DETERMINISTIC6G

Tutorial:
TSN & DetNet

Balázs Varga (Ericsson)

European Wireless, Rome – October 2nd, 2023

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TSN & DetNet Tutorial

TSN: Time-Sensitive Networking
DetNet: Deterministic Networking

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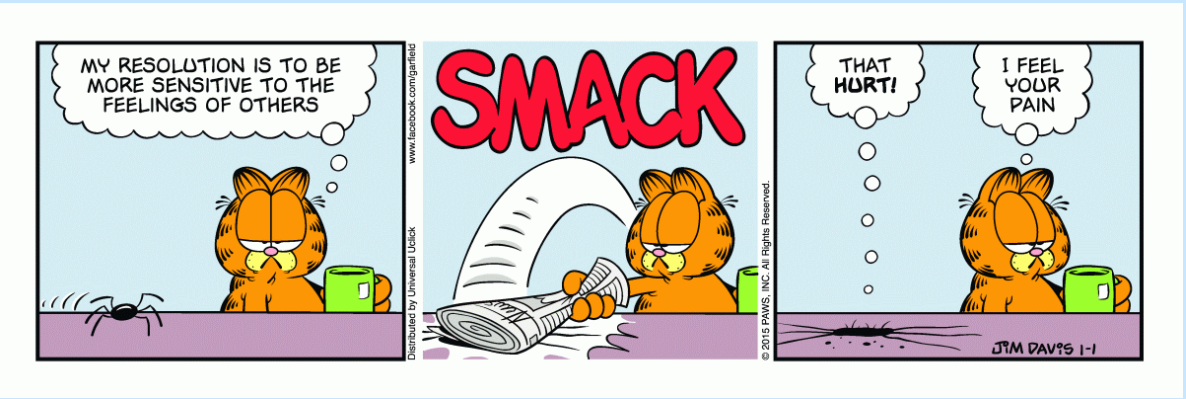
DetNet: Deterministic Networking



Balázs Varga, János Farkas [Ericsson]
EW2023, Rome

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Overview

- IEEE 802.1 Time-Sensitive Networking (TSN) standards specify the base technology for deterministic behavior in IEEE 802 networks and are continuing to evolve to address market needs. Furthermore, TSN profile specifications are being developed to ensure interoperability and ease integration of TSN into various markets, e.g., industrial automation, automotive, and aerospace.
- In addition, the technology is being extended to cover a wider range in networking, which includes, e.g., IETF Deterministic Networking (DetNet) for IP and MPLS networks.
- Furthermore, TSN and DetNet are being extended to wireless technologies, e.g., Cellular and Wi-Fi to support mixed wireline and wireless deployments.

Deterministic Packet Transport
What is it?

Deterministic transport:

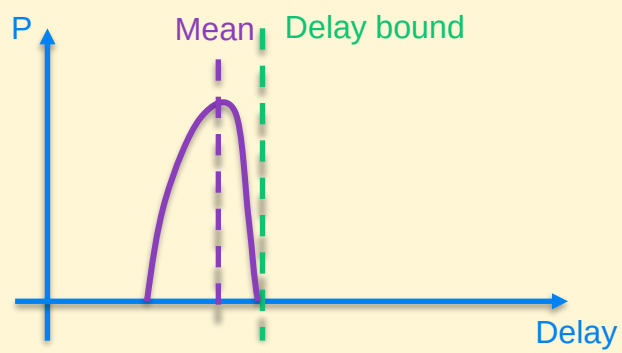
- provides guaranteed delivery with bounded low latency, low delay variation, and extremely low loss
- extreme values (µsec, lossless, …) often appear, but the main target is guaranteed upper bound on these parameters
- operates over Layer-2 bridged and Layer-3 routed segments

Traditional Service

- Target: Elastic traffic
- Network centric:
  - Optimal network utilization
  - Maximize throughput (stat.mpx)
  - Good average latency
- Delay probability curves with tail
- Bounding the latency means losing packets (or overprovisioning)

Deterministic Service

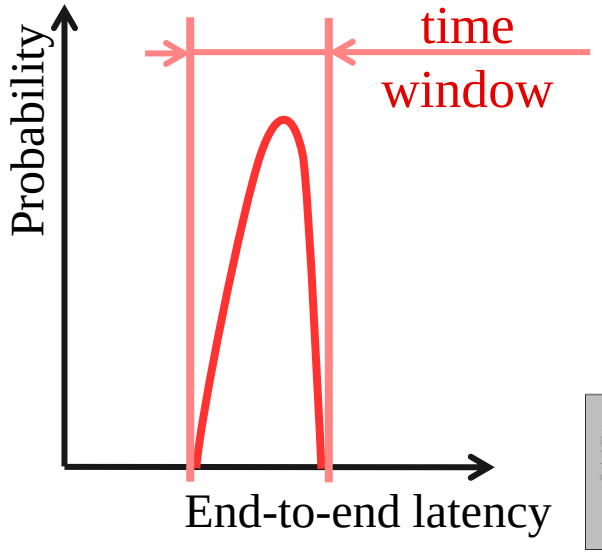
- Target: Delivery sensitive traffic
- Service centric:
  - Optimal service parameters
  - Zero congestion loss
  - Bounded latency
- Delay probability curves bounded
- In-time delivery ensured by resource allocation

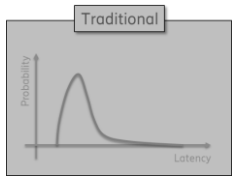


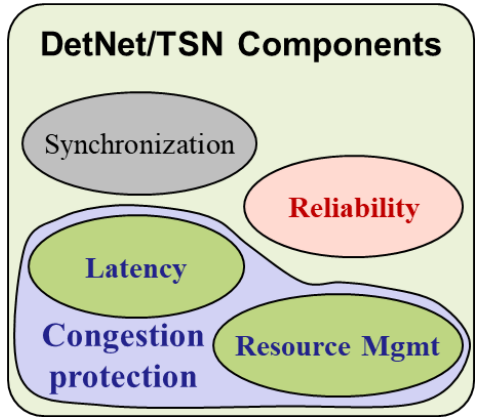
TSN and DetNet: Deterministic Packet Networking

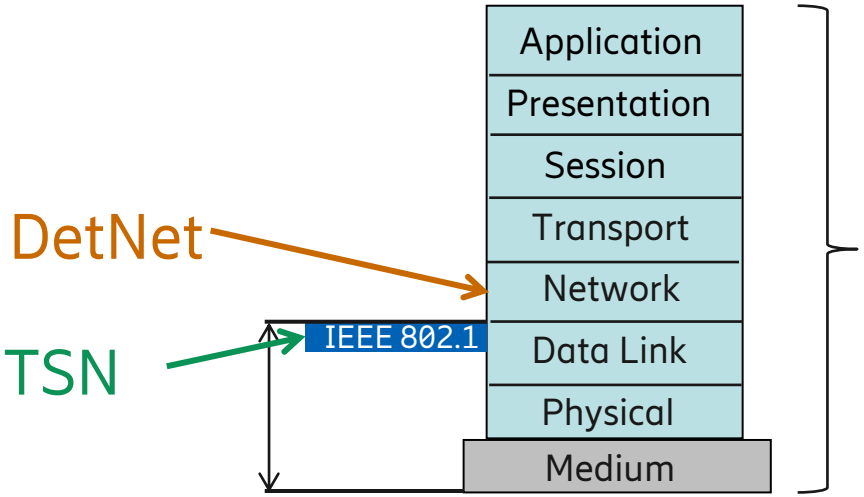
At-a-glance

- **The Right Packet at The Right Time**
  - Deterministic data packet delivery
  - Packet delivery within a time window without loss or delay due to congestion or errors
- Provided by
  - IETF Deterministic Networking (DetNet) at Layer 3 (IP/MPLS routing)
  - IEEE 802.1 Time-Sensitive Networking (TSN) at Layer 2 (Ethernet bridging)



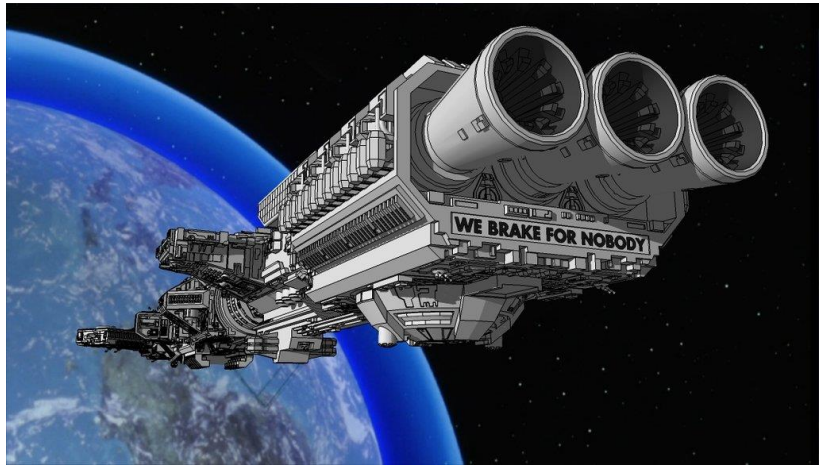






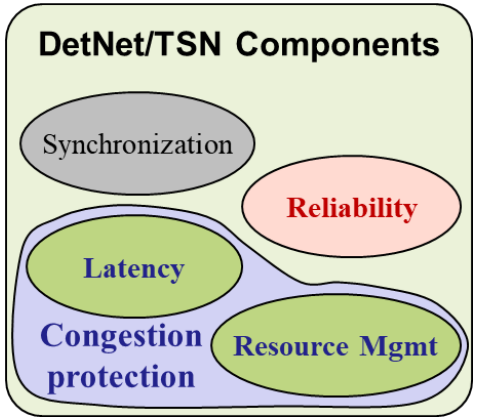
Essence of Deterministic Communications

We brake for nobody …



- Endpoints:
  - NO TRAFFIC CONTROL LOOP: endpoints do not throttle back

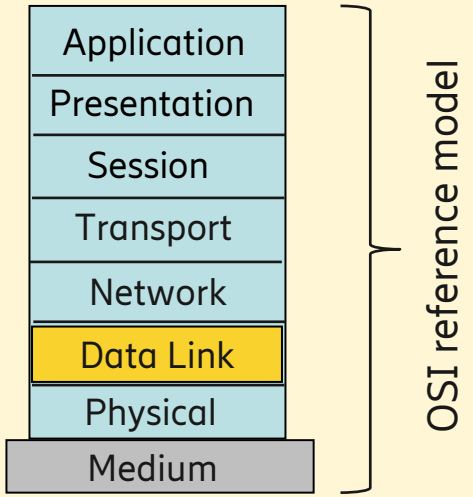
- Congestion Protection (Queuing + Reservation)
  - ZERO LOSS: due to congestion
  - GUARANTED: bounded latency (note: average is not as important)
- Service Protection (Packet Replication/Elimination)
  - ZERO SWITCHOVER TIME: Outage-less operation
    (Addresses random media errors and equipment failures)
- Explicit Routes (Nailed Down Paths)
  - ZERO CONVERGENCE TIME: impact of the convergence of bridging/routing protocols (i.e., temporary interruptions) are bypassed. TSN/DetNet uses already defined explicit routing techniques (no new ones).



Agenda

- TSN (IEEE 802.1)
  - Some history
  - Building Blocks
  - Standards, Profiles
  - Selected functionalities
- DetNet (IETF DetNet WG)
  - Architecture
  - Building blocks
  - Data Planes
  - Selected functionalities

TSN


Application
Presentation
Session
Transport
Network
Data Link
Physical
Medium
OSI reference model

Standardization: History and presence

From AVB to TSN and DetNet

IEEE 802.1 Audio Video Bridging (AVB) Task Group

- Started in 2005
- Address professional audio, video market
- Consumer electronics
- Automotive infotainment

AVB Standards

- IEEE Std. 802.1AS-2011 – generalized Precision Time Protocol (gPTP)
  - A Layer 2 profile of the IEEE 1588 Precision Time Protocol (PTP)
- IEEE Std. 802.1Qav – Forwarding and Queuing Enhancements for Time-Sensitive Streams (FQTSS):
  - Specifies Credit-Based Shaper (CBS)
- IEEE Std. 802.1Qat – Stream Reservation Protocol (SRP)
  - Registration and reservation of time-sensitive streams
- IEEE Std. 802.1BA – AVB Systems
  - Provides an overall AVB architecture and AVB profiles
- CBS + SRP to provide delays under 250 µs per bridge

IEEE 802.1 Time-Sensitive Networking (TSN) TG

- AVB features become interesting for other use cases, e.g.
  - Industrial, Automotive, etc.
- AVB was not an appropriate name to cover all use cases
- AVB TG was renamed to TSN TG in 2012

IETF DetNet WG

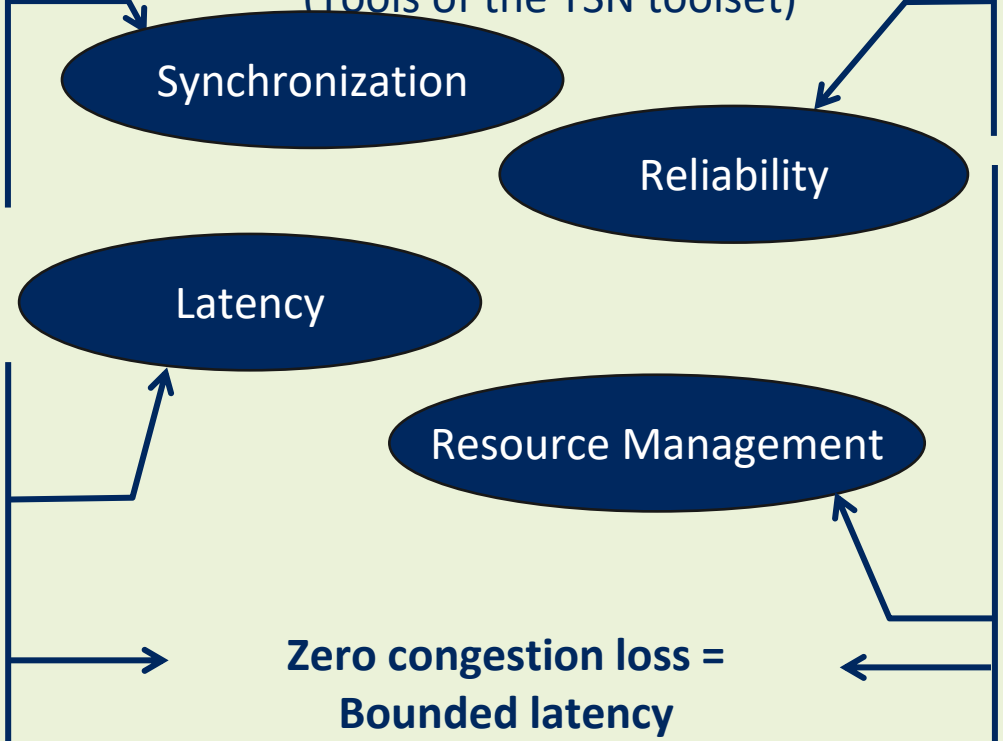
- BoF session in 2014 (IETF-91)
- DetNet WG started in October 2015
- In close cooperation with IEEE 802.1 TSN

Time-Sensitive Networking (TSN) Profiles (Selection and Use of TSN tools)

Audio Video Bridging [802.1BA-2021]	Fronthaul [802.1CM/de]	Industrial Automation [IEC/IEEE 60802]	Automotive In-Vehicle [P802.1DG]	Service Provider [P802.1DF]	Aerospace Onboard [IEEE P802.1DP / SAE AS6675]

TSN Components

(Tools of the TSN toolset)



Time synchronization:
- Timing and Synchronization [802.1AS-2020] (a profile of IEEE 1588)
- Hot Standby [P802.1ASdm]
- YANG [P802.1ASdn]
- Inclusive Terminology [P802.1ASdr]
- Support for Half-duplex [P802.1ASds]

Bounded low latency:
- Credit Based Shaper [802.1Qav]
- Frame Preemption [802.1Qbu & 802.3br]
- Scheduled Traffic [802.1Qbv]
- Cyclic Queuing and Forwarding [802.1Qch]
- Asynchronous Traffic Shaping [802.1Qcr]
- Shaper Parameter Settings [P802.1Qdq]
- Enhanced CQF [P802.1Qdv]
- QoS Provisions [P802.1DC]
- Cut-Through Forwarding [P802.1DU]

Zero congestion loss = Bounded latency

High availability / Ultra reliability:
- Frame Replication and Elimination [802.1CB]
- Path Control and Reservation [802.1Qca]
- Per-Stream Filtering and Policing [802.1Qci]
- Hot Standby [P802.1ASdm]

Dedicated resources & API:
- Stream Reservation Protocol [802.1Qat]
- Link-local Registration Protocol [802.1CS]
- TSN Configuration [802.1Qcc]
- Foundational Bridge YANG [802.1Qcp]
- YANG for CFM [802.1Qcx]
- YANG for 802.1Qbv/Qbu/Qci [802.1Qcw]
- YANG for CBS [P802.1Qdx]
- YANG for MSTP [P802.1Qdy]
- YANG for LLDP [P802.1ABcu]
- YANG & MIB for FRER [P802.1CBcv]
- Extended Stream Identification [P802.1CBdb]
- LLDPv2 for Multiframe Data Units [P802.1ABdh]
- Resource Allocation Protocol [P802.1Qdd]
- TSN Configuration Enhancements [P802.1Qdj]
- Multicast and Local Address Assignment [P802.1CQ]

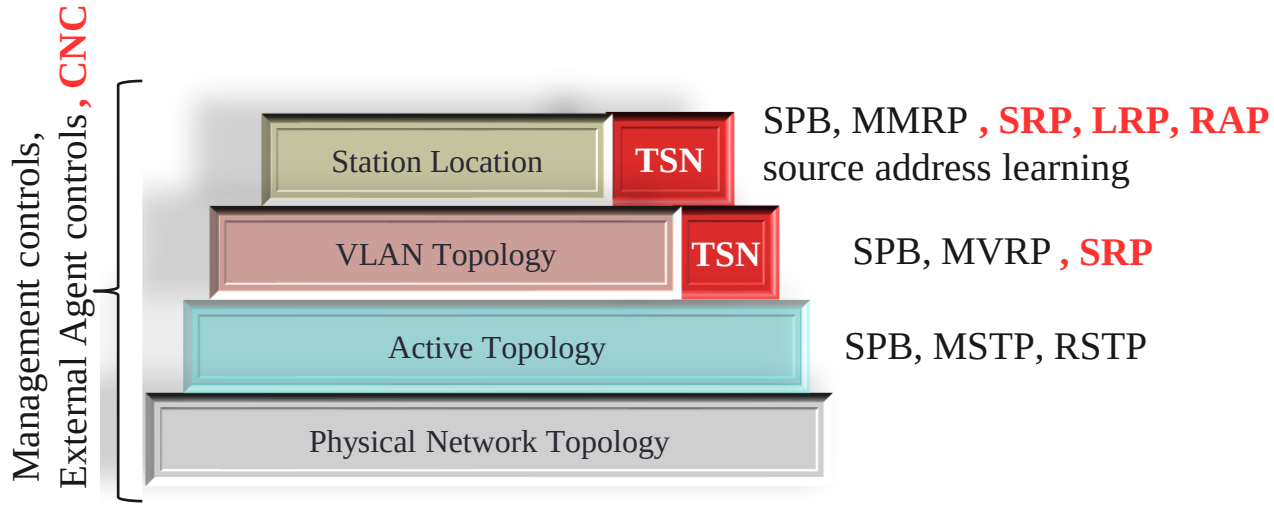
Note: A 'P' in front of '802.1' indicates an ongoing Project.

