Preamble

The subsequent slides (not including this slide) contain **draft** material proposed for a planned IEEE 802 tutorial on CTF
(see https://mentor.ieee.org/802.1/dcn/21/1-21-0015-04-ICne-ctf-study-item-planning-proposal.pdf):

- **At the time this draft slide set is published, an IEEE 802 tutorial has not been approved!**
- However, the contents of the following slides are designed to show content as it would like in a final version, including indications for such a tutorial, as it would look like if such a tutorial would be approved.
- All contents in this slide set are subject to discussion, change/correction, removal and addition. Nonetheless, this slide set is intended to give a preview of the merged individual contributions for the planned tutorial.

Discussions and contributions are welcome!

Tutorial: Cut-Through Forwarding (CTF) in Bridges and Bridged Networks

Johannes Specht, Jordon Woods, Paul Congdon/Lily Lv, Henning Kaltheuner, <<TBD>>

Abstract

Cut-Through Forwarding (CTF) is a known method to improve the delay performance in Bridged Networks. In contrast to the store and forward operation of standardized switched Ethernet, CTF allows frame transmission in Bridges before reception is completed. Although not standardized in IEEE 802, CTF is already implemented in existing Bridge implementations. It is therefore technically feasible, but different implementations face interoperability problems that can be resolved by standardizing CTF in IEEE 802.1 and IEEE 802.3.

This tutorial introduces CTF on a technical level, explains application areas, markets and use-cases for CTF, and addresses technical and procedural aspects on integrating CTF into IEEE 802.1 and IEEE 802.3 Standards.

Disclaimer

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At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

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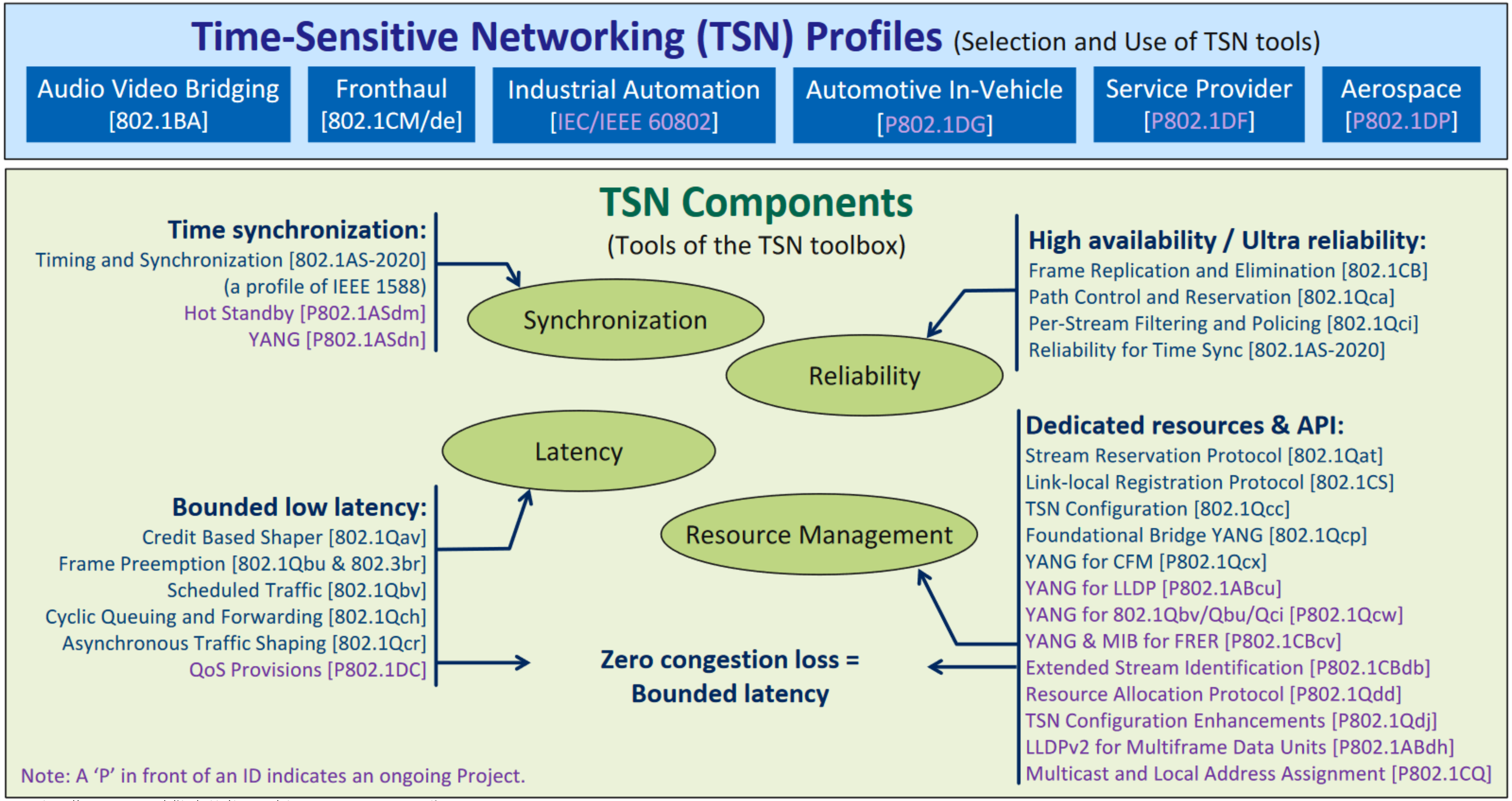
Introduction

Johannes Specht

IEEE 802.1 TSN Context, Basic CTF Operation Guaranteed Latency, CTF Performance, Reasons for standardizing CTF

