

# AN13995

使用i.MX 8M Plus进行TSN 802.1Qbv演示

第1版 — 2023年6月28日

应用笔记

## 文档信息

信息	内容
关键词	AN13995、TSN 802.1Qbv、i.MX 8M Plus、i.MX 8M Mini、流量调度、时间感知整形器、UDP iPerf、摄像头流
摘要	本文介绍了TSN 802.1Qbv如何利用两款恩智浦处理器（i.MX 8M Plus和i.MX 8M Mini）增强流量调度。



## 1 介绍

TSN 802.1Qbv是IEEE规范，允许为网络流量队列定义传输时隙。它引入了时间感知整形器（time-aware shaper）来增强流量调度功能。

本文介绍了TSN 802.1Qbv如何使用i.MX 8M Plus和i.MX 8M Mini这两款恩智浦处理器增强流量调度。

### 1.1 缩略语

[表1](#)列出了本文中使用的缩略语。

表1. 缩略语

缩略语	说明
FPS	Frames per second每秒帧数
GCL	Gate Control List门控列表
GUI	Graphical user interface图形用户界面
HDMI	High-Definition Multimedia Interface高清多媒体接口
IP	Internet Protocol互联网协议
Mbit/s	Megabits per second每秒传输的百万比特数
PTP	Precision Time Protocol精确时间协议
TC	Traffic control流量控制
TSN	Time-sensitive networking时间敏感网络
UDP	User Datagram Protocol用户数据报协议
USB	Universal Serial Bus通用串行总线

## 2 流量调度的增强功能 — 时间感知整形器

TSN 802.1Qbv为网络流量调度增加了以下增强功能：

- 它将以太网上的通信分隔成固定长度，重复时间周期，因此有助于传输对时间要求较高的流量。
- 每个流量类别在指定时间都有一个打开的流量窗口，供特定的通话者（talker）与其监听者（listener）进行通信。
- 网络上的路径会实时（T）为高优先级的流量腾出空间，确保通话者的流量在整个网络上可靠地传输并具有确定性延迟。

## 3 演示所用的流量

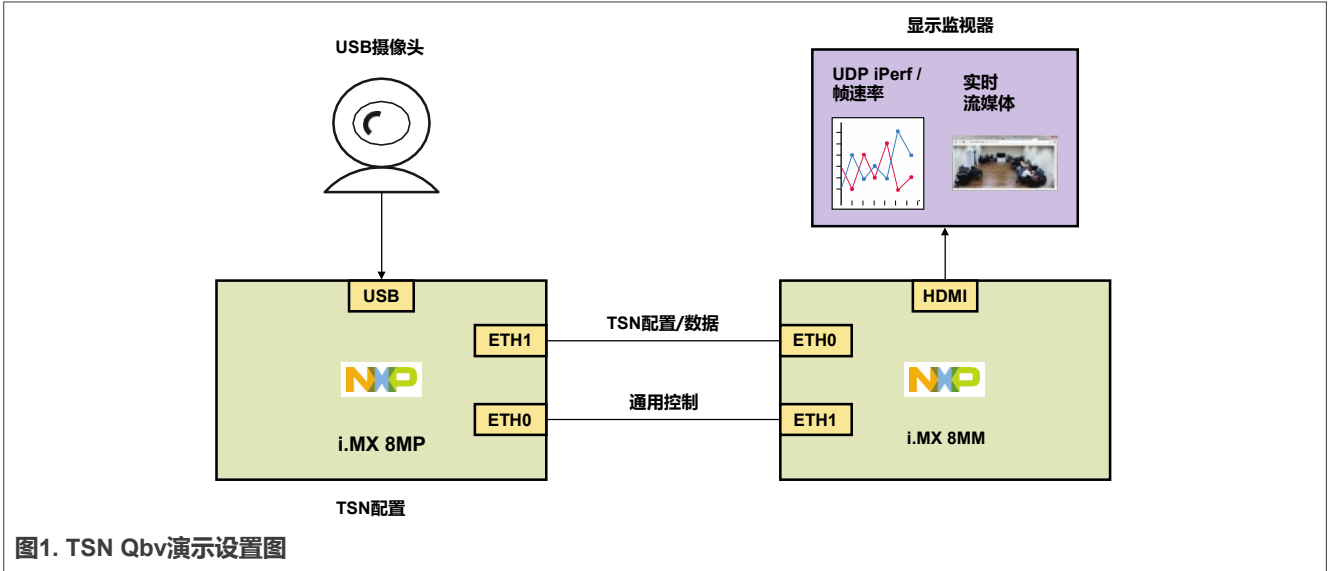
[表2](#)介绍了演示TSN 802.1Qbv所用的流量。

表2. 802.1Qbv演示所用的流量

流量类型	服务器	客户端	默认端口
UDP iPerf	i.MX 8M Mini	i.MX 8M Plus	5001
通过Gstreamer的摄像头流	i.MX 8M Plus	i.MX 8M Mini	5000

