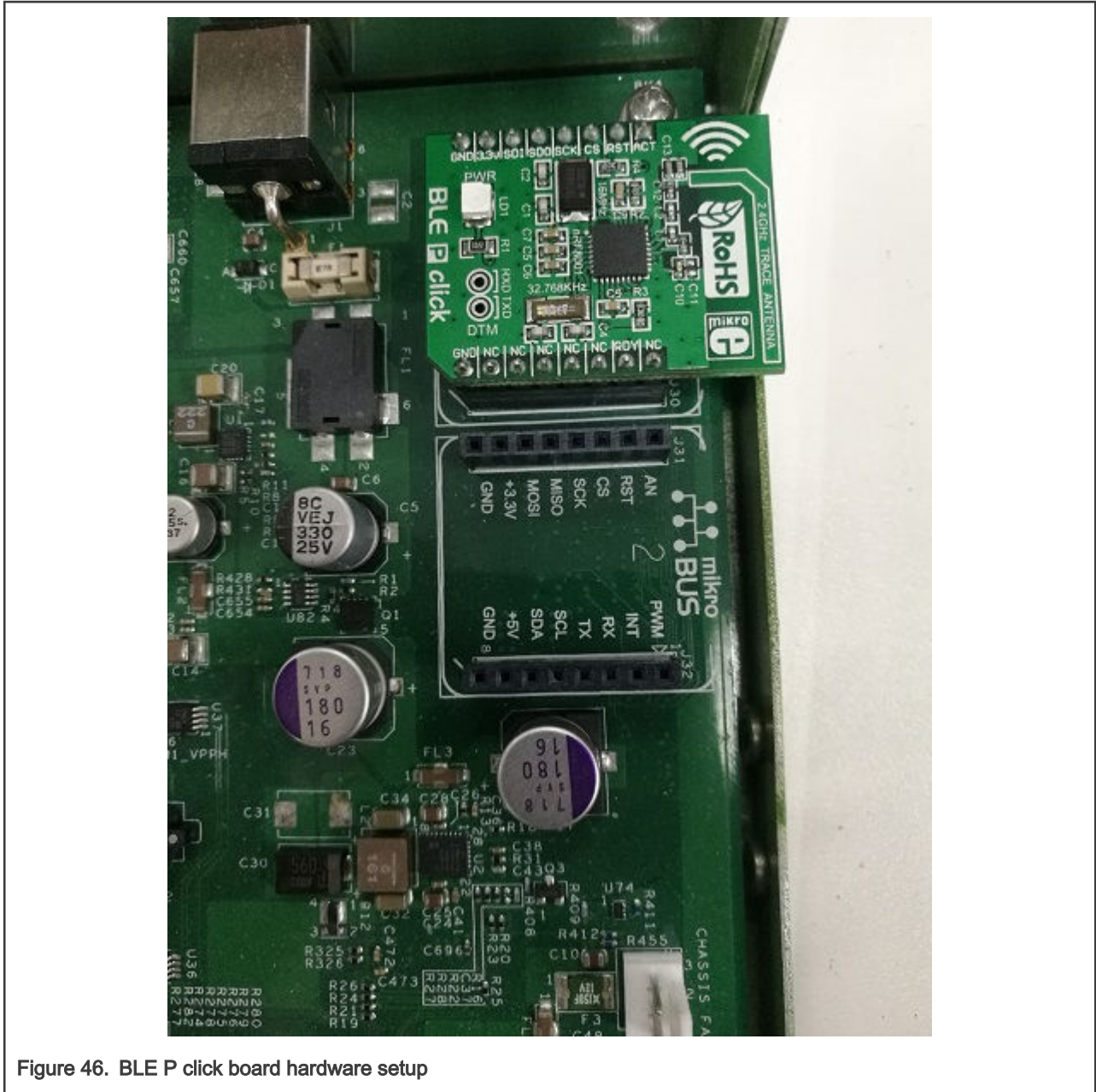


Figure 46. BLE P click board hardware setup

14.4 Software preparation

Use these steps for the BLE P click board demo software setup:

- Download the JUMA UART (Android app) by using the link: <https://apkpure.com/juma-uart/com.juma.UART>
- Then, run the steps below in order to support BLE P click board:
 1. In OpenIL environment, use the command `make menuconfig` to enable the below options:

```
$make menuconfig
Target packages --->
  Hardware handling --->
    [*] i2c-tools
```

```
NXP QorIQ libraries --->
[*] qorIQ-libblep
```

2. In Linux kernel environment, make sure the below options are enabled:

```
$make linux-menuconfig
Device Drivers --->
  SPI support --->
    <*> Freescale DSPI controller
    <*> User mode SPI device driver support
```

3. Use the `make` command to create the images.

NOTE

The above operation can be replaced by executing the `make nxp_ls1028ardbXXXX_defconfig` file.

14.5 Testing the BLE P click board

Use the following steps for testing the BLE P click board:

1. **Running the `blep_demo` application.**

The following log is displayed to indicate that the BLE P click board is initialized. At this time, user can scan for BLE P click board from user's mobile phone or user's computer's Bluetooth device. The name of the BLE P click board used is "MikroE"

```
root@OpenIL-Ubuntu:~# blep_demo
spi mode: 0x0
bits per word: 8
max speed: 500000 Hz (500 KHz)
Please input a command!
Event device started: Setup
Error:no
Start setup command
.....
Setup complete
Event device started: Standby
Advertising started : Tap Connect on the nRF UART app
Error:no
Send broadcast command successfully
```

2. **Connection log**

Connect the BLE P click board via mobile app. On successful connection, the following log is displayed. Thereafter, the application can communicate with the BLE P click board.

```

Evt Connected
Evt Pipe Status
Evt link connection interval changed
ConnectionInterval:0x0006
SlaveLatency:0x0000
SupervisionTimeout:0x01F4
Evt Pipe Status
Evt link connection interval changed
ConnectionInterval:0x0027
SlaveLatency:0x0000
SupervisionTimeout:0x01F4

```

3. Disconnection log

Click the **Disconnect** button of the Android APP to disconnect from the BLE P click board. The following log displays that the disconnection is successful:

```

Evt Disconnected
Advertising started : Tap Connect on the nRF UART app Send broadcast command successfully

```

4. Command line introduction

The **blep_demo** application supports four command lines: **devaddr**, **name=**, **version**, and **echo**.

a. devaddr

This command is used to obtain the MAC address of the BLE P click board. User can run this command at any time.

```

devaddr
Please input a command!
Device address:DC:E2:6C:17:07:45

```

b. name=

This command is used to set the Bluetooth name of the ble p click board when broadcasting. No spaces are required after the equal sign "=", and the content after the equal sign is the set name. The maximum length is 16 characters.

```

name=ble_demo
Name set. New name: ble_demo, 8
Please input a command!
Unknow event:0x00
Set local data successfully

```

c. version

This command is used to obtain the version of the BLE P click board. User can run this command at any time.

```
version
Please input a command!
Unknow event:0x00
Device version
Configuration ID:0x41
ACI protocol version:2
Current setup format:3
Setup ID:0x00
Configuration status:open(VM)
```

d. **echo**

This command is used to send a string to the Android app. This command should be executed after the connection is established. The maximum length is 20 characters.

The below log displays the message displayed after user tries to send a string when no connection is established:

```
echo hi
Please input a command!
Unknow event:0x00
ACI Evt Pipe Error: Pipe #9
Pipe Error Code: 0x83
Pipe Error Data: 0x00
Please connect the device before sending data
```

The below log is displayed when user sends a string after a connection is established:

```
echo hello,world!
Please input a command!
Unknow event:0x00
The number of data command buffer is 1
```

5. Receiving data

When the Android app sends a string:

```
DataReceivedEvent: hi.yugxdr
```

Chapter 15

BEE

This chapter introduces the features of the BEE Click Board and how to use it on LS1028ARDB.

15.1 Introduction

The BEE Click Board features the MRF24J40MA 2.4 GHz IEEE 802.15.4 radio transceiver module from Microchip. The click is designed to run on 3.3 V power supply only. It communicates with the target controller over an SPI interface.

15.2 Features

The features of the BEE Click Board are listed below:

- PCB antenna
- MRF24J40MA module
- Low current consumption (Tx 23 mA, Rx 19 mA, Sleep 2 μ A)
- ZigBee stack
- MiWi™ stack
- SPI Interface
- 3.3 V power supply

15.3 Hardware preparation

Use the following hardware items for the BEE Click Board demo setup:

- Two LS1028ARDB Boards
- Two BEE Click Boards

The figure below describes the hardware setup for the BEE Click Board.

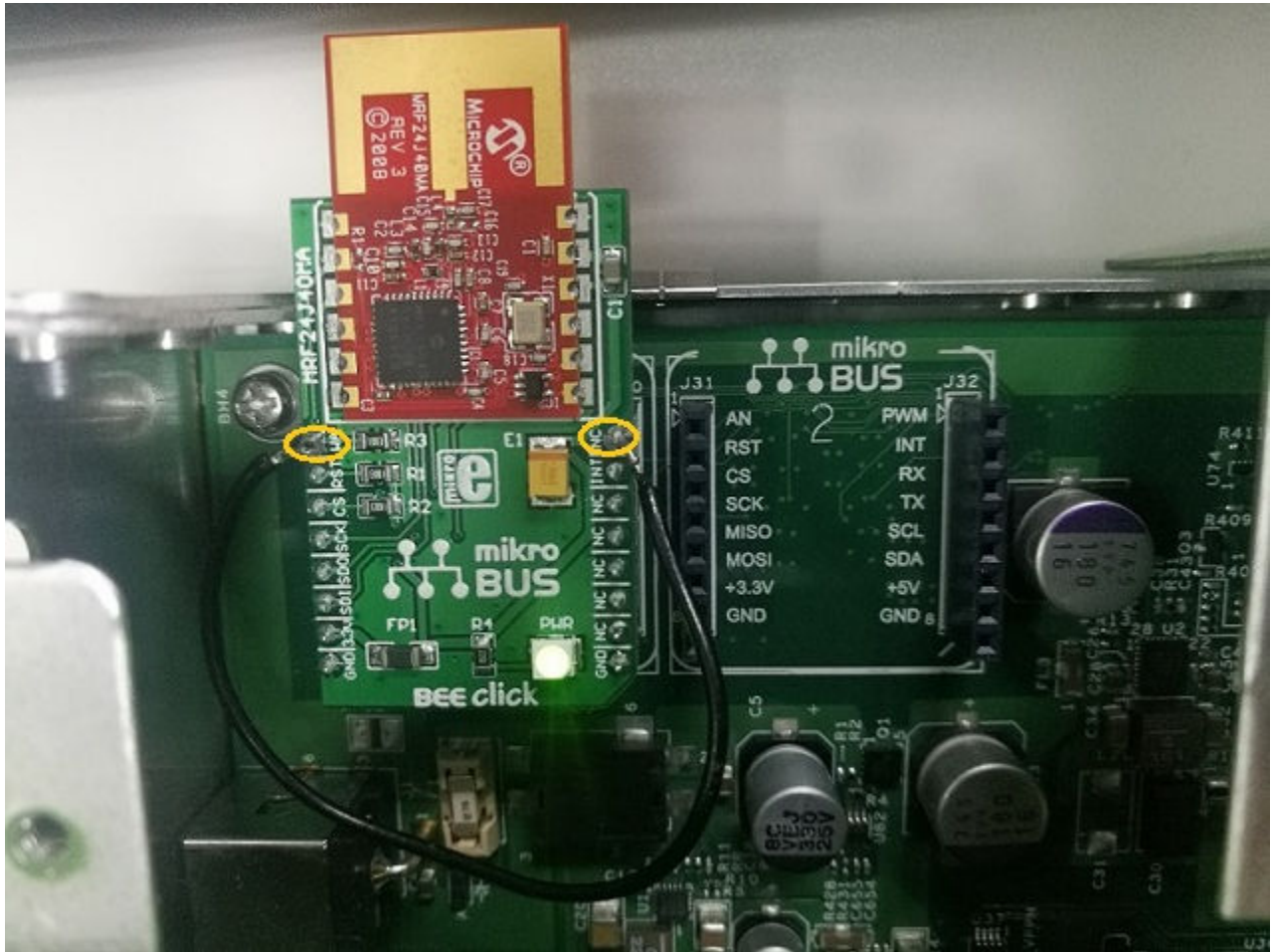


Figure 47. BEE Click Board hardware setup

NOTE

The WA pin of BEE Click Board connects with the NC pin.

15.4 Software preparation

In order to support BEE click board, use the following steps:

1. In OpenIL environment, use the command `make menuconfig` to enable the below options:

```
$make menuconfig
Target packages --->
Hardware handling --->
[*] i2c-tools
NXP QorIQ libraries --->
[*] qorIQ-libbee
```

2. In Linux kernel environment, make sure the below options are enabled:

```
$make linux-menuconfig
Device Drivers --->
SPI support --->
<*> Freescale DSPI controller
<*> User mode SPI device driver support
```

```

--*-- GPIO Support --->
[*] /sys/class/gpio/... (sysfs interface)
Memory mapped GPIO drivers --->
[*] MPC512x/MPC8xxx/QorIQ GPIO support

```

NOTE

The above operation can be replaced by executing the command: `make nxp_ls1028ardbXXXX_defconfig`.

3. Use the `make` command to create the images.

15.5 Testing the BEE click board

The test application `bee_demo` is created by using the BEE Click Board library. This application can transfer the file between two BEE Click Boards.

1. User need to create a file in any path. For example, `./samples/test.txt`.
2. First, start a server node by running the command below:

```
bee_demo -s -f=XXX
```

The command parameters are as below:

- **-s:** This device node acts as a server.
- **-f=XXX:** This parameter is valid only on the server node. XXX is the file path (relative or absolute) to be transferred.

```

root@OpenIL-Ubuntu-LS1028ARDB:~# ls
samples
root@OpenIL-Ubuntu-LS1028ARDB:~# bee_demo -s -f=./samples/test.txt
spi mode: 0x0
bits per word: 8
max speed: 500000 Hz (500 KHz)
BEE Click Board Demo.
This node is a server node.
Waiting for a client
Reading the content of the file

```

3. Start a client node on another LS1028ARDB by running the command `bee_demo -c`. In the above command, the parameter `-c` implies that this device node acts as a client. After receiving the file, the client node automatically exits. The received file is saved in the current path.

```

root@OpenIL-Ubuntu-LS1028ARDB:~# ls
samples
root@OpenIL-Ubuntu-LS1028ARDB:~# bee_demo -c
spi mode: 0x0
bits per word: 8
max speed: 500000 Hz (500 KHz)
BEE Click Board Demo.
This node is a client node.
Starting to get a file
Send the SEQ_REQ command.
Send the SEQ_START command.
Send the SEQ_START command.
root@OpenIL-Ubuntu-LS1028ARDB:~# ls
samples test.txt
root@OpenIL-Ubuntu-LS1028ARDB:~#

```

4. The following log is displayed to indicate that the server node finished sending a file.

```
Send the SEQ_INFO command.  
Start to send the file  
It's completed to send a file.
```


Chapter 16

4G-LTE Modem

16.1 Introduction

4G-LTE USB modem functionality is supported on NXP's LS1021-IoT, LS1012ARDB, LS1043ARDB, LS1046ARDB, and LS1028ARDB platforms.

16.2 Hardware preparation

A HuaWei E3372 USB Modem (as example) is used for the 4G-LTE network verification.

Insert this USB modem into USB slot of LS1012ARDB board (LS1012ARDB as example).

16.3 Software preparation

In order to support 4G-LTE modem, some options are needed.

1. In OpenIL environment, use command “make menuconfig” to enable the below options:

```
$make menuconfig
System configuration --->
    <*> /dev management (Dynamic using devtmpfs + eudev)

Target packages --->
    Hardware handling --->
        <*> usb_modeswitch
    <*> usb_modeswitch_data
```

2. In Linux kernel environment, make sure the below options are enabled:

```
$make linux-menuconfig
Device Drivers --->
    [*] Network device support --->
        <*> USB Network Adapters --->
            <*> Multi-purpose USB Networking Framework
            <*> CDC Ethernet support
            <*> CDC EEM support
            <*> CDC NCM support
```

Finally, update the images, refer to [Updating target images for LS1012ARDB](#).

16.4 Testing 4G USB modem link to the internet

Perform the following instructions to set up the 4G Modem .

After booting up the Linux kernel, an Ethernet interface will be identified, for example “eth2”.

1. Set eth2 connected to the network.

```
$ udhcpc -BFs -i eth2
```

2. Test the 4G modem link to the internet.

```
$ ping www.nxp.com
PING www.nxp.com (210.192.117.231): 56 data bytes
64 bytes from 210.192.117.231: seq=0 ttl=52 time=60.223 ms
```

```
64 bytes from 210.192.117.231: seq=1 ttl=52 time=95.076 ms
64 bytes from 210.192.117.231: seq=2 ttl=52 time=89.827 ms
64 bytes from 210.192.117.231: seq=3 ttl=52 time=84.694 ms
64 bytes from 210.192.117.231: seq=4 ttl=52 time=68.566 ms
```

Chapter 17

SELinux

SELinux is a security enhancement to Linux that allows users and administrators better access control.

In OpenIL, SELinux is enabled with Ubuntu root file system.

17.1 Running SELinux demo

This section describes the procedure for running the SELinux demo on NXP's LS1043ARDB-64bit and LS1046ARDB-64bit platforms.

17.1.1 Obtaining the image for SELinux

The SELinux can run on the NXP platforms:- LS1028ARDB, LS1043ARDB-64bit, and LS1046ARDB-64bit with Ubuntu file system.

Use the below commands for building these two platforms for the SELinux demo:

```
$ cd openil
$ make clean

$ make nxp_ls1043ardb-64b_ubuntu_defconfig # for ls1043ardb-64b platform
# or
$ make nxp_ls1046ardb-64b_ubuntu_defconfig # for ls1046ardb-64b platform
# or
$ make nxp_ls1028ardb-64b_ubuntu_defconfig # for ls1028ardb-64b platform

$ make
# or make with a log
$ make 2>&1 | tee build.log
```

17.1.2 Installing basic packages

Install the following basic packages before running the SELinux demo:

1. Basic packages:

- \$ apt-get update
- \$ apt-get install dpkg
- \$ apt-get install vim
- \$ apt-get install wget
- \$ apt-get install bzip2
- \$ apt-get install patch
- \$ apt-get install bison
- \$ apt-get install flex
- \$ apt-get install xz-utils
- \$ apt-get install auditd
- \$ apt-get install ssh
- \$ apt-get install apache2
- apt-get install policycoreutils

- `$ apt-get install selinux-utils`
 - `$ apt-get install selinux-basics`
2. Reboot the board to u-boot prompt, add parameters "security=selinux selinux=1 enforcing=0" to bootargs (ls1028ardb as example):

```
=> setenv bootcmd 'setenv bootargs root=/dev/mmcbk0p2 rootwait rw earlycon=uart8250,0x21c0500
console=ttyS0,115200 cma=256M video=1920x1080-32@60 security=selinux selinux=1
enforcing=0;mmcinfo;fatload mmc 0:1 ${dp_load} ${dp_file}; hdp load ${dp_load} $
{dp_offset};fatload mmc 0:1 ${loadaddr} ${bootfile};fatload mmc 0:1 ${fdtaddr} ${fdtfile};booti
${loadaddr} - ${fdtaddr}'
=> saveenv
```

3. Run the boot command to boot the board:

```
=> boot
```

NOTE

During booting, SELinux relabels the entire file system as shown below and then reboots the board automatically.

```

*** Warning -- SELinux default policy relabel is required.
*** Relabeling could take a very long time, depending on file
*** system size and speed of hard drives.
[ 16.531853] 001: cdns-mhdp-imx f200000.display: IRQ plug_in not found
[ 16.531865] 001: cdns-mhdp-imx f200000.display: IRQ plug_out not found
[ OK ] Reached target Sound Card.
Warning: Skipping the following R/O filesystems:
/sys/fs/cgroup
Relabeling / /dev /dev/hugepages /dev/mqueue /dev/pts /dev/shm /run /run/
lock /sys /sys/fs/cgroup/blkio /sys/fs/cgroup/cpu,cpuacct /sys/fs/
cgroup/cpuset /
sys/fs/cgroup/devices /sys/fs/cgroup/freezer /sys/fs/cgroup/hugetlb /sys/fs/
cgroup/memory /sys/fs/cgroup/perf_event /sys/fs/cgroup/pids /sys/fs/cgroup/sys
temd /sys/fs/cgroup/unified /sys/fs/pstore /sys/kernel/debug
/ 100.0%
/dev 100.0%
/dev/hugepages 100.0%
Warning no default label for /dev/mqueue
/dev/mqueue 100.0%
/dev/pts 100.0%
/dev/shm 100.0%
/run 100.0%
/run/lock 100.0%
/sys 100.0%
Warning no default label for /sys/fs/cgroup/blkio
/sys/fs/cgroup/blkio 100.0%
Warning no default label for /sys/fs/cgroup/cpu,cpuacct
/sys/fs/cgroup/cpu,cpuacct 100.0%
Warning no default label for /sys/fs/cgroup/cpuset
/sys/fs/cgroup/cpuset 100.0%
Warning no default label for /sys/fs/cgroup/devices
/sys/fs/cgroup/devices 100.0%
Warning no default label for /sys/fs/cgroup/freezer
/sys/fs/cgroup/freezer 100.0%
Warning no default label for /sys/fs/cgroup/hugetlb
/sys/fs/cgroup/hugetlb 100.0%
Warning no default label for /sys/fs/cgroup/memory
/sys/fs/cgroup/memory 100.0%
Warning no default label for /sys/fs/cgroup/perf_event
/sys/fs/cgroup/perf_event 100.0%
Warning no default label for /sys/fs/cgroup/pids
/sys/fs/cgroup/pids 100.0%
Warning no default label for /sys/fs/cgroup/systemd
/sys/fs/cgroup/systemd 100.0%
Warning no default label for /sys/fs/cgroup/unified
/sys/fs/cgroup/unified 100.0%
/sys/fs/pstore 100.0%
/sys/kernel/debug 100.0%

Cleaning up labels on /tmp

```

4. After booting the board, check the file system labels using the following command in Linux prompt:

```

$ ls -Z /
system_u:object_r:unlabeled_t:s0 bin
system_u:object_r:unlabeled_t:s0 boot

```

```

system_u:object_r:unlabeled_t:s0 data
  system_u:object_r:device_t:s0 dev
system_u:object_r:unlabeled_t:s0 etc
system_u:object_r:home_root_t:s0 home
system_u:object_r:unlabeled_t:s0 lib
system_u:object_r:unlabeled_t:s0 lost+found
system_u:object_r:unlabeled_t:s0 media
system_u:object_r:unlabeled_t:s0 mnt
system_u:object_r:unlabeled_t:s0 opt
  system_u:object_r:proc_t:s0 proc
system_u:object_r:unlabeled_t:s0 root
  system_u:object_r:var_run_t:s0 run
system_u:object_r:unlabeled_t:s0 sbin
  system_u:object_r:var_t:s0 srv
  system_u:object_r:sysfs_t:s0 sys
  system_u:object_r:tmp_t:s0 tmp
system_u:object_r:unlabeled_t:s0 usr
  system_u:object_r:var_t:s0 var

```

5. If in the above log, the "unlabeled_t" message is observed, it means the file system is not labeled correctly. In this case use another command to label them:

```

$ touch /.autorelabel
$ reboot

```

Then, SELinux will relabel the entire file system.

17.1.3 Basic setup

Perform the following basic steps before running the SELinux demo.