VLAN Bridging Is The Foundation

TSN as add-on

TSN extends IEEE 802.1 bridging

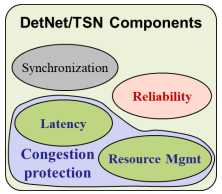
Bridging basics still apply!



SRP: Stream Reservation Protocol
LRP: Link-local Registration Protocol
RAP: Resource Allocation Protocol

RSTP: Rapid Spanning Tree Protocol
MSTP: Multiple Spanning Tree Protocol
SPB: Shortest Path Bridging
MVRP: Multiple VLAN Registration Protocol
MMRP: Multiple MAC Registration Protocol

Timing and Synchronization
[802.1AS-2020]



- IEEE Std 802.1AS
  - specifies the generalized Precision Time Protocol (gPTP)
  - is a proper profile of the IEEE Std 1588 Precision Time Protocol (PTP)
  - includes protocol features additional to PTP
  - includes performance requirements
  - provides transport of time synchronization
  - specifies the Best Master Clock Algorithm (BMCA)
- 802.1AS-2020 adds
  - multiple gPTP domains
  - external port configuration
  - basic redundancy
  - and more ...

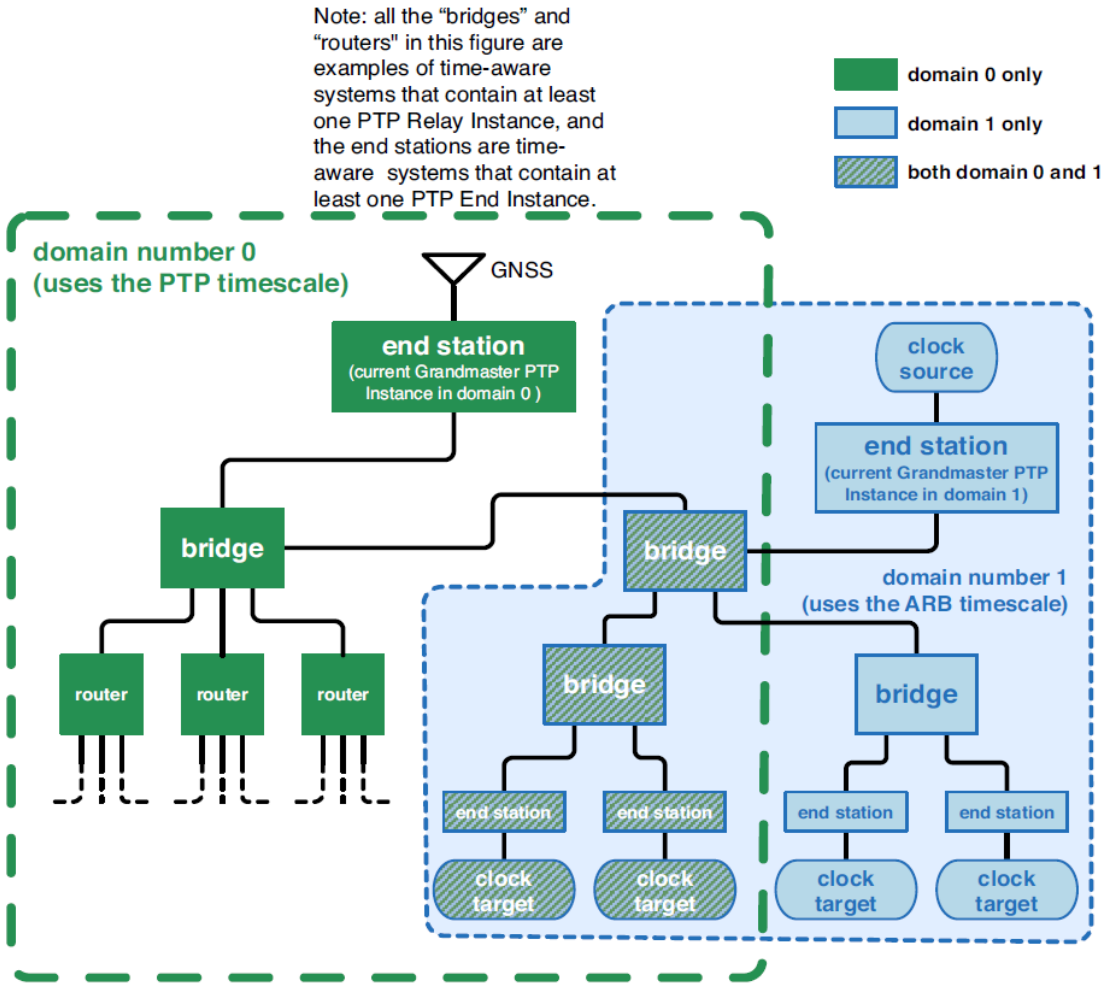
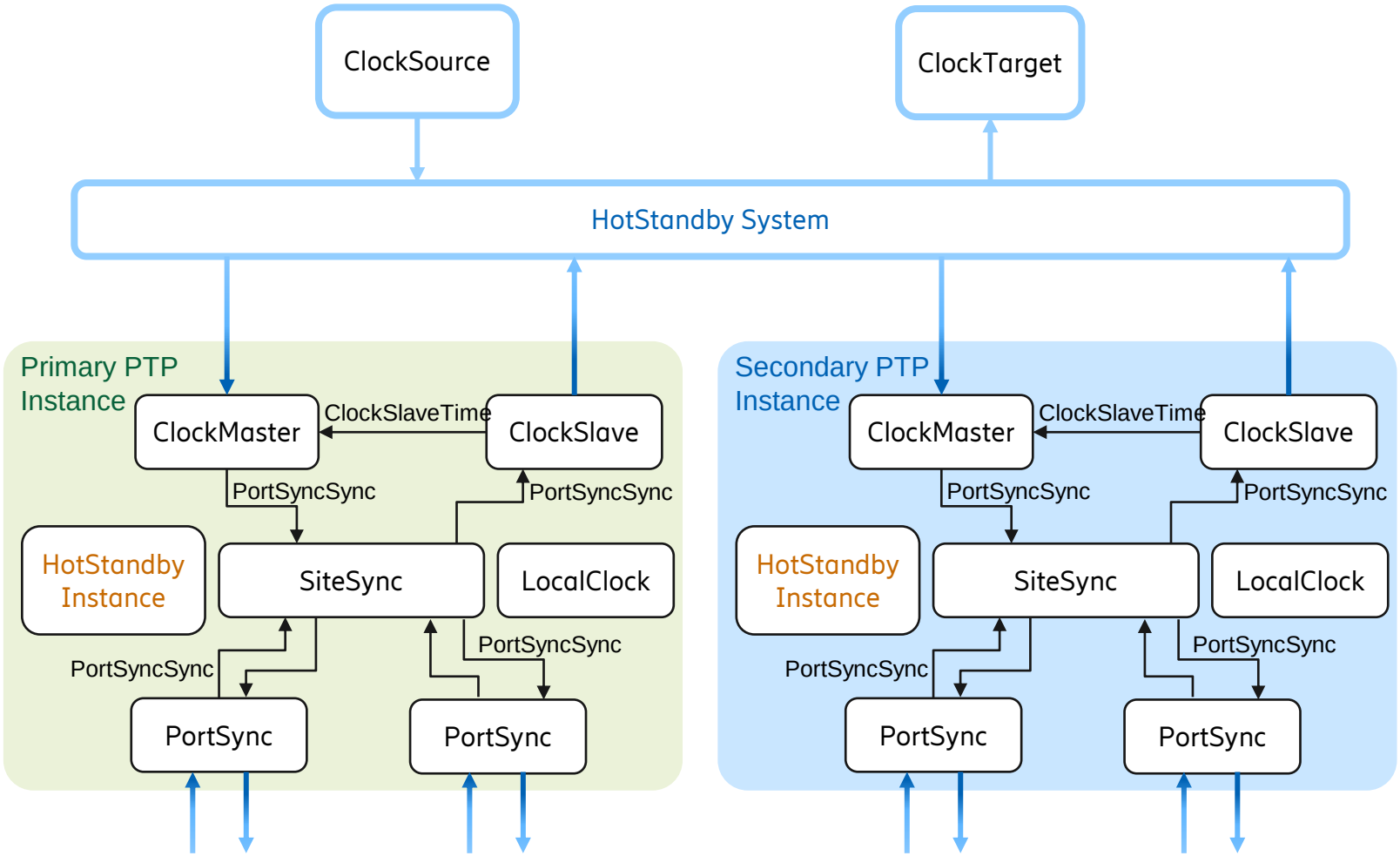


Figure 7-3—Time-aware network example for multiple gPTP domains

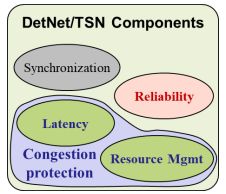
Sync: Hot Standby [P802.1ASdm]



HotStandbySystem entity interacts with the primary and secondary PTP Instances in order to provide a single redundant time to the application

HotStandbyInstance entity monitors the PTP Instance to determine whether it is faulted

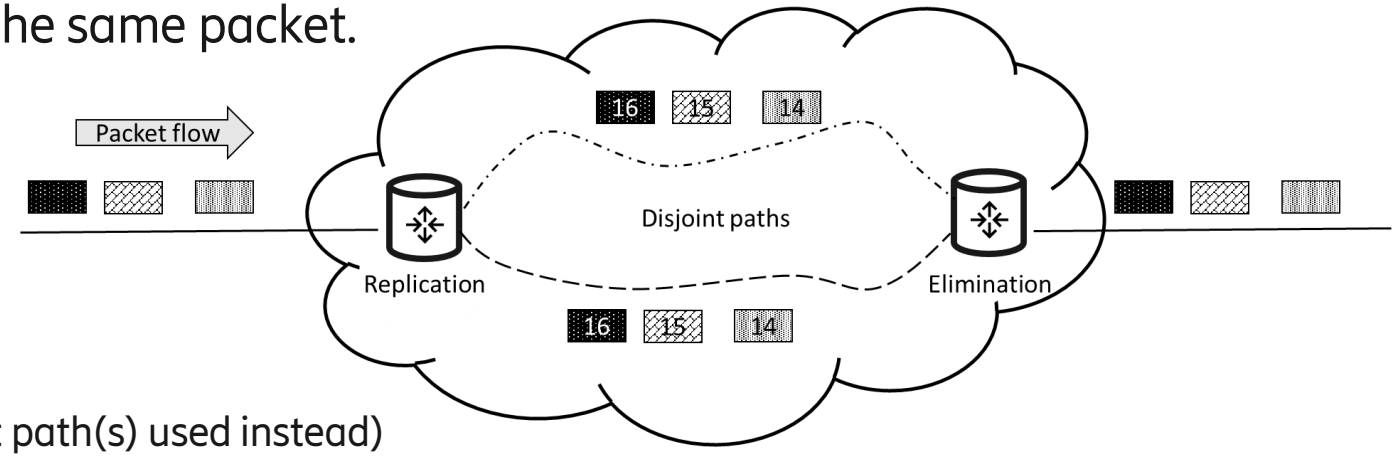
Frame Replication and Elimination for Reliability [802.1CB-2017]



- Avoids frame loss due to equipment/link failure
  - Send frames on multiple maximally disjoint paths, then combine and delete extras
- Replication and Elimination (R/E) are per-packet reliability functions
  - Use meta-data carried with the packets
    - (1) to which flow the packet belongs and
    - (2) which packets i.e., are replicas of the same packet.
- NO failure detection or switchover !!!

Upper layer
Sequencing function (7.4)
Stream splitting function (7.7)
Individual recovery function (7.5)
Sequence encode/decode function (7.6)
Stream identification (Clause 6)
Lower layer

Figure 7-2—Frame Replication and Elimination for Reliability functions



- Solved issues:
  - Link/Node failure (replica packet(s) over redundant path(s) used instead)
  - Any other packet drop/loss (e.g., due to BER, etc.)

TSN: FRER function

How it works …

- IEEE 802.1CB details:
  - Stream Identification functions (passive, active)
  - Sequence Number: R-Tag (format defined)
  - Replication: per packet replication (and generates Sequence Numbers)
  - Elimination: per packet duplicate elimination (2 algorithms defined: VectorRecovery, MatchRecovery) (SequenceHistory, History-window, TakeAny, etc.)

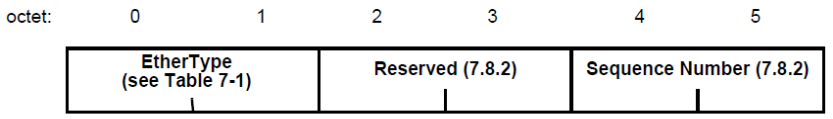
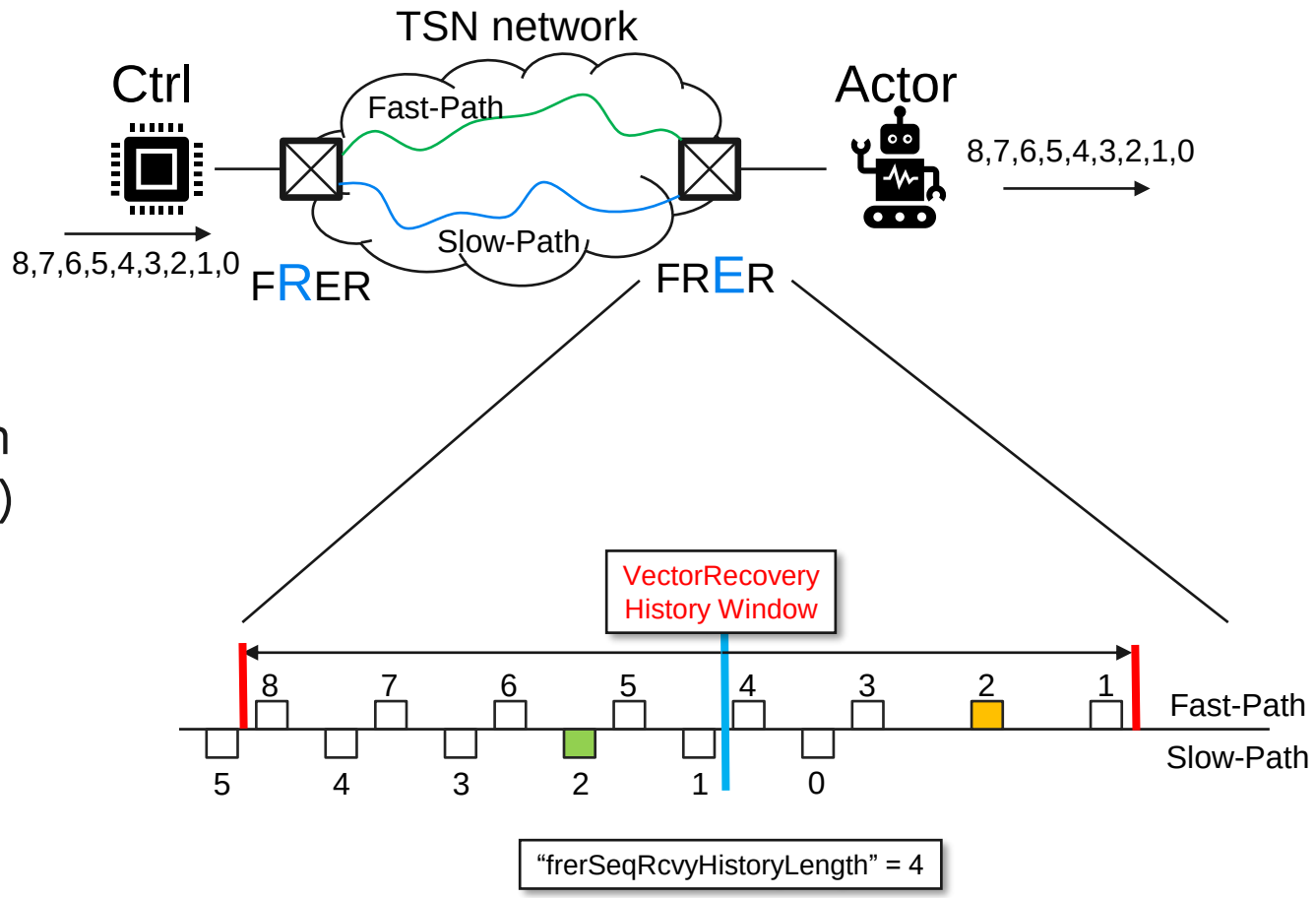


Figure 7-4—R-TAG format

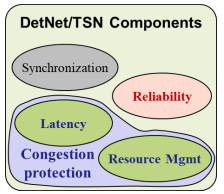
Field	Offset	Length
Destination MAC address	0	6
Source MAC address	6	6
C-TAG EtherType	12	2
Priority, DE, VLAN ID	14	2
R-TAG EtherType	16	2
Reserved	18	2
Sequence number	20	2
Payload Length/EtherType	22	2
Data	24	*n*
Frame Check Sequence	24+*n*	4

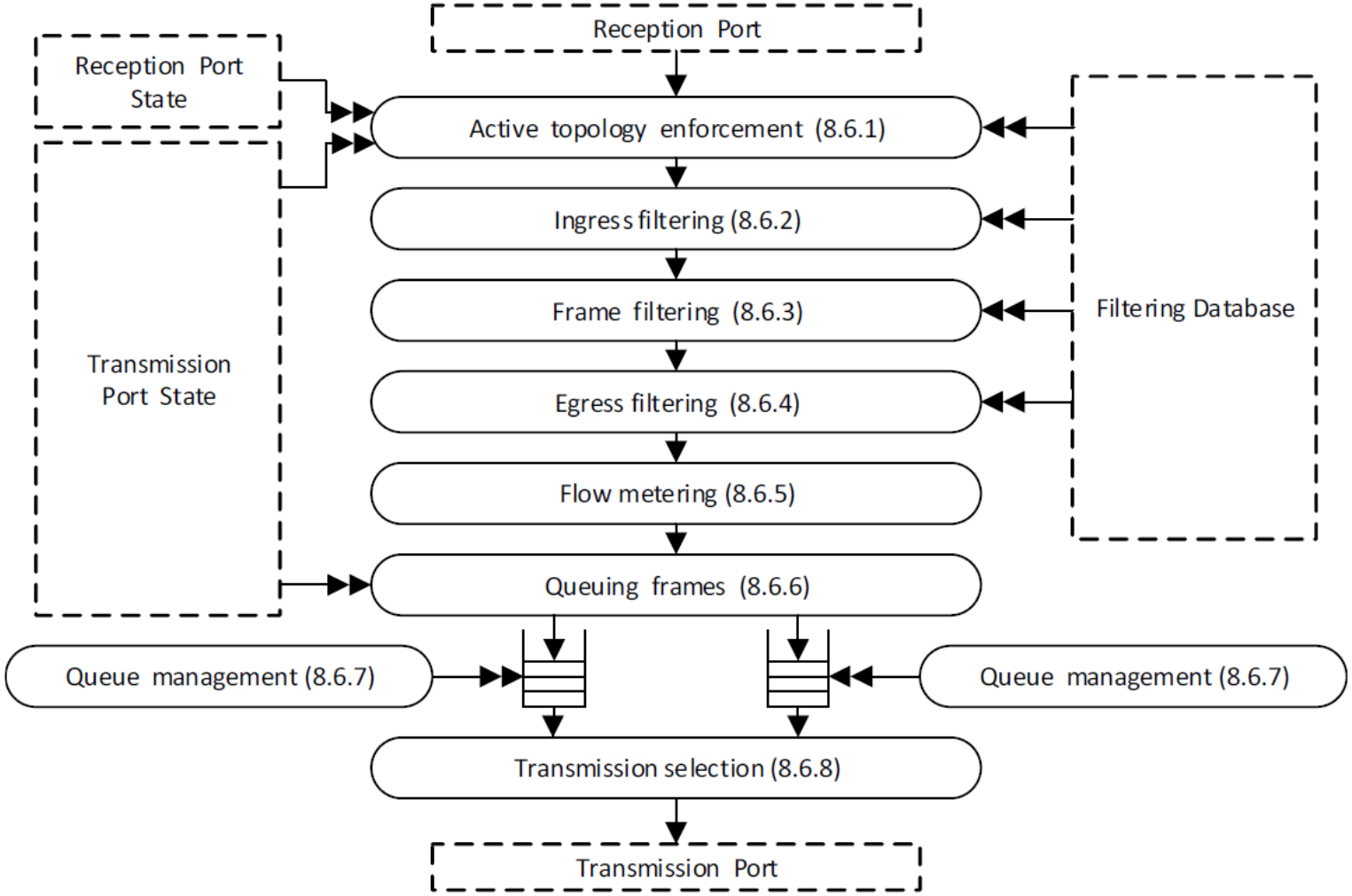
Figure 8-3—Example Ethernet frame format



