Latency Analysis in TSN for Service Provider Networks

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TSN for Service Provider Networks
- Use cases / Requirement

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume(NOTE 2)	Default Averaging Window	Example Services
1	GBR NOTE 1	20	100 ms	10^{-2}	N/A	2000 ms	Conversational Voice
2		40	150 ms	10^{-3}	N/A	2000 ms	Conversational Video (Live Streaming)
3		30	50 ms	10^{-3}	N/A	2000 ms	Real Time Gaming, V2X messages Electricity distribution – medium voltage, Process automation - monitoring
4		50	300 ms	10^{-6}	N/A	2000 ms	Non-Conversational Video (Buffered Streaming)
65		[illegible]	[illegible]	[illegible]	[illegible]	2000 ms	Mission Critical user plane Push To Talk voice (e.g., MCPTT)
66		[illegible]	[illegible]	[illegible]	[illegible]	2000 ms	Non-Mission-Critical user plane Push To Talk voice
67		15	100 ms	10^{-3}	N/A	2000 ms	Mission Critical Video user plane
75		25	50 ms	10^{-2}	N/A	2000 ms	V2X messages
5	Non-GBR NOTE 1	10	100 ms	10^{-6}	N/A	N/A	IMS Signalling
6		60	300 ms	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		70	100 ms	10^{-3}	N/A	N/A	Voice, Video (Live Streaming) Interactive Gaming
8		80	[illegible]	[illegible]	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9		[illegible]					
69		[illegible]	[illegible]	[illegible]	N/A	N/A	Mission Critical delay sensitive signalling (e.g., MC-PTT signalling)
70		55	200 ms	10^{-6}	N/A	N/A	Mission Critical Data (e.g. example services are the same as QCI 6/8/9)
79		65	50 ms	10^{-2}	N/A	N/A	V2X messages
80		68	10 ms	10^{-6}	N/A	N/A	Low Latency eMBB applications Augmented Reality
81	Delay Critical GBR	11	5 ms	10^{-5}	160 B	2000 ms	Remote control (see TS 22.261 [2])
82		12	10 msNOTE 5	10^{-5}	320 B	2000 ms	Intelligent transport systems
83		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Intelligent Transport Systems
84		19	10 ms	[illegible]	255 B	2000 ms	Discrete Automation
85		22	10 ms	10^{-4}	1358 B NOTE 3	2000 ms	Discrete Automation

Bandwidth Sensitive Services

Connection Services

URLLC Latency Sensitive Services

3GPP SA2 Table 5.7.4-1: Standardized 5QI to QoS characteristics mapping

Three main types for services co-exist in 5G carrier networks, especially in backhaul networks or metro networks, according to 3GPP requirement document.

- *Bandwidth sensitive services* care more about throughput as long as its short term bursting can be buffered and transit later.
- *Latency sensitive services* are new applications appear with new era carrier networks. TSN techniques are most useful on this aspect.
- *Connection services* are the legacy services on 802 or IP networks.

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Compare to P60802 traffic types

Step 2: Traffic Type Definitions

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Types	Periodicity	Period	Synchronized to network	Data delivery requirements	Tolerance to interference	Tolerance to loss	Application data size	Criticality
Isochronous	Periodic	< 2ms	Yes	Deadline	0	None	Fixed: 30 - 100 Bytes	High
Cyclic	Periodic	2 - 20ms	No	Latency	<= latency	1 - 4 Frames	Fixed: 50 - 1000 Bytes	High
Events	Sporadic	n.a.	No	Latency	n.a.	Yes	Variable: 100 - 1500 Bytes	High
Network Control	Periodic	50ms - 1s	No	Bandwidth	Yes	Yes	Variable: 50 - 500 Bytes	High
Config & Diagnostics	Sporadic	n.a.	No	Bandwidth	n.a.	Yes	Variable: 500 - 1500 bytes	Medium
Best Effort	Sporadic	n.a.	No	None	n.a.	Yes	Variable: 30 - 1500 Bytes	Low
Video	Periodic	Frame Rate	No	Latency	n.a.	Yes	Variable: 1000 - 1500 Bytes	Low
Audio/Voice	Periodic	Sampling Rate	No	Latency	n.a.	Yes	Variable: 1000 - 1500 Bytes	Low

