AN13995

TSN 802.1Qbv Demonstration using i.MX 8M Plus

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Document information

Information	Content
Keywords	AN13995, TSN 802.1Qbv, i.MX 8M Plus, i.MX 8M Mini, traffic scheduling, time-aware shaper, UDP iPerf, camera streaming
Abstract	This document demonstrates how TSN 802.1Qbv enhances traffic scheduling, using two NXP processors, i.MX 8M Plus and i.MX 8M Mini.

1 Introduction

TSN 802.1Qbv is an IEEE specification that allows to define transmission time slots for networking traffic queues. It adds enhancements to traffic scheduling with the introduction of time-aware shaper.

This document demonstrates how TSN 802.1Qbv enhances traffic scheduling, using two NXP processors, i.MX 8M Plus and i.MX 8M Mini.

1.1 Acronyms

Table 1 lists the acronyms used in this document.

Table 1. Acronyms

Acronym	Description
FPS	Frames per second
GCL	Gate Control List
GUI	Graphical user interface
HDMI	High-Definition Multimedia Interface
IP	Internet Protocol
Mbit/s	Megabits per second
PTP	Precision Time Protocol
TC	Traffic control
TSN	Time-sensitive networking
UDP	User Datagram Protocol
USB	Universal Serial Bus

2 Enhancements to traffic scheduling — Time-aware shaper

TSN 802.1Qbv adds the following enhancements to networking traffic scheduling:

- It separates communication on the Ethernet network into a fixed length, repeating time cycles; therefore, contributing to the delivery of time-critical traffic.
- Each traffic class has an open traffic window at a specified time for a particular talker to communicate with its listener.
- The path across the network is cleared for any high-priority traffic at real time (T), ensuring that the traffic from a talker is delivered reliably and with deterministic latency across the network.

3 Traffic used for demonstration

Table 2 describes the traffic used for demonstrating TSN 802.1Qbv.

Table 2. Traffic used for 802.1Qbv demo

Traffic type	Server	Client	Default port
UDP iPerf	i.MX 8M Mini	i.MX 8M Plus	5001
Camera streaming via GStreamer	i.MX 8M Plus	i.MX 8M Mini	5000

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4 Setup diagram

Figure 1 shows the setup diagram of the TSN Qbv demo.

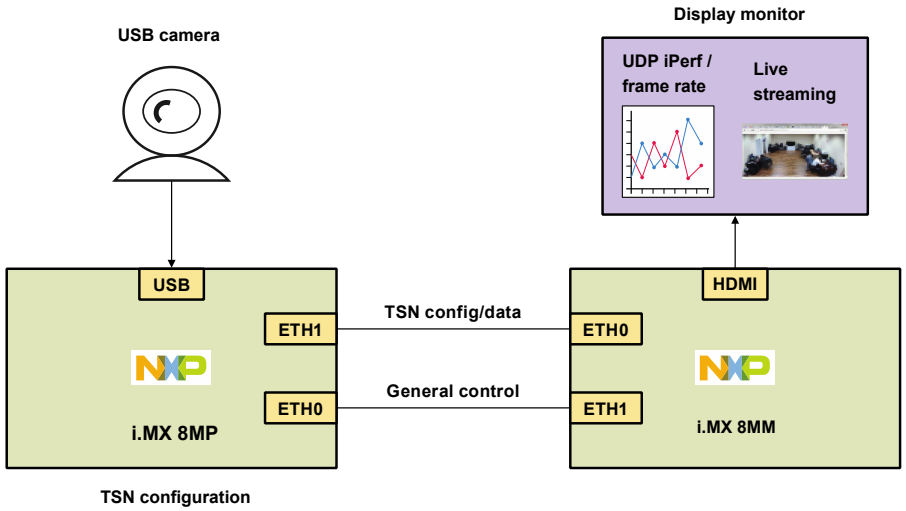

Figure 1. TSN Qbv demo setup diagram

TSN Qbv is demonstrated with USB camera generating time-sensitive traffic and iPerf generating best-effort traffic over Ethernet. These traffic types are passed in different queues at different priorities via the TSN port. On applying the Qbv configuration, the traffic is prioritized and scheduled as desired. The iPerf bandwidth, camera frame rate, and live camera streaming are displayed on the GUI of i.MX 8M Mini.