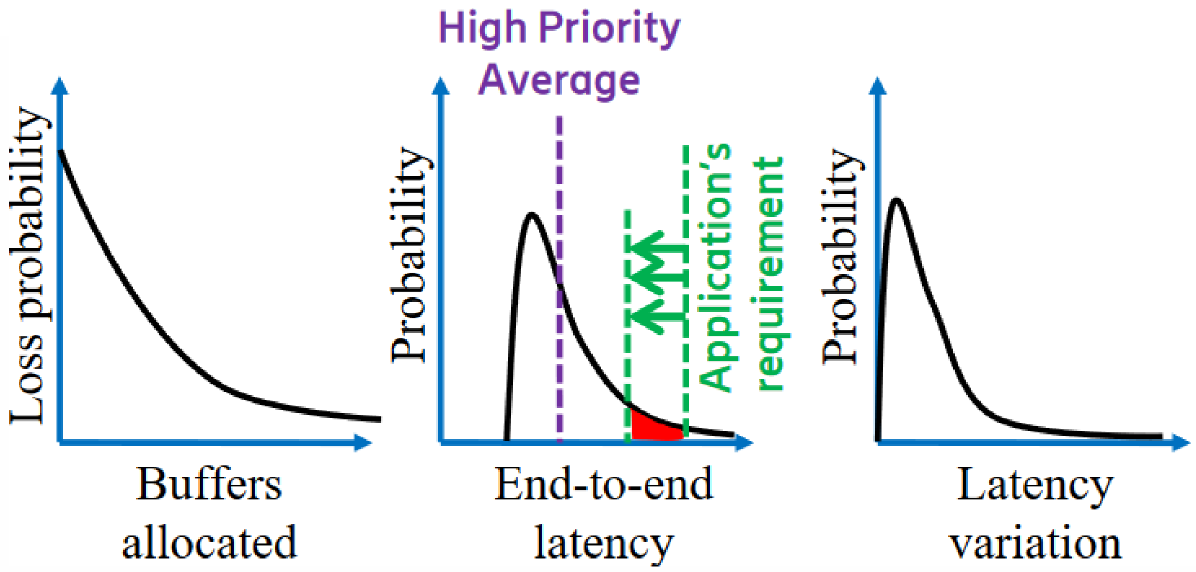
TSN Context

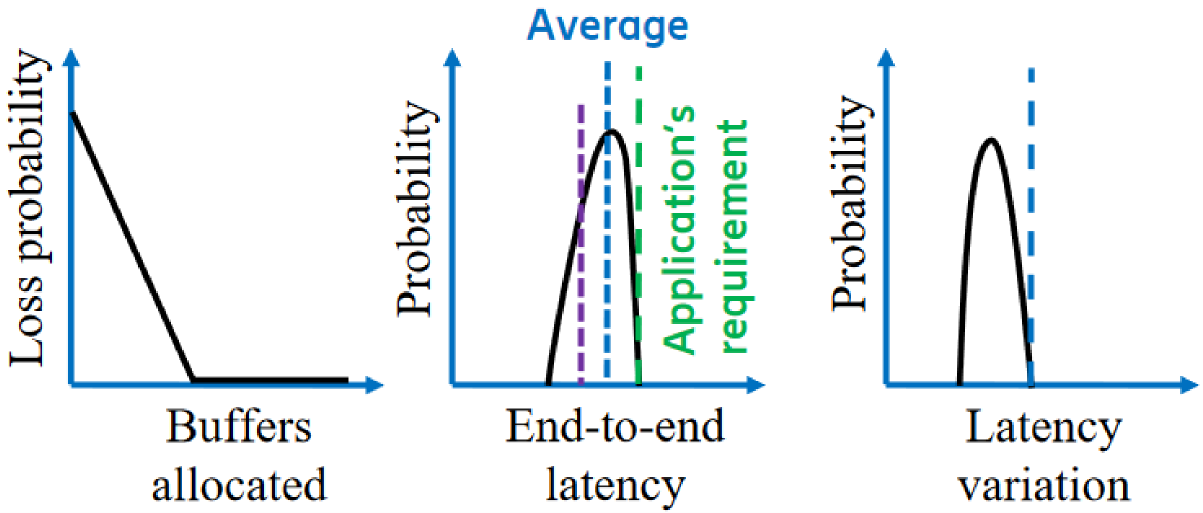


Source: https://www.ieee802.org/1/files/public/docs2021/admin-tsn-summary-0221-v01.pdf