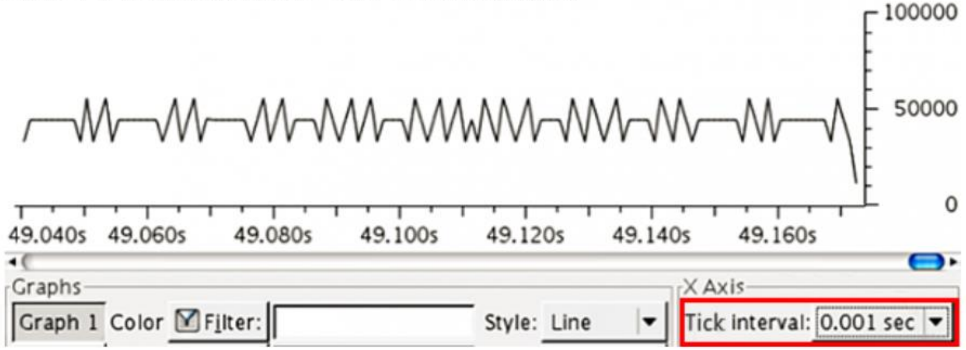
http://www.ieee802.org/1/files/public/docs2019/60802-ademaj-traffic-type-introduction-0319-v03.pdf

- Similar traffic type definitions are used in requirements discussed in industrial automation scenarios.
- Deadline requirement with ZERO tolerance to interference and packet loss, implies higher resource cost to reduce jitter (e.g. with global sync network and scheduling or dedicate devices/interfaces)

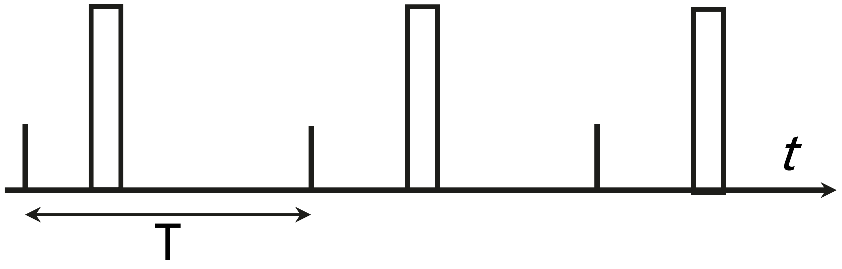
Differentiated SLA in Service Provider Networks

- Type 1 Bandwidth sensitive application
  - Care more about average rate and peak rate, usually have CIR/PIR parameters to specify user requirements. Not so much on latency, have tolerance on microburst and congestion, use buffering to solve bursting and gaps in data stream.
  - Use cases : TV/Sport Videos, Surveillance Video, etc.

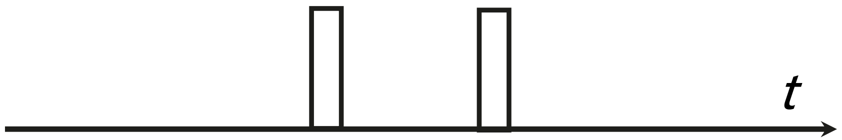
Figure 1-2 Traffic statistics at a lower level of granularity



- Type 2 Latency sensitive application
  - Care more about bounded latency, have T-SPEC parameter to specify traffic model (TrafficInterval, BurstSize), and latency bound requirement.
  - Use cases : Smart Grid Teleprotection, Cloud VR.



- Type 3 Connection services
  - Messages



TSN Toolbox on Forwarding Plane

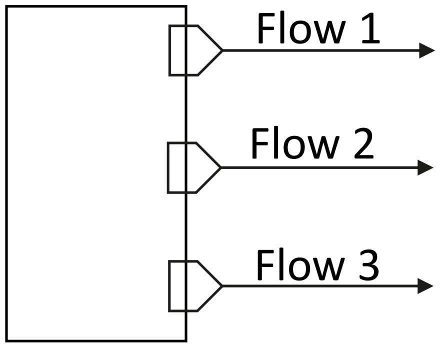
Both scheduling and shaping functions affect latency bound. For some specific TSN techniques, they have shaping and scheduling function combined together.

- TAS/Async TAS; (Refer to IEEE Std 802.1Qbv)
- Generic CQF; (Refer to IEEE Std 802.1Qch)
- Strict Priority/WRR; (Refer to IEEE Std 802.1Q-2018)
- CBS/BLS; (Refer to IEEE Std 802.1Qav)
- ATS; (Refer to P802.1Qcr)
- Dedicated physical lines

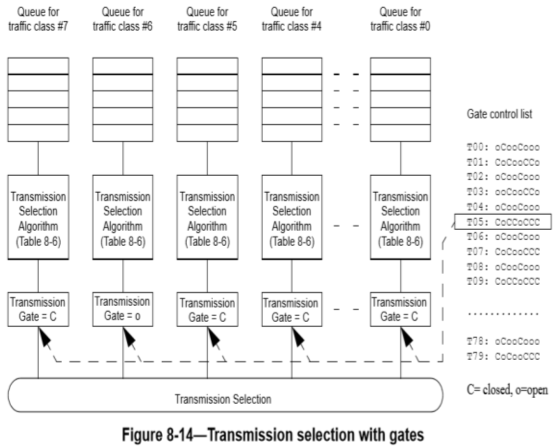
Some techniques are more for bounded latency, some others are more about to get low jitter; while Strict Priority/WRR algorithms generally have lower average delay and may benefit on bandwidth utilizations.