Dealing with latency

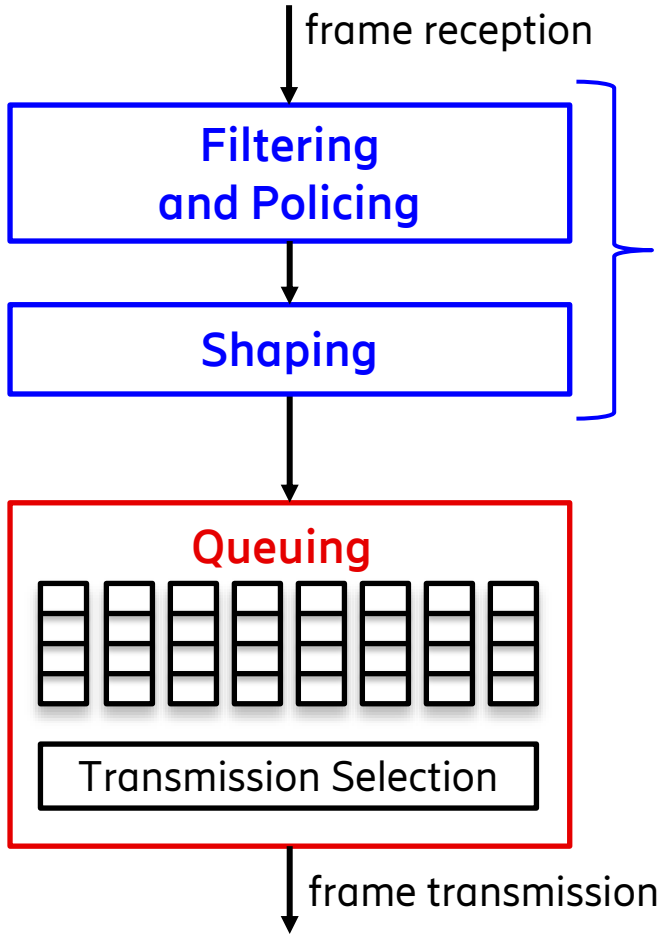
Bridge Forwarding Process Functions





Dealing with latency …

Illustration of QoS Functions



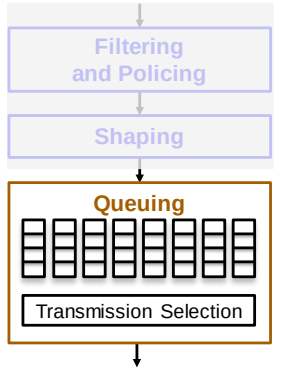
can be **Per Stream, Per Class**, etc.

Per Class

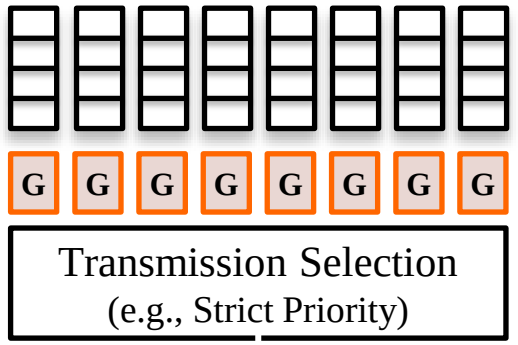
can be viewed as a hierarchical approach

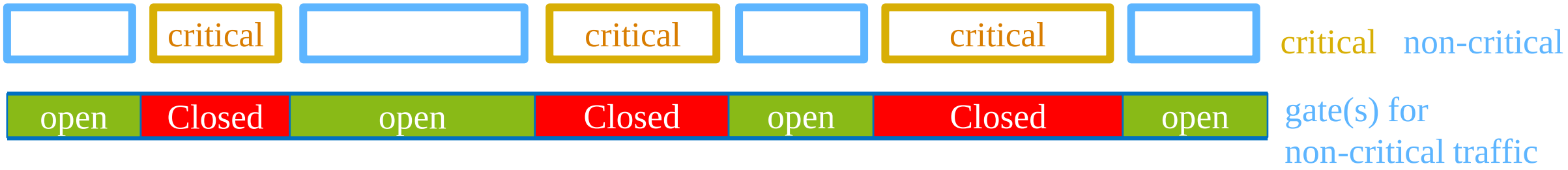
note: other functions are not shown in this figure, e.g., relay, reliability

Scheduled Traffic
[802.1Qbv-2015]



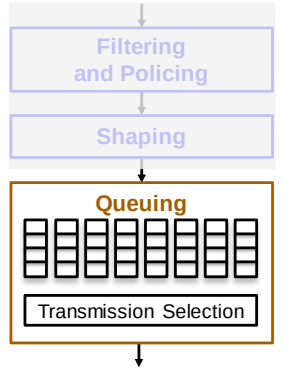
- Reduces latency variation for frames with known timing
- Time-based control and programming of the bridge queues
- Time-Gated queues
  - Gate (G): Open or Closed
- Periodically repeated time schedule
- Time synchronization is needed



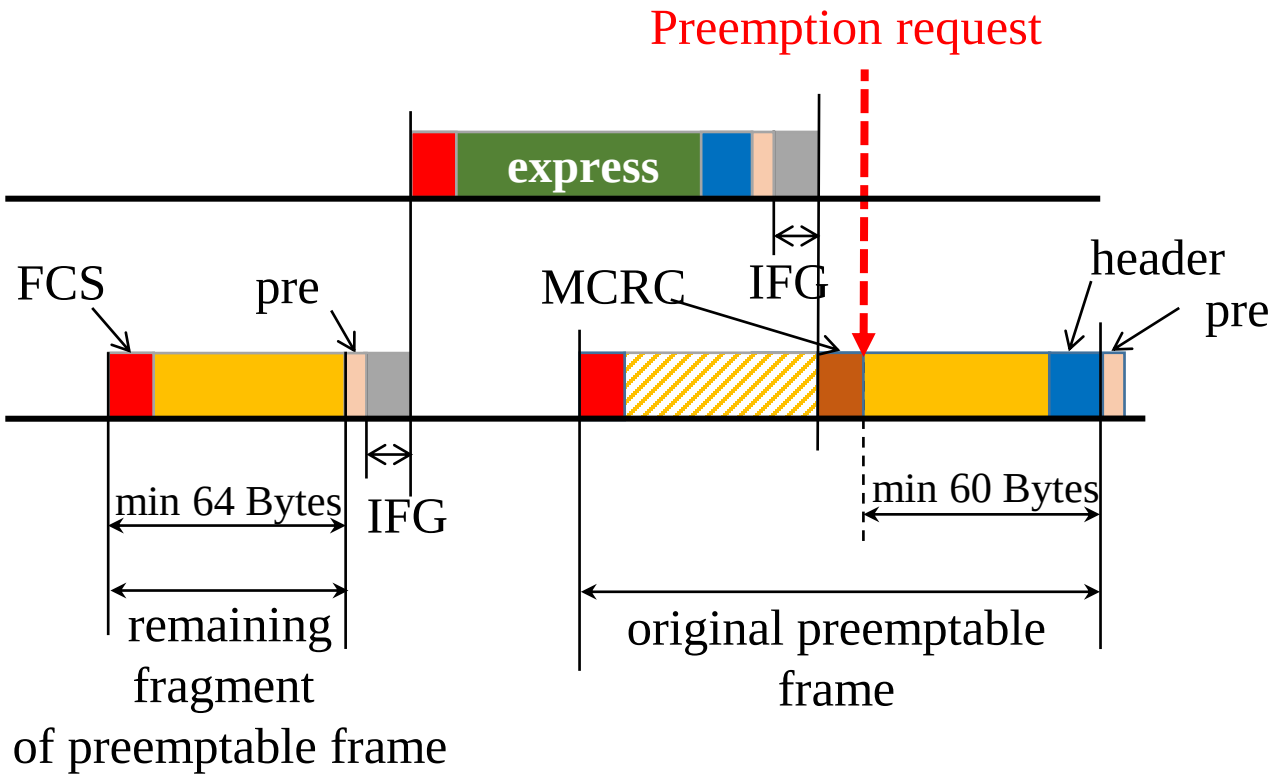


Note: gate of non-critical data can be closed in advance to protect critical data

Interspersing Express Traffic
[802.3br] Frame Preemption



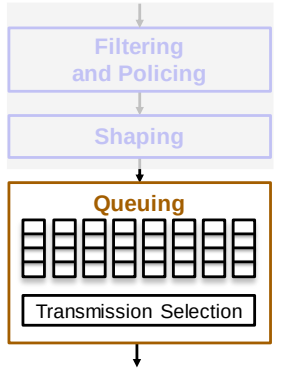
- Express frames can suspend the transmission of preemptable frames



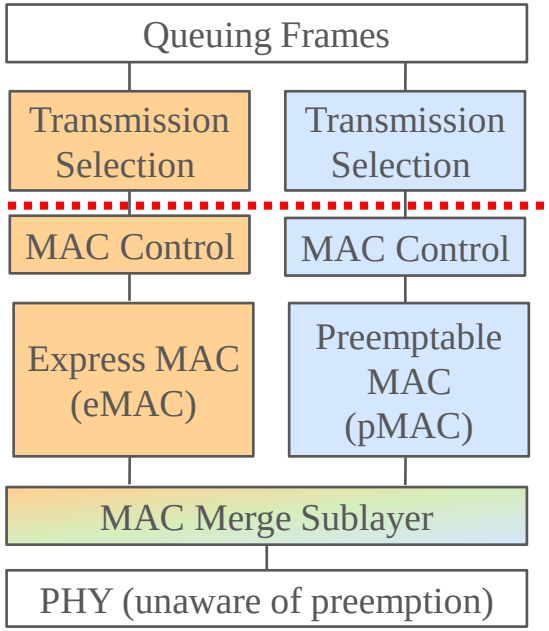
frame flow direction

pre includes Preamble and Start mPacket delimiter (SMD)

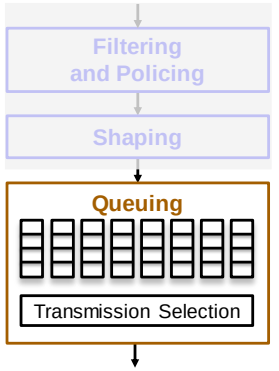
Interspersing Express Traffic …
Frame Preemption



- Time-critical frames can suspend the transmission of non-time-critical frames while one or more time-critical frames are transmitted
- Specified by
  2. 802.1Qbu – Frame Preemption
  1. 802.3br – Interspersing Express Traffic (IET)
- 802.1Qbu makes the adjustments needed in 802.1Q in order to support 802.3br, e.g.
  - each traffic class queue supported by the Port is assigned a value of frame preemption status
  - the possible values of frame preemption status are ***express*** or ***preemptable***
- Minimum fragment size is 64 bytes including CRC

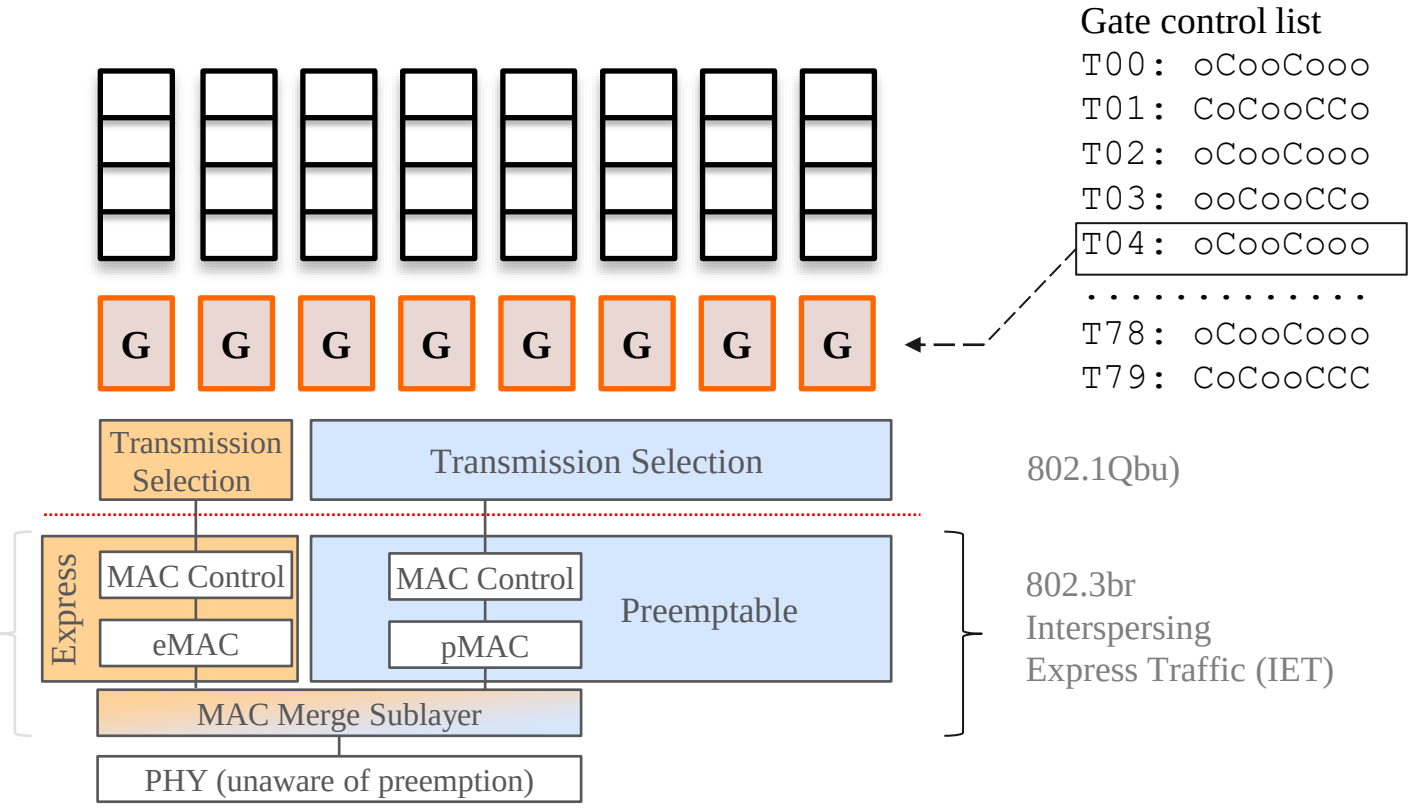


Scheduled Traffic and Frame Preemption
Combined



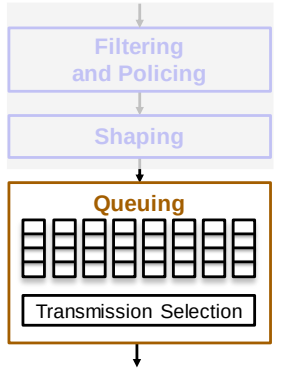
- Scheduled Traffic [802.1Qbv]
  - Time-Gated queues: open or Closed
  - Periodically repeated time schedule (gate control list)
  - Time synchronization is needed

- Frame preemption [802.1Qbu & 802.3br]
  - Express frames can suspend the transmission of preemptable frames while one or more time-critical express frames are transmitted

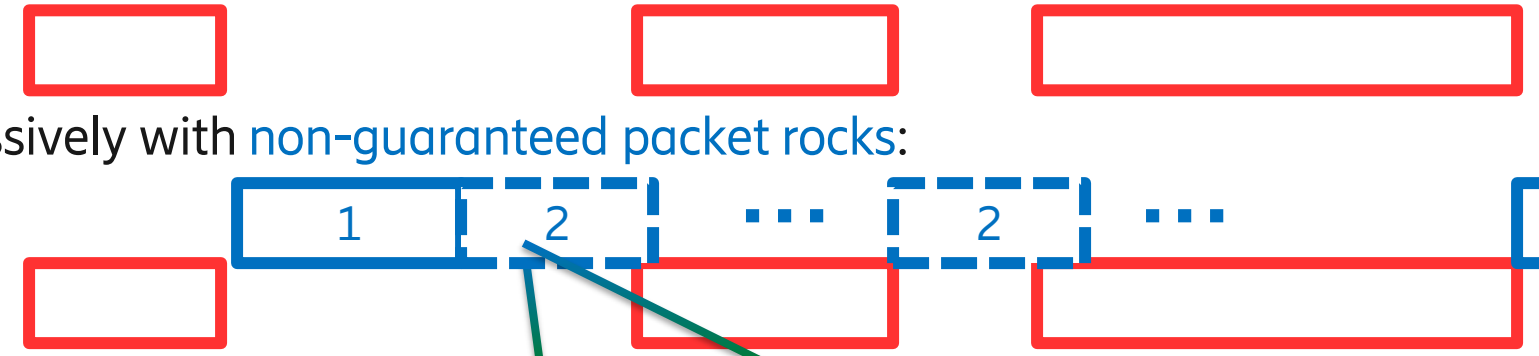


Benefits of Frame Preemption

Win-Win situation

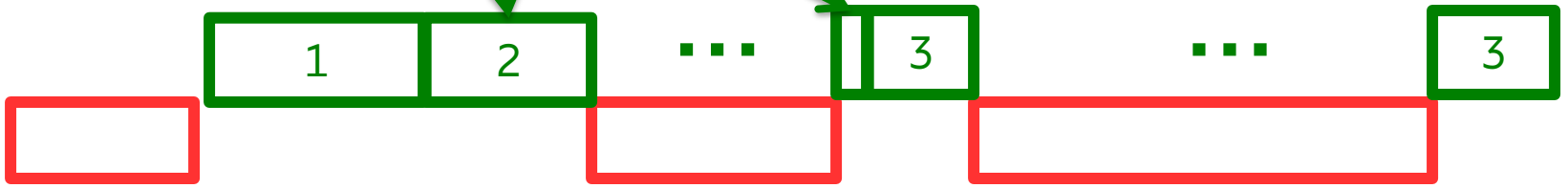


- Express frames suspend the transmission of preemptable frames
  - Decrease delay variation for express, increase bandwidth for preemptable
  - It is link local per hop, i.e., it is not IP fragmentation
- Scheduled rocks of critical packets in each cycle:

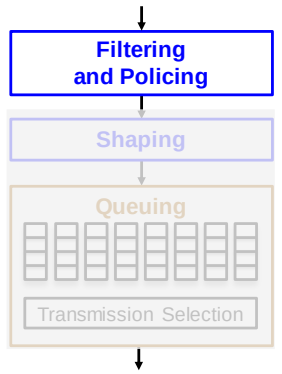


- Conflict excessively with non-guaranteed packet rocks:

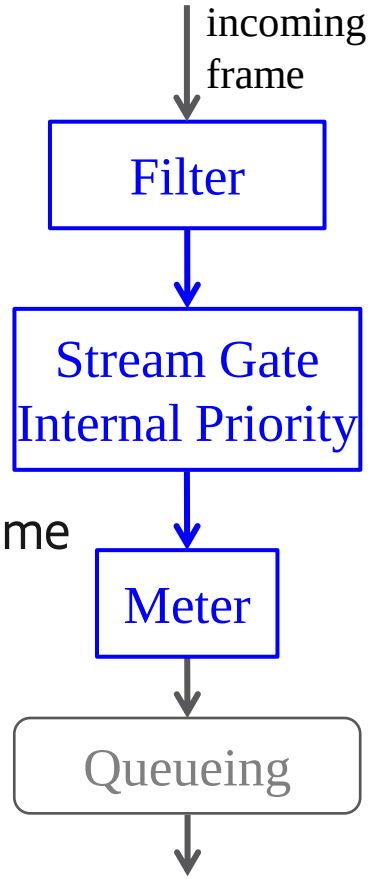
- Problem solved by preemptable sand between the rocks:

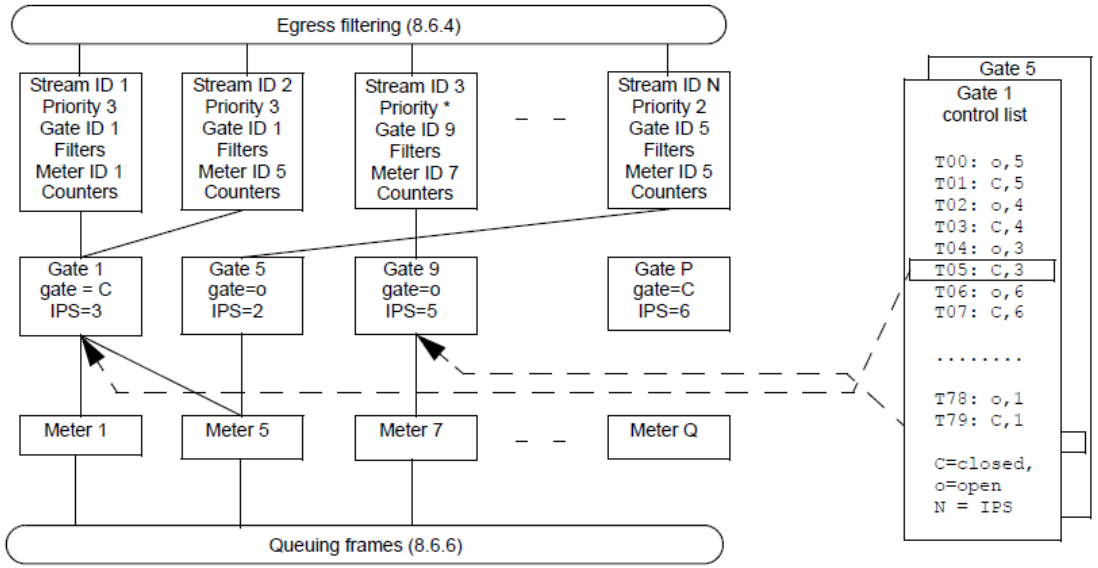


Per-Stream Filtering and Policing (PSFP)
[802.1Qci]



- Protection against bandwidth violation, malfunctioning, attacks, etc.
- Decisions on per-stream, per-priority, etc.
- Filter
  - Filters, Counters
- Stream Gate
  - Time scheduled gate
  - Open or Closed
- Internal Priority Value (IPV)
  - Bridge internal traffic class of the frame
- Meter
  - Bandwidth Profile of MEF 10.3
  - Red/Yellow/Green Marking

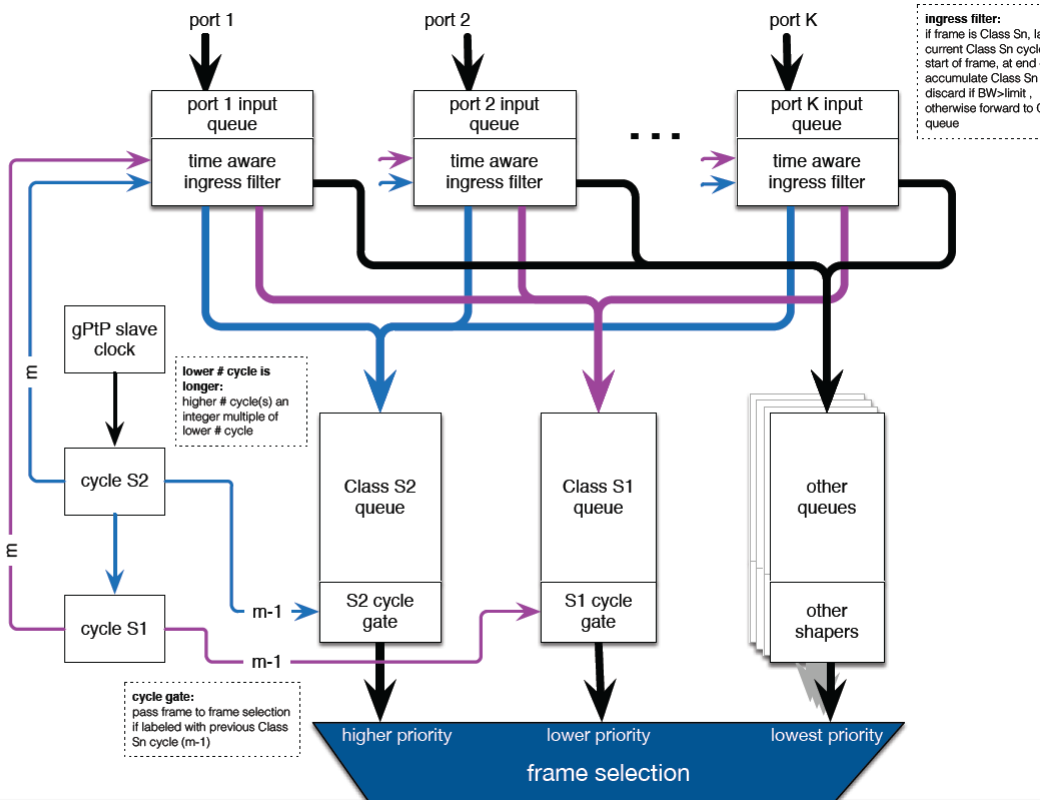




Cyclic Queueing and Forwarding (CQF) [802.1Qch]

- Synchronized cyclic enqueuing and queue draining achieve zero congestion loss and deterministic latency
- Two buffers served alternated, e.g., that of S1 and S2

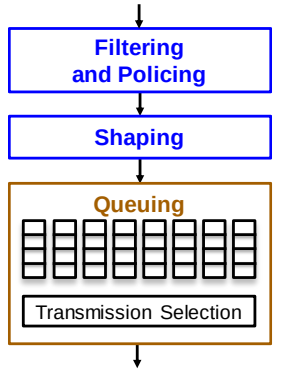
Example bridge with two delay classes, S1 and S2



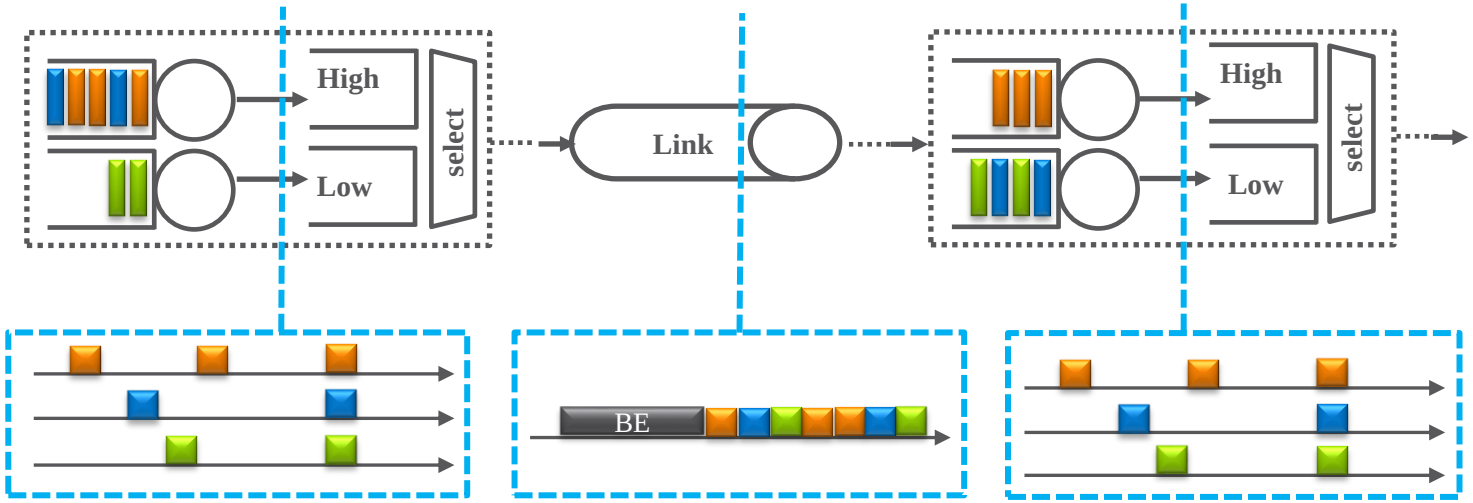
Note: Can be combined with frame preemption

http://www.ieee802.org/1/files/public/docs2014/new-tsn-mjt-peristaltic-shaper-0114.pdf

Asynchronous Traffic Shaping (ATS) [802.1Qcr]

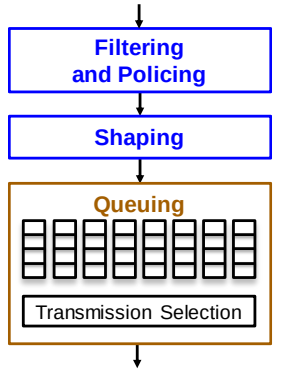


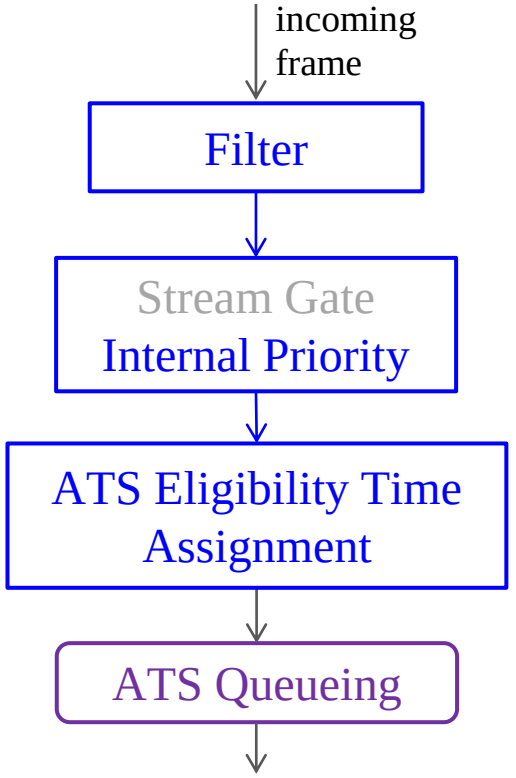
- Zero congestion loss without time synchronization
- Similar to per-flow IntServ shaping, except that:
  - All streams from one input port to the same output port share the same queue
  - A shaper state machine for a set of streams of the queue
- Smoothen traffic patterns by re-shaping per hop
- Prioritize urgent traffic over relaxed traffic
- 802.Qcr is part of 802.1Q-2022



ATS Components
[802.1Qcr]

- Filter
  - Selects treatment for frames of a stream, e.g., IPV, shaper
- Internal Priority Value (IPV)
  - Bridge internal traffic class of the frame
  - Used for ATS operations
- ATS Shaper
  - Applies a token bucket algorithm
  - Uses bridge local time variables
  - Pre-computes and assigns local eligibility times to frames
  - Eligibility time becomes effective in the queueing
  - Transmit frames that reached their Eligibility Time

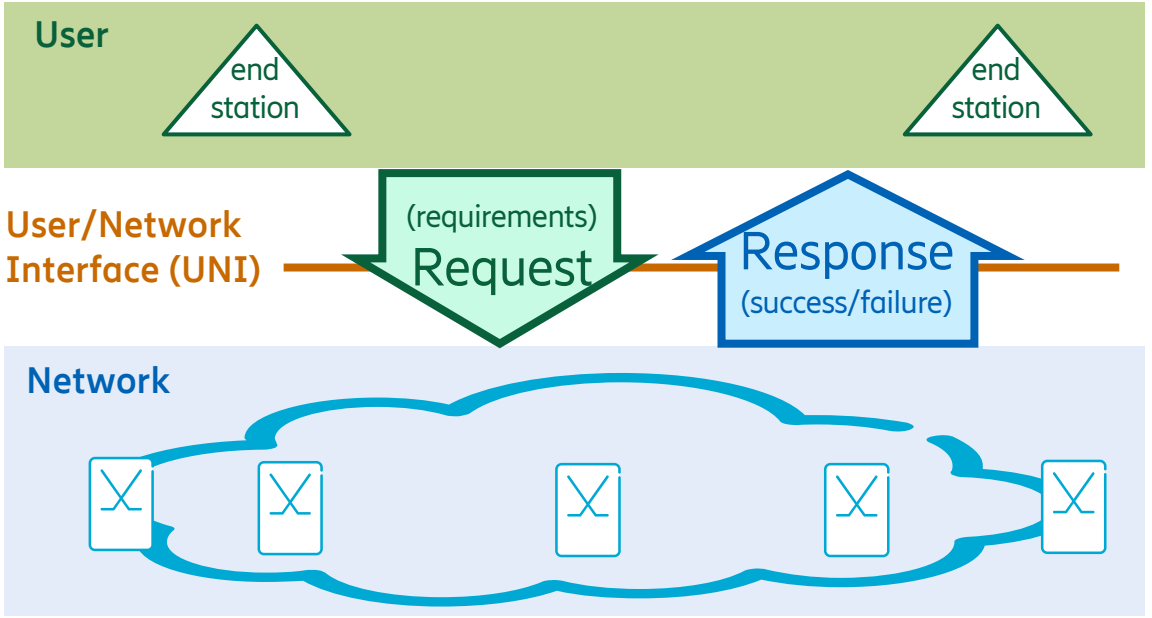




TSN Configuration

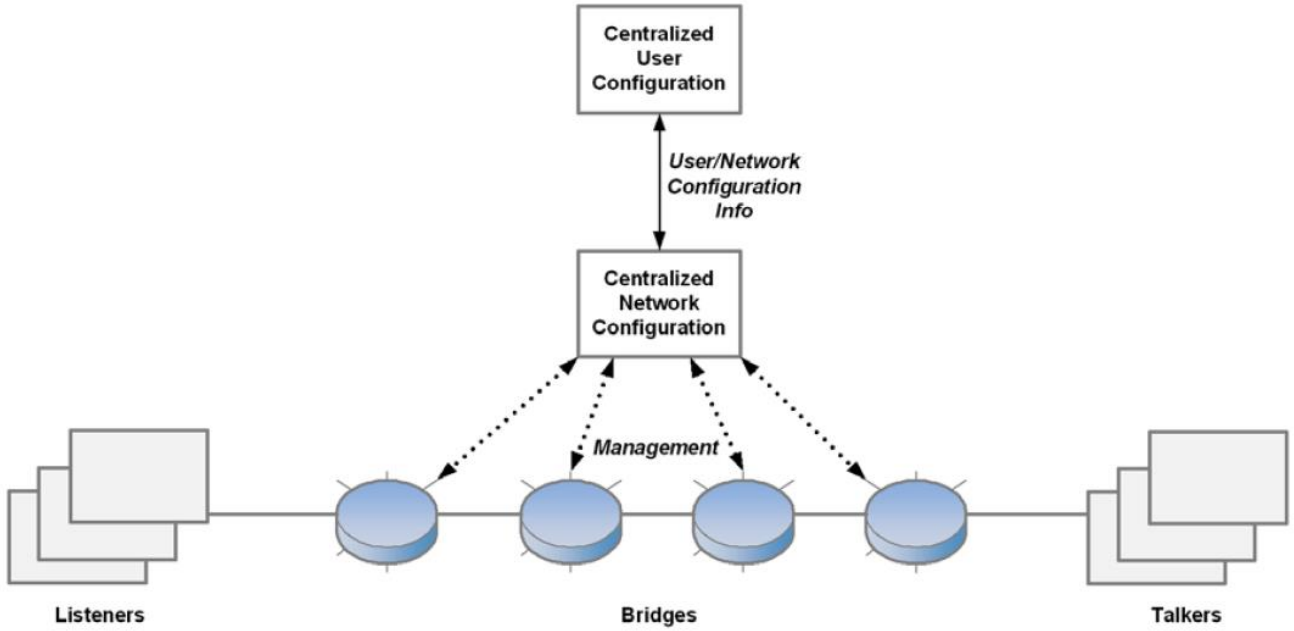
TSN configuration models and principles are specified by 802.1Qcc

- The network obtains requirements from users
- The network configures the bridges to meet user requirements
- The network returns the success or failure to the user
- Configuration information is exchanged over the User/Network Interface (UNI)
- Various protocols can be used to exchange the configuration information, e.g.:
  - remote network management protocols
  - signaling protocols
- The user/network configuration information is specified in a manner that is independent of schema, encoding, or protocol.
- Three configuration models are defined by 802.1Qcc as described in the following

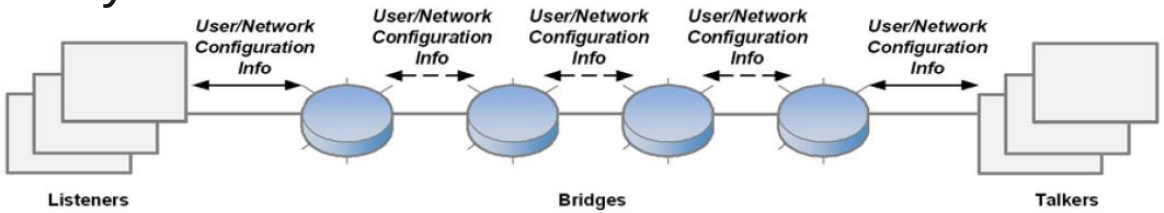


TSN Configuration
[802.1Qcc]