Traditional and Deterministic Services

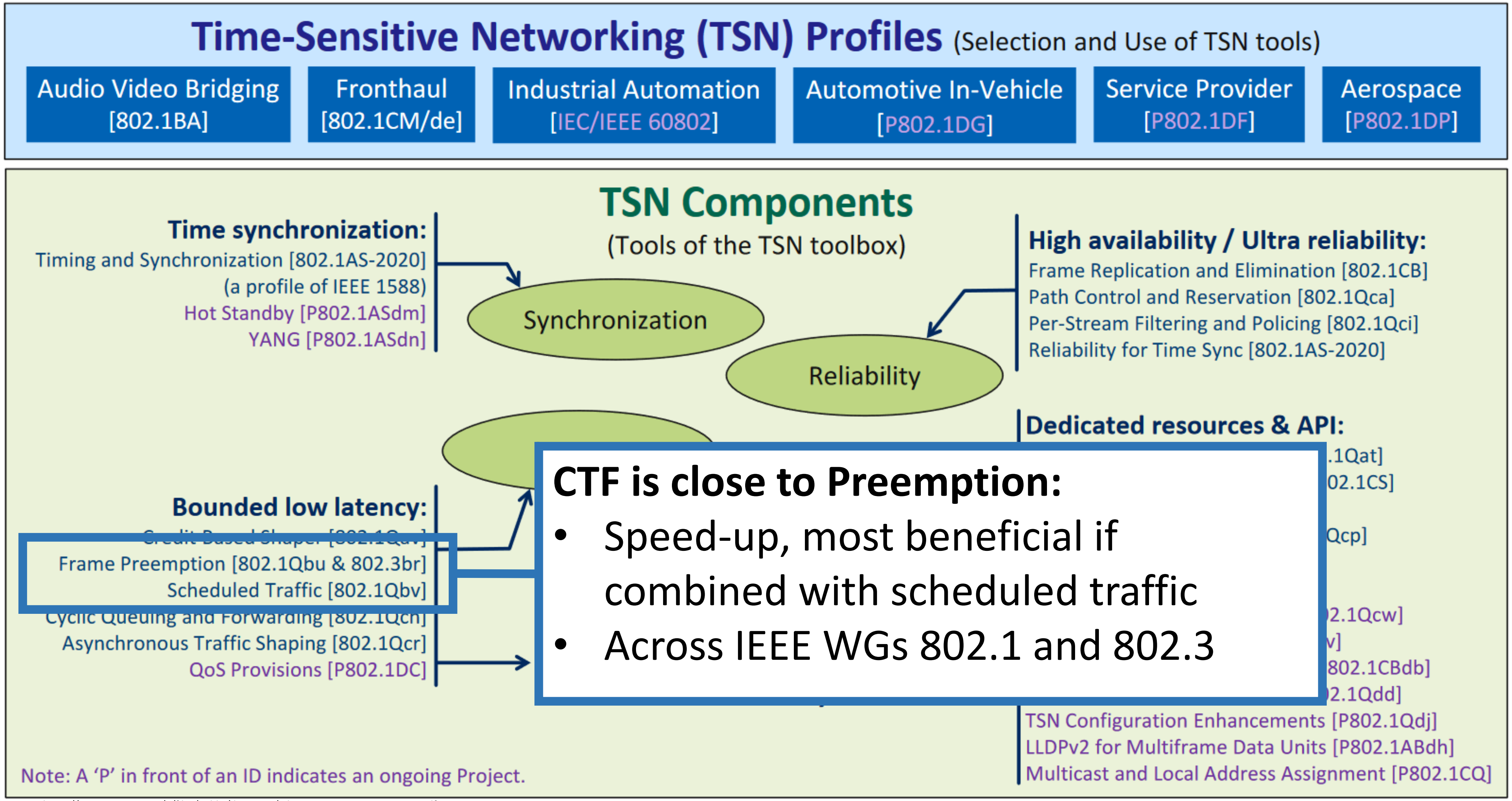
- Traditional Service
  - Curves have long tail
  - Average latency is good
  - Lowering the latency means losing packets (or overprovisioning)
- Deterministic Service
  - Packet loss is at most due to equipment failure (zero congestion loss)
  - Bounded latency, no tails
  - The right packet at the right time





Source: https://www.ieee802.org/1/files/public/docs2018/detnet-tsn-farkas-tsn-basic-concepts-1118-v01.pdf

CTF in the TSN Context



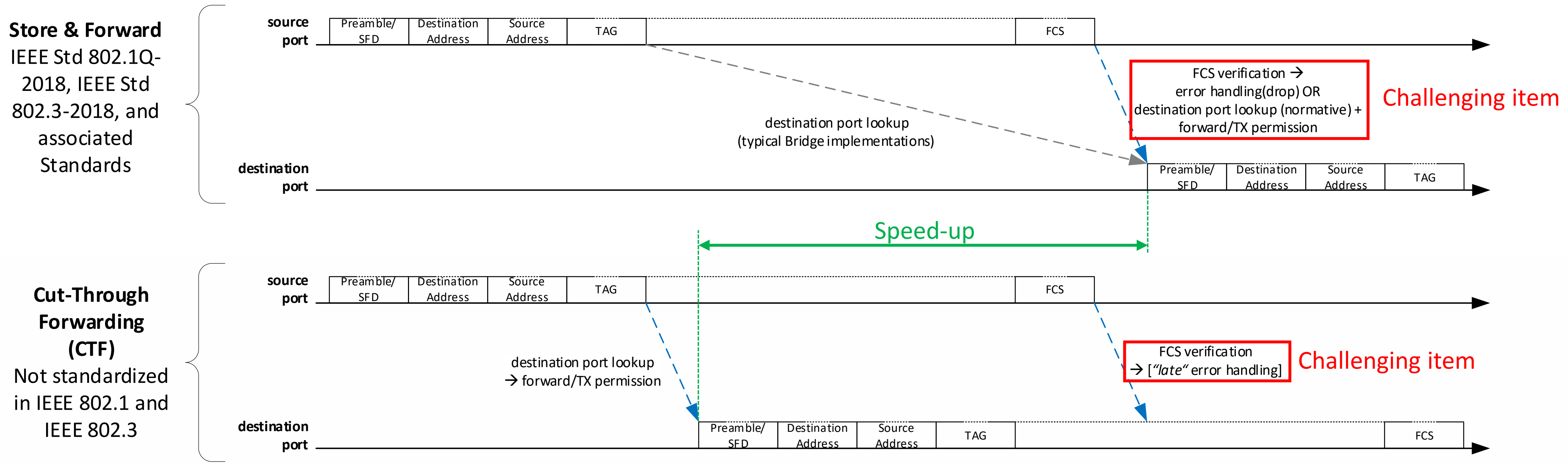
CTF is close to Preemption:

- Speed-up, most beneficial if combined with scheduled traffic
- Across IEEE WGs 802.1 and 802.3

Source: https://www.ieee802.org/1/files/public/docs2021/admin-tsn-summary-0221-v01.pdf

Basic CTF Operation

CTF is an alternative forwarding method to Store & Forward (S&F) in Bridges



Delay performance enhancements

- Reduced residence times of frames in Bridges ("speed-up")
- Reduced frame length dependent jitter/delay variation