Within Smart Grid scenarios, we compared legacy QoS algorithms(Strict Priority/Deficit Round Robin/etc.) and dedicated physical lines to ensure that with fundamental 802.1 TSN techniques , bounded latency services can be achieved in service provider networks; nevertheless, performance on latency and jitter varies.

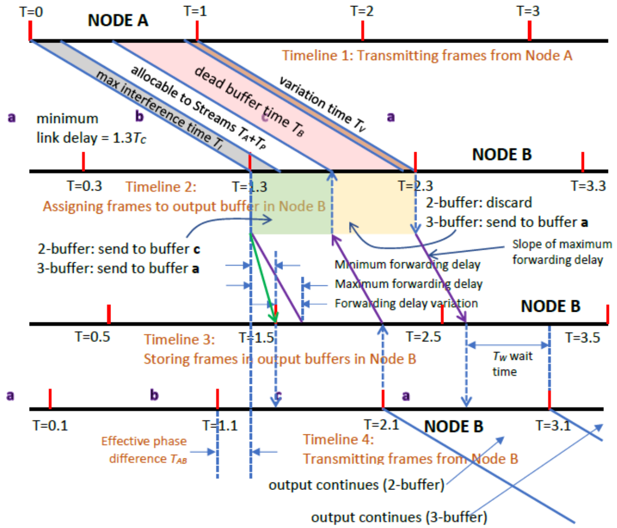
TSN Toolbox on Forwarding Schedulers and Shapers



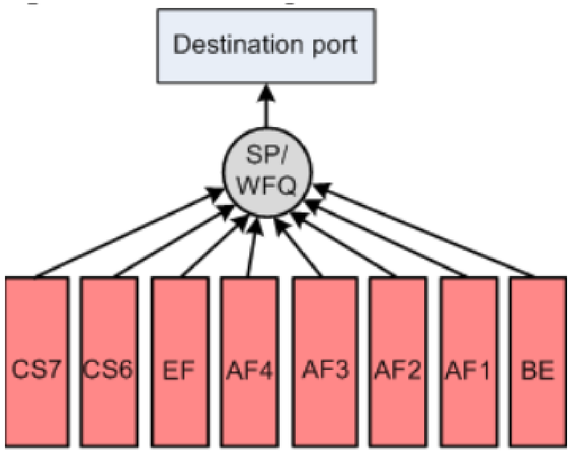
Dedicate Ports/Links



Time Aware Shaper



Generic CQF
(2 buffer/3buffer/etc.)



Strict Priority/Weight Fair Queueing

By using different schedulers and shapers, multiple types of traffic are transmitted with differentiated service levels (SLA) on shared network resources;
This is similar to network slicing concept, to divide network up and share among users/applications;
TSN techniques are capable to support network slicing with multiple levels of service guarantee;

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Delay Decomposition and Comparison

```
      DetNet transit node A            DetNet transit node B
    +-------------------------+       +-------------------------+
    |              Queuing    |       |              Queuing    |
    |   Regulator subsystem   |       |   Regulator subsystem   |
    |   +-+-+-+-+ +-+-+-+-+   |       |   +-+-+-+-+ +-+-+-+-+   |
 -->+    | | | | | | | | | +   +------>+   | | | | | | | | | +   +--->
    |   +-+-+-+-+ +-+-+-+-+   |       |   +-+-+-+-+ +-+-+-+-+   |
    |                         |       |                         |
    +-------------------------+       +-------------------------+
    |<->|<------>|<------->|<->|<---->|<->|<------>|<------>|<->|<--
 2,3  4      5        6      1    2,3   4      5        6     1   2,3
                1: Output delay       4: Processing delay
                2: Link delay         5: Regulation delay
                3: Preemption delay   6: Queuing delay.

               Figure 1: Timing model for DetNet or TSN
```

https://tools.ietf.org/html/draft-finn-detnet-bounded-latency-04

	Queueing Delay
Dedicate Port	$D_{Port} = \frac{b}{R}$; //R is output port data rate
TAS	Depends on GCL configuration and traffic timing; //need more assumption to compare
CQF	2 * Tc; //more analysis from Norman's whitepaper
SP/DRR	$\frac{b_i}{R\frac{Q_i}{\sum Q}} + \frac{b}{R}$ //Q_i is the share of the bandwidth for flow i
*CBS	$T^A = \frac{1}{R}(L^{BE})$ //for Class A traffic, assuming no CDT $T^B = \frac{1}{R}\left(L^A + L^{BE} + L^{BE} * \frac{R^A}{R - R^A}\right)$ //for Class B traffic;