1. Make sure SELinux is enabled

```

$ sestatus
SELinux status:                enabled
SELinuxfs mount:              /sys/fs/selinux
SELinux root directory:      /etc/selinux
Loaded policy name:          default
Current mode:                 permissive
Mode from config file:       permissive
Policy MLS status:           enabled
Policy deny_unknown status:   allowed
Memory protection checking:   actual (secure)
Max kernel policy version:    31

```

```

$ id -Z
system_u:system_r:kernel_t:s0
# or
unconfined_u:unconfined_r:unconfined_t:s0-s0:c0.c1023

```

```

$ semanage login -l

```

| Login Name | SELinux User | MLS/MCS Range | Service |
|-------------|--------------|----------------|---------|
| __default__ | unconfined_u | s0-s0:c0.c1023 | * |
| root | unconfined_u | s0-s0:c0.c1023 | * |

2. Map root to sysadm_u, modify the mapping of root and selinux user:

```
$ semanage login -m -s sysadm_u root
```

Logout and login again. Check root's SELinux login user:

```
$ id -z
sysadm_u:sysadm_r:sysadm_t:s0-s0:c0.c1023
```

3. Map linux user to a selinux user named user_u:

```
$ semanage login -m -s user_u -r s0 __default__
```

Check all the selinux users logged in:

```
$ semanage login -l
```

| Login Name | SELinux User | MLS/MCS Range | Service |
|-------------|--------------|----------------|---------|
| __default__ | user_u | s0 | * |
| root | sysadm_u | s0-s0:c0.c1023 | * |

4. Label the system. Modify the SELinux config file with SELINUXTYPE=default using the command below:

```
$ vim /etc/selinux/config
```

Restore the type of files in /root:

```
$ mkdir /root_home
$ semanage fcontext -a -t home_root_t '/root_home(/.*)?'
$ restorecon -Rv /root_home/
```

5. Check ssh server:

```
$ systemctl status ssh
ssh.service - OpenBSD Secure Shell server
Loaded: loaded (/lib/systemd/system/ssh.service; enabled; vendor preset: enabled) Active: active
(running) since 2017-05-09 07:23:56 CST; 1 weeks 6 days ago
Main PID: 908 (sshd)
CGroup: /system.slice/ssh.service
└─908 /usr/sbin/sshd -D
```

If checking the ssh server status fails, restart the ssh server using the command below:

```
$ systemctl restart ssh
```

6. Check the http server:

```
$ systemctl status apache2
└─apache2.service - LSB: Apache2 web server
Loaded: loaded (/etc/init.d/apache2; bad; vendor preset: enabled) Drop-In: /lib/systemd/
system/apache2.service.d
└─apache2-systemd.conf
Active: active (running) since Thu 2016-02-11 16:30:39 UTC; 2min 3s ago Docs: man:systemd-sysv-
generator(8)
Process: 3975 ExecStart=/etc/init.d/apache2 start (code=exited, status=0/SUCCE CGroup: /
system.slice/apache2.service
└─3990 /usr/sbin/apache2 -k start
```

```
└─3993 /usr/sbin/apache2 -k start
└─3994 /usr/sbin/apache2 -k start
```

If checking the apache2 status fails, restart apache2 service:

```
$ systemctl restart apache2
```

7. Add the user test1: Add a linux user named test1. Specify password for test1 and other configurations can be defaultMap root to sysadm_u.

```
$ adduser test1
Adding user `test1' ...
Adding new group `test1' (1001) ...
Adding new user `test1' (1001) with group `test1' ... Creating home directory `/home/test1' ...
Copying files from `/etc/skel' ... Enter new UNIX password:
Retype new UNIX password:
passwd: password updated successfully Changing the user information for test1
Enter the new value, or press ENTER for the default Full Name []:
Room Number []: Work Phone []: Home Phone []: Other []:
Is the information correct? [Y/n] y
```

17.1.4 Demo 1: local access control

This demo shows how SELinux protects a local file. The process cannot access local files if it is unauthorized.

Example 1: Denying a process from reading a wrong file type

In this example, a vi process created by user with uid: test1, acts as a subject to access a common file, which has a DAC permission of 777.

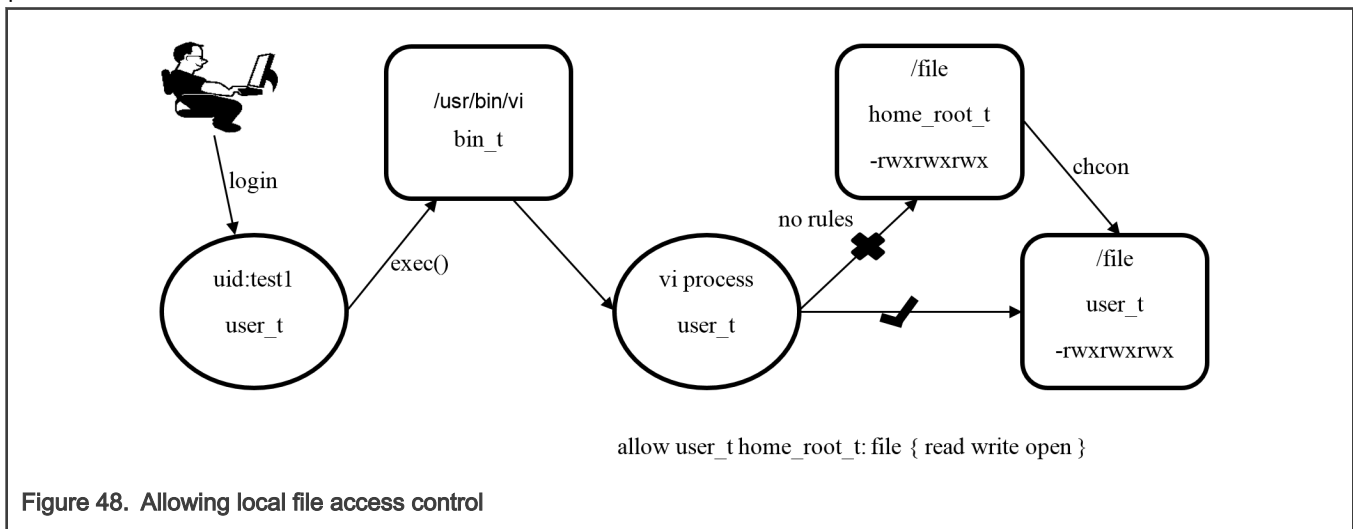


Figure 48. Allowing local file access control

1. root: create a test file:

```
$ echo "file created in root_home" > /root_home/file
$ chmod 777 /root_home/file
$ mv /root_home/file /file
$ ls -Z /file
sysadm_u:object_r:home_root_t:s0 /file
```


2. root: enable SELinux:

```
$ setenforce 1
$ getenforce
Enforcing
```

3. User test1: logs in (can use "ssh" command from another machin to login) and visits the file. User test1 logs in the system via ssh and checks id info:

```
$ id -Z
user_u:user_r:user_t:s0
```

User test1 visits the file using the vi command.

```
$ vi /file
```

SELinux denies access to the file, even though the file is 777.

Figure 49. The VI command log

Because there is no allowed rule such as the following

```
allow user_t home_root_t: file {write append}
```

4. root: change the type/user of file

```
$ setenforce 0
$ chcon -t user_t /file
$ chcon -u user_u /file
$ ls -Z /file
user_u:object_r:user_t:s0 /file
$ setenforce 1
```

5. User test1: visits the file of correct type, and his request is approved. The user test1 visits the file again and succeeds.

```
$ vi /file
```

6. root: Refer to the audit log: /var/log/audit/audit.log with commands audit2why and audit2allow.

```
$ audit2why -a
```

There is an AVC information about access denied and a reasonable root cause as shown in the below figure.

Figure 50. Audit log for vi

```
$ audit2allow -a
```

This command suggests the rules that can approve the access.

```
#===== user_t =====
#!!!! The source type 'user_t' can write to a 'file' of the following types:
# wireshark_home_t, telepathy_logger_data_home_t, screen_home_t, screen_var_run
_t, xdm_tmp_t, mplayer_tmpfs_t, gconf_tmp_t, rssh_rw_t, httpd_user_script_exec
_t, evolution_home_t, tvtime_home_t, tvtime_tmp_t, httpd_user_content_t, irc_hom
e_t, telepathy_mission_control_data_home_t, pulseaudio_tmp_t, spamassassin_tmp
_t, git_user_content_t, pulseaudio_home_t, telepathy_tmp_content, mozilla_plugin
_tmp_t, rssh_ro_t, wireshark_tmpfs_t, razor_home_t, gift_home_t, user_home_t, p
pp_home_t, xauth_home_t, uml_tmpfs_t, ssh_home_t, pyzor_tmp_t, session_dbusd_tm
p_t, httpd_user_rw_content_t, hadoop_home_t, zookeeper_tmp_t, java_tmpfs_t, use
r_fonts_t, games_tmpfs_t, uml_ro_t, mail_home_rw_t, vmware_conf_t, gpg_agent_tm
p_t, spamd_home_t, krb5_home_t, gnome_home_t, telepathy_sunshine_home_t, telepa
thy_logger_cache_home_t, uml_tmp_t, vmware_file_t, irc_tmp_t, pulseaudio_tmpfsf
ile, user_home_t, gnome_keyring_home_t, evolution_exchange_tmpfs_t, iceauth_hom
e_t, razor_tmp_t, telepathy_mission_control_cache_home_t, cgroup_t, bluetooth_h
elper_tmp_t, pulseaudio_tmpfs_t, wireshark_tmp_t, mail_spool_t, alsa_home_t, th
underbird_home_t, evolution_tmpfs_t, vmware_tmpfs_t, mozilla_tmpfs_t, telepathy
_mission_control_home_t, irc_log_home_t, gift_tmpfs_t, screen_tmp_t, vmware_tmp
_t, mail_home_t, mozilla_tmp_t, mplayer_home_t, pulseaudio_home_t, httpd_user_h
taccess_t, usbfs_t, mozilla_plugin_home_t, telepathy_gabble_cache_home_t, spamc
_tmp_t, evolution_webcal_tmpfs_t, user_mail_tmp_t, spamassassin_home_t, evoluti
on_alarm_tmpfs_t, hadoop_tmp_t, security_t, mysqld_home_t, oidentd_home_t, tele
pathy_cache_home_t, uml_rw_t, user_fonts_config_t, bluetooth_helper_tmpfs_t, mo
zilla_plugin_tmpfs_t, games_tmp_t, user_tmp_t, mozilla_home_t, nfsd_rw_t, uml_e
xec_t, java_tmp_t, mpd_user_data_t, telepathy_data_home_t, tvtime_tmpfs_t, http
d_user_ra_content_t, pyzor_home_t, user_tmpfs_t, user_fonts_cache_t, gpg_secret
_t, anon_inodefs_t, gconf_home_t, xserver_tmpfs_t, session_dbusd_home_t

allow user_t home_root_t:file { read write open };
```

Figure 51. Audit suggestion for Vi

Example 2: Denying a root user from changing SELinux running mode

In this example, the root user is restricted to have no permission to change the SELinux running mode when SELinux is enforced.

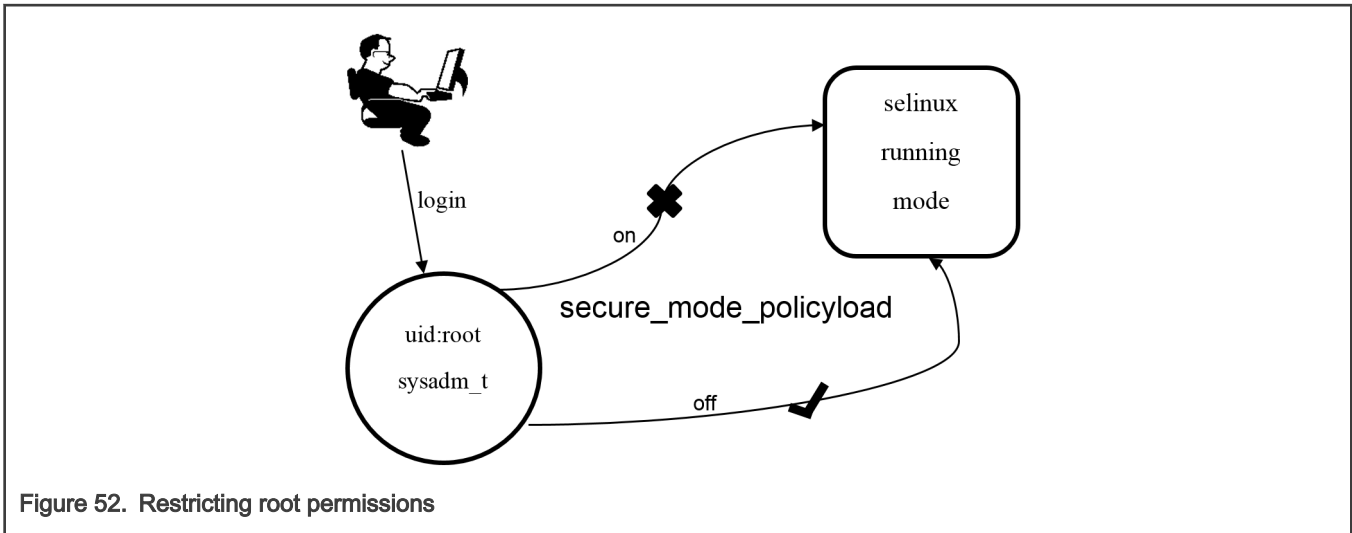


Figure 52. Restricting root permissions

1. Root: Turn on and then turn off Selinux.

Booleans are shortcuts for the user to modify the SELinux policy dynamically. The policy, `secure_mode_policyload` is one of these policies, which can deny a root user from changing SELinux running mode. By default, it is Off.

```
$ getsebool secure_mode_policyload
secure_mode_policyload --> off
```

Root can turn on SELinux:

```
$ setenforce 1
```

Root can then turn off SELinux:

```
$ setenforce 0
```

2. root: enable `secure_mode_policyload`

Now the SELinux is permissive. Run the `setsebool` command to enable `secure_mode_policyload`:

```
$ setsebool secure_mode_policyload on
```

Check the status of `secure_mode_policyload` again:

```
$ getsebool secure_mode_policyload
secure_mode_policyload --> on
```

3. Root: Try to turn on and turn off SELinux.

Root can still turn on SELinux:

```
$ setenforce 1
```

Root tries to turn off SELinux but gets permission denied:

```
$ setenforce 0
setenforce:          setenforce() failed
```

If root user want to disable Enforcing, should do following:

```
$ setsebool secure_mode_policyload off
$ setenforce 0
$ getenforce
Permissive
```

17.1.5 Demo 2: enabling remote access control

This demo shows how SELinux can also be used to provide website visiting permissions. A web client cannot access website files remotely if it is not authorized.

Example 1: Denying an HTTP client from visiting a private website

Use the following commands for running this sample demo:

1. root: Copy `index.html` to `/root`

```
$ cp /var/www/html/index.html /root
```

2. root: Move `index.html` to `apache2`

```
$ mv /root/index.html /var/www/html/index.html
```

3. root: turn on SELinux and `wget` website

```
$ setenforce 1
$ wget localhost
```

```
--2020-05-28 21:01:33-- http://localhost/
Resolving localhost (localhost)... ::1, 127.0.0.1
Connecting to localhost (localhost)|::1|:80... failed: Connection refused.
Connecting to localhost (localhost)|127.0.0.1|:80... connected.
HTTP request sent, awaiting response... 403 Forbidden
2020-05-28 21:01:33 ERROR 403: Forbidden.
```

```
# Note: Make sure localhost is ready
$ cat /etc/hosts
127.0.0.1      localhost
```

Now `wget`, as a `http` client, fails to visit `apache2` home page.

4. root: check type of `index.html`.

```
$ ls -Z /var/www/html/index.html
sysadm_u:object_r:user_home_t:SystemLow /var/www/html/index.html
```

The `index.html` has a type of `home_root_t` which cannot be access by the `http` client with type `httpd_t`.

5. root: restore `index.html` to a right type.

```
$ setenforce 0
$ restorecon /var/www/html/index.html
$ ls -Z /var/www/html/index.html
sysadm_u:object_r:httpd_sys_content_t:SystemLow /var/www/html/index.html
```

The `index.html` now contains the `httpd_sys_content_t` and can be access by `httpd_t`.

6. root: turn on SELinux and visit again.

```
$ setenforce 1
$ wget localhost
--2020-05-28 21:03:39-- http://localhost/
Resolving localhost (localhost)... ::1, 127.0.0.1
Connecting to localhost (localhost)|::1|:80... failed: Connection refused.
Connecting to localhost (localhost)|127.0.0.1|:80... connected.
HTTP request sent, awaiting response... 200 OK
Length: 10918 (11K) [text/html]
Saving to: 'index.html'

index.html      100%[=====>] 10.66K  --.-KB/s   in 0s

2020-05-28 21:03:39 (109 MB/s) - 'index.html' saved [10918/10918]
```

Example 2 Denying `ssh` client from remote login with root

The following figure shows how to deny `ssh` remote login permission for a root user.

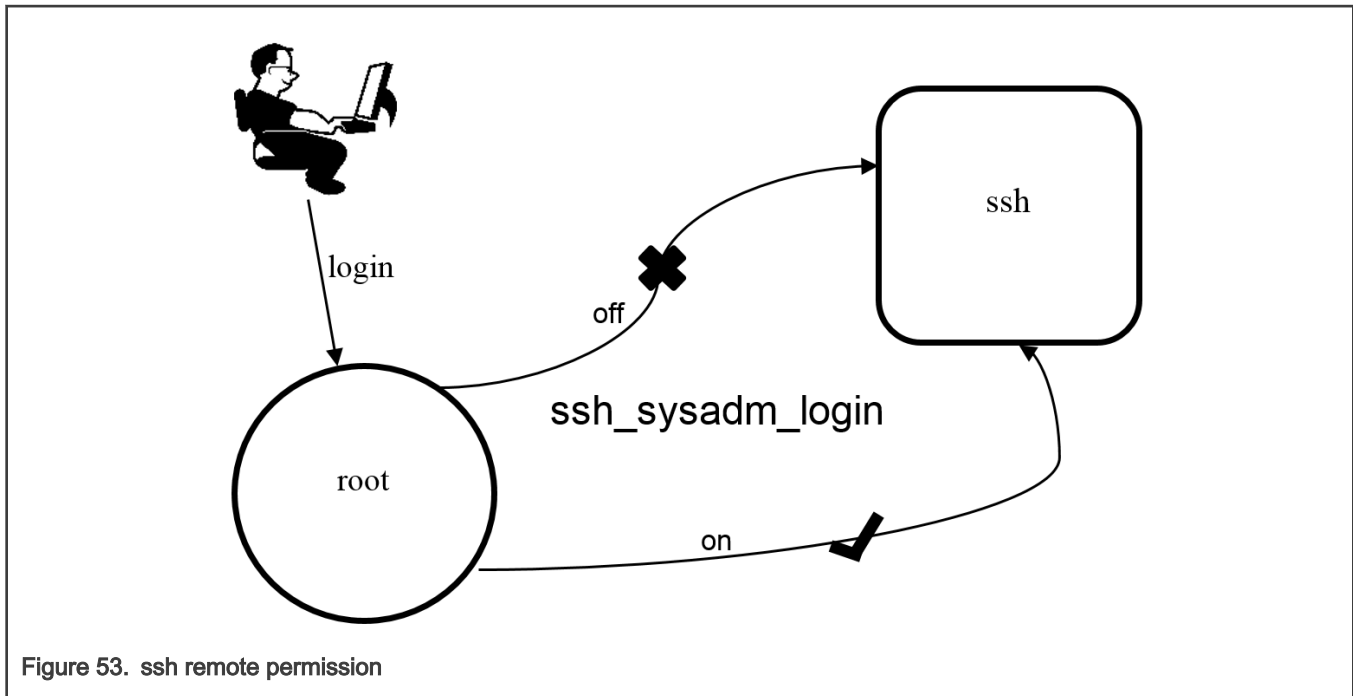


Figure 53. ssh remote permission

1. root: config sshd to permitrootlogin

```
$ setenforce 0
$ vi /etc/ssh/sshd_config
```

Find “PermitRootLogin prohibit-password” and change it to “PermitRootLogin yes”

2. root: restart ssh server

```
$ systemctl restart ssh
```

Now root should be allowed to access the system from remote side with ssh.

3. root: turn on SELinux and ssh.

```
$ setenforce 1
$ ssh root@localhost
/bin/bash: Permission denied
Connection to localhost closed.
```

Even though sshd_config file has permitted root login but still fails in ssh.

4. root: turn on ssh login boolean

Check that the following settings are configured:

```
$ getsebool -a | grep ssh
allow_ssh_keysign --> off
fenced_can_ssh --> off
sftpd_write_ssh_home --> off
ssh_sysadm_login --> off
ssh_use_gpg_agent --> off
```

There is a boolean named `ssh_sysadm_login`. This denies a root user from ssh login. Turn on it.

```
$ setenforce 0
$ setsebool ssh_sysadm_login on
```

5. root: enforcing and ssh again.

```
$ setenforce 1
$ ssh root@localhost
```

Now root user can ssh successfully.

6. root: refer to the audit log.

```
$ audit2why -a
```

```
type=AVC msg=audit(1455211133.736:523): avc: denied { transition } for pid=4
255 comm="sshd" path="/bin/bash" dev="mmcblk0p3" ino=258580 scontext=system_u:s
ystem_r:sshd_t:s0-s0:c0.c1023 tcontext=sysadm_u:sysadm_r:sysadm_t:s0 tclass=pro
cess permissive=0
    Was caused by:
    The boolean ssh_sysadm_login was set incorrectly.
    Description:
    Allow ssh to sysadm login

    Allow access by executing:
    # setsebool -P ssh_sysadm_login 1
```

Figure 54. Audit log for sshd

```
$ audit2allow -a
```

Chapter 18

NETCONF/YANG

This chapter provides an overview of the NETCONF protocol and Yang (a data modelling language for NETCONF). It describes the applications, installation and configuration steps, operation examples, Web UI demo, and troubleshooting aspects of NETCONF. It also describes how to enable the NETCONF feature in OpenIL.

18.1 Overview

The NETCONF protocol defines a mechanism for device management and configuration retrieval and modification. It uses a remote procedure call (RPC) paradigm and a system of exposing device (server) capabilities, which enables a client to adjust to the specific features of any network equipment. NETCONF further distinguishes between state data (which is read-only) and configuration data (which can be modified). Any NETCONF communication happens on four layers as shown in the table below. XML is used as the encoding format.

Table 49. The NETCONF layers

| Layer | Purpose | Example |
|-------|------------|---------------------------------------|
| 1 | Content | Configuration data, Notification data |
| 2 | Operations | <edit-config> |
| 3 | Messages | <rpc>, <rpc-reply>, <notification> |
| 4 | Secure | Transport SSH, TLS |

YANG is a standards-based, extensible, hierarchical data modeling language that is used to model the configuration and state data used by NETCONF operations, remote procedure calls (RPCs), and server event notifications. The device configuration data are stored in the form of an XML document. The specific nodes in the document as well as the allowed values are defined by a model, which is usually in YANG format or possibly transformed into YIN format with XML-based syntax. There are many such models created directly by IETF to further support standardization and unification of the NETCONF interface of the common network devices. For example, the general system settings of a standard computer are described in the IETF-system model ([rfc7317](#)) or the configuration of its network interfaces defined by the IETF-interfaces model ([rfc7223](#)). However, it is common for every system to have some specific parts exclusive to it. In that case there are mechanisms defined to enable extensions while keeping the support for the standardized core. Also, as this whole mechanism is designed in a liberal fashion, the configuration does not have to concern strictly network. Even RPCs additional to those defined by NETCONF can be characterized, thus allowing the client to request an explicit action from the server.

A YANG module defines a data model through its data, and the hierarchical organization of and constraints on that data. A module can be a complete, standalone entity, or it can reference definitions in other modules and sub-modules as well as augment other data models with additional nodes. The module dictates how the data is represented in XML.

A YANG module defines not only the syntax but also the semantics of the data. It explicitly defines relationships between and constraints on the data. This enables user to create syntactically correct configuration data that meets constraint requirements and enables user to validate the data against the model before uploading it and committing it on a device.