(Main) Challenges

- Transmission of frames with errors discovered by FCS verification, and the associated consequences
- S&F operation "deeply" manifested in IEEE 802.1 and 802.3 Standards

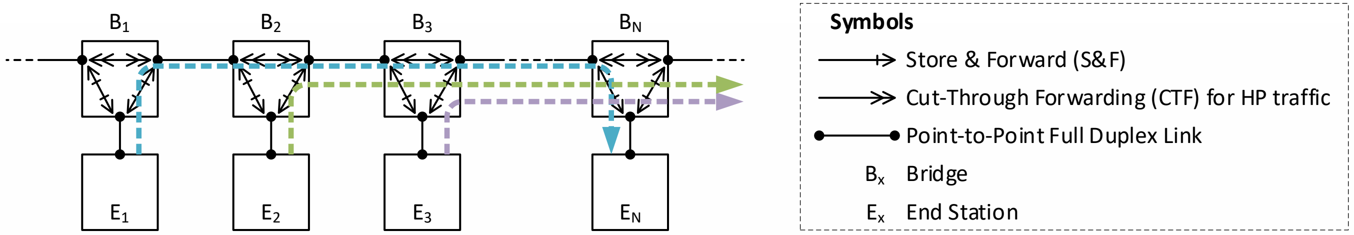
CTF Speed-up Analysis: Assumptions (1)

Purpose

- The following assumptions assemble a simplified model to focus on a simple speed-up analysis:
  - Some assumptions can be valid for some real systems, while being invalid for others.
  - The assumptions here are not intended as requirements or limitations for real systems with CTF.

Topology/Network

- Chain Network/Network segment
- Identical Link Speeds, Full-Duplex, negligible propagation delays
- CTF possible on all interconnections *except* from/to end stations (i.e., S&F at first and last hops)
- Strict Priority Transmission Selection Algorithm, optional with Enhancements for Scheduled Traffic

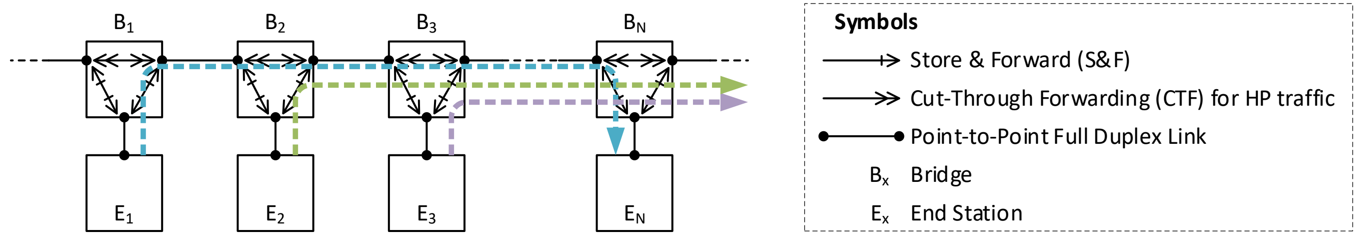


Errors

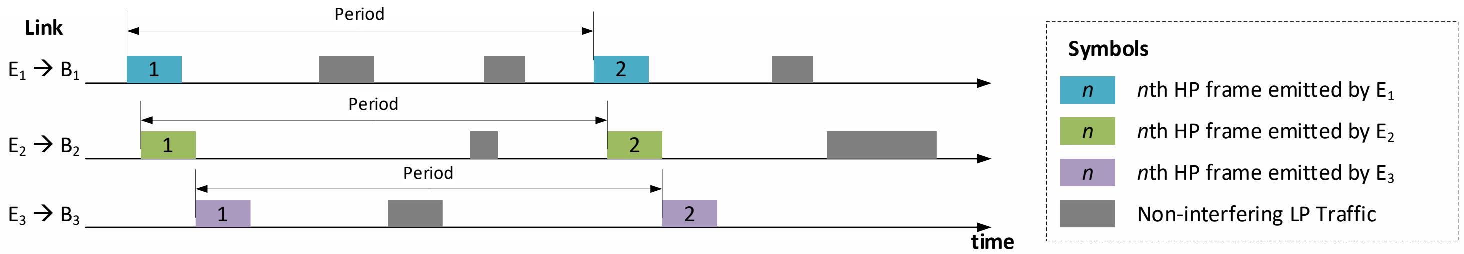
- Error free environment → no data corruption in frames
- However, errors, including late error handling, is addressed later in this tutorial

CTF Speed-up Analysis: Assumptions (2)

Traffic – Focus on Bounded Latency



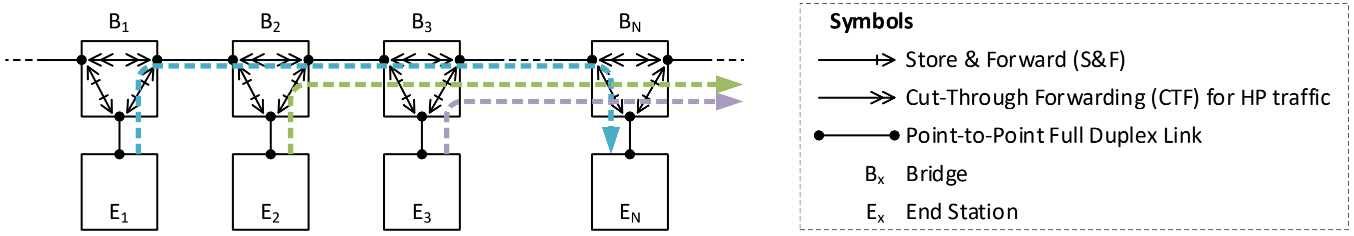
- High Priority (HP): Focus of the Analysis
  - At most one stream sent by each end station, and each end station receives HP streams from at most one direction of the chain
  - Constant frame length[1]
  - Periodic (same period for all streams)
  - Period < maximum end-to-end latency
  - Nominal transmission times at sending end stations



- Low Priority (LP): Background
  - Always Store & Forward
  - Interferes with CTF traffic
    - Without preemption: 1542 octets (max. LP frame[1,2])
    - With preemption: 155 octets (max. non-preemptible LP frame[1,3])

1) Includes all media-dependent overhead for IEEE 802.3 point-to-point full duplex media (Preamble, SFD, minimal Interpacket Gap).
2) Upper limit of 1500 octets payload in a tagged frame.
3) Defined upper limit for addFragSize=0 (cmp. 99.4.8 of IEEE Std 802.3br-2016).

