Tongtong Wang
Expert Researcher
Huawei Technologies

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Deterministic Networks for 5G Industrial Internet

5G industrial internet develops fast in recent years. Mixed types of traffic converse over 5G transport networks, enable 5G URLLC(ultra reliable low latency communications) applications, including various vertical applications. E.g. Smart Manufactory, Smart Grid, Cloud VR, etc.
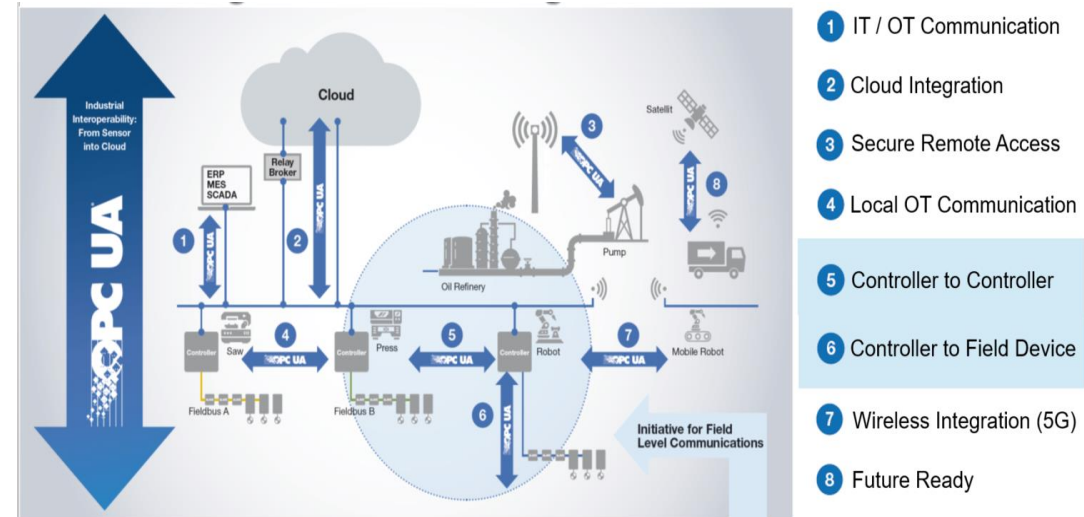
IoT   Factories   Meta World   Clouds

Deterministic Periodic Communications

Deterministic Random Communications

Non-Deterministic Communications

5G QoS
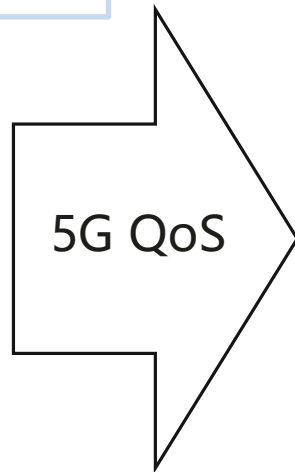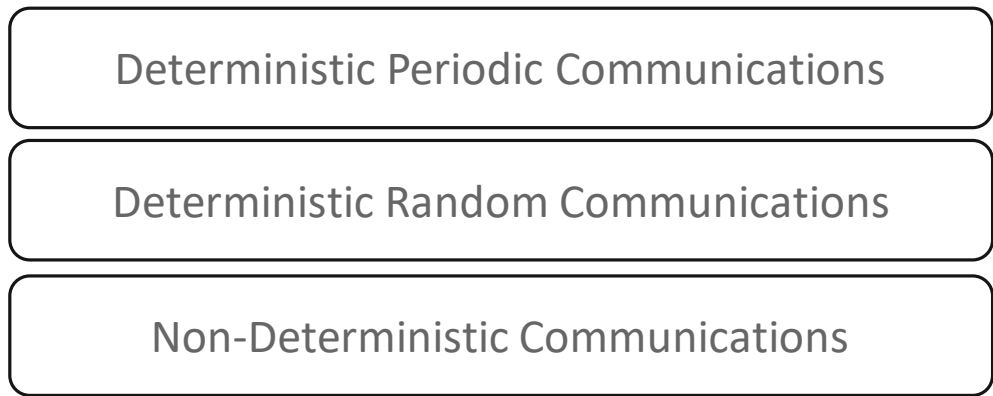
5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume(NOTE 2)	Default Averaging Window	Example Services
1	GBR NOTE 1	20	100 ms	10^-2	N/A	2000 ms	Conversational Voice
2		40	150 ms	10^-3	N/A	2000 ms	Conversational Video (Live Streaming)
3		30	50 ms	10^-3	N/A	2000 ms	Real Time Gaming, V2X messages Electricity distribution – medium voltage, Process automation - monitoring
4						2000 ms	Non-Conversational Video (Buffered Streaming)
65						2000 ms	Mission Critical user plane Push To Talk voice (e.g., MCPTT)
66		20	100 ms	10^-2	N/A	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					N/A	N/A	Video (Buffered Streaming)TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressivevideo, etc.)
9							
69		5	60 ms	10^-6	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 ms NOTE	10^-5	320 B	2000 ms	Intelligent transport systems
83						000 ms	Intelligent Transport Systems
84		19	10 ms	10^-4	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