5 Software dependency

The TSN Qbv demo uses the following kernel modules:

- CONFIG_NET_ACT_SKBEDIT
- CONFIG_NET_CLS_U32
- CONFIG_NET_SCH_INGRESS
- CONFIG_NET_SCH_MULTIQ

The following application packages are needed:

- iPerf
- GStreamer
- OpenCV
- Python3-Matplotlib
- iproute2
- iproute2-tc
- Python3-packaging
- Python3-paramiko

The following programming languages are used:

- Shell script
- Python 3

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6 Demo-related files

Table 3 lists the files related to TSN Qbv demo.

Table 3. Demo-related files

File	Description
/home/root/.nxp-demo-experience/scripts/TSN/qbv/IP_plus.sh	This script assigns IP addresses to the i.MX 8M Plus board interfaces.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/IP_mini.sh	This script assigns IP addresses to the i.MX 8M Mini board interfaces.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/start_demo.py	This script assigns IP address to the i.MX 8M Mini board and executes the demo_qbv.py script.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/demo_qbv.py	This script opens demo login page where the user can select the video source and run the demo. Before opening the login page, the connections are checked at back-end.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/tsnqbv.py	This script establishes an SSH connection and executes the Qbv configurations and iPerf and camera scripts, regarding the i.MX 8M Plus and i.MX 8M Mini boards.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/tsn_config_graph.py	This script opens a graph window that allows the user to select a particular configuration from the GUI. After selection, it invokes the tsnqbv.py file with the chosen configuration.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/start_qbv_priority.sh	This script maps and prioritizes the queue.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/stop_qbv_priority.sh	This script reverts the prioritization applied on the queues.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/no_qbv.sh	This script removes all the Qbv policies.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/qbv1.sh	This Qbv configuration file gives priority to video traffic.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/qbv2.sh	This Qbv configuration file gives priority to iPerf traffic.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/camera_server.py	This script runs in the i.MX 8M Plus board via SSH to run server GStreamer command.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/camera_client.py	This script runs in the i.MX 8M Mini board to run client GStreamer, which is attached to the OpenCV window.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/kill_server_process.sh	This script runs in the i.MX 8M Plus board to kill all the processes and files, after closing the Qbv demo.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/kill_client_process.sh	This script runs in the i.MX 8M Mini board to kill all the processes and files, after closing the Qbv demo.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/loading_window.py	This file shows “loading” window until new window opens.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/loading.gif	It is an animation for loading a window.
/home/root/.nxp-demo-experience/scripts/TSN/qbv/TSN_Qbv_setup_diagram.png	This file contains setup diagram of the TSN Qbv demo.
Files created at run time	

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Table 3. Demo-related files...*continued*

File	Description
`/home/root/.nxp-demo-experience/scripts/TSN/qbv/video.txt`	This file gets the video source selected by the user and passes it to `video1.txt`.
`/home/root/.nxp-demo-experience/scripts/TSN/qbv/video1.txt`	This file only contains the video source last selected by the user.
`/home/root/.nxp-demo-experience/scripts/TSN/qbv/iperf.txt`	This file gets the iPerf command output.
`/home/root/.nxp-demo-experience/scripts/TSN/qbv/iperf1.txt`	This file only contains the last value of iPerf Mbit/s, which is used for graph updates.
`/home/root/.nxp-demo-experience/scripts/TSN/qbv/FPS.txt`	This file is created from `camera_client.py`. It has the frames per second (FPS) value that is used for graph updates.

7 TSN Qbv demo back-end flow

This section is divided into the following subsections:

- Qbv traffic mapping, classification, and assignment
- Qbv1 — Video priority
- Qbv2 — iPerf priority
- No Qbv — No priority

7.1 Qbv traffic mapping, classification, and assignment

This section describes `tc` commands for traffic mapping, classification, and filtering and assignment.

tc command for traffic mapping

The `tc` command for traffic mapping is as follows:

```
tc qdisc replace dev eth1 parent root handle 100 taprio num_tc 5 map 0 1 2 3 4
 queues 1@0 1@1 1@2 1@3 1@4 base-time 0 sched-entry S 0x1f 1000000 flags 2
```

where:

- `tc qdisc replace`: Replace existing qdisc or create a qdisc if not created yet.
- `parent root handle 100`: As per the hierarchical ranking of queuing discipline, root is the topmost priority.
- `taprio num_tc 5 map 0 1 2 3 4 queues 1@0 1@1 1@2 1@3 1@4`: Mapping of five traffic classes, one class per hardware queue.
- `base-time 0`: `base-time` indicates the starting time of gate scheduling. It is the time with reference to the current PTP hardware clock of the device that enables a Qbv schedule to be applied at some real time, for example, in the future. It enables a Qbv schedule change to be applied at the same time across multiple nodes in a TSN. For simplicity, `base-time` is set to zero in this demo, which means a schedule change is in effect immediately after it is applied.
- `sched-entry S 0x1f 1000000`: `0x1f` (11111) indicates a bitwise mask of the five traffic classes as mapped to hardware queues in third list item above. Here, 1 indicates that the gate for the traffic class is open, and 0 indicates that the gate is closed. Therefore, `0x1F` indicates that all traffic class gates are open. The number 1000000 is the time in nanoseconds (ns) occupied by this schedule entry, before moving to the next entry.
  This Qbv gate schedule is a trivial example as it involves only one entry.

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tc command for traffic classification

The `tc` command for traffic classification is as follows:

```
tc qdisc add dev eth1 clsact
```

The qdisc added in this command is the "clsact" qdisc, which stands for "Classification and Action". This qdisc is a special type of qdisc that allows packets to be classified based on certain criteria, including source or destination IP address, protocol, and port number. Based on its classification, an action is taken on a packet.

tc command for traffic filtering and assignment

The `tc` command for traffic filtering and assignment is as follows:

```
tc filter add dev eth1 egress prio 1 u32 match ip dport 5001 0xffff action
 skbedit priority 2
```

where:

- `tc filter add dev eth1`: Adds filter to eth1, which is the interface on which the traffic egresses the device.
- `egress prio 1 u32 match`: Checks the match of the egress port as priority.
- `ip dport 5001 0xffff`: Masks 32 bits of IP destination port, and selects only destination port 5001. Using other ports, the traffic does not trigger this filter action.
- `action skbedit priority 2`: The filter action is to edit the metadata of this frame, causing it to be passed to queue 2.

Behavior

On applying the above `tc filter` command, the iPerf traffic is mapped to queue 2, and other traffic, such as the camera stream passes via queue 0.

7.2 Qbv1 — Video priority

The following command applies Qbv1 configuration:

```
tc qdisc replace dev eth1 parent root handle 100 taprio num_tc 5 map 0 1 2 3 4
 queues 1@0 1@1 1@2 1@3 1@4 base-time 0 sched-entry S 0x01 500000 sched-entry S
 0x05 500000 flags 2
```

This command is described below:

- It is a replacement of first command mentioned in Section 7.1 with a modified Qbv schedule: `sched-entry S 0x01 500000 sched-entry S 0x05 500000`.
- `0x01 500000` indicates that queue 0 (0x01 = 00001) is open for 500000 ns, whereas the other queues are closed during this time.
- `0x05 500000` indicates that queue 0 and queue 2 (0x05 = 00101) are open for 500000 ns, whereas the other queues are closed during this time.
- Total time for cycle = (500000 + 500000) ns = 1000000 ns

Behavior

The camera traffic runs at the maximum rate that the camera supports, whereas the iPerf traffic is limited to half the bandwidth.

Explanation

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- The first 500000 ns (500 µs) of the 1 ms gate schedule has only queue 0 open. This queue is used exclusively for the camera traffic.
- The second 500 µs of the 1 ms gate schedule has only queue 0 and queue 2 open. Therefore, this period is shared between any camera and iPerf traffic.
- Because camera traffic alone is mapped for specific time period; therefore, it is provided full bandwidth during this time. On the other hand, iPerf traffic is only permitted to share line rate during the second half of the gate schedule; therefore, it is in effect limited to half line rate.

7.3 Qbv2 — iPerf priority

The following command applies Qbv2 configuration:

```
tc qdisc replace dev eth1 parent root handle 100 taprio num_tc 5 map 0 1 2 3 4
 queues 1@0 1@1 1@2 1@3 1@4 base-time 0 sched-entry S 0x04 500000 sched-entry S
 0x05 40000 flags 2
```

This command is described below:

- The first Gate Control List (GCL) entry is replaced with an entry having queue 2 (iPerf traffic) open exclusively, and the second GCL entry, where queue 0 and queue 2 are open, is much shortened.
- `0x04 500000` indicates that queue 2 (0x04 = 00100) is open for 500000 ns.
- `0x05 40000` indicates that queue 0 and queue 2 (0x05 = 00101) are open for 40000 ns.
- Total time for cycle = (500000 + 40000) ns = 540000 ns

Behavior

The iPerf traffic runs in full line rate, whereas the camera traffic is limited to a much reduced bandwidth.

