

Open Industrial Linux 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 OpenIL platforms, and the various software settings involved. It describes in detail the industrial features, which include NETCONF/YANG, TSN, Xenomai, IEEE 1588, OP-TEE, and SELinux. It also includes detailed steps for running the demos such as Selinux demo, 1-board TSN Demo, 3-board TSN demo, 4G-LTE demo, and OTA implementation. It also provides a complete description of the OpenIL compilation steps.

1.1 Acronyms and abbreviations

The following table lists the acronyms used in this document.

Table 1. Acronyms and abbreviations

Term	Description
BC	Boundary clock
BMC	Best master clock
CA	Client application
CAN	Controller Area Network
DEI	Drop eligibility indication
EtherCAT	Ethernet for Control Automation Technology
FMan	Frame manager
ICMP	Internet control message protocol
IETF	Internet engineering task force
IPC	Inter process communication
KM	Key management
LBT	Latency and bandwidth tester
MAC	Medium access control
NMT	Network management
OC	Ordinary clock
OpenIL	Open industry Linux
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

Table continues on the next page...

Table 1. Acronyms and abbreviations (continued)

Term	Description
PHC	PTP hardware clock
PIT	Packet inter-arrival times
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
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](#).
 - [LS1021-IoT Getting Started Guide](#).
 - [LS1043ARDB Getting Started Guide](#).
 - [LS1046ARDB Getting Started Guide](#).
 - [i.MX6 SabreSD Board Quick Start Guide](#)
2. For booting up LS1021A-TSN board, refer to the Section [Booting up the board](#) on page 16 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.
- **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.

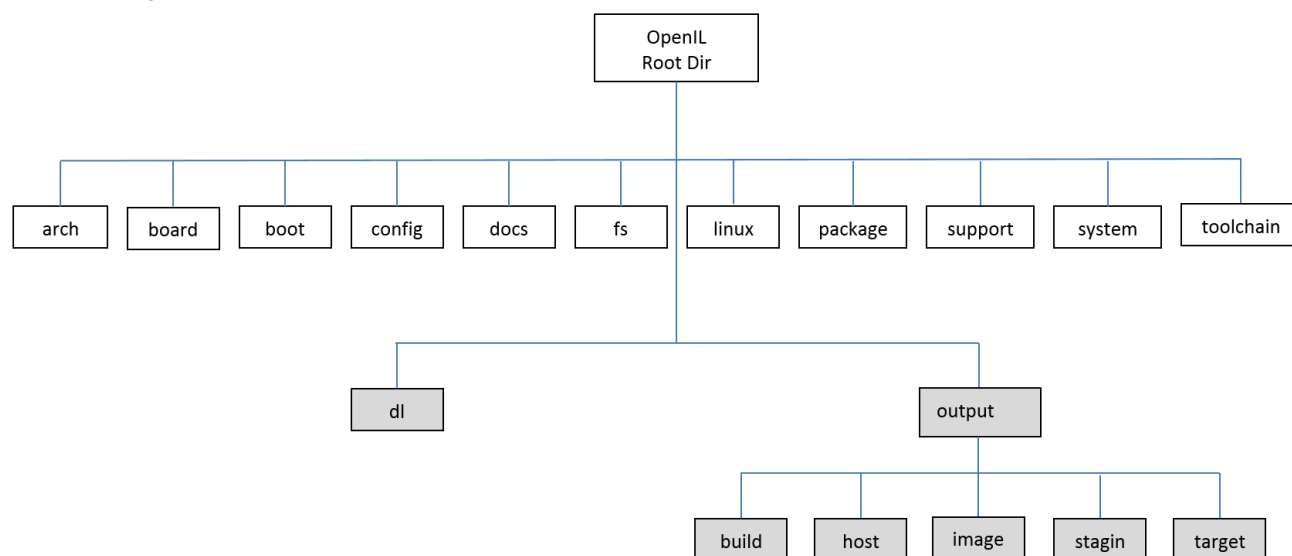


Figure 1. OpenIL structure

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

Table continues on the next page...

Table 2. Source directories (continued)

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

1.3.2 Host system requirements

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

- CentOS Linux 7 (Core)
- CentOS release 6.7 (Final)
- Ubuntu 16.10
- Ubuntu 16.04
- Ubuntu 14.04

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.

NOTE

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

Table 4. Host system mandatory packages

Mandatory packages	Note
which	

Table continues on the next page...

Table 4. Host system mandatory packages (continued)

Mandatory packages	Note
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)	

Table 5. Host system optional packages

Optional packages	Note
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. If you enable packages using any of these methods, you need to install the corresponding tool on the host system
cvs	
git	

Table continues on the next page...

Table 5. Host system optional packages (continued)

Optional packages	Note
mercurial	
scp	
javac compiler	
jar tool	Java-related packages, if the Java Classpath needs to be built for the target system
asciidoc	Documentation generation tools
w3m	
python with the argparse module	
dblatex	
graphviz	To use graph-depends and <pkg>-graph-depends
python-matplotlib	To use graph-build

1.4 Feature set summary

This section provides a summary of OpenIL's compilation and industrial features.

1.4.1 Compilation features

The following are the compilation features:

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

```
System configuration --->
(300M) Partition size of the storage for the rootfs
```

This configuration specifies the size of the storage device partition for the building rootfs and currently used by NXP platforms and SD card device. To set the size of the partition with 300M, 2G or other values, the target system can get the specific size of partition space for the using filesystem.

- **Support custom filesystem** (that is, Ubuntu)

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

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

Currently, there are five NXP platforms that can support Ubuntu filesystem:

```
— configs/nxp_ls1043ardb-64b_ubuntu_defconfig
— configs/nxp_ls1046ardb-64b_ubuntu_defconfig
— configs/nxp_ls1028ardb-64b_ubuntu_defconfig
— configs/nxp_ls1021aiot_ubuntu_defconfig
— configs/imx6q-sabresd_ubuntu_defconfig
```

1.4.2 Supported industrial features

The following are the industrial features supported by OpenIL:

- Netconf/Yang
- Netopeer
- TSN
- IEEE 1588
- IEEE 1588 2-step E2E transparent clock support
- Xenomai Cobalt mode
- SELinux (Ubuntu)
- OP-TEE
- DM-Crypt
- Baremetal
- FlexCan
- EtherCAT
- NFC-Clickboard

These are explained in detail in [Industrial features](#) on page 30.

NOTE

For the complete description of the Industrial IoT baremetal framework, refer to the document, *Industrial_IoT_Baremetal_Framework_Developer_Guide*.

1.5 Supported NXP platforms

The following table lists the NXP platforms supported by OpenIL.

Table 6. Supported NXP platforms

Platform	Architecture	Configuration file in OpenIL	Boot
ls1021atsn	ARM v7	configs/nxp_ls1021atsn_defconfig	SD
ls1021atsn (OP-TEE)	ARM v7	configs/nxp_ls1021atsn_optee-sb_defconfig	SD
ls1021aiot	ARM v7	configs/nxp_ls1021aiot_defconfig	SD
ls1021aiot (OP-TEE)	ARM v7	configs/nxp_ls1021aiot_optee_defconfig	SD
ls1043ardb (32-bit)	ARM v8	configs/nxp_ls1043ardb-32b_defconfig	SD
ls1043ardb (64-bit)	ARM v8	configs/nxp_ls1043ardb-64b_defconfig	SD
ls1043ardb (Ubuntu)	ARM v8	configs/nxp_ls1043ardb-64b_ubuntu_defconfig	SD
ls1046ardb (32-bit)	ARM v8	configs/nxp_ls1046ardb-32b_defconfig	SD
ls1046ardb (64-bit)	ARM v8	configs/nxp_ls1046ardb-64b_defconfig	SD
ls1046ardb (Ubuntu)	ARM v8	configs/nxp_ls1046ardb-64b_ubuntu_defconfig	SD

Table continues on the next page...

Table 6. Supported NXP platforms (continued)

Platform	Architecture	Configuration file in OpenIL	Boot
ls1012ardb (32-bit)	ARM v8	configs/nxp_ls1012ardb-32b_defconfig	QSPI
ls1012ardb (64-bit)	ARM v8	configs/nxp_ls1012ardb-64b_defconfig	QSPI
i.MX6Q SabreSD	ARM v7	configs/imx6q-sabresd_defconfig	SD
i.MX6Q SabreSD	ARM v7	configs/imx6q-sabresd_ubuntu_defconfig	SD
ls1028ardb (64-bit)	ARM v8	configs/nxp_ls1028ardb-64b_defconfig	SD
ls1028ardb (Ubuntu)	ARM v8	configs/nxp_ls1028ardb-64b_ubuntu_defconfig	SD

1.5.1 Default compilation settings for NXP platforms

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

Table 7. Default compilation settings

Platform	Toolchain	libc	Init system	Filesystem
ls1021atsn	gcc 5.x	glibc 2.23	BusyBox	OpenIL default
ls1021atsn (OP-TEE)	gcc 5.x	glibc 2.23	BusyBox	OpenIL default
ls1021aiot	gcc 5.x	glibc 2.23	BusyBox	OpenIL default
ls1021aiot (OP-TEE)	gcc 5.x	glibc 2.23	BusyBox	OpenIL default
ls1043ardb (32-bit)	gcc 5.x	glibc 2.23	BusyBox	OpenIL default
ls1043ardb (64-bit)	gcc 5.x	glibc 2.23	BusyBox	OpenIL default
ls1043ardb (Ubuntu)	gcc 5.x	glibc 2.23	Systemd	ubuntu-base-16.04.3-arm64
ls1046ardb (32-bit)	gcc 5.x	glibc 2.23	BusyBox	OpenIL default
ls1046ardb (64-bit)	gcc 5.x	glibc 2.23	BusyBox	OpenIL default
ls1046ardb (Ubuntu)	gcc 5.x	glibc 2.23	Systemd	ubuntu-base-16.04.3-arm64
ls1012ardb (32-bit)	gcc 5.x	glibc 2.23	BusyBox	OpenIL default
ls1012ardb (64-bit)	gcc 5.x	glibc 2.23	BusyBox	OpenIL default
i.MX6Q SabreSD	gcc 5.x	glibc 2.23	BusyBox	OpenIL default
i.MX6Q SabreSD	gcc 5.x	glibc 2.23	Systemd	ubuntu-base-16.04.5-arm
ls1028ardb	gcc 5.x	glibc 2.23	BusyBox	OpenIL default

Chapter 2

Getting started

After reading this section, you 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.

2.1 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 201904 v1.5 release
$ git checkout OpenIL-201904 -b OpenIL-201904
```

2.2 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.

2.2.1 Important notes

- Build everything as a normal user. There is no need to be a root user to configure and use OpenIL. By running all commands as a regular user, you protect your system against packages behaving badly during compilation and installation.
- Do not use `make -jN` command to build OpenIL as the top-level parallel `make` is currently not supported.
- The `PERL_MM_OPT` issue: You might encounter an error message for the `PERL_MM_OPT` parameter when using the `make` command in some host Linux environment 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
```

2.2.2 Building the final 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 8. Default configuration

Platform	Configuration file in OpenIL
ls1021atsn	configs/nxp_ls1021atsn_defconfig
ls1021atsn (OP-TEE)	configs/nxp_ls1021atsn_optee-sb_defconfig
ls1021aiot	configs/nxp_ls1021aiot_defconfig
ls1021aiot (OP-TEE)	configs/nxp_ls1021aiot_optee_defconfig
ls1028ardb (64-bit)	configs/nxp_ls1028ardb-64b_defconfig
ls1028ardb (Ubuntu)	configs/nxp_ls1028ardb-64b_ubuntu_defconfig
ls1043ardb (32-bit)	configs/nxp_ls1043ardb-32b_defconfig
ls1043ardb (64-bit)	configs/nxp_ls1043ardb-64b_defconfig
ls1043ardb (Ubuntu)	configs/nxp_ls1043ardb-64b_ubuntu_defconfig
ls1046ardb (32-bit)	configs/nxp_ls1046ardb-32b_defconfig
ls1046ardb (64-bit)	configs/nxp_ls1046ardb-64b_defconfig
ls1046ardb (Ubuntu)	configs/nxp_ls1046ardb-64b_ubuntu_defconfig
ls1012ardb (32-bit)	configs/nxp_ls1012ardb-32b_defconfig
ls1012ardb (64-bit)	configs/nxp_ls1012ardb-64b_defconfig
i.MX6Q SabreSD	configs/imx6q-sabresd_defconfig
i.MX6Q SabreSD (Ubuntu)	configs/imx6q-sabresd_ubuntu_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, you can build a complete Linux environment for the target platforms.

To build the final images for an NXP platform (for example, LS1021ATSN), run the following commands:

```
$ cd openil
$ make nxp_ls1021atsn_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 a root filesystem in selected formats.

After the correct compilation, you can find all the images for the platform at `output/images`.

```
images/
├─ boot.vfat
├─ ls1021a-tsn.dtb          --- dtb file for ls1021atsn
├─ rootfs.ext2
├─ rootfs.ext2.gz
├─ rootfs.ext2.gz.uboot    --- ramdisk can be used for debug
├─ rootfs.ext4.gz -> rootfs.ext2.gz
├─ rootfs.tar
├─ sdcard.img              --- entire image can be programmed into the SD
├─ uboot-env.bin
├─ u-boot-with-spl-pbl.bin --- uboot image for ls1021atsn
└─ uImage                  --- kernel image for ls1021atsn
```

2.3 Booting up 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](#) on page 7.

NOTE

- Before booting up the board, you 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 you have already installed the mbed driver on your system (PC or laptop). You 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 you are 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 9. Switch settings for the NXP boards

Platform	Boot	Final image	Board software setting (ON = 1)
LS1021A-TSN	SD card	sdcard.img	SW2 = 0b'111111
LS1021A-IOT	SD card	sdcard.img	SW2[1] = 0b'0
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
LS1012ARDB	QSPI	qspi.img	SW1 = 0b'10100110 SW2 = 0b'00000000
LS1028ARDB	SD card	sdcard.img	SW2[1-8] = 0b'10001000
i.MX6Q SabreSD	SD card	sdcard.img	SW6 = 0b'01000010

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.

2.3.1 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 2G 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 your 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.

2.3.2 QSPI 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.

```
=>i2c mw 0x24 0x7 0xfc; i2c mw 0x24 0x3 0xf5
=>tftp 0x80000000 qspi.img
=>sf probe 0:0
=>sf erase 0x0 +$filesize
=>sf write 0x80000000 0x0 $filesize
=>reset
```

2.3.3 Starting up the board

After the sdcard.img/qspi.img programming, startup the board. You should see the following information.

```
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.
```

The logo for Open Industrial Linux features the text "Open Industrial Linux" in a monospaced font. To the left of the text is a square composed of dashed lines. To the right of the text are three vertical dashed lines of varying heights. Below the text and the vertical lines is the website address "openil.org".

```
[root@OpenIL:~]#
```

Figure 2. OpenIL system startup

The system will be logged in automatically.

2.4 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`.

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 10. Package build targets

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

Chapter 3

NXP OpenIL platforms

OpenIL supports the following NXP Layerscape ARM® platforms: LS1012ARDB, LS1021A-TSN, LS1021-IoT, LS1043ARDB, LS1046ARDB, and i.MX6QSabreSD. 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

3.1 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
- 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.

3.2 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.

3.2.1 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 11. LS1021ATSN SD boot software setting

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

3.2.2 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 with RCW 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.ext2.gz.uboot
=>tftp 8f000000 ls1021a-tsn.dtb
=>bootm 83000000 88000000 8f000000
```

3.3 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.

3.3.1 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 12. LS1021A-IoT SD boot software setting

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

3.3.2 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 with RCW 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.ext2.gz.uboot
=>tftp 8f000000 ls1021a-iot.dtb
=>bootm 83000000 88000000 8f000000
```

3.4 LS1043ARDB and LS1046ARDB

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.

3.4.1 Switch settings

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

Table 13. 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

NOTE

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

3.4.2 Updating target images

For LS1043ARDB and LS1046ARDB platforms, the OpenIL can support 32-bit and 64-bit systems. Use the following commands to build the images for the LS1043ARDB or LS1046ARDB platforms:

- **Building images**

```
$ cd openil
$ make nxp_ls1043ardb-32b_defconfig
# or
$ make nxp_ls1046ardb-32b_defconfig
$ make
# or make with a log
$ make 2>&1 | tee build.log
```

- **Programming U-Boot with RCW, FMan ucode, and PPA in SD card**

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

```
# programming U-Boot with RCW
=> tftpboot 82000000 u-boot-with-spl-pbl.bin
=> mmc write 82000000 8 800
# programming the FMan ucode
=> tftpboot 82000000 fsl_fman_ucode_ls1043_r1.0_108_4_5.bin
=> mmc write 82000000 820 50
# programming the PPA firmware
=> tftpboot 82000000 ppa.itb
=> mmc write 82000000 2800 36

#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 ls1043ardb
=>tftp a0000000 kernel-ls1043a-rdb-aarch32.itb
# for ls1046ardb
=>tftp a0000000 kernel-ls1046a-rdb-aarch32.itb

=>bootm a0000000
```

3.5 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.

3.5.1 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 14. 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

3.5.2 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-32b_defconfig
$ make
# or make with a log
$ make 2>&1 | tee build.log
```

- **Programming U-Boot, RCW, and PPA in QSPI**

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

```
# programming U-Boot
=>i2c mw 0x24 0x7 0xfc; i2c mw 0x24 0x3 0xf5
=>tftp 0x80000000 <u-boot_file_name>.bin
=>sf probe 0:0
=>sf erase 0x100000 +$filesize
=>sf write 0x80000000 0x100000 $filesize
# programming RCW
=>i2c mw 0x24 0x7 0xfc; i2c mw 0x24 0x3 0xf5
=>tftp 0x80000000 <rcw_file_name>.bin
=>sf probe 0:0
=>sf erase 0x0 +$filesize
=>sf write 0x80000000 0x0 $filesize
# programming PPA
=> tftp 0x80000000 ppa.itb
=> sf probe 0:0
=> sf erase 0x500000 +$filesize
=> sf write 0x80000000 0x500000 $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-aarch32.itb
=>bootm a0000000
```

3.6 i.MX6QSabreSD

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.

3.6.1 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 15. 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

3.6.2 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 sdcard.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 your 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.

3.7 LS1028ARDB

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.

3.7.1 Switch settings

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

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

3.7.2 Interface naming

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

3.7.2.1 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 *enetc#0* is functional.

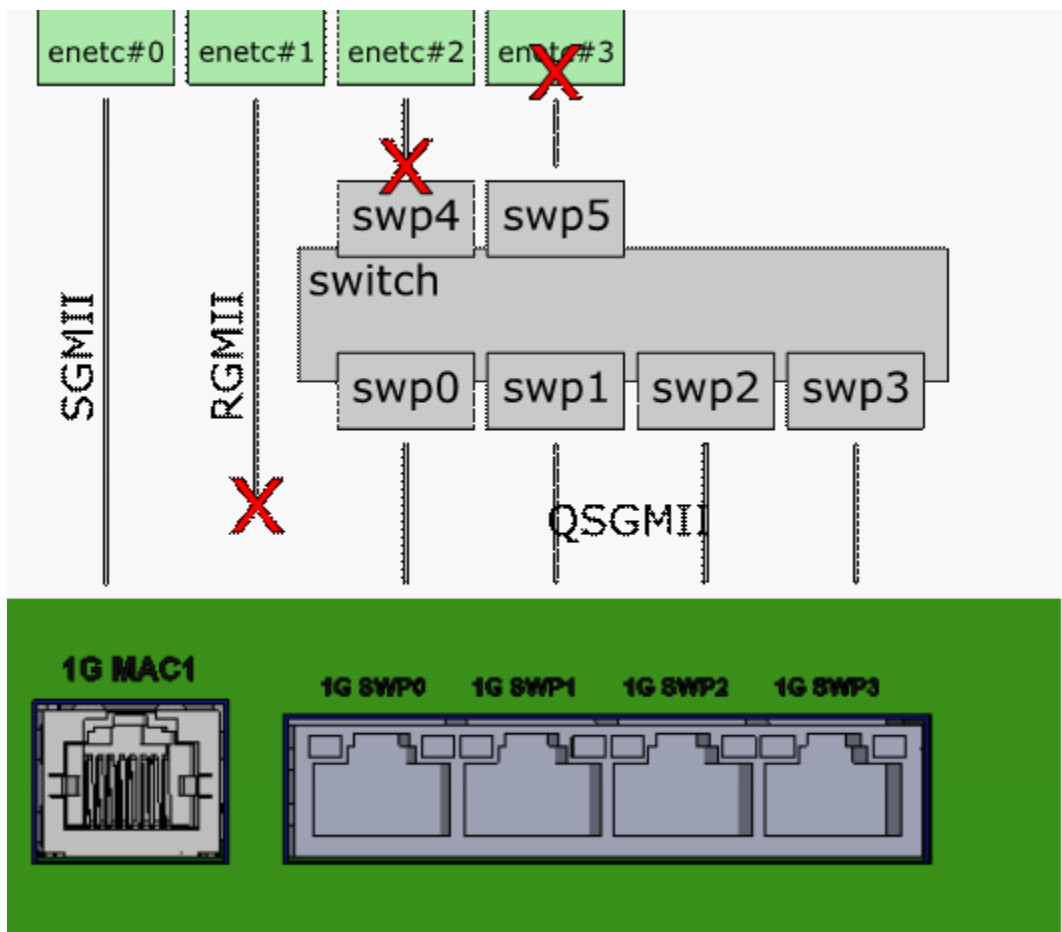


Figure 3. Ethernet ports in U-Boot

Table 16. 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.

3.7.2.2 Interface naming in Linux

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

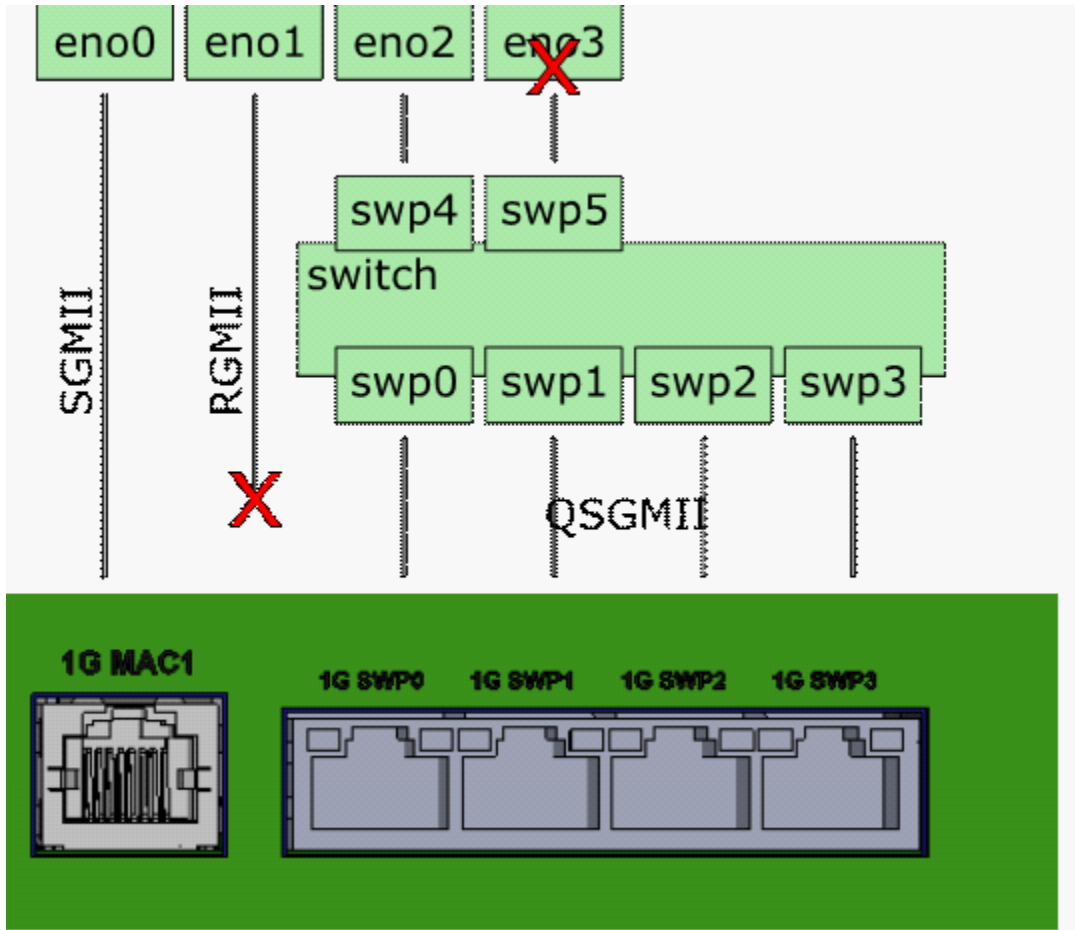


Figure 4. Ethernet ports in Linux

Table 17. Interface naming in Linux

RDB port	Linux netdev	PCI function	Comments
1G MAC1	eno0	0000:00:00.0	
N/A	eno1	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	eno2	0000:00:00.2	Connected internally (MAC to MAC) to swp4. This is used to carry traffic between the switch and software running on ARM cores.

Table continues on the next page...

Table 17. 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. For detail on how to enable switching across these ports, see Felix Ethernet switch on page 78.
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.

3.7.3 Updating target images

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

1. Building images

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

2. Programming U-Boot, Kernel images, RCW, DP firmware and PPA in SD card:

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

```
# programming the RCW binary
=> tftpboot 82000000 cw_1300_sd.bin
=> mmc write 82000000 8 $filesize
# programming U-Boot
=> tftpboot 82000000 u-boot-with-spl.bin
=> mmc write 82000000 800 $filesize
# programming the u-boot environment
=> tftpboot 82000000 uboot-env.bin
=> mmc write 82000000 1800 $filesize
# programming the PPA firmware
=> tftpboot 82000000 ppa.itb
=> mmc write 82000000 2000 $filesize
#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 a0000000 kernel-ls1028a-rdb.itb
=> bootm a0000000
```

Chapter 4

Industrial features

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

4.1 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](#))

4.2 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)

4.3 Xenomai

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 you 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/>.

4.3.1 Xenomai running mode

The dual kernel core is codenamed Cobalt, whereas the native Linux implementation is called Mercury. Both Mercury and Cobalt are supported.

4.3.1.1 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>.

4.3.1.2 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:

```
$ 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/pipe/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 you run short on memory, try reducing the trace log depth which is set to 16000 trace points by default.
- e. CONFIG_IPIPE_TRACE_VMALLOCC (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"
```

4.3.2 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.

4.3.2.1 Hardware requirements

Following are the hardware requirements for implementing the RTnet protocol in your 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 you use an e1000e NIC, insert the e1000e NIC into the P4 slot of the LS1043ARDB or LS1046ARDB board.

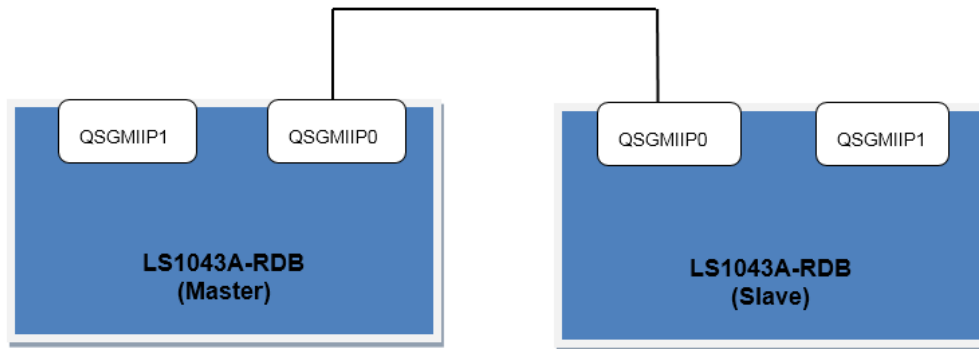


Figure 5. Hardware setup for RTnet (LS1043A as an example)

4.3.2.2 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
```

- Now, run the `make` command to build all images.
- After flashing images to the SD card, boot LS1043ARDB or LS1046ARDB from the SD card and enter the Linux prompt.
- 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"

4.3.2.3 Verifying RTnet

Use the following steps to verify your RTnet connection:

- Step1: Load all modules related with Xenomai RTnet and analyze the configuration file **both** on master and slave sides.

```
$ rtinet 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, you 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
```

4.4 IEEE 1588

This section provides an introduction to the IEEE 1588 features of Open IL. It includes a description of the Precision Time Protocol (PTP) device types, Linux PTP stack, quick start guide for implementing PTP based on the IEEE standard 1588 for Linux, known issues and limitations, and long term test results.

4.4.1 Introduction

IEEE Std 1588-2008 (IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems) defines a protocol enabling precise synchronization of clocks in measurement and control systems implemented with technologies such as network communication, local computing, and distributed objects.

The 1588 timer module on NXP QorIQ platform provides hardware assist for 1588 compliant time stamping. Together with a software PTP (Precision Time Protocol) stack, it implements precision clock synchronization defined by this standard. Many open source PTP stacks are available with a little transplant effort, such as linuxptp, which are used for this release demo.

4.4.2 PTP device types

There are five basic types of PTP devices, as follows:

- 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.

4.4.3 Linux PTP stack

The Linux PTP stack software is an implementation of the Precision Time Protocol (PTP) based on the IEEE standard 1588 for Linux. Its dual design goals are:

- To provide a robust implementation of the standard.
- To use the most relevant and modern Application Programming Interfaces (API) offered by the Linux kernel.

Supporting legacy APIs and other platforms is not an objective of this software. Following are the main features of the Linux PTP 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 new clock_adjtimex system call.
- Implements Boundary Clock (BC) and Ordinary Clock (OC).
- Transport over UDP/IPv4, UDP/IPv6, and raw Ethernet (Layer 2).
- Supports IEEE 802.1AS-2011 in the role of end station.
- Modular design allows painless addition of new transports and clock servo algorithms.

4.4.4 Quick start guide for setting up IEEE standard 1588 demonstration

This quick start guide explains the procedure to set up demos of IEEE 1588, including master-slave synchronization, boundary clock synchronization, and transparent clock synchronization.

1. Hardware requirement

- Two boards for basic master-slave synchronization
- Three or more boards for BC synchronization
- Three or more boards for TC synchronization (One must be LS1021ATSN board)

2. Software requirement

- Linux BSP of industry solution release
- PTP software stack

3. Ethernet interfaces connection for master-slave synchronization

Connect two Ethernet interfaces between two boards in a back-to-back manner. Then, one board works as master and the other works as a slave when they synchronize. Both the master and the slave work as Ordinary Clocks (OCs).

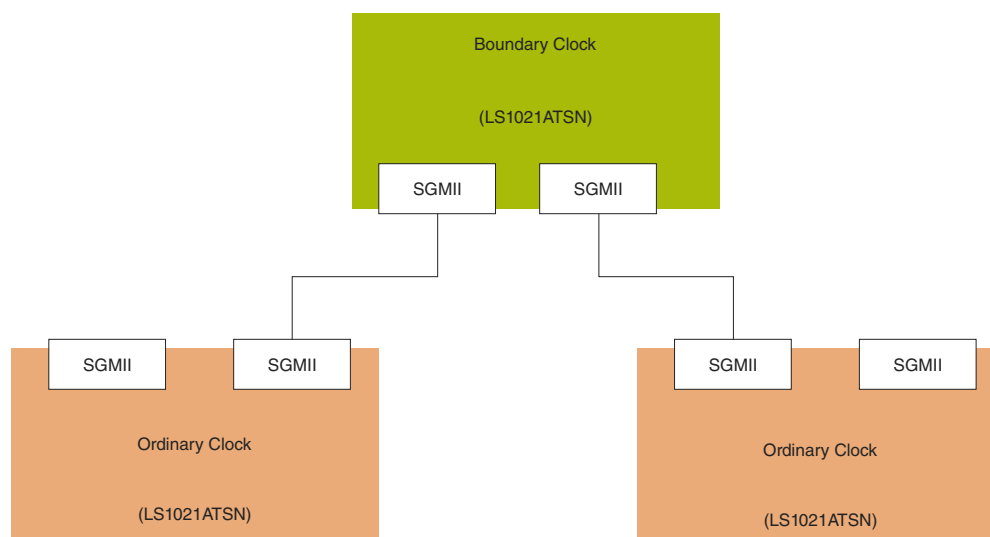
4. Ethernet interfaces connection for BC synchronization

At least three boards are required for BC synchronization. When three boards are used for BC synchronization, assuming board A works as boundary clock (BC) with two PTP ports, board B and board C work as OCs.

Table 18. Connecting Ethernet interfaces for boundary clocks (BC) synchronization

Board	Clock type	Interfaces used
A	BC	Interface 1, Interface 2.
B	OC	Interface 1
C	OC	Interface 1

5. Connect board A interface 1 to board B interface 1 in back-to-back manner.
6. Connect board A interface 2 to board C interface 1 in back-to-back manner. For example, LS1021ATSN BC synchronization connection is shown in the following figure.

**Figure 6. LS1021ATSN BC synchronization**

7. Ethernet interfaces connection for transparent clock (TC) synchronization

At least three boards are required for TC synchronization. One must be LS1021ATSN board, which is needed as a transparent clock since there is a SJA1105 switch on it. When three boards are used for TC synchronization, assuming board A (LS1021ATSN) works as TC with two PTP ports, board B and board C work as OCs.

NOTE

i.MX6Q SabreSD supports only the master-slave mode.

Table 19. Connecting Ethernet interfaces for TC (transparent clock)

Board	Clock Type	Interfaces used
A (LS1021ATSN)	TC	Interface 1, Interface 2. (These are two ports of SJA1105 switch.)
B	OC	Interface 1
C	OC	Interface 1

- Connect board A interface 1 to board B interface 1 in a back-to-back manner.
- Connect board A interface 2 to board C interface 1 in a back-to-back manner. For example, LS1021ATSN TC synchronization connection is shown in the following figure.

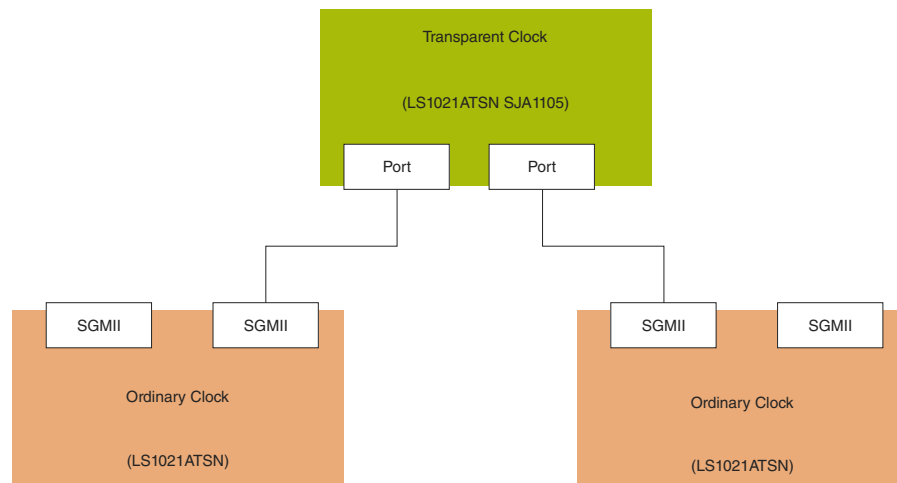


Figure 7. LS1021ATSN TC synchronization

8. PTP stack startup

Before starting up the kernel to run PTP stack, make sure there is no MAC address conflict in the network. Different MAC addresses should be set for each MAC on each board in U-Boot. For example,

Board A:

```
=> setenv ethaddr 00:04:9f:ef:00:00
=> setenv eth1addr 00:04:9f:ef:01:01
=> setenv eth2addr 00:04:9f:ef:02:02
```

Board B:

```
=> setenv ethaddr 00:04:9f:ef:03:03
=> setenv eth1addr 00:04:9f:ef:04:04
=> setenv eth2addr 00:04:9f:ef:05:05
```

Board C:

```
=> setenv ethaddr 00:04:9f:ef:06:06
=> setenv eth1addr 00:04:9f:ef:07:07
=> setenv eth2addr 00:04:9f:ef:08:08
```

Linux PTP stack supports both OC and BC. It is included in the SD card images of LS1021ATSN, LS1043ARDB, LS1046ARDB, and i.MX6Q SabreSD, built using buildroot.

9. Basic master-slave synchronization

For basic master-slave synchronization, use the below command. It can be observed that the slave synchronizes with the master with time.

- **For LS platforms:**

```
$ ptp4l -i eth0 -p /dev/ptp0 -f /etc/ptp4l_default.cfg -m
```

- **For i.MX platforms:**

First create ptp config file as follow for both board A and B:

```
cat ptp.cfg
[global]
#
# Run time options
#
logAnnounceInterval -4
logSyncInterval -4
logMinDelayReqInterval -4
logMinPdelayReqInterval -4
tx_timestamp_timeout 10
```

— Board A

```
sysctl -w net.ipv4.igmp_max_memberships=20
ifconfig eth0 up 192.168.0.100
ptp4l -f ./ptp.cfg -A -4 -H -m -i eth0
```

— Board B

```
sysctl -w net.ipv4.igmp_max_memberships=20
ifconfig eth0 up 192.168.0.101
ptp4l -f ./ptp.cfg -A -4 -H -m -i eth0
```

10. BC synchronization

For BC synchronization, run OC using the below command. It can be observed that the slave synchronizes with the master with time.

```
$ ptp4l -i eth0 -p /dev/ptp0 -f /etc/ptp4l_default.cfg -m
```

If the board is used as BC with several PTP ports, the '-i' argument could point more interfaces. For running BC with more than one interfaces, use the below command:

```
$ ptp4l -i eth0 -i eth1 -p /dev/ptp0 -f /etc/ptp4l_default.cfg -m
```

11. TC synchronization

For TC synchronization, set the two-step end-to-end transparent clock configuration for SJA1105 on TC (LS1021ATSN). Free running PTP clock is used for TC because the residence time is very short (about 2 ~ 3 μ s as per test results). Even if synchronization is implemented for TC, the improvement for residence time accuracy is still very small and can be ignored.

```
$ sja1105-ptp-free-tc.sh
```

Run OC using the below command:

```
$ ptp4l -i eth0 -p /dev/ptp0 -2 -m
```

It can be observed that slave synchronizes its time with the master clock. If you use the '-l 7' argument to enable debug message for slave, the correction field value of Sync and Delay_resp messages are displayed, which are the residence time of Sync and Delay_req messages.

NOTE

- For all the three cases mentioned above, the master clock could be selected by using the software BMC (Best Master Clock) algorithm.
- The interface name and PTP device name in commands should be changed accordingly.

4.4.5 Known issues and limitations

1. For LS1021ATSN, the Linux PTP stack only supports LS1021A Ethernet interfaces. It cannot be used for SJA1105 switch Ethernet interfaces.
2. Packet loss issue could be observed on LS1021ATSN SGMII interfaces connected in back-to-back manner. The root cause is that the PHY supports IEEE 802.11az EEE mode, by default. The low speed traffic makes it switch to low power mode, which affects 1588 synchronization performance greatly.

Use the below workaround to disable this feature.

```
$ ifconfig eth0 up
$ ethtool --set-eee eth0 advertise 0
$ ifconfig eth0 down
$ ifconfig eth0 up
```

3. The ptp4l stack may report a timeout for getting the tx timestamp, but this rarely appears. This is not a bug. The stack tries to get the tx timestamp after sending a message, but cannot get it if the driver has not completed tx timestamp processing, in time. Just increasing the tx_timestamp_timeout parameter and re-running the stack will resolve this problem.