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TSN and Deterministic Network Standards

Bounded Latency	High Reliability	converged	Cross L2/L3 layers

FlexE&MTN(L1) / TSN(L2) / DetNet(L3)

OIF **FlexE: Flex Ethernet**
OPTICAL INTERNETWORKING FORUM
https://www.oiforum.com/technical-work/hot-topics/flex-ethernet-flexe-2/

IEEE **TSN : Time Sensitive Networking (IEEE)**
http://www.ieee802.org/1/pages/tsn.html

ITU **MTN Metro Transport Network (ITU-T)**
https://www.itu.int/rec/T-REC-G.8312/en

IETF **DetNet: Deterministic Networking (IETF)**
https://tools.ietf.org/wg/detnet/

1. IT / OT Communication
2. Cloud Integration
3. Secure Remote Access
4. Local OT Communication
5. Controller to Controller
6. Controller to Field Device
7. Wireless Integration (5G)
8. Future Ready

OPC-F "Field Level Communications Initiative"
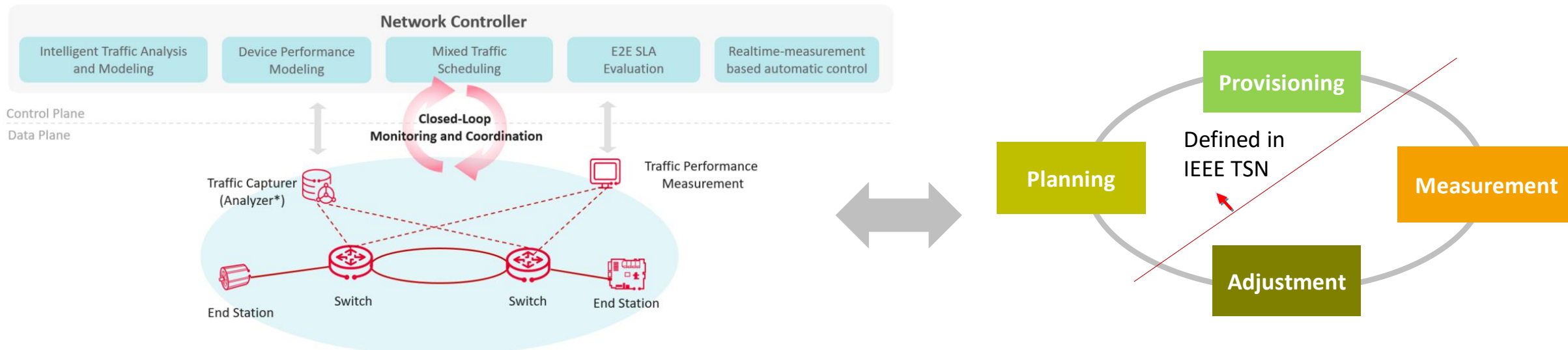*Extending OPC from cloud to field level*

The goal of these standards is to support the creation of multi-vendor networks, any ONE of which can provide BOTH:
- Hard real-time services for applications demanding ultra-low packet loss and guaranteed on-time delivery.
- Normal enterprise best-effort traffic services.

Huawei is investing in these standards in the belief that they will help to expand the growth of the Industrial Internet.