Explanation:

- Initially, the iPerf traffic mapped queue 2 is open for 500000 ns.
- The second GCL entry has the camera and iPerf queues open together for 40000 ns.
- Because the iPerf traffic alone is mapped for specific time period; therefore, it is provided full bandwidth. On the other hand, the camera traffic is provided limited bandwidth.

7.4 No Qbv — No priority

The following commands revert all Qbv configurations:

```
tc qdisc del dev eth1 parent root handle 100 taprio num_tc 5 map 0 1 2 3 4
 queues 1@0 1@1 1@2 1@3 1@4 base-time 0 sched-entry S 0x01 500000 sched-entry S
 0x05 500000 flags 2
tc qdisc del dev eth1 parent root handle 100 taprio num_tc 5 map 0 1 2 3 4
 queues 1@0 1@1 1@2 1@3 1@4 base-time 0  sched-entry S 0x04 500000 sched-entry S
 0x05 40000 flags 2
```

These commands are described below:

- The above two commands remove the priorities assigned to all the queues used in the TSN Qbv demo.
- `0x01` indicates that queue 0 (0x01 = 00001) priority is deleted.
- `0x04` indicates that queue 2 (0x04 = 00100) priority is deleted.
- `0x05` indicates that queue 0 and queue 2 (0x05 = 00101) priorities are deleted.

Behavior

Both the iPerf traffic and camera traffic run in full line rate.

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8 TSN Qbv demo software workflow

Figure 2 explains the software workflow of TSN Qbv demo from GUI to back-end.

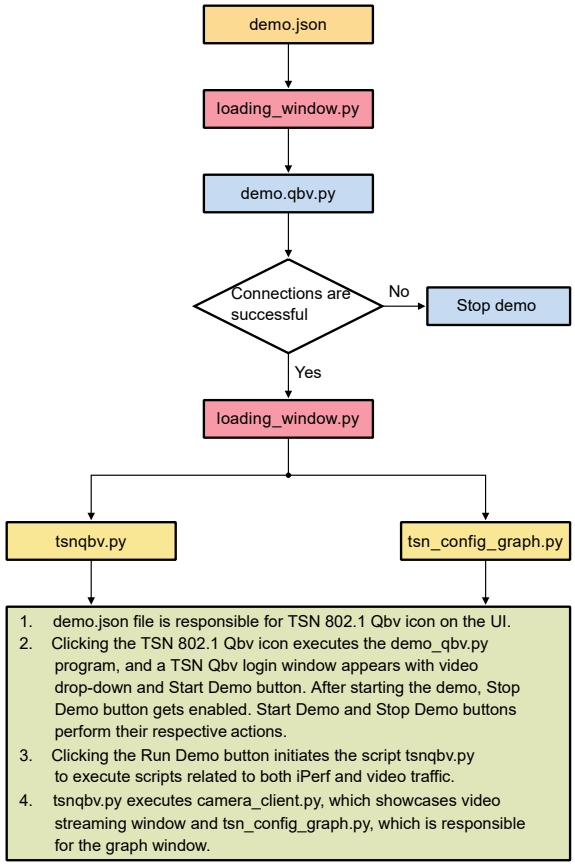

Figure 2. TSN Qbv demo software workflow

9 Limitations

Keep the following limitations in mind while working on the TSN Qbv demo:

- During verification, the TSN Qbv demo setup should not be disturbed.
- For a smooth demo experience, Ethernet cables and camera should not be disturbed.
- Mostly Logitech and Papalook cameras are used to verify the TSN Qbv demo.
- Camera frame rate (number of frames captured per second, FPS) depends on lighting conditions of the area where camera is placed. For example, in a dark, low light, or moderate light area, camera frame rate is 10-15 FPS.
- For TSN Qbv demo, the recommended frame rate is 25-30 FPS. To achieve this frame rate, camera should be placed in an area with bright light.
- The TSN Qbv demo windows open on the monitor in random order. The windows must be re-arranged manually.
- During verification, the TSN Qbv demo windows should not be closed.
- Initially, the iPerf drops to 800 Mbit/s on selecting Qbv2 configuration and streams with full line rate. However, this behavior is achieved in very rare cases.
- The TSN Qbv demo should be stopped before switching to any other demo.

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10 Revision history

Table 4 summarizes the revisions to this document.

Table 4. Revision history

Revision number	Date	Substantive changes
1	28 June 2023	Initial public release

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