## 4 设置图

图1所示为TSN Qbv演示的设置图。



在TSN Qbv演示中，USB摄像头通过以太网生成时间敏感流量，iPerf通过以太网生成best-effort流量。这些流量类型通过TSN端口以不同的优先级在不同队列中传输。在应用Qbv配置时，流量会根据需要进行优先级排序和调度。i.MX 8M Mini的图形用户界面上显示iPerf带宽、摄像头帧速率和实时摄像头流。

## 5 软件依赖包

TSN Qbv演示使用以下内核模块：

- CONFIG\_NET\_ACT\_SKBEDIT
- CONFIG\_NET\_CLS\_U32
- CONFIG\_NET\_SCH\_INGRESS
- CONFIG\_NET\_SCH\_MULTIQ

需要以下应用软件包：

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

使用以下编程语言：

- Shell script
- Python 3

## 6 演示相关文件

表3列出了与TSN Qbv演示相关的文件。

表3. 演示相关文件

文件	说明
/home/root/.nxp-demo-experience/scripts/TSN/qbv/IP_plus.sh	该脚本为i.MX 8M Plus板接口分配IP地址。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/IP_mini.sh	该脚本为i.MX 8M Mini板接口分配IP地址。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/start_demo.py	该脚本为i.MX 8M Mini板分配IP地址并执行demo_qbv.py脚本。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/demo_qbv.py	该脚本将打开演示登录页面，用户可在此选择视频源并运行演示。在打开登录页面之前，系统会在后端检查连接。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/tsnqbv.py	该脚本会建立SSH连接，并执行有关i.MX 8M Plus和i.MX 8M Mini板的Qbv配置、iPerf和摄像头脚本。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/tsn_config_graph.py	该脚本会打开一个图形窗口，允许用户从图形用户界面选择特定配置。选择后，它将调用tsnqbv.py文件，并显示所选的配置。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/start_qbv_priority.sh	该脚本映射队列并确定优先级。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/stop_qbv_priority.sh	该脚本恢复队列的优先级。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/no_qbv.sh	该脚本删除所有Qbv策略。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/qbv1.sh	此Qbv配置文件优先处理视频流量。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/qbv2.sh	此Qbv配置文件优先处理iPerf流量。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/camera_server.py	该脚本通过SSH在i.MX 8M Plus板上运行，以运行服务器GStreamer命令。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/camera_client.py	该脚本在i.MX 8M Mini板上运行，可运行连接到OpenCV窗口的客户端GStreamer。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/kill_server_process.sh	该脚本在i.MX 8M Plus板上运行，在关闭Qbv演示后终止（kill）所有进程和文件。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/kill_client_process.sh	该脚本在i.MX 8M Mini板上运行，在关闭Qbv演示后终止（kill）所有进程和文件。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/loading_window.py	该文件显示“加载”窗口，直至新窗口打开。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/loading.gif	这是加载窗口的动画。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/TSN_Qbv_setup_diagram.png	该文件包含TSN Qbv演示的设置图。
<b>运行时创建的文件</b>	

表3. 演示相关文件 (续)

文件	说明
/home/root/.nxp-demo-experience/scripts/TSN/qbv/video.txt	该文件获取用户选择的视频源，并将其传递给video1.txt。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/video1.txt	该文件仅包含用户最后选择的视频源。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/iperf.txt	该文件获取iPerf命令输出。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/iperf1.txt	该文件仅包含iPerf Mbit/s的最后一个值，该值用于图表更新。
/home/root/.nxp-demo-experience/scripts/TSN/qbv/FPS.txt	该文件由camera_client.py创建。它包含用于图表更新的每秒帧数 (FPS) 值。

## 7 TSN Qbv演示后端流程

本章节分为以下小节：

- [Qbv流量映射、分类和分配](#)
- [Qbv1 — 视频优先级](#)
- [Qbv2 — iPerf优先级](#)
- [无Qbv — 无优先级](#)

### 7.1 Qbv流量映射、分类和分配

本节介绍用于流量映射、分类、过滤和分配的tc命令。

#### 用于流量映射的tc命令

用于流量映射的tc命令如下：

```
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
```

其中：

- tc qdisc replace：替换现有的qdisc或创建一个qdisc（如果尚未创建）。
- parent root handle 100：按照队列规则的等级排列，root是最高优先级。
- taprio num\_tc 5 map 0 1 2 3 4 queues 1@0 1@1 1@2 1@3 1@4：映射五个流量类别，每个硬件队列一个类别。
- base-time 0：base-time表示门控调度的开始时间。它是参考设备当前PTP硬件时钟的时间，可在未来某个实际时间应用Qbv调度。它能使Qbv调度改为在同一时间应用于TSN中的多个节点。为简单起见，在此演示中，base-time设置为零，这意味着调度更改在应用后立即生效。
- sched-entry S 0x1f 1000000 : 0x1f ( 11111 ) 表示上述[第三项列表](#)中映射到硬件队列的五个流量类别的按位掩码。这里，1表示流量类别的门控已打开，0表示门控已关闭。因此，0x1F表示所有流量类别的门控均打开。数字1000000是在转到下一个条目之前，该调度条目所占用的时间（纳秒）。  
此Qbv门控调度是一个简单的示例，因为它仅涉及一个条目。