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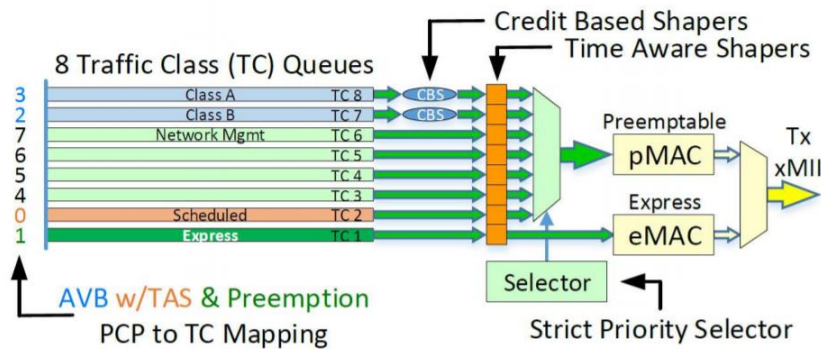
Huawei TSN Technologies and Solution

- **D**ifferentiated Performance KPIs – Provides multiple levels of Latency and Jitter guarantees

- **A**pplication driven networks – interpret user/application intent to network provisioning

- **R**eliability and Robustness – Self adaptive to solve non-prefect real world issues (clocking shift, interference traffics)

- **E**volution – Gradually update existing QoS switch/routers with TSN Switch/Routers with TSN/Non-TSN mixture solution

Network Controller

| Intelligent Traffic Analysis and Modeling | Device Performance Modeling | Mixed Traffic Scheduling | E2E SLA Evaluation | Realtime-measurement based automatic control |

Control Plane
Data Plane

Closed-Loop Monitoring and Coordination

Traffic Performance Measurement

Traffic Capturer (Analyzer*)

End Station — Switch — Switch — End Station

Provisioning

Planning

Defined in IEEE TSN

Measurement

Adjustment

Closed-loop monitoring and coordination for critical applications (time sensitive, highly reliable services)
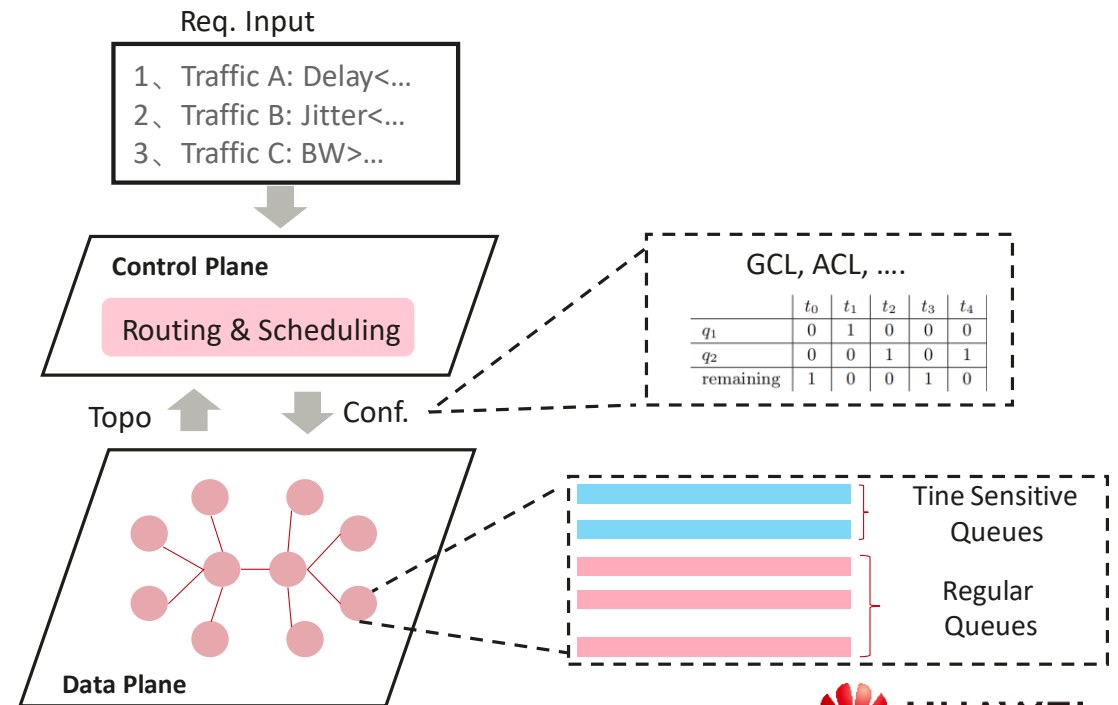
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Differentiated SLA levels: Smart TSN Network Planning