For information about NETCONF, see [RFC 6241](#), NETCONF Configuration Protocol.

For information about YANG, see [RFC 6020](#), YANG - A Data Modeling Language for the Network Configuration Protocol (NETCONF), and related RFCs.

18.2 Netopeer2

18.2.1 Overview

[Netopeer2](#) is a set of tools implementing network configuration tools based on the NETCONF protocol. This is the second generation of the toolset, originally available as the Netopeer project. It is based on the new generation of the NETCONF and

YANG libraries - **libyang** and **libnetconf2**. The Netopeer2 server uses **sysrepo** as a NETCONF datastore implementation. In OpenIL, version **v0.7-r2** was used. It allows developers to control their devices via NETCONF and operators to connect to their NETCONF-enabled devices.

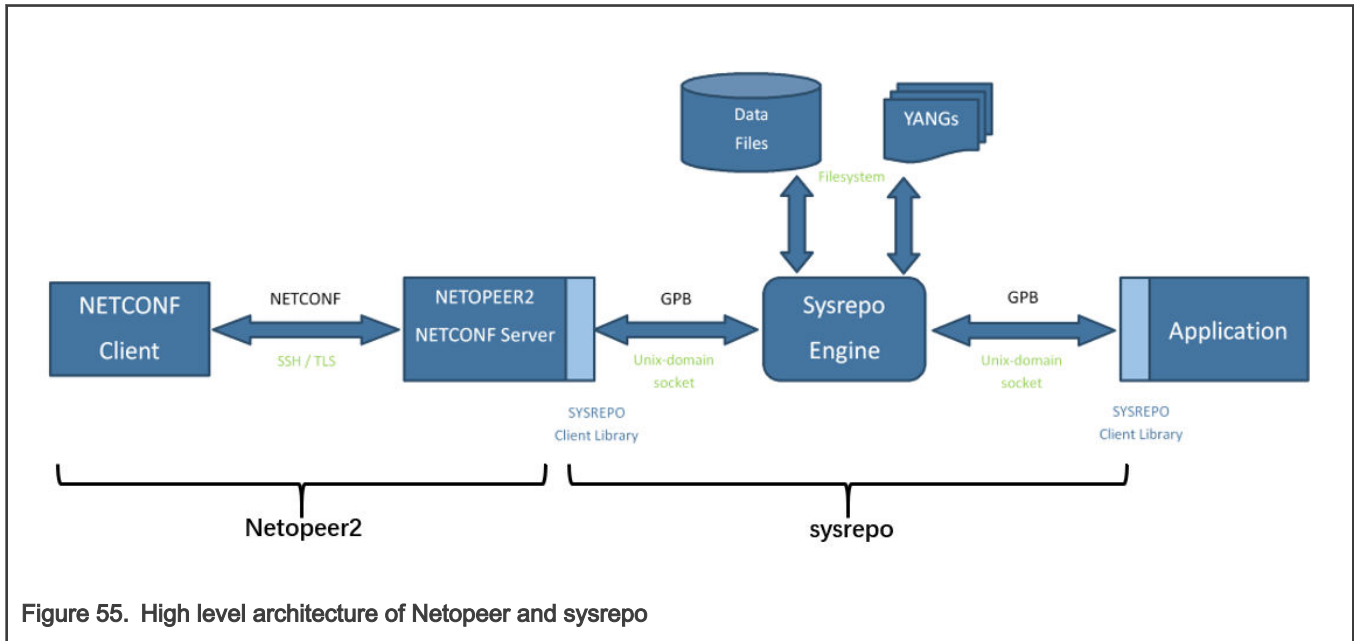


Figure 55. High level architecture of Netopeer and sysrepo

18.2.2 Sysrepo

Sysrepo is an **YANG**-based configuration and operational state data store for Unix/Linux applications.

Applications can use **sysrepo** to store their configuration modeled by provided **YANG** model instead of using e.g. flat configuration files. In OpenIL, version **v0.7.8** was used. **Sysrepo** will ensure data consistency of the data stored in the datastore and enforce data constraints defined by **YANG** model. Applications can currently use **C language API** of **sysrepo Client Library** to access the configuration in the datastore, but the support for other programming languages is planned for later too (since **sysrepo** uses **Google Protocol Buffers** as the interface between the datastore and client library, writing of a native client library for any programming language that supports **GPB** is possible).

For information about **sysrepo**, see:

<http://www.sysrepo.org/static/doc/html/index.html>

18.2.3 Netopeer2 server

Netopeer2 software is a collection of utilities and tools to support the main application, **Netopeer2 server**, which is a **NETCONF** server implementation. It uses **libnetconf2** for all **NETCONF** communication. Conforming to the relevant **RFCs2** and still being part of the aforementioned library, it supports the mandatory **SSH** as the transport protocol but also **TLS**. Once a client successfully connects using either of these transport protocols and establishes a **NETCONF** session, it can send **NETCONF** RPCs and the **Netopeer2** server responds with correct replies.

The following set of tools are a part of the **Netopeer** server:

- **Netopeer2-keystore** as a tool for the storage and process of keys.
- **Netopeer2-server** as the main service daemon integrating the **SSH/TLS** server.

18.2.4 Netopeer2 client

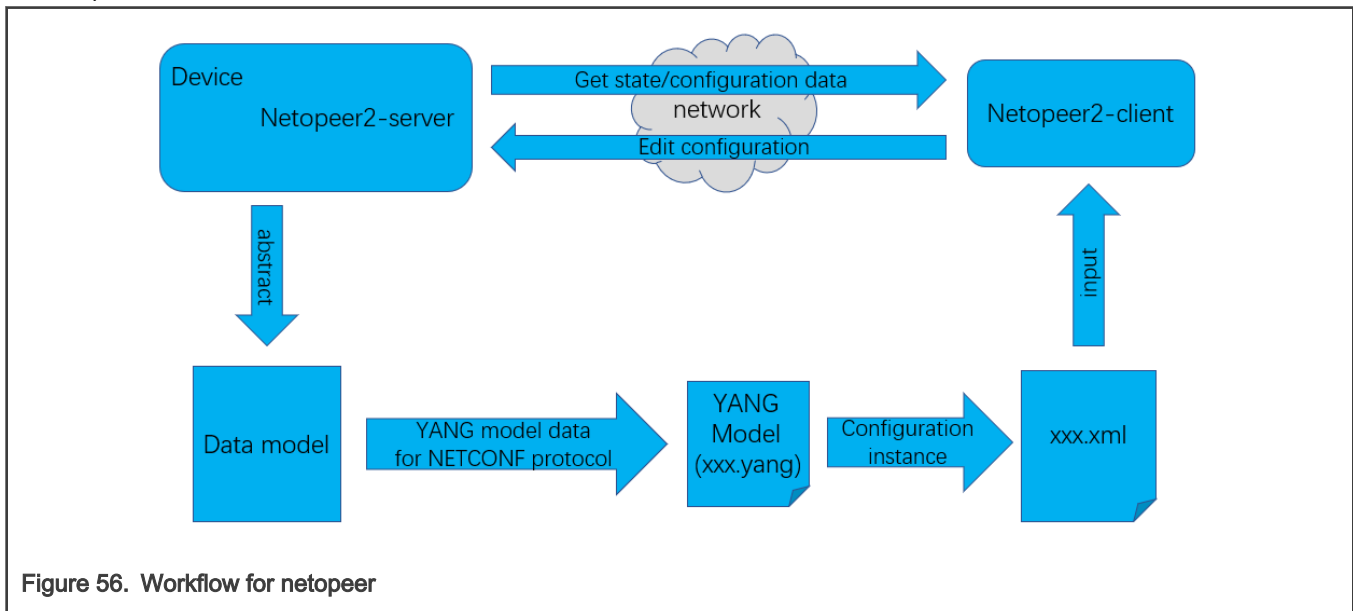
Netopeer2-cli is a **CLI** interface that allows user to connect to a **NETCONF**-enabled device and obtain and manipulate its configuration data.

This application is a part of the Netopeer2 software bundle, but compiled and installed separately. It is a NETCONF client with a command line interface developed and primarily used for Netopeer2 server testing, but allowing all the standards and even some optional features of a full-fledged NETCONF client.

Netopeer2-cli serves as a generic NETCONF client providing a simple interactive command line interface. It allows user to establish a NETCONF session with a NETCONF-enabled device on the network and to obtain and manipulate its configuration data.

18.2.5 Workflow in application practice

In practical application, we use the YANG language to model the device and generate the YANG model. The model is then instantiated to generate configuration files in XML format. The device was then configured using this configuration file as input via netopeer.



18.3 Installing Netopeer2-cli on Ubuntu18.04

Use the following steps for installing Netopeer2-cli on Ubuntu18.04 operating systems.

1. Install the following packages:

```
$ sudo apt install -y git cmake build-essential bison autoconf dh-autoreconf flex
$ sudo apt install -y libavl-dev libprotobuf-c-dev protobuf-c-compiler zlib1g-dev
$ sudo apt install -y libgcrypt20-dev libssh-dev libev-dev libpcre3-dev
```

2. Install libyang:

```
$ git clone https://github.com/CESNET/libyang.git
$ cd libyang;
$ git checkout v1.0-r4 -b v1.0-r4
$ mkdir build; cd build
$ cmake -DCMAKE_INSTALL_PREFIX:PATH=/usr ..
$ make
$ sudo make install
```

3. Install sysrepo (v0.7.8):

```
$ git clone https://github.com/sysrepo/sysrepo.git
$ cd sysrepo
$ git checkout v0.7.8 -b v0.7.8
```

```
$ mkdir build; cd build
$ cmake -DCMAKE_BUILD_TYPE=Release -DCMAKE_INSTALL_PREFIX:PATH=/usr ..
$ make
$ sudo make install
```

4. Install libnetconf2:

```
$ git clone https://github.com/CESNET/libnetconf2.git
$ cd libnetconf2
$ git checkout v0.12-r2 -b v0.12-r2
$ mkdir build; cd build
$ cmake -DCMAKE_INSTALL_PREFIX:PATH=/usr ..
$ make
$ sudo make install
```

5. Install protobuf:

```
$ git clone https://github.com/protocolbuffers/protobuf.git
$ cd protobuf
$ git submodule update --init --recursive
$ ./autogen.sh
$ ./configure
$ make
$ sudo make install
$ sudo ldconfig # refresh shared library cache.
```

6. Install Netopeer2-cli(v0.7-r2):

```
$ git clone https://github.com/CESNET/Netopeer2.git
$ cd Netopeer2
$ git checkout v0.7-r2 -b v0.7-r2
$ cd cli
$ cmake -DCMAKE_INSTALL_PREFIX:PATH=/usr .
$ make
$ sudo make install
```

18.4 Configuration

18.4.1 Enabling NETCONF feature in OpenIL

Build the image using the below command to enable the NETCONF feature:

```
make nxp_ls1028ardb-64b_defconfig
```

or

```
make nxp_ls1021atsn_defconfig
```

Users can find detailed configuration with the `make menuconfig` command, as shown below:

```
Target packages ->
  Hardware handling --->
    NXP QorIQ libraries --->
      *- qorIQ-netopeer2-keystored
      *- qorIQ-netopeer2-server
      [*] qorIQ-sysrepo-tsn
```

sysrepo-tsn is daemon application to implement tsn configuration based on **sysrepo**. It was enabled in **nxp_ls1028ardb-64b_defconfig**, **nxp_ls1021atsn_defconfig** and **imx8mpevk_defconfig**.

NOTE

- For LS1028ARDB board, Qbv, Qbu, Qci, stream identification in CB, IP, MAC, and VLAN are supported.
- For LS1021ATSN board, Qbv, IP, MAC and VLAN are supportet.
- sysrepo-tsn was only verified in environment build by **nxp_ls1028ardb-64b_defconfig**, **nxp_ls1021atsn_default** and **imx8mpevk_defconfig** configuration.

18.4.2 Netopeer2-server

The netopeer2-server is the NETCONF protocol server running as a system daemon. The netopeer2-server is based on sysrepo and libnetconf2 library.

- -U listen locally on a unix socket
- -d debug mode (do not daemonize and print verbose messages to stderr instead of syslog)
- -V: Show program version.
- -v level verbose output level(0 : errors, 1 : errors and warnings, 2 : errors, warnings and verbose messages).

18.4.3 Netopeer2-cli

The netopeer2-cli is command line interface similar to the NETCONF client. It serves as a generic NETCONF client providing a simple interactive command line interface. It allows user to establish a NETCONF session with a NETCONF-enabled device on the network and to obtain and manipulate its configuration data. netopeer2-cli is limited to a single NETCONF connection at a time via a forward or a reverse (Call Home) connecting method.

18.4.3.1 Netopeer2 CLI commands

Following are the Netopeer2 CLI commands:

1. **help**: Displays a list of commands. The `--help` option is also accepted by all commands to show detailed information about the command.
2. **connect**: Connects to a NETCONF server.

```
connect [--help] [--ssh] [--host <hostname>] [--port <num>] [--login <username>]
```

The **connect** command has the following arguments:

- **--login** username: Specifies the user to log in as on the NETCONF server. If not specified, current local username is taken.
 - **--port** num
 - Port to connect to on the NETCONF server. By default, port 830 for SSH or 6513 for TLS transport is used.
 - **host**
 - Hostname or ip-address of the target NETCONF server.
3. **disconnect**: disconnects from a NETCONF server.
 4. **commit**
 - Performs the NETCONF `commit` operation. For details, see RFC 6241 section 8.3.4.1.

5. **copy-config**: Performs NETCONF `copy-config` operation. For details, see RFC 6241 section 7.3.

```
copy-config [--help] --target running|startup|candidate|url:<url> (--source running|startup|
candidate|url:<url> | --src-config[=<file>])
  [--defaults report-all|report-all-tagged|trim|explicit]
```

Where, the arguments are the following:

- **--defaults** mode: Use: with the `--defaults` capability with specified retrieval mode. For details, refer to the RFC 6243 section 3 or WITH-DEFAULTS section of this manual.
 - **--target** datastore: Specifies the target datastore for the `copy-config` operation. For description of the datastore parameter, refer to [Netopeer2 CLI datastore](#).
 - **--source** datastore: Specifies the source datastore for the `copy-config` operation. For description of the datastore parameter, refer to [Netopeer2 CLI datastore](#).
6. **delete-config** Performs NETCONF `delete-config` operation. For more details see RFC 6241 section 7.4.

```
delete-config [--help] --target startup|url:<url>
```

Where

- **target** datastore: Specifies the target datastore for the `delete-config` operation.

7. edit-config

Performs NETCONF `edit-config` operation. For details, see RFC 6241 section 7.2.

```
edit-config [--help] --target running|candidate (--config[=<file>] | --url <url>)
  [--defop merge|replace|none] [--test set|test-only|test-then-set] [--error stop|
continue|rollback]
```

Where

- **--defop** operation
 - Specifies default operation for applying configuration data.
 - `merge`: Merges configuration data at the corresponding level. This is the default value.
 - `replace`: Edits configuration data completely replaces the configuration in the target datastore.
 - `none`: The target datastore is unaffected by the edit configuration data, unless and until the edit configuration data contains the operation attribute to request a different operation. For more info, see the EDIT-CONFIG section of this document.

NOTE

To delete non-mandatory items, `nc:operation="delete"` needs to be added into the end of start tag of the item to be deleted. At the same time, the namespace `xmlns:nc="urn:ietf:params:xml:ns:netconf:base:1.0"` also needs to be added into start tag of the root node. Mandatory items can't be deleted individually, they can only be deleted with their parent node.

- **--error** action
 - Sets reaction to an error.
 - `Stop`: Aborts the operation on first error. This is the default value.
 - `Continue`: Continues to process configuration data on error. The error is recorded and negative response is returned.
 - `Rollback`: Stops the operation processing on error and restore the configuration to its complete state at the start of this operation. This action is available only if the server supports rollback-on-error capability (see RFC 6241 section 8.5).

- **--test** option
 - Performs validation of the modified configuration data. This option is available only if the server supports `:validate:1.1` capability (see RFC 6241 section 8.6).
 - `set`: Does not perform validation test.
 - `test-only`: Does not apply the modified data, only perform the validation test.
 - `test-then-set`: Performs a validation test before attempting to apply modified configuration data. This is the default value.
 - **--config** file
 - Specify path to a file containing edit configuration data. The content of the file is placed into the `config` element of the edit-config operation. Therefore, it does not have to be a well-formed XML document with only a single root element. If neither `--config` nor `--url` is specified, user is prompted to write edit configuration data manually. For examples, see the EDIT-CONFIG section of this document.
 - **--url** URI
 - Specifies remote location of the file containing the configuration data hierarchy to be modified, encoded in XML under the element `config` in the `urn:ietf:params:xml:ns:netconf:base:1.0` namespace. Note, that this differs from file parameter, where the `config` element is not expected.
 - **--target**
 - Target datastore to modify. For description of possible values, refer to [Netopeer2 CLI datastore](#). Note that the url configuration datastore cannot be modified.
8. **get**: Performs NETCONF `get` operation. Receives both the status as well as configuration data from the current running datastore. For more details see RFC 6241 section 7.7. The command format is as follows:

```
get [--help] [--filter-subtree[=<file>] | --filter-xpath <XPath>] [--defaults report-all|report-all-tagged|trim|explicit] [--out <file>]
```

- **--defaults** mode
 - Use with the `-defaults` capability with specified retrieval mode. For more details see RFC 6243 section 3 or WITH-DEFAULTS section of this manual.
 - **--filter** [file]
 - Specifies if the request will contain subtree filter (RFC 6241 section 6). The option is able to accept path to the file containing the filter specification. If the path is not specified, user is prompted to write the filter specification manually.
9. **get-config** Performs NETCONF `get-config` operation. Retrieves only configuration data from the specified `target_datastore`. For details, refer to RFC 6241 section 7.1.

```
get-config [--help] --source running|startup|candidate [--filter-subtree[=<file>] | --filter-xpath <XPath>] [--defaults report-all|report-all-tagged|trim|explicit] [--out <file>]
```

10. **--defaults** mode
- Use: with the `-defaults` capability with specified retrieval mode. For more details see RFC 6243 section 3 or WITH-DEFAULTS section of this manual.
11. **--filter** [file]
- Specifies if the request will contain subtree filter (RFC 6241 section 6). The option is able to accept path to the file containing the filter specification. If the path is not specified, user is prompted to write the filter specification manually.
12. **--target**

- Target datastore to retrieve. For description of possible values, refer to [Netopeer2 CLI datastore](#). Note, that the url configuration datastore cannot be retrieved.

13. lock

Performs the NETCONF `lock` operation to lock the entire configuration datastore of a server. For details, see RFC 6241 section 7.5.

```
lock [--help] --target running|startup|candidate
```

Where the

- **--target:** specifies the target datastore to lock. For description of possible values, refer to [Netopeer2 CLI datastore](#). Note, that the url configuration datastore cannot be locked.

14. unlock:

Performs the NETCONF `unlock` operation to release a configuration lock, previously obtained with the `lock` operation. For more details see RFC 6241 section 7.6.

```
unlock [--help] --target running|startup|candidate
```

where

- **--target:** specifies the target datastore to unlock. For description of possible values, refer to [Netopeer2 CLI datastore](#). Note, that the url configuration datastore cannot be unlocked.

15. verb

- Enables/disables verbose messages.

16. quit

- Quits the program.

18.4.3.2 Netopeer2 CLI datastore

Following are the netopeer2 CLI datastores:

- **running**
 - This is the base NETCONF configuration datastore holding the complete configuration currently active on the device. This datastore always exists.
- **startup**
 - The configuration datastore holding the configuration loaded by the device when it boots. This datastore is available only on servers that implement the `:startup` capability.
- **candidate**
 - The configuration datastore that can be manipulated without impacting the device's current configuration and that can be committed to the running configuration datastore. This datastore is available only on servers that implement `:candidate` capability.
- **url:URI**
 - Refers to a remote configuration datastore located at URI. The file that the URI refers to contains the configuration data hierarchy to be modified, encoded in XML under the element `config` in the `urn:ietf:params:xml:ns:netconf:base:1.0` namespace. This datastore is available only on servers that implement the `:url` capability.

18.4.4 Sysreped

Sysreped daemon provides the functionality of the datastore on the system (executes the system-wide Sysreped Engine) and should normally be automatically started by system startup. However, auto-start is not configured by cmake install operation and user need to configure it manually, according to the guidelines of user's system.

Usage: sysrepo [-h] [-v] [-d] [-l <level>]

Options:

- -h Prints usage help.
- -v Prints version.
- -d Debug mode - daemon will run in the foreground and print logs to stderr instead of syslog.
- -l <level> Sets verbosity level of logging:
 - 0 = all logging turned off
 - 1 = log only error messages
 - 2 = (default) log error and warning messages
 - 3 = log error, warning and informational messages
 - 4 = log everything, including development debug messages

18.4.5 Sysrepoctl

sysrepoctl is a command-line tool for editing, importing and exporting configuration stored in Sysrepo datastore. It allows the user to edit startup or running configuration of specified module in preferred text editor and to propagate the performed changes into the datastore transparently for all subscribed applications. Moreover, the user can export the current configuration into a file or get it printed to the standard output and, similarly, an already prepared configuration can be imported from a file or read from the standard input.

In the background, **sysrepoctl** uses Sysrepo client library for any data manipulation rather than directly accessing configuration data files, thus effectively inheriting all main features of Sysrepo, such as YANG-based data validation, full transaction and concurrency support, and, perhaps most importantly, subscribed applications are notified about the changes made using `libSysrepoctl` and can immediately take the new configuration into account.

18.4.6 Sysrepoctl

The `sysrepoctl` provides functions to manage modules. It can be configured using the options and commands described below.

operation-operations

- **--help**: Prints the generic description and a list of commands. The detailed description and list of arguments for the specific command are displayed by using `--help` argument of the command.
- **--install**: Installs specified schema into sysrepo (`--yang` or `--yin` must be specified).
- **--uninstall**: Uninstalls specified schema from sysrepo (`--module` must be specified).
- **--list**: Lists YANG modules installed in sysrepo (note that Conformance Installed implies also Implemented).
- **--change** : Changes specified module in sysrepo (`--module` must be specified).
- **--feature-enable**: Enables a feature within a module in sysrepo (feature name is the argument, `--module` must be specified).
- **--feature-disable**: Disables a feature within a module in sysrepo (feature name is the argument, `--module` must be specified).