CTF Speed-up Analysis: Math



Delay until forwarding to destination ports happens. Assumed that the lookup starts after l_{Hdr} octets and finishes after d_{LU} µs. Note that the lookup can finish after frame completion during reception.

$$d_{SFF}^{max} = (H+2)\left(\boxed{\max\{l_{HP}d_{Oct}, l_{Hdr}d_{Oct} + d_{LU}\}} + d_Q\right) + \boxed{\left((H+1)l_{LP} + Hl_{HP}\right)d_{Oct}}$$

Maximum interference by crossing high priority traffic (l_{HP}) and crossing low priority traffic (l_{LP}). Dependent on the subsequently introduced communication schemes, either one or both types of interference exist or not (e.g., full TDM avoids both).

$$d_{CTF}^{max} = 2\left(\max\{l_{HP}d_{Oct}, l_{Hdr}d_{Oct} + d_{LU}\} + d_Q\right) + \boxed{H\left(l_{Hdr}d_{Oct} + d_{LU} + d_Q\right)} + \left((H+1)l_{LP} + Hl_{HP}\right)d_{Oct}$$

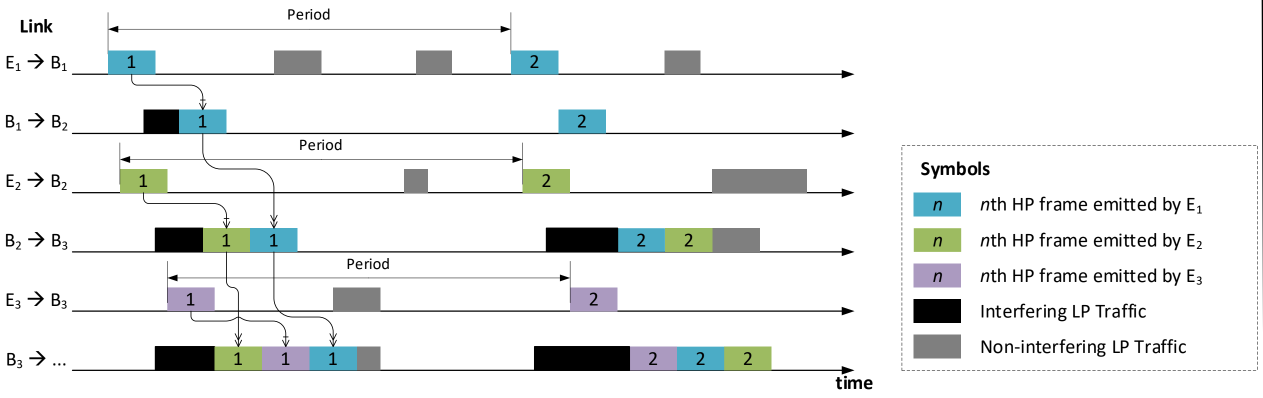
Separates the H interconnections (CTF) from the first and last ones (S&F). Note that, if the lookup finishes after frame completion during reception, then CTF provides no lower delay than S&F. The other way around, if the lookup is "fast enough", then CTF provides lower delays than S&F.

Symbol	Description
d_{SFF}^{max}	Maximum end-to-end delay without CTF of HP frames, in μs.
d_{CTF}^{max}	Maximum end-to-end delay with CTF of HP frames, in μs.
H	Number of possible CTF interconnections (e.g., N-2 for the stream of E_1).
l_{HP}	Frame size of high priority traffic (i.e., the traffic that can be subject to CTF), including all media dependent overhead, in octets.
l_{LP}	Frame size of low priority traffic (always S&F), including all media dependent overhead, in octets. <u>Assumption:</u> 1542 octets without preemption, 155 octets with preemption.
l_{Hdr}	Header length required for destination port lookup in Bridges, in octets. <u>Assumption:</u> 24 octets (preamble, start of frame delimiter, DA, SA, VLAN-Tag).
d_{Oct}	Nominal duration of an octet reflecting the link speed, in μs.
d_{LU}	Destination port lookup duration after l_{Hdr} octets were received, in μs. <u>Assumption:</u> 0.16 μs (e.g., 20 clock cycles @ 125 MHz).
d_Q	Interference-independent queuing delay (MAC delay, PHY delay, etc.), in μs. <u>Assumption:</u> 0.32 μs.