```
ptp4l[574.149]: timed out while polling for tx timestamp
ptp4l[574.152]: increasing tx_timestamp_timeout may correct this issue, but it is likely
caused by a driver bug
```

4.4.6 Long term test results for Linux PTP

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

Linux PTP

Connection: back-to-back master to slave

Configuration: Sync interval is -3

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

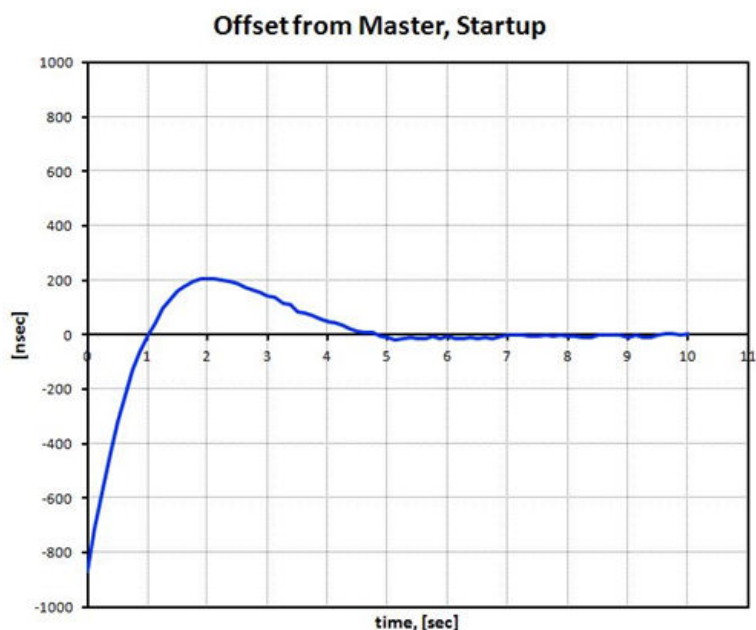


Figure 8. Offset from master in start up state

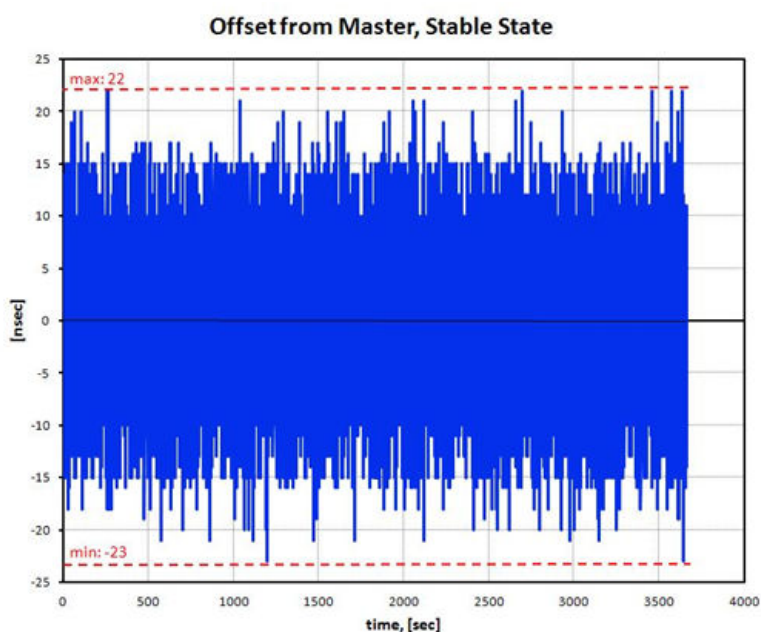


Figure 9. Offset from master in stable state

4.5 OP-TEE

This section explains how to run Open Portable Trusted Execution Environment (OP-TEE) on ARM® based NXP platforms, such as LS1021A-TSN and LS1021A-IoT platforms. OP-TEE started as collaboration between ST Microelectronics and Linaro. Later, it was made available to the open source community. It contains the complete stack from normal world client APIs (optee_client), the Linux kernel TEE driver (optee_linuxdriver), and the Trusted OS and the secure monitor (optee_os).

4.5.1 Introduction

This section describes the operating environment, tools and, dependencies necessary for deploying OP-TEE. It describes the installation based on the design and setup of one specific environment. Thereafter, users need to adapt the setup and deployment for their specific environment and requirements.

It includes the following:

- Getting OP-TEE and relevant test program
- Compiling the image
- Prerequisites of integrating TEE binary image into the final images.
- Installation and usage steps for the TEE application and output obtained on the LS1021A platform.

The TEE used for this demo is Open Portable Trusted Execution Environment (OP-TEE).

This release supports the following features:

- Supports the LS1021A-TSN and LS1021A-IOT platforms
- Secure boot by SD boot
- TrustZone Controller enabled
- U-boot: v2016.09.
- Linux Kernel v4.1 with OP-TEE drivers backported from mainline kernel v4.11
- OP-TEE OS: v2.4.0
- OP-TEE Client: v2.4.0
- OP-TEE Test: v2.4.0.

NOTE

For LS1021AIOT, the `nxp_ls1021aiot_optee_defconfig` configuration file does not support secure boot, it just includes OP-TEE.

4.5.2 Deployment architecture

The following figure shows the deployment architecture of OP-TEE on ARM TrustZone enabled SoCs.

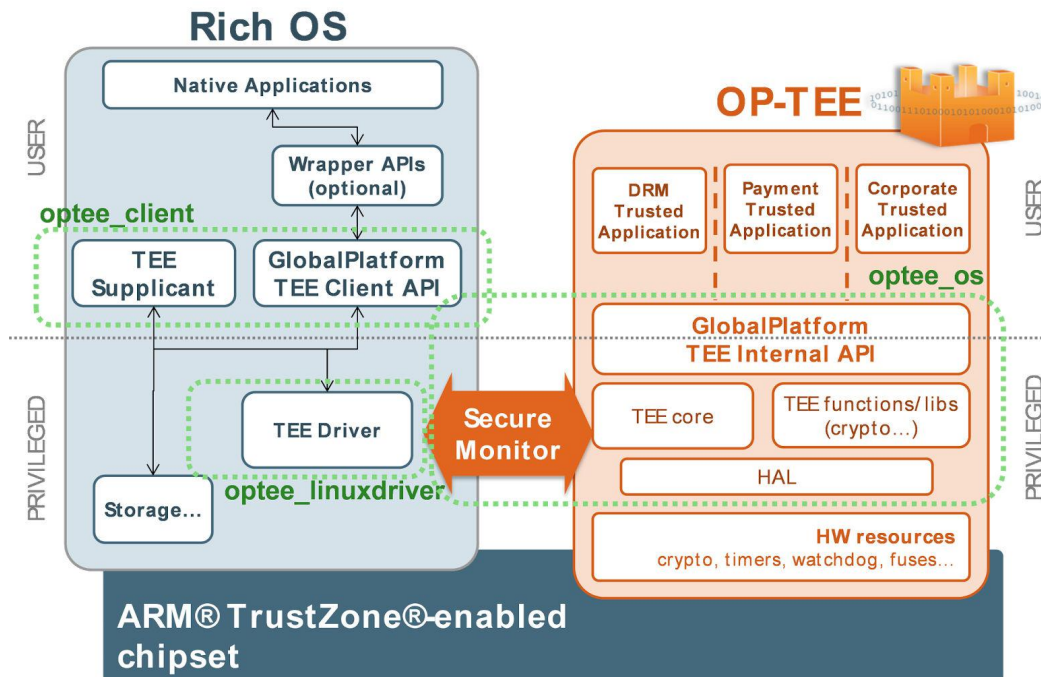


Figure 10. Architecture of OP-TEE on an ARM TrustZone enabled SoC

4.5.3 DDR memory map

The following figure shows the DDR memory map for LS1021A-TSN platform with OP-TEE implementation.

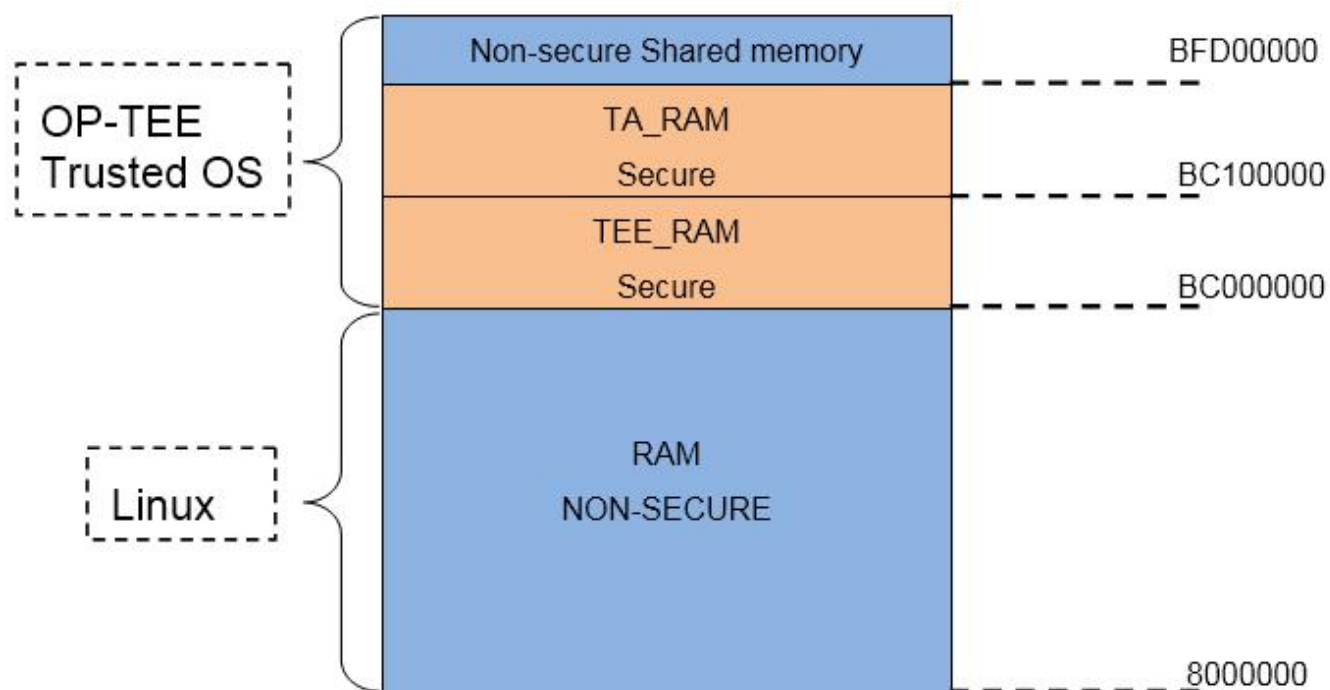


Figure 11. DDR memory map

4.5.4 Configuring OP-TEE on LS1021A-TSN platform

Use the following commands to build the images with the OP-TEE feature on the LS1021A-TSN platform.

```
$ cd openil
$ make clean
$ make nxp_ls1021atsn_optee-sb_defconfig
$ make
#or make with a log
$ make 2>&1 | tee build.log
```

NOTE

The host Linux machine must have the following libraries:

- libmagickwand-dev for APT on Debian/Ubuntu.
- ImageMagick-devel for Yum on CentOS.

The `nxp_ls1021atsn_optee-sb_defconfig` configuration file includes some default configurations for secure boot and OP-TEE. These are listed below:

1. `ls1021atsn_sdcard_SECURE_BOOT_TEE` U-Boot configuration.
2. `kernel CONFIG_OPTEE` configuration.
3. OP-TEE OS, client, and test applications.
4. `CST tool` to create secure boot keys and headers.

The CST tool can support two special functions, which are:

1. **Using custom `srk.pri` and `srk.pub` files to maintain the consistent keys.** For this feature, move the custom `srk.pri` and `srk.pub` files into the directory named `board/nxp/ls1021atsn/`. Then, the CST tool creates all the keys and header files for secure boot based on the two files, each time. In addition, after running `gen_keys 1024` to get the `srk.pri` and `srk.pub` files at the first instance, if there are no custom files in `board/nxp/ls1021atsn/`, the CST tool always uses the existing `srk.pri` and `srk.pub`, until the two files are deleted.
2. **Enabling/disabling the core hold-off switch for the secure boot, by using the `make menuconfig` command.**

This can be done by using the following command:

```
Host utilities --->
[*]host cst tool
*** core hold-off ***
  [*] secure boot core hold-off
```

After the correct building, the final SD card image named `sdcard.img` can be located at `output/images`. The keys for secure boot that should be programmed into the silicon can be located in the file `output/images/srk.txt`.

4.5.5 Running OP-TEE on LS1021A-TSN platform

This section provides the commands for running OP-TEE on the LS1021A-TSN platform. It includes commands for secure boot, executing OP-TEE daemon, and executing OP-TEE test cases.

4.5.5.1 Running secure boot

OP-TEE must run together with secure boot in order to protect all images to avoid being attacked. For details about secure boot, refer to the section, *Secure Boot* in the Chapter, *Boot Loaders* in the online LSDK document: https://freescaleeach01.sdlproducts.com/LiveContent/web/pub.xql?c=t&action=home&pub=QorIQ_SDK&lang=en-US

Refer to the following useful CCS commands for secure boot:

```
#Connect to CCS and configure Config Chain
delete all
config cc cwtap:<ip address of cwtap> show cc
ccs::config_server 0 10000
ccs::config_chain {ls1020a dap sap2} display ccs::get_config_chain

#Check Initial SNVS State and Value in SCRATCH Registers
ccs::display_mem <dap chain pos> 0x1e90014 4 0 4
ccs::display_mem <dap chain pos> 0x1ee0200 4 0 4

#Write the SRK Hash Value in Mirror Registers
ccs::write_mem <dap chain pos> 0x1e80254 4 0 <SRKH1>
ccs::write_mem <dap chain pos> 0x1e80258 4 0 <SRKH2>
ccs::write_mem <dap chain pos> 0x1e8025c 4 0 <SRKH3>
ccs::write_mem <dap chain pos> 0x1e80260 4 0 <SRKH4>
ccs::write_mem <dap chain pos> 0x1e80264 4 0 <SRKH5>
ccs::write_mem <dap chain pos> 0x1e80268 4 0 <SRKH6>
ccs::write_mem <dap chain pos> 0x1e8026c 4 0 <SRKH7>
ccs::write_mem vdap chain pos> 0x1e80270 4 0 <SRKH8>

#Get the Core Out of Boot Hold-Off
ccs::write_mem <dap chain pos> 0x1ee00e4 4 0 0x00000001
```

If the image verification passes, the board boot up starts in the secure mode.

4.5.5.2 Executing Op-tee Daemon

Run OPTee client daemon using the command below:

```
tee-suppllicant /dev/teepriv0 &
```

4.5.5.3 Executing OP-Tee test cases

OP-Tee test cases can be run using the steps listed below.

1. Run xtest binary in Linux console:

```
xtest
```

2. Then you should get a log similar to the following as a test result:

```
Run test suite with level=0
TEE test application started with device [(null)]
#####
#
# regression
#
#####
...
24003 subtests of which 0 failed
76 test cases of which 0 failed
0 test case was skipped
TEE test application done!
```

4.6 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 you specify who can unlink, append only, move a file, and so on. SELinux allows you 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>.

4.6.1 Running SELinux demo

This section describes the procedure for running the SELinux demo on NXP's LS1043ARDB-64bit and LS1046ARDB-64bit platforms.

4.6.1.1 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
```

4.6.1.2 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 selinux-utils
- \$ apt-get install policycoreutils
- \$ apt-get install auditd
- \$ apt-get install ssh
- \$ apt-get install apache2
- \$ apt-get install selinux-basics
- \$ apt-get install selinux-policy-default

2. Install Grub Common from source code:

```
$ wget http://archive.ubuntu.com/ubuntu/pool/main/g/grub2/grub2_2.02~beta2.orig.tar.xz
$ tar -xvf grub2_2.02~beta2.orig.tar.xz$ cd grub-2.02~beta2/
$ ./configure
$ make
$ make install
```

NOTE

It would take considerable time to run the `make` and `make install` commands.

3. Install SELinux from source code:

```
$ wget http://archive.ubuntu.com/ubuntu/pool/universe/s/selinux/selinux_0.11.tar.gz
$ tar -xvf selinux_0.11.tar.gz
$ cd selinux-0.10/
$ make
$ make install
```

4. Install SELinux policy from source code:

```
$ wget http://archive.ubuntu.com/ubuntu/pool/universe/r/refpolicy-ubuntu/refpolicy-ubuntu_0.2.20091117.orig.tar.bz2
$ wget http://archive.ubuntu.com/ubuntu/pool/universe/r/refpolicy-ubuntu/refpolicy-ubuntu_0.2.20091117-0ubuntu2.debian.tar.gz
$ tar jxvf refpolicy-ubuntu_0.2.20091117.orig.tar.bz2
$ tar zxvf refpolicy-ubuntu_0.2.20091117-0ubuntu2.debian.tar.gz
$ cd refpolicy
$ cp -r ../debian/patches/ ./
patch -p1 < patches/bashisms.patch
patch -p1 < patches/*.patch
patch -p1 < patches/conf.patch
patch -p1 < patches/users.patch
patch -p1 < patches/xserver.patch
patch -p1 < patches/sysnetwork.patch
patch -p1 < patches/cups.patch
patch -p1 < patches/ssh.patch
patch -p1 < patches/hal.patch
patch -p1 < patches/dbus.patch
patch -p1 < patches/bluetooth.patch
patch -p1 < patches/avahi.patch
patch -p1 < patches/networkmanager.patch
patch -p1 < patches/consolekit.patch
patch -p1 < patches/usermanage.patch
patch -p1 < patches/cron.patch
patch -p1 < patches/corecommands.patch
```

```

patch -p1 < patches/userdomain.patch
patch -p1 < patches/fstools.patch
patch -p1 < patches/kernel.patch
patch -p1 < patches/locallogin.patch
patch -p1 < patches/unconfined.patch
patch -p1 < patches/libraries.patch
patch -p1 < patches/init.patch
patch -p1 < patches/mount.patch
patch -p1 < patches/udev.patch
patch -p1 < patches/devtmpfs.patch
patch -p1 < patches/rtkit.patch
patch -p1 < patches/devkit.patch
patch -p1 < patches/gnome.patch
patch -p1 < patches/apt.patch
patch -p1 < patches/policykit.patch
patch -p1 < patches/modemmanager.patch
patch -p1 < patches/fix-ftbfs.patch
$ make conf
$ make policy
$ make install

```

4.6.1.3 Basic setup

Perform the following basic steps before running the SELinux demo.

1. 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
```

2. Map linux user to a selinux user named user_u:

```
$ semanage login -m -s user_u __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	*
system_u	system_u	s0-s0:c0.c1023	*

3. 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:

```
$ semanage fcontext -a -t home_root_t '/root(/.*)?'
```

Restore the system using the command below:

```
$ restorecon -R /
$ reboot
```

4. Check ssh server after the kernel boots up:

```
$ 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
```

5. 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/SUCCESS) 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
```

6. 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
```

4.6.1.4 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.

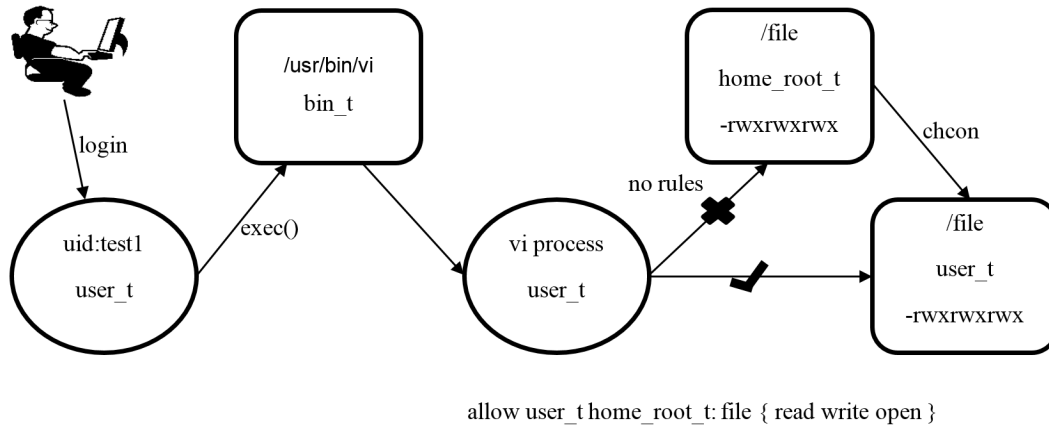


Figure 12. Allowing local file access control

1. root: create a test file:

```
$ echo "file created in root home" > /root/file
$ chmod 777 /root/file
$ mv /root/file /
$ ls -Z /file
sysadm_u:object_r:home_root_t:s0 /file
```

2. root: enable SELinux:

```
$ setenforce 1
$ getenforce 0
Enforcing
```

3. User test1: logs in 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.

```
"/file" [Permission Denied]
```

Figure 13. 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 of file

```
$ setenforce 0
$ chcon -t user_t /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.

```
type=AVC msg=audit(1455223344.656:204): avc: denied { write } for pid=3263 c
omm="vi" name="file" dev="mmcblk0p3" ino=146470 scontext=user_u:user_r:user_t:s0
tcontext=sysadm_u:object_r:home_root_t:s0 tclass=file permissive=1
Was caused by:
    Missing type enforcement (TE) allow rule.

    You can use audit2allow to generate a loadable module to allow
this access.
```

Figure 14. 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_ho
me_t, telepathy_mission_control_data_home_t, pulseaudio_tmp_t, spamassassin_tm
p_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_ho
me_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 15. 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.

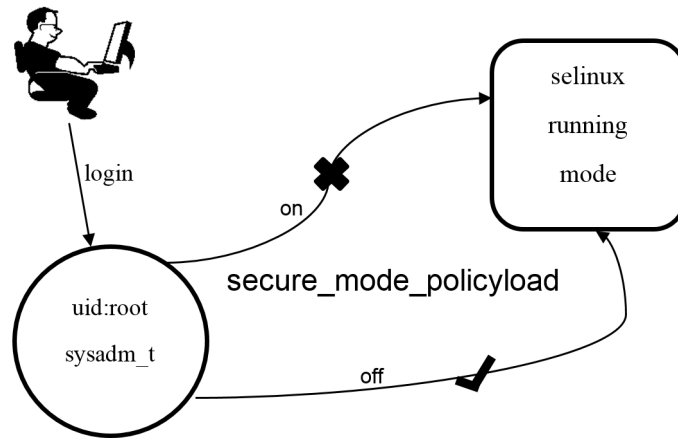


Figure 16. Restricting root permissions

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 tries to disable `secure_mode_policyload`, it fails too:

```
$ setsebool secure_mode_policyload off
Segmentation fault
```

Now there is no superuser in the system even if you are the root user.

Reboot the system. Booting with kernel option `enforcing=0` can make the system running in permissive mode. In this way, you can proceed with use cases similar to the ones described above.

4.6.1.5 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
--2016-02-11 16:41:08-- http://localhost/
Resolving localhost [ 795.609868] systemd-journald[1983]: recvmsg() failed: Permission denied
(localhost)... :.:1, 127.0.0.1
Connecting to localhost (localhost)|.:.:1|:80... connected.
HTTP request sent, awaiting response... 403 Forbidden
2016-02-11 16:41:08 ERROR 403: Forbidden.
```

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:home_root_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
```

```

Resolving localhost (localhost)... ::1, 127.0.0.1
Connecting to localhost (localhost)|::1|:80... connected.
HTTP request sent, awaiting response... 200 OK
Length: 11321 (11K) [text/html]
Saving to: 'index.html.1'
index.html.1      100%[=====>]  11.06K  --.-KB/s    in 0s
2016-02-11 16:57:16 (148 MB/s) - 'index.html.1' saved [11321/11321]

```

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.

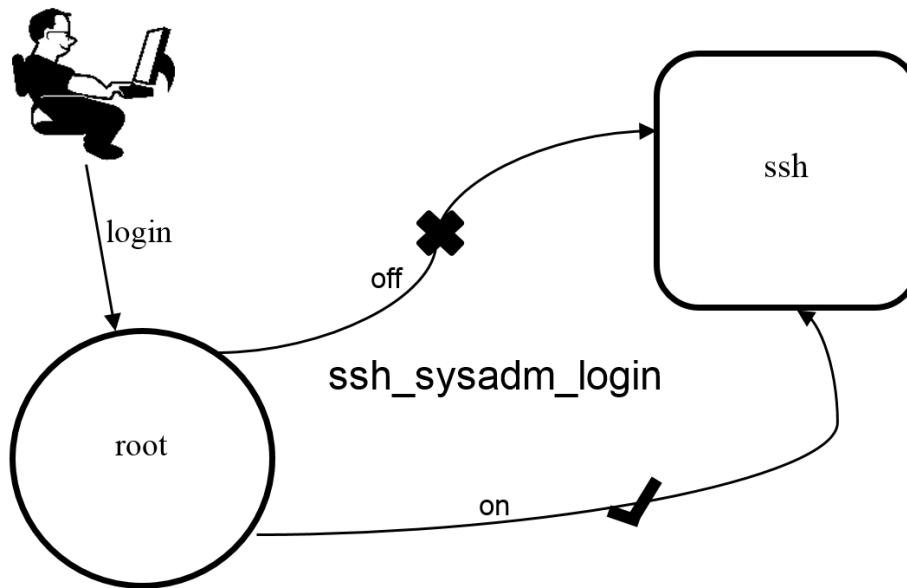


Figure 17. ssh remote permission

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

```

$ /etc/init.d/sshd restart

```

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 18. Audit log for sshd

```
$ audit2allow -a
```

Chapter 5

NETCONF/YANG

5.1 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 20. 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 you to create syntactically correct configuration data that meets constraint requirements and enables you 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.

5.2 Netopeer

Netopeer is a set of NETCONF tools built on the libnetconf (<https://github.com/CESNET/libnetconf>) library. It allows developers to control their devices via NETCONF and operators to connect to their NETCONF-enabled devices.

5.2.1 Overview

Netopeer is a set of NETCONF tools built on the libnetconf (<https://github.com/CESNET/libnetconf>) library. It allows developers to control their devices via NETCONF and operators to connect to their NETCONF-enabled devices.

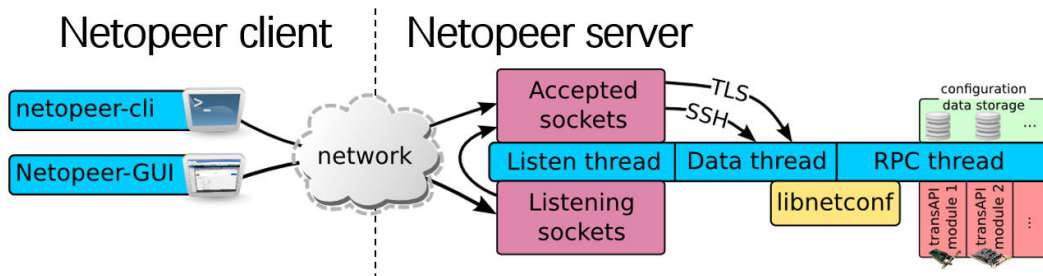


Figure 19. Netopeer overview

5.2.2 libnetconf

libnetconf is a NETCONF library in C intended for building NETCONF clients and servers. It provides basic functions to connect NETCONF client and server to each other via SSH, to send and receive NETCONF messages and to store and work with the configuration data in a datastore. libnetconf implements the NETCONF protocol introduced by IETF. libnetconf is maintained and further developed by the [Tools for Monitoring and Configuration](#) department of CESNET.

For information about libnetconf see:

<https://github.com/CESNET/libnetconf>

<https://rawgit.com/CESNET/libnetconf/master/doc/doxygen/html/index.html>

5.2.3 Netopeer server

Netopeer software is a collection of utilities and tools to support the main application, Netopeer server, which is a NETCONF server implementation. It uses libnetconf 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 Netopeer server responds with correct replies.

Most of the standard capabilities mentioned in the RFC 6241 are implemented including validating the new configuration before applying it or being able to return to a previous configuration if the new one failed to be applied. Except these, Netopeer server supports additional features such as these:

- Sending notifications on certain events to a client, provided that the client subscribes to them
- Access control, when every user has the available parts of the configuration for reading and for writing specified and cannot access any other.

The following set of tools are a part of the Netopeer server:

- Netopeer-server as the main service daemon integrating the SSH/TLS server.
- Netopeer-manager as a tool to manage the netopeer server modules.
- Netopeer-configurator as a tool for the server's first run configuration.

5.2.4 Netopeer client

Netopeer-cli is a CLI interface that allows you to connect to a NETCONF-enabled device and obtain and manipulate its configuration data.

This application is a part of the Netopeer software bundle, but compiled and installed separately. It is a NETCONF client with a command line interface developed and primarily used for Netopeer server testing, but allowing all the standards and even some optional features of a full-fledged NETCONF client.

Netopeer-cli serves as a generic NETCONF client providing a simple interactive command line interface. It allows you to establish a NETCONF session with a NETCONF-enabled device on the network and to obtain and manipulate its configuration data. Netopeer-cli is limited to a single NETCONF connection at a time via a forward or a reverse (Call Home) connecting method.

5.2.5 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.

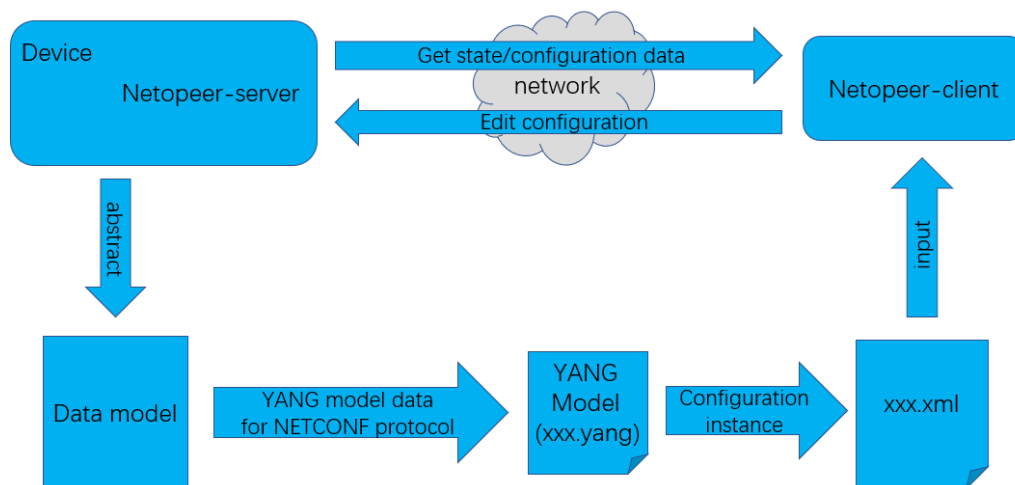


Figure 20. Workflow for netopeer

5.3 Installing Netopeer-cli on Centos/Ubuntu

Use the following steps for installing Netopeer-cli on Centos or Ubuntu operating systems.

Steps for installation on Centos 7.2:

1. Install the following packages:

```
$ sudo yum install libxml2-devel libxslt-devel openssl-devel libgcrypt dbus-devel doxygen
libevent readline.x86_64 ncurses-libs.x86_64 ncurses-devel.x86_64 libssh.x86_64
libssh2-devel.x86_64 libssh2.x86_64 libssh2-devel.x86_64
```

2. Install pyang :

```
$ git clone https://github.com/mbj4668/pyang.git
$ cd pyang
$ sudo python setup.py install
```

3. Pull, configure, make, and install libnetconf:

```
$ git clone https://github.com/CESNET/libnetconf.git
$ cd libnetconf
```



```
$ ./configure
$ sudo make
$ sudo make install
```

4. Pull netopeer and configure, make, and install cli:

```
$ git clone https://github.com/CESNET/netopeer.git
$ cd netopeer/cli
$ ./configure
$ make
$ make install
```

Steps for installation on Ubuntu 16.04

1. Install the following packages:

```
$ sudo apt-get install libxml2-dev libxslt-dev libssl-dev libssh2-1-dev xsltproc
doxygen pkg-config libtool-bin cmake libssh-dev libevent-dev libreadline-dev
libcurl4-openssl-dev python-libxml2 autoconf
```

2. Install pyang:

```
$ git clone https://github.com/mbj4668/pyang.git
$ cd pyang
$ sudo python setup.py 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.

```
$ dpkg -r libssh-dev
$ wget https://red.libssh.org/attachments/download/195/libssh-0.7.3.tar.xz --no-check-certificate
$ unxz libssh-0.7.3.tar.xz
$ tar -xvf libssh-0.7.3.tar
$ cd libssh-0.7.3/
$ mkdir build
$ cd build/
$ cmake ..
$ make
$ sudo make install
```

3. Pull, configure, make, and install libnetconf:

```
$ git clone https://github.com/CESNET/libnetconf.git
$ cd libnetconf
$ ./configure
$ sudo make
$ sudo make install
```

4. Pull netopeer and configure, make, and install cli:

```
$ git clone https://github.com/CESNET/netopeer.git
$ cd netopeer/cli
$ ./configure
$ make
$ sudo make install
```

5.4 Configuration

5.4.1 Netopeer-server

The netopeer-server is the NETCONF protocol server running as a system daemon. The netopeer-server is based on the libnetconf library. It provides an environment to run transAPI modules for configuring a specific device or application according to its data model.

- **-d**: Run in daemon mode.
- **-h**: Show help.
- **-V**: Show program version.
- **-v**: level Set the verbosity level. Possible values are from 0 (default) to 3. This overrides any NETOPEER_VERBOSE environment variable.

5.4.2 Netopeer-manager

The netopeer-manager provides access to the configuration of the netopeer-server modules. The netopeer-server modules extend its functionality to control another devices or applications via transAPI or just by storing configuration data. It can be configured using the options and commands described below.

OPTIONS

- **--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.

COMMANDS

- **add**: Adds a new netopeer-server module. The added module is enabled by default and it is loaded by the netopeer-server during its next start. Use the following example:

```
add [--help] --name NAME (--model MODEL | --augment AUGMENT | --import IMPORT)
    [--transapi TRANSAPI] [--features FEATURE [FEATURE ...]] [--datastore DATASTORE]
```

Where the arguments are as follows:

- **--name** NAME Specifies the name of the netopeer-server module. The NAME is used as an identifier of the module in the netopeer-server configuration.
- **--model** MODEL Specifies path (absolute or relative) to the module's main data model in YIN format. In this option, the whole module configuration is created.
- **--augment** AUGMENT Specifies path (absolute or relative) to an augment model of the main data model in YIN format. This model is always appended at the end of the model list.
- **--import** IMPORT Specifies path (absolute or relative) to a model in YIN format that is imported by the main model. This model is always prepended at the beginning of the model list.
- **--transapi** TRANSAPI Optional parameter to specify path to the transAPI module related to the module's main data model. If the transAPI module is not specified, netopeer-server allows the connection and configuration data manipulation according to the data model, but the changes are not applied to any device. This part of the process is handled just by the trans API module.
- **--features** FEATURE [FEATURE ...] Data model can define various features that extend its basic functionality. By default, netopeer-server supposes all features to be disabled. This option explicitly specifies the list of features to enable. To enable all features, use the format `value *`.

- **--datastore** DATASTORE specifies the path to the file where the configuration data is stored. If not specified, the datastore is implemented as empty and it does not store any configuration data.

- **list**: Prints the list of all netopeer-server modules. The command format is as follows:

```
list [--help] [--name NAME]
```

Where:

- **--name**: specifies the name of the main netopeer-server module for which, the list of extending data models would be printed.

- **rm**: Removes the specified netopeer-server main module. The command format is as follows:

```
rm [--help] --name NAME [--model MODEL]
```

Where the arguments are

- **--name**: NAME Specifies the name of the main netopeer-server module to remove.
- **--model**: If MODEL is specified, only this extending model is removed instead of the whole module.

5.4.3 netopeer-cli

The netopeer-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. netopeer-cli is limited to a single NETCONF connection at a time via a forward or a reverse (Call Home) connecting method.

5.4.3.1 Netopeer CLI commands

Following are the Netopeer 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] [--login username] [--port num] host
```

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.
- **--tls**: Uses NETCONF over TLS transport instead of default SSH. Default client certificate and trusted CA directory are used for TLS handshake. This option is available only when the netopeer-cli is compiled with configure's **--enable-tls** option.
- **--cert** cert_path
 - Uses a specific certificate for TLS handshake. **cert_path** specifies path to the client certificate in CRT format. If **--key** option is not specified, **cert_path** is expected to contain also the private key for the client certificate, in PEM format.
 - This option is available only when the netopeer-cli is compiled with configure's **--enable-tls** option.
- **--key** key_path
 - Specifies path to the private key for the client certificate in KEY format. If not specified, **cert_path** is expected to contain also the private key for the client certificate, in PEM format.
 - This option is available only when the netopeer-cli is compiled with configure's **--enable-tls** option.

- **--trusted** trusted_CA_store
 - Specifies path to a trusted CA certificate bundle in PEM format to be used exclusively for server verification for this connection instead of the default CA directory.
 - This option is available only when the netopeer-cli is compiled with configure's `--enable-tls` option.
 - **--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 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] [--defaults mode] [--source datastore | --config file] target_datastore
```

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.
- **--source** datastore: Specifies the source datastore for the `copy-config` operation. For description of the datastore parameter, refer to [Netopeer CLI datastore](#) on page 67.

NOTE

This option is available only when the netopeer-cli is compiled with configure's `--enable-tls` option.

- **--config** file
 - Specifies the path to a local file containing the complete configuration to copy. This option alternates the `--source` option.
 - **target_datastore**
 - Target datastore to be rewritten. For description of possible values, refer to [Netopeer CLI datastore](#) on page 67.
6. **delete-config** Performs NETCONF `delete-config` operation. For more details see RFC 6241 section 7.4.

```
delete-config [--help] target_datastore
```

Where

- **target_datastore** is the Target datastore to delete. For description of possible values, refer to [Netopeer CLI datastore](#) on page 67. Note that the running configuration datastore cannot be deleted.
- **discard-changes**: Performs NETCONF `<discard-changes>` operation. It reverts the candidate configuration to the current running configuration. For more details see RFC 6241 section 8.3.4.2.

7. edit-config

Performs NETCONF `edit-config` operation. For details, see RFC 6241 section 7.2.

```
edit-config [--help] [--defop operation] [--error action] [--test
option] [--config file | --url URI] target_datastore
```

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.
 - **--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_datastore**
 - Target datastore to modify. For description of possible values, refer to [Netopeer CLI datastore](#) on page 67. 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] [--defaults mode] [--filter [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.

- **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] [--defaults mode] [--filter [file]] target_datastore
```

- **--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.

- **target_datastore**

- Target datastore to retrieve. For description of possible values, refer to [Netopeer CLI datastore](#) on page 67. Note, that the url configuration datastore cannot be retrieved.

9. **get-schema:** Performs NETCONF `get-schema` operation that retrieves specified data model used by the server. This operation is available only if the server implements the YANG module for NETCONF monitoring. The list of available schemas can be retrieved from `/netconf-state/schemas` subtree via the `get` operation. For more details see RFC 6022 sections 3.1 and 4.

```
get-schema [--help] [--version version] [--format format] identifier
```

- **--version version**

- Version of the requested schema.

- **--format format**

- The data modeling language (format) of the requested schema. The default value is yang.

- **identifier**

- Identifier for the schema list entry.

10. 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_datastore
```

Where the

- **target_datastore:** specifies the target datastore to lock. For description of possible values, refer to [Netopeer CLI datastore](#) on page 67. Note, that the url configuration datastore cannot be locked.

11. **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_datastore
```

where

- **target_datastore:** specifies the target datastore to unlock. For description of possible values, refer to [Netopeer CLI datastore](#) on page 67. Note, that the url configuration datastore cannot be unlocked.

12. **user-rpc**: Sends your own content in an RPC envelope. This can be used for RPC operations defined in data models not supported by the netopeer-cli.