Other-options

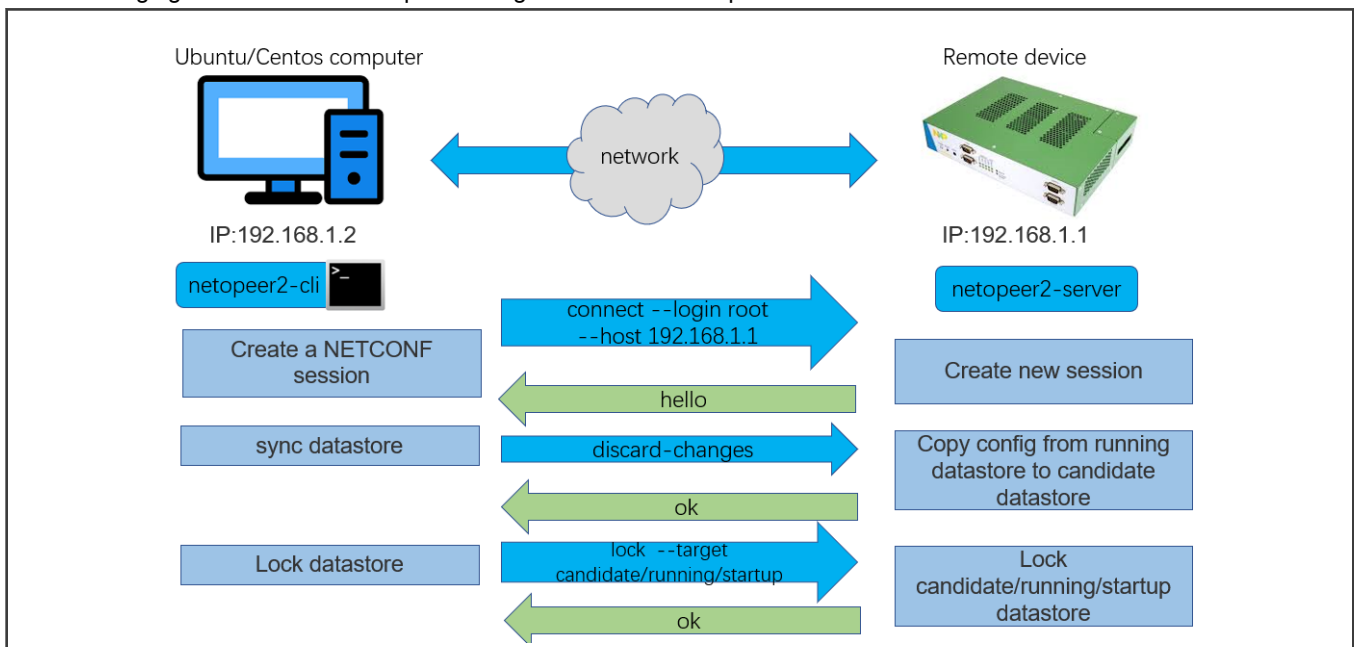
- **--yang** : Path to the file with schema in YANG format (`--install` operation).
- **--yin** : Path to the file with schema in YIN format (`--install` operation).
- **--module** : Name of the module to be operated on (`--change`, `--feature-enable`, `--feature-disable` operations, `--uninstall` - several modules can be delimited with ',').
- **--permissions** : Access permissions of the module's data in `chmod` format (`--install`, `--change` operations).

Examples

- Install a new module by specifying YANG file, ownership and access permissions:
`sysrepoctl --install --yang=/home/user/ietf-interfaces.yang --owner=admin:admin --permissions=644`
- Change the ownership and permissions of an existing YANG module:
`sysrepoctl --change --module=ietf-interfaces --owner=admin:admin --permissions=644`
- Enable a feature within a YANG module:
`sysrepoctl --feature-enable=if-mib --module=ietf-interfaces`
- Uninstall 2 modules, second one is without revision:
`sysrepoctl --uninstall --module=mod-a,mod-b --revision=2035-05-05`

18.4.7 Operation examples

The following figure describes the steps to configure device via netopeer2:



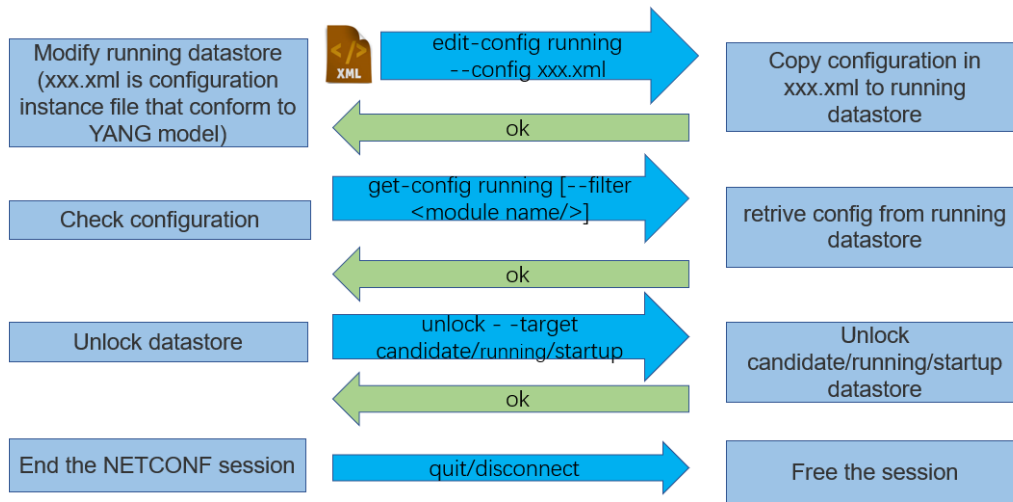


Figure 57. Steps to configure device via netopeer2

In [sysrepo-tsn](#), there are some instance files to configure TSN features on LS1028ARDB board:

- [Instance files for TSN configuration](#)

Users can configure TSN functions of LS1028ARDB board using these instance files. Before starting, make sure that **sysrepopd**, **sysrepo-pluginind**, **sysrepo-tsn** and **netopeer2-server** are running on the board. Use the following steps to configure TSN feature on LS1028ARDB board.

1. Start netopeer2-cli on the computer with netopeer2-cli installed:

```
$ netopeer2-cli
```

2. Connect to netopeer2-server on LS1028ARDB board (use the IP on LS1028ARDB, here 10.193.20.53 is example):

```
> connect --login root --host 10.193.20.53
```

3. Get status data of server:

```
> get
```

4. Get configuration data in running datastore:

```
> get-config --source running
```

5. Configure QBV feature of LS1028ARDB with [qbv-eno0-enable.xml](#)

```
> edit-config --target running --config=qbv-eno0-enable.xml
```

6. Check configuration data of QBV:

```
> get-config --source running --filter-xpath /ietf-interfaces:interfaces/interface[name='eno0']/
ieee802-dot1q-sched:gate-parameters
```

7. Copy configuration data in **running** datastore to **startup** datastore:

```
> copy-config --source running --target startup
```

8. Disconnect with netopeer2-server:

```
> disconnect
```

18.4.8 Application scenarios

NOTE

The related xml file in the following case can be got from the link: <https://github.com/openil/sysrepo-tsn/blob/master/Instances>.

NOTE

The interface name in the xml file should be matching with the real interface name in the board.

1. Prerequisites

- a. Start netopeer2-cli on the computer with netopeer2-cli installed:

```
$ netopeer2-cli
```

- b. Connect to the netopeer2-server using the command below:

```
> connect --login root --host 10.193.20.53
```

2. Configure the IP address

- a. Edit configuration file, change Ethernet interface name and IP:

```
$ vim ietf-ip-cfg.xml
```

- b. Send the configuration file:

```
> edit-config --target running --config=ietf-ip-cfg.xml
```

3. Configure the MAC address for the bridge:

- a. Create a bridge named br1:

```
$ ip link add name br1 type bridge
```

- b. Edit the configuration file, change bridge name and MAC:

```
$ vim ietf-mac-cfg.xml
```

- c. Send the configuration file:

```
$ edit-config --target running --config=ietf-mac-cfg.xml
```

4. Add VLAN for Ethernet interface

- a. Create bridge named "br1" if not existing:

```
$ ip link add name br1 type bridge
```

- b. Edit the configuration file, change interface name and VLAN ID:

```
$ vim ietf-vlan-cfg.xml
```

- c. Send the configuration file:

```
> edit-config --target running --config=ietf-vlan-cfg.xml
```

5. Configure LS1028ARDB Qbv via tc

- a. Edit the configuration file, change interface name and VLAN ID:

```
$ vim qbv-swp0-enable.xml
```

- b. Send the configuration file:

```
> edit-config --target running --config=qbv-swp0-enable.xml
```

- c. Show the result

```
# tc qdisc show dev swp0
```

NOTE

If you want to use `tc` or `ethtool` instead of `libtsn`, enable the following definition in menu config:

```
config BR2_PACKAGE_QORIQ_SYSREPO_TSN_TC
bool "enable tc command to configure tsn"
```

- For LS1028ARDB board, if enable `BR2_PACKAGE_QORIQ_SYSREPO_TSN_TC`, should set prerequisite for `swpx(swp0 swp1 or swp2 ...)` port using the following commands:

```
tc qdisc add dev swpx ingress
tc filter add dev swpx ingress chain 0 pref 49152 flower skip_sw action goto chain 10000
tc filter add dev swpx ingress chain 10000 pref 49152 flower skip_sw action goto chain 11000
tc filter add dev swpx ingress chain 11000 pref 49152 flower skip_sw action goto chain 12000
tc filter add dev swpx ingress chain 12000 pref 49152 flower skip_sw action goto chain 20000
tc filter add dev swpx ingress chain 20000 pref 49152 flower skip_sw action goto chain 21000
tc filter add dev swpx ingress chain 21000 pref 49152 flower skip_sw action goto chain 30000
```

6. Configure LS1028ARDB Qci via tc

- a. Create a bridge named "switch" if not existing:

```
# ip link add name switch type bridge
```

- b. Edit and send configuration file:

```
edit-config --target running --config=switch-qci-fm-gate-enable.xml
```

- c. Show the result

```
# tc filter show dev swp0 ingress
```

- d. Disable the configuration

```
> edit-config --target running --config=switch-qci-fm-gate-disable.xml
```

NOTE

- The destination-address in instance file should be learned by switch.
- Users should send `switch-qci-fm-gate-disable.xml` after `switch-qci-fm-gate-enable.xml`

7. Configure LS1028ARDB Qbu via ethtool

- a. Edit and send configuration file:

```
> edit-config --target running --config=qbu-swp0.xml
```

- b. Show the result:

```
# ethtool --show-frame-preemption swp0
```

8. Configure LS1028ARDB VLAN ID and priority filter via tc

- a. Edit configuration file, change the interface name and action_spec:

```
$ vim ietf-br-vlan-cfg.xml
```

- b. Send the configuration file:

```
> edit-config --target running --config=ietf-br-vlan-cfg.xml
```

9. Configure SJA1105 Qbv via tc

- a. Edit and send configuration file

```
> edit-config --target running --config=qbv-swp5-tc.xml
```

- b. Show the result:

```
# tc qdisc show dev swp5
```

Note: because of hardware limitation of SJA1105, if want to config qbv again, should delete the former qdisc using the following command:

```
# tc qdisc del dev swp5 parent root handle 100
```

10. Configure SJA1105 Qci gate via tc

- a. Create bridge named "switch" if not existing:

```
# ip link add name switch type bridge
```

- b. Edit and send configuration file:

```
> edit-config --target running --config=switch-qci-gate-swp2-enable.xml
```

- c. Show the result:

```
# tc filter show dev swp2 ingress
```

NOTE

If you want to test Qci flow meter, you need to send switch-qci-fm-swp2-enable.xml

NOTE

The engine used to schedule the ingress gate operations is the same that the one used for the tc-taprio offload. Therefore, the restrictions regarding the fact that no two gate actions (either tc-gate or tc-taprio gates) may fire at the same time (during the same 200 ns slot) still apply.

11. Configure i.MX8MP Qbv via tc

- a. Edit and send configuration file:

```
> edit-config --target running --config=qbv-eth1-enable.xml
```

- b. Show the result

```
# tc qdisc show dev eth1
```

12. Configure i.MX8MP Qbu via ethtool

- a. Edit and send configuration file:

```
> edit-config --target running --config=qbu-eth1.xml
```

- b. Show the result

```
# ethtool --show-frame-preemption eth1
```

18.5 Web UI demo

The Web UI allows the remote control of the YANG model. This demo is already added to tsntool (<https://github.com/openil/tsntool>) in the folder `tsntool/demos/cnc/`. Follow the procedure mentioned below for this demo.

1. Install related libraries

Suppose user is installing the demo on a Centos PC or Ubuntu PC as the WebServer. CNC demo requires python3 and related libraries: `pyang`, `libnetconf`, and `libssh`.

For Ubuntu18.04

```
$ sudo apt install -y libtool python-argparse libtool-bin python-sphinx libffi-dev
$ sudo apt install -y libxslt1-dev libcurl4-openssl-dev xsltproc python-setuptools
$ sudo apt install -y zlib1g-dev libssl-dev python-libxml2 libaugeas-dev
$ sudo apt install -y libreadline-dev python-dev pkg-config libxml2-dev
$ sudo apt install -y cmake openssh-server
$ sudo apt install -y python3-sphinx python3-setuptools python3-libxml2
$ sudo apt install -y python3-pip python3-dev python3-flask python3-pexpect
$ sudo apt install -y libnss-mdns avahi-utils
```

For Centos 7.2

```
$ sudo yum install libxml2-devel libxslt-devel openssl-devel libcrypt dbus-devel
$ sudo yum install doxygen libevent readline.x86_64 ncurses-libs.x86_64
$ sudo yum install ncurses-devel.x86_64 libssh.x86_64 libssh2-devel.x86_64
$ sudo yum install libssh2.x86_64 libssh2-devel.x86_64
$ sudo yum install nss-mdns avahi avahi-tools
```

2. Install pyang

```
$ git clone https://github.com/mbj4668/pyang.git
$ cd pyang
$ git checkout b92b17718de53758c4c8a05b6818ea66fc0cd4d8 -b fornetconf1
$ sudo python setup.py install
```

3. Install libssh

```
$ git clone https://git.libssh.org/projects/libssh.git
$ cd libssh
$ git checkout fe18ef279881b65434e3e44fc4743e4b1c7cb891 -b fornetconf1
$ mkdir build; cd build/
```

```
$ cmake ..
$ make
$ sudo make install
```

NOTE

There is a version issue for `libssh` installation on Ubuntu below version 16.04. `Apt-get install libssh` may get version 0.6.4. But `libnetconf` needs a version of 0.7.3 or later. Remove the default one and reinstall by downloading the source code and installing it manually.

4. Install libnetconf

```
$ git clone https://github.com/CESNET/libnetconf.git
$ cd libnetconf
$ git checkout 8e934324e4b1e0ba6077b537e55636e1d7c85aed -b fornetconf1
$ autoreconf --force --install
$ ./configure
$ make
$ sudo make install
```

5. Get tsntool source code

```
git clone https://github.com/openil/tsntool.git
cd tsntool/demos/cnc/
```

6. Install python library

In the below command segments,

- `PATH-to-libnetconf` is the path to the `libnetconf` source code.
- `PATH-to-tsntool` is the path to the `tsntool` source code.

```
$ cd PATH-to-libnetconf/libnetconf
```

The `libnetconf` needs to add two patches based on the below commit point to fix the demo python support.

Ensure that the commit id is `313fdadd15427f7287801b92fe81ff84c08dd970`.

```
$ git checkout 313fdadd15427f7287801b92fe81ff84c08dd970 -b cnc-server
$ cp PATH-to-tsntool/demos/cnc/*patch .
$ git am 0001-lnctool-to-make-install-transapi-yang-model-proper.patch
$ git am 0002-automatic-python3-authorizing-with-root-password-non.patch
$ cd PATH-to-libnetconf/libnetconf/python
$ python3 setup.py build; sudo python3 setup.py install
```

NOTE

If rebuilding python lib, user need to remove the `build` folder by command `rm build -rf` before rebuilding. On the OpenIL board, `avahi-daemon` and `netopeer server` are required. Remember to also add the `netopeer2-server` run at boards.

7. Setup avahi daemon and disable the ipv6:

For this, edit `/etc/avahi/avahi-daemon.conf`

```
use-ipv6=no
publish-a-on-ipv6=no
```

```
sudo systemctl start avahi-daemon.service
#If the hostname is not the OpenIL, change to OpenIL
avahi-set-host-name OpenIL
```

8. Packages required by OpenIL Board

On the OpenIL board, `avahi-daemon`, and `netopeer` server are required:

```
BR2_PACKAGE_AVAHI=y
BR2_PACKAGE_AVAHI_AUTOIPD=y
BR2_PACKAGE_AVAHI_DAEMON=y
BR2_PACKAGE_AVAHI_LIBDNSSD_COMPATIBILITY=y
BR2_PACKAGE_NSS_MDNS=y
BR2_PACKAGE_NETOPEER2_SERVER=y
```

Openil update the `netopeer` server to version2. Remember to make the `netopeer2-server` run at boards.

9. Start the web server

- Input the command below at shell into the folder `/tsntool/demos/cnc/`:

```
sudo python3 cnc.py
```

- Then, input the IP of WebServer with the port 8180 at browser. For example:

```
http://10.193.20.147:8180
```

- It is recommended to tracking the boards by `tsntool` to checking the real configuration for comparison.
- It is also recommended to tracking if the `netopeer2-server` is running ata board or not.

NOTE

Limitations of Web UI are:

- Setup server on a Centos PC or Ubuntu PC could be more compatible.
- Supports Qbv, Qbu and Qci in current version.
- For Qci setting, Stream-gate entry should be set ahead of setting the Stream-filter as sysrepo required. Or else, user will got failure for setting Stream-filter without a stream gate id link to.
- The boards and the web server PC are required to be in same IP domain since the bridge may block the probe frames.

18.6 Troubleshooting

1. Connect fails at client side:

```
nc ERROR: Remote host key changed, the connection will be terminated!
nc ERROR: Checking the host key failed.
cmd_connect: Connecting to the 10.193.20.4:830 as user "root" failed.
```

Fixing:

The reason is that the SSHD key changed at the server.

- User need to get host list with command `knownhosts` first.

- Then remove related item. For example **knownhosts --del 19**.
2. Request could not be completed because the relevant data model content does not exist.

```
type:      application
tag:       data-missing
severity:  error
path:      /ietf-interfaces:interfaces/interface[name='eno0']/ieee802-dot1q-sched:gate-
parameters/admin-gate-states
message:   Request could not be completed because the relevant data model content does not exist.
```

Fixing:

The reason is that the configuration data in xpath does not exist in the datastore. Such as deleting a node that does not exist.

When encountering such an error, user can get configuration data in the board with **get-config** command, and check whether the operation type(add/delete/modify) of the node in the path is reasonable or not,.

Chapter 19

Vivante GPU

The GPU consists of a 3D graphics core and a 2D graphics core.

3D graphics core features are the following:

- Supports 166 million triangles/sec
- Supports 1 Giga pixel/sec fill rate
- Supports 16 GFLOPs
- Supports OpenGL ES 1.1, 2.0, 3.0, 3.1
- Supports OpenCL 1.2
- Vulkan

2D graphics core features are:

- Supports multi-source composition
- Supports one-pass filter
- Supports tile format from 3D graphics core
- Supports tile format from VPU

Step1: Software setting and configuration

Use the following steps to enable GPU support on the target board:

- Configure the target board with `nxp_ls1028ardb-64b*` or `imx8mpevk_*`, for example: `nxp_ls1028ardb-64b_defconfig`

```
$ make nxp_ls1028ardb-64b_defconfig
```

- Enable weston and related package using the `make menuconfig` command:

```
Target packages --->
  Hardware handling --->
    [*] Freescale i.MX libraries --->
      [*]   firmware-imx
      [*]   imx-gpu-g2d
      [*]   imx-gpu-viv
      [*]   Output option (Wayland) --->
      [*]   install examples
      [*]   libdrm-imx
```

- Build the image:

```
make -j8
```

Step 2: Hardware setup

- For LS1028ARDB, connect the monitor and LS1028ARDB with DP cable.
- For i.MX8MMEVK, connect MIPI-DSI to HDMI module, then connect to monitor
- For i.MX8MPEVK, connect the monitor and i.MX8MPEVK with HDMI cable.

Insert the USB mouse into USB port in the keyboard.

Step 3: Implement the demo of GPU

OpenCL demo (example A and B) just suites to LS1028ARDB and i.MX8MPEVK, because i.MX8MMEVK does not support this feature.

A. OpenCL information

```

root@LS1028ARDB:~# cd /usr/share/examples/viv_samples/cl11/UnitTest
root@LS1028ARDB-Ubuntu:/usr/share/examples/viv_samples/cl11/UnitTest# ./clinfo

>>>>>>> ./clinfo Starting...

Available platforms: 1

Platform ID: 0
  CL_PLATFORM_NAME:      Vivante OpenCL Platform
  CL_PLATFORM_PROFILE:   FULL_PROFILE
  CL_PLATFORM_VERSION:   OpenCL 1.2 V6.4.0.p2.234062
  CL_PLATFORM_VENDOR:    Vivante Corporation
  CL_PLATFORM_EXTENSIONS: cl_khr_icd

Available devices:      1

Device ID:              0
Device Ptr:              0xd04742f0
  CL_DEVICE_NAME:       Vivante OpenCL Device GC7000UL.6202.0000
  CL_DEVICE_VENDOR:     Vivante Corporation
  CL_DEVICE_TYPE:       GPU
  CL_DEVICE_OPENCL_C_VERSION: OpenCL C 1.2
  CL_DEVICE_VENDOR_ID:  0x00564956
  CL_DEVICE_PLATFORM:   0x9e272728
  CL_DEVICE_VERSION:    OpenCL 1.2
  CL_DEVICE_PROFILE:    FULL_PROFILE
  CL_DRIVER_VERSION:    OpenCL 1.2 V6.4.0.p2.234062
  CL_DEVICE_MAX_COMPUTE_UNITS: 1
  CL_DEVICE_MAX_WORK_ITEM_DIMENSIONS: 3
    CL_DEVICE_MAX_WORK_ITEM_SIZES[0]: 512
    CL_DEVICE_MAX_WORK_ITEM_SIZES[1]: 512
    CL_DEVICE_MAX_WORK_ITEM_SIZES[2]: 512
  CL_DEVICE_MAX_WORK_GROUP_SIZE: 512
  CL_DEVICE_MAX_CLOCK_FREQUENCY: 650 MHz
  CL_DEVICE_IMAGE_SUPPORT: Yes
    CL_DEVICE_MAX_READ_IMAGE_ARGS: 128
    CL_DEVICE_MAX_WRITE_IMAGE_ARGS: 8
    CL_DEVICE_IMAGE2D_MAX_WIDTH: 8192
    CL_DEVICE_IMAGE2D_MAX_HEIGHT: 8192
    CL_DEVICE_IMAGE3D_MAX_WIDTH: 8192
    CL_DEVICE_IMAGE3D_MAX_HEIGHT: 8192
    CL_DEVICE_IMAGE3D_MAX_DEPTH: 8192
    CL_DEVICE_MAX_SAMPLERS: 16
  ...

```

B. Fourier transform based on GPU

```

root@LS1028ARDB-Ubuntu:~# cd /usr/share/examples/viv_samples/cl11/fft/
root@LS1028ARDB-Ubuntu:/usr/share/examples/viv_samples/cl11/fft# ./fft 16
Block size: 16
Print result: yes

Initializing device(s)...
Get the Device info and select Device...

```

```

# of Devices Available = 1
# of Compute Units = 1
# compute units = 1
Creating Command Queue...
log2(fft size) = log2(16)=4
Compiling radix-2 FFT Program for GPU...
creating radix-2 kernels...
Creating kernel fft_radix2 0 (p=1)...
Creating kernel fft_radix2 1 (p=2)...
Creating kernel fft_radix2 2 (p=4)...
Creating kernel fft_radix2 3 (p=8)...
Setting kernel args for kernel 0 (p=1)...
Setting kernel args for kernel 1 (p=2)...
Setting kernel args for kernel 2 (p=4)...
Setting kernel args for kernel 3 (p=8)...
running kernel 0 (p=1)...
running kernel 1 (p=2)...
running kernel 2 (p=4)...
running kernel 3 (p=8)...
Kernel execution time on GPU (kernel 0) : 0.000118 seconds
Kernel execution time on GPU (kernel 1) : 0.000122 seconds
Kernel execution time on GPU (kernel 2) : 0.000102 seconds
Kernel execution time on GPU (kernel 3) : 0.000076 seconds
Total Kernel execution time on GPU : 0.000418 seconds
Successful.

```

C. OpenGL ES demo

kmscube is used to test OpenGL ES, it supports HDMI and eDP interface.