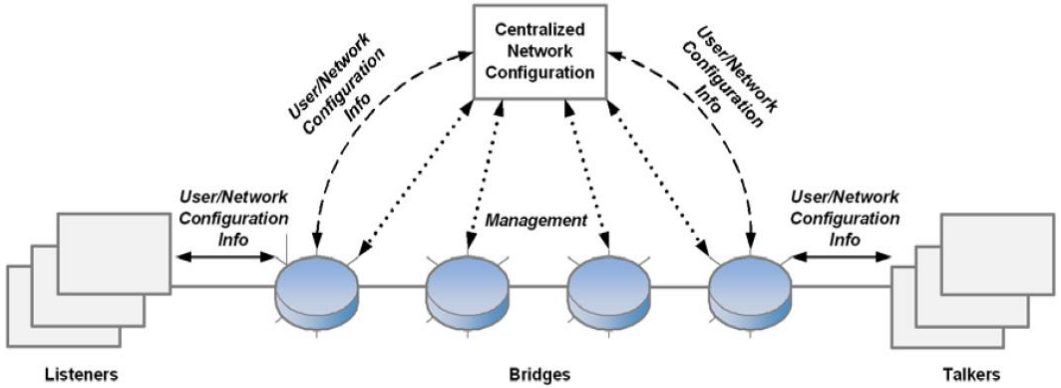
Fully centralized



Fully distributed



Centralized network & distributed user



TSN Profiles
for Various Application Areas

An IEEE 802.1 TSN Profile specification

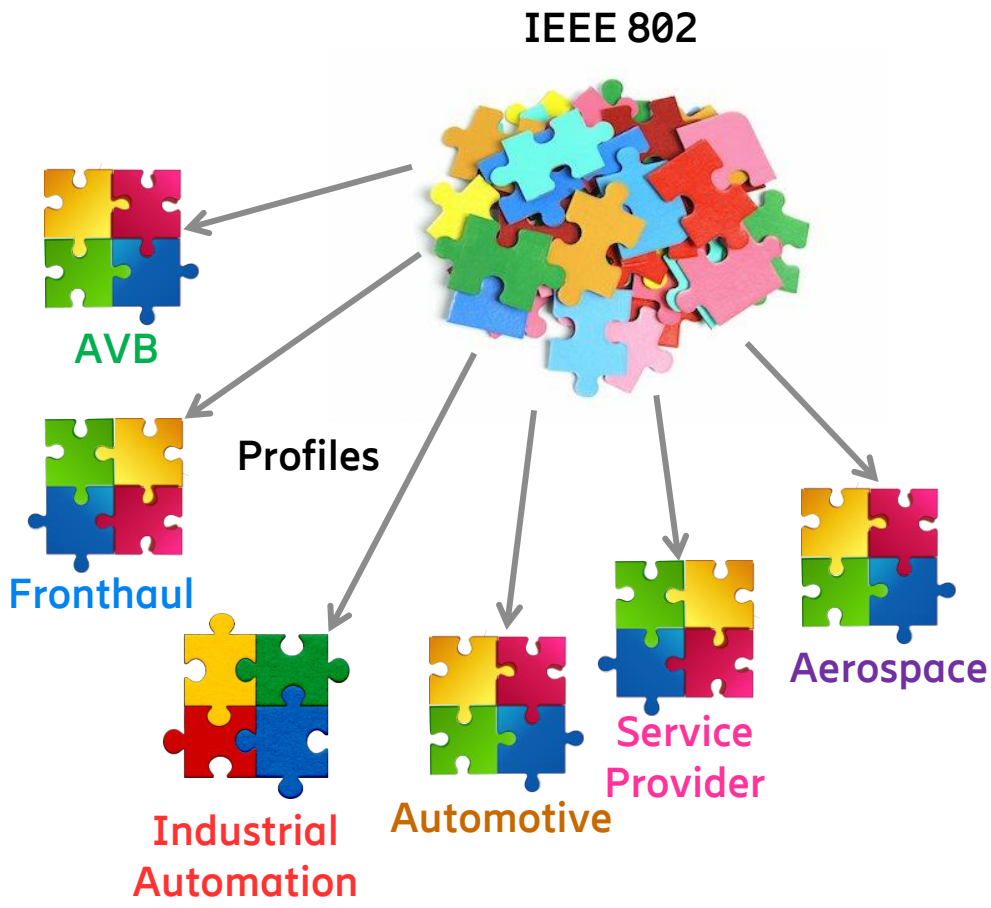
- Selects features, options, defaults, protocols, and procedures

Published IEEE 802.1 TSN profile standards:

- IEEE Std 802.1BA for Audio-Video Bridging (AVB) networks
- IEEE Std 802.1CM TSN for Fronthaul
- IEEE Std 802.1CMde Amendment on enhancements

Ongoing IEEE 802.1 TSN profile projects:

- IEC/IEEE 60802 TSN Profile for Industrial Automation
- P802.1DG TSN Profile for Automotive In-Vehicle Ethernet Communications
- P802.1DF TSN Profile for Service Provider Networks
- P802.1DP / AS6675 TSN Profile for Aerospace onboard Ethernet



Future View
Recent Developments & Hot Topics

Recent Developments

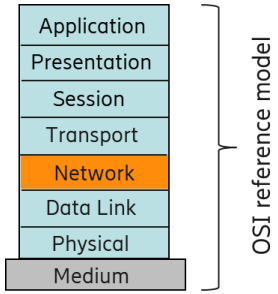
- Approved for publication by IEEE SA Standards Board
  - **802.1Qcw-2021** – *YANG Data Models for Scheduled Traffic, Frame Preemption, and Per-Stream Filtering and Policing*
- New projects
  - **P802.1DU** – *Cut-Through Forwarding Bridges and Bridged Networks*
  - **P802.1Qdx** – *YANG Data Models for the Credit-Based Shaper*
  - **P802.1Qdy** – *YANG for the Multiple Spanning Tree Protocol*
- Upcoming project
  - **P802.1AXdz** – *YANG for Link Aggregation*

Hot Topics

- All TSN profiles
- Time synchronization
  - See the ongoing 802.1AS amendment projects
- Configuration
  - **P802.1Qdj** – *Configuration Enhancements for TSN*
  - **P802.1Qdd** – *Resource Allocation Protocol*
- New projects, e.g.:
  - **P802.1DU** – *Cut-Through Forwarding Bridges and Bridged Networks*
- All ongoing work: https://1.ieee802.org/tsn/#Ongoing_TSN_Projects

DetNet

Overview …
IETF DetNet essentials

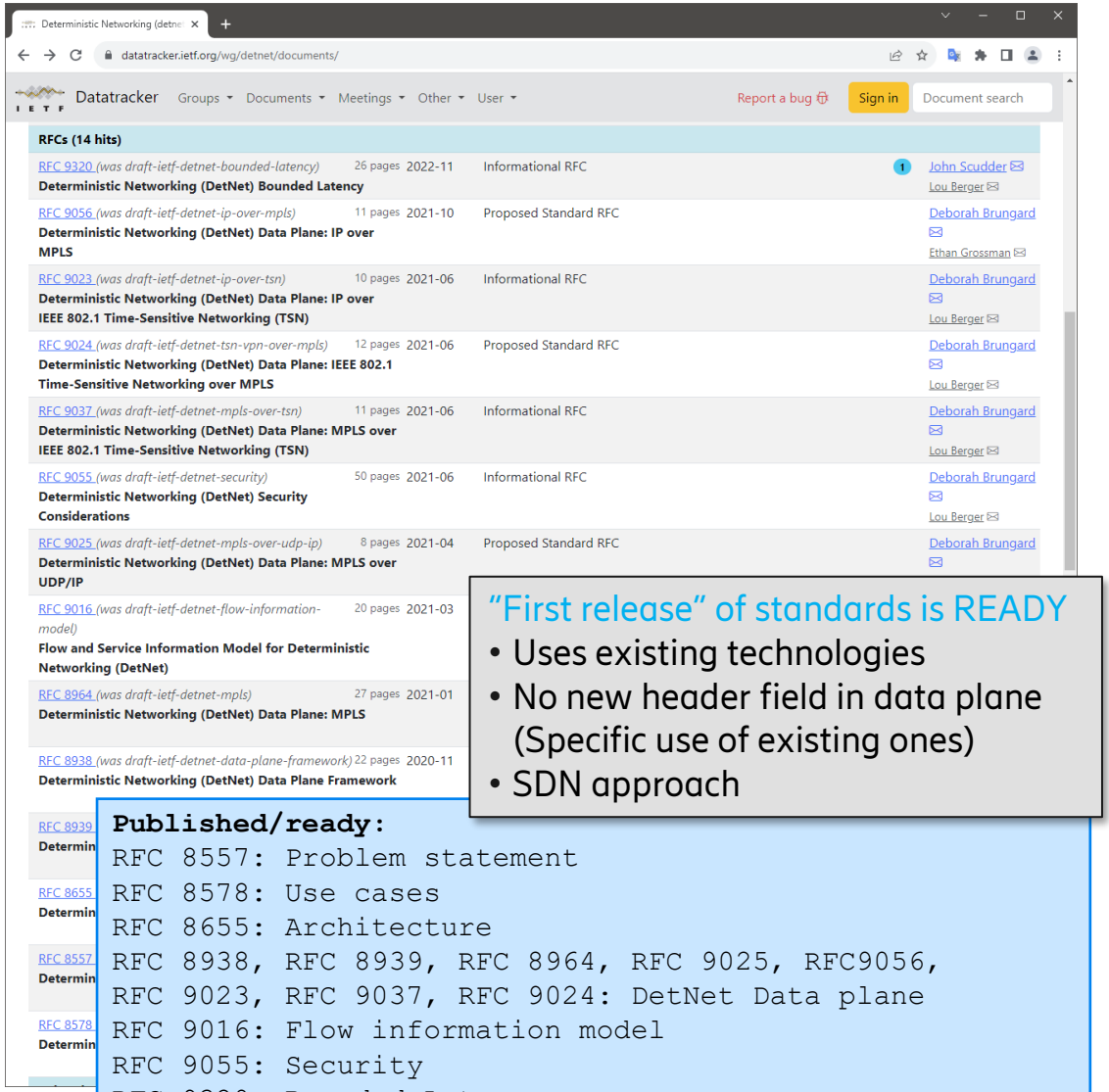


DetNet
- operates at the IP/MPLS layer
- is for networks that are under a single administrative control or within a closed group of administrative control.
- is NOT for large groups of domains such as the Internet.

- DetNet service provides a capability for the delivery of data flows with
  - (1) extremely low packet loss rates and/or
  - (2) bounded end-to-end delivery latency

Note1: These characteristics are accomplished by dedicating network resources such as link bandwidth and buffer space to DetNet flows and/or classes of DetNet flows, and by protecting packets (e.g., by replicating them along multiple paths.

Note2: Unused reserved resources are available to non-DetNet flows as long as all guarantees are fulfilled.



"First release" of standards is READY
- Uses existing technologies
- No new header field in data plane (Specific use of existing ones)
- SDN approach

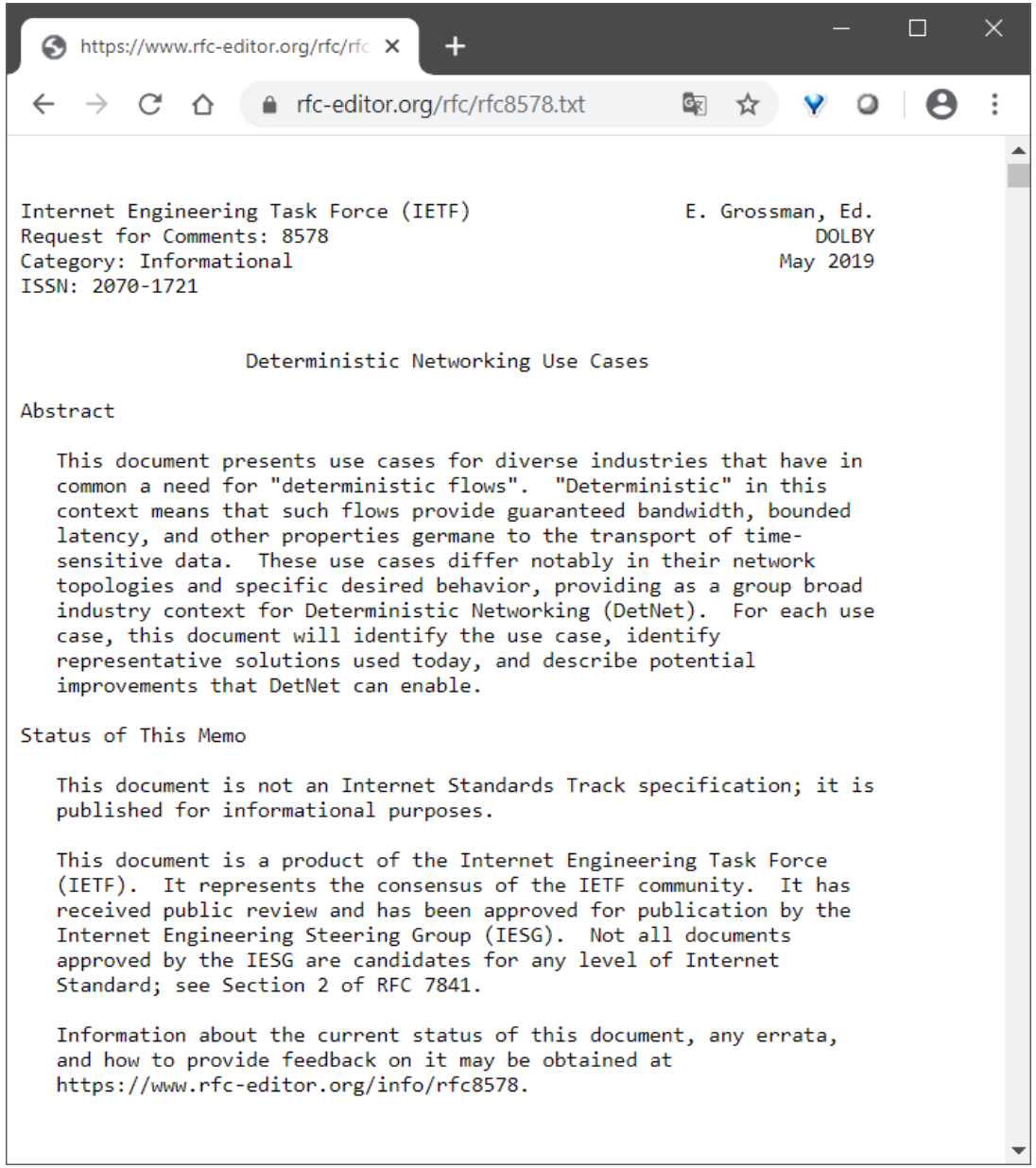
Published/ready:
RFC 8557: Problem statement
RFC 8578: Use cases
RFC 8655: Architecture
RFC 8938, RFC 8939, RFC 8964, RFC 9025, RFC9056,
RFC 9023, RFC 9037, RFC 9024: DetNet Data plane
RFC 9016: Flow information model
RFC 9055: Security
RFC 9320: Bounded Latency

In progress:
- YANG model
- DetNet OAM
- Enhanced data plane (IP PREOF, POF)
- DetNet Controller plane framework
- Scaling requirements
- Others … (queuing, further metadata, measurements)

Overview
DetNet use-cases

DetNet use-cases

- Pro Audio
- Electrical Utilities
- Building Automation Systems (BASs)
- Wireless for Industrial Applications
- Cellular Radio
- Industrial Machine to Machine (M2M)
- Mining Industry
- Private Blockchain
- Network Slicing

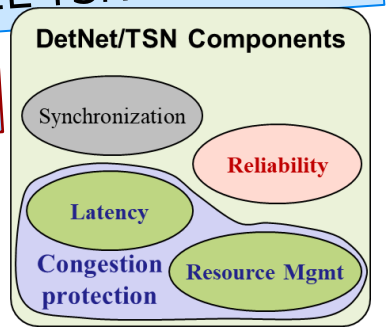


DetNet building blocks

Combinations depends on flow requirements

In close cooperation with IEEE TSN folks …

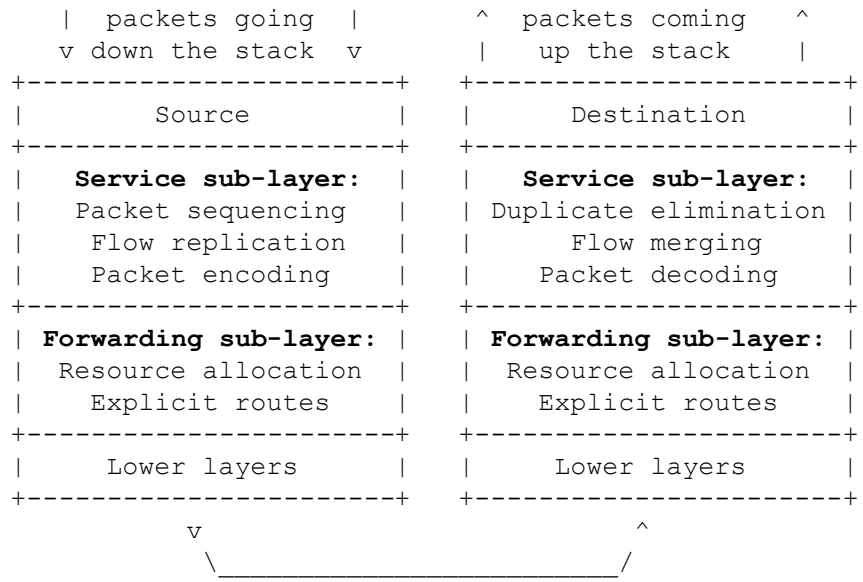
NO change to packets on the wire!



Service protection
- addresses random media errors and equipment failures
- e.g., packet replication and elimination (against failures), packet encoding (against media errors), re-ordering (ensure in-order delivery)

Resource allocation
- allocating resources along the path of a DetNet flow, e.g., buffer space or link bandwidth
- addresses two of the DetNet QoS requirements: latency and packet loss.

Explicit routes
- addresses impact of the convergence of routing or bridging protocols (i.e., temporary interruptions)



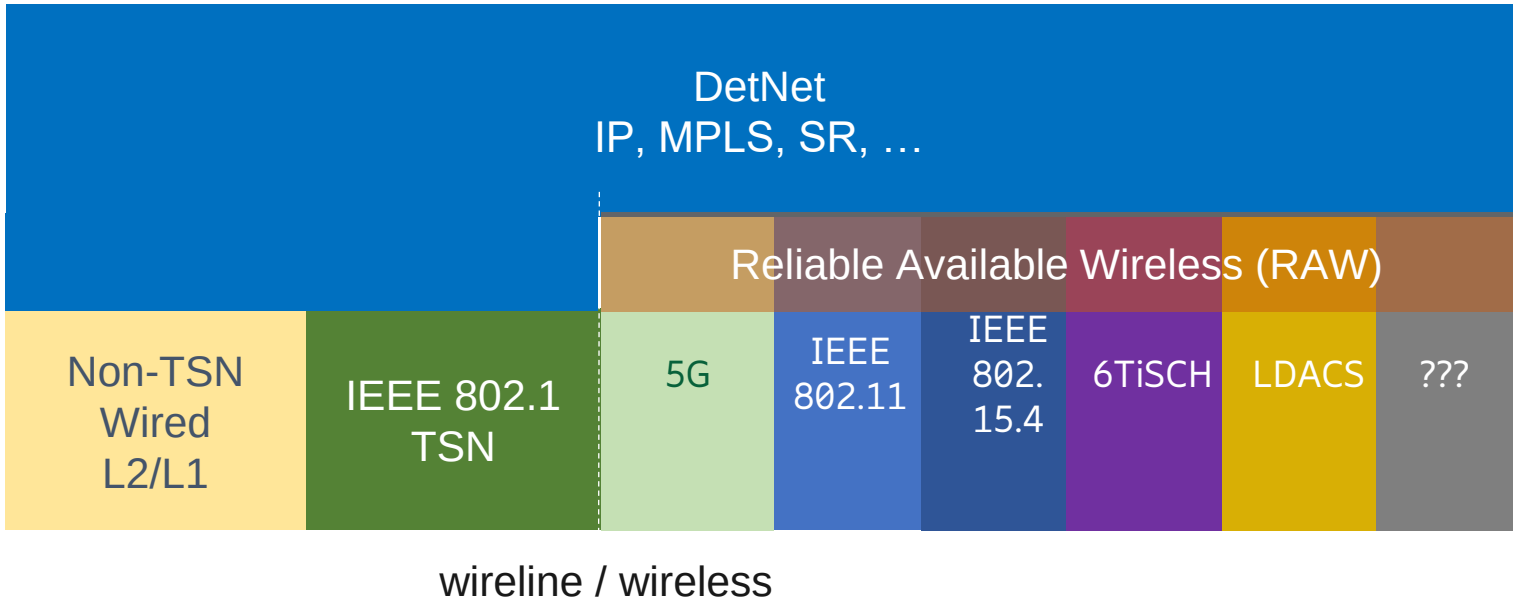
DetNet functionality is implemented in two adjacent sub-layers in the protocol stack

Note: congestion protection provided via congestion detection and notification is explicitly excluded from consideration in DetNet.
Note2: synchronization out-of-scope in DetNet discussions. It is expected to be provided by appropriate solutions.