- TSN packet schedulers suggested in IEEE TSN profiles use combination of time aware shapers and asynchronous traffic shapers defined in 802.1 TSN standards.

- Based on Network Calculus and TAS planning theories, smart TSN planning algorithms can allocate adequate resource(bandwidth, buffer) along flow path, to differentiated levels of bounded latency, bounded jitter in a converged network.
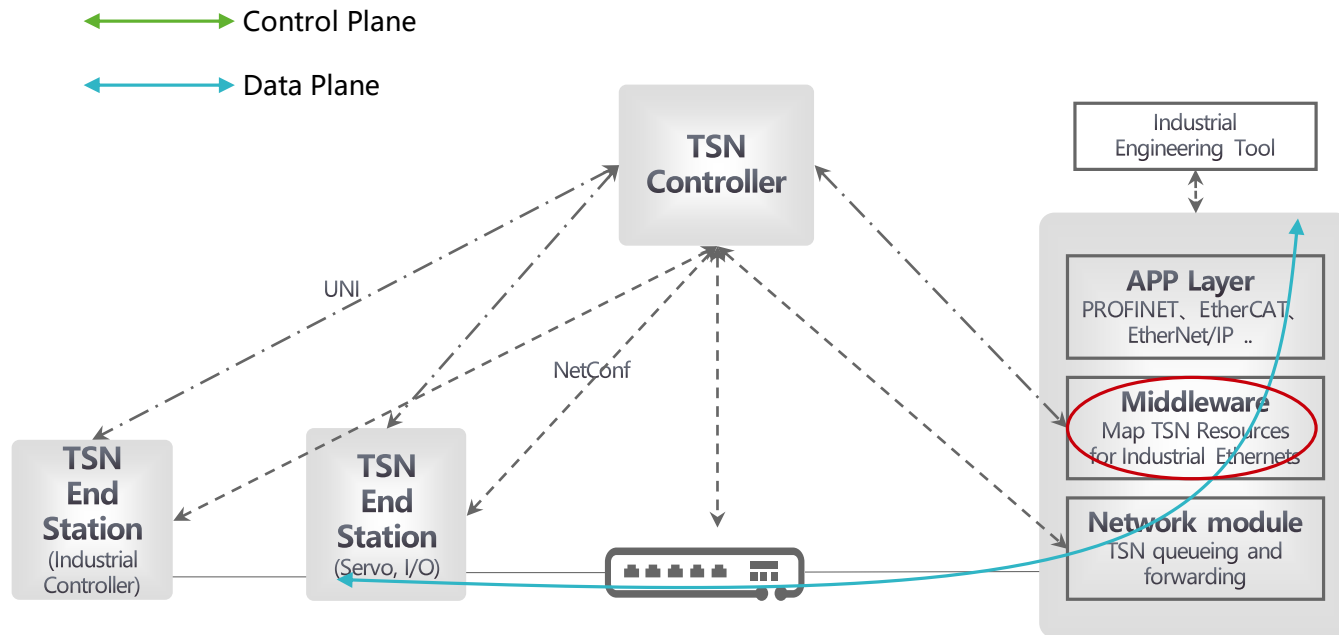
Example of TSN packet scheduler*

*https://www.ieee802.org/1/files/public/docs2021/dg-pannell-ChoosingTheRightTSNToolsToMeetABoundedLatency-whitePaper-0821-v01.pdf

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Application Driven TSN Provisioning

Intent based TSN networks

Control Plane

Data Plane

UNI

NetConf

TSN Controller

Industrial Engineering Tool

APP Layer
PROFINET、EtherCAT、
EtherNet/IP ..