For eDP interface, 4K resolution is not supported due to firmware limitation.

```

root@LS1028ARDB:~# kmscube
Using display 0x3107b6d0 with EGL version 1.5
=====
EGL information:
  version: "1.5"
  vendor: "Vivante Corporation"
  client extensions: "EGL_EXT_client_extensions EGL_EXT_platform_base EGL_KHR_platform_wayland
EGL_EXT_platform_wayland EGL_KHR_platform_gbm"
  display extensions: "EGL_KHR_fence_sync EGL_KHR_reusable_sync EGL_KHR_wait_sync EGL_KHR_image
EGL_KHR_image_base EGL_KHR_image_pixmap EGL_KHR_gl_texture_2D_image EGL_KHR_gl_texture_cubemap_image
EGL_KHR_gl_renderbuffer_image EGL_EXT_image_dma_buf_import EGL_EXT_image_dma_buf_import_modifiers
EGL_KHR_lock_surface EGL_KHR_create_context EGL_KHR_no_config_context EGL_KHR_surfaceless_context
EGL_KHR_get_all_proc_addresses EGL_EXT_create_context_robustness EGL_EXT_protected_surface
EGL_EXT_protected_content EGL_EXT_buffer_age EGL_ANDROID_native_fence_sync
EGL_WL_bind_wayland_display EGL_WL_create_wayland_buffer_from_image EGL_KHR_partial_update
EGL_EXT_swap_buffers_with_damage EGL_KHR_swap_buffers_with_damage"
=====
OpenGL ES 2.x information:
  version: "OpenGL ES 3.1 V6.4.0.p2.234062"
  shading language version: "OpenGL ES GLSL ES 3.10"
  vendor: "Vivante Corporation"
  renderer: "Vivante GC7000UL"
  extensions: "GL_OES_vertex_type_10_10_10_2 GL_OES_vertex_half_float GL_OES_element_index_uint
GL_OES_mapbuffer GL_OES_vertex_array_object GL_OES_compressed_ETC1_RGB8_texture
GL_OES_compressed_paletted_texture GL_OES_texture_npot GL_OES_rgb8_rgba8 GL_OES_depth_texture
GL_OES_depth_texture_cube_map GL_OES_depth24 GL_OES_depth32 GL_OES_packed_depth_stencil
GL_OES_fbo_render_mipmap GL_OES_get_program_binary GL_OES_fragment_precision_high
GL_OES_standard_derivatives GL_OES_EGL_image GL_OES_EGL_sync GL_OES_texture_stencil8

```

```
GL_OES_shader_image_atomic GL_OES_texture_storage_multisample_2d_array GL_OES_required_internalformat
GL_OES_surfaceless_context GL_OES_draw_buffers_indexed GL_OES_texture_border_clamp
GL_OES_texture_buffer GL_OES_texture_cube_map_array GL_OES_draw_elements_base_vertex
GL_OES_texture_half_float GL_OES_texture_float GL_KHR_blend_equation_advanced GL_KHR_debug
GL_KHR_robustness GL_KHR_robust_buffer_access_behavior GL_EXT_texture_type_2_10_10_10_REV
GL_EXT_texture_compression_dxt1 GL_EXT_texture_format_BGRA8888 GL_EXT_texture_compression_s3tc
GL_EXT_read_format_bgra GL_EXT_multi_draw_arrays GL_EXT_frag_depth GL_EXT_discard_framebuffer
GL_EXT_blend_minmax GL_EXT_multisampled_render_to_texture GL_EXT_color_buffer_half_float
GL_EXT_color_buffer_float GL_EXT_robustness GL_EXT_texture_sRGB_decode GL_EXT_draw_buffers_indexed
GL_EXT_texture_border_clamp GL_EXT_texture_buffer GL_EXT_texture_cube_map_array
GL_EXT_multi_draw_indirect GL_EXT_draw_elements_base_vertex GL_EXT_texture_rg
GL_EXT_protected_textures GL_EXT_sRGB GL_VIV_direct_texture "
=====
Rendered 120 frames in 2.000008 sec (59.999758 fps)
Rendered 241 frames in 4.016689 sec (59.999663 fps)
Rendered 361 frames in 6.016730 sec (59.999368 fps)
```

Below is the snapshot on screen.

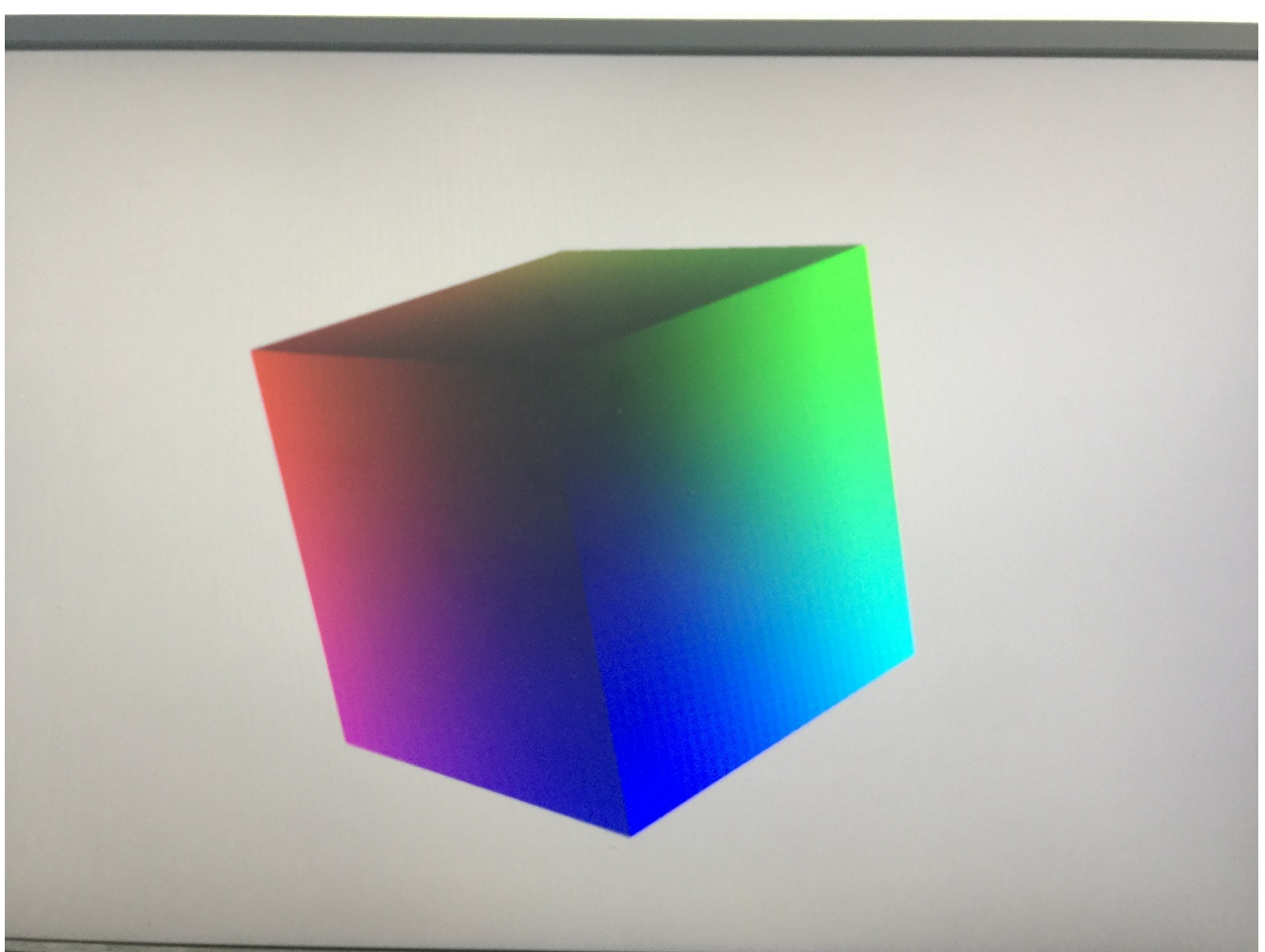


Figure 58. OpenGL ES demo with kmscube

Chapter 20

Weston

Weston is the reference implementation of a Wayland, this section describes how to enable Weston on NXP platforms. Weston is supported by LS1028ARDB, iMX8MPEVK and iMX8MMEVK platforms.

1. Software setting and configuration

Following the steps to enable Weston support on the target board:

- Configure the target board with `nxp_ls1028ardb-64b*` or `imx8mpevk_*`, for example: `nxp_ls1028ardb-64b_defconfig`

```
$ make nxp_ls1028ardb-64b_defconfig
```

- Enable weston and related packages using the command "make menuconfig":

```
Target packages --->
  Libraries --->
    Graphics --->
      *- wayland
  Hardware handling --->
    [*] Freescale i.MX libraries --->
      [*] firmware-imx
      [*] imx-gpu-g2d
      *- imx-gpu-viv
          Output option (Wayland) --->
      [*] install examples
      *- libdrm-imx
      *- wayland-protocols-imx
  Graphic libraries and applications (graphic/text) --->
    [*] weston-imx
    [*] X.org X Window System --->
    *- xkeyboard-config
```

- Build the image

```
make -j8
```

2. Hardware setup

- For LS1028ARDB, connect the monitor and LS1028ARDB with DP cable.
- For i.MX8MPEVK, connect the monitor and i.MX8MPEVK with HDMI cable.
- For i.MX8MMEVK, connect MIPI-DSI to HDMI module, then connect to monitor. Then, insert USB mouse and keyboard into USB port.

3. Run the lightweight desktop

```
root@LS1028ARDB:~# mkdir -p /run/user/0/
root@LS1028ARDB:~# export XDG_RUNTIME_DIR="/run/user/0/"
root@LS1028ARDB:~# weston --tty=1
# With parameter "-i" or "---idle-time" to set the time to enter idle state, default is 300s.
# "0" means weston will not enter idle state.
root@LS1028ARDB:~# weston --tty=1 -i 0 # or
root@LS1028ARDB:~# weston --tty=1 --idle-time=0

Date: 2020-08-20 UTC
[14:38:00.002] weston 8.0.0
https://wayland.freedesktop.org
```

```

Bug reports to: https://gitlab.freedesktop.org/wayland/weston/issues/
Build: 8.0.0
[14:38:00.002] Command line: weston --tty=1
[14:38:00.002] OS: Linux, 5.4.3-rt1, #1 SMP PREEMPT_RT Tue Aug 18 14:49:14 CST 2020, aarch64
[14:38:00.002] Starting with no config file.
[14:38:00.005] Output repaint window is 16 ms maximum.
[14:38:00.007] Loading module '/usr/lib/libweston-8/drm-backend.so'
[14:38:00.050] initializing drm backend
[14:38:00.054] using /dev/dri/card0
[14:38:00.054] DRM: supports universal planes
[14:38:00.054] DRM: supports atomic modesetting
[14:38:00.054] DRM: supports picture aspect ratio
[14:38:00.056] Loading module '/usr/lib/libweston-8/gl-renderer.so'
[14:38:00.208] EGL client extensions: EGL_EXT_client_extensions
EGL_EXT_platform_base EGL_KHR_platform_wayland
EGL_EXT_platform_wayland EGL_KHR_platform_gbm
[14:38:00.224] EGL version: 1.5
[14:38:00.224] EGL vendor: Vivante Corporation
[14:38:00.224] EGL client APIs: OpenGL_ES OpenGL_OpenVG
[14:38:00.224] EGL extensions: EGL_KHR_fence_sync EGL_KHR_reusable_sync
EGL_KHR_wait_sync EGL_KHR_image EGL_KHR_image_base
EGL_KHR_image_pixmap EGL_KHR_gl_texture_2D_image
EGL_KHR_gl_texture_cubemap_image EGL_KHR_gl_renderbuffer_image
EGL_EXT_image_dma_buf_import
EGL_EXT_image_dma_buf_import_modifiers EGL_KHR_lock_surface
EGL_KHR_create_context EGL_KHR_no_config_context
EGL_KHR_surfaceless_context EGL_KHR_get_all_proc_addresses
EGL_EXT_create_context_robustness EGL_EXT_protected_surface
EGL_EXT_protected_content EGL_EXT_buffer_age
EGL_ANDROID_native_fence_sync EGL_WL_bind_wayland_display
EGL_WL_create_wayland_buffer_from_image EGL_KHR_partial_update
EGL_EXT_swap_buffers_with_damage
EGL_KHR_swap_buffers_with_damage
[14:38:00.224] EGL_KHR_surfaceless_context available
[14:38:00.310] GL version: OpenGL ES 3.1 V6.4.0.p2.234062
[14:38:00.311] GLSL version: OpenGL ES GLSL ES 3.10
[14:38:00.311] GL vendor: Vivante Corporation
[14:38:00.311] GL renderer: Vivante GC7000UL
[14:38:00.311] GL extensions: GL_OES_vertex_type_10_10_10_2
GL_OES_vertex_half_float GL_OES_element_index_uint
GL_OES_mapbuffer GL_OES_vertex_array_object
GL_OES_compressed_ETC1_RGB8_texture
GL_OES_compressed_paletted_texture GL_OES_texture_npot
GL_OES_rgb8_rgba8 GL_OES_depth_texture
GL_OES_depth_texture_cube_map GL_OES_depth24 GL_OES_depth32
GL_OES_packed_depth_stencil GL_OES_fbo_render_mipmap
GL_OES_get_program_binary GL_OES_fragment_precision_high
GL_OES_standard_derivatives GL_OES_EGL_image GL_OES_EGL_sync
GL_OES_texture_stencil8 GL_OES_shader_image_atomic
GL_OES_texture_storage_multisample_2d_array
GL_OES_required_internalformat GL_OES_surfaceless_context
GL_OES_draw_buffers_indexed GL_OES_texture_border_clamp
GL_OES_texture_buffer GL_OES_texture_cube_map_array
GL_OES_draw_elements_base_vertex GL_OES_texture_half_float
GL_OES_texture_float GL_KHR_blend_equation_advanced
GL_KHR_debug GL_KHR_robustness
GL_KHR_robust_buffer_access_behavior
GL_EXT_texture_type_2_10_10_10_REV
GL_EXT_texture_compression_dxt1 GL_EXT_texture_format_BGRA8888
GL_EXT_texture_compression_s3tc GL_EXT_read_format_bgra

```

```

GL_EXT_multi_draw_arrays GL_EXT_frag_depth
GL_EXT_discard_framebuffer GL_EXT_blend_minmax
GL_EXT_multisampled_render_to_texture
GL_EXT_color_buffer_half_float GL_EXT_color_buffer_float
GL_EXT_robustness GL_EXT_texture_sRGB_decode
GL_EXT_draw_buffers_indexed GL_EXT_texture_border_clamp
GL_EXT_texture_buffer GL_EXT_texture_cube_map_array
GL_EXT_multi_draw_indirect GL_EXT_draw_elements_base_vertex
GL_EXT_texture_rg GL_EXT_protected_textures GL_EXT_sRGB
GL_VIV_direct_texture
[14:38:00.311] GL ES 2 renderer features:
read-back format: BGRA
wl_shm sub-image to texture: yes
EGL Wayland extension: yes
[14:38:00.343] warning: no input devices on entering Weston. Possible causes:
- no permissions to read /dev/input/event*
- seats misconfigured (Weston backend option 'seat', udev device property ID_SEAT)
[14:38:00.343] failed to create input devices
[14:38:00.349] DRM: head 'DP-1' found, connector 56 is connected, EDID make 'DEL', model 'DELL
P2417H', serial 'C9G5D7561ECB'
[14:38:00.349] Registered plugin API 'weston_drm_output_api_v1' of size 24
[14:38:00.357] Chosen EGL config details: id: 41 rgba: 8 8 8 0 buf: 24 dep: 0 stcl: 0 int: 1-60
type: win|pix|pbf|swap_preserved vis_id: XRGB8888 (0x34325258)
[14:38:00.357] Output DP-1 (crtc 48) video modes:
1920x1080@60.0, preferred, current, 148.5 MHz
1600x900@60.0, 108.0 MHz
1280x1024@75.0, 135.0 MHz
1280x1024@60.0, 108.0 MHz
1152x864@75.0, 108.0 MHz
1024x768@75.0, 78.8 MHz
1024x768@60.0, 65.0 MHz
800x600@75.0, 49.5 MHz
800x600@60.3, 40.0 MHz
640x480@75.0, 31.5 MHz
640x480@59.9, 25.2 MHz
720x400@70.1, 28.3 MHz
[14:38:00.357] Output 'DP-1' enabled with head(s) DP-1
[14:38:00.357] Compositor capabilities:
arbitrary surface rotation: yes
screen capture uses y-flip: yes
presentation clock: CLOCK_MONOTONIC, id 1
presentation clock resolution: 0.000000001 s
[14:38:00.359] Loading module '/usr/lib/weston/desktop-shell.so'
[14:38:00.367] launching '/usr/libexec/weston-keyboard'
[14:38:00.373] launching '/usr/libexec/weston-desktop-shell'
[14:39:23.341] event0 - Logitech USB Optical Mouse: is tagged by udev as: Mouse
[14:39:23.341] event0 - Logitech USB Optical Mouse: device is a pointer
[14:39:23.341] libinput: configuring device "Logitech USB Optical Mouse".
[14:39:23.342] associating input device event0 with output DP-1 (none by udev)
could not load cursor 'dnd-move'
could not load cursor 'dnd-copy'
could not load cursor 'dnd-none'
[14:39:33.459] event0 - Logitech USB Optical Mouse: device removed
[14:39:51.794] event0 - Dell Dell USB Keyboard: is tagged by udev as: Keyboard
[14:39:51.794] event0 - Dell Dell USB Keyboard: device is a keyboard
[14:39:51.859] libinput: configuring device "Dell Dell USB Keyboard".
[14:39:51.859] associating input device event0 with output DP-1 (none by udev)
[14:40:03.937] event0 - Dell Dell USB Keyboard: device removed
[14:40:11.758] event0 - Logitech USB Optical Mouse: is tagged by udev as: Mouse
[14:40:11.758] event0 - Logitech USB Optical Mouse: device is a pointer

```

```
[14:40:11.758] libinput: configuring device "Logitech USB Optical Mouse".
[14:40:11.758] associating input device event0 with output DP-1 (none by udev)
[14:40:19.403] event0 - Logitech USB Optical Mouse: device removed
[14:40:29.454] event0 - Dell Dell USB Keyboard: is tagged by udev as: Keyboard
[14:40:29.454] event0 - Dell Dell USB Keyboard: device is a keyboard
[14:40:29.454] libinput: configuring device "Dell Dell USB Keyboard".
[14:40:29.454] associating input device event0 with output DP-1 (none by udev)
[14:41:00.156] event0 - Dell Dell USB Keyboard: device removed

[14:42:29.287] event0 - Logitech USB Optical Mouse: is tagged by udev as: Mouse
[14:42:29.287] event0 - Logitech USB Optical Mouse: device is a pointer
[14:42:29.287] libinput: configuring device "Logitech USB Optical Mouse".
[14:42:29.287] associating input device event0 with output DP-1 (none by udev)
[14:42:35.418] event1 - Dell Dell USB Keyboard: is tagged by udev as: Keyboard
[14:42:35.419] event1 - Dell Dell USB Keyboard: device is a keyboard
[14:42:35.419] libinput: configuring device "Dell Dell USB Keyboard".
[14:42:35.419] associating input device event1 with output DP-1 (none by udev)
```

Below is the snapshot



Figure 59. Weston demo

Chapter 21

QT

This chapter introduces the QT feature for OpenIL and provides instructions on how to enable this feature on NXP's LS1028A reference design board.

21.1 Introduction

Qt is a full development framework with tools designed to streamline the creation of applications and user interfaces for desktop, embedded, and mobile platforms. For details, see <http://doc.qt.io/qt-5/index.html>

This section describes how to enable QT5 in OpenIL.

21.2 Software settings and configuration

Use the following steps to configure QT5 on target board and build the images (for example ls1028ardb).

1. **Configure the target board:** Use the configuration file `nxp_ls1028ardb-64b_defconfig` to enable QT following below commands:

```
make nxp_ls1028ardb-64b_defconfig
```

2. **Enable QT5:** Use the command `make menuconfig` to configure the QT5:

```
Target packages ->
Graphic libraries and applications (graphic/text) ->
[*] Qt5 ->
    [*] Compile and install examples (with code)
    [*] concurrent module
    [*] MySQL Plugin
    [*] PostgreSQL Plugin
    [*] gui module
    [*] widgets module
    [*] fontconfig support
    [*] GIF support
    [*] JPEG support
    [*] PNG support
    [*] qt5imageformats
    [*] qt5multimedia
    [*] qt5quickcontrols
    [*] qt5quickcontrols2
```

3. **Build the image using the command:**

```
make -j8
```

21.3 Hardware setup

For the QT setup, the following hardware items are required:

1. Monitor that supports DP interface. Make sure it supports 1080P format, otherwise the parameters in U-Boot should be adjusted.
2. Cable connecting DisplayPort to DisplayPort (DP to DP Cable).
3. USB wired/wireless mouse or keyboard.

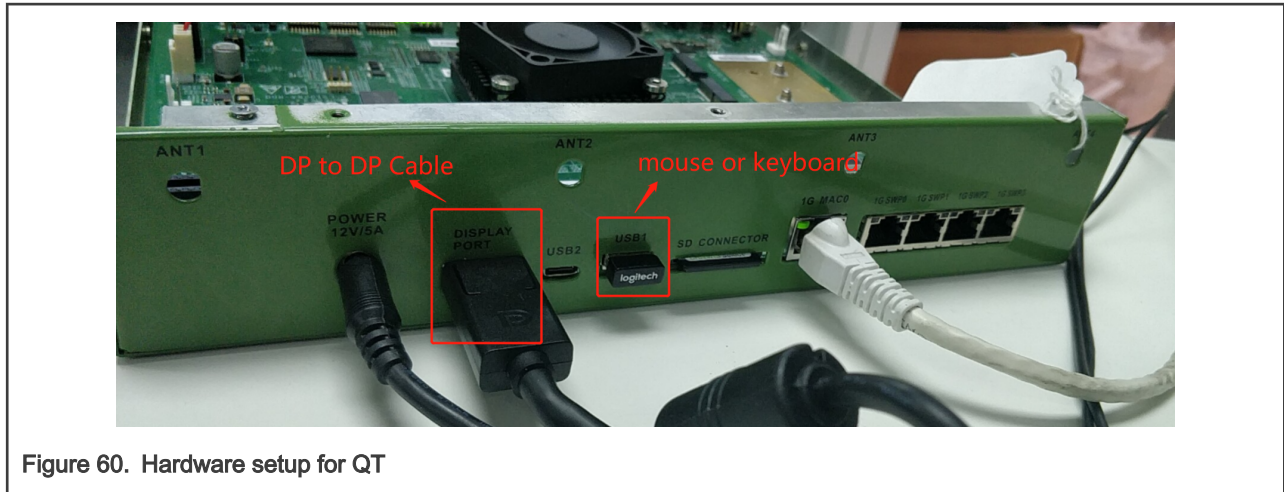


Figure 60. Hardware setup for QT

21.4 Running the QT5 demo

This section describes the steps for configuring the environment and running the QT demos for LS1028ARDB.