Reliable and Available Wireless (RAW)

Wireless extensions to DetNet

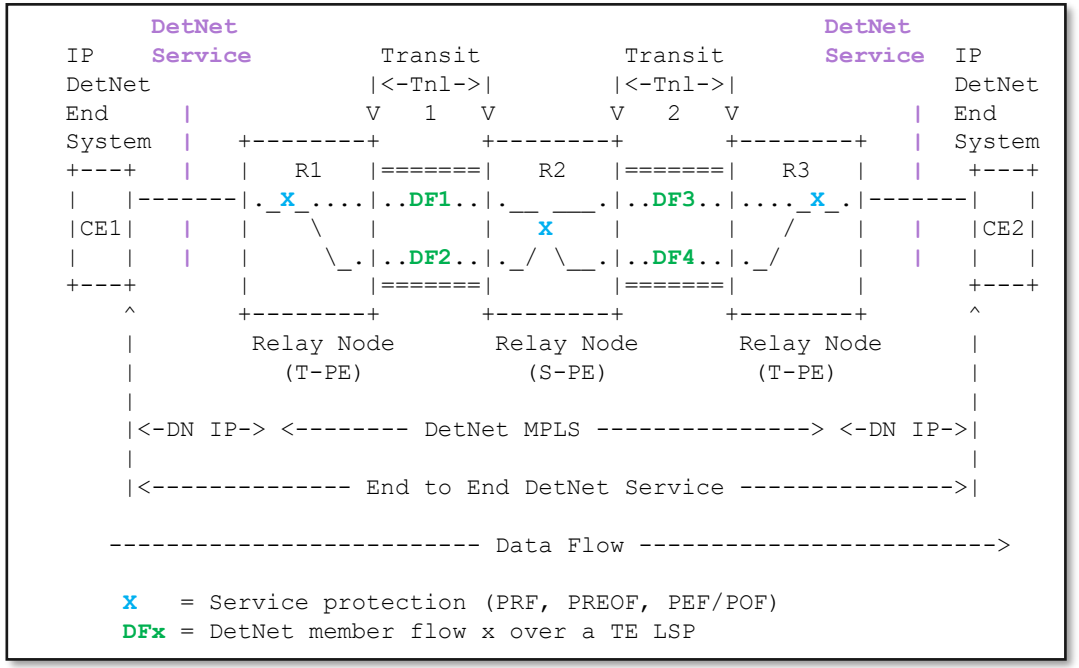
- IETF Reliable and Available Wireless (RAW)
  - DetNet solutions apply to both wireless and wired
  - BUT wireless medium presents significant challenges to achieve deterministic properties such as low packet error rate, bounded consecutive losses, and bounded latency
  - RAW adds wireless extensions
- Medias
  - IEEE Std. 802.15.4 time-slotted channel hopping (TSCH)
  - 3GPP 5G ultra-reliable low latency communications (URLLC)
  - IEEE 802.11ax/be
  - L-band Digital Aeronautical Communications System (LDACS)
  - …



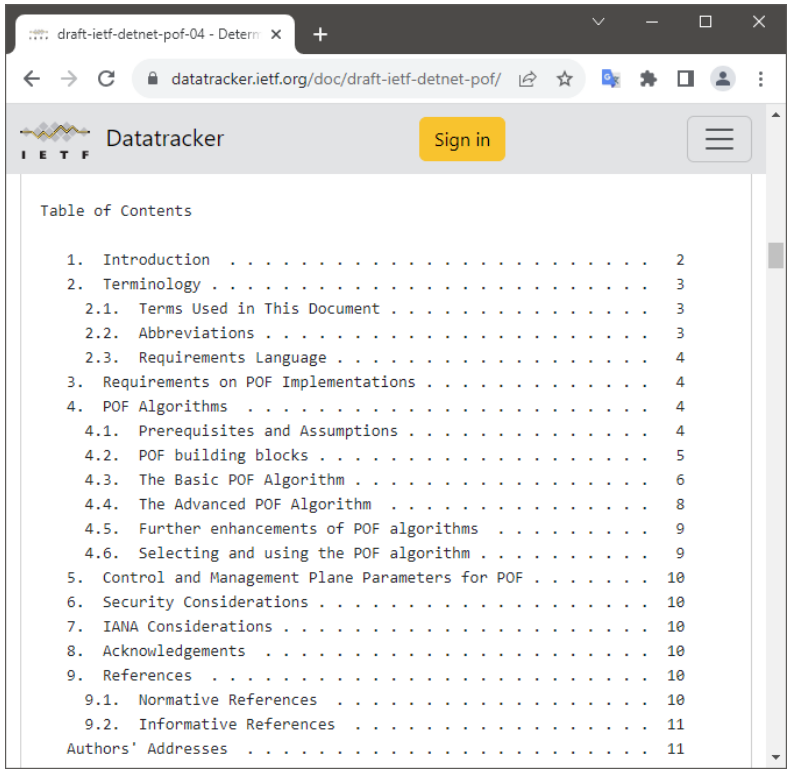
DetNet Service sub-layer

E.g., PREOF (replication, elimination and ordering)

- Service protection: Addresses random media errors and equipment failures
- Functionality
  - PREOF:
    - Packet replication (PRF) and elimination (PEF) (against failures), re-ordering (POF) (ensure in-order delivery)
    - Implementation
      - IETF defines on wire characteristics (RFC9056)
      - Not defined in details, E.g., methods & algorithms defined in IEEE 802.1CB
  - Packet encoding (against media errors)
  - Other …



DetNet Service sub-layer
Packet Ordering Function (POF)



- Abstract:
  - Replication and Elimination functions of DetNet (RFC8655) may result in out-of-order packets, which may not be acceptable for some time-sensitive applications. The Packet Ordering Function (POF) algorithm described herein enables to restore the correct packet order when replication and elimination functions are used in DetNet networks.

- Goals:
  - Consider the delay bound requirement of a DetNet Flow.
  - Minimal or no additional delay to the forwarding process of packets.
  - Keep it simple with minimum set of states/configuration
  - Require no time synchronization between PREOF nodes.

- Clarification (on possible delay variation caused by POF)
  - It is out-of-scope: to eliminate the PDV caused by POF.
  - Dealing with PDV is a DetNet forwarding sub-layer target and it can be achieved for example by placing a de-jitter buffer or flow regulator (e.g., shaping) function after the POF functionality.

Note: DetNet functions are defined as building blocks to achieve a given target. Several of these building blocks may be needed to ensure the envisioned deterministic end2end characteristics, required by an application.

Two POF Algorithms Defined

draft-ietf-detnet-pof

- Basic POF Algorithm
  - Max incremental packet delay: "POFMaxDelay" time.
  - In-order packets are not delayed.
  - Applicable to all scenarios where the delay budget of a flow allows "POFMaxDelay" time for ordering.
  - Management & Control: "POFMaxDelay", "POFTakeAnyTime"
- Advanced POF Algorithm adds the following extensions to the basic algorithm
  1. Identify the path of the received packet at the POF location
  2. Path dependent "POFMaxDelay": "POFMaxDelay_i", where "i" denotes the path.
  - Management & Control : "POFMaxDelay_i", "POFTakeAnyTime", path identification related configuration(s)

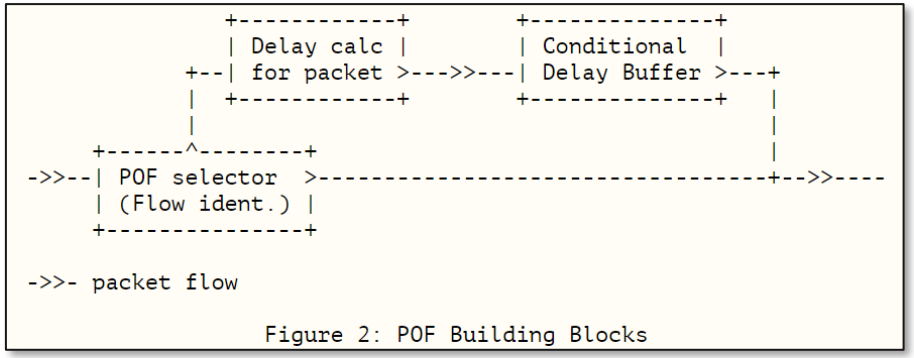


Figure 2: POF Building Blocks

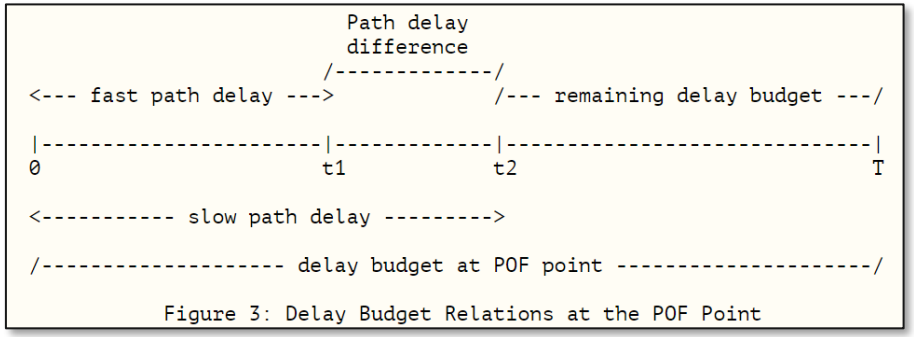
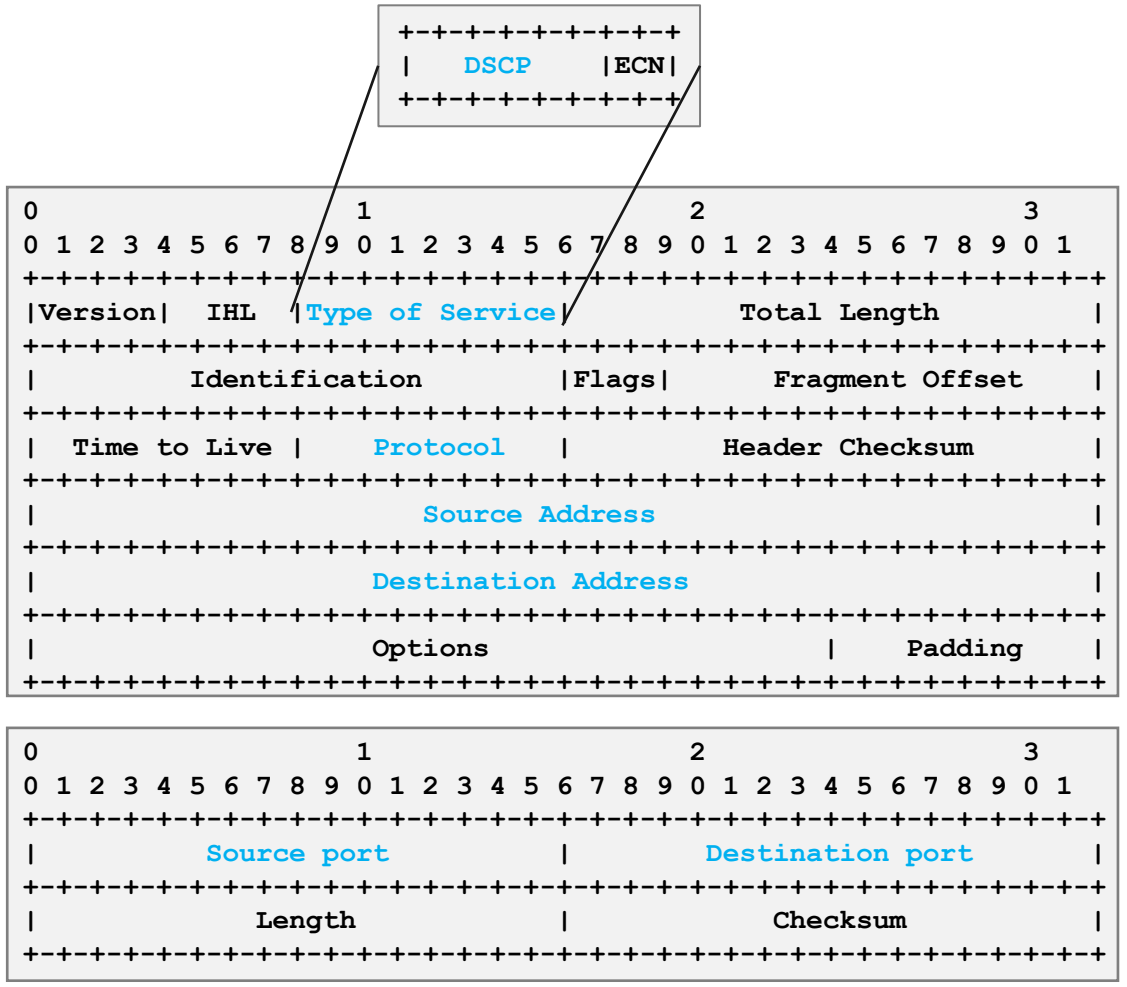


Figure 3: Delay Budget Relations at the POF Point

DetNet IP Data Plane

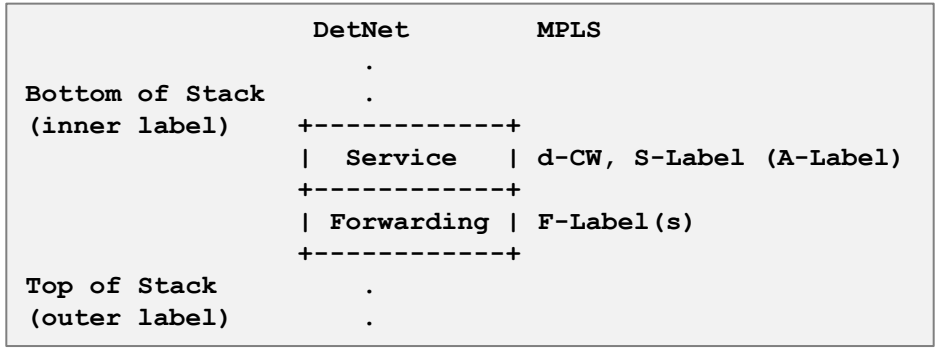
Flow identification via 6-tuple

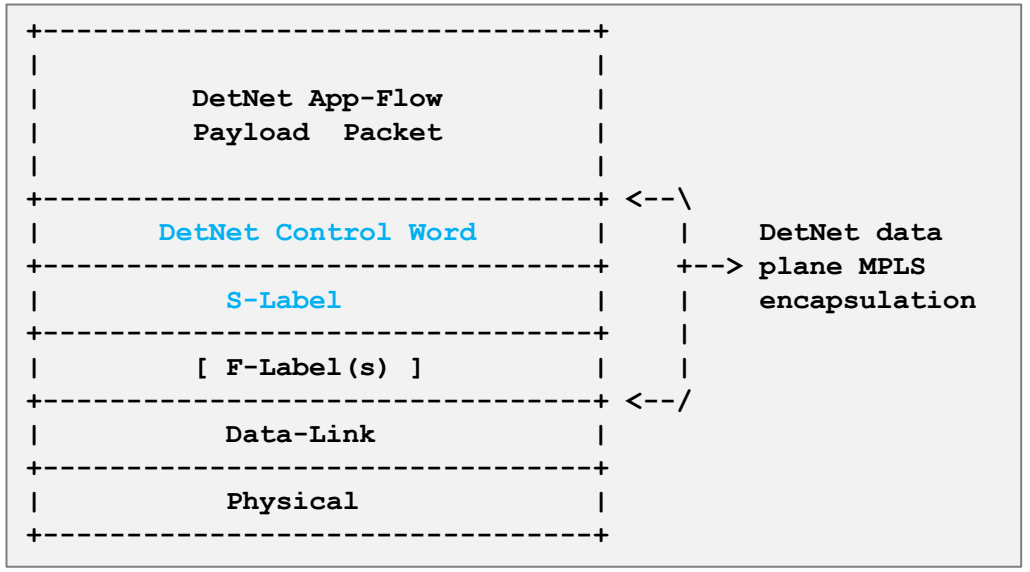
- Flow identification
  - based on IP (both IPv4 and IPv6) header information.
  - "6-tuple": the traditional 5-tuple + DSCP
    - IP source and destination address fields,
    - the next level protocol or header field,
    - the next level protocol specific fields (e.g. TCP or UDP source and destination ports or IPSec AH/ESP SPI field)
    - the IPv4 Type of Service or IPv6 Traffic Class field (i.e., DSCP)
  - any of the fields can be ignored (wildcarded), and bit masks, prefix based longest match, and ranges can also be used
- No sequence number field !!!
  - PREOF/FRER provided by subnet technology … or via data plane extensions …



DetNet MPLS data plane
DetNet PW

- DetNet PW encapsulation:
  - DetNet control word (d-CW)
    - containing sequencing information for packet replication and duplicate elimination purposes, and the OAM indicator. [MANDATORY]
  - DetNet service Label (S-label)
    - that identifies a DetNet flow to the peer node that is to process it.
  - [F-label(s)]
    - Zero or more MPLS transport LSP label(s) used to direct the packet along he label switched path (LSP) to the next peer node along the path.
  - The necessary data-link encapsulation is then applied prior to transmission over the physical media.