Middleware
Map TSN Resources
for Industrial Ethernets

Network module
TSN queueing and
forwarding

**TSN
End
Station**
(Industrial
Controller)

**TSN
End
Station**
(Servo, I/O)

Decoupled application and network

- User designs in engineering tool by HMI environments;

- Application network coordination via Middleware and automatic resource computation and provisioning in TSN controller;

- TSN middleware support legacy Industrial Ethernet, interpret traffic specification and communication cycle parameters, thus enable Legacy IEC 61158 protocols over TSN

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Robust Self-adaptive TSN

TSN bridges could learn traffic features via netflow functions, either to protect misbehavior flows from TSN end stations, or self–adaptive to legacy non-TSN industrial devices and help setup TSN data path between legacy devices and TSN end stations as a proxy.
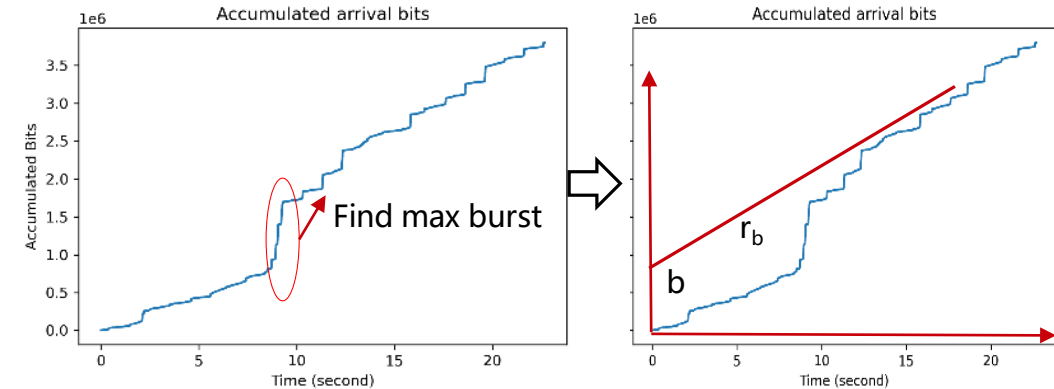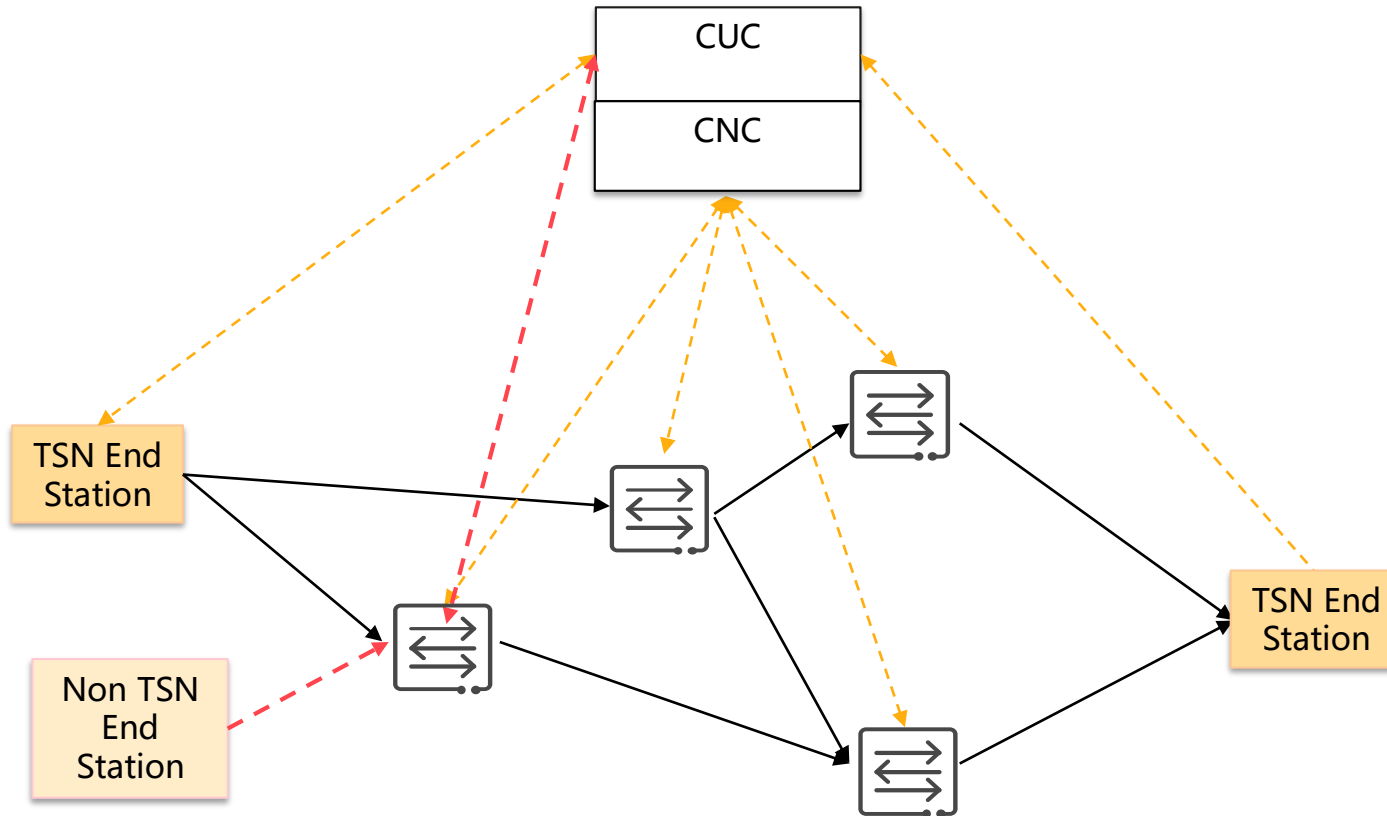
A traffic fitting example