**Latency and Backlog Bounds in TSN with CBS and ATS*

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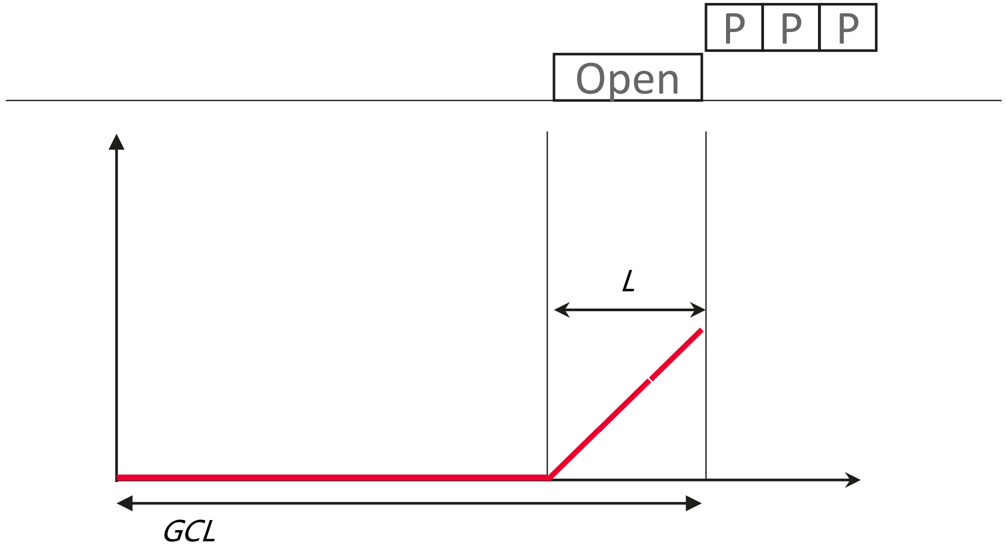
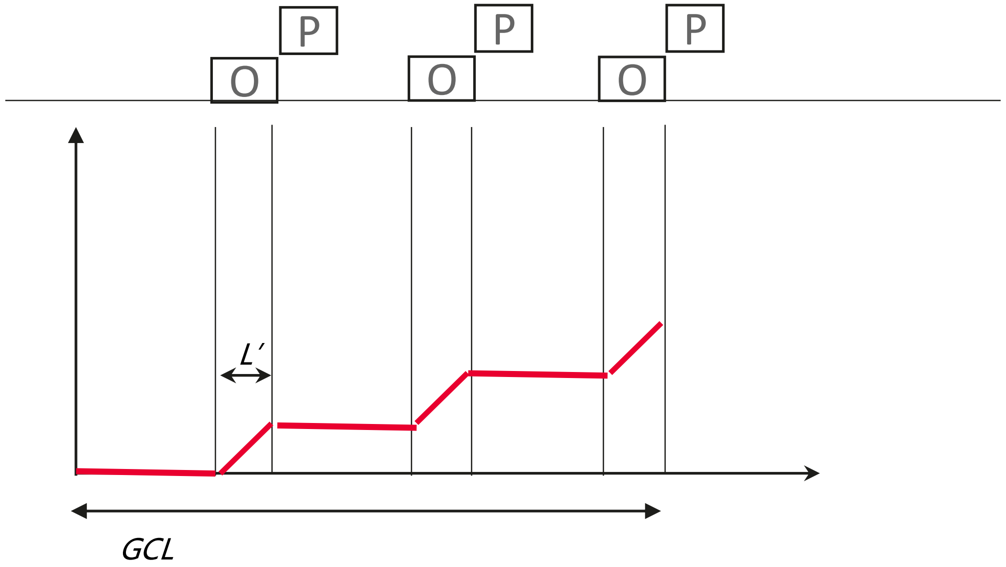
TAS Latency Analysis