DetNet Data Plane: IP with PREOF

draft-ietf-detnet-mpls-over-ip-preof

- Abstract:
  - This document describes how DetNet IP data plane can support the Packet Replication, Elimination, and Ordering Functions (PREOF) based on [RFC9025].
- Goal:
  - Provide DetNet service sub-layer for IP with minimal effort
    minimal standardization and implementation effort
    (i.e., add PREOF to DetNet IP, but reuse existing DetNet data plane)
  - Maintain DetNet service sub-layer and DetNet forwarding sub-layer characteristics
    - Service sub-layer includes PREOF functions, e.g., sequencing
    - Forwarding sub-layer includes routing functions,
      e.g., explicit routing provided by, e.g., Segment Routing (SR)
  - Enable seamless use of existing routing techniques, e.g., SR (SRv6 in case of IPv6)

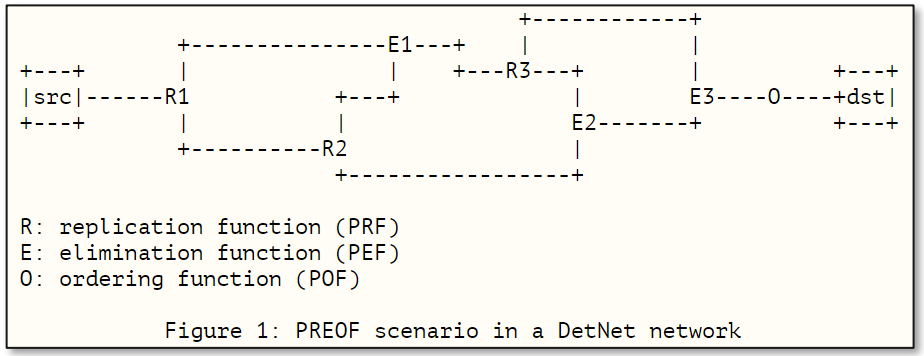
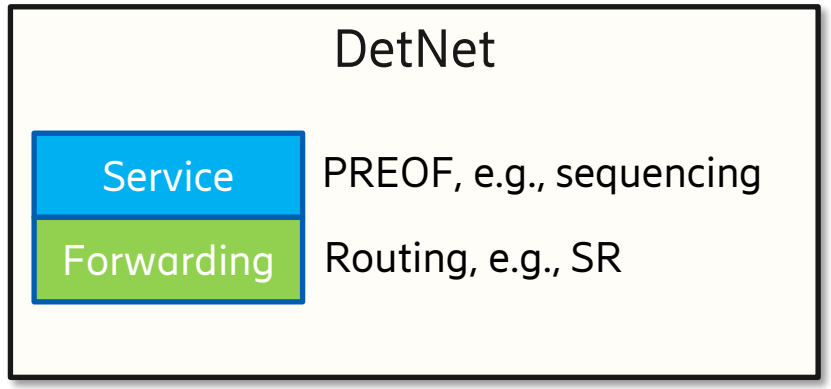


Figure 1: PREOF scenario in a DetNet network



DetNet Data Plane: IP with PREOF

Concept details

- Basic Concept
  - "UDP tunneling" between relay nodes
  - Maintain the 6-tuple-based DetNet flow identification in DetNet transit nodes

- Document provides
  - Encapsulation
  - Packet Processing
  - Flow aggregation
  - PREOF procedures
  - Control and management parameters

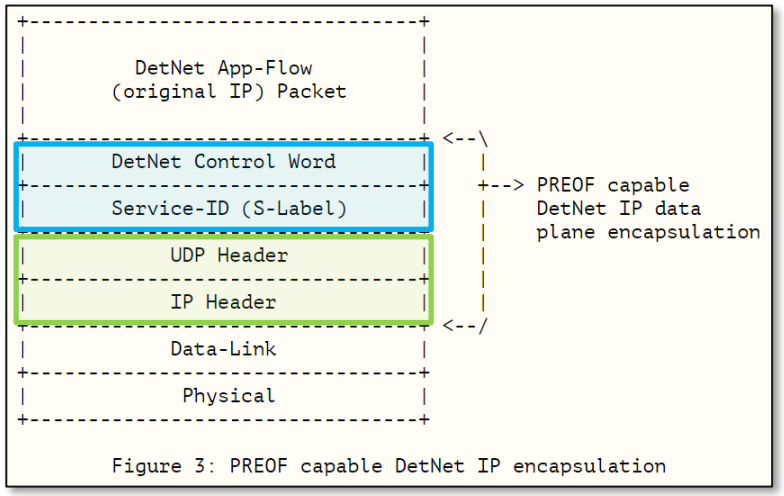


Figure 3: PREOF capable DetNet IP encapsulation

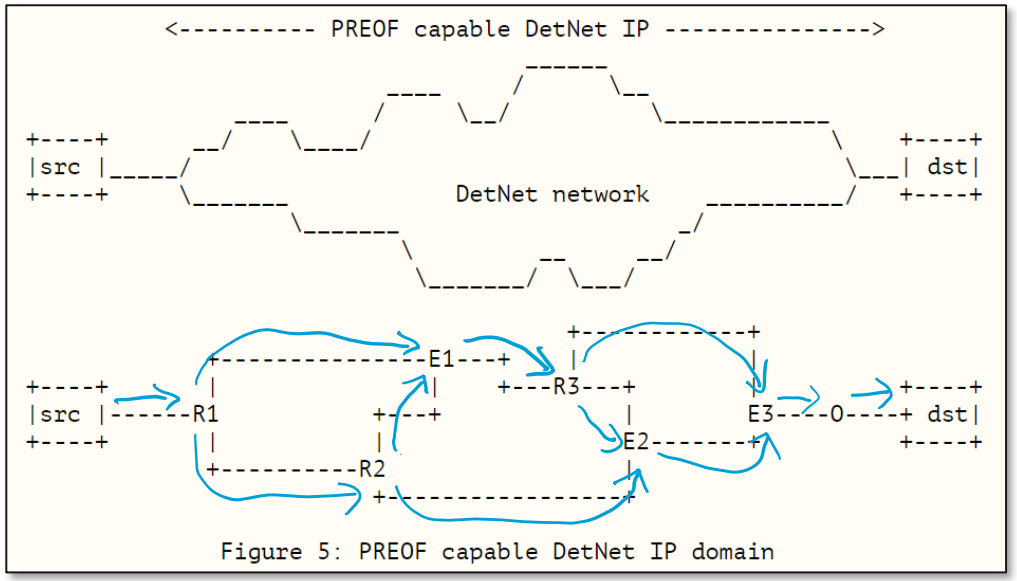


Figure 5: PREOF capable DetNet IP domain

DetNet being TSN-aware

Subnetwork vs. Service scenarios

- RFC9023: IP over TSN
- RFC9037: MPLS over TSN

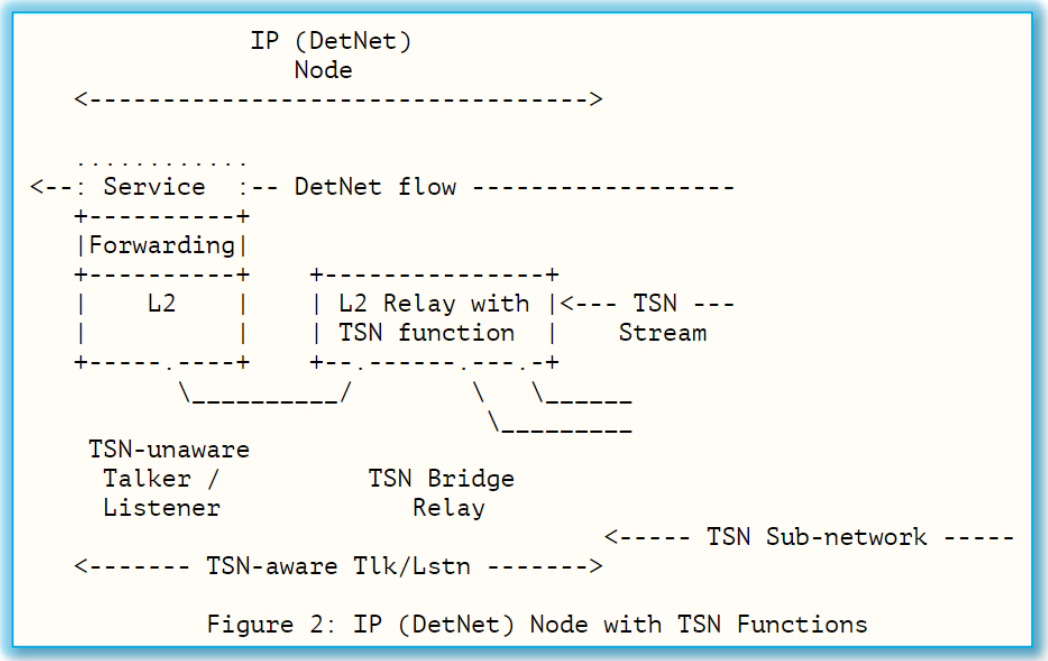


Figure 2: IP (DetNet) Node with TSN Functions

- RFC9024: TSN VPN over MPLS

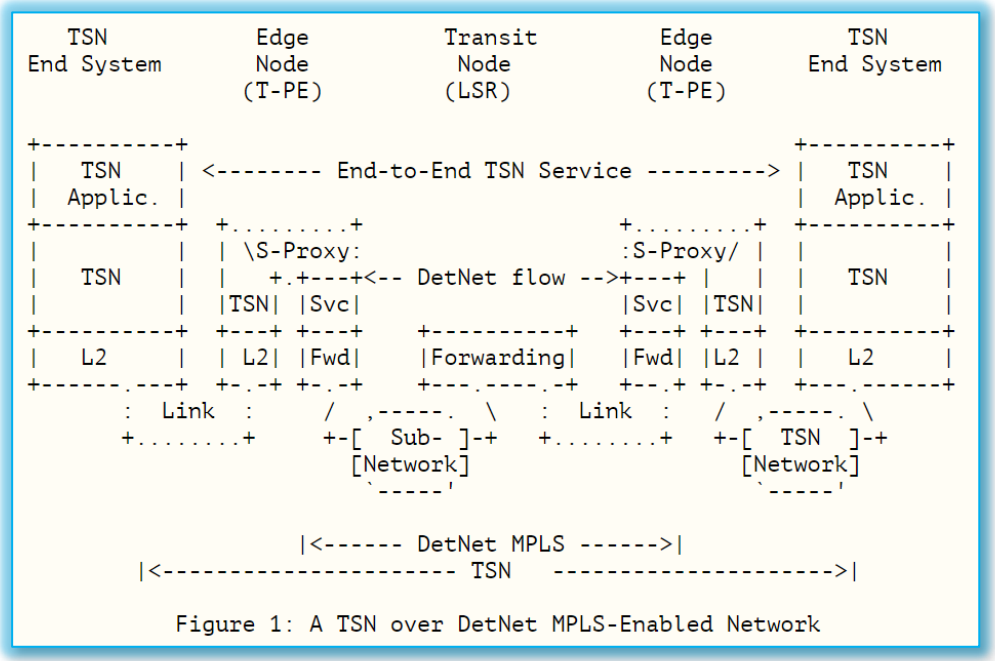
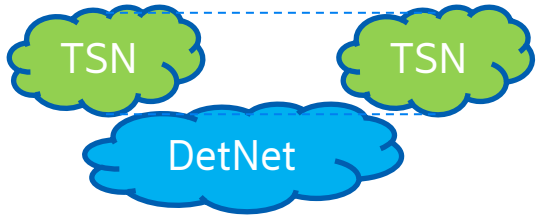


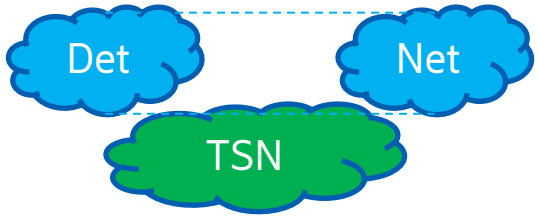
Figure 1: A TSN over DetNet MPLS-Enabled Network

Service scenarios example

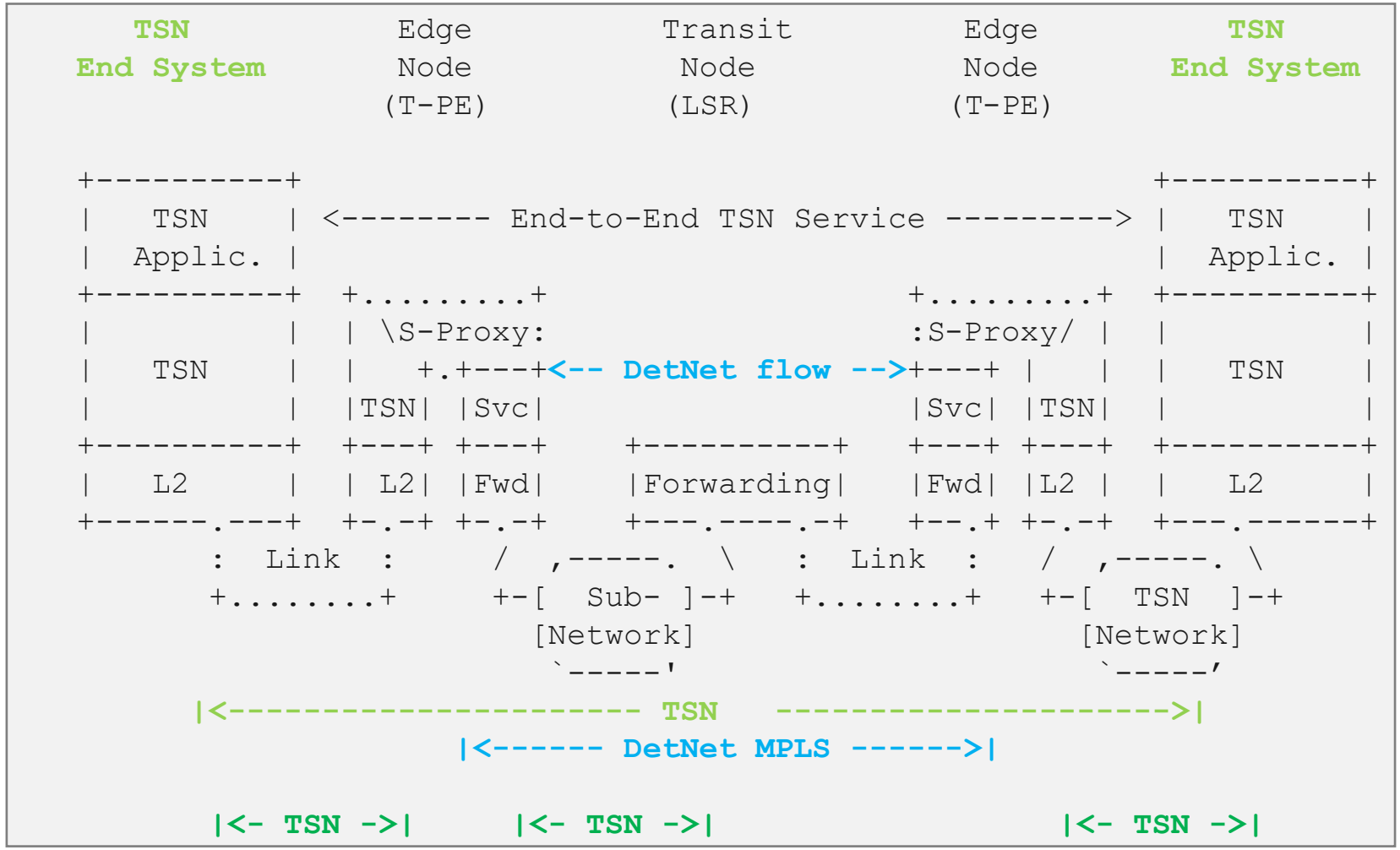
DetNet Layer-2 service: TSN over DetNet (MPLS)



TSN over DetNet
(e2e service)

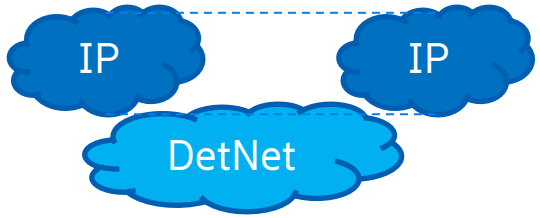


DetNet over TSN
(link, sub-network)

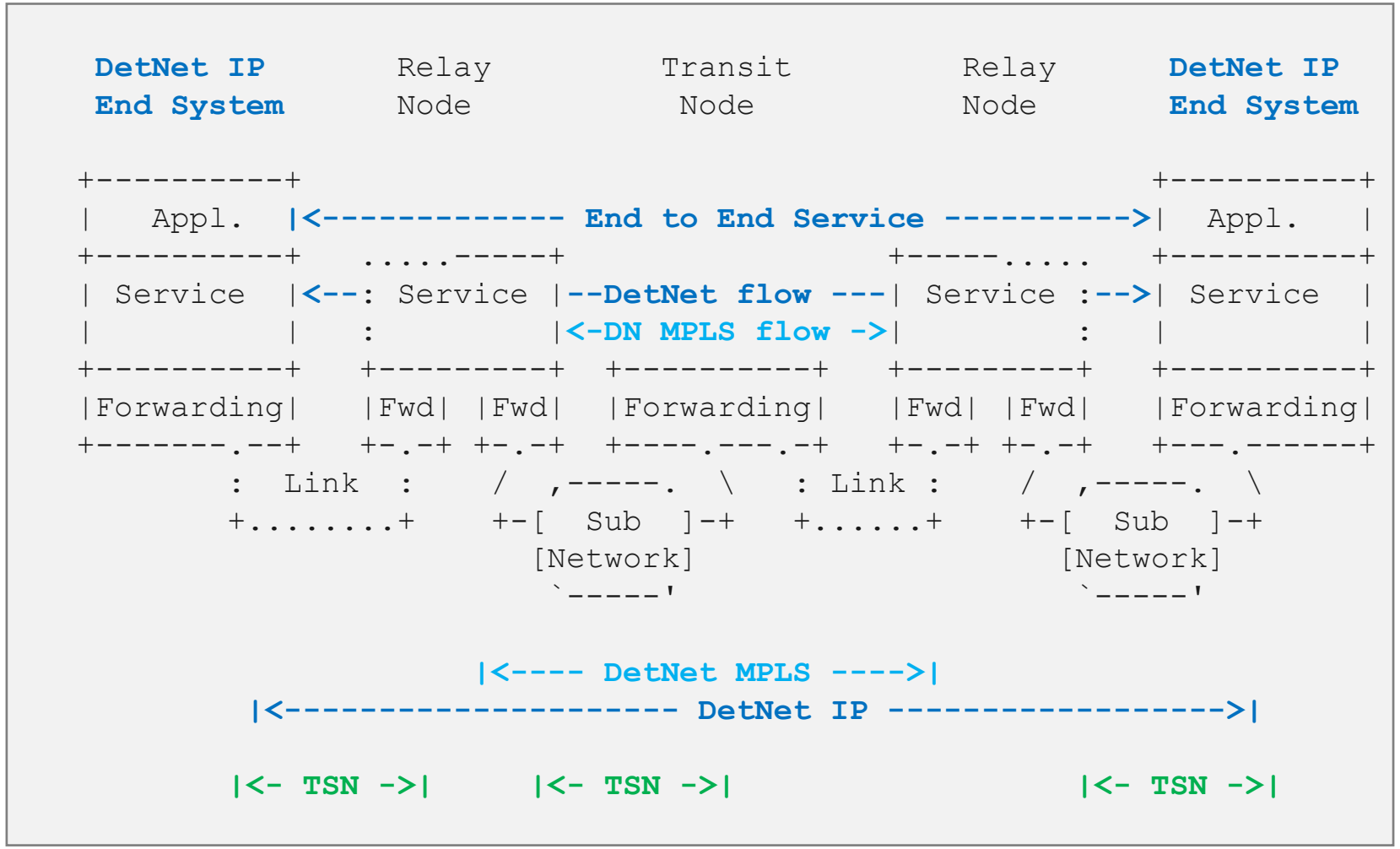


Service scenarios example

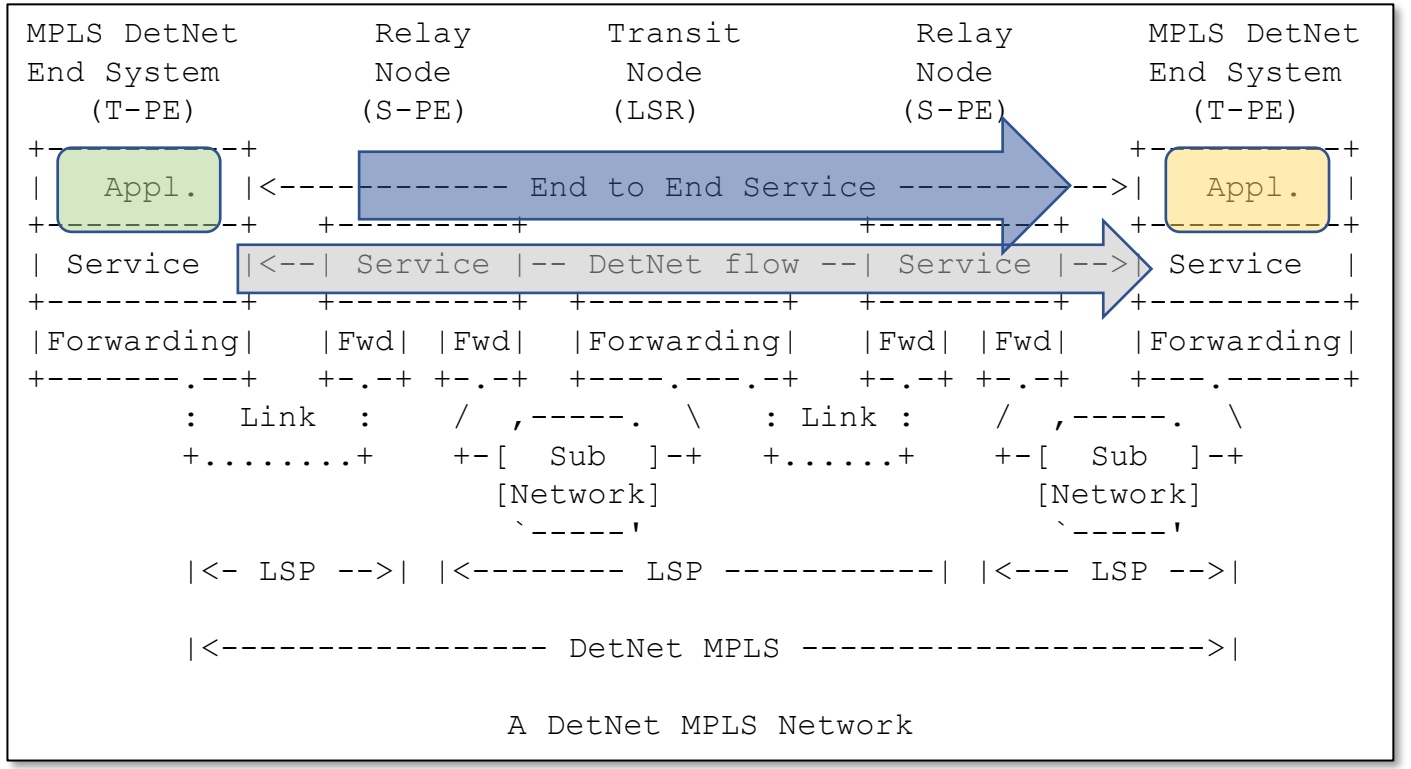
DetNet Layer-3 service: IP over DetNet (MPLS)



IP over DetNet
(e2e service)



DetNet Management
Service model, YANG



- DetNet: three models are distinguished:
  - Flow information model (RFC9016): describes characteristics of data flows. It includes in detail all relevant aspects of a flow that are needed to support the flow properly by the network between the source and the destination(s).
  - Service information model (RFC9016): describes characteristics of services being provided for data flows over a network. It can be treated as a network operator independent information model.
  - Configuration data model (draft-ietf-detnet-yang): describes in detail the settings required on network nodes to serve a data flow properly.