By netflow (RFC 3954) similar approach, Huawei TSN bridge could collect statistics for Layer 2 field, like MAC addresses, VLAN IDs and record packet and byte counts, timestamps, Type of Service etc. to check and learn traffic specifications from legacy end devices.

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Evolve Smoothly - Mixed TSN Shaper Coordination

Gradually update network with TSN capable devices and make most advantages out of existing QoS/A-synchronized Profiles

Profile	Shapers	Advantages	implementations
Synchronized	TAS/CQF	Low latency / Jitter control	New TAS Devices + gPTP
A-synchronized	ATS/TBS/Priority	Bounded latency	Existing QoS Devices
New TSN	mCQF	Bounded latency / Jitter control	N/A

Challenge is for network controlling tools to support QoS/TSN resource calculation and provisioning.
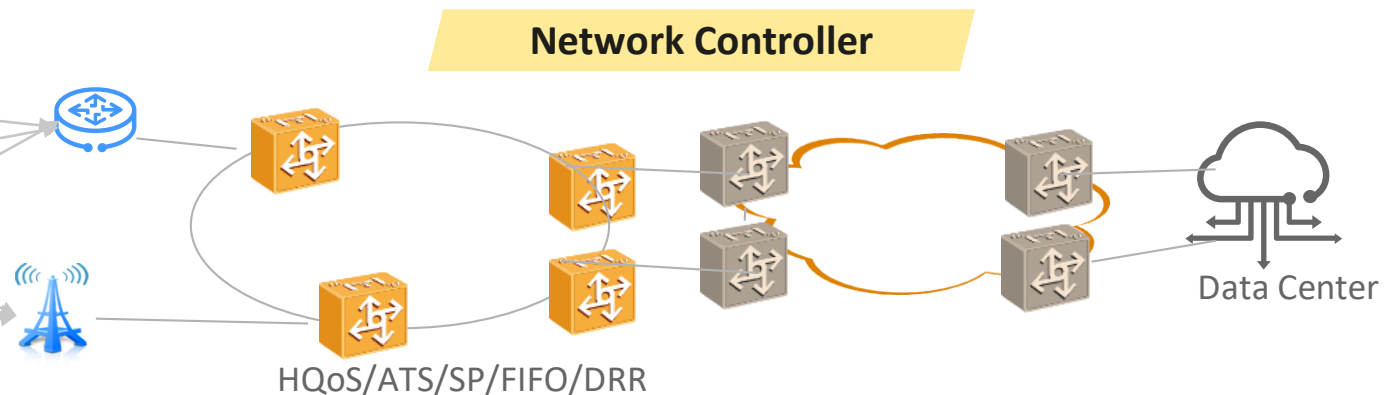
Applications