### 用于流量分类的tc命令

用于流量分类的tc命令如下：

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

此命令中添加的qdisc是“clsact” qdisc，代表“分类和操作”。此qdisc是一种特殊类型的qdisc，可根据某些标准（包括源或目标IP地址、协议和端口号）对数据包进行分类。根据分类，对数据包进行相应的操作。

### 用于流量过滤和分配的tc命令

用于流量过滤和分配的tc命令如下：

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

其中：

- `tc filter add dev eth1`：向eth1添加过滤器，eth1是流量传出设备的接口。
- `egress prio 1 u32 match`：检查出口端口的匹配优先级。
- `ip dport 5001 0xffff`：屏蔽32位IP目的端口，仅选择目的端口5001。使用其他端口时，流量不会触发此过滤操作。
- `action skbedit priority 2`：过滤器操作是编辑该帧的元数据，使其通过队列2传输。

### 表现

应用上述tc filter命令后，iPerf流量将映射到队列2，而其他流量（例如摄像头流）则通过队列0传输。

## 7.2 Qbv1 — 视频优先级

以下命令用于Qbv1配置：

```
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
```

该命令描述如下：

- 它是用修改后的Qbv调度替换[第7.1节](#)中提到的第一条命令：`sched-entry S 0x01 500000 sched-entry S 0x05 500000`。
- `0x01 500000`表示队列0 (`0x01 = 00001`)打开时间为500000ns，而其他队列在此期间关闭。
- `0x05 500000`表示队列0和队列2 (`0x05 = 00101`)打开时间为500000ns，而其他队列在此期间关闭。
- 周期总时间 = (500000 + 500000) ns = 1000000 ns

### 表现

摄像头流量以摄像头支持的最大速率运行，而iPerf流量则以带宽的一半速率运行。

### 说明

- 1 ms门控调度的前500000ns (500µs)仅打开队列0。该队列专门用于摄像头流量。
- 1 ms门控调度的第二个500µs仅打开队列0和队列2。因此，任何摄像头和iPerf流量都共享此时间段。
- 由于摄像头流量仅在特定时间段映射，因此，在此期间提供全带宽。另一方面，iPerf流量只允许在门控调度的后半段共享线路速率；因此，它实际上只能使用一半的线路速率。

### 7.3 Qbv — Perf优先级

以下命令用于Qbv2配置：

```
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
```

该命令描述如下：

- 第一个门控制列表（GCL）条目被替换为仅打开队列2（iPerf流量）的条目，并且队列0和队列2打开的第二个GCL条目时间大大缩短。
- 0x04 500000表示队列2（0x04 = 00100）打开时间为500000ns。
- 0x05 40000表示队列0和队列2（0x05 = 00101）打开时间为40000ns。
- 周期总时间 = (500000 + 40000) ns = 540000 ns

#### 表现

iPerf流量以全线速运行，而摄像头流量只能以更低的带宽速率运行。

#### 说明：

- 最初，iPerf流量映射队列2的打开时间为500000ns。
- 第二个GCL条目将摄像头和iPerf队列一起打开的时间为40000ns。
- 由于iPerf流量仅在特定时间段内映射，因此可获得全带宽。另一方面，摄像头流量只能使用有限的带宽。

### 7.4 无Qbv — 无优先级

以下命令可恢复所有Qbv配置：

```
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
```

这些命令的说明如下：

- 上述两个命令删除了分配给TSN Qbv演示中使用的所有队列的优先级。
- 0x01表示删除队列0（0x01 = 00001）的优先级。
- 0x04表示删除队列2（0x04 = 00100）的优先级。
- 0x05表示删除队列0和队列2（0x05 = 00101）的优先级。