```
user-rpc [--help] [--file file]
```

13. **file** file

- Specifies a file containing NETCONF RPC operation in XML format. Only the NETCONF `rpc` envelope is added to the file content and then it is sent to a server. If the option is omitted, user is prompted to type the RPC content manually.

14. **verbose**

- Enables/disables verbose messages.

15. **debug**

- Enables/disables debug messages. Available only if the netopeer-cli is compiled with configure's `--enable-debug` option.

16. **quit**

- Quits the program.

5.4.3.2 Netopeer CLI datastore

Following are the netopeer 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.

5.4.4 Operation examples

The following figure describes the basic process of operating netopeer:

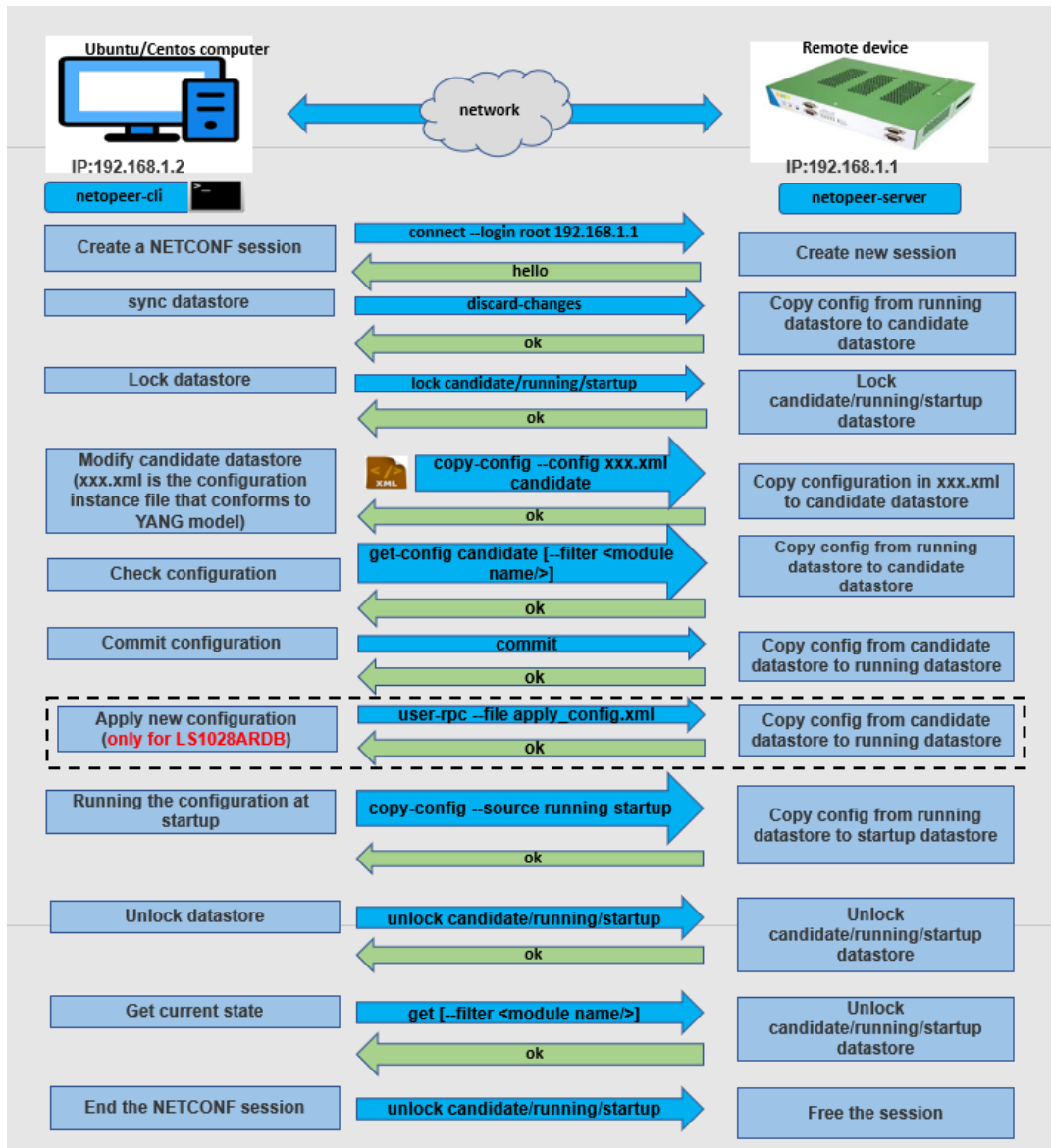


Figure 21. Examples of Netopeer operation process

In the sj1105 YANG model, you may set any register of sj1105 or a whole register map by netopeer-cli.

Make sure the netconf server is running (check the netopeer-server is running at ls1021atsn).

If the netopeer-server is not running, input the below command to allow it to run (in verbose mode):

```
$ /usr/local/bin/netopeer-server -v 3
```

Test commands at netopeer-client (a CentOS/Ubuntu PC to run netopeer-cli as an example):

1. Start client software

```
$ netopeer-cli
```

2. Connect the netconf server ls1021atsn board (use the IP on ls1021atsn, here 10.193.20.53 is example):

```
$ Netconf> connect --port 830 --login root 10.193.20.53
```


3. Get status data of server

```
$ netconf> get
```

4. User can get data what he wants by --filter option

```
$ netconf> get --filter
```

5. Then input the filtered node you want to see in the text editor:

```
<sjal105>
  <static>
    <ports/>
  </static>
</sjal105>
```

6. Get config data what he wants in running/candidate/startup space:

```
$ netconf> get-config running
$ netconf> get-config candidate
$ netconf> get-config startup
```

7. You can also add --filter parameter to filter what you want to see.
8. You can use `discard-changes` command to copy data from running to candidate space.

```
$ netconf> discard-changes
```

NOTE

It is recommended to run `discard-changes` at the first instance when the board boots up. Refer the step No. 5 in [Section Troubleshooting](#) on page 71.

9. Use the `commit` command to copy data from 'candidate' to 'running' space.

```
$ netconf> commit
```

10. You can edit any elements in the tables or multiple tables elements for running/candidate/startup space.

```
$ netconf> edit-config candidate
```

NOTE

The 'candidate' modification only edits the candidate registers map. It does not actually modify this information in the sjal105 true registers.

- a. The 'running' modification only edits the running registers map. It actually modifies the sjal105 true registers.

```
$ netconf> edit-config running
```

- b. The 'startup' modification only edits the startup registers map. It does not actually modify this information in the sjal105 true registers.

```
$ netconf> edit-config startup
```

- c. Input below text into the editor as an example and wait for got 'OK' message:

```
sjal105 xmlns="http://nxp.com/ns/yang/tsn/sjal105"
```

```
<static>
<l2-policing-table>
<entry>
<index>1</index>
<sharindx>0x1</sharindx>
<smax>0x8000</smax>
<rate>0xFA00</rate>
<maxlen>0x5EE</maxlen>
<partition>0x0</partition>
</entry>
</l2-policing-table>
</static>
</sjal105>
```

The preceding example shows how to edit the 'index 1' entry in the l2-policing-table.

- d. Refer to [Operation examples](#) on page 67 to check the YANG model of the sjal105 data design.

11. You can edit config a saved xml file with all of or part of the full yang model nodes list. You can refer the files under board/nxp/ls1021atsn/rootfs_overlay/etc/sjal105/*.xml for how to input edit-config content in the cross compiler buildroot folder.

```
$ ls board/nxp/ls1021atsn/rootfs_overlay/etc/sjal105/*.xml
policing.xml prioritizing.xml standard.xml
```

12. You can even check the server board to see the xml file that has been saved on the server:

```
$ netconf> get --filter
<sjal105><static><config-files/></static></sjal105>
```

So as an example of the edit-config command would be (suppose we are under buildroot source code root folder):

```
$ netconf> edit-config --config board/nxp/ls1021atsn/rootfs_overlay/etc/sjal105/policing.xml
candidate
```

- Use `running` option to directly edit in the physical registers of sjal105.
- Use `candidate` option to edit the register into candidate space.

13. You can copy data between the running/candidate/startup by using `copy-config` or source xml file in the client:

```
$ netconf> copy-config --source running startup
```

14. Here is an example of copying the running space data to startup space. Three more RPC calls are provided in the sjal105 YANG model.

15. If user wants to save current registers mapping into a file (must extend with .xml. This 'save-local-config' command would save current 'running' space config registers value into the file.)

16. In the netopeer-cli shell, by `user-rpc` command:

```
$ netconf> user-rpc
```

17. Input below text into the editor (nc_standard.xml is an example file name):

```
<save-local-config xmlns="http://nxp.com/ns/yang/tsn/sjal105">
<configfile>
```

```
nc_standard.xml
</configfile>
</save-local-config>
```

Then, a file `nc_standard.xml` would be saved to the `/etc/sja1105/` directory in the server (board).

NOTE

You can get all saved xml files by using the 'get' command and the 'config-files' filter.

If user wants to load a xml to set the sja1105 registers into `running` and `candidate` space, user can use `rpc` command 'load-local-config'. The xml file must list in the `/etc/sja1105/`. (Get file list by using the `get` command and with `config-files` filter.)

In the `netopeer-cli` shell, by 'user-rpc' command:

```
$ netconf> user-rpc
```

Use the commands below to achieve this (`policing.xml` is an example name):

```
<load-local-config xmlns="http://nxp.com/ns/yang/tsn/sja1105">
<configfile>
policing.xml
</configfile>
</load-local-config>
```

18. Users can load a default registers mapping mode (sja1105 as a normal switch mode). In the `netopeer-cli` shell, you can do this by using the 'user-rpc' command:

```
$ netconf> user-rpc
```

19. Input the below text in the editor (`policing.xml` is an example name):

```
<load-default xmlns="http://nxp.com/ns/yang/tsn/sja1105" />
```

5.5 Troubleshooting

1. Connect fails at client side:

```
libnetconf ERROR: Remote host key changed, the connection will be terminated!
libnetconf ERROR: Checking the host key failed.
```

Fixing:

The reason is that the SSHD key changed at the server.

You need to input command 'quit' `netopeer-cli` first. Then remove `~/.ssh/known_hosts` and restart `netopeer-cli`.

2. Command error shows:

```
libnetconf ERROR: Input channel error (Socket error: Connection reset by peer)
user-rpc: receiving rpc-reply failed.

Closing the session.
```

Fixing:

Lost connection in few minutes later if not to communicate with server.

Reconnect server.

3. Run command at netopeer-server (board):

```
[# /usr/local/bin/netopeer-server -v 3
```

Got error:

```
netopeer-server[216]: sock_listen: could not bind ":::0" port 830 (Address already in use)
netopeer-server[216]: Server is not listening on any address!
```

Fixing:

There should another netopeer-server is running. Use command to check:

```
$ ps | grep netopeer-server
```

If there is a netopeer-server process:

```
$ /usr/local/bin/netopeer-server -d
```

4. Terminating netopeer-server.

The right way to terminate the server is by using Ctrl ^ C or the below command:

```
$ /etc/init.d/S90netconf stop
```

5. Get an empty candidate contend:

```
$ netconf> get-config candidate

Result:
```

Fixing:

It is recommend to input a 'discard-changes' command when the first time for netopeer-server boot up and connected by client.

```
$ netconf> discard-changes
```

6. When you operate command 'edit-config' 'get-config' got error:

```
NETCONF error: operation-failed (application) - There is no device/data that could be affected.
```

Fixing:

The reason is that the server was not properly terminated. If you killed the server several times then all this is stored in the shared memory and that many times on next server startup the candidate datastore is not replaced by the running datastore. Do not use kill -9 to terminate netopeer-server process. Use Ctrl ^ C in the terminal with netopeer-server (or you can send SIGINT instead SIGKILL). You should restart netopeer-server (Ctrl^ C or /etc/init.d/S90netconf restart)

```
$ /etc/init.d/S90netconf restart
```

Then, in the client netopeer-cli soon after connection:

```
$ netconf> discard-changes
```

7. The netopeer-server default to set nothing registers of sj1105 chip when server startup. If user wants to let netopeer-server auto set a series registers in sj1105 at netopeer-server boot up time, you need to set the registers value to the startup space. Below contend introduce how to set 'startup' space. Edit 'startup' space configuration.

startup' space configures are for setting sj1105 registers when netopeer-server start time. There are several ways to edit 'startup' space configures data. Here are the examples:

From the 'running' space configure copy to 'startup' space:

```
$ netconf> copy-config --source running startup
```

Copy from client local file (policing.xml is example file name) to server 'startup' space:

```
$ netconf> copy-config copy-config --config policing.xml startup
```

Modify some sub-tree registers from client local file (policing.xml is example file name) to server 'startup' space:

```
$ netconf> edit-config --config policing.xml startup
```

8. Validate command shows:

```
NETCONF error: operation-not-supported (application) - Request could not be completed because the requested operation is not supported by this implementation.
```

NOTE

The 'validate' command is not supported in the current version of NETCONF.

9. Datastores dead lock: When the server crashes or is terminated with SIGKILL, it may happen that the internal datastore locks stay locked. In such a case, the next time the netopeer-server (or any other libnetconf based application) tries to access the configuration datastores, it freezes. To solve this problem, release the locks manually removing the /dev/shm/sem.NCDS_FLOCK_* files.

Refer to the [point No. 4](#) above, for how to terminate the netopeer-server properly.

10. Modifying /etc/network/interfaces might cause the netopeer-server segment fault when netopeer-server starts if ietf-interfaces is selected in the buildroot. Use the below command to remove the ietf-interfaces model.

```
$ /usr/local/bin/netopeer-manager rm --name ietf-interfaces
$ /usr/local/bin/netopeer-manager list
```

Chapter 6

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

6.1 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 you 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.

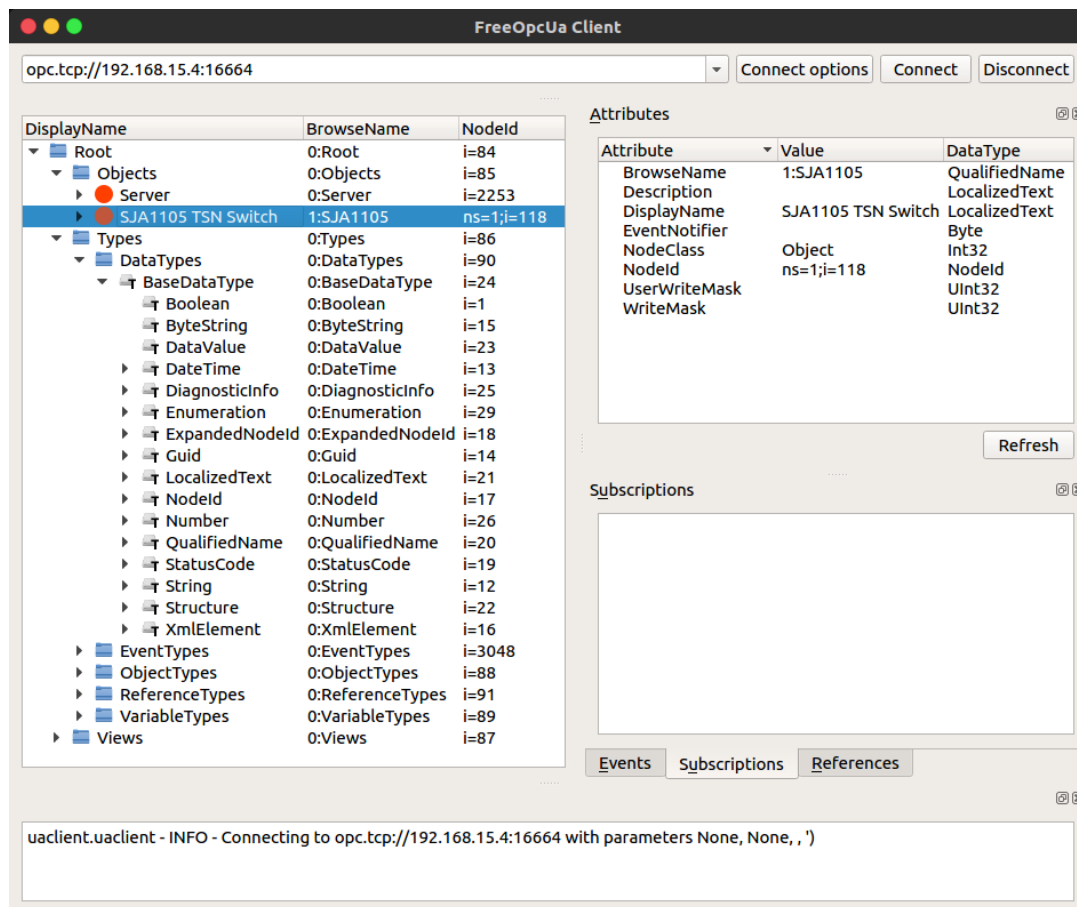
6.2 The node model

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 22. 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`.

6.3 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*.

6.4 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*.

6.5 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.

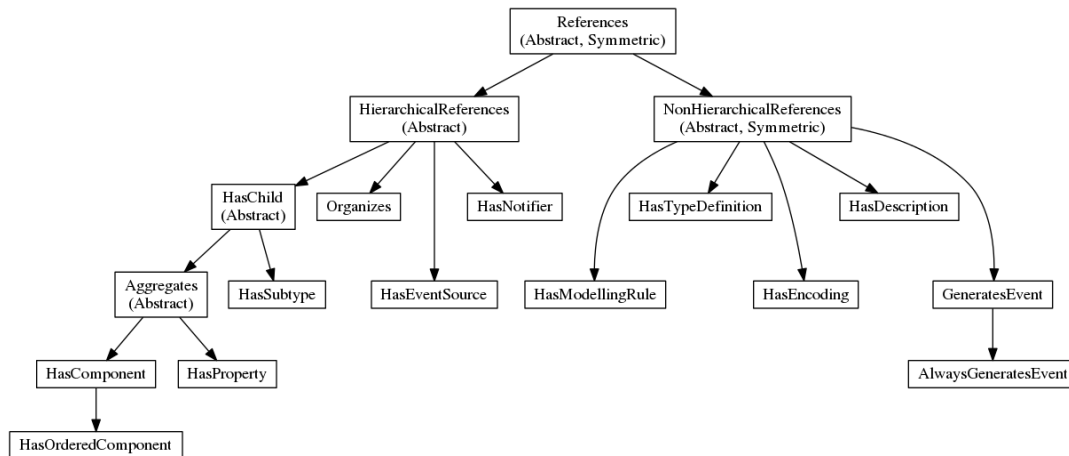


Figure 23. Hierarchy of the standard ReferenceTypes, defined in Part 3 of the OPC UA specification (Image taken from www.open62541.org)

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.

Attributes

Attribute	Value	DataType
BrowseName	1:RGMII4	QualifiedName
Description		LocalizedText
DisplayName	RGMII4	LocalizedText
EventNotifier		Byte
NodeClass	Object	Int32
Nodeid	ns=1;i=197	Nodeid
UserWriteMask		UInt32
WriteMask		UInt32

References

ReferenceType	Nodeid	BrowseName	TypeDefinition
HasTypeDefinition	ns=1;i=117	1:EthPortType	Null
HasComponent	ns=1;i=198	1:ChassisLabel	BaseDataVariableType
HasComponent	ns=1;i=199	1:Counters	BaseObjectType

Figure 24. 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:RGMI14` node is of the custom ObjectType `EthPortType`.

6.6 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.

When building with the `BR2_PACKAGE_OPEN62541_EXAMPLES` flag, the following Open62541 example applications are included in the OpenIL target image:

- `open62541_client`
- `open62541_server_instantiation`
- `open62541_tutorial_client_firststeps`
- `open62541_tutorial_server_firststeps`
- `open62541_tutorial_server_variable`
- `open62541_server`
- `open62541_server_mainloop`
- `open62541_tutorial_datatypes`
- `open62541_tutorial_server_method`
- `open62541_tutorial_server_variabletype`
- `open62541_server_inheritance`
- `open62541_server_repeated_job`
- `open62541_tutorial_server_datasource`
- `open62541_tutorial_server_object`

6.7 Example of a server application: OPC SJA1105

In addition to the default Open62541 examples, OpenIL includes an application for monitoring the SJA1105 traffic counters on the LS1021A-TSN board. It can be started by running:

```
[root@openil] $ /usr/bin/opc-sja1105
```

The application's information model hierarchically describes the per-port traffic counters of the L2 switch under the `1:SJA1105` node.

On the server, a repeated job runs once per second, reads the port counters over SPI, and manually updates the port counter nodes.

6.8 FreeOpcUa Client GUI

FreeOpcUa (<http://freeopcua.github.io/>) is another open source framework for OPC UA communication (both server- and client-side). For this example, the client GUI available at <https://github.com/FreeOpcUa/opcua-client-gui> can be used to interact with the `opc-sja1105` server application from OpenIL.

1. Follow the instructions from the `opcua-client-gui` `README.md` to install it on a host PC (either Windows or GNU/Linux). As noted, a Python runtime with Qt5 support is required.
2. In Windows, navigate to the location of your WinPython installation, and open `WinPython Command Prompt.exe`.
3. Execute the following command:

```
opcua-client
```

The FreeOpcUa client GUI window pops up.

4. In the address drop-down input field, insert the following text:

```
opc.tcp://192.168.15.2:16664
```

After selecting **Connect**, a connection to the OPC UA server running on Board 2 is established.

5. In the OPC UA client, navigate to the node **Root -> Objects -> SJA1105 TSN Switch -> RGMII2 -> Traffic Counters -> ETH3 ::: N_TXBYTE**. This should correspond to the Node ID `ns=1;i=173`. Right click on this node, and select **Subscribe to data change**.
6. After this step, the OPC UA client should look like this:

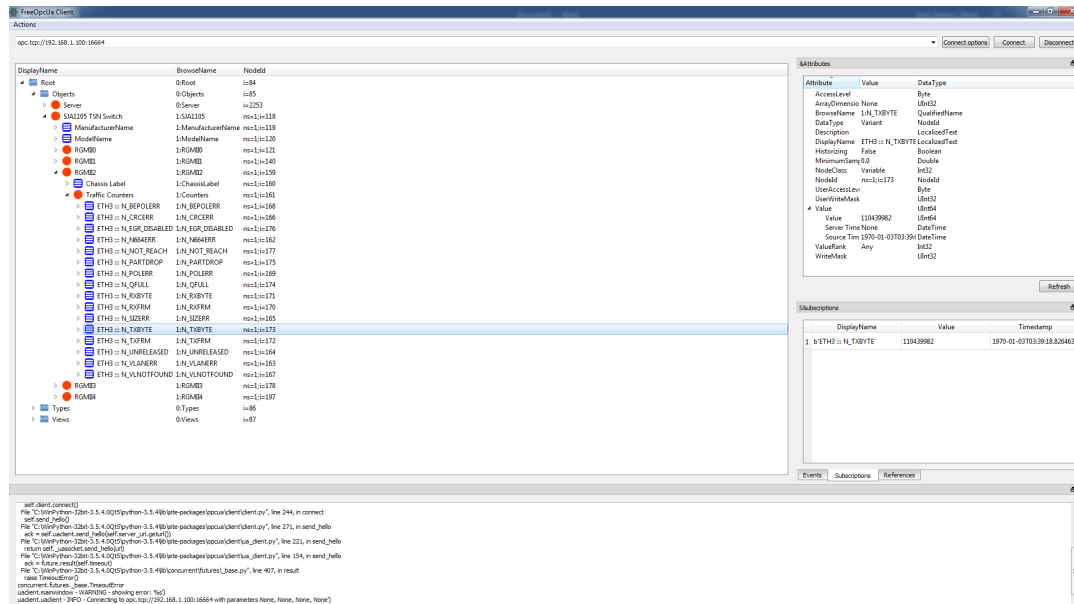


Figure 25. Subscribing to data changes of the ETH3 ::: N_TXBYTE node of the OPC-SJA1105 server

In the FreeOpcUa GUI, it is possible to create subscriptions to Data Changes on port counters of interest (by right-clicking on the individual nodes in the Address Space).

A dedicated OPC client might run custom code upon receiving Data Change notifications from the server, whereas the FreeOpcUa GUI only displays the updated values.

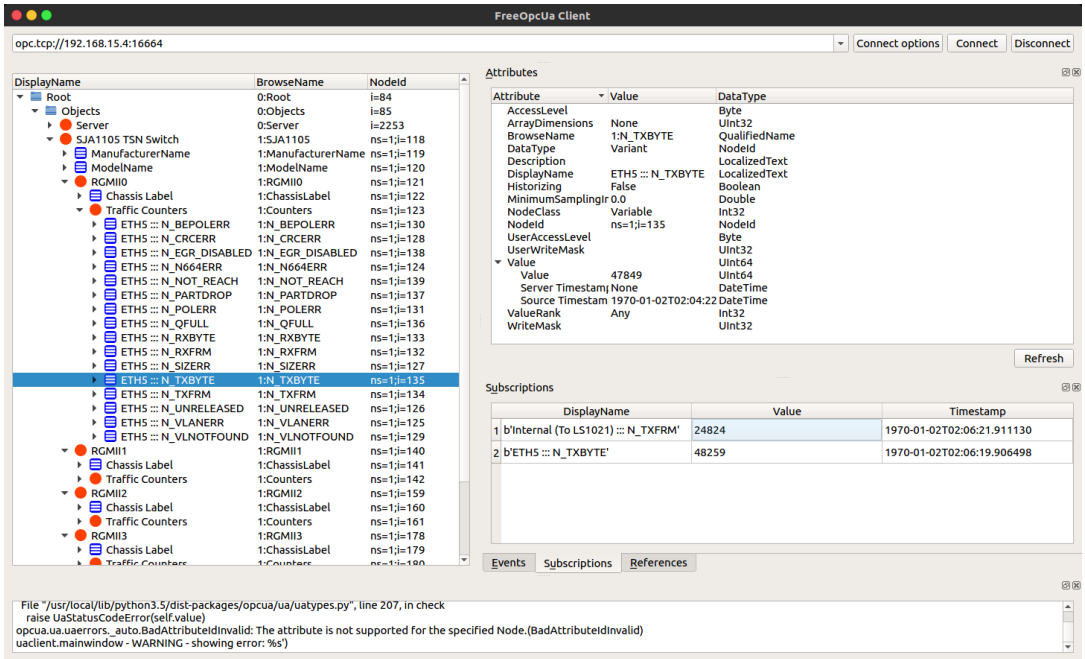


Figure 26. Data change notification

The preceding figure shows the Data Change Subscriptions to two counters: the Tx Frames of the L2 switch towards the LS1021, and the Tx Bytes towards chassis port ETH5.

Note that the subscribed value of `ETH5 :: N_TXBYTE` (48259) is higher than the Value of its Attribute (47849). This is because the Subscriptions view updates automatically, while the Attributes do not.

Chapter 7

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 Using TSN features on LS1028ARDB

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.

7.1.1 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

Currently the Tsntool supports only the LS1028ARDB platform. Other hardware platforms might be supported in future.

7.1.1.1 Getting the source code

Github of the tsntool code is:

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

7.1.1.2 Tsn tool commands

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

Table 21. 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>

Table continues on the next page...

Table 21. TSN tool commands and their description (continued)

Command	Description
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
qcisficounterget	Gets stream filter counters
qcifmiset	Sets flow metering instance
qcifmiget	Gets flow metering instance
cbsset	Sets TCs credit-based shaper configure
cbsget	Gets TCs credit-based shaper status
qbuset	Sets one 8-bits vector showing the preemptable traffic class
qbugetstatus	Not supported
tsdset	Not supported
tsdget	Not supported
ctset	Sets cut through queue status (specific for ls1028 switch)
cbgen	Sets sequence generate configure (specific for ls1028 switch)
cbrec	Sets sequence recover configure (specific for ls1028 switch)
pcpmap	Sets queues map to PCP tag (specific for ls1028 switch)
dscpset	Sets queues map to DSCP of Qos tag (specific for ls1028 switch)
sendpkt	Not supported
regtool	Register read/write of bar0 of PFs (specific for ls1028 enetc)

Table continues on the next page...

Table 21. TSN tool commands and their description (continued)

Command	Description
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)

7.1.1.3 Tsntool commands and parameters

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

Table 22. Tsntool command parameters and arguments

qbvset parameter <argument>	Description
--device <ifname>	An interface such as eno0/swp0
--entryfile <filename>	<p>A file script to input gatelist format. It has the following arguments:</p> <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: xxxxxxxxb . # 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 10000 t1 11011111b 10000 <p style="text-align: center;">NOTE</p> <p>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>	<p>AdminBaseTime</p> <p>A 64-bit hex value means nano second until now.</p> <p>OR a value input format as: Seconds.nanoSeconds</p> <p>Example: 115.532038675</p>
--cycletime <value>	AdminCycleTime
--cycleextend <value>	AdminCycleTimeExtension

Table continues on the next page...

Table 22. Tsntool command parameters and arguments (continued)

qbvset 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 23. qbvget

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

Table 24. 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.
--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 • -ipstreamid: not supported

Table continues on the next page...

Table 24. cbstreamidset (continued)

Parameter <argument>	Description
--nulldmac <value>	tsnCpeNullDownDestMac
--nulltagged <value>	tsnCpeNullDownTagged
--nullvid <value>	tsnCpeNullDownVlan
--sourcemac <value>	tsnCpeSmacVlanDownSrcMac
--sourcetagged <value>	tsnCpeSmacVlanDownTagged
--sourcevid <value>	tsnCpeSmacVlanDownVlan

Table 25. 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 26. 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.
--streamhandle <value>	StreamHandleSpec This value corresponds to <code>tsnStreamIdHandle</code> of <code>cbstreamidset</code> command.
--priority <value>	PrioritySpec
--gateid <value>	StreamGateInstanceID
--oversizeenable	StreamBlockedDueToOversizeFrameEnable
--oversize	StreamBlockedDueToOversizeFrame

Table 27. qcisfiget

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 28. qcisgiset

parameter <argument>	Description
--device <ifname>	An interface such as <code>eno0/swp0</code>
--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. <code>PSFPGateEnabled</code> • disable: disable the entry for this index • default to set enable if no enable or disable input
--configchange	<code>configchange</code>
--enblkinvr	<code>PSFPGateClosedDueToInvalidRxEnable</code>
--blkinvr	<code>PSFPGateClosedDueToInvalidRx</code>
--initgate	<code>PSFPAdminGateStates</code>
--initip	<code>AdminIPV</code>
--cycletime	Default not set. Get by <code>gatelistfile</code> .
--cycletimeext	<code>PSFPAdminCycleTimeExtension</code>
--basetime	<p><code>PSFPAdminBaseTime</code></p> <p>A 64-bit hex value means nano second until now.</p> <p>OR a value input format as: <code>Seconds.nanoSeconds</code></p> <p>Example: <code>115.532038675</code></p>
--gatelistfile	<p><code>PSFPAdminControlList</code>. A file input the gate list: 'NUMBER' 'GATE_VALUE' 'IPV' 'TIME_LONG' 'OCTET_MAX'</p> <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 29. qcisgiget

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

Table 30. qcifmisset

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 31. qcifmiget parameter

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

Table 32. qbuset parameter

parameter <argument>	Description
--device <ifname>	An interface such as eno0/swp0
--preemptable <value>	8-bit hex value. Example: 0xfe 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 33. cbsset command

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

Table 34. cbsget

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

Table 35. regtool

parameter <argument>	Description
Usage: regtool { pf number } { offset } [data]	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 36. ctset

parameter <argument>	Description
--device <ifname>	An interface such as eno0/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 37. cbgen

parameter <argument>	Description
--device <ifname>	An interface such as eno0/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

Table continues on the next page...

Table 37. cbgen (continued)

parameter <argument>	Description
--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 0xFFF.
--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 38. cbrec

parameter <argument>	Description
--device <ifname>	An interface such as eno0/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 0xFFF.
--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 39. pcpmap

parameter <argument>	Description
--device <ifname>	An interface such as eno0/swp0
--enable	Enable pcp to traffic class for frames.

Table 40. dscpset

parameter <argument>	Description
--device <ifname>	An interface such as eno0/swp0
--disable	Disable DSCP to traffic class for frames.
--index	DSCP value

Table continues on the next page...

Table 40. dscpset (continued)

parameter <argument>	Description
--cos	Priority number of queue which is mapped to
--dpl	Drop level which is mapped to

7.1.1.4 Input tips

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

- When you 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 you input parameters, if you don't remember the parameter name. You can just input "--" then press **TAB** key. It displays all the parameters.

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

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

7.1.1.5 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
```

7.1.2 Kernel configuration

Before compiling the Linux kernel, we need to configure it. In the kernel, select the configuration settings displayed below:

```
Symbol: TSN [=y]
| Type : boolean
| Prompt: 802.1 Time-Sensitive Networking support
| Location:
| -> Networking support (NET [=y])
| -> Networking options
| Depends on: NET [=y] && VLAN_8021Q [=y] && PTP_1588_CLOCK [=y]
|
Symbol: ENETC_TSN [=y]
| Type : boolean
| Prompt: TSN Support for NXP ENETC driver
| Location:
```

```

| -> Device Drivers
| -> Network device support (NETDEVICES [=y])
| -> Ethernet driver support (ETHERNET [=y])
| -> Freescale devices (NET_VENDOR_FREESCALE [=y])
| Defined at drivers/net/ethernet/freescale/enetc/Kconfig:41
| Depends on: NETDEVICES [=y] && ETHERNET [=y] && NET_VENDOR_FREESCALE [=y] && FSL_ENETC [=m] &&
TSN [=y]
|
| Symbol: FSL_ENETC_PTP_CLOCK [=y]
|   Type : tristate
|   Prompt: ENETC PTP clock driver
|   Location:
|   -> Device Drivers
|   -> Network device support (NETDEVICES [=y])
|   -> Ethernet driver support (ETHERNET [=y])
|   -> Freescale devices (NET_VENDOR_FREESCALE [=y])
|
| Symbol: FSL_ENETC_HW_TIMESTAMPING [=y]
|   Type : boolean
|   Prompt: ENETC hardware timestamping support
|   Location:
|   -> Device Drivers
|   -> Network device support (NETDEVICES [=y])
|   -> Ethernet driver support (ETHERNET [=y])
|   -> Freescale devices (NET_VENDOR_FREESCALE [=y])
|
| Symbol: MSCC_FELIX_SWITCH_TSN [=y]
|   Type : tristate
|   Prompt: TSN on FELIX switch driver
|   Location:
|   -> Device Drivers
|   -> Network device support (NETDEVICES [=y])
|   -> Ethernet driver support (ETHERNET [=y])
|   -> Microsemi devices (NET_VENDOR_MICROSEMI [=y])
|   -> Ocelot switch driver (MSCC_OCELOT_SWITCH [=y])
|   -> FELIX switch driver (MSCC_FELIX_SWITCH [=y])
|   Defined at drivers/net/ethernet/mscc/Kconfig:38
|
| Symbol: NET_PKTGEN [=y]
|   Type : tristate
|   Prompt: Packet Generator (USE WITH CAUTION)
|   Location:
|   -> Networking support (NET [=y])
|   -> Networking options
|   -> Network testing
|   Defined at net/Kconfig:325
|   Depends on: NET [=y] && INET [=y] && PROC_FS [=y]
|
| Symbol: MSCC_FELIX_SWITCH_PTP_CLOCK [=y]
|   Type : boolean
|   Prompt: FELIX switch PTP clock support
|   Location:
|   -> Device Drivers
|   -> Network device support (NETDEVICES [=y])
|   -> Ethernet driver support (ETHERNET [=y])
|   -> Microsemi devices (NET_VENDOR_MICROSEMI [=y])
|   -> Ocelot switch driver (MSCC_OCELOT_SWITCH [=y])
|   -> FELIX switch driver (MSCC_FELIX_SWITCH [=y])
|   Defined at drivers/net/ethernet/mscc/Kconfig:38

```

```
| Depends on: NETDEVICES [=y] && ETHERNET [=y] && NET_VENDOR_MICROSEMI
| Selects: PTP_1588_CLOCK [=y]
```

7.1.3 Basic TSN configuration examples on ENETC

The `tsntool` is an application configuration tool to configure the TSN capability. You 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, you need to enable `mqprio` by using the command:

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

7.1.3.1 Linuxptp test

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
```

7.1.3.2 Qbv test

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

7.1.3.2.1 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.
```

7.1.3.2.2 Basetime test

Base on case 1 qbv1.txt gate list.

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

tsntool> regtool 0 0x18
tsntool> regtool 0 0x1c

#read the current time
tsntool> ptptool -g

#add some seconds, for example, you get 200.666 time clock, then set 260.666 as result

tsntool> qbvset --device eno0 --entryfile qbv1.txt --basetime 260.666
tsntool> qbvget --device eno0 #You 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
```

7.1.3.2.3 Qbv performance test

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

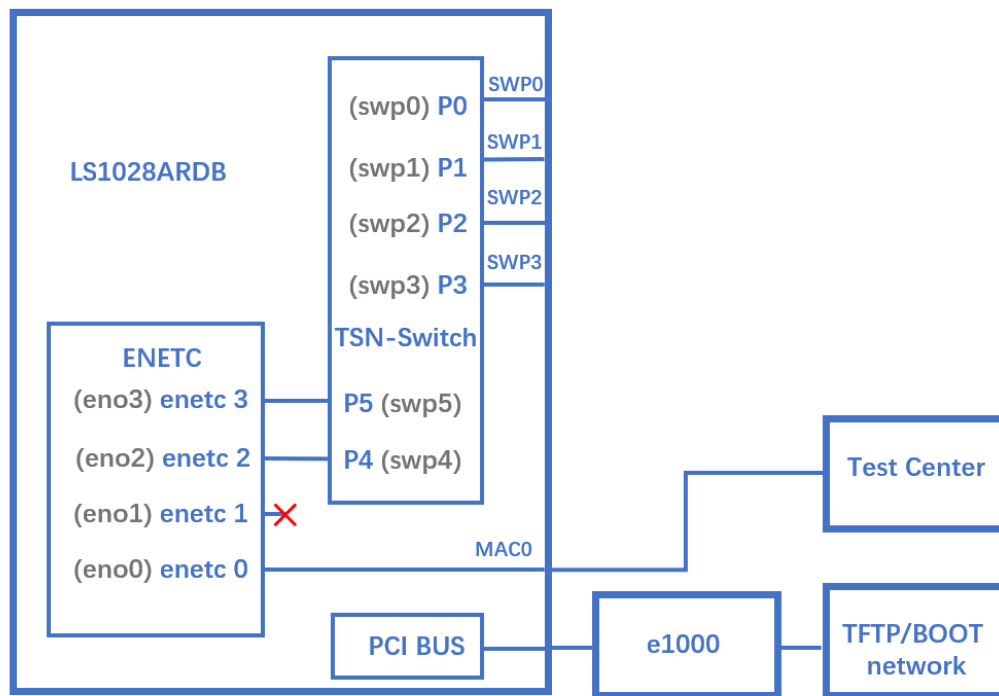


Figure 27. Setup for testing ENETC port0

```
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
```

7.1.3.3 Qci test cases

Use the following as the background setting:

- Set eno0 MAC address

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

TestCenter MAC address **99:aa:bb:cc:dd:ee** as an example.

- Use the figure below as the hardware setup.

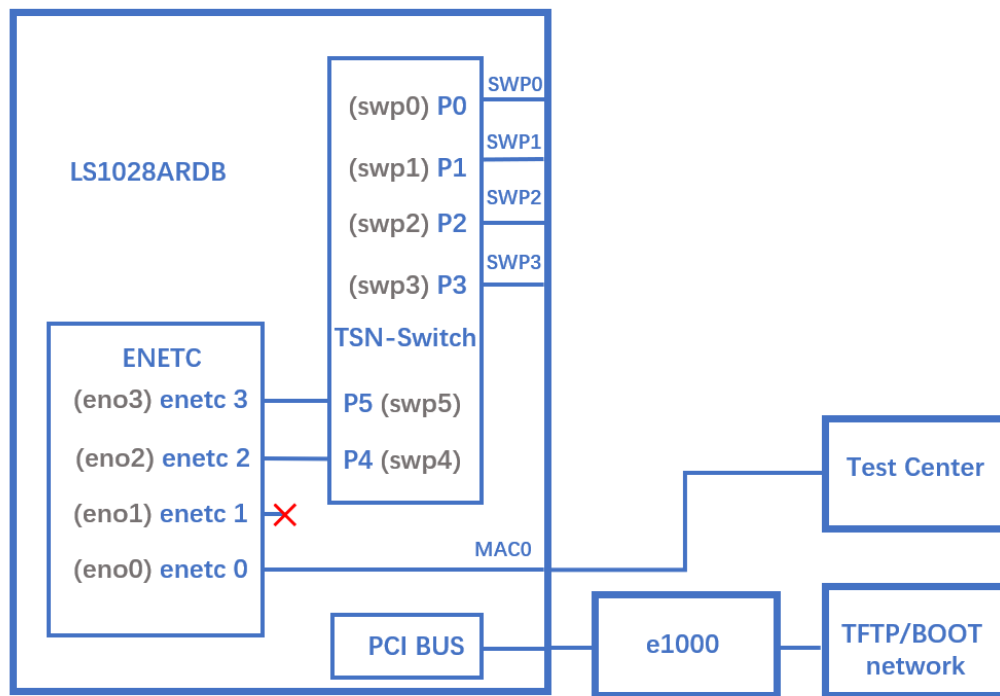


Figure 28. Qci test case setup

7.1.3.3.1 Test SFI No Streamhandle

To test no streamhandle for a stream filter, set a close gate stream id 2. Then no stream identifies the package check and other streams would pass the gate, 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 Test center.

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

- Set Stream Gate entry 2

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

- Send a frame from the Test center.

```
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 Test center.

```
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
```

7.1.3.3.2 Testing null stream identify entry

Use the following steps:

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

```
tsntool> cbstreamidset --device eno0 --index 1 --nullstreamid --nulldmac
0x0000000800010 --nulltagged 3 --nullvid 10 --streamhandle 100
```

3. Get SID index 1.

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

4. Set Stream filter entry 1.

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

5. Set Stream Gate entry 1.

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

6. Send one frame from the Test center.

```
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
```

7.1.3.3.3 Testing source stream identify entry

Use the following steps for this test:

1. Keep Stream Filter entry 1 and Stream gate entry 1.
2. Add stream2 in test center: SMAC is 66:55:44:33:22:11 DMAC:20:00:80:00:00:00
3. Set Stream identify Source stream identify entry 3

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

4. Send frame from test center. The frame passes to stream filter index 1.

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

7.1.3.3.4 SGI stream gate list

Use the command below for this test:

```
cat > sgi1.txt << EOF
t0 0b -1 1000 0
t1 1b -1 1000 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 at test center
tsntool> qcisfiget --device eno0 --index 2
```

Check the frames dropped and passed, they should be the same.