21.4.1 Environment setting

Use the steps listed below to configure the environment settings:

- Make sure that the `fonts` directory exists in the `/usr/share/` directory. If it does not exist, they can be found in the `root` directory, and copy one or more to `/usr/share`, as shown in the example below:

```
[root@OpenIL:~]# cd /
[root@OpenIL:]# find ./ -name fonts
./usr/lib/qt/examples/quickcontrols2/texteditor/fonts
./usr/lib/qt/examples/quickcontrols2/swipetoremove/fonts
./usr/lib/qt/examples/quick/text/fonts
./usr/lib/qt/examples/quick/text/fonts/content/fonts
./usr/lib/qt/examples/quickcontrols/extras/dashboard/fonts
./usr/lib/qt/examples/quickcontrols/extras/gallery/fonts
./usr/share/imlib2/data/fonts
./usr/share/fonts
./usr/share/fonts/content/fonts
./etc/fonts
[root@OpenIL:]# cp -r /usr/lib/qt/examples/quick/text/fonts /usr/share/
[root@OpenIL:]#
```

1. The QT5 framework is configured now, and user can add any applications.

21.4.2 Running the demos

There are many sample demos in the directory `/usr/lib/qt/examples`. Following are some of the demos and their corresponding commands:

1. **Example1:** Wiggly text

```
/usr/lib/qt/examples/widgets/widgets/wiggly/wiggly --platform linuxfb
```

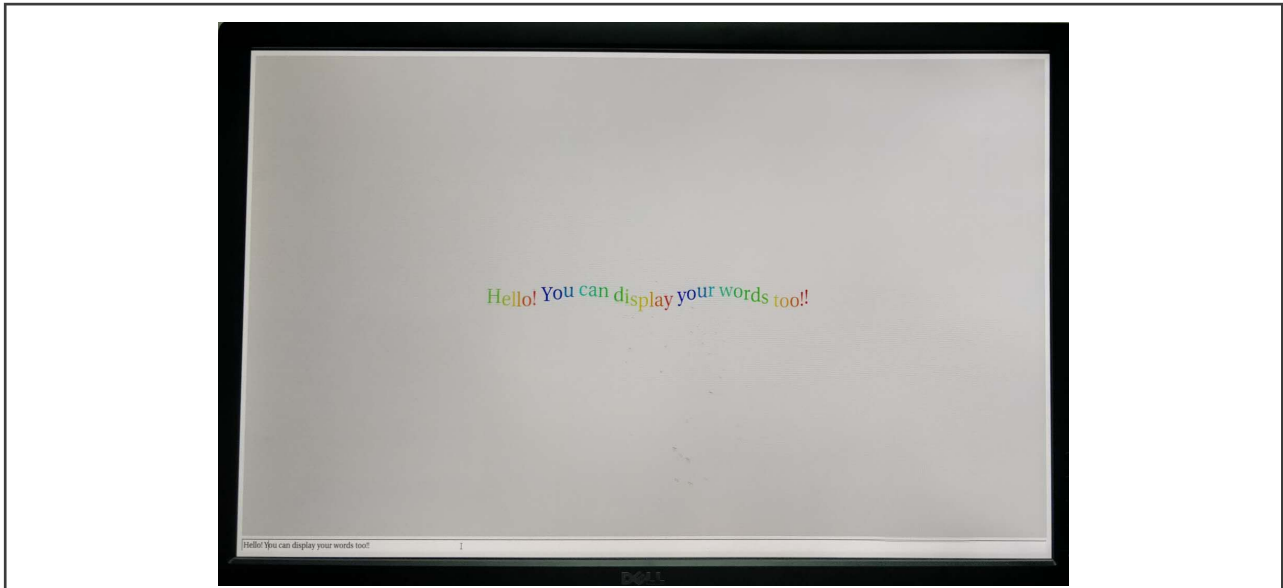


Figure 61. Example 1: Wiggly text

2. Example 2: Wearable system

```
/usr/lib/qt/examples/quickcontrols2/wearable/wearable --platform linuxfb
```

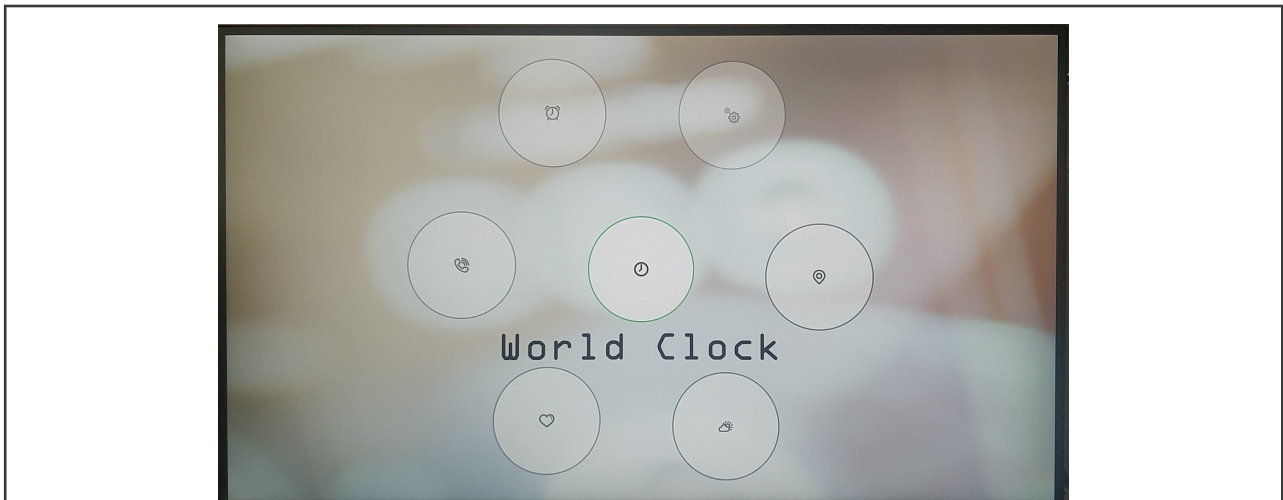


Figure 62. Example 2: Wearable system

3. Example 3: Analog clock

```
/usr/lib/qt/examples/gui/analogclock/analogclock --platform linuxfb
```



Figure 63. Example 3: Analog clock

Chapter 22

GenAVB/TSN stack

22.1 Introduction

The GenAVB/TSN Stack is a NXP proprietary software stack that provides advanced implementation for Audio Video Bridging (AVB) and Time-Sensitive Networking (TSN) functionalities on NXP SoCs and hardware platforms. These functions require TSN hardware support, and are only available in the LS1028ARDB and I.MX8MP boards.

This section provides information on how to set up and evaluate the GenAVB/TSN Stack. In that context, it provides information on supported SoCs and boards, compile time software package configuration, and runtime configuration settings.

22.1.1 gPTP stack

The gPTP stack implements IEEE 802.1AS-2020 standard, and supports both time-aware Endpoint and Bridge systems. The stack runs fully in userspace, using Linux socket API's for packet transmit, receive and timestamping. Linux clock API's are used for clock adjustment. Configuration files are used to configure the stack at initialization time and extensive logging is available at run time.

22.1.2 TSN Endpoint example application

The TSN example application provides example code and re-usable middleware exercising the GenAVB TSN API. It is used to exercise and verify the real time behavior of the local system as well as TSN properties of the network between endpoints.

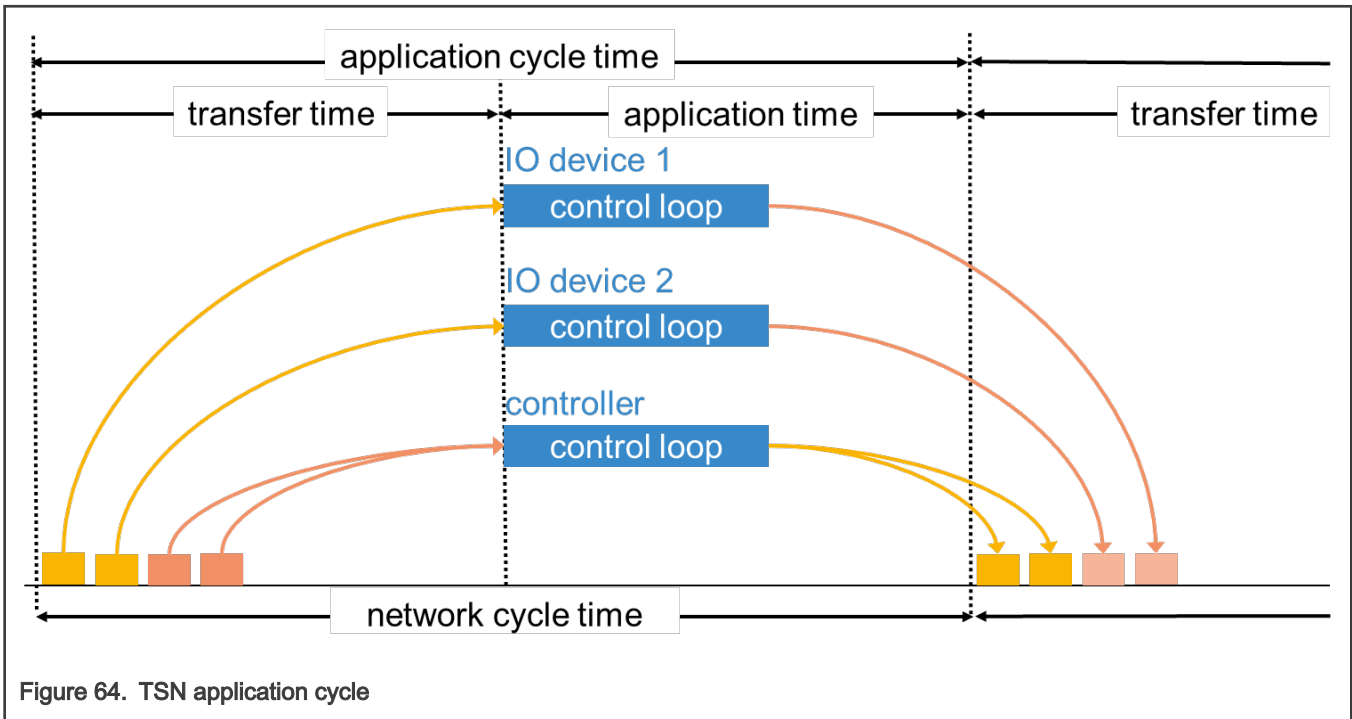
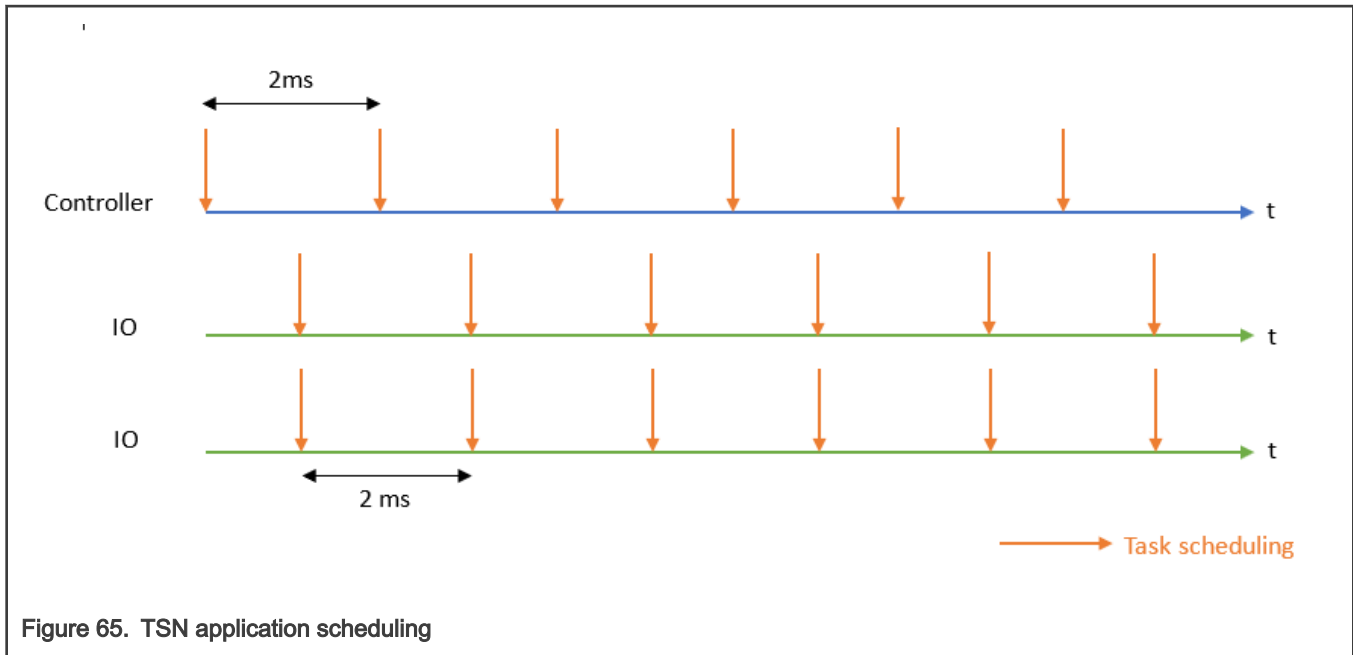


Figure 64. TSN application cycle

The TSN example application implements a control loop similar to industrial use cases requiring cyclic isochronous exchanges over the network.

The TSN endpoints run their application synchronized to a common time grid in the same gPTP domain so that they can send and receive network traffic in a cyclic isochronous pattern (the application cycle time is equal and synchronous to the network cycle time as shown in above figure). Currently the cycle is configured with a period of 2ms. When the application is scheduled, frames from other endpoints are ready to be read and at the end of the application time frames are sent to other endpoints.



As shown in the figure above, the controller and the IO devices are scheduled with a half cycle offset in order to reduce the processing latency.

The time sensitive traffic is layer 2 multicast with VLAN header and proprietary EtherType. Its priority is defined using the PCP field of the VLAN header.

In addition, the TSN application provides detailed logs and time sensitive traffic timing statistics (based on hardware timestamping of packets) which allow characterization of an entire real time distributed system.

22.1.3 Supported configurations

GenAVB/TSN Stack currently supports the following boards and the associated roles:

- LS1028ARDB: gPTP Time-aware Bridge
- I.MX8MPEVK: gPTP Time-aware Endpoint station and TSN Endpoint example application

The stack supports and is enabled in the following OpenIL configurations:

- nxp_ls1028ardb-64b_defconfig
- nxp_ls1028ardb-64b-emmc_defconfig
- nxp_ls1028ardb-64b-xspi_defconfig
- imx8mpevk_defconfig

22.2 Software preparation

GenAVB/TSN bridge/endpoint-tsn packages are included by default when available for a given board configuration. In order to enable/disable the package in OpenIL distribution, use the “make menuconfig” command:

```
Target packages --->
  Hardware handling --->
    NXP QorIQ libraries --->
```

To enable/disable GenAVB/TSN bridge package:

```
[ ] qorIQ-genavb-tsn-bridge
```

To enable/disable GenAVB/TSN endpoint-tsn package:

```
[ ] qoriq-genavb-tsn-endpoint-tsn
```

22.3 GenAVB/TSN stack start/stop

GenAVB/TSN stack can be manually started/stopped at run time by using the following commands:

```
# avb.sh <start|stop>
```

This will start all stack components and example application. The stack can be automatically started during system startup, by setting the variable `CFG_AUTO_START` to 1 in the file `/etc/genavb/config`.

To just start/stop the gPTP stack use:

```
# fgptp.sh <start|stop>
```

22.4 Use cases description

22.4.1 gPTP Bridge

LS1028ARDB can be used as a generic time-aware bridge, connected to other time-aware end stations or bridges.

By default, LS1028ARDB does not forward packets if no bridge interface is configured under Linux. Enabling bridge interface is dependent on the board used. For example, how to configure bridge interface on LS1028ARDB is described in section [Linux switch configuration](#).

Once gPTP stack is started, logs can be displayed with the following command:

```
# tail -f /var/log/fgptp-br
```

In this log file, one can observe which ports are connected, which ports are currently communicating a synchronized time and what is the role of the port in the time-aware system.

If a port of the bridge is connected to another port capable of communicating a synchronized time, the following log should appear for each enabled gPTP domain:

```
gptp_stats_dump : Port(1) domain(0,0): Role: Master Link: Up AS_Capable: Yes
...
gptp_stats_dump : Port(1) domain(1,20): Role: Master Link: Up AS_Capable: Yes
```

Role status can also take the value *Slave* depending on *parameters* described in section [Grandmaster parameters](#).

If a port is not connected, *Link* status takes the value *Down*.

If a port is not capable of communicating a synchronized time, *AS_Capable* status takes the value *No*.

For further details about gPTP logs, refer to section [gPTP Bridge](#).

22.4.2 gPTP Endpoint

Once gPTP stack is started, logs can be displayed with the following command:

```
# tail -f /var/log/fgptp
```

In this log file, one can observe the role of the port in the time-aware system.

If the port of the endpoint is connected to another port capable of communicating a synchronized time, the following log should appear for each gPTP domain:

```
gptp_stats_dump : Port(0) domain(0,0): Role: Slave Link: Up AS_Capable: Yes
...
gptp_stats_dump : Port(0) domain(1,20): Role: Slave Link: Up AS_Capable: Yes
```

Role status can also take the value *Master* depending on *Grandmaster Parameters* described in section [Grandmaster parameters](#).

If a port is not connected, *Link* status takes the value *Down*.

If a port is not capable of communicating a synchronized time, *AS_Capable* status takes the value *No*.

For further details about gPTP logs, refer to section [gPTP Endpoint](#).

22.4.3 gPTP multiple domains

This use case illustrates two gPTP domains co-existing independently on a TSN network, over different 802.1AS-2020 Time-aware systems.

The first domain uses the PTP timescale whereas the second domain uses the ARB (arbitrary) timescale.

22.4.3.1 Requirements

The reference setup for gPTP multiple domains is made of:

- Two gPTP endpoints (i.MX8MPEVK): EP1-DUT and EP2-DUT
- One gPTP bridge (LS1028ARDB): BR-DUT

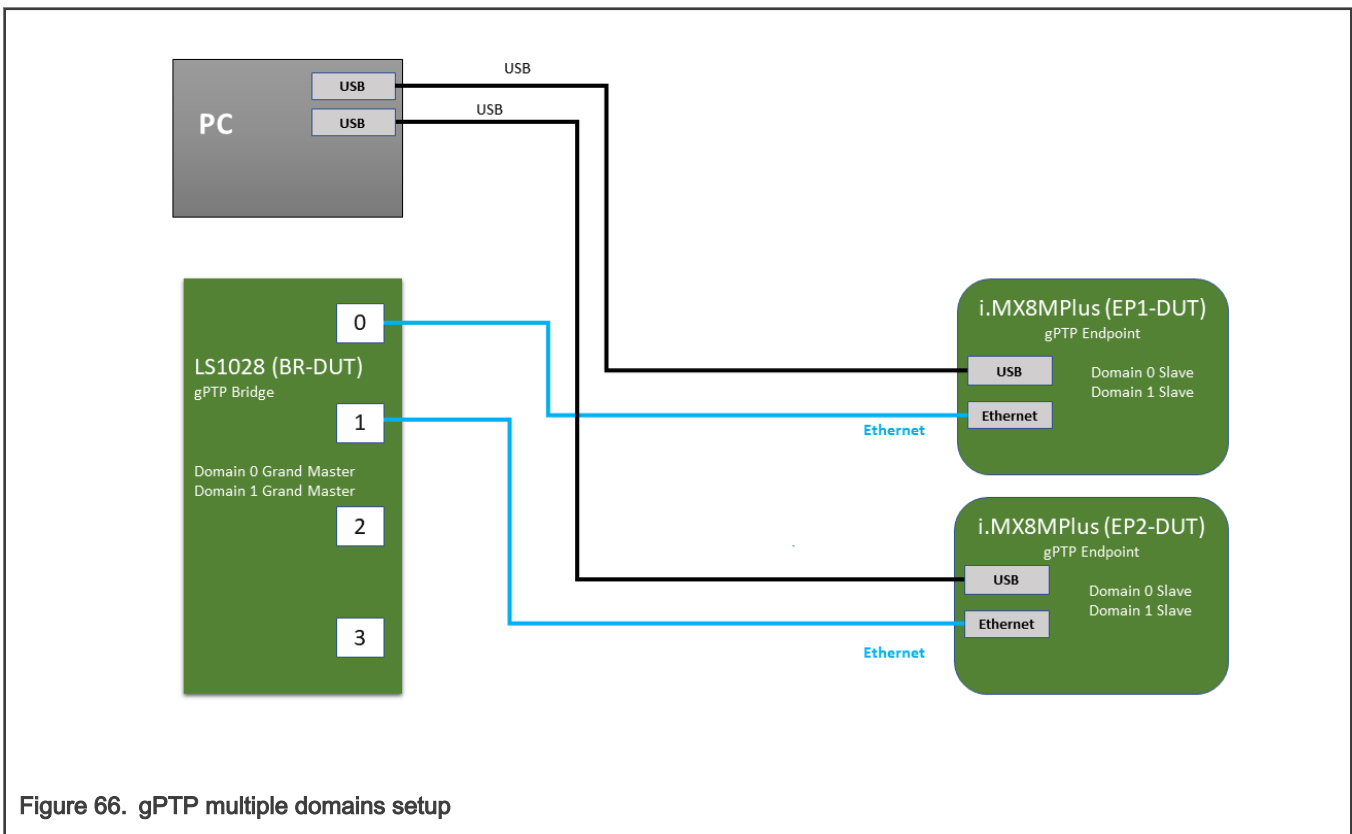


Figure 66. gPTP multiple domains setup

22.4.3.2 gPTP Stack Configuration

The gPTP stack can enable or disable each domain independently through a configuration file.

The default configuration file (e.g.: `/etc/genavb/fgptp.cfg`) is for general gPTP parameters as well as domain 0 parameters. To enable other domains, new files must be created with '-N' appended to the filename (e.g.: `/etc/genavb/fgptp.cfg-1` for domain 1).

For gPTP multiple domains, all devices configuration should be changed to support two domains. The first domain (domain 0) must be assigned domain number 0. The second domain (domain 1) is assigned domain number 20.

On EP1-DUT and EP2-DUT, edit the file `/etc/genavb/fgptp.cfg-1` and change `domain_number` parameter as follow:

```
domain_number = 20
```

On BR-DUT, edit the file `/etc/genavb/fgptp-br.cfg-1` and change `domain_number` parameter as follow:

```
domain_number = 20
```

ATTENTION

On both Domain 0 and Domain 1, BR-DUT is the GrandMaster with the highest priority among all devices (BR-DUT priority1=246, EP1-DUT and EP2-DUT priority1=248)

22.4.3.3 Evaluation Instructions

Test Procedure

1. start gPTP stack manually on all DUT's by issuing the command

```
# fgptp.sh start
```

2. wait 30s
3. check gPTP stack logs on EP1-DUT and EP2-DUT (`/var/log/fgptp`)

Verification

After Step 3, logs in EP1-DUT and EP2-DUT are reporting Port 0 as synchronized:

```
Port(0) domain(0, 0) SYNCHRONIZED - synchronization time (ms): 250
```

```
Port(0) domain(1, 20) SYNCHRONIZED - synchronization time (ms): 250
```

The "*Initial adjustment*" message should be reported only once per domain on each DUT:

```
domain(0,0) Initial Adjustment, offset: 125486471315484 ns, freq_adj: 32764
```

```
domain(1,20) Initial Adjustment, offset: 125455671332661 ns, freq_adj: 16384
```

Once synchronization is achieved on EP1-DUT and EP2-DUT, all the reported clock offset average values should be stable within -50 to +50 ns range:

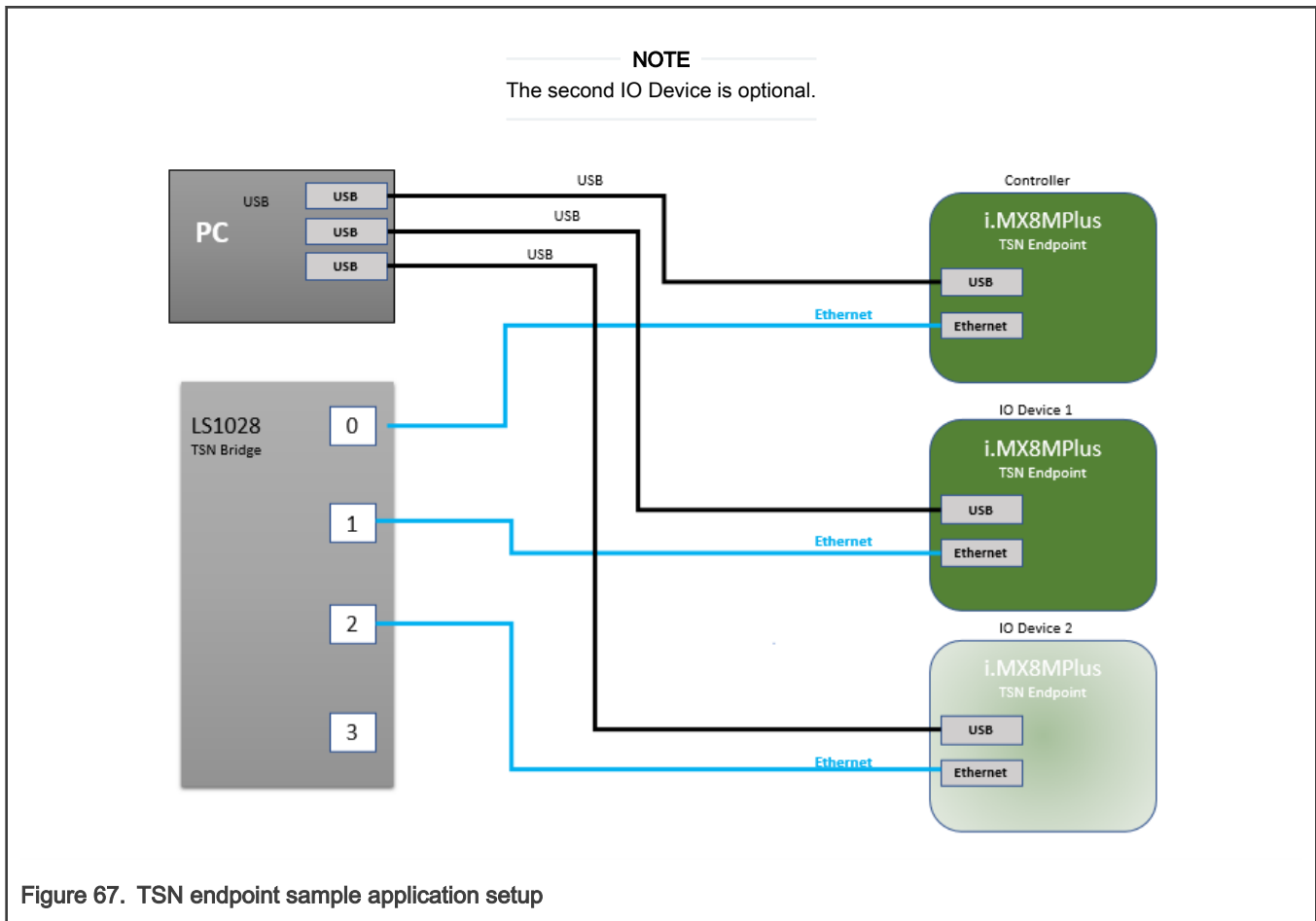
```
domain(0,0) Offset between GM and local clock (ns): min -45 avg 0 max 35
```

```
domain(1,20) Offset between GM and local clock (ns): min -66 avg 0 max 15
```

22.4.4 TSN endpoint sample application

22.4.4.1 Requirements

- Two TSN endpoints (i.MX8MPEVK)
- One TSN bridge (LS1028ARDB)



22.4.4.2 Configuring GenAVB/TSN stack and example applications

The change from one configuration to another is made by modifying the `/etc/genavb/config` file. This file specifies a pair of configuration files:

1. APPS_CFG_FILE (apps-*.cfg) points to a file containing a demo configuration (application to use, options...). It is parsed by the startup script `avb.sh`
2. GENAVB_CFG_FILE (genavb-*.cfg) points to a file containing the configuration of the GenAVB/TSN stack and is parsed by the stack.