Latency Guaranteed
- Service 1 ~ 2ms
- Service 2 ~ 20ms

Bandwidth Guaranteed
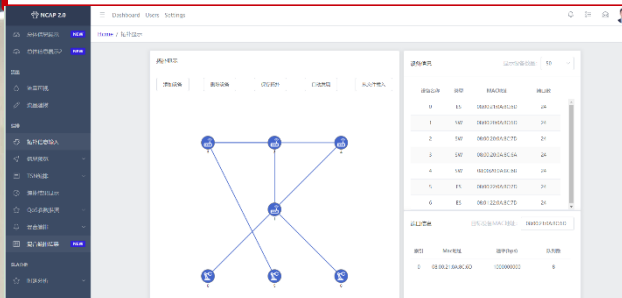- Service 3 ~ 20 Mbps
- Service 4 ~ 50 Mbps

Connection services
- Service 5
- Service 6

Network Controller

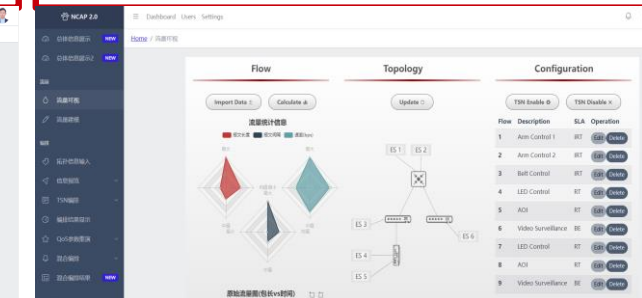HQoS/ATS/SP/FIFO/DRR

Data Center

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Huawei OPC UA over TSN testbed
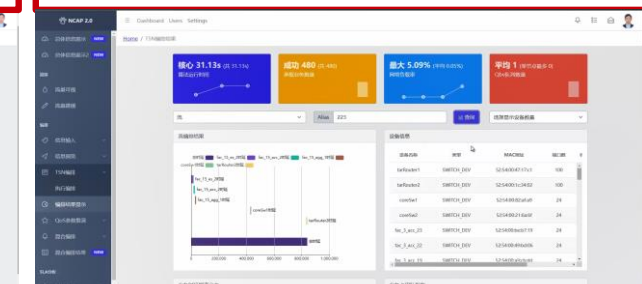