#### 表现

iPerf流量和摄像头流量均以全线速运行。

## 8 TSN Qbv演示软件工作流程

图2展示了TSN Qbv演示从图形用户界面到后端的软件工作流程。

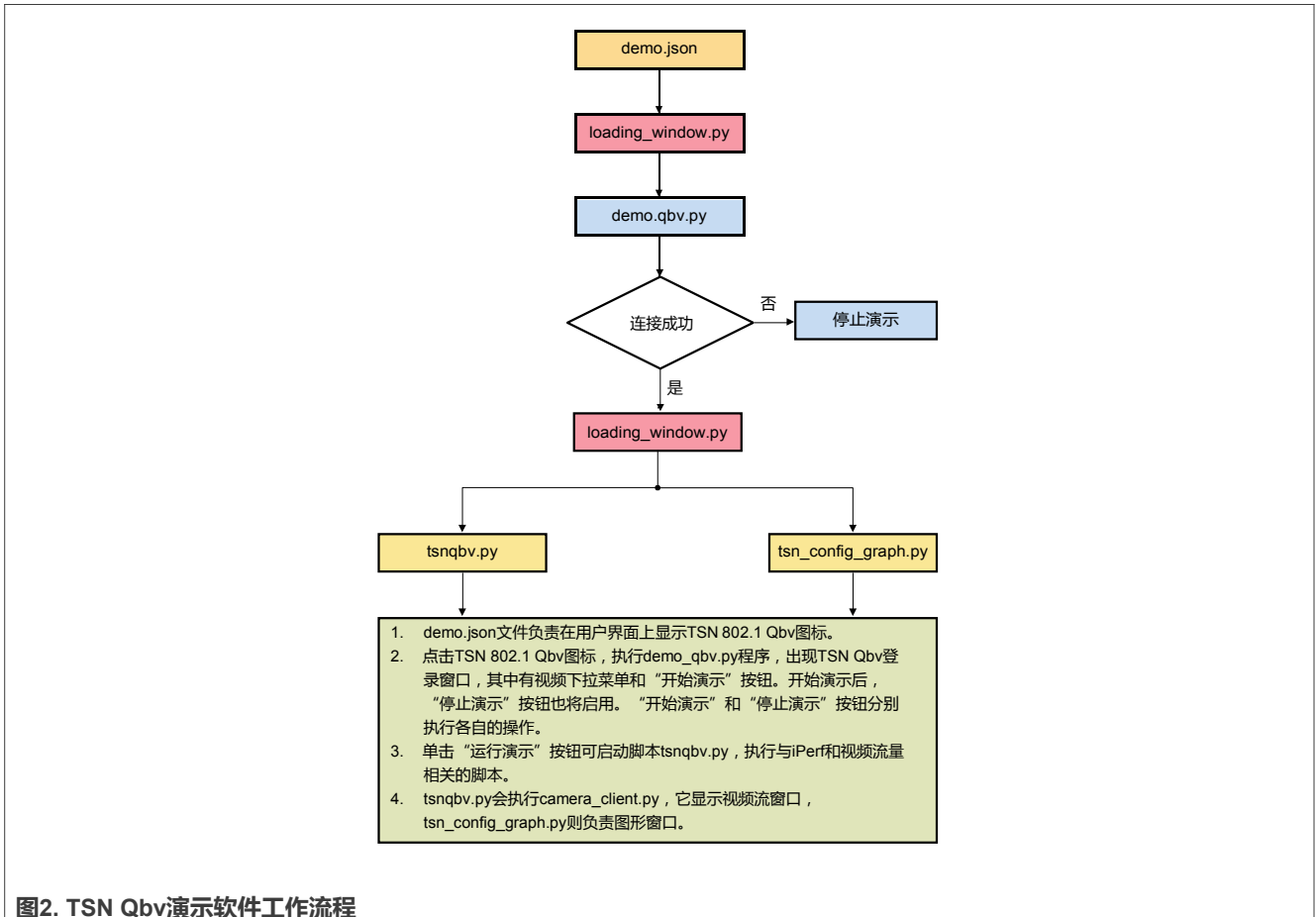


图2. TSN Qbv演示软件工作流程

## 9 限制

在使用TSN Qbv演示时，请注意以下限制：

- 在验证过程中，不应干扰TSN Qbv演示设置。
- 为获得流畅的演示体验，以太网电缆和摄像头不应受到干扰。
- 大多数情况下，可使用Logitech和Papalook摄像头验证TSN Qbv演示。
- 摄像头帧速率（每秒捕获的帧数，FPS）取决于放置摄像头区域的照明条件。例如，在黑暗、弱光或中等光照区域，摄像头帧速率为10-15 FPS。
- 对于TSN Qbv演示，建议帧速率为25-30 FPS。要达到这一帧速率，应将摄像头放置在光线明亮的地方。
- TSN Qbv演示窗口以随机顺序在显示器上打开。必须手动重新排列窗口。
- 在验证过程中，不应关闭TSN Qbv演示窗口。
- 最初，在选择Qbv2配置和全线路速率流时，iPerf会降至800 Mbit/s。但这种情况极少发生。
- 在切换到其他演示之前，应停止TSN Qbv演示。



## 10 修订历史

[表4](#)总结了本文的修订内容。

表4. 修订历史

版本号	日期	实质性变更
第1版	2023年6月28日	初版发布

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