7.1.3.3.5 FMI test

Only send green color frames, set the test center speed to 10000000 bsp/s:

```
tsntool> qcisfiset --device eno0 --index 2 --gateid 2 --flowmeterid 2
tsntool> qcifmiset --device eno0 --index 2 --cm --cf --cbs 1500 --cir 5000000 --ebs 1500 --eir 5000000
```

The below setting shows the dropped frames:

```
tsntool> qcifmiset --device eno0 --index 2 --cm --cf --cbs 1500 --cir 5000000 --ebs 1500 --eir 2000000
```

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
```

7.1.3.4 Qbu test

Set the frame path from eno0 to external by linking enetc MAC0 - SWP0. Use the setup as shown in the following figure for the Qbu test.

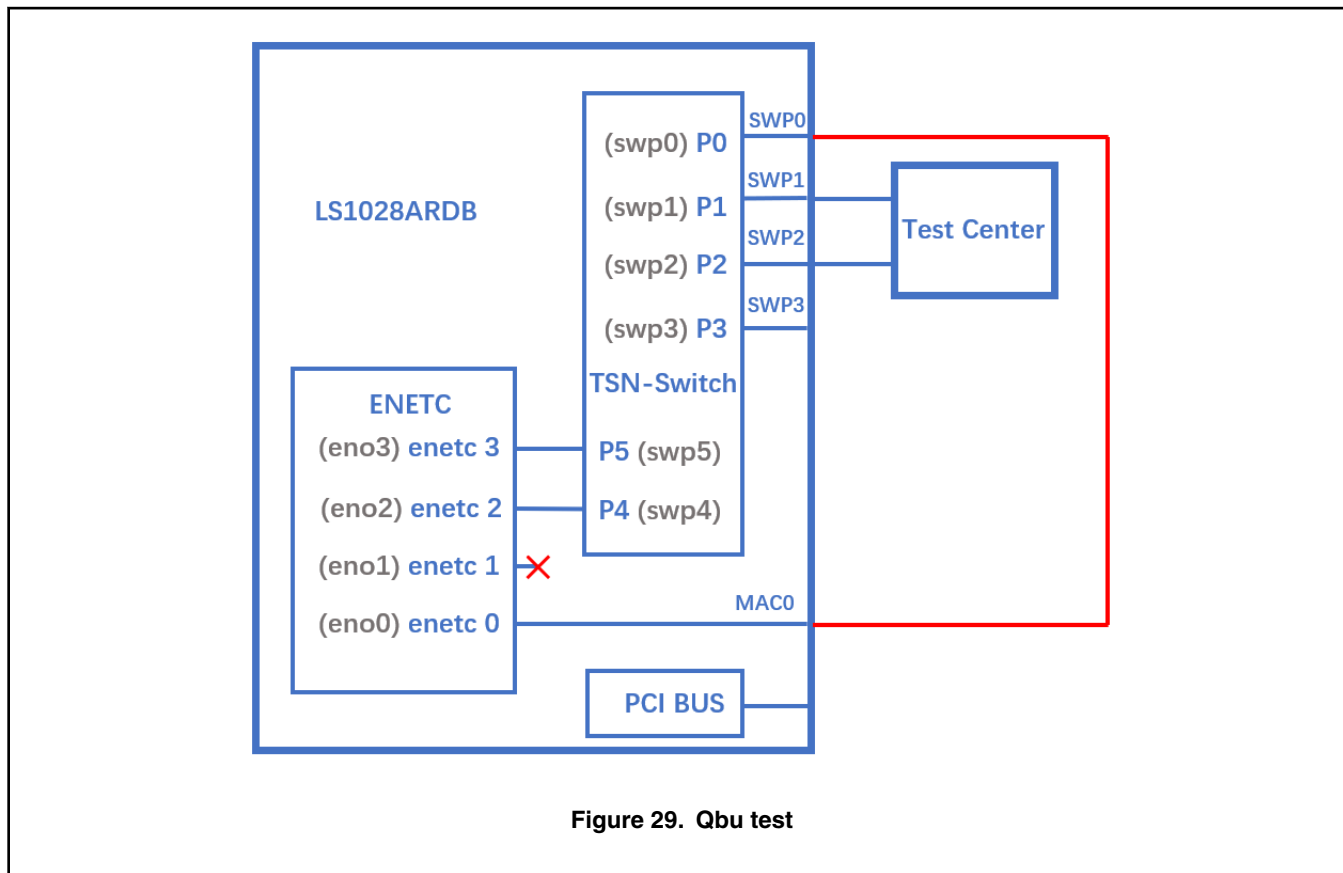


Figure 29. Qbu test

NOTE

0x11f10 Port MAC Merge Frame Assembly OK Count Register

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

For linking the ENETC port0 to SWP0, use the steps below:

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:

```
devmem 0x1fc100048 32 0x111 #DEV_GMII:MM_CONFIG:ENABLE_CONFIG
```

4. Use the below ENETC port setting:

```
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
```

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

```
tsntool> regtool 0 0x11f18
```

7.1.3.5 Qav test

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

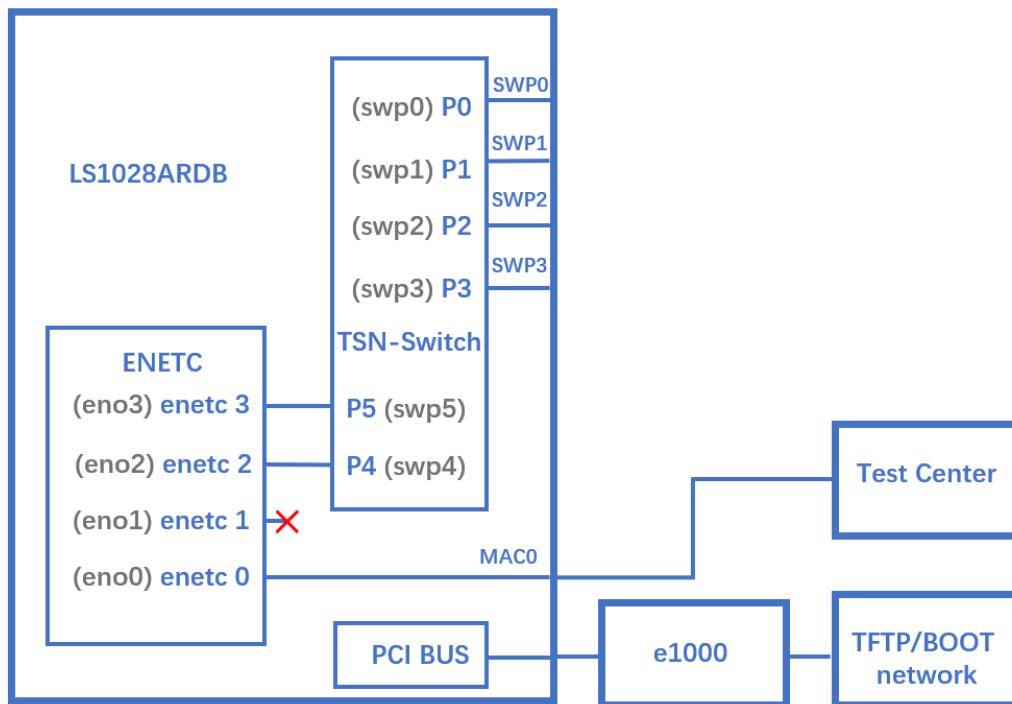


Figure 30. Qav test setup

1. Run the following commands:

```
cbsset --device eno0 --tc 7 --percentage 60
cbsset --device eno0 --tc 6 --percentage 20
./pktgen/pktgen_twoqueue.sh -i eno0 -q 6 -s 1500 -n 0 -m 10:11:12:13:14:15
```

2. Check the test center result, TC6 should have 1/3 frames of TC7.
3. Check one queue:

```
./pktgen/pktgen_sample01_simple.sh -i eno0 -q 7 -s 500 -n 0
```

It should get about 60% percentage line rate.

7.1.4 Basic TSN configuration examples on the switch

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

7.1.4.1 Switch configuration

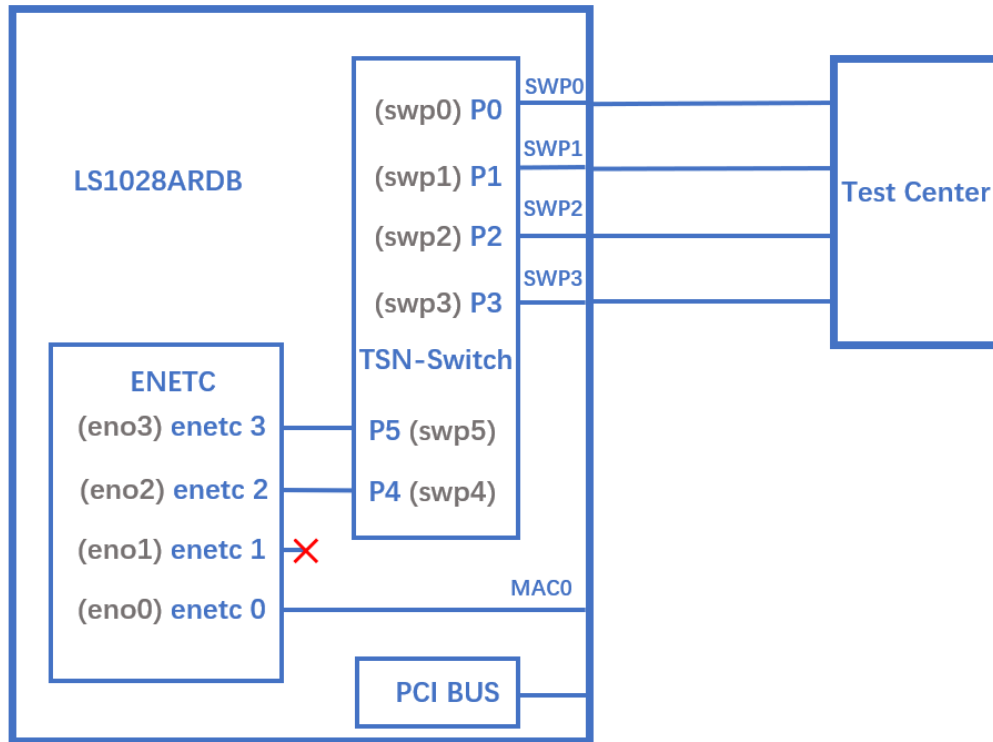


Figure 31. TSN switch configuration

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 swp4 swp5>

```
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
ip link set swp4 master switch && ip link set swp4 up
ip link set swp5 master switch && ip link set swp5 up
```

7.1.4.2 Linuxptp test

To test 1588 synchronization on felix-switch interfaces, 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
...
```

Check PTP clock and timestamping capability

```
# 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)

```

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 -m
```

7.1.4.3 Qbv test

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

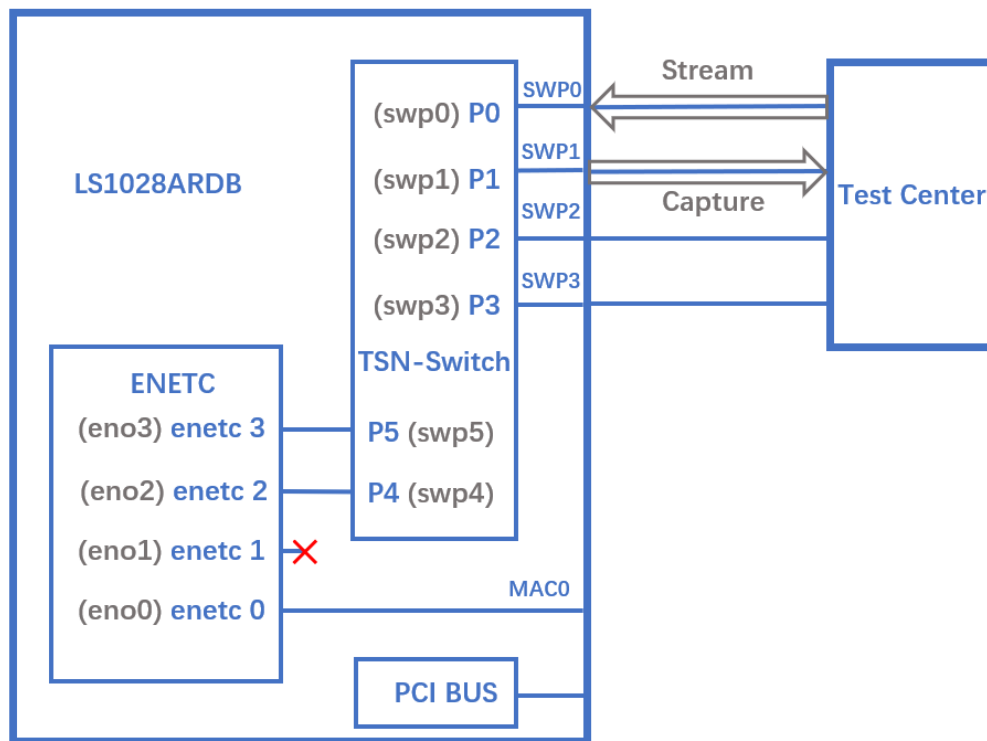


Figure 32. Qbv test

7.1.4.3.1 Closing basic gates

Use the set of commands below for basic gate closing.

```

echo "t0 00000000b 20000" > qbv0.txt
#Explanation:
# 'NUMBER'      : t0
# 'GATE_VALUE'   : 00000000b

```

```
# 'TIME_LONG' : 20000 ns

cp libtsn.so /lib
./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 11111111b 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.
```

7.1.4.3.2 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 you get 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.
```

7.1.4.3.3 Gate time limitation

Use the following commands for testing the gate time limitation:

```
echo "t0 00000000b 20000" > qbv0.txt
echo "t1 11111111b 100" >> qbv0.txt
tsntool> qbvset --device swp1 --entryfile ./qbv0.txt
tsntool> qbuset --device swp1 --preemptable 0xff
```

#Send one broadcast frame (frame size = 1500) to swp0 on Test Center.

#Frame could not pass swp1.

We can get one fragment frame (frame size less than 1500) from swp1 on Test Center.

7.1.4.3.4 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.

7.1.4.4 Qbu test

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

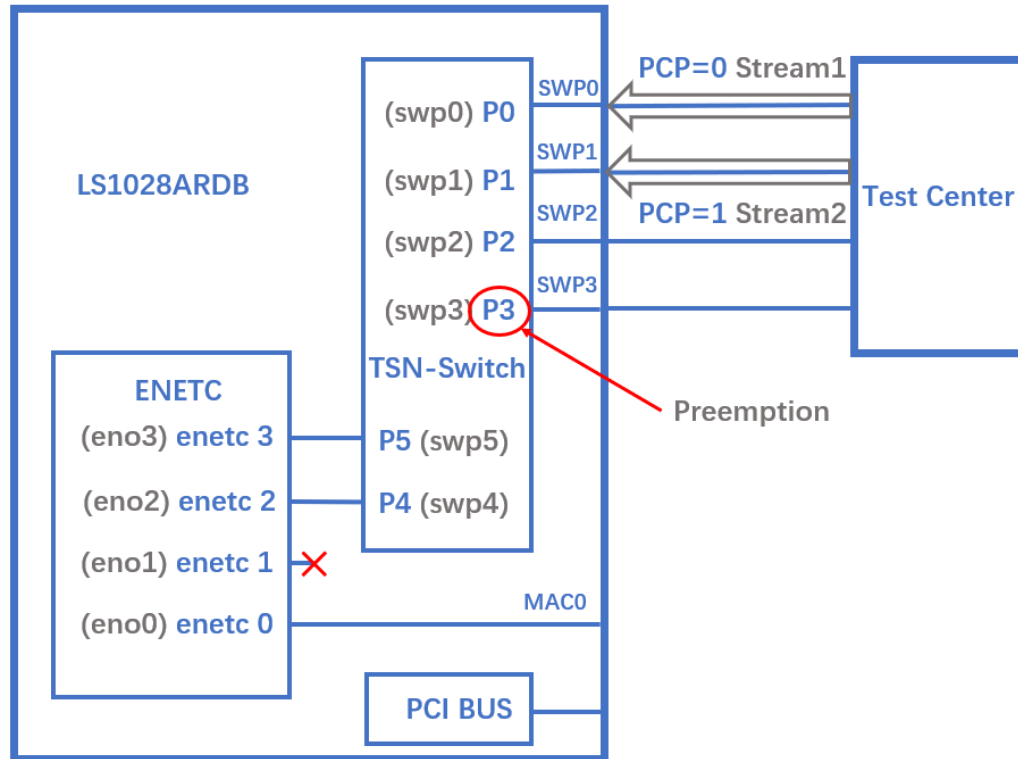


Figure 33. Qbu test on switch

1. Map PCP value of Vlan to queues on port 0.

```
tsntool> pcpmap -device swp0 -enable
```

2. Next, map PCP value of Vlan to queues on port 1.

```
tsntool> pcpmap -device swp1 -enable
```

3. Set queue 1 to be preemptable.

```
tsntool> qbuset --device swp3 --preemptable 0x02
```

4. Send two streams from TestCenter, then check the number of additional mPackets transmitted by PMAC:

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

7.1.4.5 Qci test cases

The figure below illustrates the Qci test case setup.

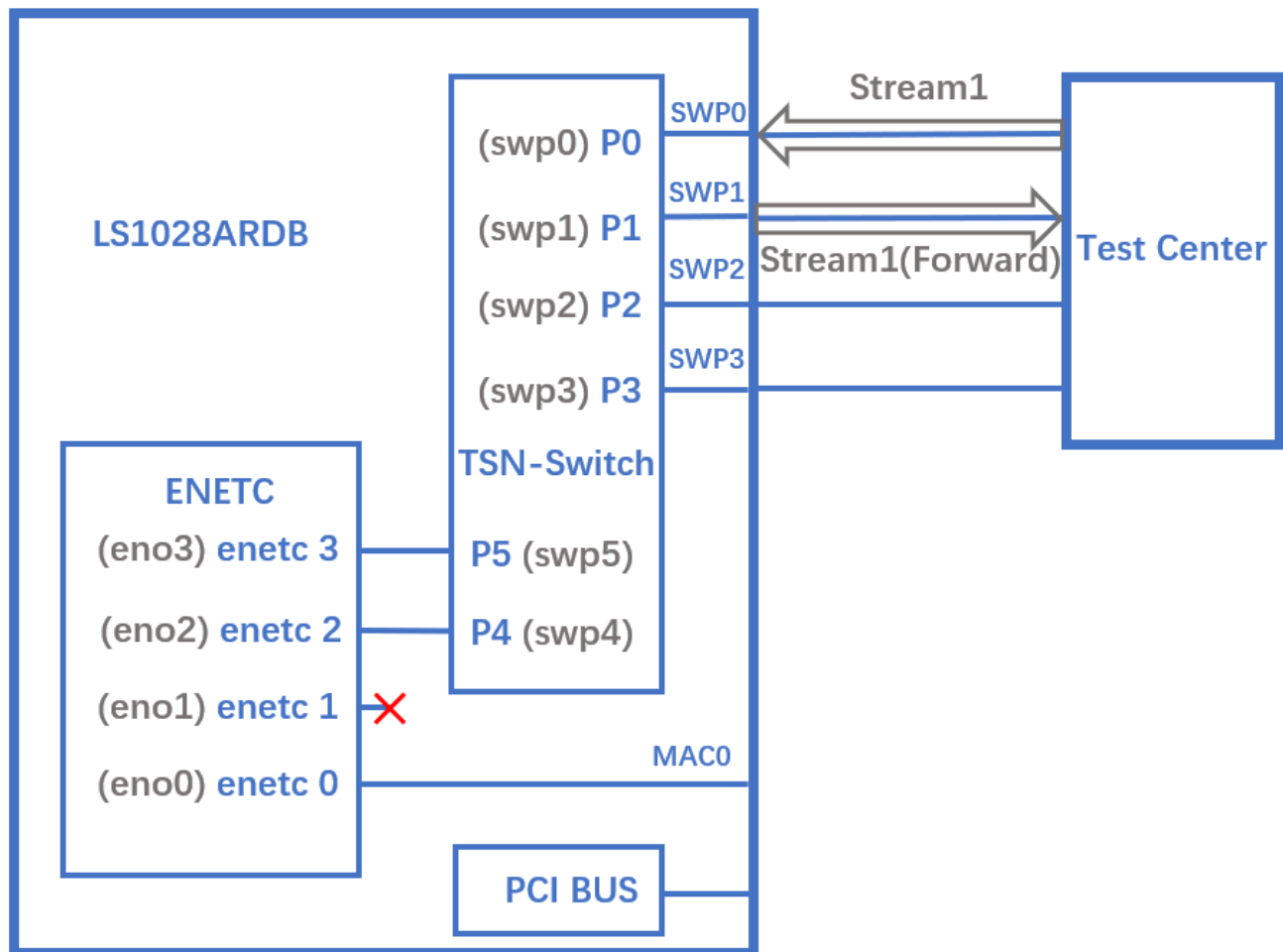


Figure 34. Qci test case

7.1.4.5.1 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 --nullldmac 0x000183fe1201 --
nullvid 1 --streamhandle 1
tsntool> qcisfiset --device swp0 --streamhandle 1 --index 1 --gateid 1 --priority 0 --flowmeterid
68
#Explanation:
# 'flowmeterid': PSFP Policer id, ranges from 63 to 383.
```

3. Send one frame.

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

Only `swp1` can get the frame.

7.1.4.5.2 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:

- 'index': gateid
- 'basetime' : It is the same as Qbv set.

2. Send one frame on TestCenter.

```
ethtool -S swp1
```

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.

7.1.4.5.3 SFI maxSDU test

Use the following command to run this test:

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

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

```
ethtool -S swp1
```

You can observe that the frame could not pass.

7.1.4.5.4 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 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.

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

```
ethtool -S swp0
```

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

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

```
ethtool -S swp0
```

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

- Map the CFI value of VLAN to dp value on port 0 to recognize yellow frames.

```
tsntool> pcpmap --device swp0 --enable
```

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

```
ethtool -S swp0
```

All frames pass and get all yellow frames.

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

```
ethtool -S swp0
```

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

- Test cf mode.

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

- 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).

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

```
ethtool -S swp0
```

NOTE

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

7.1.4.6 Qav test case

The below figure illustrates the Qav test case setup.

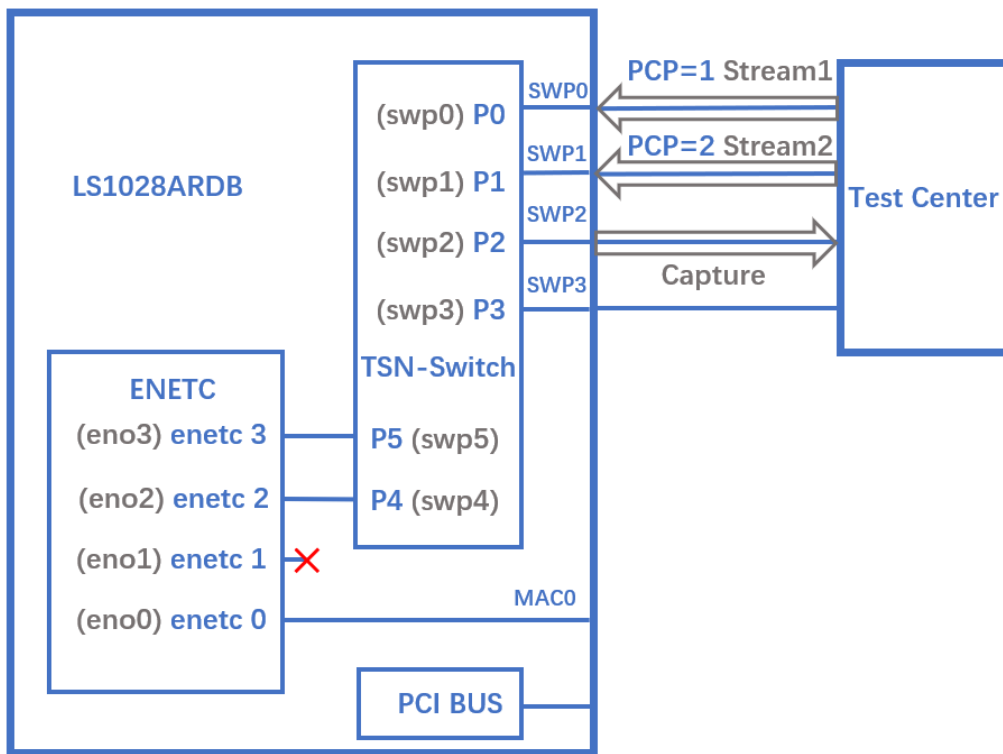


Figure 35. Qav test case

1. Map PCP value of Vlan to queues on port 0 using the command:

```
tsntool> pcpmap --device swp0 --enable
```

2. Now, map PCP value of Vlan to queues on port 1:

```
tsntool> pcpmap --device swp1 --enable
tsntool> cbsset --device swp2 --tc 1 --percentage 20
tsntool> cbsset --device swp2 --tc 2 --percentage 40
```

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.

NOTE

Stream rate must larger than bandwidth limited of queue.

4. Capture frames on swp2 on TestCenter.

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

7.1.4.7 Seamless redundancy test case

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

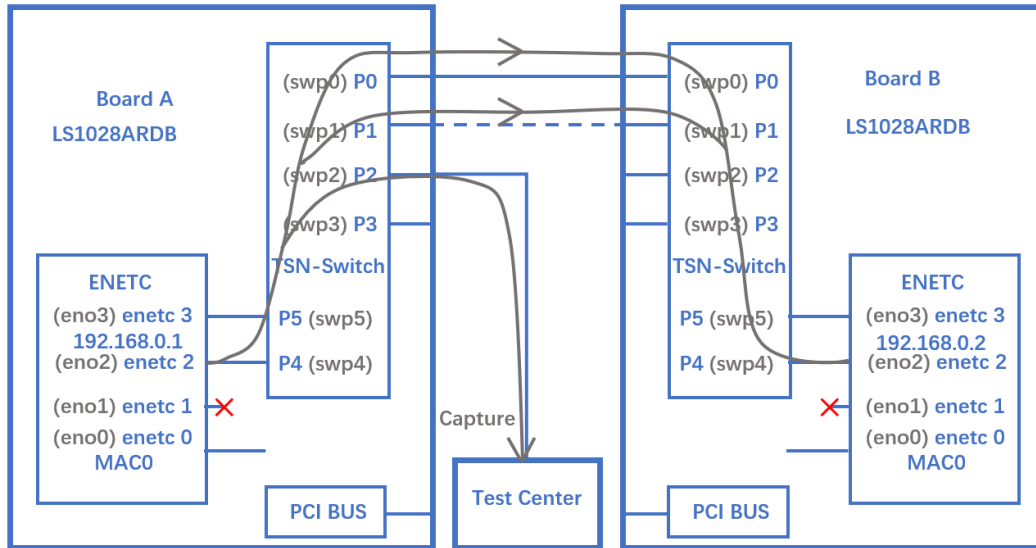


Figure 36. Seamless redundancy test

7.1.4.7.1 Sequence Generator test

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

1. Use the following commands on board B:

```
ifconfig eno2 192.168.0.2 up
ifconfig eno2
```

Get the MAC address of eno2: 7E:A8:8C:9B:41:DD

2. Use the following commands on board A:

```
ifconfig eno2 192.168.0.1 up
ping 192.168.0.2
```

The network is connected now.

3. On board A, run the commands:

```
tsntool> cbstreamidset --device swp0 --nullstreamid --index 1 --nullldmac 0x7EA88C9B41DD --
nullvid 1 --streamhandle 1
tsntool> cbgen --device swp0 --index 1 --iport_mask 0x3f --split_mask 0x07 --seq_len 16 --
seq_num 2048
```

Capture frames on swp2 on TestCenter.

4. Now run the command below:

```
ping 192.168.0.2
```

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

5. On board B, run the below command:

```
tcpdump -i eno2 -w eno2.pcap
```

Users can also get a copy of frames from eno2 on board B, which are transmitted through swp0 of board A.

7.1.4.7.2 Sequence Recover test

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

1. On board B, run the following commands:

```
tsntool> cbstreamidset --device swp4 --nullstreamid --index 1 --nulldmac 0x7EA88C9B41DD --
nullvid 1 --streamhandle 1
tsntool> cbrec --device swp0 --index 1 --seq_len 16 --his_len 31 --rtag_pop_en
tcpdump -i eno2 -w eno2.pcap
```

2. On board A, run the command:

```
ping 192.168.0.2
```

Then on board B, we can get a frame without sequence tags from board A.

3. Connect `swp1` of board A with `swp1` of board B.
4. On board B, run the following commands:

```
tsntool> cbrec --device swp1 --index 1 --seq_len 16 --his_len 31 --rtag_pop_en
tcpdump -i eno2 -w eno2.pcap
```

5. On board A, run the command:

```
ping 192.168.0.2
```

On board B, we can get only one frame without sequence tag, another frame from `swp0` or `swp1` is dropped.

NOTE

The index of `cbrec` must be the same as streamhandle of `cbstreamidset`.

7.1.4.8 Netconf usage on LS1028ARDB

For accessing the qbv YANG model, click [here](https://github.com/openil/openil/blob/master/package/yang-tsn/tsn/tsn.yang) (<https://github.com/openil/openil/blob/master/package/yang-tsn/tsn/tsn.yang>).

7.1.4.8.1 Examples to configure qbv

User can configure the qbv feature of LS1028ARDB. For this purpose, follow the **Recommended operational steps** listed in the README of the [yang-tsn package](https://github.com/openil/openil/blob/master/package/yang-tsn/README) (<https://github.com/openil/openil/blob/master/package/yang-tsn/README>).

7.2 Using TSN features on LS1021ATSN board

On the OpenIL platforms, TSN features are provided by the SJA1105TEL Automotive Ethernet switch present on the LS1021ATSN board. These hardware features can be used to implement the following IEEE standards:

- 802.1Qbv - Time Aware Shaping
- 802.1Qci - Per-Stream Filtering and Policing
- 1588v2 - Precision Time Protocol

There are two separate use cases being shown as part of this TSN demonstration:

- Rate limiting
- Synchronized Qbv

Both these use cases require a common topology comprising three LS1021ATSN boards and a host PC.

7.2.1 Bill of Materials

For the TSN demo, the Bill of Materials contains:

- 3 LS1021ATSN boards
- 1 host PC or laptop running Windows or a GNU/Linux distribution
- 1 regular L2 switch with 4 Ethernet ports
- Cabling, power adapters, microSD cards

7.2.2 Topology

The TSN demo topology consists of three IP networks :

- The **management network** (192.168.15.0/24) contains the eth0 interfaces of the three LS1021ATSN boards, connected together through the regular L2 switch, and to the host PC which has a static IP address of 192.168.15.100.
- The **untagged TSN network** (172.15.0.0/24), where the three participating network interfaces are the eth2 ports of each board (the Ethernet interface connected internally to the SJA1105 switch).
- The **tagged TSN network** (172.15.100.0/24) physically overlaps with the untagged network, but packets are transmitted with a VLAN ID of 100.

This topology is depicted in the following figure.

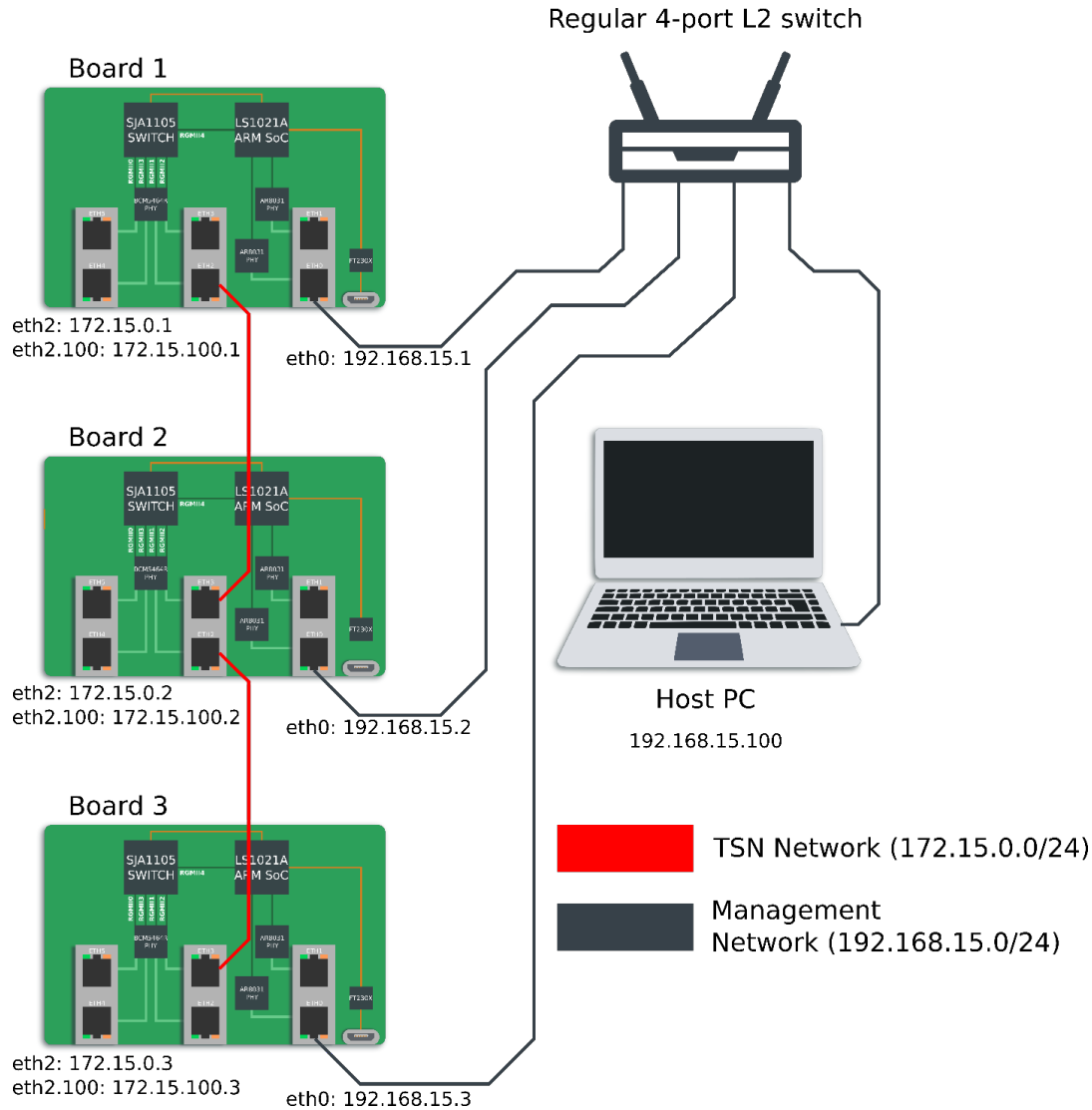


Figure 37. Topology of the demo network

7.2.3 Running the demo with a single LS1021ATSN board

Out of the two upcoming use cases of the TSN demo, only the Synchronized Qbv strictly requires the use of three LS1021ATSN boards. For the rate-limiting use case, a single LS1021ATSN board is sufficient (Board 2).

Boards 1 and 3 can be replaced with other hosts, which satisfy the following criteria:

- Have a 1 Gbps Ethernet port (that will replace the eth2 port of the LS1021 board)
- The Ethernet port is configured for a static IP in the 172.15.0.0/24 network (untagged TSN)
- Are able to run a GNU/Linux environment
- Have the following packages installed:
 - openssh-server
 - openssh-client
 - iperf3
 - tcpdump

— prl (Pipe Rate-Limiter: <https://github.com/openil/openil/tree/master/package/prl>)

- Board 2 is able to log into these hosts via SSH without asking for password.
- For key-based authentication, the public RSA key of Board 2 (`/etc/ssh/ssh_host_rsa_key.pub` in OpenIL) must be copied into the `~/.ssh/authorized_hosts` configuration file of the GNU/Linux user that LBT would attempt to log in.

NOTE

- The VLAN-tagged TSN network is not needed for the rate-limiting use case, so do not configure it.
- If Board 1 and Board 3 are replaced with PCs or laptops, there is no longer a need for having the L2 switch and the `192.168.15.0/24` management network.
- The LBT web application must be run by connecting to <http://172.15.0.2:8000>
- In OpenIL (Board 2), edit the `/usr/lib/node_modules/lbt/config.json` file and replace this line:

```
"measurementInterface": "eth2"
```

With the actual interface name of the Ethernet port of the TSN board replacement.

- Porting the `prl` program to the replacement hosts most likely involves compiling it from source and adding it to `/usr/bin` by running `make install`. If this is not desirable, view the `/usr/lib/node_modules/lbt/README.md` for instructions on how to patch the LBT application as to not require the `prl` program as dependency, and the drawbacks of doing so.

NOTE

NXP provides a separate document that describes how to run the rate-limiting TSN demo using one LS1021A-TSN board, a bootable live Ubuntu USB image, and a FRDM-LS1012A board. For more details about this setup, refer to *LS1021A TSN 1Board Demo Quick Start Guide*.

7.2.4 Host PC configuration

Required software:

- An SSH client (`openssh-client` for GNU/Linux; PuTTY, MobaXTerm, TeraTerm etc. for Windows)
- An application for serial communication (`screen`, `minicom`, etc. for GNU/Linux; PuTTY, MobaXTerm, TeraTerm etc. for Windows)

Follow these steps if you have a **Windows PC**:

1. On the PC, assign the static IP address of `192.168.15.100` to the Ethernet interface that is connected directly to the L2 switch, and indirectly to the 3 boards. In Windows, this is done by editing the network settings from the Control Panel as in the figure below:

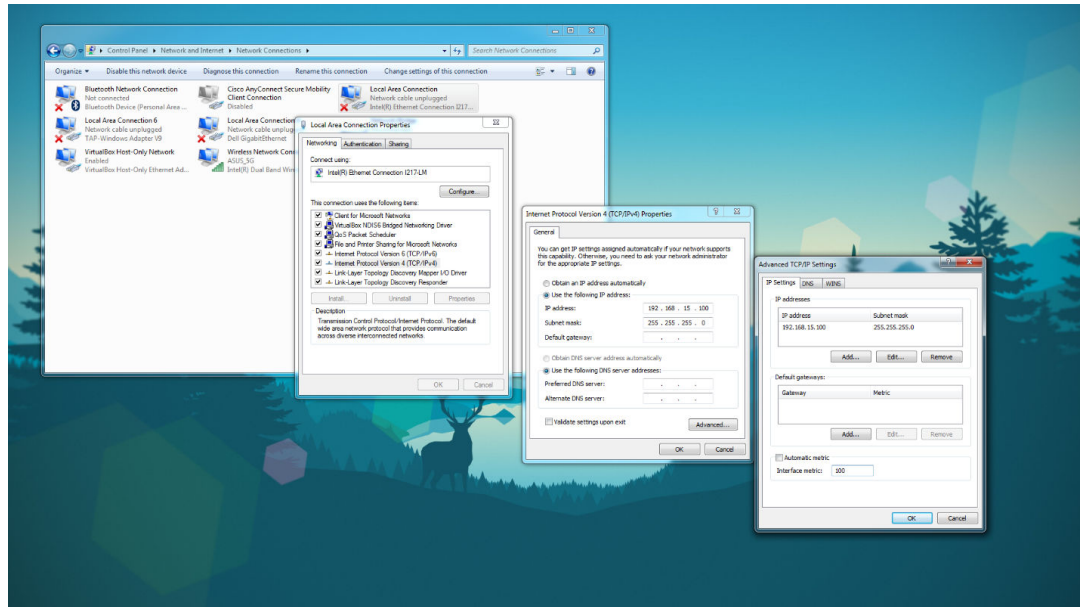


Figure 38. Windows network settings

2. Go to **Advanced settings** (in the same window) and configure a manual metric of 100 for this interface. This way, Internet traffic should not be routed through the Ethernet connection if the laptop is also connected to Wi-Fi.

Follow the below steps if you have a **GNU/Linux PC**:

1. Open GNOME NetworkManager by clicking on its system tray icon and then choosing “**Edit Connections...**” from the drop-down menu.
2. Choose your Ethernet interface from the dialog box, click “Edit” and go to the IPv4 Settings tab.
3. Change the Method to Manual and Add an IP address of 192.168.15.100.
4. Press the “Routes...” button and tick the “Use this connection only for resources on its network” checkbox.
5. Close all NetworkManager windows and click again on the system tray icon, this time selecting the newly configured Ethernet interface, in order to reload its configuration.

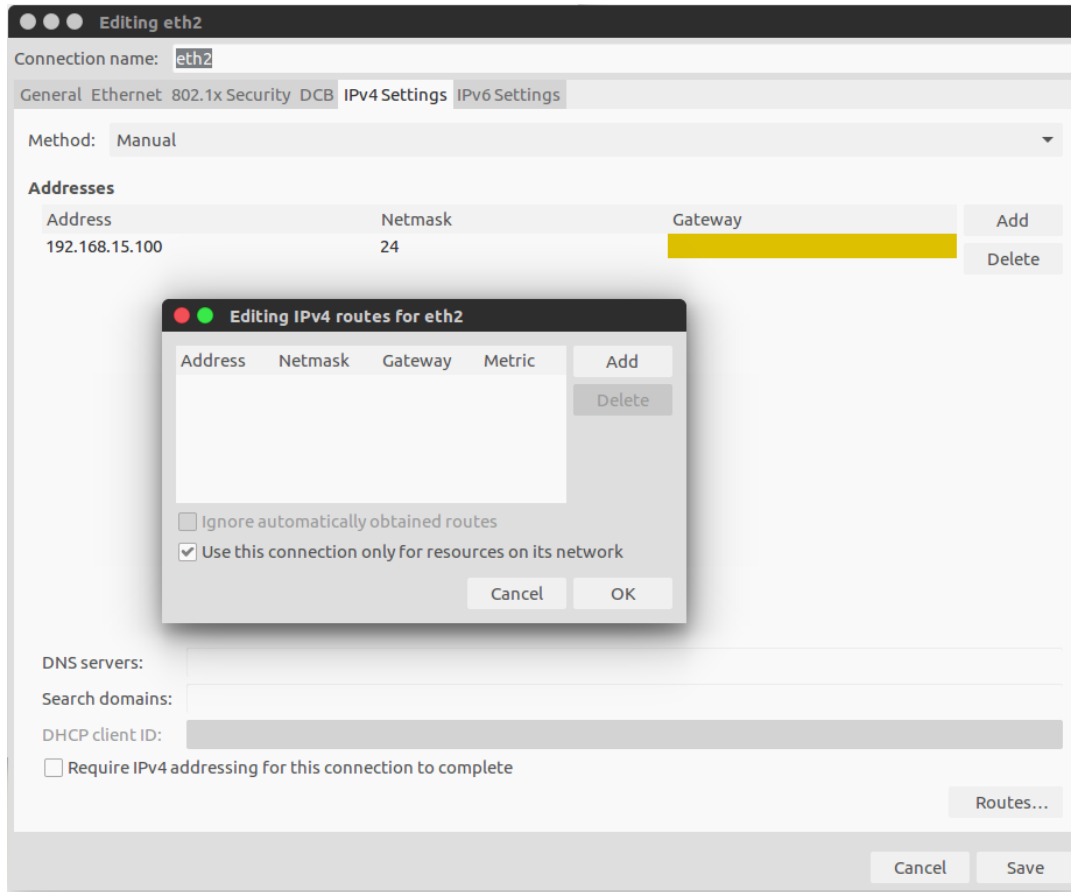


Figure 39. Ubuntu network settings (GNOME NetworkManager)

Connection to the three boards over SSH can be verified using MobaXTerm for Windows PC only:

1. Open MobaXTerm, click **Session -> SSH** and type in the IP address of Board 1: “192.168.15.1” with username “root”

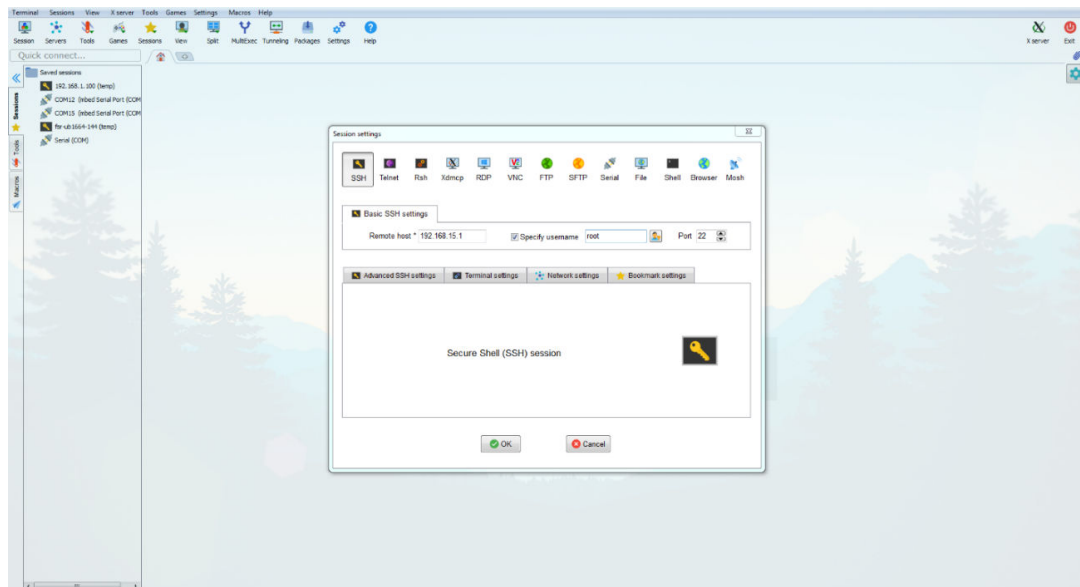


Figure 40. MobaXTerm session settings

2. Connect to Board 1 via MobaXTerm. You should be able to view this interface:



Figure 41. Login shell to OpenIL on Board 1 in MobaXTerm

3. Repeat the previous steps for Board 2 and Board 3.

7.2.5 Hardware Setup

Perform the following steps for each board individually (without having the whole topology assembled). You will need a serial connection.

1. Boot the boards to U-Boot. Then, change the MAC addresses of the three boards by executing these U-boot commands:

Board 1:

```
=> setenv ethaddr 00:04:9f:ef:00:00
=> setenv eth1addr 00:04:9f:ef:01:01
=> setenv eth2addr 00:04:9f:ef:02:02
```

Board 2:

```
=> setenv ethaddr 00:04:9f:ef:03:03
=> setenv eth1addr 00:04:9f:ef:04:04
=> setenv eth2addr 00:04:9f:ef:05:05
```

Board 3:

```
=> setenv ethaddr 00:04:9f:ef:06:06
=> setenv eth1addr 00:04:9f:ef:07:07
=> setenv eth2addr 00:04:9f:ef:08:08
```

2. Resume the boot process for each board:

```
=> saveenv
=> boot
```

3. In Linux, modify the following files, by adapting the address to the board number (172.15.0.{1,2,3}, 172.15.100.{1,2,3}, 192.168.15.{1,2,3}):

/etc/network/interfaces (customize for boards 1, 2, 3):

```
# /etc/network/interfaces - configuration file for ifup(8), ifdown(8)
# The loopback interface
```

```

auto lo
iface lo inet loopback
auto eth2
iface eth2 inet static
address 172.15.0.1
netmask 255.255.255.0
auto eth1
iface eth1 inet dhcp
auto eth0
iface eth0 inet static
address 192.168.15.1
netmask 255.255.255.0

```

/etc/init.d/S45vlan (customize for boards 1, 2, 3):

```
IPADDR="172.15.100.1/24"
```

/etc/hosts (copy as-is for boards 1, 2, 3):

```

127.0.0.1      localhost
127.0.1.1      OpenIL
172.15.0.1     board1
172.15.0.2     board2
172.15.0.3     board3
172.15.100.1   board1-vlan
172.15.100.2   board2-vlan
172.15.100.3   board3-vlan
192.168.15.1   board1-mgmt
192.168.15.2   board2-mgmt
192.168.15.3   board3-mgmt
192.168.15.100 host-pc

```

4. Now, disconnect the USB-serial cables and assemble the 3 boards, PC, and L2 switch in their final position:
5. Place the 3 LS1021ATSN boards in a stack, with Board 1 on top and Board 3 at the bottom.
6. Make the following connections between the 3 boards:
 - a. Board 1 ETH2 to Board 2 ETH3
 - b. Board 2 ETH2 to Board 3 ETH3
 - c. Board 1 ETH0 to Regular L2 Switch
 - d. Board 2 ETH0 to Regular L2 Switch
 - e. Board 3 ETH0 to Regular L2 Switch
 - f. Laptop to Regular L2 Switch

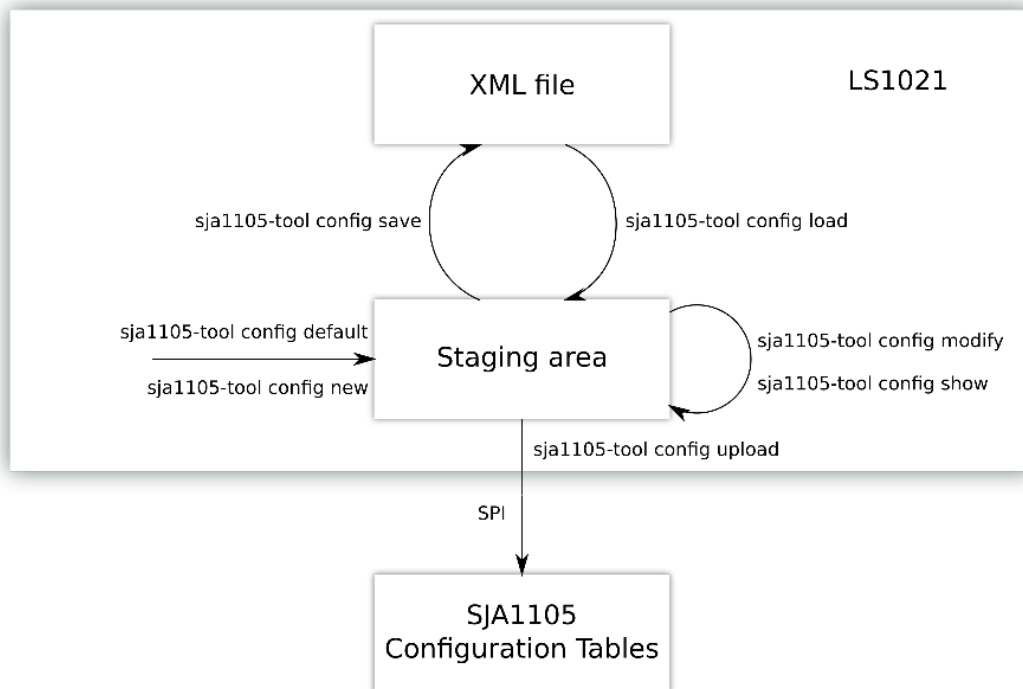
7.2.6 Managing configurations with the sja1105-tool

The `sja1105-tool` is a Linux user space application for configuring the SJA1105 TSN switch. The tool supports:

- Importing a configuration for the SJA1105 switch from an XML file
- Exporting the current SJA1105 configuration as an XML file
- Uploading the current SJA1105 configuration to the switch through its SPI interface
- Inspecting the current SJA1105 configuration

- On-the-fly modification of the current SJA1105 configuration through command line or scripting interface

Figure 42. State machine view of the sja1105-tool commands and configuration formats



The physical SPI registers of the SJA1105 switch are write-only. Therefore, a copy of these registers is kept in the staging area, which is effectively a file in the LS1021A OpenIL filesystem. The staging area keeps a binary image of the configuration to be uploaded over SPI using `sja1105-tool config upload`, and can also be read back by the user with `sja1105-tool config show`.

More documentation on the sja1105-tool is distributed as man pages along with the source code:

```
[ubuntu:~] $ git clone https://github.com/openil/sja1105-tool.git
[ubuntu:~] $ cd sja1105-tool
[ubuntu:sja1105-tool] $ cd docs/man
[ubuntu:man] $ man -l ./sja1105-tool.1
[ubuntu:man] $ man -l ./sja1105-tool-config.1
[ubuntu:man] $ man -l ./sja1105-tool-status.1
[ubuntu:man] $ man -l ./sja1105-tool-reset.1
[ubuntu:man] $ man -l ./sja1105-conf.5
[ubuntu:man] $ man -l ./sja1105-tool-config-format.5
```

7.2.6.1 SJA1105-tool helper scripts

In order to create other customized configurations, the sja1105-tool may be used as a host tool (run in a GNU/Linux userspace environment on a PC) and may generate XML files.

Install dependencies for sja1105-tool and its helper scripts (shown here for Ubuntu 16.04):

```
sudo apt-get install build-essential jq libxml2-dev
```

Set up sja1105-tool for host usage:

```
[ubuntu:~] $ git clone git@github.com:openil/sja1105-tool.git
[ubuntu:~] $ cd sja1105-tool/src/helpers
[ubuntu:~] $ source envsetup
```

Inside the sja1105-tool source files, there are two helper scripts in the src/helpers/bin/ folder:

- scheduler-create
- policer-limit

The two helper scripts above constitute the recommended high-level way of interacting with the SJA1105 ingress policer and Qbv engine. The input to the **policer-limit** script is provided through command-line arguments, while the **scheduler-create** script expects to read a JSON description of Qbv cycles and timeslots.

Actual examples of using the helper scripts are the files in the **src/helpers/configs/rate-limiting/** folder. These represent the four configurations presented in this use case and are named:

- standard.sh
- prioritizing.sh
- policing.sh
- scheduling.sh

Running each of these scripts produces an XML configuration of the same name that can be uploaded to Board 2 and loaded into the sja1105-tool.

7.2.7 Latency and bandwidth tester

Latency and bandwidth tester (LBT) is a web application written in Node JS that is distributed with the OpenIL image for LS1021ATSN and as such, runs on each of the three boards.

It serves as a web interface on the HTTP port 8000, through which users may configure the parameters of a traffic test. The two types of network tests it can perform are iPerf3 (for bandwidth measurements) and ping (for latency measurements). For each of these two types of traffic, users can define an arbitrary amount of flows (their source, destination, and flow-specific parameters).

After the configuration phase is finished and the traffic is started, the web server automatically connects over SSH to the source and destination host of each flow (ping and iPerf). The web server collects network traffic information in real-time from the source and destination hosts, and plots it inside the browser window.

For the following two use cases, we use the LBT web application to generate traffic and characterize the behavior of the SJA1105 TSN switch under different loads and configurations.

1. From a shell connected to any of the three LS1021ATSN boards, the LBT server can be started by running the following command:

```
[root@openil] $ /usr/lib/node_modules/lbt/server.js
```

2. A successful invocation of the server displays this as the final line:

```
Server listening for http requests on port 8000
```

3. If the server displays the following on the final line of its output, it means that the LBT server was already started and is running:

```
Error: listen EADDRINUSE :::8000
```

4. In order to kill current nodes and start it again, run the command:

```
killall node
```

5. In a browser window, navigate to the management IP (in the 192.168.15.0/24 network) of the board, on port 8000, in order to view the application.

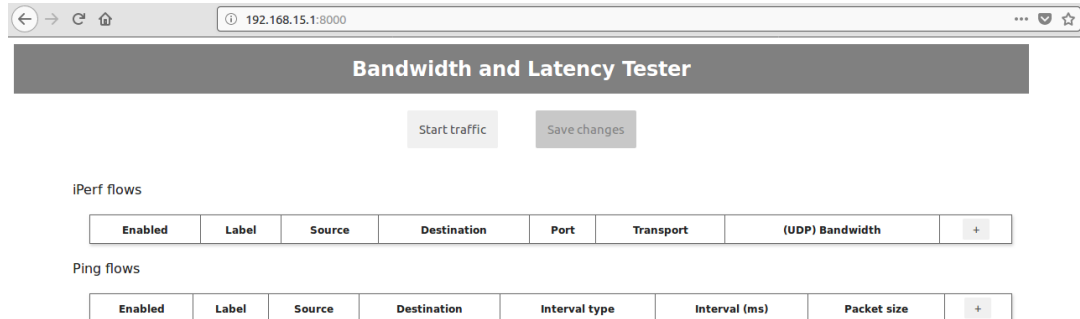


Figure 43. Latency and bandwidth tester default interface

As shown in the above figure, the traffic is stopped, and the two tables with iPerf and ping flows are empty. New flows can be added to the tables by pressing the “+” button.

NOTE

Traffic generation using LBT is absolutely equivalent, from an expected performance perspective, to running 'iperf' and 'ping' commands manually between boards from the command line.

The LBT web application has a configuration file under the following path:

```
/usr/lib/node_modules/lbt/config.json.
```

7.2.8 Rate limiting demo

7.2.8.1 Demo overview

The rate-limiting demo focuses on configuring the QoS features of a single SJA1105 switch, as to handle the congestion created by two competing traffic flows.

The use case conceptually employs three machines connected through the SJA1105 switch under test. Of the three machines, 2 generate traffic, while the third receives it. In practice, all three machines are in fact the LS1021A cores running OpenIL on each of the 3 boards.

The TSN switch under test is that of Board 2. The SJA1105 switches of Board 1 and Board 3 also forward traffic, but their configuration is fixed (not subject to change) for the entirety of the demonstration, and is “standard” (equivalent to a non-TSN-enabled L2 switch).

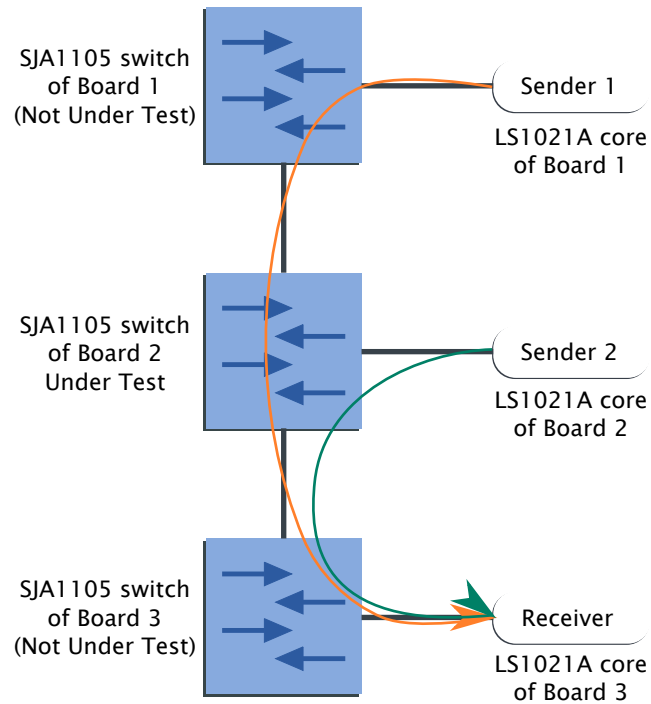


Figure 44. Connections of the three hosts and their roles as traffic senders/receivers

Through the SJA1105 switch of Board 2, there are two TCP flows competing for bandwidth:

- An iPerf3 connection running from client Board 1 to server Board 3
- An iPerf3 connection running from client Board 2 to server Board 3

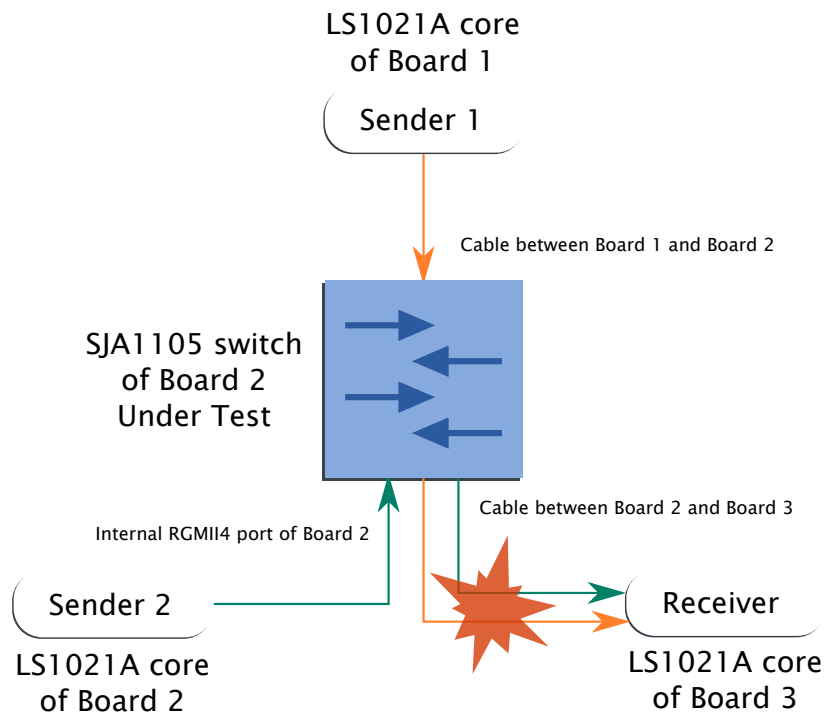


Figure 45. Simplified traffic flows for the rate limiting use case

Flows directed from Board 1 and Board 2 towards Host 3 are bottlenecked at the middle switch's egress interface. The schematic diagram of the two iPerf3 flows is shown above. Flows directed from Board 1 and Board 2 towards Host 3 are bottle-necked at the middle switch's egress interface. The LS1021 on Board 3 is acting as iPerf server, whereas the ones on Board 1 and Board 2 are the iPerf clients. Since both these flows share the same link between the SJA1105 switches of Board 2 and Board 3, they are bottlenecked and compete for the 1000 Mbps total bandwidth of that link. The demo shows 3 approaches to isolate the flows' impact on one another (each of these approaches can be seen as an XML configuration applied to the SJA1105 switch of Board 2):

- Standard switch configuration: This is the behavior of traditional Ethernet switches.
- Ingress Policing: Rate-limit traffic coming from the LS1021 of Board 2 (in order to protect the flow Board 1 -> Board 3).
- Time Gating: Schedule the 2 flows on different time slots.

NOTE

In the following sections, unless otherwise specified, the term 'SJA1105' or just 'TSN switch' implicitly refers to the SJA1105 switch present on Board 2.

7.2.8.2 Objectives

- Manage bandwidth problems related to network contention
- Demonstrate the features of the L2 Ingress Policer
- Create time slots for scheduled traffic
- Show the usage of the sja1105-tool and helper scripts

7.2.8.3 Latency and bandwidth tester configuration

For this use case, two iPerf flows would be used as shown in the following figure.

Figure 46. iperf flows for bandwidth and latency tester

Bandwidth and Latency Tester

Start traffic Save changes

iPerf flows

Enabled	Label	Source	Destination	Port	Transport	(UDP) Bandwidth	+
<input checked="" type="checkbox"/>	Host 1	root@192.168.15.1:22	root@172.15.0.3:22	5201	TCP	n/a	-
<input checked="" type="checkbox"/>	Host 2	root@192.168.15.2:22	root@172.15.0.3:22	5202	TCP	n/a	-

Ping flows

Enabled	Label	Source	Destination	Interval type	Interval (ms)	Packet size	+
---------	-------	--------	-------------	---------------	---------------	-------------	---

The preceding figure shows the LBT configured to generate two flows labeled “Host 1” and “Host 2”, both destined to 172.15.0.3 (eth2 interface of Board 3), and originating from Board 1 and Board 2, respectively. It bears no importance whether the IP addresses of the iPerf sources are part of the management network (192.168.15.0/24) or TSN network (172.15.0.0/24). The route of the iPerf traffic is decided based on the requested destination address of the flow (in this situation, traffic goes through the TSN network).

7.2.8.4 Use of VLAN tags in the demo

The 802.1Q standard specifies that VLAN-encapsulated Ethernet frames have an additional 4 octet header with the following fields:

- **VLAN Ethertype:** must be set to 0x8100
- **VLAN Priority Code Point (PCP)**
- **Drop Eligibility Indication (DEI)**
- **VLAN ID**

In the second and third approaches of the demo (*Ingress Policing* and *Time Gating*), the SJA1105 must distinguish between the two flows, in order to prioritize them. To do so, it uses VLAN tags, specifically the PCP (priority) field.

The SJA1105 switch has three main stages in its packet processing pipeline:

- Ingress
- Forwarding
- Egress

On the ingress stage, the switch is configured to assign a default ("native") VLAN header on frames, based on their incoming port. Based on the default VLAN tagging, the flows receive differentiated treatment:

- In the policing configuration, one of the flows is rate-limited on the ingress port.
- In the scheduling configuration, similar rate-limiting effect is achieved as each flow gets its own time slot allocated for the forwarding and egress stages.

On the egress stage, the default VLAN tag is removed, so the connected hosts (Board 1, Board 2, Board 3) are oblivious to this VLAN tagging.

7.2.8.5 Standard configuration

Prepare the 3 boards with default L2 switch configurations:

- Ingress Policer is disabled on all ports
- All frames are internally tagged with a VLAN priority of 0 and are, as such, treated as equal when forwarded
- Qbv engine is not configured
- All ports are enabled for forwarding traffic

The XML configuration for this case was generated by running this sja1105-tool helper script:

Boards 1 and 3 make use of the default, built-in configuration of the sja1105-tool, while Board 2 loads it from standard.xml.

Board 1:

```
[root@board1] $ sja1105-tool config default ls1021atsn
[root@board1] $ sja1105-tool config upload
# Shorthand version:
# sja1105-tool config default -f ls1021atsn
```

Board 2:

```
[root@board2] $ sja1105-tool config load standard.xml
[root@board2] $ sja1105-tool config upload
# Shorthand version:
# sja1105-tool config load -f standard.xml
```

Board 3:

```
[root@board3] $ sja1105-tool config default ls1021atsn
[root@board3] $ sja1105-tool config upload
# Shorthand version:
# sja1105-tool config default -f ls1021atsn
```

Note that the configuration provided in standard.xml is equivalent to that of the built-in one. This can be seen by running:

Board 2:

```
# Load the built-in configuration into the staging area (no SPI write)
[root@board2] $ sja1105-tool config default ls1021atsn
# Export the configuration from the staging area to an XML file
[root@board2] $ sja1105-tool config save builtin.xml
# Compare the two
[root@board2] $ diff builtin.xml standard.xml
# No output means match
```

7.2.8.5.1 Ingress Policer

The L2 Ingress Policer inside the SJA1105 is implemented as a Token Bucket:

- Bucket max size (also known as burst size) is called SMAX (maximum is 0xFFFF)
- Bucket refill speed is RATE bytes per second (up to a maximum of 64000)
- Each ingress packet removes from the bucket a number of tokens equal to its length in bytes
- Can also police traffic based on maximum frame size

The Policing table has 45 entries:

- One for each Ingress Port x VLAN PRIO (5 x 8)
- One for Broadcast Traffic coming from each Ingress Port (5)

In the standard configuration, the L2 Ingress Policer is “**deactivated**”. This means that RATE and SMAX are set to maximum (0xFFFF, 0xFA00) for all entries, so rate limiting can never occur at the maximum ingress rate of 1000Mbps.

This can be seen by looking at the l2-policing-table entries:

```
[root@board2] $ sja1105-tool conf show l2-pol
```

7.2.8.5.2 Default VLAN assignments

These are configurable through the MAC Configuration Table (5 entries, one per port are available through the SPI registers of the SJA1105 switch). Default VLAN tags are added only if the switch received the packets as untagged. The user can select whether the switch includes the VLAN tags in the egress packet or not. VLAN priorities are taken into consideration for the L2 Forwarding stage.

In the standard configuration, all ingress ports get by default VLAN priority 0 (best-effort) and all egress ports remove VLAN tags from packets.

7.2.8.5.3 Queuing diagram

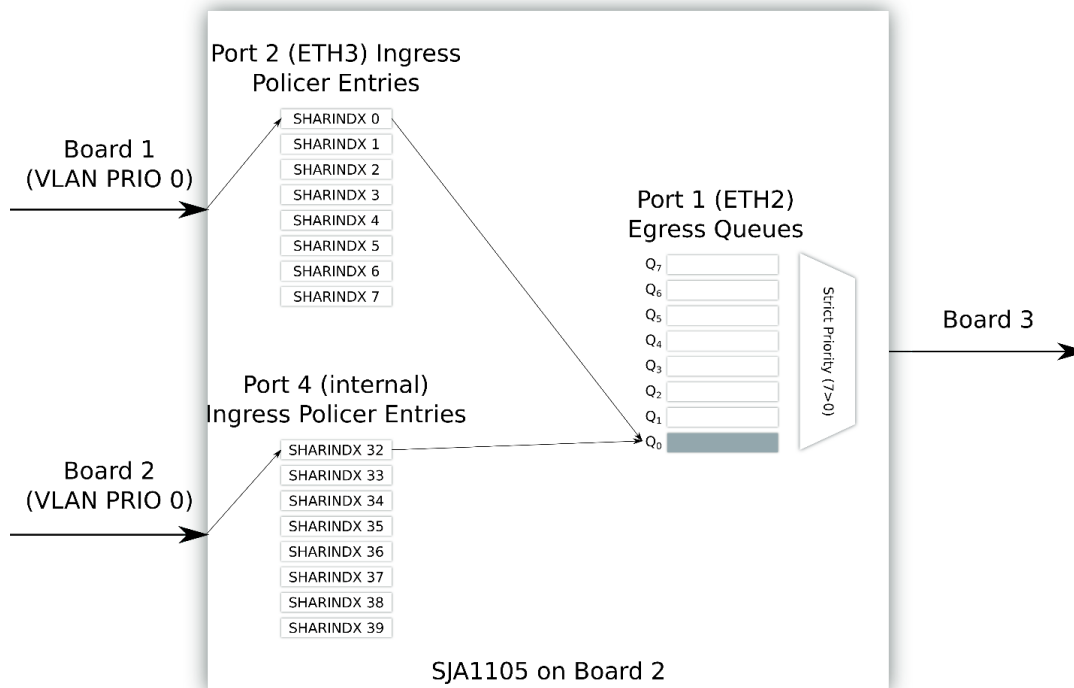


Figure 47. Queuing diagram

/>

The above figure shows how all traffic gets assigned to VLAN priority 0, causing contention on the same egress queue.

7.2.8.5.4 Results for the standard configuration

This section describes the results for different flows for the standard configuration.

In the LBT web app, run the following three tests:

- Only flow 1 enabled

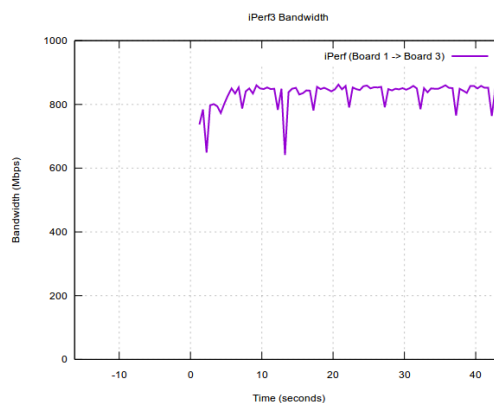


Figure 48. Standard configuration: Flow 1 run by its own

- Only flow 2 enabled

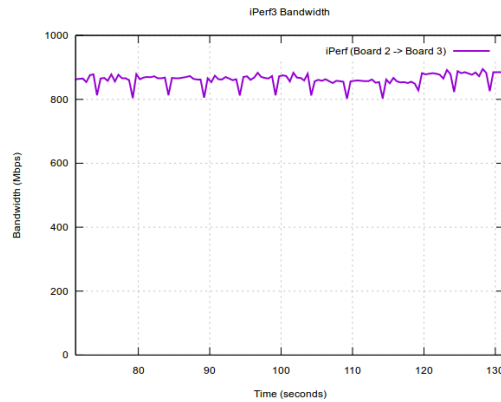


Figure 49. Standard configuration: Flow 2 run by its own

- Both flows enabled

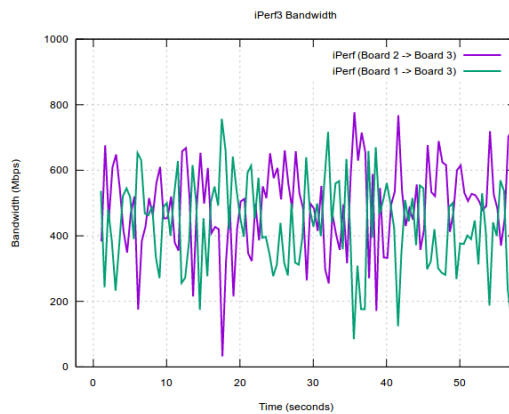


Figure 50. Standard configuration: Both flows run at the same time

Comments:

- Individually, both Board 1 and 2 get around 950 Mbps.
- Run at the same time, bandwidths for Flow 1 and Flow 2 oscillate.
- Bandwidth allocation is suboptimal (sum of the flows is much lower than 1000 Mbps).

7.2.8.6 Prioritizing configuration

In this case, configure the SJA1105 switch of Board 2 to assign these default VLAN priorities for untagged traffic:

- Board 1: VLAN PCP 5
- Board 2: VLAN PCP 3

This is done on a per-ingress port basis (Board 1 - Port RGMII0 (ETH3), Board 3 - Port 4 (internal)). This means that all untagged traffic received by the SJA1105 under test (Board 2) on the respective ports would have this VLAN tag appended for internal processing. Frames that are already VLAN tagged (not applicable to this scenario) are not altered.

On the egress port 2 (ETH3, towards Board 3), if flow 1's queue is not empty, the switch always prefers to send packets from that instead of flow 2's queue, because of its higher VLAN priority.

The XML configuration for this case was generated by running this sjal105-tool helper script:

```
[ubuntu@sjal105-tool/src/helpers] $ ./configs/rate-limiting/prioritizing.sh --flow1-prio 5 --flow2-prio 3
Configuration saved as ./configs/rate-limiting/prioritizing.xml.
View with: "sjal105-tool config load ./configs/rate-limiting/prioritizing.xml; sjal105-tool config show | less"
```

The SJA1105 configurations to use on Board 1 and Board 3 are the default, built-in ones that were programmed in the standard case.

7.2.8.6.1 Queuing diagram

The following figure shows the queuing diagram for the prioritizing configuration. It shows that Board 2 traffic is assigned a higher VLAN priority than Board 1. On egress, Board 2 dominates because of the strict priority queuing discipline of the switch.

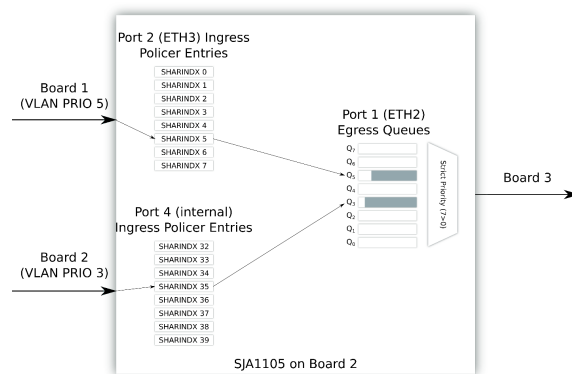


Figure 51. Prioritizing configuration

7.2.8.6.2 Results for the prioritizing configuration

This section describes the results for different flows for the prioritizing configuration.

In the LBT web app, run the following tests:

- Flow 1 run by its own

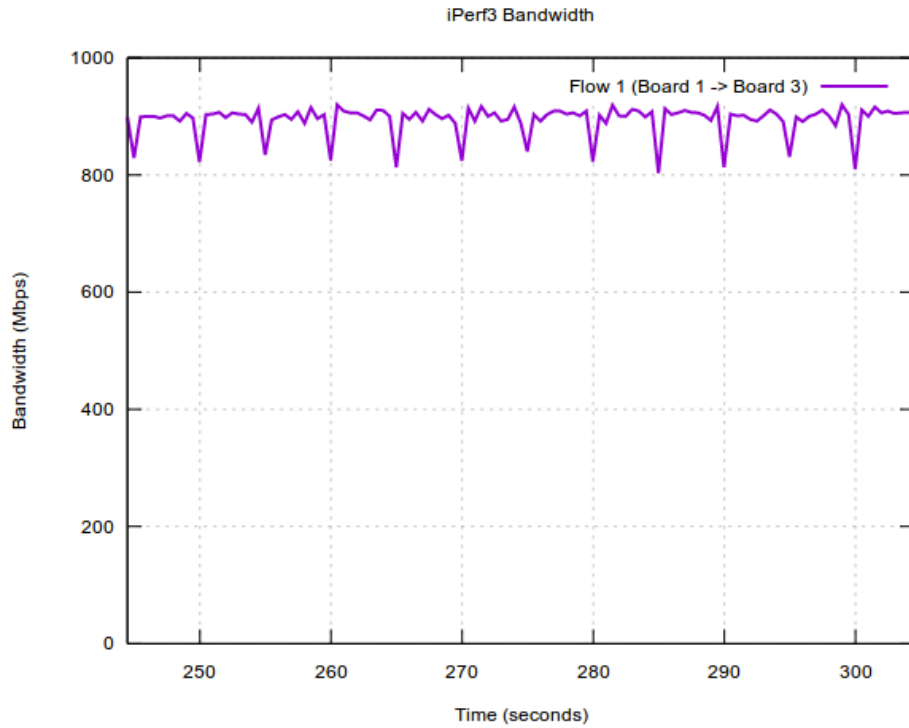


Figure 52. Prioritizing configuration: Flow 1 run by its own

- Flow 2 run by its own

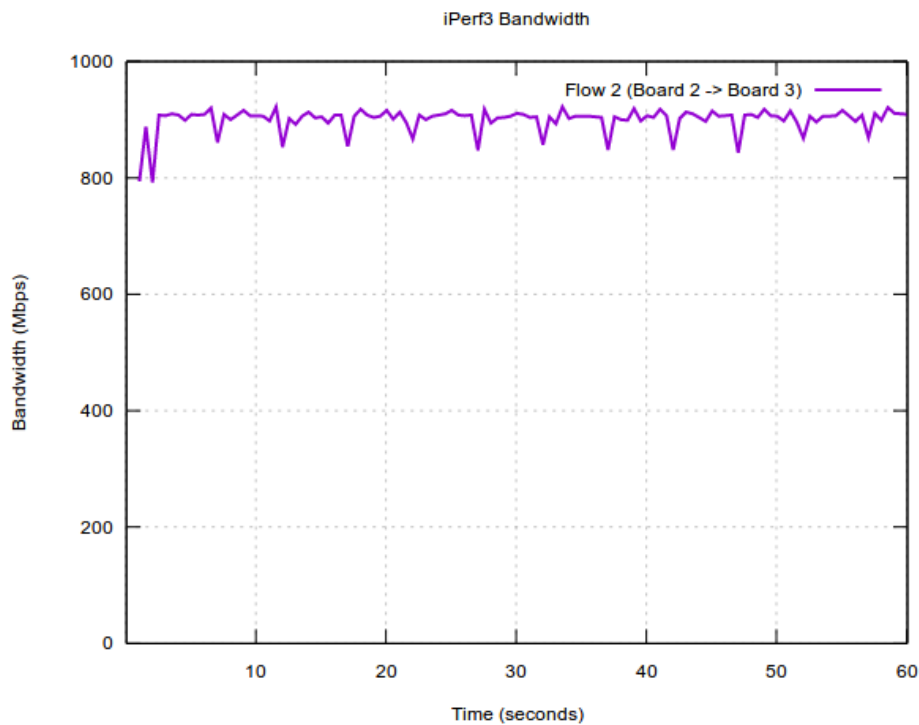


Figure 53. Prioritizing configuration: Flow 2 run by its own

- Both flows run at the same time

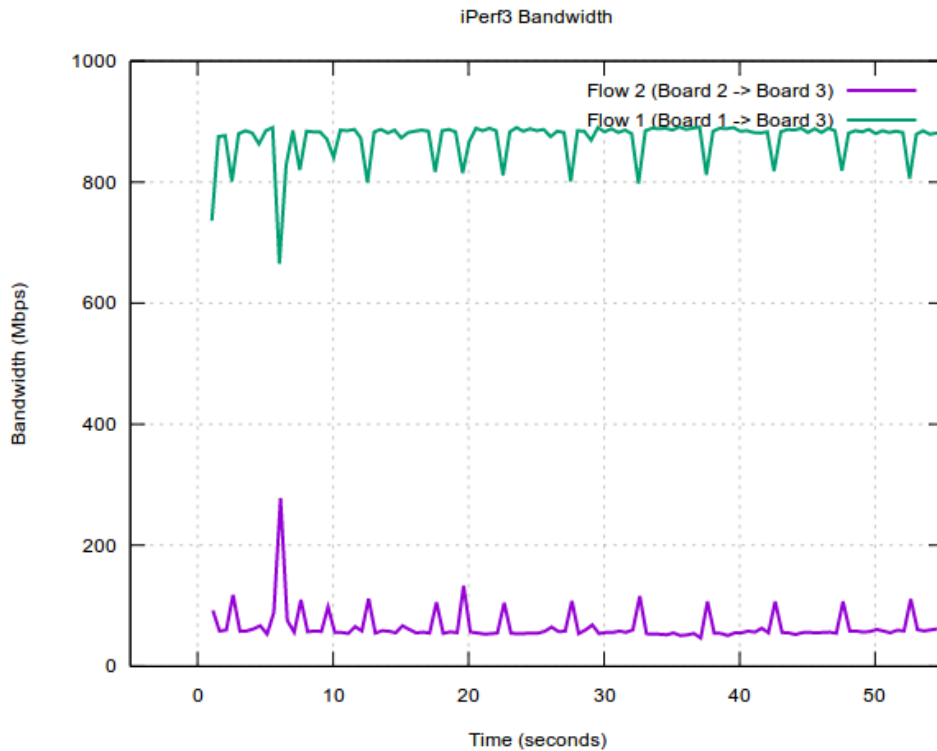


Figure 54. Prioritizing configuration: both flows run at the same time

Comments:

- Each flow, when run by its own, gets access to the full link bandwidth.
- When run at the same time, the switch applies strict priority between the flows, and Flow 1 (with a VLAN priority of 5) is protected, keeping the same bandwidth as when running alone.
- Flow 2 can only get the remaining bandwidth up to 1000 Mbps, which is typically very low.

7.2.8.7 Policing configuration

Based on the prioritizing configuration, we can apply rate limiting on Flow 1, since it has a higher VLAN priority and will obtain its rate-limited slice of the bandwidth, anyway.

The XML configuration for this case can be generated by running this sja1105-tool helper script:

```
[ubuntu@sja1105-tool/src/helpers] $ ./configs/rate-limiting/policing.sh --flow1-
prio 5 --flow2-prio 3 --flow1-rate-mbps 600
Configuration saved as ./configs/rate-limiting/policing.xml.
View with: "sja1105-tool config load ./configs/rate-limiting/policing.xml; sja1105-tool config show |
less"
```

7.2.8.7.1 Queuing diagram

The following figure shows the queuing diagram for the policing configuration. It shows the same queues as with the prioritizing configuration. The higher-priority traffic is rate-limited to allow the lower-priority traffic to use more of the remaining space.

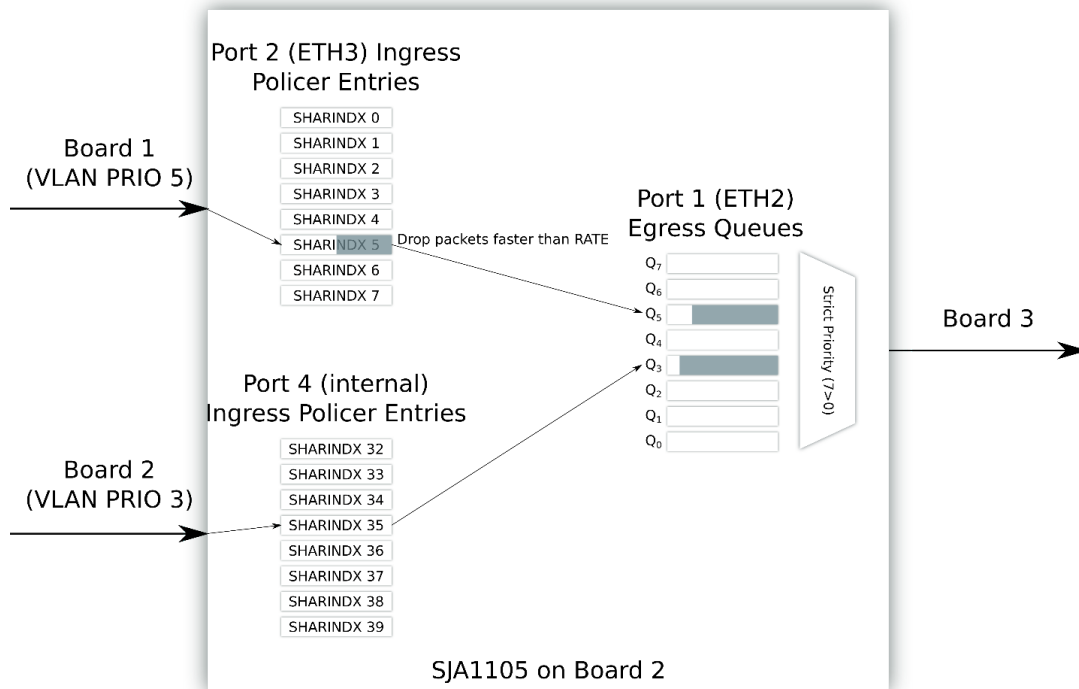


Figure 55. Queuing diagram for policing configuration

7.2.8.7.2 Results for the policing configuration

This section describes the results for different flows for the policing configuration. Run the following tests:

- Flow 1 run by its own

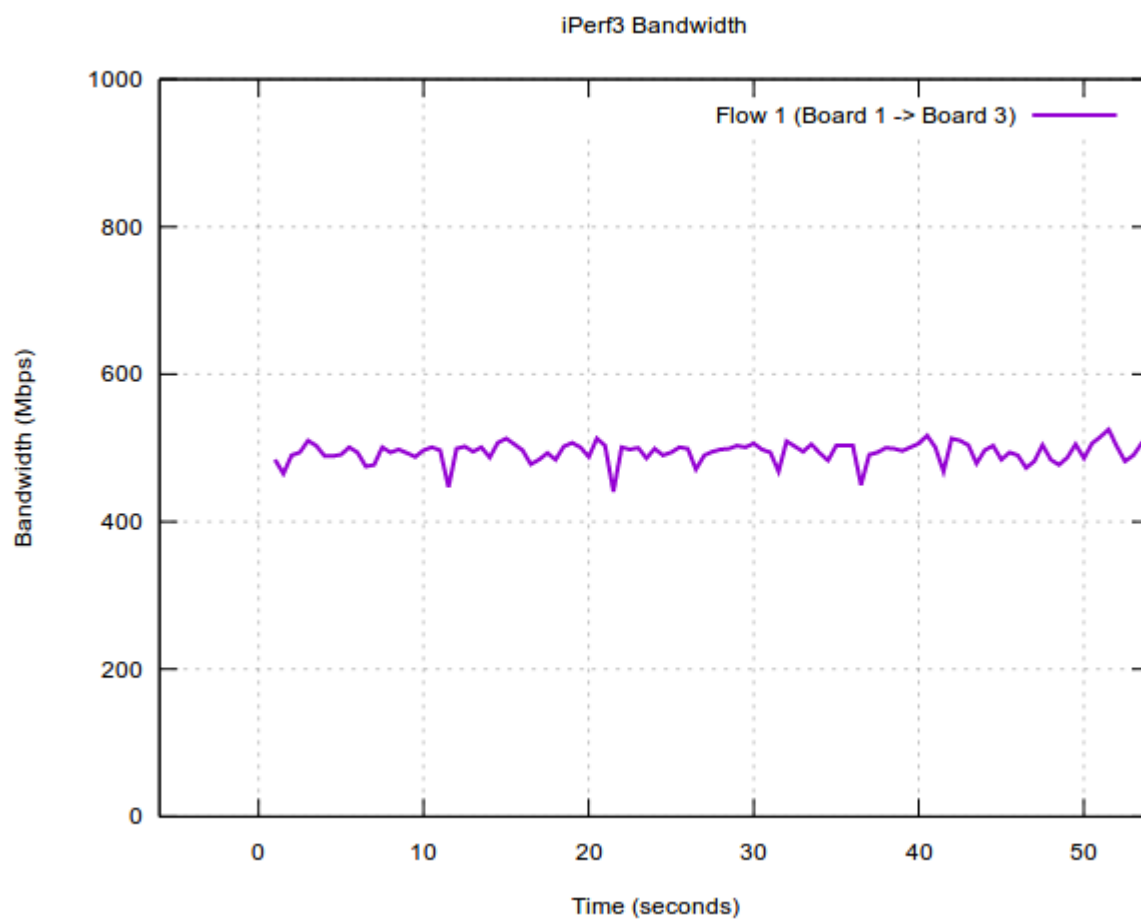


Figure 56. Policing configuration: Flow 1 run by its own

- Flow 2 run by its own

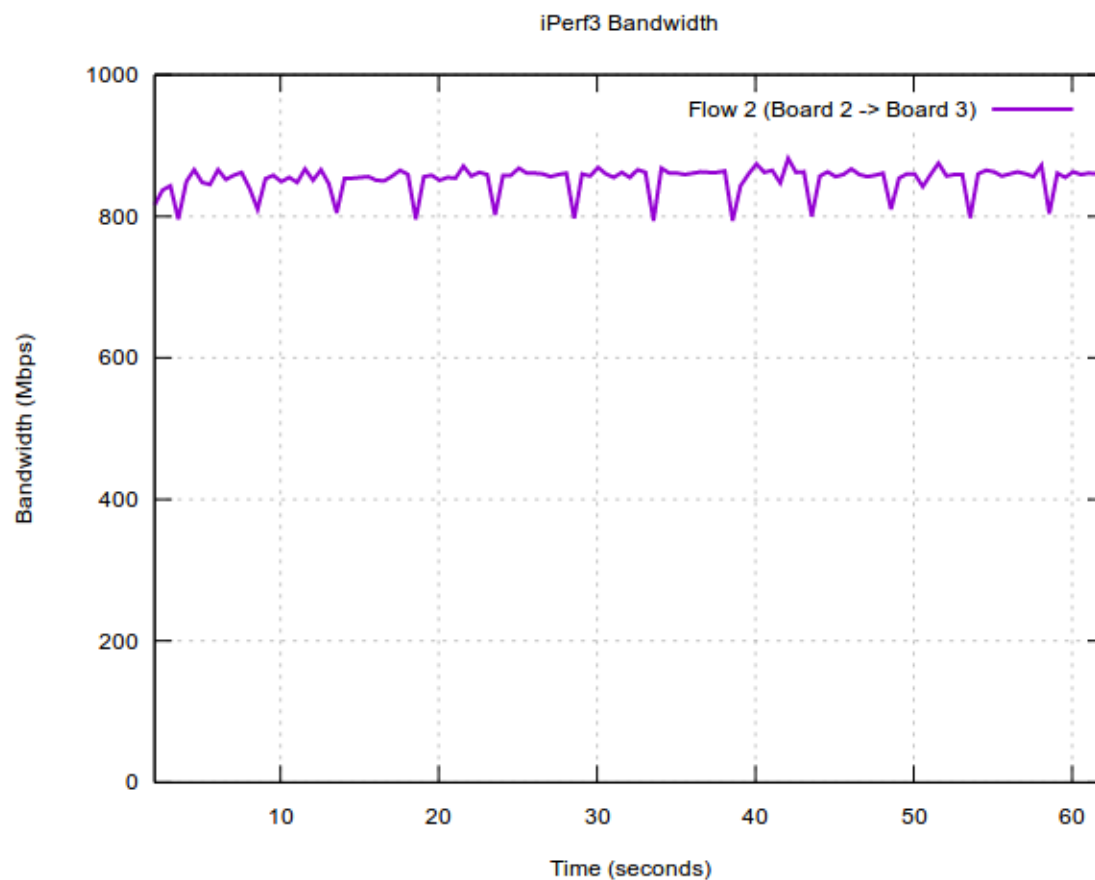


Figure 57. Policing configuration: Flow 2 run by its own

- Both flows run at the same time

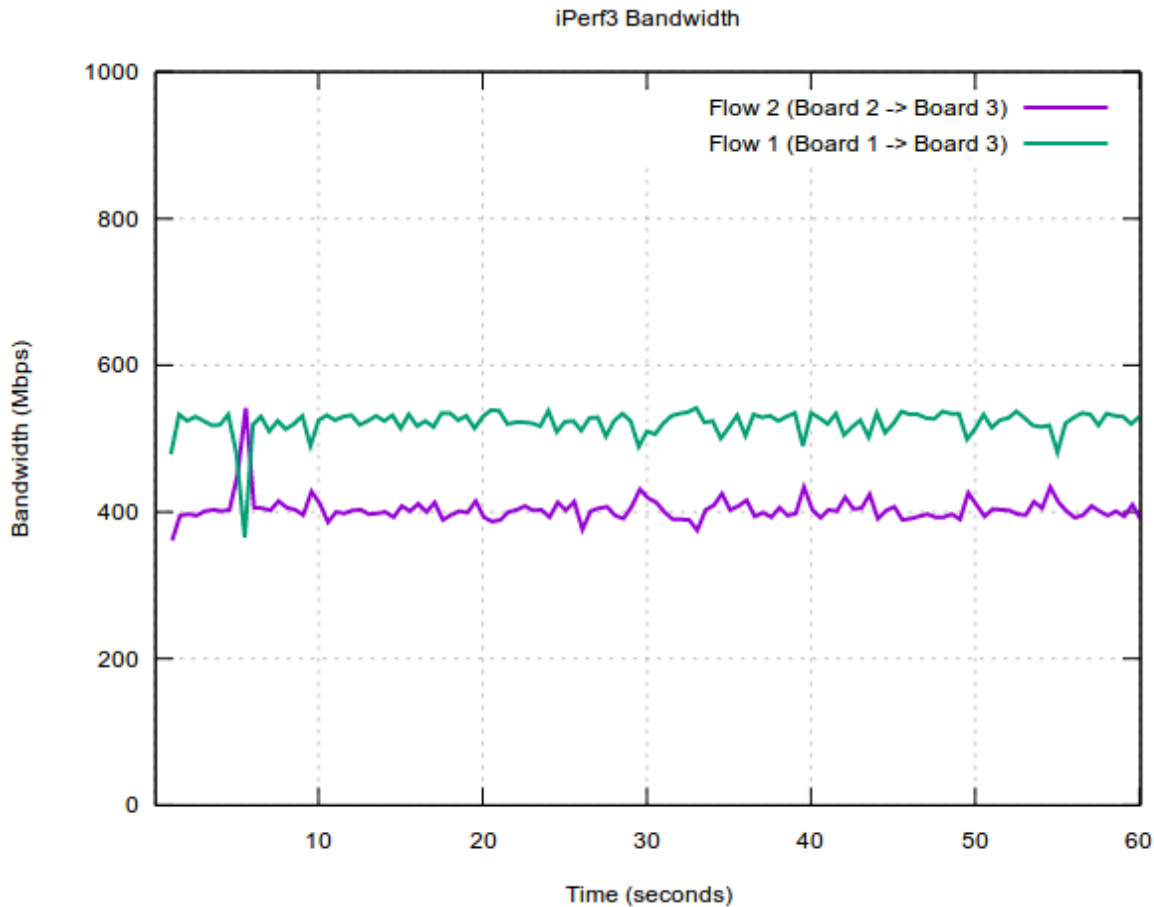


Figure 58. Policing configuration: both flows running at the same time

Comments:

- Using a combination of prioritization and policing, you can obtain the desired bandwidth allocation for both Flow 1 and Flow 2 (600-400).
- This is done by dropping part of the packets from Flow 1 (which might not always be desirable).
- In absence of the higher priority flow, Flow 2 is able to obtain line rate, because it is not rate-limited. The same cannot be said about Flow 1.

7.2.8.8 Scheduling configuration

The Time-Aware Scheduler of the SJA1105 switch works by following the guidelines in 802.1Qbv:

- Its 5 Ethernet ports each have 8 *gates* on egress, which can be open or closed
- Each *gate* controls its associated *queue* (there are 8 *queues*, one per traffic class priority)
- Whenever a *gate* is open, packets from its respective *queue* can be sent out the wire
- The Time Aware Scheduler (or Qbv engine) functions based on a clock ticking with a period of 200ns
- *Time slots* can be created, where some *gates* can be opened (allow certain traffic classes) and some can be closed. Each *time slot's* action applies to some specified egress ports. A *time slot* has a defined period of time for which it is active, and is chained together with other *time slots* in a periodic *cycle*.

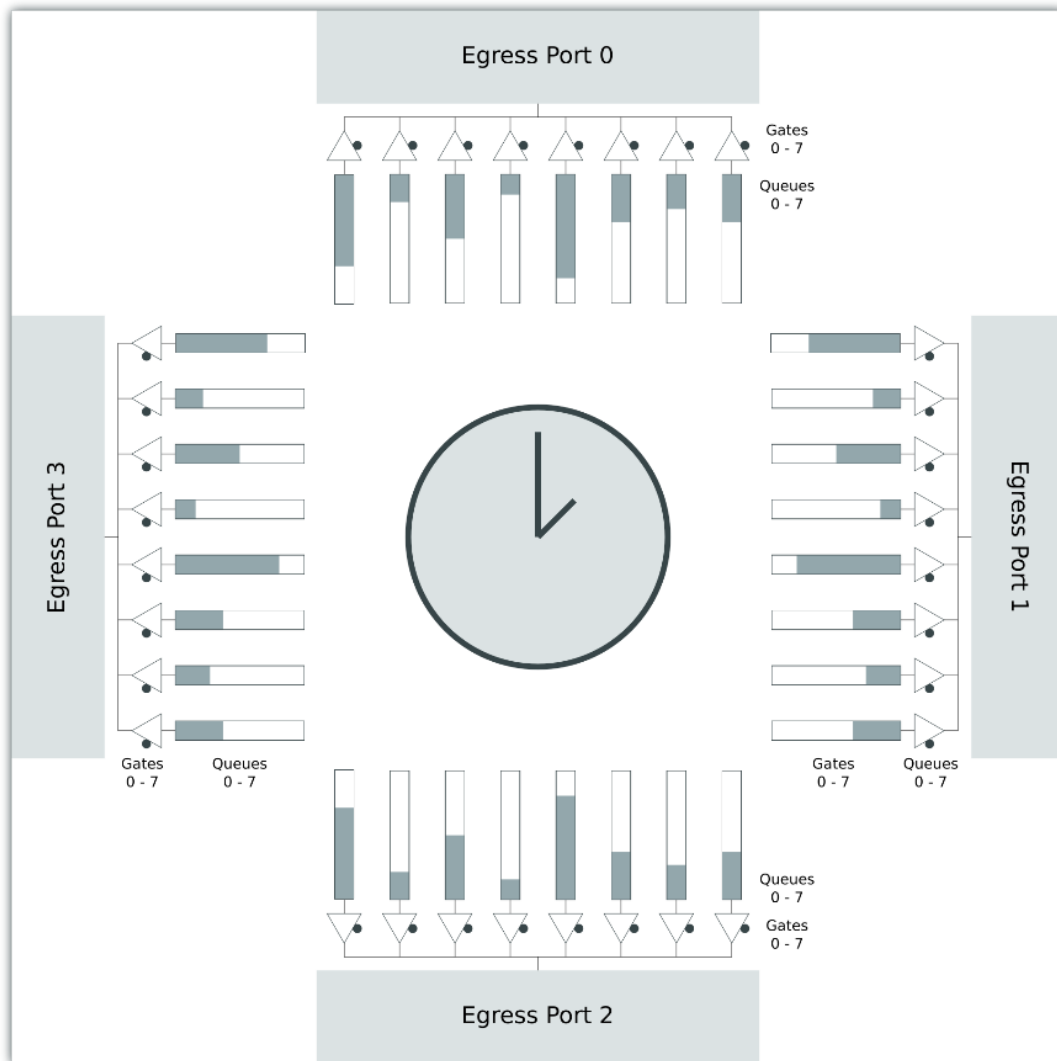


Figure 59. Structure of the Time Aware Scheduler

The user defines how many clock ticks each time slot (called *subschedule*, in SJA1105 terminology) takes, and also which flows (identified by their VLAN PRIO bits) are allowed to dequeue packets on each time slot. Once the Time-Aware Scheduler goes through each *time slot* (*subschedule*) in a round-robin fashion, it starts over again periodically. A complete period of subschedules is called a *schedule*.

In 802.1Qbv terminology, a *time slot* corresponds to a *SetGateStates* operation, and the length of the *cycle* is equal to *OperCycleTime*.

There are a total of 1024 entries allowed by the SJA1105 hardware for *time slots*. These can be grouped together to form at most 8 *cycles*, that run independently.

When defining multiple concurrent *cycles*, care must be taken to manually ensure that no two *time slots* ever trigger at the exact same moment in time.

In the third approach of the rate-limiting use case, the Time Aware Scheduler is active on the SJA1105 under test (that of Board 2) for egress port 1 (ETH2). This is the link towards Board 3, where the contention between Flow 1 and Flow 2 happens.

The XML configuration for this case was generated by running this sja1105-tool helper script:

```
[ubuntu@sja1105-tool/src/helpers] $ ./configs/rate-limiting/scheduling.sh --flow1-prio 5
--flow2-prio 3 --flow1-time-ms 6 --flow2-time-ms 4
```

```
Configuration saved as ./configs/rate-limiting/scheduling.xml.
View with: "sja1105-tool config load ./configs/rate-limiting/scheduling.xml;
sja1105-tool config show | less"
```

The SJA1105 switch is configured to create a subschedule for VLAN PRIO 3 and one for PRIO 5. The total egress bandwidth is split 60% to Flow 1 (a time slot duration of 6 ms out of a total cycle length of 10 ms) and 40% to Flow 2.

In this configuration, Flow 1 is completely isolated from Flow 2, and there is minimal interference between the two, which allows better utilization of bandwidth.

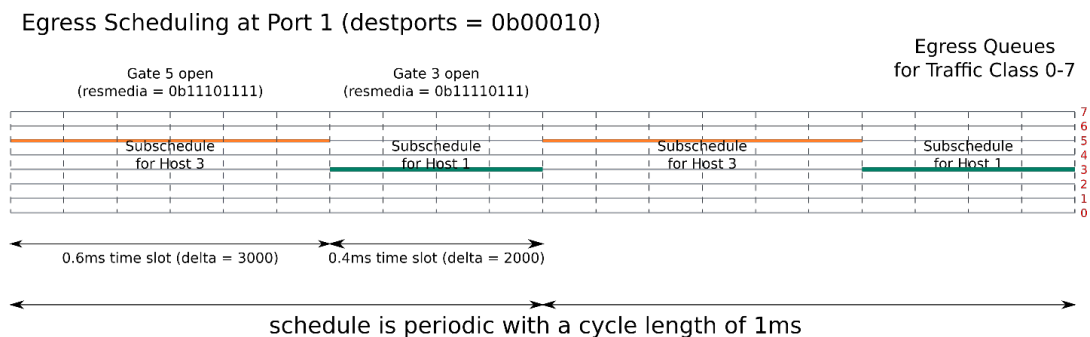


Figure 60. Time gating for Host 1 and Host 3, viewed on the time axis

There are four SJA1105 configuration tables that control the behavior of the Time-Aware Scheduler:

- Schedule Table
- Schedule Entry Points Table
- Schedule Parameters Table
- Schedule Entry Points Parameters Table

The Schedule Table contains the definitions of all the subschedules (time slots), or SetGateStates operations in Qbv terminology:

- What egress ports is the subschedule active on
- Which gates (egress queues for traffic classes) should be open and which should close
- The duration of the subschedule, in 200 ns increments

The Schedule Table does **NOT** define how the subschedules are linked together.

Each schedule has a starting point and an ending point, defined as indices to subschedules from the Schedule Table:

- The starting point is defined in the Schedule Entry Points table
- The ending point is defined in the Schedule Parameters table

For a more complete description of how the SJA1105 should be configured for Qbv operation, refer to the sja1105-tool helper script under `src/helpers/bin/scheduler-create`.

7.2.8.8.1 Results for the scheduling configuration

This section describes the results for ping testing for different flows for the Scheduling configuration.

- Flow 1 run by its own

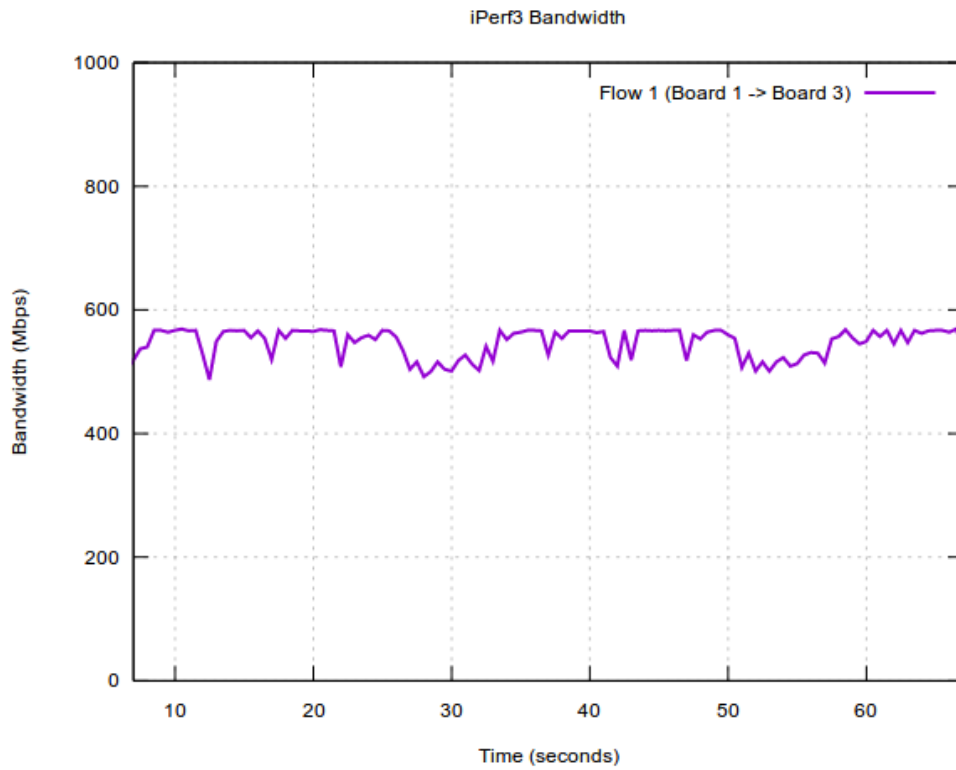


Figure 61. Scheduling configuration: Flow 1 run by its own

- Flow 2 run by its own

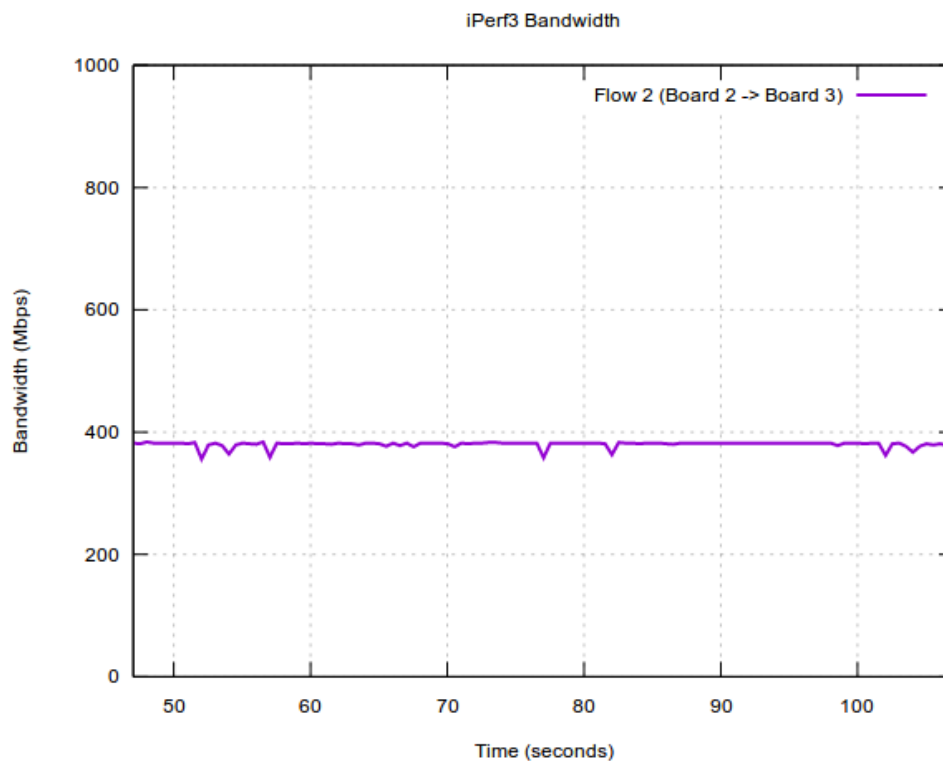


Figure 62. Scheduling configuration: Flow 2 run by its own

- Both flows run at the same time

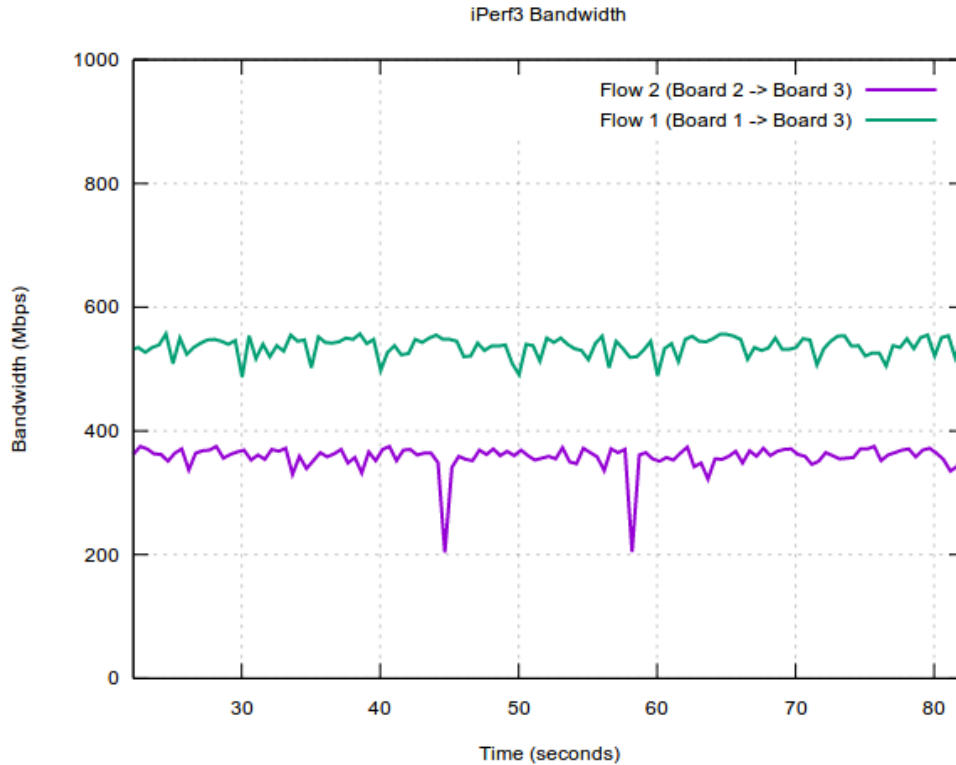


Figure 63. Both flows run at the same time

Comments:

- Regardless of being run separately or simultaneously, the two flows are allocated at 60% and 40% of the total Port 1 egress bandwidth by the Time-Aware Scheduler of SJA1105 on Board 2.
- The Time Aware Scheduler of the SJA1105 allows finer-grained control over bandwidth allocation.

7.2.8.9 Results of the demo

After running the steps described in the preceding sections, the following four XML files can be located in the OpenIL home directory of Board 2:

- standard.xml
- prioritizing.xml
- policing.xml
- scheduling.xml

The walkthrough must be followed step-by-step only once. Afterwards, a specific configuration can be loaded as shown in the commands below:

```
[root@openil] $ sja1105-tool config load standard.xml
[root@openil] $ sja1105-tool config upload
```

The SJA1105 configuration on the other boards must be kept default. Ensure these commands are run once, at the beginning of the tests:

```
[root@board1] $ sja1105-tool config default -f ls1021atsn
[root@board3] $ sja1105-tool config default -f ls1021atsn
```

7.2.9 Synchronized Qbv demo

This section describes the synchronized Qbv demo in brief, its objectives, Qbv schedule analysis, the various scenarios, setup preparation, and Latency and Bandwidth Tester (LBT) configuration.

7.2.9.1 Introduction

This demo covers a possible use case of the following TSN standards combined:

- IEEE 1588 (Precision Time Protocol)
- IEEE 802.1Qbv (Time-Aware Scheduling)

The scenario is to assure deterministic, fixed latency for a particular control flow in a switched Ethernet network, regardless of interfering traffic. Let's assume that Node A generates control events periodically, every 5 ms, and that these need to be propagated *as soon as possible* to Node B, which is situated 3 Ethernet switches away (3 hops) from Node A.

Trying to do this inside a regular, unconfigured Ethernet switched network usually results in latencies between Node A and Node B that invariably and uncontrollably increase as soon as there is any sort of background traffic through the network. This is because, by default, all frames are treated equally (best-effort) by the switches, which makes all traffic susceptible to unpredictable queuing delays.

The naïve solution to the queuing issue would be to simply raise the L2 priority of that specific control flow, such that Ethernet switches along its path always schedule that flow for transmission first.

The problems with this initial solution are twofold.

- Firstly, simply increasing a flow's priority puts too much trust in its well-behaving. If Node A malfunctions, or simply decides to send packets quicker than the 5 ms interval we accounted for, there is a high chance it will cause the other traffic flows, with less priority, to suffer from starvation.
- Secondly, although the control flow has the highest priority possible, it might still happen that it experiences forwarding delays. This is because by the time a control flow frame should be sent, the transmission medium might already be occupied transmitting a frame with less priority, which the switch must first finish sending. This is a form of priority inversion.

For the first issue, we can apply rate limiting on the control flow we just prioritized. This way, through prioritization we ensure a minimum guarantee of service, while through rate limiting we put a maximum limit to that guarantee.

Rate limiting can be applied in two ways: either with egress shaping on that specific port, or with ingress policing on the receiving side of that flow. Both these algorithms are generally implemented as a Token Bucket, which is a simple method to spread out heavy bursts of packets, either by dropping some (ingress policer) or delaying the sending of some (egress shaping).

The simple Token Bucket algorithm is only able to generate packets that are spread out evenly, given a specific time resolution. If more complex "waveforms" of packet transmission are desired, or if the timing accuracy must be very low, a different approach called Time-Aware Scheduling (TAS) can be employed.

The Time-Aware Scheduler, defined in **IEEE 802.1Qbv**, associates "gates" with each of the 8 priority queues connected to the egress ports. A gate is said to be "open" if frames are allowed to be selected for transmission from that gate's associated queue, or "closed" otherwise. A cyclic schedule is kept, where multiple timeslots define what is the state of every one of the gates (open or closed), and for how long.

Revisiting the question of how to minimize the impact of competing traffic flows on one another, one can configure the Time-Aware Scheduler with a single gate open per timeslot, effectively isolating the flows in time, and creating a Time-Division Multiple Access (TDMA) type of forwarding policy.

Even with the Time-Aware Scheduler, one issue still remains: the priority inversion caused by unfinished frame transmission at the end of its allocated timeslot. For this issue, two solutions exist: either IEEE 802.1Qbu (frame preemption), or allocation of an empty extra timeslot which serves as a guard band.

But even then, if there are multiple Time-Aware Schedulers in the same L2 network, they need to have a common notion of time. By synchronizing the clocks of all Time-Aware Schedulers using **IEEE 1588** (PTP), frames can be forwarded in a coordinated manner, similar to synchronized traffic lights.

With careful planning of the schedule, each packet always reaches the destination with the same predictable latency. The goal of the synchronized Qbv demo is for frames to spend almost no time being buffered on nodes internal to the TSN network, but instead only at the entry point. Once the time comes for a frame to be transmitted towards the TSN network, it passes with minimal delay through it.

7.2.9.2 Objectives

The objectives of the demo are the following:

- Synchronize the SJA1105 PTP clocks using IEEE 1588.
- Generate SJA1105 XML configurations offline (on host) using a simplified JSON description, and upload them to the 3 boards over SSH or NETCONF.
- Run the SJA1105 Time-Aware Scheduler (Qbv engine) based off the PTP clock.
- Create a 3-switch TSN network with deterministic latency.
- Use ping traffic to determine the degree of synchronization between boards.
- Use iPerf3 as source of interfering traffic and prove it does not alter the ping latency.

7.2.9.3 Qbv schedule analysis

The Qbv schedule common to all three boards comprises of six timeslots, numbered 0 to 5.

The JSON description can be found inside the `src/helpers/configs/synchronized-qbv/qbv-ptp.sh` helper script from the `sja1105-tool` source tree and is displayed here for reference:

```
{
  "clksrc": "ptp",
  "cycles": [
    {
      "start-time-ms": "1",
      "timeslots": [
        {
          "duration-ms": "4",
          "ports": [${echo_port}, ${reply_port}],
          "gates-open": [0, 1, 2, 3, 4, 5, 6],
          "comment": "regular traffic 1"
        },
        {
          "duration-ms": "10",
          "ports": [${echo_port}, ${reply_port}],
          "gates-open": [],
          "comment": "guard band 1"
        },
        {
          "duration-ms": "1",
          "ports": [${echo_port}],
          "gates-open": [7],
          "comment": "icmp echo request"
        },
        {
          "duration-ms": "4",
          "ports": [${echo_port}, ${reply_port}],
          "gates-open": [0, 1, 2, 3, 4, 5, 6],
          "comment": "regular traffic 2"
        },
        {
          "duration-ms": "10",
```