Max Delay = GCL -L + $\frac{B}{R}$

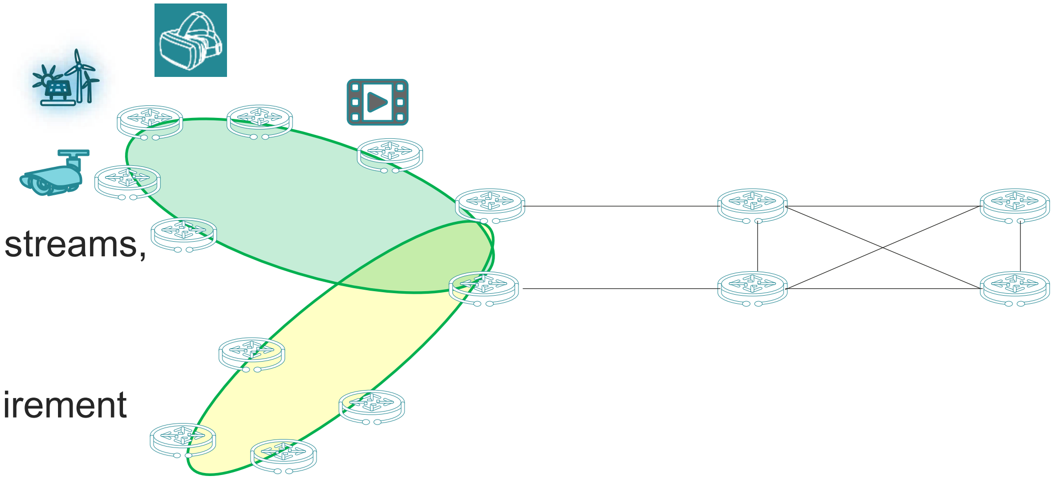


Max Delay = GCL/3 – L/3 + $\frac{B}{3R}$

- Max Delay on TAS scheme depends on whether gate control configurations suits with traffic bursts;
- Complex TAS configuration schemes may cause more complicated latency formula;

L. Zhao, P. Pop and S. S. Craciunas, "Worst-Case Latency Analysis for IEEE 802.1Qbv Time Sensitive Networks Using Network Calculus," in IEEE Access, vol. 6, pp. 41803-41815, 2018.

Delay Analysis in TSN for Service Provider Networks
- Comparison Between Schedulers



- Typical topology on carrier network, with access ring, aggregate layer and backbone layer.
- Assume 8 DTU(digital transmitting unit) on access ring、16 VR stream and 40 video streams, with periodic burst traffic model.
  - Smart grid：in every 5ms，14*380Byte. //Tight latency requirement ~2ms.
  - VR Game：in every 15ms，60*1522Byte（ ~50Mbps） //medium latency requirement ~10ms
  - Video：in every 70ms，168*1522Byte（~30Mbps） //loose latency requirement ~10ms
- Different ways of bandwidth sharing(scheduling and shaping) cause performance varying.

Worst Case Latency Calculation (ms)	Dedicate Link	FIFO @10G	Strict Priority @10G	Strict Priority @10G + Edge Shaping	CQF @10G③
Smart Grid Teleprotection	0.267 @2G	12.883	0.077 (H) ①	1.081 (H)	TBA
VR Game	3.796 @6G	13.347	2.565 (M)	8.138 (M)	
Video	73.438 @2G	14.778	23.019(L)	19.121(L) ②	

Worst case Latency in Simulation (ms)	Dedicate Link	FIFO @10G	Strict Priority @10G	Strict Priority @10G + Edge Shaping	CQF @10G
Smart Grid Teleprotection	0.244 @2G	7.991	0.050	0.728	TBA
VR Game	3.219 @6G	8.797	1.896	7.845	
Video	50.257 @2G	10.378	11.456	11.432	

TSN for Service Provider Networks Annex :
- Network Calculus

- Briefly introduce Network calculus as necessary to explain delay analysis for different schedulers and shapers. //This work may update CBS latency analysis and bring up amendment request.
- Arrival Curves :
  - Current research on Network calculus use token bucket attributes on traffic models to setup arrive curve α (t) , such as

$$\alpha_{\sigma,\rho}(t) = \begin{cases} \rho t + \sigma, & t \geq 0 \\ 0, & t < 0, \end{cases}$$

    while each flow has a burstsize σ, and data rate ρ;

  //Note: TSN standard usually use T-SPEC to describe input traffic model, need conversion here.

  //Aggregating behavior also changes traffic model
- Service Curves:
  - The service offer by the scheduler on an outgoing port can be characterized by a minimum service curve, denoted by β(t).
  - Service Curves for different schedulers(Strict Priority/WRR/CBS/TAS) will be sorted out and then evaluate the queueing latency

Thank you.

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