Auto. Topology Discovery

Centralized Configuration
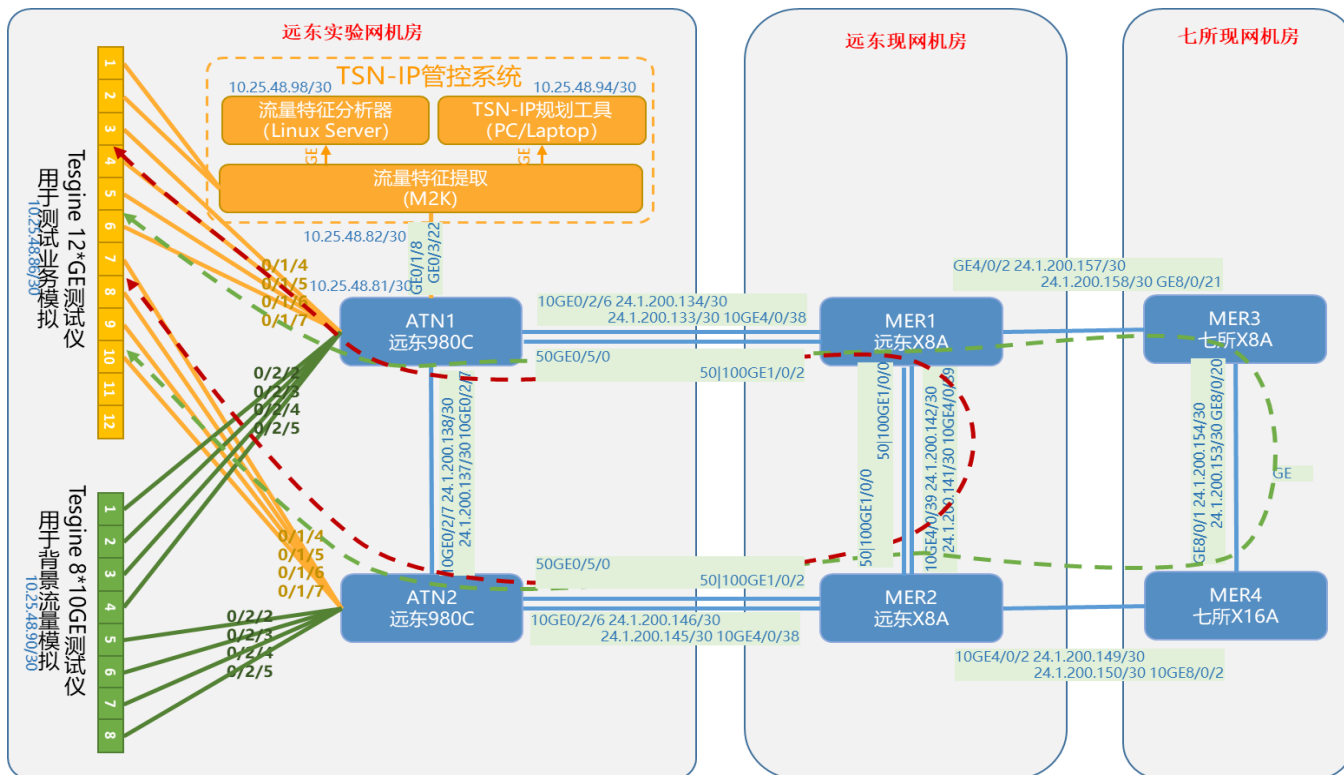
Online Traffic Analysis

TAS Scheduler Service

Visible SLA Performance

Real Time SLA Analysis

Huawei "TSN-IP" demo project

- "TSN-IP is a joint demo project between China Unicom and Huawei, using SRv6 over TSN queueing and forwarding.
- This demonstration shows that multiple time critical communications can be served in one converged transport network , while maximum delay is always lower than required and planned delay, ensuring E2E boundedness of service latency even when background traffic congestion and instantaneous traffic burst happens.

Standard Contributions

Area	Topic	Standard/Drafts
IETF DetNet	RFC 8655	Deterministic Networking Architecture
	RFC 8939	Deterministic Networking (DetNet) Data Plane: IP
	RFC 9023	Deterministic Networking (DetNet) Data Plane: IP over IEEE 802.1 Time-Sensitive Networking (TSN)
	DetNet bounded latency	draft-ietf-detnet-bounded-latency
	Controller Plane	draft-ietf-detnet-controller-plane-framework
	Ring Protection	draft-jiang-detnet-ring
	Detnet YANG Model	draft-ietf-detnet-yang
	Redundancy Protection	draft-geng-spring-sr-redundancy-protection
	Redundancy Policy	draft-geng-spring-redundancy-policy
	DetNet SRv6 Data Plane Encapsulation	draft-geng-detnet-dp-sol-srv6
	SRv6 for DetNet	draft-geng-spring-srv6-for-detnet
	IPv6 Extension Header for DetNet	draft-pthubert-detnet-ipv6-hbh

Area	Standard Draft
IEEE 802.1 TSN	IEEE Std 802.1Qav/Qbv/Qci/Qch TSN shapers
	IEEE Std 802.1AS-2020 Clock synchronization
	IEEE Std 802.1CB Frame replication and elimination for reliability
	IEEE Std 802.1CS Link-local Registration Protocol
	P802.1DC Quality of Service Provision by Network Systems
	P802.1ASdm/ASdr Clock sync hot standby
	P802.1DF TSN for Service Provider Networks
	IEEE/IEC 60802 TSN for Industrial Automation
	P802.1 Qdj Configuration Enhancements for Time-Sensitive Networking
	P802.1 Qcw YANG Data Models for Scheduled Traffic, Frame Preemption, and Per-Stream Filtering and Policing

Blue colored standards are published

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Thank you