A configuration profile is made of a pair of cfg files. The file `/etc/genavb/config` already groups the cfg files by pairs. Set the `PROFILE` variable to choose the desired configuration profile.

22.4.4.3 TSN network configuration

22.4.4.3.1 Streams

The stream details can be used for analysis and also for computing scheduled traffic timings.

Table 50. TSN streams definition

| | Source | Destination | Unicast/ Multicast | Destination MAC Address | Vlan ID | Vlan PCP | Frame Length ¹ (bytes) |
|----------------|-------------|--------------|-----------------------|----------------------------|---------|----------|---|
| Stream1 | Controller | IO device(s) | Multicast | 91:e0:f0:00:fe :70 | 2 | 5 | 84 |
| Stream2 | IO device 1 | Controller | Multicast | 91:e0:f0:00:fe :71 | 2 | 5 | 84 |
| Stream3 | IO device 2 | Controller | Multicast | 91:e0:f0:00:fe :80 | 2 | 5 | 84 |

1. The frame length includes inter frame gap, preamble, start of frame and CRC (can be used as is for timing calculations)

22.4.4.3.2 Scheduled traffic

For deterministic packet transmission the use of scheduled traffic is required both on endpoints and bridges.

The default scheduling configuration for the TSN endpoint example application, as shown in [Figure 65](#), leads to the following traffic schedules.

22.4.4.3.2.1 Endpoints

Endpoints are running a schedule with a 2000us period. The base offset of the schedule is aligned to gPTP time modulo 1 second.

Controller transmit gate (for Stream1) opens at 500us offset (relative to the period start).

IO device transmit gate (for Stream2/3) opens at 1000us + 500us offset (relative to the period start).

The gate open interval is around 4us (enough to accommodate the stream frame length plus some margin).

The 500us offset is related to the worst case application latency to send its frame to its peer(s). This value provides a good margin for a Linux PREEMPT-RT system but can be lowered on a well-tuned system.

22.4.4.3.2.2 Bridges

The schedule for all Bridges and all Bridge ports that transmit one of the streams above, must have a 2000us period and a base offset aligned to gPTP time modulo 1 second.

One possible schedule is to open transmit gate (for the ports and queues transmitting Stream 1) at offset 500us and use a gate open interval that accommodates the worst propagation delay.

It's also possible to use a fixed gate open interval but increase the transmit time offset at each hop along the stream path.

For ports and queues transmitting Stream 2 and 3, open the transmit gate at offset 1000 + 500us.

22.4.4.4 Setup preparation

One of the TSN endpoint needs to be configured as “controller” and the other one as “IO device”. Both endpoints are connected to the TSN bridge.

22.4.4.4.1 Preparing the controller

To be done once:

1. Edit the GenAVB configuration file using the following command at the Linux prompt:

```
# vi /etc/genab/config
```

2. Set the configuration profile to PROFILE 1:

```
PROFILE=1
```

3. Exit and save.

To be done at each boot:

1. Setup scheduled traffic using tc (may be done before or after starting tsn-app):

```
# tc qdisc add dev eth1 parent root handle 100 taprio \  
num_tc 3 \  
map 0 0 0 0 0 1 2 0 0 0 0 0 0 0 0 0 \  
queues 1@0 1@1 1@2 \  
base-time 000500000 \  
sched-entry S 0x2 4000 \  
sched-entry S 0x5 1996000 \  
flags 0x2
```

2. Start the tsn-app application:

```
# avb.sh start
```

22.4.4.4.2 Preparing IO device(s)

To be done once:

1. Edit the GenAVB configuration file using the following command at the Linux prompt:

```
# vi /etc/genab/config
```

2. Set the configuration profile to PROFILE 2:

```
PROFILE=2
```

3. Exit and save.

To be done at each boot:

1. Setup scheduled traffic using tc (may be done before or after starting tsn-app):

```
# tc qdisc add dev eth1 parent root handle 100 taprio \  
num_tc 3 \  
map 0 0 0 0 0 1 2 0 0 0 0 0 0 0 0 0 \  
queues 1@0 1@1 1@2 \  
base-time 001500000 \  
sched-entry S 0x2 4000 \  
sched-entry S 0x5 1996000 \  
flags 0x2
```

2. Start the tsn-app application:

```
# avb.sh start
```

22.4.4.4.3 Preparing the Bridge

Refer to section [TSN configuration](#) and [Tc-taprio usage](#) to configure scheduled traffic on the LS1028ARDB board.

The schedule described in section [Bridges](#) should be followed.

To be done at each boot:

1. Setup bridge forwarding:

```
# ip link add name br0 type bridge
# ip link set br0 up
# ip link set master br0 swp0
# ip link set master br0 swp1
# ip link set master br0 swp2
# ip link set master br0 swp3
```

2. Setup scheduled traffic (see above)

```
# echo "t0 00100000b 10000" > qbv.txt
# echo "t1 11011111b 1990000" >> qbv.txt
# tsntool qbvset --device swp0 --entryfile ./qbv.txt --basetime 1500000
# tsntool qbvset --device swp1 --entryfile ./qbv.txt --basetime 500000
# tsntool qbvset --device swp2 --entryfile ./qbv.txt --basetime 500000
```

3. Start the gPTP stack:

```
# fgptp.sh start
```

22.4.4.5 Evaluation instructions

1. Reset all endpoints.
2. Using the procedures described above, start the gPTP stack on the bridge, and the tsn-app application on the endpoints.
3. Enable scheduled traffic on the endpoints (and the bridge) with the configuration(s) described above.
4. After a few seconds, TSN endpoints should be synchronized through gPTP and exchanging packets at the rate of 500 packets per second (pps). In order to observe this behavior, logs need to be checked.

If the gPTP protocol is running correctly on an endpoint or on the bridge, the following line should appear in the gptp log file (refer to [gPTP Endpoint](#) for more details):

```
gptp_stats_dump: Port(0) domain(0,0) : Role: Slave Link : Up AS_Capable: Yes
```

If the device is grand master, the role field should be "Master" otherwise it should be "Slave".

If the TSN endpoint sample application is running and receiving valid packets, the following line should appear in the tsn_app log file (refer to [TSN Endpoint example application](#) for more details).

```
socket_stats_print : link up
```

Between two appearances of the following log, the number represented by XXXXX should increment by 2500 (500 pps for 5 seconds):

```
socket_stats_print : valid frames : XXXXX
```

22.4.4.5.1 Scheduled traffic evaluation

With scheduled traffic enabled, the measurements on the received frames show a stable latency and reduced jitter.

Observe traffic latency stats:

```
stats_print stats(0x419a28) traffic latency min 503417 mean 503503 max 503637 rms^2 253515981945
stddev^2 2004 absmin 503397 absmax 504337
```

- Latency is around 503us (time offset at which the time sensitive traffic gate opens plus transit time)
- Latency jitter is around 300 ns

22.5 Configuration files

22.5.1 System

The system configuration file, located in `/etc/genavb/system.cfg`, lists system network interface names and PTP hardware clock device names. The default values are used if the configuration file or the option key are missing. The values in the installed file may also need to be updated to match the system configuration.

This section lists network interface names.

Currently endpoint package supports a single endpoint and bridge package a single bridge (with up to 5 ports).

Table 51. Logical ports

| Name | Key | Default value | Description |
|----------------------------|----------|--|---|
| Endpoint interface | endpoint | eth0 | Endpoint network interface name. Only valid for endpoint package, otherwise should be set to "off" |
| Bridge 0 interfaces | bridge_0 | SJA1105P_p0, SJA1105P_p1, SJA1105P_p2, SJA1105P_p3, SJA1105P_p4* | Bridge 0 network interface names (comma separated). Only valid for bridge package, otherwise should be set to "off" |

This section lists clock device names.

Clocks names are either a PHC device name or a generic software clock (`sw_clock`). Local clock points to a PHC device, target clocks point to either:

- The same PHC device as local clock (gPTP time is reflected in the local clock)
- A generic software clock (in which case gPTP time is not reflected in the local clock).

Table 52. Clock

| Name | Key | Default value | Description |
|--|-----------------|---------------|---|
| Endpoint gPTP domain 0 target clock | endpoint_gptp_0 | /dev/ptp0 | Endpoint clock for gPTP domain 0 target clock. Only valid for endpoint package. |
| Endpoint gPTP domain 1 target clock | endpoint_gptp_1 | sw_clock | Endpoint clock for gPTP domain 1 target clock. Only valid for endpoint package. |

Table continues on the next page...

Table 52. Clock (continued)

| Name | Key | Default value | Description |
|-----------------------------------|----------------|---------------|---|
| Endpoint local clock | endpoint_local | /dev/ptp0 | Endpoint clock for the local clock. Only valid for endpoint package. |
| Bridge gPTP domain 0 target clock | bridge_gptp_0 | /dev/ptp1 | Bridge clock for gPTP domain 0 target clock. Only valid for bridge package. |
| Bridge gPTP domain 1 target clock | bridge_gptp_1 | sw_clock | Bridge clock for gPTP domain 1 target clock. Only valid for bridge package. |
| Bridge local clock | bridge_local | /dev/ptp1 | Bridge clock for the local clock. Only valid for bridge package. |

22.5.2 gPTP

The gPTP general parameters as well as default domain (domain 0) parameters are defined in the following configuration files depending on the package used:

- Endpoint package: `/etc/genavb/fgptp.cfg`
- Bridge package: `/etc/genavb/fgptp-br.cfg`

To enable other domains, new configuration files must be created with the associated domain instance appended to the configuration file name e.g.:

- Endpoint package, domain 1: `/etc/genavb/fgptp.cfg-1`
- Bridge package, domain 1: `/etc/genavb/fgptp-br.cfg-1`

ATTENTION

By default the GenAVB/TSN gPTP stack is packaged with the general parameters configuration file (`fgptp.cfg` or `fgptp-br.cfg`) and a reference configuration for domain 1 (`fgptp.cfg-1` or `fgptp-br.cfg-1`)

22.5.2.1 General

Profile

The gPTP stack can operate in two different modes known as 'standard' or 'automotive' profiles.

When the 'standard' profile is selected, the gPTP stack operates following the specifications described in IEEE 802.1AS. When the 'automotive' profile is selected, the gPTP stack operates following the specifications described in the AVnu AutoCDSFunctionalSpec_1.4 which is a subset of the IEEE 802.1AS standard optimized for automotive applications. IEEE 802.1AS-2020 features are not available in 'automotive' profile (e.g. Multiple domains).

The automotive environment is unique in that it is a closed system. Every network device is known prior to startup and devices do not enter or leave the network, except in the case of failures. Because of the closed nature of the automotive network, it is possible to simplify and improve gPTP startup performance. Specifically, functions like election of a grand master and calculations of wire delays are tasks that can be optimized for a closed system.

Reverse sync feature control

The Reverse Sync feature (Avnu specification) should be used for test/evaluation purpose only. Usually, to measure the accuracy of the clock synchronization, the traditional approach is to use a 1 Pulse Per Second (1PPS) physical output. While this is a good approach, there may be cases where using a 1PPS output is not feasible. More flexible and fully relying on software

implementation the Reverse Sync feature serves the same objective using the standard gPTP Sync/Follow-Up messages to relay the timing information, from the Slave back to the GM.

Neighbor propagation delay threshold

The parameter `neighborPropDelayThresh` defines the propagation time threshold, above which a port is not considered capable of participating in the IEEE 802.1AS protocol (see IEEE 802.1AS-2020 - 11.2.2 Determination of `asCapable` and `asCapableAcrossDomains`). If a computed `neighborPropDelay` exceeds `neighborPropDelayThresh`, then `asCapable` is set to FALSE for the port. This setting does not apply to Automotive profile where a link is always considered to be capable or running IEEE 802.1AS.

General configuration parameters¹

Table 53. General parameters

| Name | Key | Default value | Range | Description |
|---|--------------------------------------|---|-------------------------------|---|
| Profile | <code>profile</code> | "standard" | "standard" or "automotive" | Set fgptp main profile. "standard" - IEEE 802.1AS specs, "automotive" - AVnu automotive profile |
| Grandmaster ID | <code>gm_id</code> | "0x0001f2ffe0025fe" | 64bits EUI format | Set static grandmaster ID in host order (used by automotive profile, ignored in case of standard profile) |
| Domains | <code>domain_number</code> | 0: for default domain -1: for domains different from 0 | -1 to 127 | Disable (-1) or assign a gPTP domain number to a domain instance. |
| Log output level | <code>log_level</code> | info | crit, err, init, info, or dbg | Set this configuration to dbg to enable debug mode |
| Reverse sync feature control | <code>reverse_sync</code> | 0 | 0 or 1 | Set to 1 to enable reverse sync transmit on slave side |
| Reverse sync feature interval | <code>reverse_sync_interval</code> | 112 | 32 to 10000 | Reverse sync transmit interval in ms units |
| Neighbor propagation delay threshold | <code>neighborPropDelayThresh</code> | 800 | 32 to 10000000 | Neighbor propagation delay threshold expressed in ns |
| Statistics output interval | <code>statsInterval</code> | 10 | 0 to 255 | Statistics output interval expressed in seconds. Use 0 to disable statistics |

1. For domain instances other than 0, only `domain_number` is configurable in this section.

22.5.2.2 Grandmaster parameters

This section defines the native Grand Master capabilities of a time-aware system (see IEEE 802.1AS-2020 - 8.6.2 PTP Instance attributes). Grand Master capabilities parameters are defined in the main configuration file for gPTP domain 0 (e.g. `fgptp.cfg`) and in the additional per domain configuration files for other domains (e.g. `fgptp.cfg-1`).

`gmCapable` defines if the time-aware system is capable of being a grandmaster. By default `gmCapable` is set to 1 as in standard profile operation the Grand Master is elected dynamically by the BMCA. In case of automotive profile `gmCapable` must be set on

each AED node to match the required network topology (i.e. within a given gPTP domain only one node must have its gmCapable property set to 1).

priority1, priority2, clockClass, clockAccuracy and offsetScaledLogVariance are parameters used by the Best Master Clock algorithm to determine which of the Grand Master capable node within the gPTP domain has the highest priority/quality. Note that the lowest value for these parameters matches the highest priority/quality.

Grandmaster capabilities parameters¹

Table 54. Grandmaster parameters

| Name | Key | Default value | Range | Description |
|---|-------------------------|---------------------------------|---------------|--|
| Grandmaster capable setting | gmCapable | 1 | 0 or 1 | Set to 1 if the device has grandmaster capability. Ignored in automotive profile if the port is SLAVE. |
| Grandmaster priority1 value | priority1 | 248 for AED-E and 246 for AED-B | 0 to 255 | Set the priority1 value of this clock |
| Grandmaster priority2 value | priority2 | 248 | 0 to 255 | Set the priority2 value of this clock |
| Grandmaster clock class value | clockClass | 248 | 0 to 255 | Set the class value of this clock |
| Grandmaster clock accuracy value | clockAccuracy | 0xfe | 0x0 to 0xff | Set the accuracy value of this clock |
| Grandmaster variance value | offsetScaledLogVariance | 17258 | 0x0 to 0xffff | Set the offset scaled log variance value of this clock |

1. The parameters in this section are configurable for all supported domains.

22.5.2.3 Automotive parameters

The static pdelay feature is used only if the gPTP stack operates in automotive profile configuration.

At init time the gPTP stack's configuration file is parsed and based on neighborPropDelay_mode the specified initial_neighborPropDelay is applied to all ports and used for synchronization until a pdelay response from the peer is received. This is done only if no previously stored pdelay is available from the nvram database specified by nvram_file. As soon as a pdelay response from the peer is received the 'real' pdelay value is computed, and used for current synchronization. An indication may then be sent via callback up to the OS-dependent layer. Upon new indication the Host may update its nvram database and the stored value will be used at next restart for the corresponding port instead of the initial_neighborPropDelay. The granularity at which pdelay change indications are sent to the Host is defined by the neighborPropDelay_sensitivity parameter.

In the gPTP configuration file the neighborPropDelay_mode parameter is set to 'static' by default, meaning that a predefined propagation delay is used as described above while pdelay requests are still sent to the network.

The 'silent' mode behaves the same way as the 'static' mode except that pdelay requests are never sent at all to the network.

Optionally the neighborPropDelay_mode parameter can be set to standard forcing the stack to operate propagation delay measurements as specified in the 802.1AS specifications even if the automotive profile is selected.

(see AutoCDSFunctionalSpec-1_4 - 6.2.2 Persistent gPTP Values)

Table 55. Automotive parameters

| Name | Key | Default value | Value & Range | Description |
|----------------------------------|-------------------------------|-----------------------------|----------------------------------|--|
| Pdelay mode | neighborPropDelay_mode | static | 'static', 'silent' or 'standard' | Defines pdelay mechanism used |
| Static pdelay value | initial_neighborPropDelay | 250 | 0 to 10000 | Predefined pdelay value applied to all ports. Expressed in ns. |
| Static pdelay sensitivity | neighborPropDelay_sensitivity | 10 | 0 to 1000 | Amount of ns between two pdelay measurements required to trigger a change indication. Expressed in ns. |
| Nvram file name | nvram_file | /etc/genavb/ fgptp.nvram | | Path and nvram file name. |

22.5.2.4 Timing

Pdelay requests and Sync messages sending intervals have a direct impact on the system synchronization performance. To reduce synchronization time while optimizing overall system load, two levels of intervals are defined. The first level called 'Initial', defines the messages intervals used until pdelay values have stabilized and synchronization is achieved. The second level called 'Operational', defines the messages intervals used once the system is synchronized.

initialLogPdelayReqInterval and operLogPdelayReqInterval define the intervals between the sending of successive Pdelay_Req messages. initialLogSyncInterval and operLogSyncInterval define the intervals between the sending of successive Sync messages. initialLogAnnounceInterval defines the interval between the sending of successive Announce messages

(see AutoCDSFunctionalSpec-1_4 - 6.2.1 Static gPTP Values, IEC-60802 section 5, 802.1AS-2020 sections 10.7 and 11.5)

Table 56. Timing parameters

| Name | Key | Default value | Value and Range | Description |
|--|-----------------------------|---------------|-----------------|---|
| Initial pdelay request interval value | initialLogPdelayReqInterval | 0 | 0 to 3 | Set pdelay request initial interval between the sending of successive Pdelay_Req messages. Expressed in log2 unit (default 0 -> 1s). |
| Initial sync interval value | initialLogSyncInterval | -3 | -5 to 0 | Set sync transmit initial interval between the sending of successive Sync messages. Expressed in log2 unit (default -3-> 125ms). |
| Initial announce interval value | initialLogAnnounceInterval | 0 | 0 to 3 | Set initial announce transmit interval between the sending of successive Announce messages. Expressed in log2 unit (default 0 -> 1s). |

Table continues on the next page...

Table 56. Timing parameters (continued)

| Name | Key | Default value | Value and Range | Description |
|---|--------------------------|---------------|-----------------|--|
| Operational pdelay request interval value | operLogPdelayReqInterval | 0 | 0 to 3 | Set pdelay request transmit interval used during normal operation state. Expressed in log2 unit (default 0 -> 1s). |
| Operational sync interval value | operLogSyncInterval | -3 | -5 to 0 | Set sync transmit interval used during normal operation state. Expressed in log2 unit (default -3 -> 125ms). |

22.5.2.5 PORTn

This section describes the settings per port where n represents the port index starting at n=1.

Table 57. Port related parameters

| Name | Key | Default value | Value & Range | Description |
|------------------|----------------|---------------|-------------------------------|--|
| Port role | portRole | disabled | 'slave', 'master', 'disabled' | Static port role (ref. 802.1AS-2011, section 14.6.3, Table 10-1), applies to "automotive" profile only. |
| Ptp port enabled | ptpPortEnabled | 1 | 0 or 1 | Set to 1 if both time-synchronization and best master selection functions of the port should be used (ref. 802.1AS-2011, sections 14.6.4 and 10.2.4.12). |

22.6 Log files

Several log files are available at run time to monitor the different stack components.

22.6.1 gPTP Endpoint

Logs are stored in /var/log/fgptp.