DetNet OAM

Focus on DetNet service sub-layer

- Service sub-layer
  - Multiple service segments (forwarding layer/tunnel is terminated at DetNet service sub-layer)
- New characteristics of DetNet PW
  - Per packet (DetNet) vs. per path (legacy) protection (PREOF results in extra challenges, no similar scenario so far in networking. PEF is the brand-new functionality, due to per packet merge.)
  - All paths are active and forward traffic (hop count & latency of paths are different !)
  - Mandatory usage of sequence number (at PREOF nodes, RFC8964 defines d-CW)
- Requirement:
  - Same treatment of OAM and DetNet data flow. The OAM packets must follow precisely the same graph as the data packets of the corresponding DetNet flow(s).

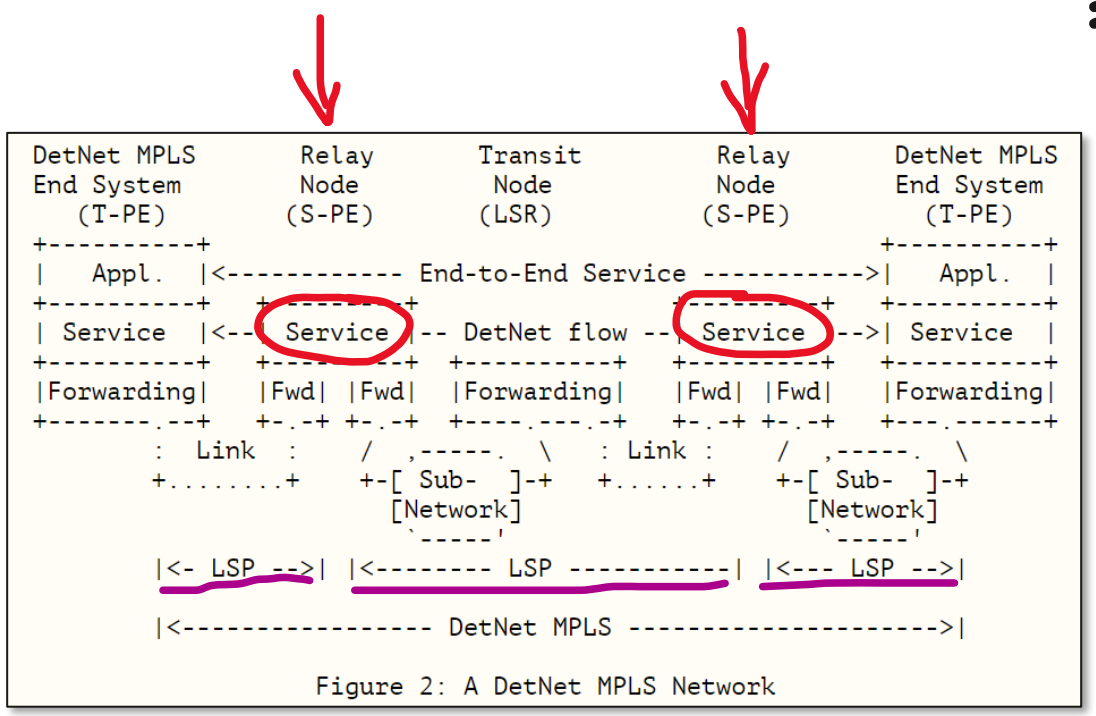


Figure 2: A DetNet MPLS Network

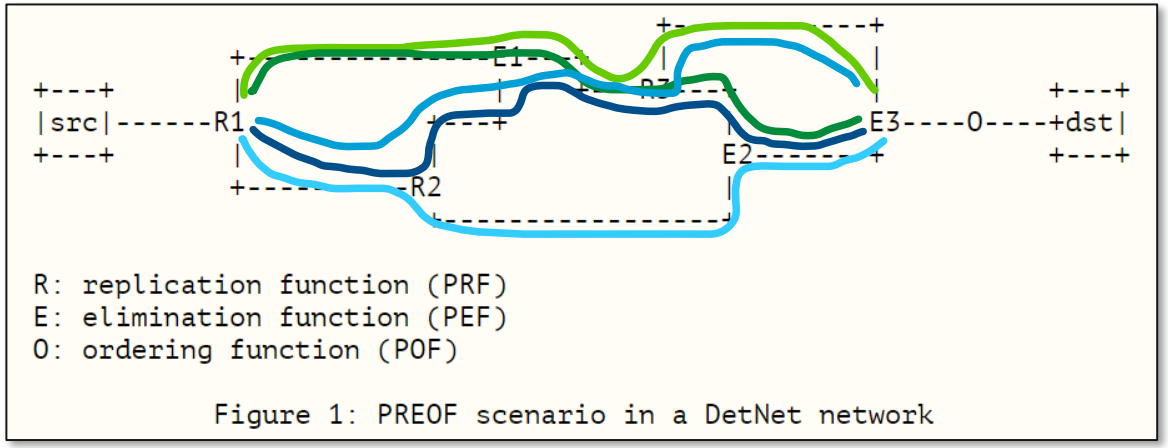
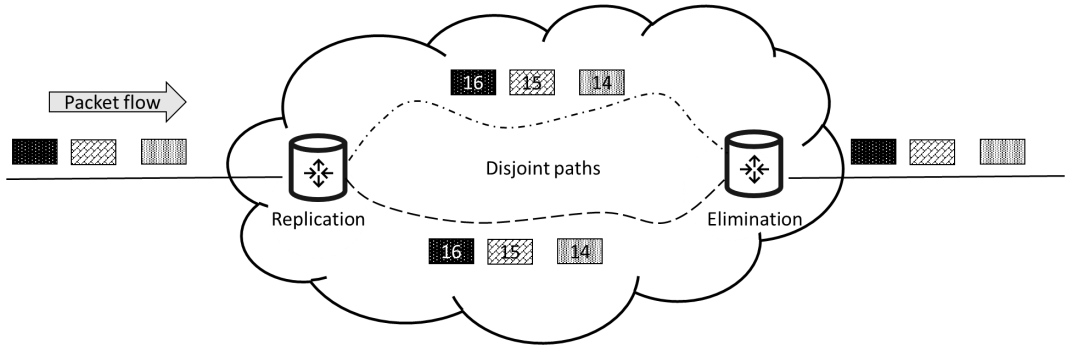


Figure 1: PREOF scenario in a DetNet network

Service Protection (R/E)
Challenges for OAM tools



- Replication and Elimination (R/E) are per-packet reliability functions
- Sequence Number information carried in the packet header

- Some closely related questions to answer for FRER/PREF specific OAM are:
  - (1) How to inject OAM traffic into the data flow?
  - (2) How to process OAM by R/E entities?
  - (3) How to limit the forwarding of OAM packets?
  - (4) How to trigger OAM execution on R/E nodes?

Solution:
R/E specific OAM shim layer

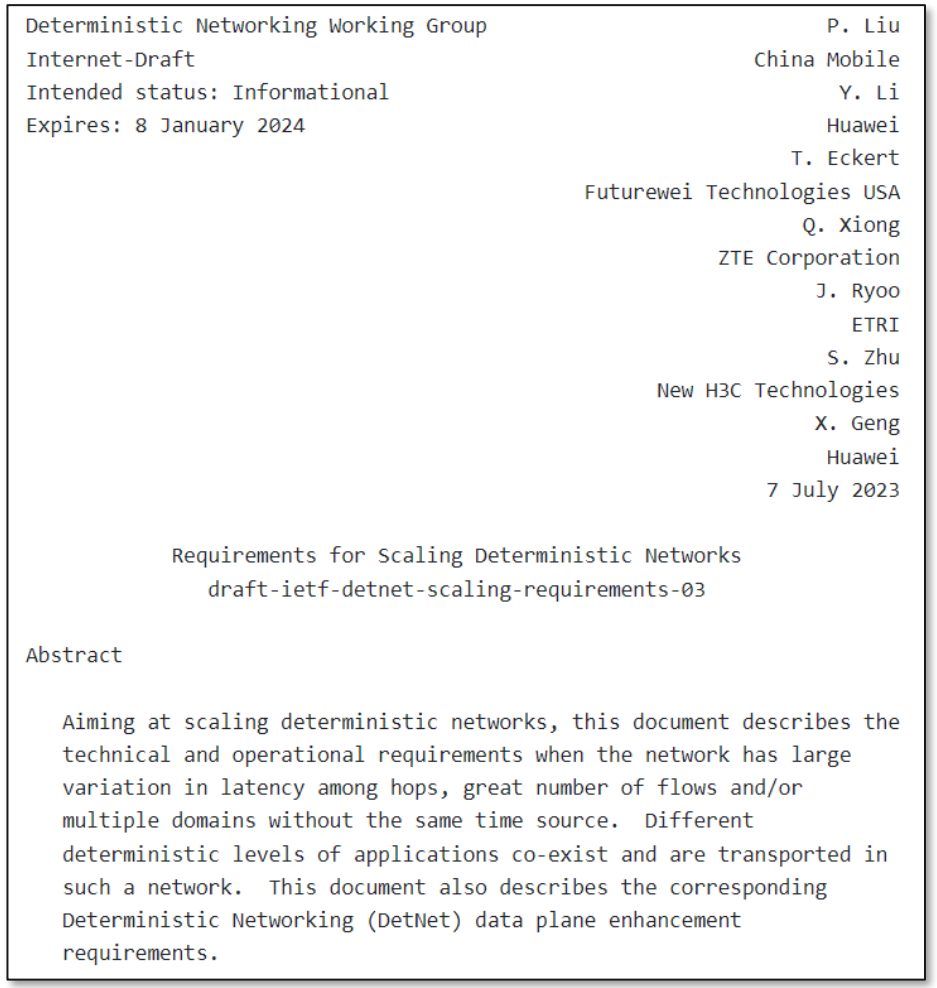
Good news: no need for fast OAM (R/E is not based on triggered switchover)

Enhanced Requirements
"Large scale", Queuing

- "Large scale deterministic networks":
  - Synch related challenges
  - Latency differences needs extra attention
  - Scalability (IntServ vs. DiffServ attitude)

- Proposed mechanism (discussed in "Open working meetings on enhanced data plane")
  - New queuing mechanism(s) (beyond RFC 9320)
  - Many individual drafts under evaluation (AND C-SCORE playout buffering, Deadline Forwarding, CSQF, CQF-Variant TCQF, TQF, gLBF)

  - New packet header information for functions addressing deterministic latency, ...



Deterministic Networking Working Group — P. Liu, China Mobile
Internet-Draft — Y. Li, Huawei
Intended status: Informational — T. Eckert, Futurewei Technologies USA
Expires: 8 January 2024 — Q. Xiong, ZTE Corporation
J. Ryoo, ETRI
S. Zhu, New H3C Technologies
X. Geng, Huawei
7 July 2023

Requirements for Scaling Deterministic Networks
draft-ietf-detnet-scaling-requirements-03

Abstract

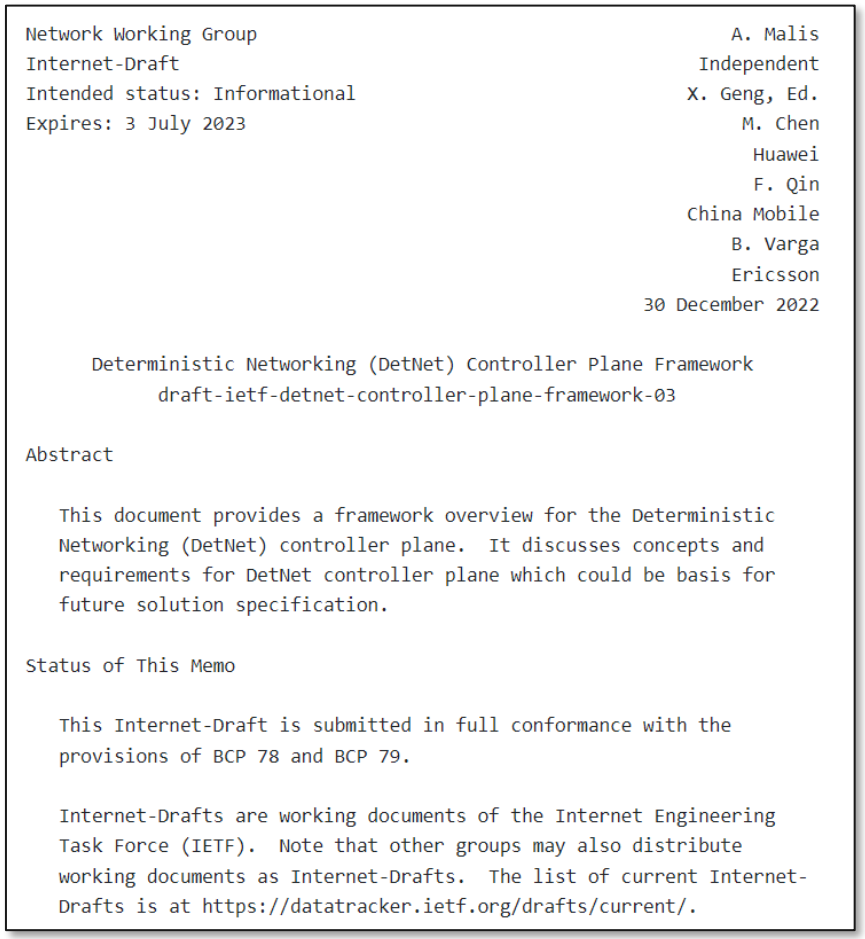
Aiming at scaling deterministic networks, this document describes the technical and operational requirements when the network has large variation in latency among hops, great number of flows and/or multiple domains without the same time source. Different deterministic levels of applications co-exist and are transported in such a network. This document also describes the corresponding Deterministic Networking (DetNet) data plane enhancement requirements.

draft-ietf-detnet-scaling-requirements

Controller Plane Framework

draft-ietf-detnet-controller-plane-framework

- It discusses concepts and requirements for DetNet controller plane which could be basis for future solution specification.
  (dynamic creation, modification, and deletion of DN flows.)
- Content
  - DetNet Controller Plane Requirements
  - DetNet Control Plane Architecture
    - Fully Distributed Control Plane (via signaling)
    - SDN/Fully Centralized Control Plane
    - Hybrid Control Plane (partly centralized/distributed)
  - DetNet Control Plane for DetNet Mechanisms
    - Explicit Paths
    - Resource Reservation
    - PREOF Support
    - Data Plane specific considerations (MPLS, IP, SR)



Network Working Group — A. Malis
Internet-Draft — Independent
Intended status: Informational — X. Geng, Ed.
Expires: 3 July 2023 — M. Chen
Huawei
F. Qin
China Mobile
B. Varga
Ericsson
30 December 2022

Deterministic Networking (DetNet) Controller Plane Framework
draft-ietf-detnet-controller-plane-framework-03

Abstract

This document provides a framework overview for the Deterministic Networking (DetNet) controller plane. It discusses concepts and requirements for DetNet controller plane which could be basis for future solution specification.

Status of This Memo

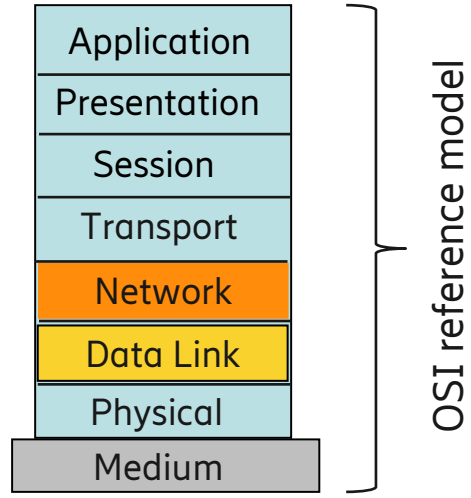
This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at https://datatracker.ietf.org/drafts/current/.

Summary

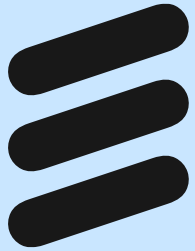
Summary

- TSN and DetNet provide guaranteed delivery with bounded low latency, low delay variation, and extremely low loss
  - Extreme values (µsec, lossless, …) appear; the main target is guaranteed upper bound
- TSN
  - Still evolving
  - A lot can be done still; including refinements and filling gaps
  - Profiles bring together TSN experts and application area experts for the benefit of the ecosystem
- DetNet
  - DetNet base standards are ready
  - OAM is being added
  - Controller Plane is new work



Further Reading

- TSN feature topic in the IEEE Communications Standards Magazine June 2018 and December 2022
- IEEE SA TSN webinar series (see also related posts)
- "The Quick and the Dead: The Rise of Deterministic Networks"
  https://www.comsoc.org/publications/ctn/quick-and-dead-rise-deterministic-networks
- Presentations at DetNet – TSN workshop
  https://1.ieee802.org/november-2018-plenary-meeting-in-bangkok-thailand-tsn-tg-agenda/#Sunday_DetNet_8211_TSN_workshop
- Tutorial on TSN at IETF 99
  https://datatracker.ietf.org/meeting/99/materials/slides-99-edu-sessf-time-sensitive-networking-tutorial-english-language-janos-farkas-norman-finn-patricia-thaler
- Tutorial on IEEE 802 Ethernet Networks for Automotive
  http://www.ieee802.org/802_tutorials/2017-07/tutorial-Automotive-Ethernet-0717-v02.pdf
- "A Time-Sensitive Networking Primer: Putting It All Together"
  https://drive.google.com/file/d/0B6Xurc4m_PVsZ1lzWWoxS0pTNVE/view?usp=sharing
- "Heterogeneous Networks for Audio and Video: Using IEEE 802.1 Audio Video Bridging"
  http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6595589
- Tutorial on IEEE 802.3br Interspersing Express Traffic (IET) and IEEE 802.1 Time-Sensitive Networking
  http://www.ieee802.org/802_tutorials/2015-03/8023-IET-TF-1501-Winkel-Tutorial-20150115_r06.pptx
- Tutorial on Deterministic Ethernet http://www.ieee802.org/802_tutorials/2012-11/8021-tutorial-final-v4.pdf
- Tutorial on IEEE 802.1Q at IETF 86 https://www6.ietf.org/meeting/86/tutorials/86-IEEE-8021-Thaler.pdf
- Paper on 802.1Q bridging https://arxiv.org/ftp/arxiv/papers/1405/1405.6953.pdf



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