CTF Speed-up Analysis: Both Extremes

Uncoordinated

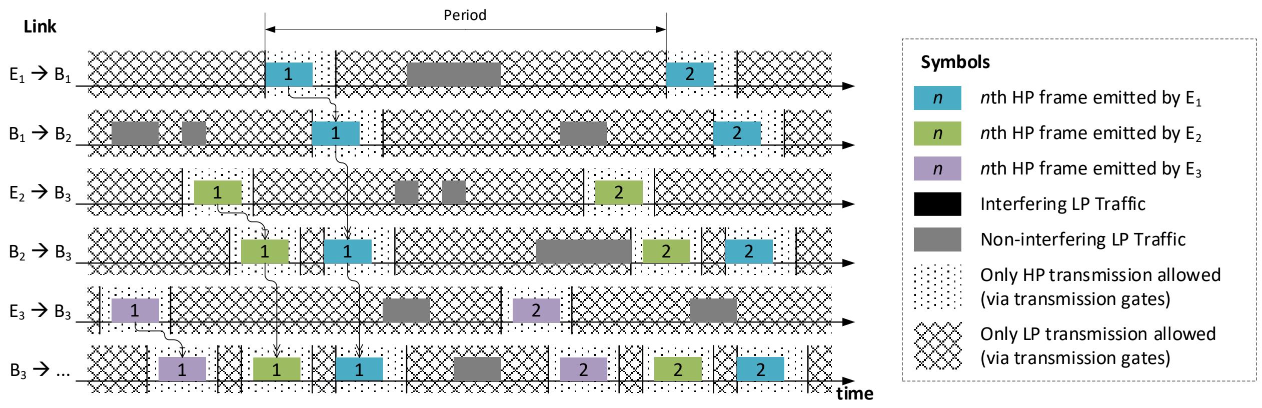
Interference by low priority <u>and</u> other high priority (CTF) traffic



		SFF-to-CTF ratio									
		Preemption unsupported					Preemption supported				
H	Link \ l_{HP}	128	256	512	1024	1542	128	256	512	1024	1542
2	100 Mbps	96%	93%	88%	83%	80%	85%	80%	76%	74%	73%
4	100 Mbps	96%	91%	85%	79%	75%	82%	75%	70%	67%	66%
16	100 Mbps	95%	90%	82%	74%	70%	77%	68%	62%	59%	57%
64	100 Mbps	94%	89%	81%	73%	68%	76%	66%	60%	56%	54%
2	1 Gbps	97%	94%	89%	84%	81%	89%	82%	78%	75%	74%
4	1 Gbps	96%	92%	86%	80%	76%	86%	78%	72%	68%	67%
16	1 Gbps	96%	91%	83%	75%	70%	83%	72%	65%	60%	58%
64	1 Gbps	96%	90%	82%	74%	69%	82%	71%	62%	57%	55%
2	2,5 Gbps	98%	95%	90%	84%	81%	94%	86%	80%	76%	75%
4	2,5 Gbps	98%	93%	87%	81%	77%	92%	83%	75%	70%	68%
16	2,5 Gbps	97%	92%	85%	76%	71%	90%	78%	69%	62%	60%
64	2,5 Gbps	97%	92%	84%	75%	70%	90%	77%	67%	60%	57%

Full Time Division Multiplexing

No Interference



		SFF-to-CTF ratio				
		Preemption supported or not				
H	Link \ l_{HP}	128	256	512	1024	1542
2	100 Mbps	61%	56%	53%	51%	51%
4	100 Mbps	48%	41%	37%	35%	35%
16	100 Mbps	31%	21%	16%	14%	13%
64	100 Mbps	25%	14%	9%	6%	5%
2	1 Gbps	75%	64%	58%	54%	53%
4	1 Gbps	67%	52%	43%	39%	37%
16	1 Gbps	56%	36%	25%	18%	16%
64	1 Gbps	52%	31%	18%	11%	8%
2	2,5 Gbps	88%	74%	64%	58%	55%
4	2,5 Gbps	84%	66%	52%	44%	40%
16	2,5 Gbps	79%	55%	36%	25%	21%
64	2,5 Gbps	77%	50%	31%	18%	13%

Lower percent values indicate higher end to end delay performance improvements of CTF over S&F.

Reasons for standardizing CTF in IEEE 802

Interoperable and deterministic data plane (examples)

- Distinguish CTF Traffic from S&F Traffic
  - TAGs, Addresses, Ports?
- “Late” error handling
  - Shorten/truncate erroneous frames?
  - Mark erroneous frames?
  - Do nothing?
- Behavior of existing 802.1 Bridge mechanisms for CTF traffic
  - Flow Metering (e.g. Max. SDU size filters, MEF 10.3)?
  - Transmission selection algorithms?
  - Transmission gates?
  - Link speed transitions?[1]

Unified Management

- Elements
  - Configuration Parameters (e.g., enable/disable CTF)
  - Device properties (e.g., timing)
  - Status Variables (e.g., erroneous CTF frame counters)
- Required, for example, for automated, efficient and consistent TDM configuration (e.g., centralized network controller [802.1Qcc-2018])

Application and limitations of CTF in Networks

- Quality of Service[1,2]

Limit circulating erroneous frames in topological loops; limit bandwidth loss by erroneous frames

- Security [1]

Prevent exposure of frame contents (CTF <u>and</u> S&F) to untrusted network segments

1) See also https://ieee802.org/1/files/public/docs2017/new-tsn-thaler-cut-through-issues-0117-v01.pdf
2) See also https://www.ieee802.org/1/files/public/docs2019/new-seaman-cut-through-scissors-0119-v01.pdf