- Linux command:

```
# tail -f /var/log/fgptp
```

- If the stack is configured in automotive mode, then the log contains:

```
Running fgptp in automotive profile on interface eth0
```

- Port Role, Port AS-capability and link Status are reported each time there is a change in the link state (link is 802.1AS capable or not) or upon Grand Master (GM) change. This information is also displayed regularly along with current synchronization and pdelay statistics for each of the enabled gPTP domain:

```
Port(0) domain(0,0): role changed from DISABLED to SLAVE
...
Port(0) domain(0,0): Slave - Link: Up - AS_Capable: Yes
```

- Selected Grand Master (GM) capabilities are reported upon new GM selection. *Root Identity* represents the clock ID of the currently selected GM. *Priority1*, *Priority2*, *Class* and *Accuracy* describe the clock quality of the selected GM. Finally, the *Source Port Identity* of the peer master port (e.g. the bridge port the local slave port is connected to). This information is displayed for each of the enabled gPTP domain:

```
domain(0,0) Grand master: root identity 00049ffffe039e35
domain(0,0) Grand master: priority1 245 priority2
domain(0,0) Grand master: class 248 accuracy 248
domain(0,0) Grand master: variance 17258
domain(0,0) Grand master: source port identity 0001f2ffffe0025fe, port number 2
```

- Synchronization State* is reported upon GM selection (SYNCHRONIZED) or when no GM is detected (NOT SYNCHRONIZED). *Synchronization Time* expressed in ms represents the time it took for the local clock to reach synchronization threshold starting from the first SYNC message received. This information is displayed for each of the enabled domain.

```
Port(0) domain(0) SYNCHRONIZED - synchronization time (ms): 250
```

- PDelay* (propagation delay) and local clock adjustments are printed out every 5 seconds. *PDelay* is expressed in ns units and represents the one-way delay from the endpoint and its peer master. *Correction* is expressed in parts per billion and represents the frequency adjustment performed to the local clock. *Offset* is expressed in ns represents the resulting difference between the locally adjusted clock and the reference gPTP GrandMaster's clock. (Min/Max/Avg and Variance are computed for both Correction and Offset statistics). *PDelay* is displayed only for Domain 0. *Correction* and *Offset* are displayed for each of the enabled domain.

```
Port 0 domain(0,0): Propagation delay (ns): 37.60 min 34 avg 36 max 45 variance 17
Port 0 domain(0,0): Correction applied to local clock (ppb): min -5603 avg 5572 max 5538 variance 148
Port 0 domain(0,0): Offset between GM and local clock (ns) min -12 avg 4 max 22 variance 111
...
Port 0 domain(1,20): Correction applied to local clock (ppb): min 32074 avg 32314 max 32574 variance 17695
Port 0 domain(1,20): Offset between GM and local clock (ns) min -61 avg 3 max 70 variance 1149
```

- The following per port per domain statistics (32 bits counters) are printed out every 15 seconds on slave and master entities:

Table 58. Port statistics displayed on slave and master entities

| Receive counters | |
|---------------------------------|---|
| PortStatRxPkts | Number of gPTP packets received (ether type 0x88F7) |
| PortStatRxSyncCount | Number of SYNC packets received |
| PortStatRxSyncReceiptTimeouts | Number of SYNC packets receive timeout |
| PortStatRxFollowUpCount | Number of FOLLOW-UP packets received |
| PortStatRxAnnounce | Number of ANNOUNCE packets received |
| PortStatAnnounceReceiptTimeouts | Number of ANNOUNCE packets timeout |
| PortStatAnnounceReceiptDropped | Number of ANNOUNCE packets dropped by the entity |

Table continues on the next page...

Table 58. Port statistics displayed on slave and master entities (continued)

| | |
|--|--|
| PortStatRxSignaling | Number of SIGNALING packets received |
| PortStatRxPdelayRequest | Number of PDELAY REQUEST packets received |
| PortStatRxPdelayResponse | Number of PDELAY RESPONSE packets received |
| PortStatPdelayAllowedLostResponsesExceeded | Number of excess of allowed lost responses to PDELAY requests |
| PortStatRxPdelayResponseFollowUp | Number of PDELAY FOLLOW-UP packets received |
| PortStatRxErrEtype | Number of ether type errors (not 0x88F7) |
| PortStatRxErrPortId | Number or port ID errors |
| Transmit counters | |
| PortStatTxPkts | Number of gPTP packets transmitted |
| PortStatTxSyncCount | Number of SYNC packets transmitted |
| PortStatTxFollowUpCount | Number of FOLLOW-UP packets transmitted |
| PortStatTxAnnounce | Number of ANNOUNCE packets transmitted |
| PortStatTxSignaling | Number of SIGNALING packets transmitted |
| PortStatTxPdelayReques | Number of PDELAY REQUEST packets transmitted |
| PortStatTxPdelayResponse | Number of PDELAY RESPONSE packets transmitted |
| PortStatTxPdelayResponseFollowUp | Number of PDELAY FOLLOW-UP packets transmitted |
| PortStatTxErr | Number of transmit errors |
| PortStatTxErrAlloc | Number of transmit packets allocation errors |
| Miscellaneous counters | |
| PortStatAdjustOnSync | Number of adjustments performed upon SYNC received |
| PortStatMdPdelayReqSmReset | Number of reset of the PDELAY REQUEST state machine |
| PortStatMdSyncRcvSmReset | Number of reset of the SYNC RECEIVE state machine |
| PortStatHwTsRequest | Number of egress timestamp requests |
| PortStatHwTsHandler | Number of egress timestamp notification |
| PortStatNumSynchronizationLoss | Number or synchronization loss on the slave endpoint (e.g. GM change, GM reference clock discontinuity...) |

Table continues on the next page...

Table 58. Port statistics displayed on slave and master entities (continued)

| | |
|-------------------------|--|
| PortStatNumNotAsCapable | Number of transitions from AS_Capable=TRUE to AS_Capable=FALSE |
|-------------------------|--|

22.6.2 gPTP Bridge

Logs are stored in `/var/log/fgptp-br`.

- Linux command:

```
# tail -f /var/log/fgptp-br
```

- The bridge stack statistics are similar to the endpoint stack ones except that they are reported for each of the external ports of the switch (Port 0 to 3) and also for the internal port connected to the endpoint stack (Port 4) in case of Hybrid setup.
- *Pdelay* (propagation delay) is printed only for Domain 0. *Link status*, *AS capability* and *Port Role* are printed out for each port and each gPTP domain.

```
Port 0 domain(0,0): Role: Disabled Link: Up AS_Capable: No
Port 1 domain(0,0): Role: Disabled Link: Up AS_Capable: No
Port 2 domain(0,0): Role: Disabled Link: Up AS_Capable: Yes
Port 2 domain(0,0): Propagation delay (ns): 433.98 min 425 avg 438 max 457 variance 87
Port 3 domain(0,0): Role: Disabled Link: Up AS_Capable: No
Port 4 domain(0,0): Role Master Link: Up AS_Capable: Yes
Port 4 domain(0,0): Propagation delay (ns): 433.98 min 425 avg 438 max 457 variance 87
...
Port 0 domain(1,20): Role: Disabled Link: Up AS_Capable: No
Port 1 domain(1,20): Role: Disabled Link: Up AS_Capable: No
Port 2 domain(1,20): Role: Disabled Link: Up AS_Capable: Yes
Port 3 domain(1,20): Role: Disabled Link: Up AS_Capable: No
Port 4 domain(1,20): Role Master Link: Up AS_Capable: Yes
```

22.6.3 TSN Endpoint example application

Logs are stored in `/var/log/tsn_app`.

The TSN application has various counters and statistics which help to validate:

- application scheduling and processing timing statistics
- network traffic correctness and latency statistics

22.6.3.1 Main TSN task

The main TSN task logs are described below:

- Scheduling counters (“sched” should increment of 500 per second):

```
INFO 1604531064 tsn_task_stats_print tsn task(0x37d8d630)
INFO 1604531064 tsn_task_stats_print sched : 1700000
INFO 1604531064 tsn_task_stats_print sched early : 0
INFO 1604531064 tsn_task_stats_print sched late : 0
INFO 1604531064 tsn_task_stats_print sched missed : 0
INFO 1604531064 tsn_task_stats_print sched timeout : 0
INFO 1604531064 tsn_task_stats_print clock discont : 0
INFO 1604531064 tsn_task_stats_print clock err : 0
```


Chapter 23

Camera

NXP's i.MX8MMEVK board has CSI MIPI and DSI MIPI interfaces. The gstreamer video stream captures video frame from CSI camera and displays it to screen via DSI MIPI interface. The element “waylandsink” is based on wayland library and Weston desktop. Refer to [Weston](#) to enable them. Users need to follow the steps below to enable gstreamer on a target board.

1. Software setting and configuration

- Configure the target board with `imx8mpevk_*` or `imx8mmevk_defconfig`, for example: `imx8mmevk_defconfig`

```
make imx8mmevk_defconfig
```

- Enable weston and related packages using the command `make menuconfig`.

```
Target packages --->
  Hardware handling --->
    [*] Freescale i.MX libraries --->
      [*] gstreamer 1.x
      [*] enable command-line parser
      [*] enable tracing subsystem
      [*] enable gst-debug trace support
      [*] enable plugin registry
      [*] install tools
      [*] gst-plugin-imx ----
    *- gst-plugins-base --->
      [*] audioconvert (mandatory for audio playback)
      [*] videoconvert
      *- typefind
      [*] videotestsrc
      [*] videoscale (mandatory for video playback)
      [*] volume (mandatory for audio playback)
    [*] gst-plugins-good --->
      [*] autodetect
      [*] avi (*.avi video)
      [*] v4l2
    *- gst-plugins-bad --->
      [*] fbdev
      [*] wayland
```

NOTE

The current OpenIL version only supports `fbdev`, `wayland`, `v4l2`, and `videotestsrc` packages.

2. Building the Image

```
make -j8
```

3. Hardware setup

- For i.MX8MMEVK board, DSI MIPI and CSI MIPI modules are connected to board.
- MIPI-DSI to HDMI interface:



Figure 68. MIPI-DSI to HDMI interface

4. MIPI-CSI camera module: The following snapshot shows the MIPI-CSI camera module:

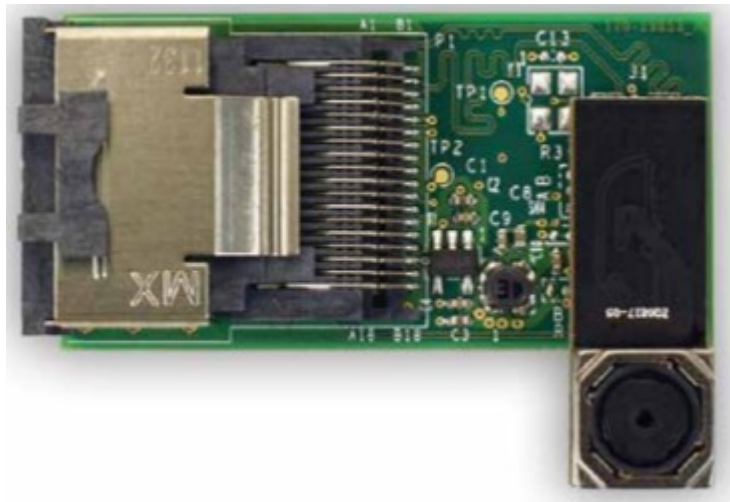


Figure 69. MIPI-CSI camera module

5. Run `gststreamer` for camera

After entering Linux prompt, run `gststreamer` command as shown in the below steps:

```
[root@IMX8MMEVK ~] # gst-launch-1.0 v4l2src device= /dev/video0 ! 'video/x-raw,width=640,height=480,framerate=(fraction)30/1' ! videoconvert ! fbdevsink
```

Below is the snapshot with `fbdevsink`:

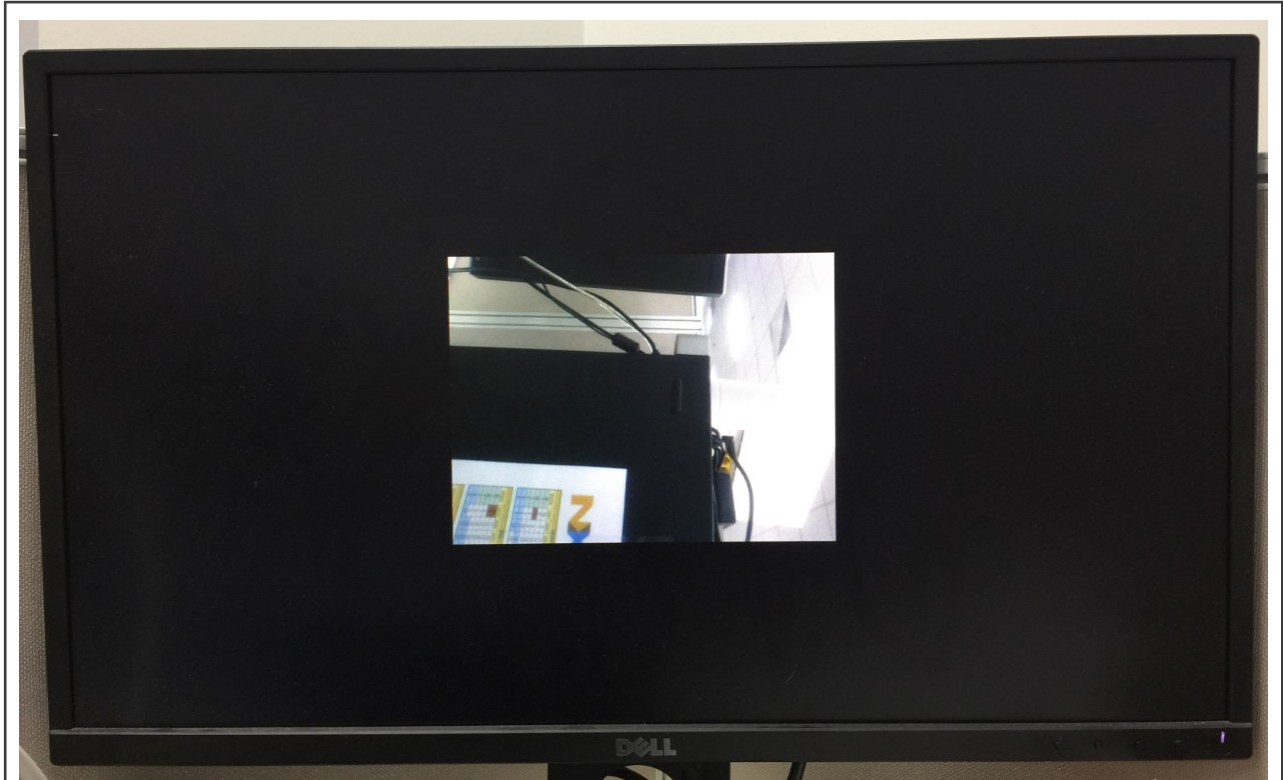


Figure 70. fbdevsink

6. Run wayland and weston for waylandsink:

```
[root@IMX8MMEVK ~] # mkdir -p /run/user/0/  
[root@IMX8MMEVK ~] # export XDG_RUNTIME_DIR="/run/user/0/"  
[root@IMX8MMEVK ~] # weston --tty=1 &  
[root@IMX8MMEVK ~] # gst-launch-1.0 v4l2src device= /dev/video0 ! 'video/x-  
raw,width=640,height=480,framerate=(fraction)30/1' ! videoconvert ! waylandsink
```

The below snapshot shows waylandsink implementation:

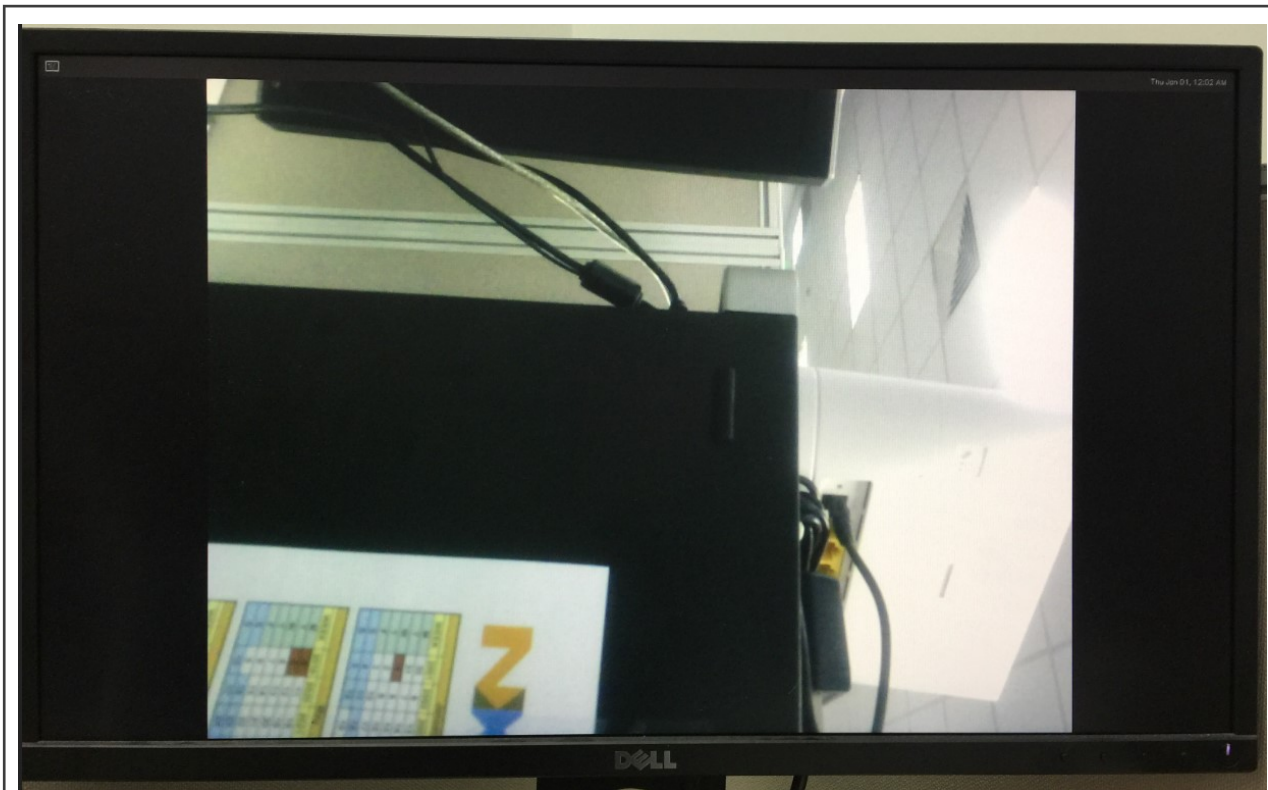


Figure 71. Waylandsink

Chapter 24

Revision history

The table below summarizes revisions to this document.

Table 59. Document revision history

| Date | Document version | Topic cross- reference | Change description |
|------------|------------------|--|---|
| 26/04/2021 | 1.11 | What's New | Added the section that describes the new features of each release. |
| | | Getting Open IL | Updated the section. |
| | | - | Deleted references to Edgescale, OP-TEE, OTA throughout the document and other minor updates. |
| 22/12/2020 | 1.10 | GenAVB/TSN stack | Added the chapter and related contents. |
| | | Camera | Added the section and related details. |
| | | i.MX8M Mini EVK | Added the section and updated i.mx8MPEVK board details. |
| 15/09/2020 | 1.9 | IEEE 1588/802.1AS | Added the section. |
| | | Vivante GPU | Added the chapter and related description.. |
| | | Weston | Added the chapter and related description.. |
| | | NXP servo stack | Made it a part of the chapter "EtherCAT". |
| 29/05/2020 | 1.8 | PREEMPT-RT | Added the section in Industrial features . |
| | | Interface naming in Linux | Updated this section included in LS1028ARDB and LS1028ATSN . |
| | | Host system requirements | Updated the section. |
| | | Running SELinux demo | Updated the section. |
| 20/02/20 | 1.7.1 | Operation examples | Updated this section. |
| 17/01/20 | 1.7 | NXP servo stack | Added the chapter (nxp servo). |
| | | IEEE 1588/802.1AS | Added the chapter |
| | | LX2160ARDB/Rev2 | Added the section. |
| | | Getting Open IL | Updated the section. |
| | | NETCONF/YANG | Other updates. |
| 31/08/19 | 1.6 | Verifying TSN features on LS1028ARDB board | <ul style="list-style-type: none"> Information related to pcpmap command removed from the section TSN configuration on ENETC and TSN configuration on Felix switch. Port names "eno/swp0" changed to "swp0" for few tsntool commands. Note added in section Stream identification for usage of <code>nulltagged</code> and <code>streamhandle</code> parameters. |

Table continues on the next page...

Table 59. Document revision history (continued)

| Date | Document version | Topic cross- reference | Change description |
|------------|------------------|--|---|
| | | | <ul style="list-style-type: none"> Added the section TSN stream identification. Other minor updates. |
| | | Table 7 | Updated the table "Host system mandatory packages". Added <code>autogen</code> <code>autoconf</code> <code>libtool</code> and <code>pkg-config</code> packages. |
| | | BEE | Added this chapter. |
| | | Web UI demo | Added this section in NETCONF/YANG . |
| | | NETCONF/YANG | <ul style="list-style-type: none"> Added the section Enabling NETCONF feature in OpenIL and other updates. |
| 01/05/2019 | 1.5 | Interface naming | Added the section. Describes interface naming for U-Boot and Linux for LS1028ARDB. |
| | | Verifying TSN features on LS1028ARDB board | Updated this section in the Chapter Time Sensitive Network (TSN) . |
| | | BLE | Added the Chapter. |
| | | #unique_352 | Added the Chapter. |
| | | Getting Open IL | Updated the OpenIL version and Git tag. |
| 01/02/2019 | 1.4 | Supported NXP platforms and configurations | Added support for LS1028ARDB (64-bit and Ubuntu). Updated various sections accordingly. |
| | | Getting Open IL | Updated the OpenIL version and Git tag. |
| | | LS1028ARDB and LS1028ATSN | Added this Section for LS1028ARDB support. |
| | | Time Sensitive Network (TSN) | Reorganized this Chapter and added separate Section for Verifying TSN features on LS1028ARDB board . |
| | | NFC | Added the Chapter. |
| | | FlexCAN | Minor updates in this Chapter. Also added the section, Hardware preparation for LS1028ARDB and Testing CAN bus . |
| | | QT | Added the Chapter. |
| 15/10/2018 | 1.3.1 | Getting Open IL | Updated the OpenIL version and Git tag |
| 31/08/2018 | 1.3 | EtherCAT | Added the chapter. |
| | | FlexCAN | Added the chapter. |
| | | i.MX6QSabreSD support | Added the section in chapter NXP OpenIL platforms . Updated other sections for i.MX6Q Sabre support. |
| | | Getting Open IL | Updated the section. |
| | | Selinux demo | Added the section, Installing basic packages and updated Basic setup . Updates in other sections. |

Table continues on the next page...

Table 59. Document revision history (continued)

| Date | Document version | Topic cross- reference | Change description |
|------------|------------------|--|---|
| 31/05/2018 | 1.2 | Hardware requirements | Updated the Section, "Hardware requirements" for RTnet. |
| | | Software requirements | Updated the Section, "Software requirements" for RTnet. |
| 18/04/2018 | 1.1.1 | RTnet | Added the Section, "RTnet". |
| | | Switch settings | Added a note for LS1043A switch setting. |
| 30/03/2018 | 1.1 | #unique_353 | Added support for industrial IoT baremetal framework in this section. |
| | | Booting the board | Added a note for steps to be performed before booting up the board. |
| | | Reference documentation | Added the section. |
| 22/12/2017 | 1.0 | OPC UA | Added the Chapter. |
| | | Time Sensitive Network (TSN) | Chapters for "1-board TSN demo" and "3-board TSN demo" replaced by a single chapter, "TSN demo". |
| | | Industrial features | <ul style="list-style-type: none"> Updated the section, 'Industrial Features'. -IEEE 1588 -'sja1105-ptp' support removed. |
| 25/08/2017 | 0.3 | - | Set up the OpenIL website http://www.openil.org/ . |
| | | #unique_354 | OTA - Xenomai Cobalt 64-bit and SJA1105 support added. |
| | | Time Sensitive Network (TSN) | Qbv support added. |
| | | SELinux | SELinux support for LS1043 / LS1046 Ubuntu Userland added. |
| | | #unique_355 | OP-TEE support for LS1021ATSN platform added. |
| | | 4G-LTE Modem | 4G LTE module - 64-bit support for LS1043ARDB, LS1046ARDB, and LS1012ARDB added. |
| | | NXP OpenIL platforms | Ubuntu Userland support for 64-bit LS1043ARDB and 64-bit LS1046ARDB added. |
| 26/05/2017 | 0.2 | - | Initial public release. |

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