```

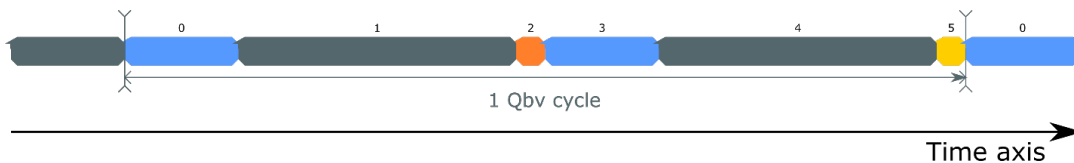
        "ports": [${echo_port}, ${reply_port}],
        "gates-open": [],
        "comment": "guard band 2"
    },
    {
        "duration-ms": "1",
        "ports": [${reply_port}],
        "gates-open": [7],
        "comment": "icmp echo response"
    }
]
}
]
}

```

The echo_port and reply_port variables take individual values for each of the three boards.

The Qbv configuration can be summarized as follows:

Figure 64. Qbv schedule



- Ping traffic (ICMP echo request and echo reply) is classified by OpenIL through the `/etc/init.d/S45vlan` script and tagged with VLAN priority 7
- The blue time slots (0 and 3) represent regular traffic (traffic classes 0 through 6). The iPerf flows (traffic class 0) fall in this category.
- The grey time slots (1 and 4) represent periods of time where the switch allows no packet to be forwarded. These are guard bands for time slots 2 and 6.
- Time slot 2 (orange) allows ICMP Echo Request packets to be forwarded from source towards destination.
- Time slot 5 (yellow) allows ICMP Echo Reply packets to be forwarded from destination back towards source.

Correct functioning of the test (only a single ping packet will come through per Qbv cycle) is ensured by the fact that the ping is being run in “Adaptive” mode (“-A” flag).

The orange and yellow time slots must be large enough in order to counter potential time offsets between the three boards. This means that once a ping packet is forwarded by the first switch at the beginning of the time slot, there should be enough time left such that the same packet would also be forwarded in the same slot by the rest of the switches along the packet’s path.

Although the orange and yellow time slots are long enough to permit forwarding multiple packets, in practice, at most two are forwarded per cycle (one ICMP echo request and one response) because ping is run in adaptive mode. Thus, there will be always be at most a single packet in flight, at any given moment.

- RTT (*Round-Trip Time*) is defined as the time interval between ICMP Echo Request *i* and ICMP Echo Reply *i*, both measured at the sender.
- PIT (*Packet Inter-arrival Time*) is defined as the time interval between ICMP Echo Request *i* and ICMP Echo Request (*i*+1), both measured at the receiver.

This use case analysis focuses on the Packet Inter-arrival Times measured at the receiver. This eliminates most delays caused by Linux user-space scheduling of the ping process and closely reflects the Qbv cycle length configured on the TSN switches.

The guard bands have two roles:

- Reduce the jitter while forwarding the ping packets through the network (ensure the switches have no other packets queued on the egress port when time slots 2 and 5 are scheduled for transmission). The guard bands are an alternative to IEEE

802.1Qbu Frame Preemption. A guard band duration of the time it takes to transmit an MTU-sized frame time at 1 Gbps is sufficient to eliminate this jitter.

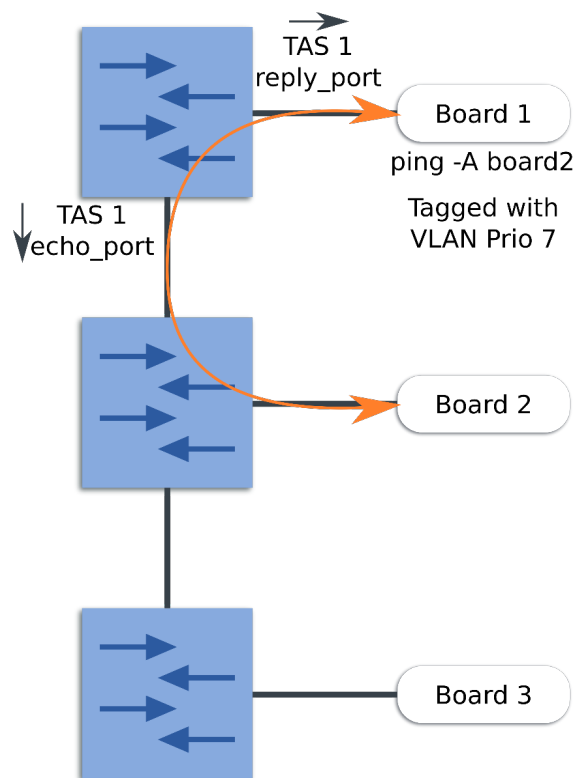
- Let the LS1021 cores of the iPerf receiver cool down from receiving Rx interrupts from the network driver and finish processing the incoming traffic. This is important because, if upon receiving an ICMP echo request during time slot 2, the destination cannot process it and generates a reply until time slot 5 (15 ms), then a full Qbv cycle will be missed. The reported inter-arrival time in this scenario would be double (60 ms).

7.2.9.4 Scenarios

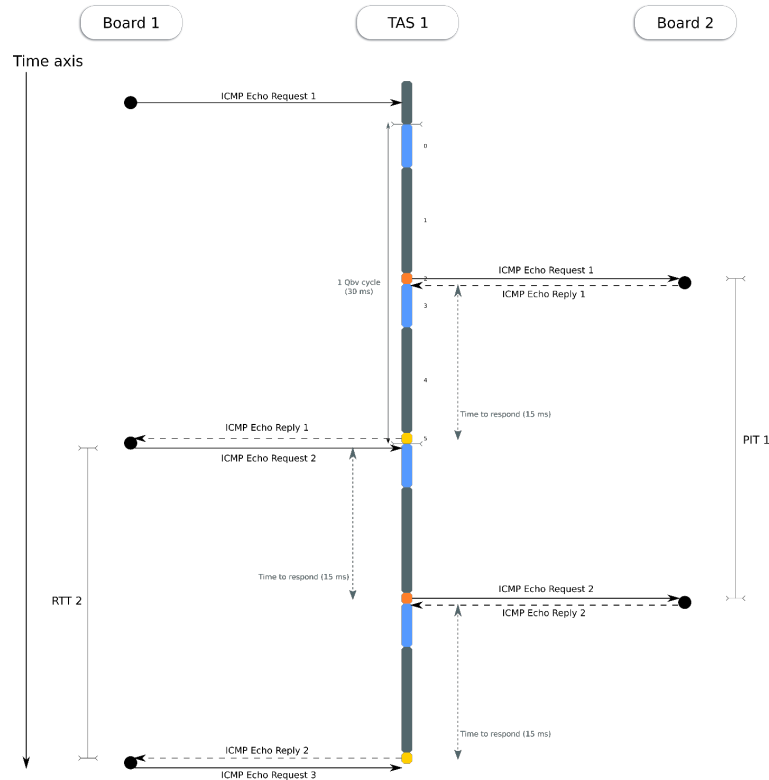
In both the 1-hop and 3-hop scenarios, adaptive ping is used to simulate the control flow packets sent from Node A to Node B. "Adaptive" ("-A" flag) means that the sending interval of Node A adapts to the RTT of the TSN network, which we are controlling directly by means of the Time-Aware Schedulers of the SJA1105 TSN switches along the path.

7.2.9.4.1 1 Hop scenario

In this scenario, Node A (ping sender) is Board 1, and Node B (ping receiver) is Board 2. Control traffic flows through a single Time-Aware Scheduler (TAS 1). The boards are connected as shown in the following figure.



A time visualization of ping packets in this 1-hop network looks as shown in the following figure.



On the time axis, on the left hand side are Round-Trip Times (RTT) reported by Node A (sender), while on the right-hand side are Packet Interarrival Times (PIT) reported by Node B (receiver).

The first RTT reported by Node A is expected to be random, since the ping sending interval is not yet aligned with the TAS cycle length. Afterwards, the forwarding of each subsequent ICMP Echo Request is expected to be delayed a full cycle by TAS 1, until it reaches Node B.

The Qbv scheduler on TSN switch 1 operates on two ports:

- On the `echo` port, during the orange time slot 2, where ICMP Echo Request packets are forwarded.
- On the `response` port, during the yellow time slot 5, where ICMP Echo Response packets are forwarded.

These time slots for ICMP traffic consume 2 ms out of the total Qbv cycle length of 30 ms (including their associated guard bands, the total rises to 22 ms out of 30 ms). In the rest of the Qbv cycle (8 ms, time slots 0 and 3), regular traffic (iPerf) is scheduled on both the echo and response port.

7.2.9.4.2 3-hop scenario

In this scenario, Node A (ping sender) is the Board 1 and Node B (ping receiver) is the Board 3. Control traffic flows through three Time-Aware Schedulers (TAS 1, TAS 2, and TAS 3). The boards are connected as shown in the following figure.

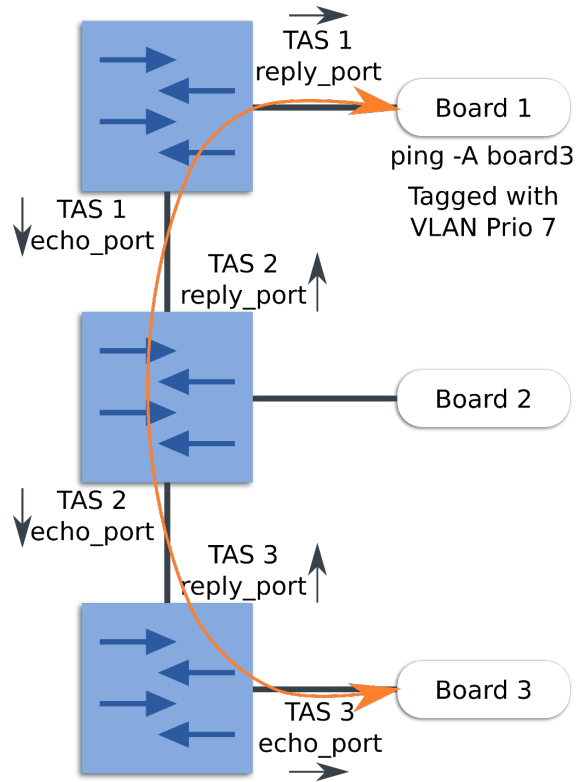


Figure 65. 3-hop scenario

The ideal scenario is when forwarding a ping packet takes a single cycle through all three hops. A time visualization of this scenario looks as shown in the following figure.

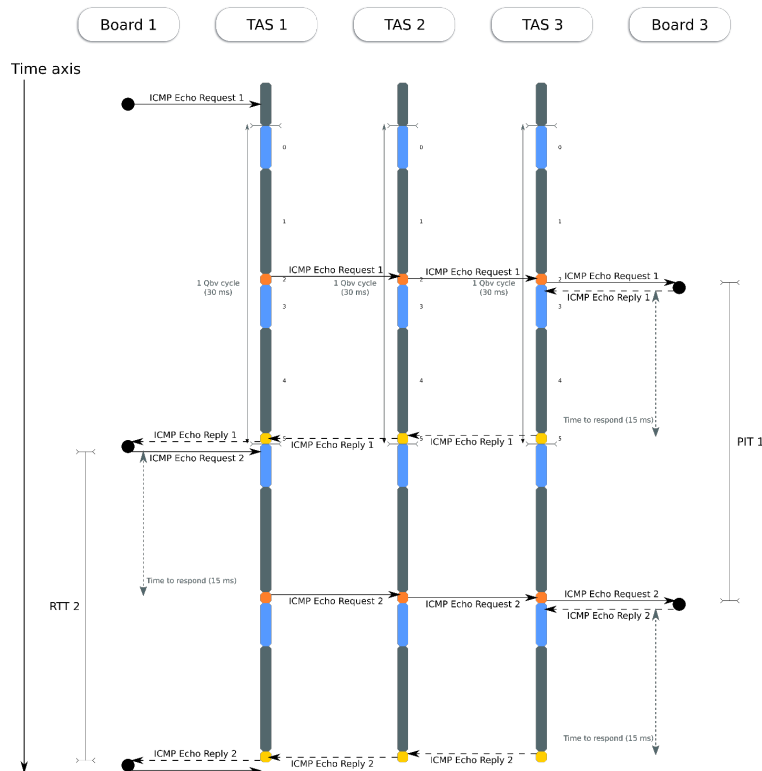


Figure 66. Timeslots in the 3 hop scenario

This scenario poses more difficulties, because the clocks of TAS 1, TAS 2, and TAS 3 must be in sync with one another. The expectation for this test is to get the same 30 ms interval reported as in the 1-hop case. This proves that using synchronized Qbv in a multi-switch network does not incur additional delays and can be used to ensure deterministic latency regardless of the number of hops.

As is the case with the 1-hop setup, TAS 1 delays the forwarding of ICMP Echo Requests until time slot 2 (orange). The key is that once TAS 1 forwards the ping packet, it is caught immediately (in the same cycle) by the orange time slot of TAS 2, and then by the green time slot of TAS 3.

As mentioned, this is possible because the lengths of the orange time slots are large enough to make up for potential PTP synchronization offsets between the boards.

The goal for the 3-hop scenario is for 100% of the ping packets to report an inter-arrival time (PIT) of 1 cycle (30 ms) at the destination, same as if it were a single hop.

7.2.9.5 Setup preparation

1. Inside a GNU/Linux environment, go to the SJA1105 helper scripts folder:

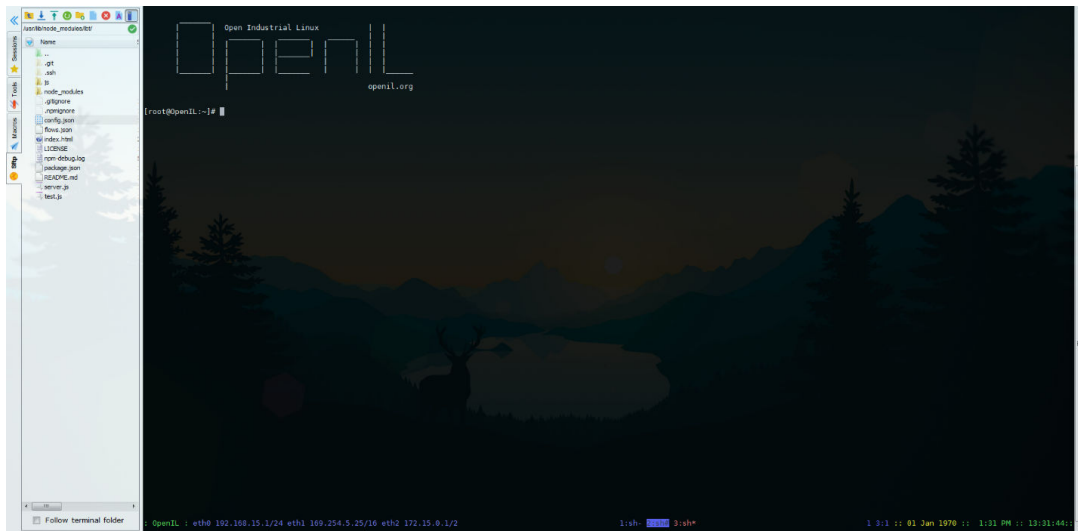
```
cd sja1105-tool/src/helpers
source envsetup
```

2. Generate the XML configurations for the 3 boards and upload them to the boards:

```
for i in 1 2 3; do ./configs/synchronized-qbv/qbv-ptp.sh --board ${i}; scp ./configs/
synchronized-qbv/qbv-ptp-board${i}.xml root@192.168.15.${i}:.; done
```

3. Open an SSH connection to Board 1.

- Run the “tmux” command inside board 1’s terminal. Tmux is a “terminal multiplexer” that allows you to have multiple shells over the same SSH connection. Inside tmux, press the following keys: “Ctrl-a” and then “c.” Do this twice. You should now have 3 shells spawned inside tmux, as can be seen in the status bar at the bottom: “1:sh 2:sh 3:sh”:



- Navigate to the first tmux shell by clicking on “1-sh.” Inside this shell, **load the XML configuration** into the sja1105-tool:

```
>sja1105-tool config load -f qbv-ptp-board1.xml
```

If successful, no output should be seen from this command.

- Navigate to the second tmux shell by clicking on “2-sh.” Inside this shell, start the **LBT web application**:

```
/usr/lib/node_modules/lbt/server.js
```

- As these XML configurations for SJA1105 use the PTP clock source for Qbv, you must run the PTP synchronization daemon inside the third tmux shell (3-sh):

```
ptp4l -i eth0 -p /dev/ptp0 -m -l 7 -t 1000
```

After a while where only this debug message is printed:

```
ptp4l[0000.000]: sja1105: sync timer timeout
```

The PTP daemon will begin to keep in sync the SJA1105 PTP clock with the eTSEC clock of the LS1021 eth0 port.

Synchronization offsets can be followed by examining these output lines:

```
ptp4l[46335.657]: sja1105: offset 202 ns, delay 94627 ns
```

The PTP daemon will also monitor and control the Qbv engine, which piggybacks its clock source from the PTP clock. The Qbv engine can be in one of 3 states:

- Disabled
- Enabled but not running (scheduled to begin in 3 seconds)
- Running

These states can be seen by examining the following output lines:

```
ptp4l[46335.658]: sja1105_qbv_monitor: state disabled
ptp4l[46335.916]: sja1105_qbv_monitor: state enabled not running
```

```
ptp4l[46335.917]: time to start: [2.870531024]
ptp4l[46702.166]: sja1105_qbv_monitor: state running
```

Under normal operation, the Qbv engine is expected to remain in the running state. Large PTP synchronization offsets will reset the PTP clock, synchronization algorithm, and thus, also the Qbv state machine.

Note that while the Qbv engine is not in the running state (either disabled or scheduled to begin), ping traffic is forwarded freely, and not rate-limited or protected.

8. Open an SSH connection to Board 2, open tmux and create 3 shells.
9. In the first shell ("1:sh"), load the XML configuration into sja1105-tool:

```
sja1105-tool config load -f qbv-ptp-board2.xml
```

10. In the second shell ("2:sh"), start the OPC UA server:

```
opc-sja1105
```

11. In the third shell, start the PTP synchronization daemon:

```
ptp4l -i eth0 -p /dev/ptp0 -m -l 7 -t 1000
```

12. Open an SSH connection to Board 3; open tmux and create 2 shells.
13. In the first shell ("1:sh"), load the XML configuration into sja1105-tool:

```
sja1105-tool config load -f qbv-ptp-board3.xml
```

14. In the second shell, start the PTP synchronization daemon:

```
ptp4l -i eth0 -p /dev/ptp0 -m -l 7 -t 1000
```

7.2.9.6 Latency and Bandwidth Tester Configuration

On Board 1, ensure that the file `/usr/lib/node_modules/lbt/config.json` has the following content:

```
{
  "listenPort": 8000,
  "sshPrivateKey": "/etc/ssh/ssh_host_rsa_key",
  "ping": {
    "plotStyle": "lineGraph",
    "xlabel": "Time (seconds)",
    "ylabel": "PIT (ms)",
    "xmin": "0",
    "ymin": "0",
    "xlen": "60",
    "binwidth": "0.01",
    "measurement": "pit",
    "measurementInterface": "eth2",
    "title": "Ping Packet Inter-arrival Time"
  },
  "iperf": {
    "plotStyle": "lineGraph",
    "xmin": "0",
    "ymin": "0",
    "xlen": "60",
    "xlabel": "Time (seconds)",
    "ylabel": "Bandwidth (Mbps)",
    "title": "iPerf3 Bandwidth"
  }
}
```

```
}
}
```

If necessary, restart the LBT server after updating its configuration file.

In the browser, navigate to <http://192.168.15.1:8000>.

Input the following flows, as shown in the following figure:

- **Flow 1:** iPerf from Board 1 to Board 3 (over untagged TSN network)
- **Flow 2:** iPerf from Board 2 to Board 3 (over untagged TSN network)
- **1 Hop:** Adaptive Ping from Board 1 to Board 2 (over VLAN-tagged TSN network)
- **3 Hops:** Adaptive Ping from Board 1 to Board 3 (over VLAN-tagged TSN network)

Latency and Bandwidth Tester

iPerf flows

Enabled	Label	Source	Destination	Port	Transport	(UDP) Bandwidth	
<input type="checkbox"/>	Flow 1	root@172.15.0.1:22	root@172.15.0.3:22	5201	TCP ▾	n/a	<input type="button" value="+"/>
<input type="checkbox"/>	Flow 2	root@172.15.0.2:22	root@172.15.0.3:22	5202	TCP ▾	n/a	<input type="button" value="+"/>

Ping flows

Enabled	Label	Source	Destination	Interval type	Interval (ms)	Packet size	
<input type="checkbox"/>	1 Hop	root@172.15.100.1:22	root@172.15.100.2:22	Adaptive ▾	n/a	64	<input type="button" value="+"/>
<input type="checkbox"/>	3 Hops	root@172.15.100.1:22	root@172.15.100.3:22	Adaptive ▾	n/a	64	<input type="button" value="+"/>

Figure 67. LBT configuration of flows for the Synchronized Qbv demo

7.2.9.7 Ping testing

The purpose of the ping test is to verify that the Qbv schedule engine is properly configured and synchronized across all three TSN boards, regardless of the number of hops and the background traffic.

7.2.9.7.1 1-hop flow

On the LBT web page, enable only the **1 Hop** flow (from 172.15.100.1 to 172.15.100.2).

This passes through the TAS of Board 1.

Expected behavior: In this case, a constant 30 ms PIT measured on Board 2, can be observed, as shown in the following figure.

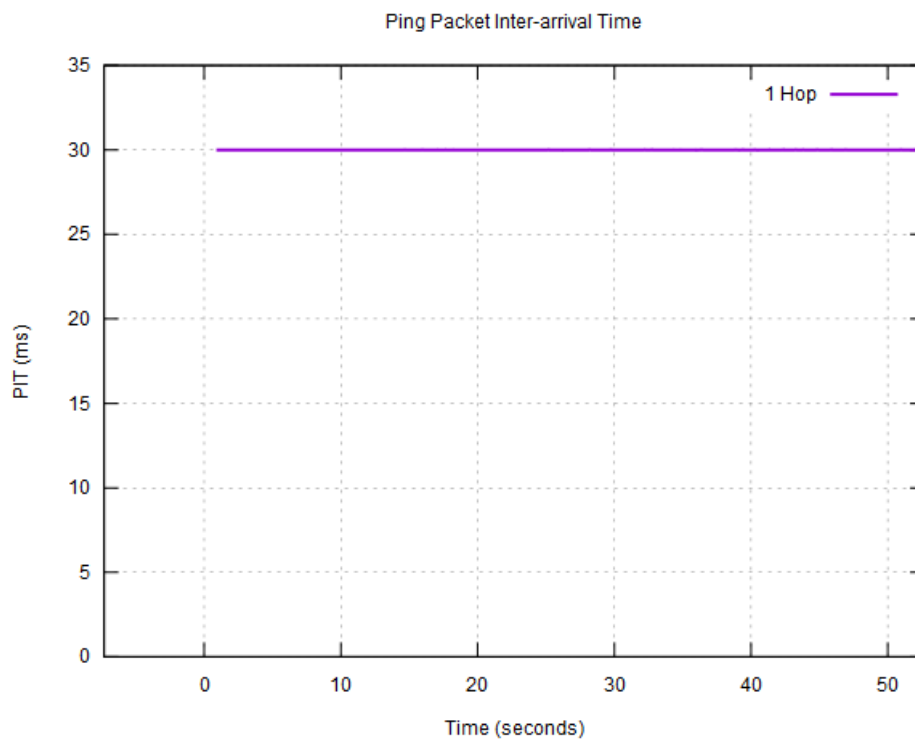


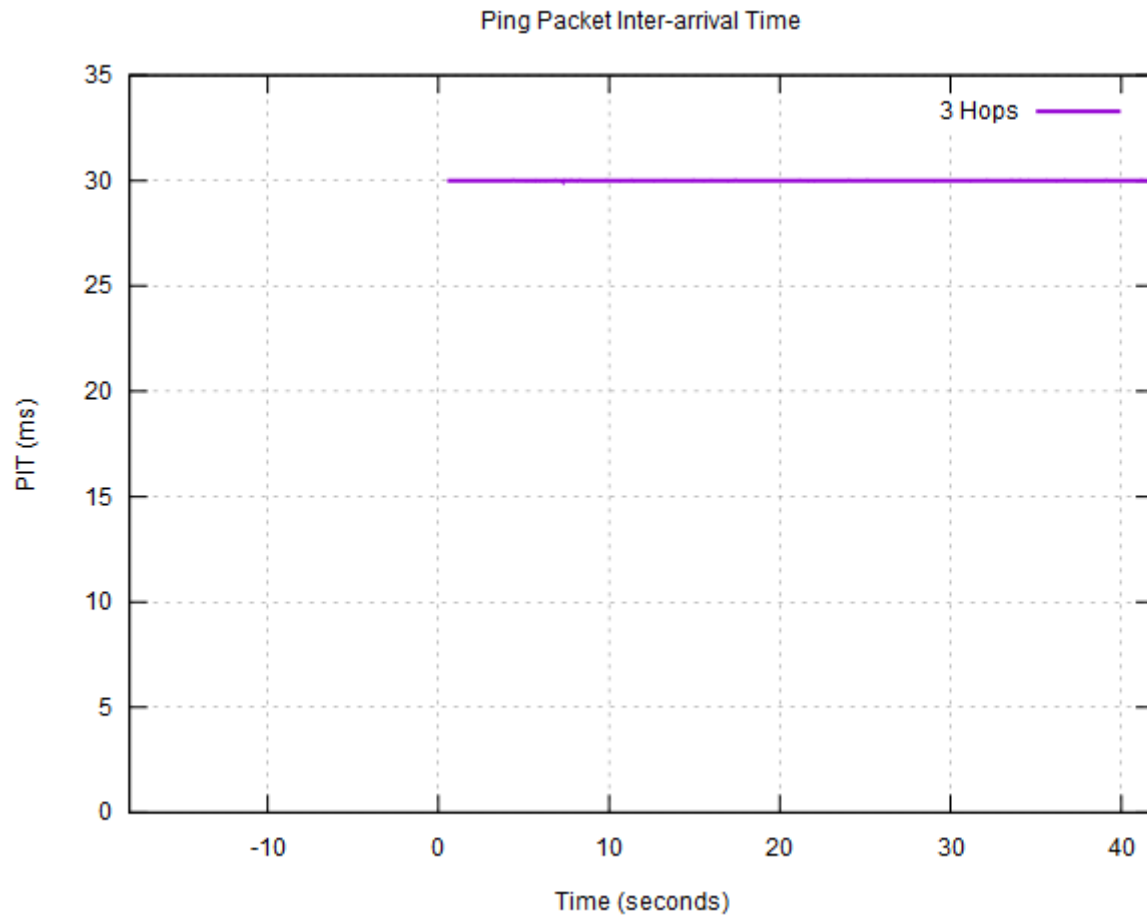
Figure 68. 1-hop flow

7.2.9.7.2 3-hops flow

Enable only the **3 Hops** flow on the LBT web page. This flow passes through the TAS of Board 1, Board 2, and Board 3.

Expected behavior: You can observe the same 30 ms PIT, despite having added two extra hops in the TSN network as shown in the following figure.

Figure 69. 3-hops flow



7.2.9.7.3 1-hop with background traffic

Enable the following flows on the LBT web page:

- Flow 1 (iPerf)
- Flow 2 (iPerf)
- 1 Hop (Ping)

Expected behavior: The ping traffic is protected by TSN switch 1 from interference with the iPerf and retains a packet inter-arrival time of 30 ms at Board 2. This is shown in the following figure.

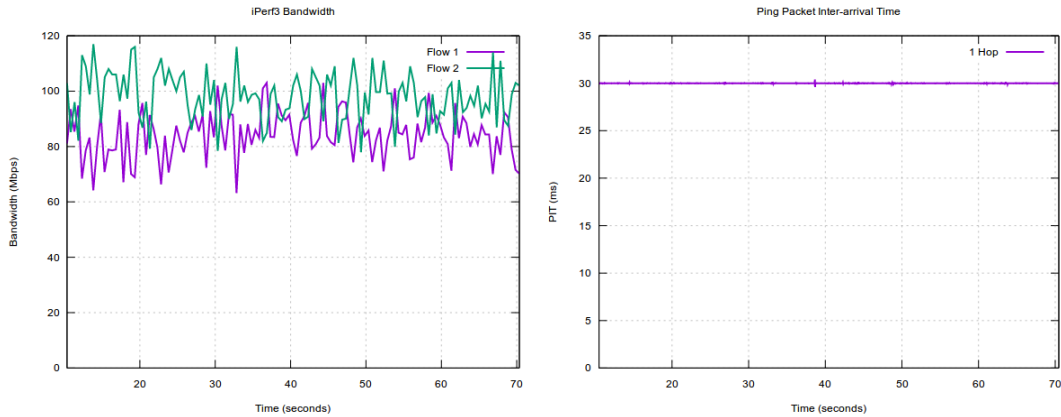


Figure 70. 1-hop ping with background traffic

7.2.9.7.4 3 Hops with background traffic

Enable the following flows on the LBT web page:

- Flow 1 (iPerf)
- Flow 2 (iPerf)
- 3 Hops (Ping)

Expected behavior: the ping traffic is protected by TSN switch 1 from interference with the iPerf and retains a packet inter-arrival time of 30 ms at Board 2.

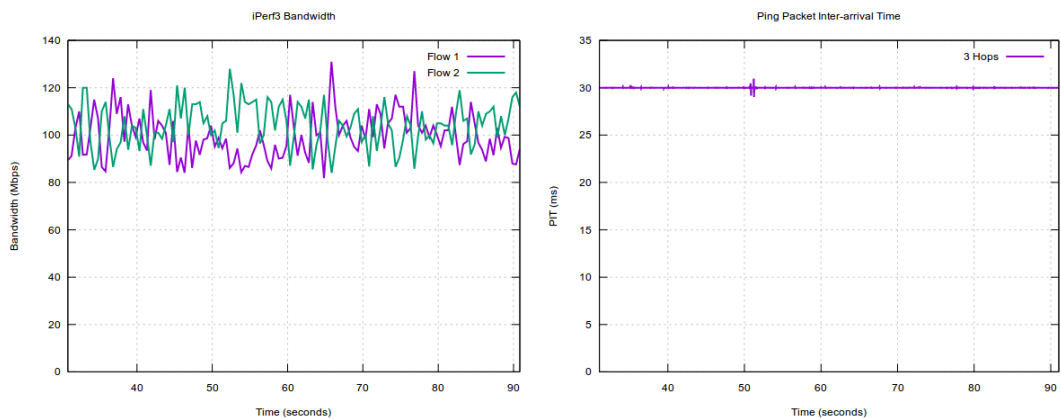


Figure 71. 3-hop ping with background traffic

7.2.10 NETCONF usage

Examples are provided only for Board 1 (IP 192.168.15.1). You need to repeat all steps described in this section for Board 2 and Board 3.

7.2.10.1 sja1105 YANG models

Following are the register tables in the sja1105 YANG model:

"schedule-table",

"schedule-entry-points-table",

```

"vl-lookup-table",
"vl-policing-table",
"vl-forwarding-table",
"I2-address-lookup-table",
"I2-policing-table",
"vlan-lookup-table",
"I2-forwarding-table",
"mac-configuration-table",
"schedule-parameters-table",
"schedule-entry-points-parameters-table",
"vl-forwarding-parameters-table",
"I2-address-lookup-parameters-table",
"I2-forwarding-parameters-table",
"clock-synchronization-parameters-table",
"avb-parameters-table",
"general-parameters-table",
"retagging-table",
"xmii-mode-parameters-table",

```

Each table owns its own registers list. The sja1105 YANG model tries to add all the table entry elements as 'leaves'.

For the YANG model of sja1105, click [here](https://github.com/openil/openil/blob/master/package/yang-sja1105/sja1105/sja1105.yang) (<https://github.com/openil/openil/blob/master/package/yang-sja1105/sja1105/sja1105.yang>).

7.2.10.2 Creating a NETCONF session

Create three connections open to all three boards, each in a separate window using the following set of commands.

```

[ubuntu] $ netopeer-cli
netconf> connect --port 830 --login root 192.168.15.<board{1|2|3}-ip>
netconf> # press Enter for no password
# You may need to run this, in case you are using the candidate
# datastore (here we are not) and it becomes locked.
# See 5.6.5.
# netconf> discard-changes

```

7.2.10.3 Applying the configuration over NETCONF

For applying the configuration over NETCONF, repeat the following commands for board1, board2, and board3:

```

# Apply qbv-ptp-board1.xml to the running datastore
# Configuration takes effect immediately
netconf> edit-config --config qbv-ptp-board1.xml running
# Inspect the running datastore
netconf> get-config running

```

7.2.10.4 Running a configuration at startup

Repeat the following commands for Board1, Board2, and Board3:

```
netconf> copy-config --source running startup
```

7.2.10.5 Loading an existing XML configuration into the NETCONF datastore

After running the synchronized Qbv demo steps, on each board there should be a configuration file named `/root/qbv-ptp-board{1,2,3}.xml`.

The NETCONF server running on the board can be instructed to load it into its datastore:

```
netconf> user-rpc
```

```
<!--#
```

Type the content of a RPC operation.

```
-->
```

```
netconf> user-rpc
<!--#
  Type the content of a RPC operation.
-->
<load-local-config xmlns="http://nxp.com/ns/yang/tsn/sja1105">
  <configfile>
    board1-qbv-sync.xml
  </configfile>
</load-local-config>
```

Running the preceding command also applies the configuration.

7.2.10.6 Transferring the SJA1105 configuration to Ubuntu

It is also possible to retrieve and inspect the configuration from the board using NETCONF and netopeer-cli commands:

```
netconf> get-config running --out qbv-ptp-board1-retrieved.xml
```

After successful completion of this operation, a new file named `qbv-ptp-board1-retrieved.xml`, is created in the current working directory on Ubuntu, with the current contents of the datastore of the netopeer-server that we are connected to. Assuming you followed along over step 0, this should match exactly the content of `qbv-ptp-board1.xml` on Board 1.

Proceed and transfer the contents of all XML configurations to the Ubuntu PC.

At the end of this step, the current working directory should have the following files:

- `qbv-ptp-board1.xml`
- `qbv-ptp-board2.xml`
- `qbv-ptp-board3.xml`
- `qbv-ptp-board1-retrieved.xml`
- `qbv-ptp-board2-retrieved.xml`
- `qbv-ptp-board3-retrieved.xml`

7.2.10.7 Viewing port statistics counters

The NETCONF protocol (and YANG data models) make a clear distinction between configuration data and state data. SJA1105 port counters are an example of state data exported by the yang-sja1105 netopeer module. These can be very useful for debugging or investigating the traffic remotely.

```
# Get all configuration + state data
# get-config, by contrast, shows just configuration data
netconf> get
# Get just the port counters
netconf> get --filter
<sja1105>
  <ports/>
</sja1105>
```

7.2.10.8 Ending the NETCONF session

Use the following command to end the NETCONF session:

```
netconf> disconnect
```

Chapter 8

4G-LTE Modem

8.1 Introduction

4G-LTE USB modem functionality is supported on NXP's LS1021-IoT, LS1012ARDB, LS1043ARDB, LS1046ARDB, and LS1028ARDB platforms.

8.2 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).

8.3 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](#).

8.4 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 9

OTA implementation

NXP's LS1021-IoT, LS1012ARDB, LS1043ARDB, LS1046ARDB, and LS1028ARDB platforms support OTA (Over-the-air) requirements. This section provides an introduction to OTA use cases, scripts, configuration settings for implementation and server preparation, and a test case. It also lists the OTA features supported by each hardware platform.

9.1 Introduction

OTA refers to a method of updating U-Boot, kernel, file system, and even the full firmware to devices through the network. If the updated firmware does not work, the device can rollback the firmware to the latest version automatically.

NOTE

While updating U-Boot, there is no hardware method to rollback the device automatically, hence the device might not be rolled back, once the U-Boot is not working.

- **version.json:** This is a JSON file which saves the board name and version of each firmware. Below is an example of version.json.

```
{
  "updatePart": "kernel", /* Name of firmware image which has been updated. */
  "updateVersion": "1.0", /* Version of firmware image which has been updated. */
  "all": "1.0", /* version of the full firmware image which has been used now */
  "u-boot": "1.0", /* version of the u-boot image which has been used now */
  "kernel": "1.0", /* version of the kernel image which has been used now */
  "filesystem": "1.0", /* version of the filesystem image which has been used now */
  "boardname": "ls1021aiot" /* used to get the corresponding firmware from server */
  "URL": "https://www.nxp.com/lgfiles/iioT" /* used to get the corresponding firmware from server */
}
```

- **update.json:** This file is stored in server, it saves the name and version of firmware image which will be updated. Below is a sample update.json file:

```
{
  "updateStatus": "yes", /* set yes or no to tell devices is it need to update. */
  "updatePart": "kernel", /* name of update firmware. */
  "updateVersion": "1.0", /* version of update firmware */
}
```

- **ota-update:** This script can get a JSON file named update.json from server, then parse the file and get the new firmware version to confirm whether to download it from server or not. It finally writes the firmware into the SD card instead of the old one. After that, save the "updatePart" and "updateVersion" into version.json, and mark the update status on 4080 block of SD card to let U-Boot know it.
- **ota-versioncheck:** This script checks if the firmware has been updated, then updates the version of the update part in version.json, and cleans the flag of update status on 4080 block of SD card. This script runs automatically each time the system restarts.
- **ota-rollback:** This script runs on the ramdisk filesystem after the filesystem update fails. It gets the old firmware version from the version.json file and then updates it from the server.

9.2 Platform support for OTA demo

The OTA demo is supported by four NXP hardware platforms. Following is the list of features supported by each platform:

1. LS1021A-IoT

- Full SD card firmware update
- U-Boot image update kernel image update
- File system image update
- Full SD card firmware update

2. LS1012ARDB

- Full SD card firmware update
- RCW and U-Boot image update on QSPI flash
- Kernel image update and rollback
- File system image update and rollback

3. LS1043ARDB

- Full SD card firmware update
- U-Boot image update
- Kernel image update and rollback
- File system image update and rollback

4. LS1046ARDB

- Full SD card firmware update
- U-Boot image update
- Kernel image update and rollback
- File system image update and rollback

9.3 Server requirements

This demo provides a sample server to update images for the v1.0 release. In case you want to use another server, you need to change the URL to your own server path at "target/linux/layercape/image/backup/version.json" such as the following:

```
"URL": "https://www.nxp.com/lgfiles/iioT/"
```

The server must include a JSON file named `update.json` that can send information to device boards. Below is a sample `update.json` file.

```
{
  /* set yes or no to tell devices is it need to update. */
  "updateStatus": "yes",

  /* which part to update, you can write "all", "u-boot", "kernel", "filesystem" */
  "updatePart": "filesystem",

  /* version of update firmware */
}
```

```
    "updateVersion": "1.0",
  }
```

Images for OTA are stored in the path:

`<updateVersion>/<boardname>/`

where the `<boardname>` can be one of these: `ls1021aiot`, `ls1012ardb-64b`, `ls1012ardb-32b`, `ls1043ardb-64b`, `ls1043ardb-32b`, `ls1046ardb-64b`, or `ls1046ardb-32b`.

Images must be named as following:

- `u-boot.bin`: U-Boot image for update. In `ls1012ardb` folder, this image includes RCW and U-Boot.
- `uImage`: kernel image for update
- `rootfs.ext4`: filesystem image for update
- `firmware_sdcard.bin`: a full firmware of SD card image.

9.4 OTA test case

1. Plug network cable into Eth1 on the board. This enables the network after the system is running.
2. Update U-Boot using the following steps:
 - Update the `.json` on server as shown in the following example:

```
{
    "updateStatus": "yes",
    "updatePart": "u-boot",
    "updateVersion": "1.0",
}
```

- Upload the `u-boot` image on server path: `1.0/<boardname>/u-boot.bin`
 - Run `ota-update` command on device board.
3. Updating the file system:
 - Set the `"updatePart"` to `"filesystem"` in `update.json`.
 - Upload the filesystem image on server path: `1.0/<boardname>/rootfs.ext4`
 - Run `ota-update` command on the device board.
 4. Updating full firmware
 - Set the `"updatePart"` to `"all"` in `update.json`.
 - Upload the full firmware image on server path: `1.0/<boardname>/firmware_sdcard.bin`
 - Run `ota-update` command on device board.
 5. Rollback test:
 - The Kernel and file system can use a wrong image to upload on the server and test update on device.

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 μs , 100 slaves: 100 μs .
- 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.

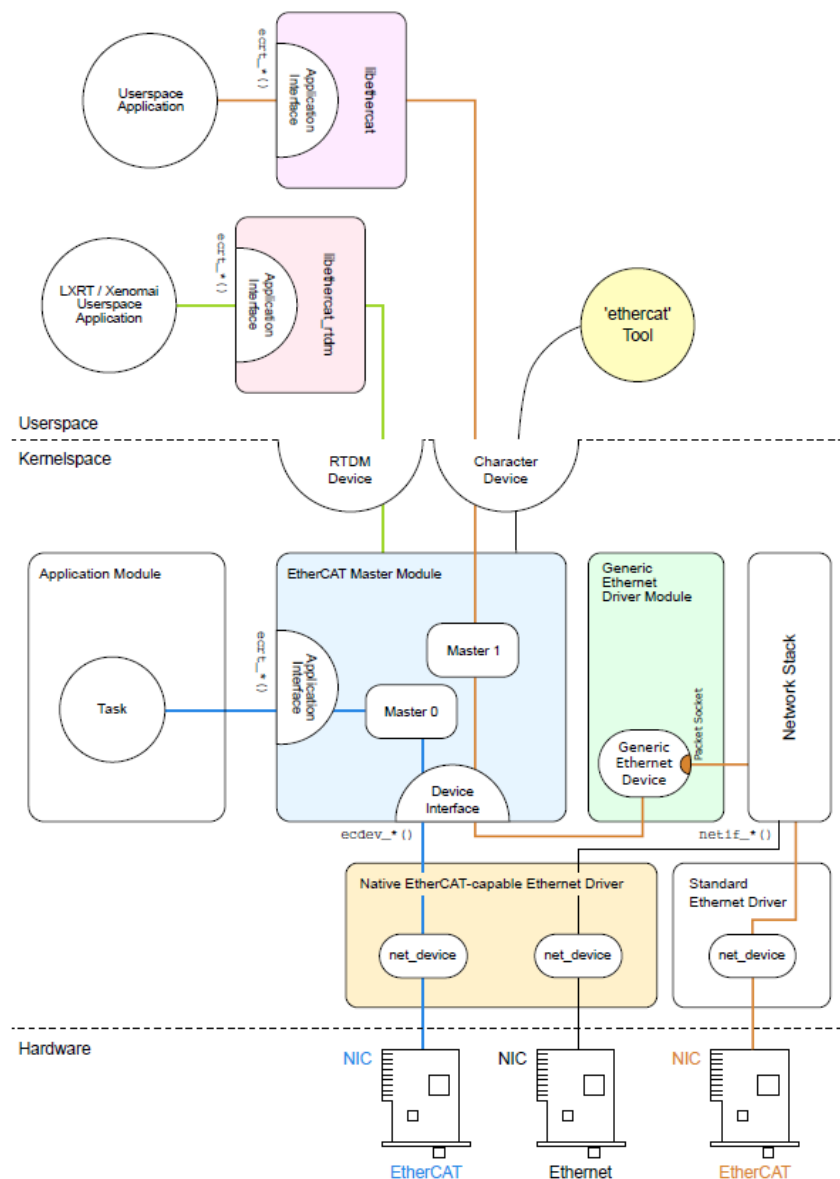


Figure 72. IGH EtherCAT master architecture

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.

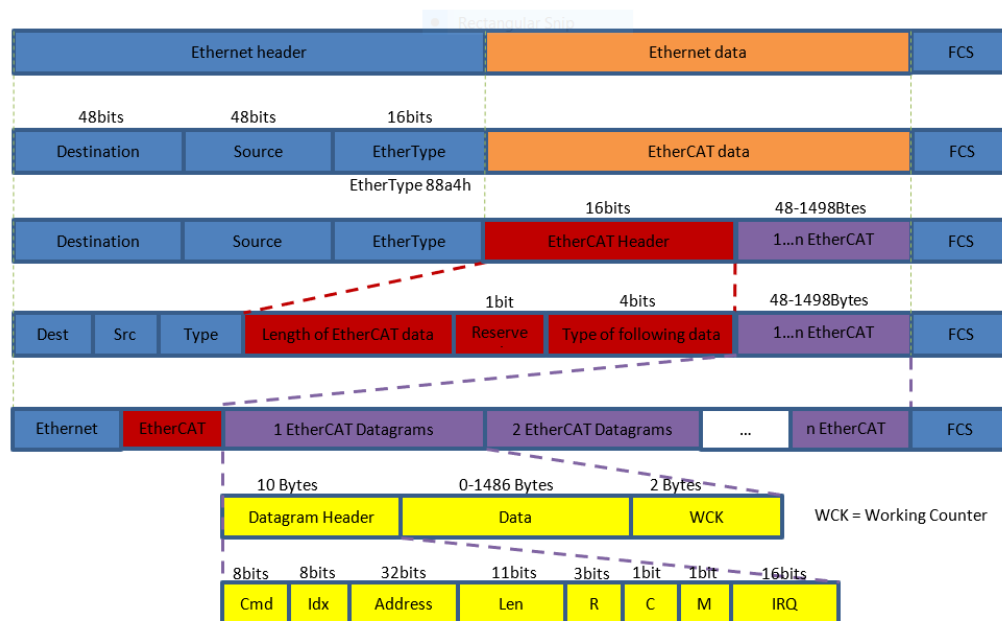


Figure 73. EtherCAT frame structure

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_optee_defconfig
- nxp_ls1021aiot_optee_ubuntu_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 41. 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.

Table continues on the next page...

Table 41. Command line tools for EtherCAT (continued)

ethercat master [OPTIONS]	Shows master and Ethernet device information.	Options: -- master -m <indices > Master indices. A comma - separated list with ranges is supported. Example: 1 ,4 ,5 ,7 -9. Default: - (all).	<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 [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>
------------------------------	---	--	--

Table continues on the next page...

Table 41. Command line tools for EtherCAT (continued)

ethercat states [OPTIONS] <STATE >	Requests application - layer states	STATE can be 'INIT ', 'PREOP ', 'BOOT ', 'SAFEOP ', or 'OP '. Options: <ul style="list-style-type: none"> • --alias -a <alias > • -- position -p <pos > Slave selection. See the help of the 'slaves' command. 	None
---	---	--	------

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
- 42-stepping motor and stepper motor driver

The figures below show the required materials:

- The figure below shows the board and BECKHOFF connected by a wire.

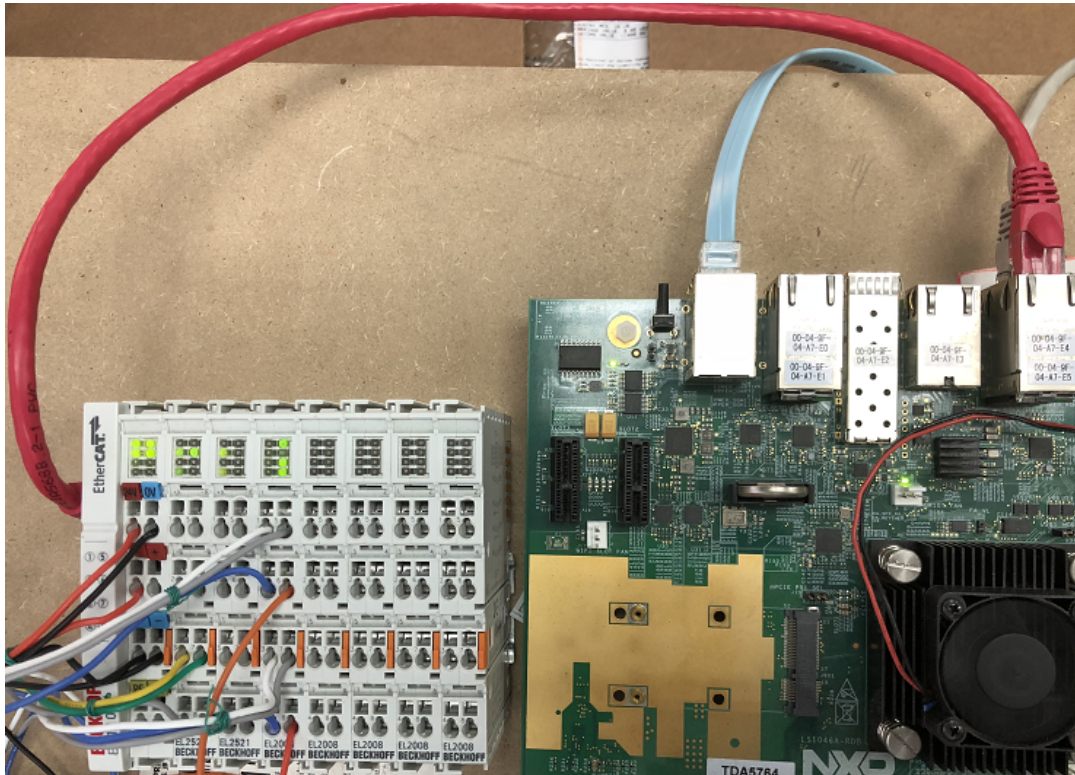


Figure 74. Board connects with BECKHOFF

- The figure below shows the BECKHOFF's EK1100 and EL2008.

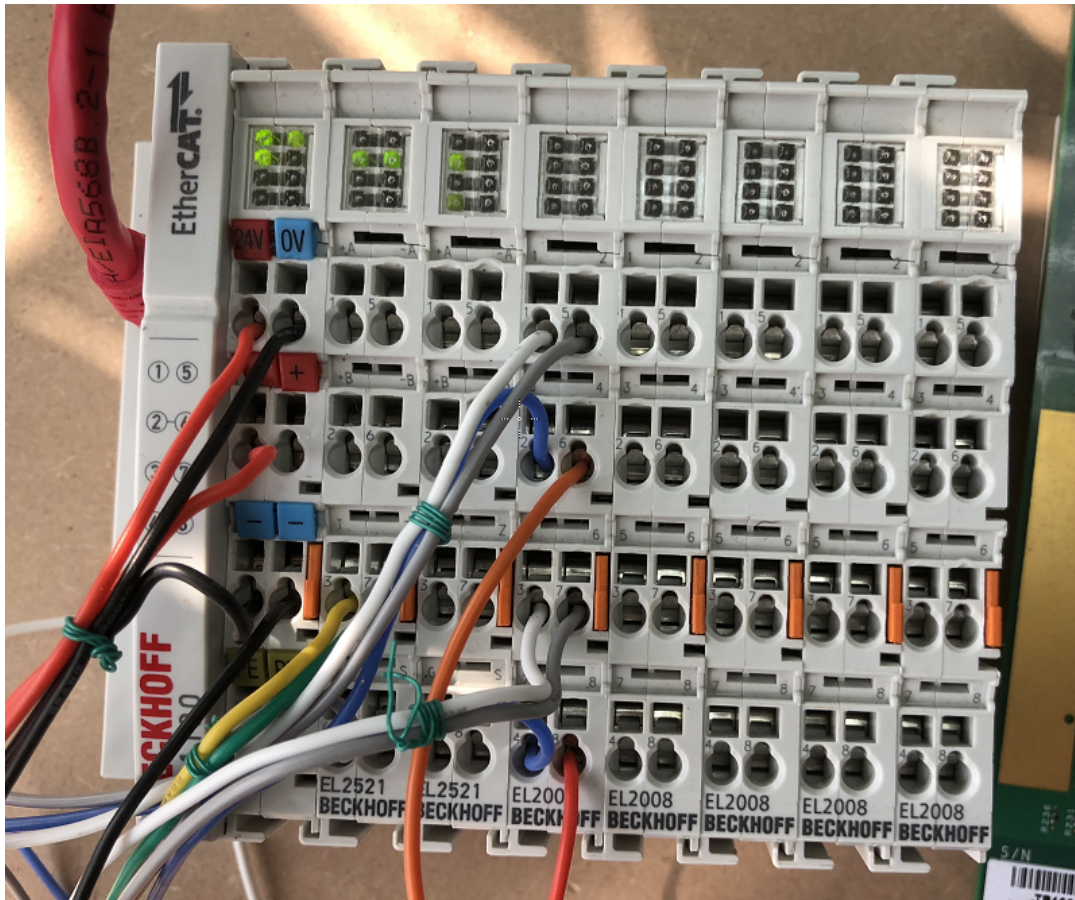


Figure 75. BECKHOFF EL2008

- The figure below shows a stepper motor driver.

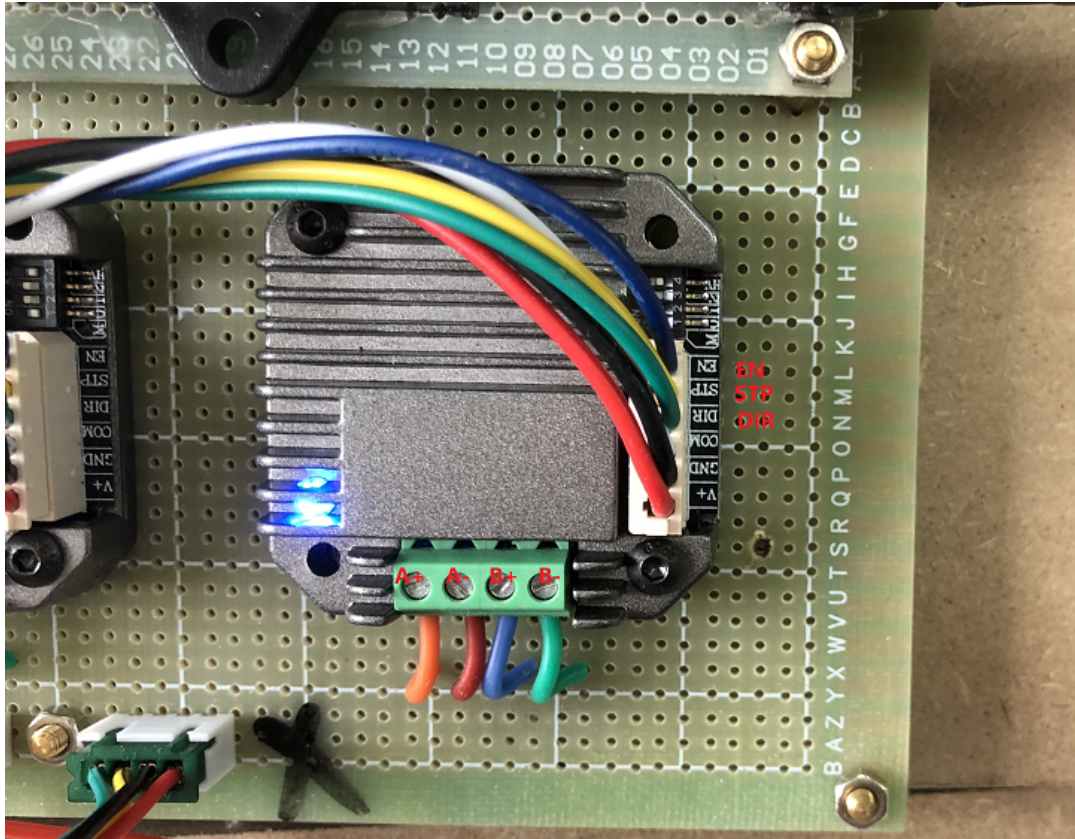


Figure 76. Stepper motor driver

The stepper motor needs to be connected to the EL2008 with a driver.

EL2008 needs connections to the EN, STP, and DIR pins of the stepping motor drive.

- The figure below shows a 42-stepper motor. Note the manner in which the stepper motor is connected to the driver:
 - A is connected to A.
 - B is connected to B.

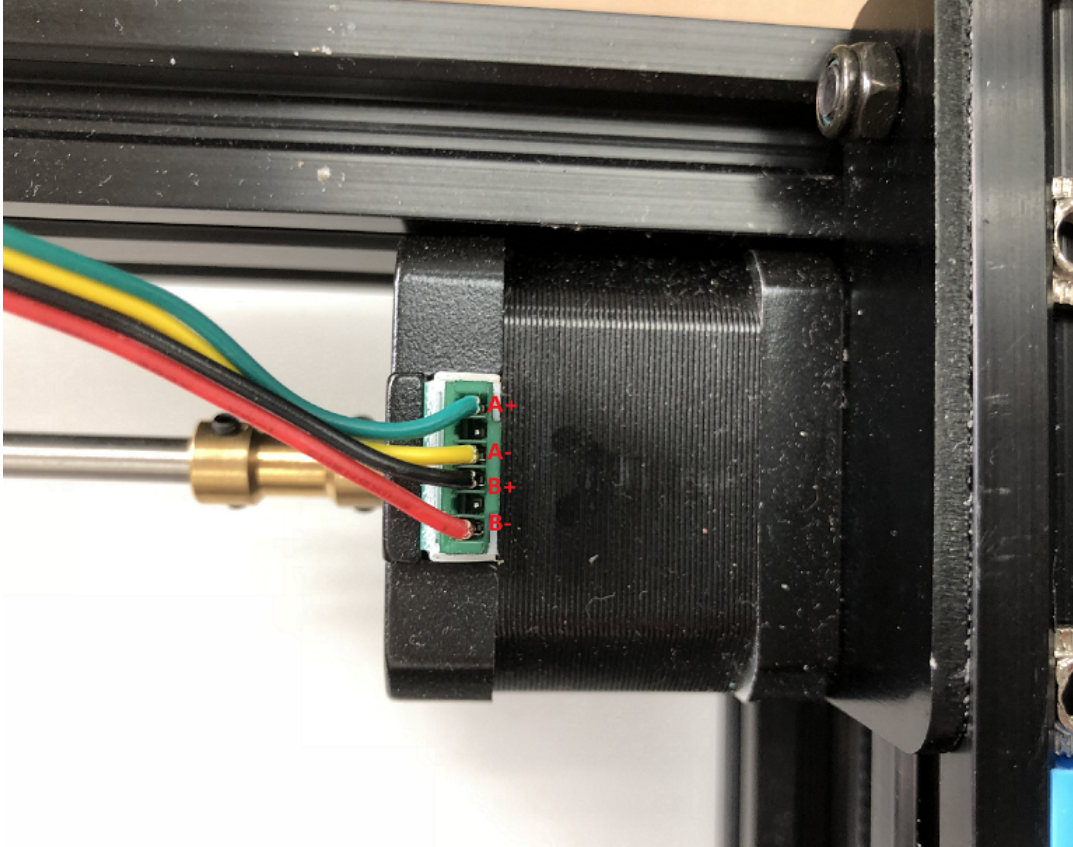


Figure 77. Stepper motor

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"
```

2. Execute the initialization script and specify the parameter `start`.

```
$ /etc/init.d/ethercat restart
```

3. 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
```

ATTENTION

If the console prompts `Failed to open /dev/EtherCAT0`, the module fails to load, please check it.

Chapter 11

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.

11.1 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.

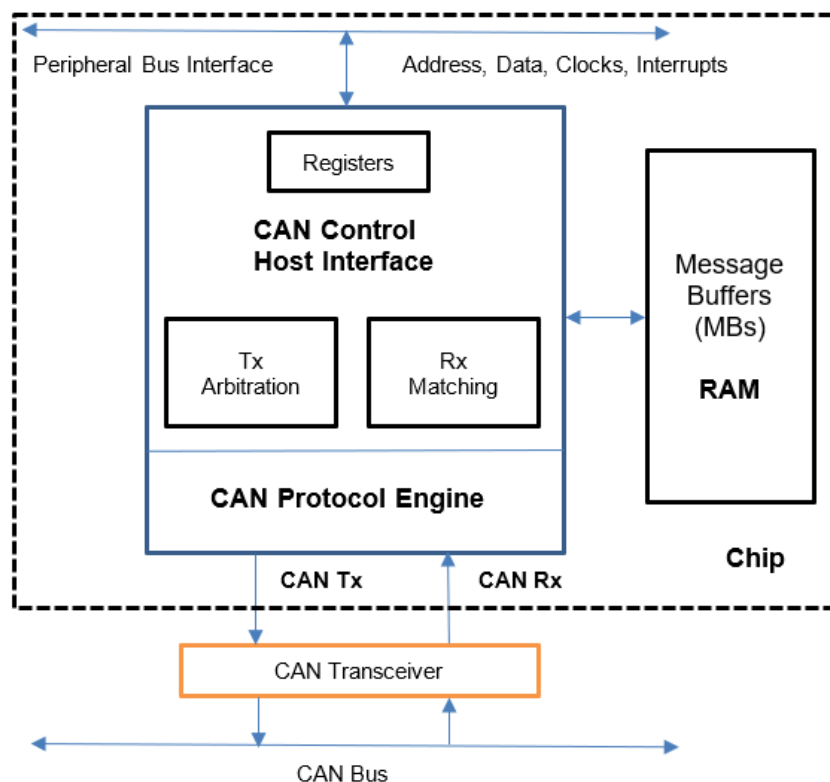


Figure 78. FlexCAN block diagram

11.1.1 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.

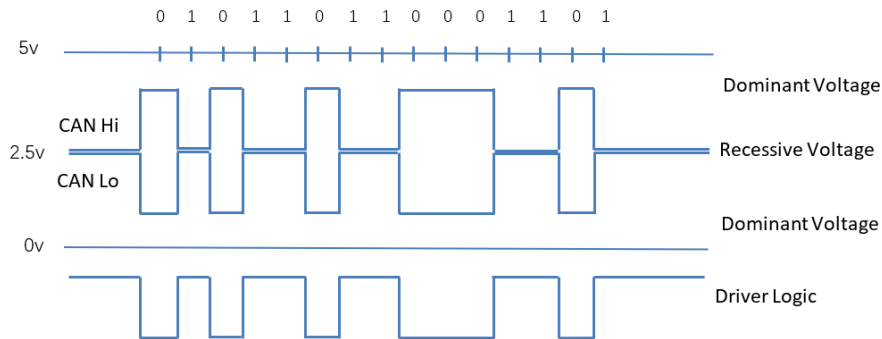


Figure 79. High speed CAN signaling

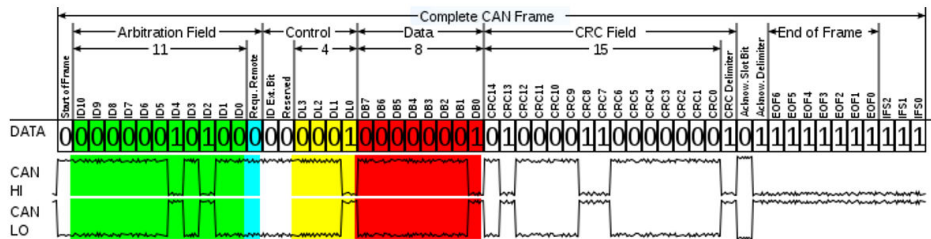


Figure 80. Base frame format

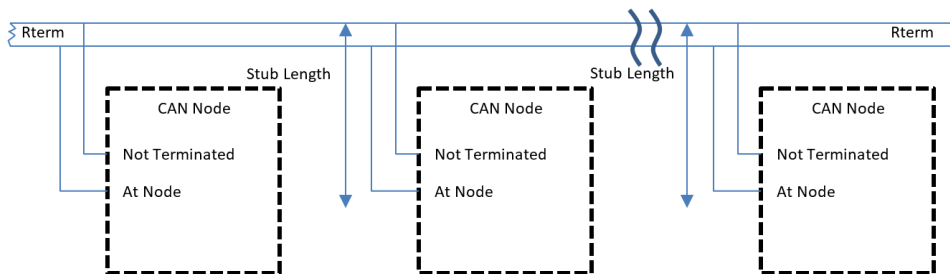


Figure 81. High speed CAN network

11.1.2 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.

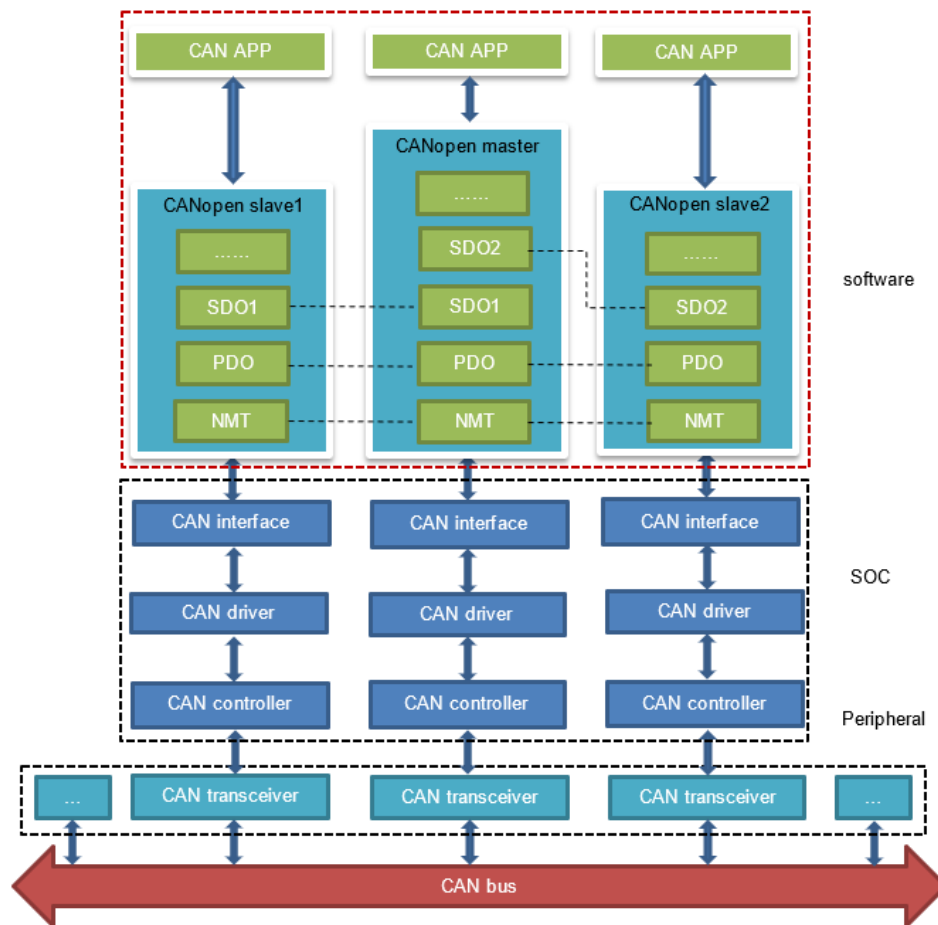


Figure 82. CANopen architecture

11.2 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.

11.2.1 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, you 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

```

11.2.2 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 42. 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

Table continues on the next page...

Table 42. CAN Net APIs and their description (continued)

API name (type)	Description
UNS8 readNetworkDictCallback (CO_Data* d, UNS8 nodeId, UNS16 index, UNS8 subIndex, UNS8 dataType, SDOCallback_t Callback, UNS8 useBlockMode)	<p>The master node gets the specified data from the slave node.</p> <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 • 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)	<p>The master node sets the specified data to the slave node.</p> <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

11.3 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](#) on page 179, [Running the CANopen application](#) on page 180, and [Running the Socketcan commands](#) on page 183 are applicable to both LS1021A-IoT and LS1028A platforms.

11.3.1 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)

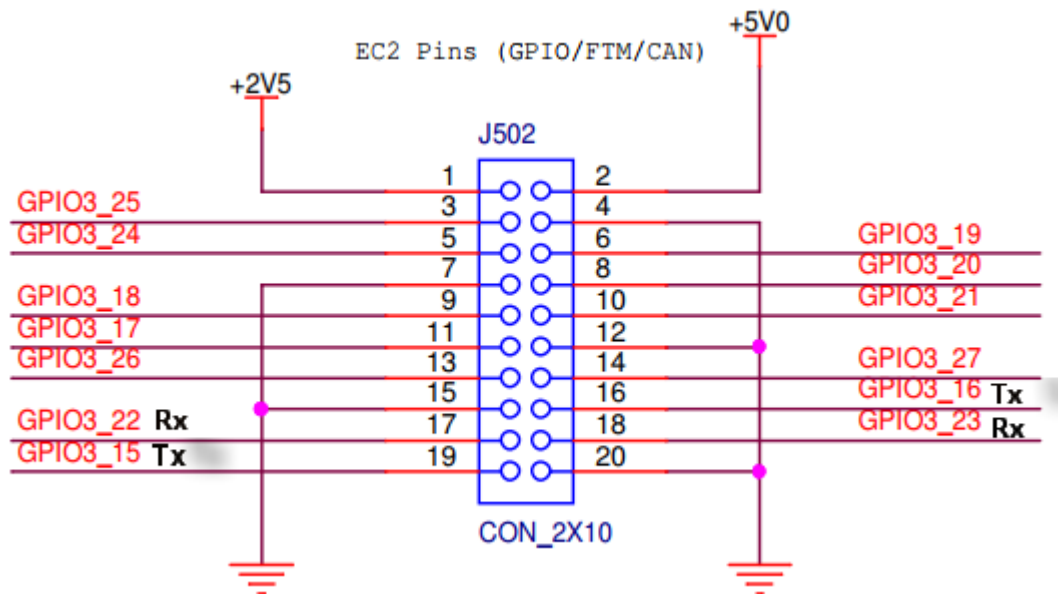
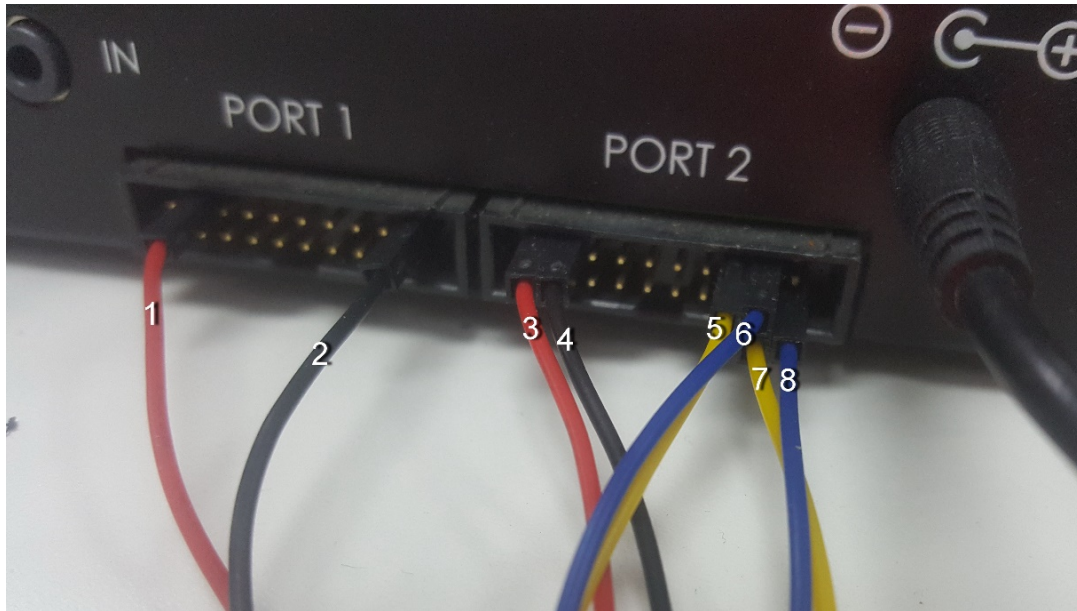


Figure 83. Hardware diagram for the FlexCan demo

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.

11.3.2 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 84. Physical connection for CAN using LS1028ARDB

11.3.3 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 your 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_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.

11.3.4 Running the CANopen application

This section describes the procedure for running the CANopen-app application, which is the same for both LS1021A and LS1028A platforms.

1. First, boot the LS1021A-IoT or LS1028ARDB board.
2. Then, run the `CANopen-app` command in any directory in Linux prompt. While executing this command, first run the test code.
3. After the test code is completed, you 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 codes 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 codes. 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 codes.

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.
----- test -----
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: You 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
```

11.3.5 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.

11.3.6 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 12

NFC click board

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

12.1 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 1.0 host protocols (NCI stands for NFC controller interface). RST and INT pins provide additional functionality. The board uses a 3.3V power supply.

12.2 PN7120 features

PN7120 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.

12.3 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

You need to insert the NFC click board into the LS1028ardb mikroBUS1 slot.

12.4 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 --->
    Libraries --->
        Hardware handling --->
            [*] libnfc-nci
```

2. In Linux kernel environment, make sure the below options are enabled:

```
$make linux-menuconfig
Device Drivers --->
    Misc devices --->
        <M> NXP PN5XX based driver
```

NOTE

The **NXP PN5XX based driver** only supports the Module mode.

3. Use the `make` command to create the images.

12.5 Testing the NFC click board

Use the following steps for testing the NFC Clickboard:

1. Install NFC driver module

```
[root@OpenIL:~]# insmod /lib/modules/4.14.47-ipipe/kernel/drivers/misc/nxp-pn5xx/pn5xx_i2c.ko
```

2. The following logs appear 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
```

3. 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...
```

4. 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...
```

Printing the above information indicates successful card reading.

Chapter 13

BLE click board

This chapter introduces the features of the BLE P click board and how to use it on NXP's LS1028A reference design board (RDB)

13.1 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 μ A
- 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

13.2 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)

13.3 Software preparation

Use these steps for the BLE Pclickboard demo software setup:

- Download the JUMA UART (Android app) by using the link: <https://apkpure.com/juma-uart/com.juma.UART>
- Then, run the below steps 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
  Libraries --->
    Hardware handling --->
      [*] 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.

13.4 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, you can scan for BLE P click board from your mobile phone or your 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. You 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. You 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 14

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.

14.1 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.

14.2 Software settings and configuration

Use the following steps to configure QT5 on target board and build the images.

1. **Configure the target board:** There are two configuration files used for LS1028ARDB board: `nxp_ls1028ardb-64b_defconfig` and `nxp_ls1028ardb-64b_ubuntu_defconfig`. Use one of them:

```
make nxp_ls1028ardb-64b_defconfig
```

or

```
make nxp_ls1028ardb-64b_ubuntu_defconfig
```

2. **Configure QT5:** Use the command `make menuconfig` to configure the QT5:

```
Target packages ->
Graphic libraries and applications (graphic/text) ->
[*] Qt5 ->
    [*] Approve free license
    [*] Compile and install examples (with code)
    [*] concurrent module
    [*] MySQL Plugin
    [*] PostgreSQL Plugin
    [*] gui module
    [*] widgets module
    [*] fontconfig support
    [*] GIF support
    [*] JPEG support
    [*] PNG support
    [*] DBus module
    [*] Enable ICU support
    [*] Enable Tslib support
    [*] qt5enginio
    [*] qt5imageformats
    [*] qt5location
    [*] qt5multimedia
    [*] qt5sensors
    [*] qt5serialbus
    [*] qt5svg
```

3. Build the images using the command:

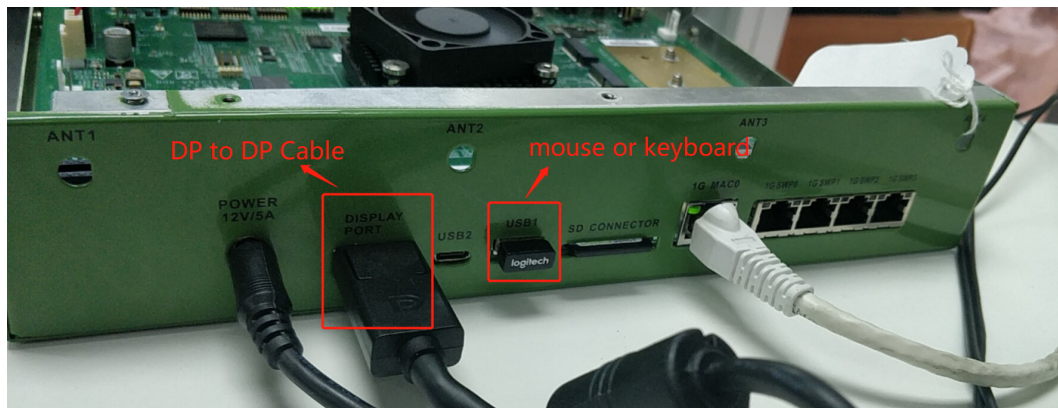
```
make -j8
```

14.3 Hardware setup

For the QT setup, you require the following hardware:

1. Monitor that supports DP interface
2. Cable matters DisplayPort to DisplayPort (DP to DP Cable)
3. USB wired/wireless mouse or keyboard

Figure 85. Hardware setup for QT



14.4 Running the QT5 demo

This section describes the steps for configuring the environment and running the Qt demos for LS1028ARDB.

14.4.1 Environment setting

Use the steps listed below to configure the environment settings:

1. For `nxp_ls1028ardb-64b_defconfig` configuration
 - Make sure that the `fonts` directory exists in the `/usr/share/` directory. If it does not exist, you can find it 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:~]#

```

2. For nxp_ls1028ardb-64b_ubuntu_defconfig configuration

- Replace /lib/aarch64-linux-gnu/libz.so.1 with the following commands:

```

rm /lib/aarch64-linux-gnu/libz.so.1
ln -s -f /usr/lib/libz.so.1.2.11 /lib/aarch64-linux-gnu/libz.so.1

```

- Make sure that the fonts directory exists in the /usr/lib/ directory. If it does not exist, you can find it in the root directory and copy one or more to /usr/lib/ using the following commands:

```

cd /
find ./ -name fonts
cp -r /usr/lib/qt/examples/quick/text/fonts/content/fonts /usr/lib

```

```

root@OpenIL-Ubuntu:~# cd /
root@OpenIL-Ubuntu:~# find ./ -name 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/lib/qt/examples/quickcontrols2/swipetoremove/fonts
./usr/lib/qt/examples/quickcontrols2/texteditor/fonts
./usr/share/fonts
./usr/libnIL-Ubuntu:~# cp -r /usr/lib/qt/examples/quick/text/fonts/content/fonts
root@OpenIL-Ubuntu:~#

```

The QT5 framework is configured now, and user can add any applications.

14.4.2 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:** /usr/lib/qt/examples/widgets/widgets/wiggly/wiggly --platform linuxfb

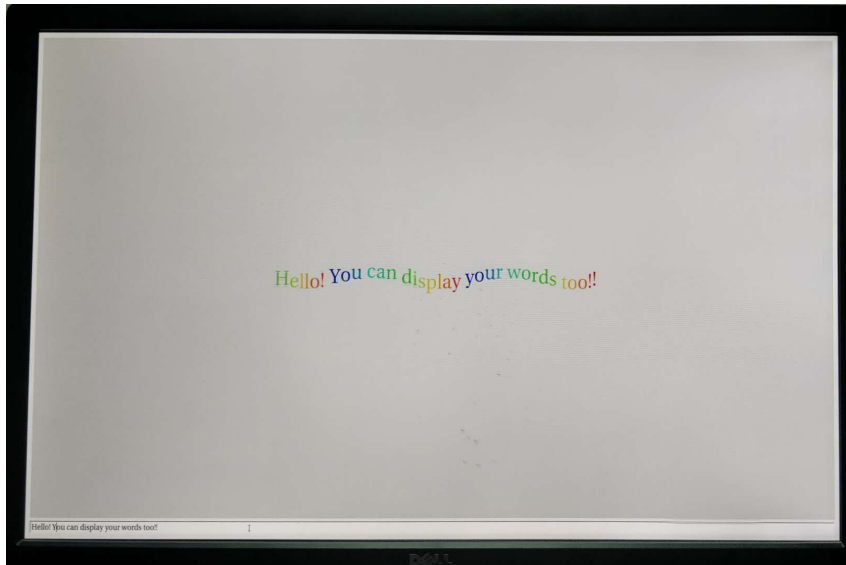


Figure 86. Example 1: Wiggly text

2. **Example 2:** `/usr/lib/qt/examples/quick/demos/calqlatr/calqlatr -- platform linuxfb`

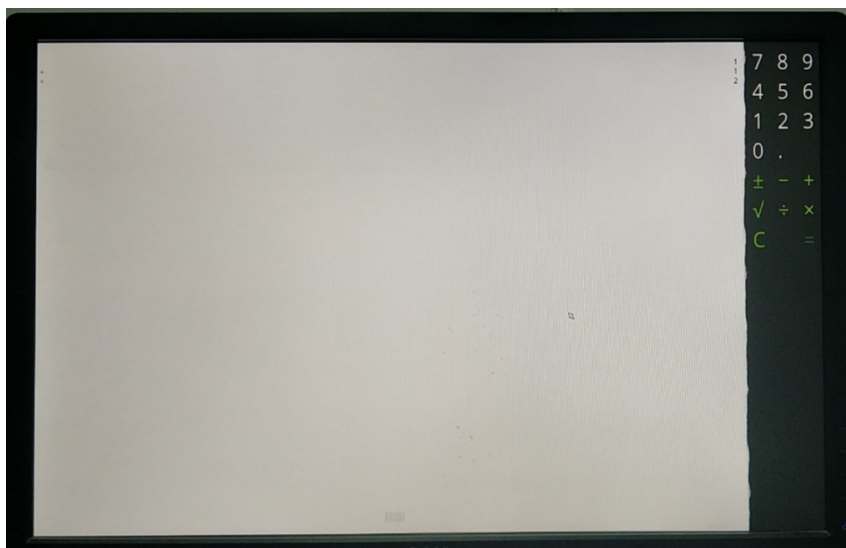


Figure 87. Example 2: Calculator

3. **Example 3:** `/usr/lib/qt/examples/quick/demos/clocks/clocks --platform linuxfb`



Figure 88. Example 3: Clocks

4. **Example 4:** `/usr/lib/qt/examples/gui/analogclock/analogclock --platform linuxfb`



Figure 89. Example 4: Analog clock

Chapter 15

EdgeScale client

This chapter describes edgescale, its features and the procedure to use Edgescale on NXP supported hardware platforms.

15.1 What is EdgeScale

EdgeScale is a unified, scalable, and secure device management solution for Edge Computing applications. It enables OEMs and developers to leverage cloud compute frameworks like AWS Greengrass, Azure IoT and Aliyun on Layerscape devices. It provides the missing piece of device security and management needed for customers to securely deploy and manage a large number of Edge computing devices from the cloud. End-users and developers can use the EdgeScale cloud dashboard to securely enroll Edge devices, monitor their health, attest and deploy container applications and firmware updates.

EdgeScale can also be used as a development environment to build containers and generate firmware.

15.2 Edgescale features

Following are the features supported by Edgescale:

- EdgeScale dashboard for users
- Secure device enrolment
- Secure key/certificate provisioning
- OTA: firmware update (LS1012A, LS1043, LS1046, or LS1028)
- Device status monitoring on the cloud
- Dynamic deployment of container-based applications
- The above specified features are currently supported in LSDK. For more details, please visit: [EDGESCALE: EdgeScale for Secure Edge Computing](#)

15.3 Building EdgeScale client

To Build the EdgeScale client in OpenIL for LS1043A, LS1046A and LS1028A, follow the configuration below:

```
Make menuconfig
Target packages --->
Edge-scale service --->
[*] qorio edgescale eds
[*] qorio eds kubelet
[*] qorio eds bootstrap
```

15.4 Procedure to start EdgeScale

For complete details on how to start EdgeScale, visit the URL <https://doc.edgescale.org/>.

NOTE

Follow these steps after downloading the device identification info file (which is a script file):

1. Copy the script file to the DUT and run it using the command below:

```
sh xxxx.sh /dev/mmcblk0
```

2. Then, reboot the board.
3. Run the below command to start edgescale client in Linux prompt:

```
sh /usr/local/edgescale/bin/startup.sh
```

Chapter 16

Known issues

The following table lists the known issues for Open Industrial Linux for this release.

Table 43. Known issues for this release

Item	Description
1	Need to define more relevant usage scenario for SAE AS6802 features (time-triggered, rate-constrained traffic). These are not used at the moment.
2	Sja1105-tool does not communicate with the BCM5464R PHY.

Chapter 17

Revision history

The table below summarizes revisions to this document.

Table 44. Document Revision History

Date	Document version	Topic cross- reference	Change description
01/05/2019	1.5	Interface naming on page 26	Added the section. Describes interface naming for U-Boot and Linux for LS1028ARDB.
		Using TSN features on LS1028ARDB on page 81	Updated this section in the Chapter "TSN Demo".
		BLE click board on page 188	Added the Chapter.
		EdgeScale client on page 197	Added the Chapter.
		Getting Open IL	Updated the OpenIL version and Git tag.
01/02/2019	1.4	Supported NXP platforms on page 12	Added support for LS1028ARDB (64-bit and Ubuntu). Updated various sections accordingly.
		Getting Open IL	Updated the OpenIL version and Git tag.
		LS1028ARDB on page 26	Added this Section for LS1028ARDB support.
		TSN on page 81	Reorganized this Chapter and added separate Section for Using TSN features on LS1028ARDB on page 81.
		NFC click board on page 185	Added the Chapter.
		FlexCAN on page 171	Minor updates in this Chapter. Also added the section, Hardware preparation for LS1028ARDB on page 178 and Testing CAN bus on page 183.
		QT on page 192	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 on page 48 and updated Basic setup . Updates in other sections.

Table continues on the next page...

Table 44. Document Revision History (continued)

Date	Document version	Topic cross- reference	Change description
31/05/2018	1.2	Hardware requirements on page 33	Updated the Section, "RTnet hardware requirements".
		Software requirements on page 34	Updated the Section, "RTnet software requirements".
18/04/2018	1.1.1	RTnet on page 33	Added the Section, "RTnet".
		Switch settings on page 22	Added a note for LS1043A switch setting.
30/03/2018	1.1	Supported industrial features on page 12	Added support for industrial IoT baremetal framework in this section.
		Booting up the board on page 16	Added a note for steps to be performed before booting up the board.
		Reference documentation on page 7	Added the section.
22/12/2017	1.0	OPC UA on page 74	Added the Chapter.
		TSN on page 81	Chapters for "1-board TSN demo" and "3-board TSN demo" replaced by a single chapter, "TSN demo".
		IEEE 1588 on page 37	<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/ .
		OTA implementation on page 156	OTA - Xenomai Cobalt 64-bit and SJA1105 support added.
		TSN on page 81	Qbv support added.
		SELinux on page 48	SELinux support for LS1043 / LS1046 Ubuntu Userland added.
		OP-TEE on page 43	OP-TEE support for LS1021ATSN platform added.
		4G-LTE Modem on page 154	4G LTE module - 64-bit support for LS1043ARDB, LS1046ARDB, and LS1012ARDB added.
		NXP OpenIL platforms on page 20	Ubuntu Userland support for 64-bit LS1043ARDB and 64-bit LS1046ARDB added.
26/05/2017	0.2	-	Initial public release.

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The logo for Arm, consisting of the word "arm" in a lowercase, blue, sans-serif font.