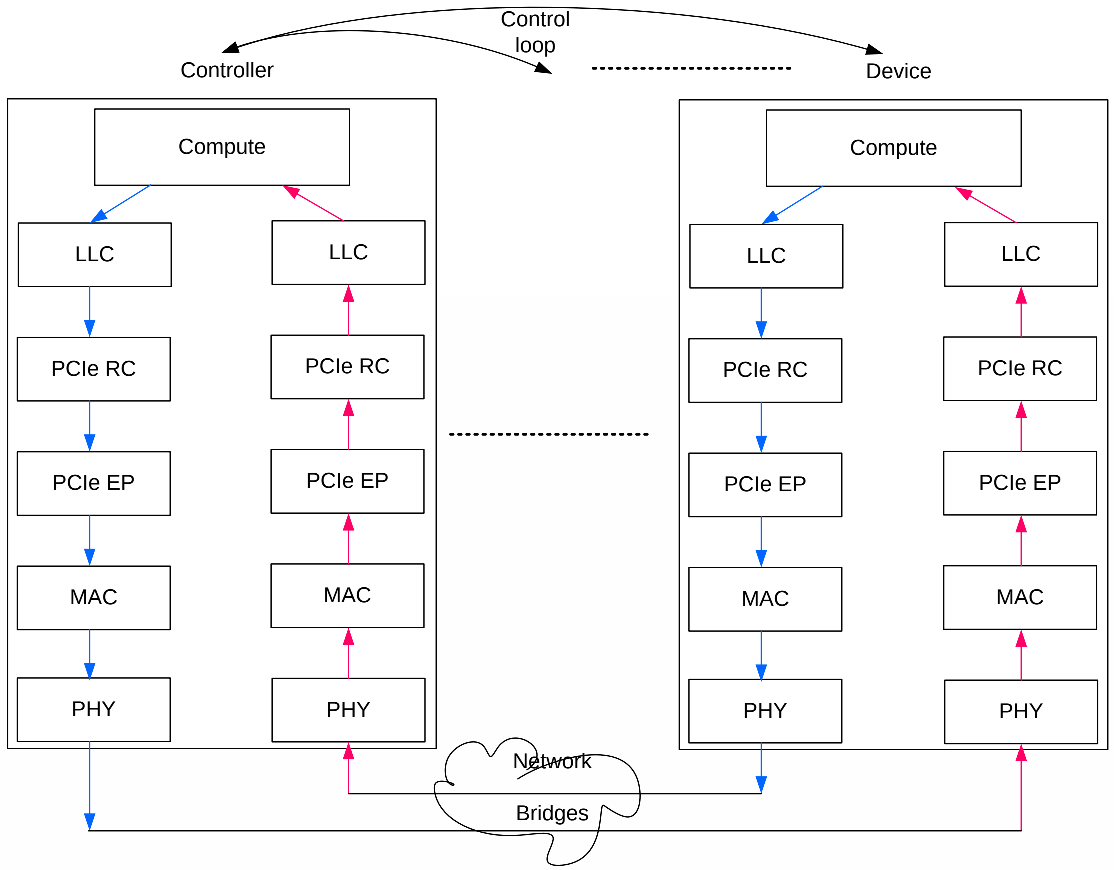
Use-Cases: Industrial Automation

Jordon Woods

Networking Requirements: Principal Data Path (Control Loop)

Principle data path between the controller and a device:

- The entities which are involved into the guaranteed latency transmission for the control loop are depicted
- Latencies for link layer control, bus interface, MAC/PHY are incurred at the controller and the device
- Combined store & forward, bridge delay and PHY delay accumulate at each hop in the network.



Networking Requirements: Summary

Industrial applications, such as machine control, are typically connected in long line configurations. For these installations, to minimize wiring cost and complexity, typical installation uses “daisy chain” where each node has (2) external switched ports and an internal port that goes to the end-node.

A common application is motion control where fast loop times are required. 125 µs cycle rate is common for 100 Mbps. Even lower rates (62.5µs/31.25µs) are desired for 1 Gbps. To support this, low latency for messages through the network is a high priority.

Even Gigabit data rates are not sufficient to solve this problem. Combined store & forward, bridge delay and PHY delay exceed timing budgets. For instance, in a line topology of 64 hops, accumulated latency would exceed a 100 µs control loop even at Gigabit speeds.

- See http://www.ieee802.org/3/ad_hoc/ngrates/public/18_01/woods_nea_01a_0118.pdf

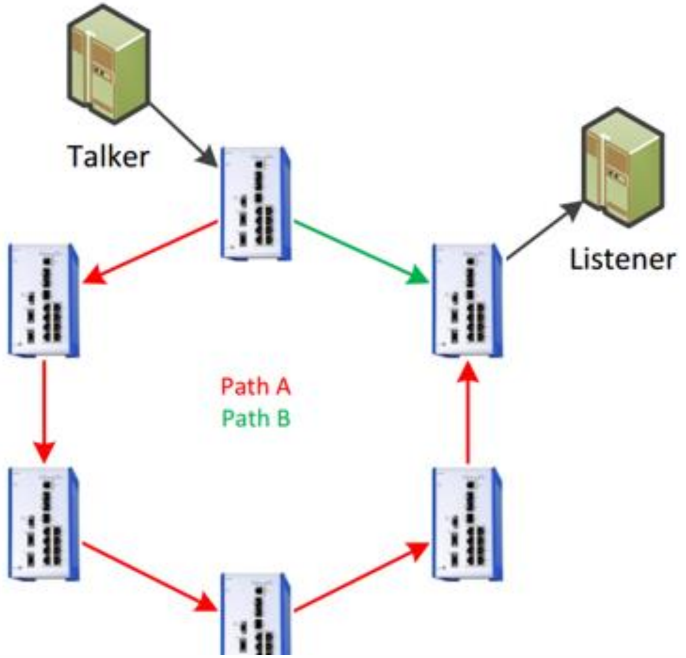
These industrial automation systems often have environmental constraints (power, space, radiated emissions, etc.) which make lower data rates desirable. There is a desire in some applications to support brown-field wiring. Often, these devices are resource, power and cost-constrained. For these applications 100Mb/s rates are desired.

Why Line Topologies?

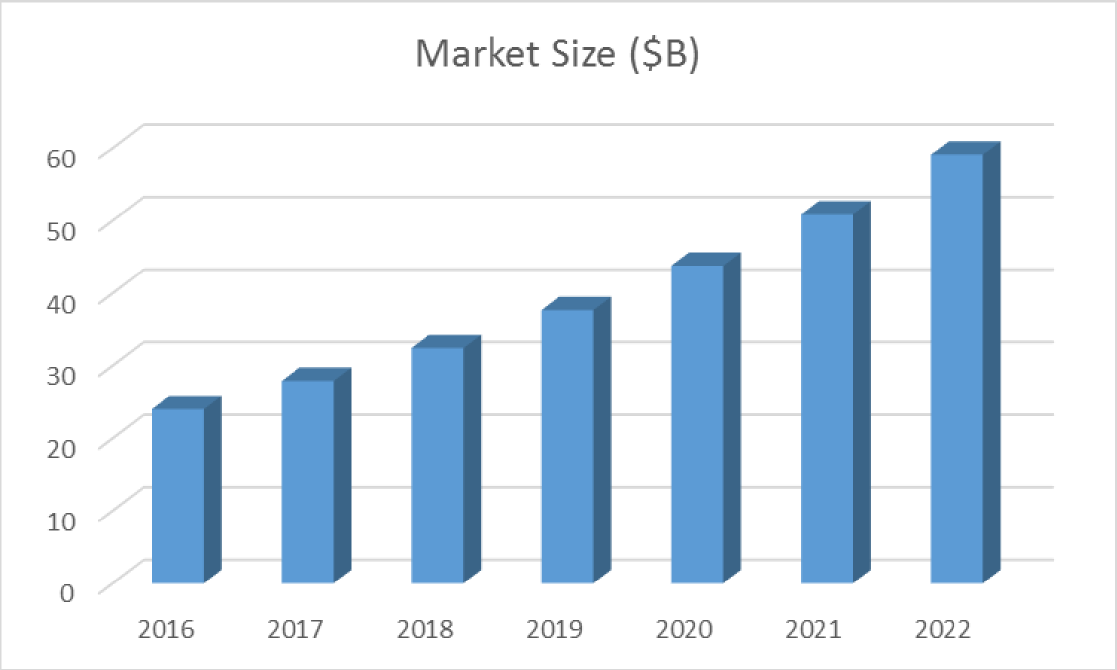
- Physical constraints make cabling for star topologies impractical
- The construction of the application naturally lends itself to point-to-point connectivity
- They are, after all, assembly “lines”

Use Case 2 - Redundancy (ring topologies)

- Typical topology for redundancy in industrial networks is a ring:
  - Inherently different packet latency on the network along the different routes
  - Depending on the setup, packet latency on the two paths can have extreme deviation
  - Depending on the allowed reception window of redundancy mechanisms, ring size is limited
  - For instance, for a 300 byte packet and 100 us packet deviation:
    - At 100 Mbit/s: the max. tolerable difference in the path is consumed in 4 hops
    - At 1 Gbit/s: the max. tolerable difference in the path is consumed in 34 hops



Industrial Network Growth



Industrial automation market > $123B in 2019

- Source: Control Global - https://www.controlglobal.com/articles/2020/top-50-automation-companies-of-2019-under-siege/

Connectivity portion is growing

- Fieldbus (58%), 7% growth
- Ethernet (38%), 20% growth
- Limited wireless adoption

With the advent of a common layer 2 (TSN), Industrie 4.0, China 2025, etc., strong growth is expected.

- Global industrial Ethernet market valued at USD $24B in 2016
- Expected to grow to $58.98 billion by 2022
- CAGR of slightly above 16.20% (2017 and 2022)
  - Source: Zion Market Research, 2017 - https://www.zionmarketresearch.com/news/global-industrial-ethernet-market

Use-cases: Data Center Networks

Paul Congdon, Lily Lv

High Performance Applications Growth in the Data Center

High Performance Computing (HPC), AI (Artificial Intelligence)/Big Data and Cloud Computing are hot growth areas.

The convergence of these 3 areas is currently a trend in the data center.

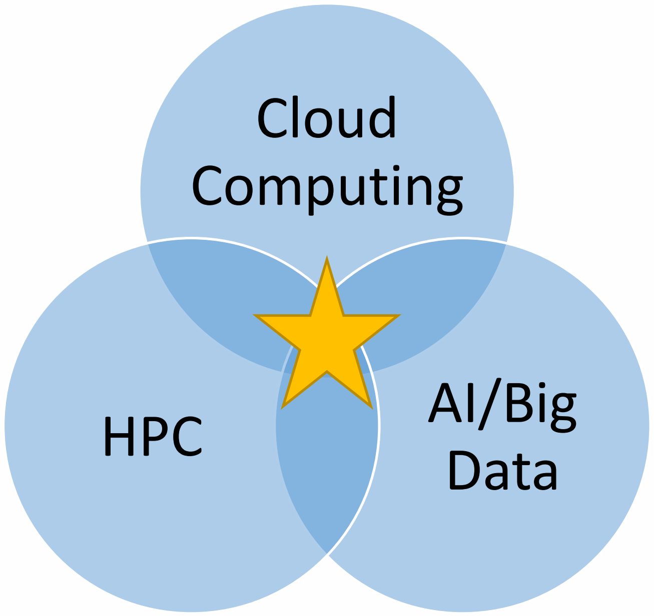
- HPC is available as a cloud service in many public offerings (AWS, Azure, Alibaba etc); growing 17.6% CAGR (Compound annual growth rate) , 2.5 times faster than on-premise HPC.
- HPDA (High performance data analytics) and HPC-based AI are fast emerging markets, with 16% and 31% CAGR respectively.

	2019	2020	2021	2022	2023	2024	CAGR
HPC cloud	$2,466	$3,910	$4,300	$5,300	$6,400	$8,800	17.6%
On-Premise HPC	$27,678	$23,981	$26,774	$31,872	$36,138	$38,214	6.7%

Source: Hyperion Research, November 2020

	2019	2020	2021	2022	2023	2024	CAGR
HPC Server Revenues	$13,713	$11,846	$13,295	$15,817	$17,942	$19,044	6.8%
HPDA Server Revenues	$3,598	$3,932	$4,737	$5,457	$6,480	$7,479	15.8%
HPC-Based AI	$918	$1,094	$1,399	$1,810	$2,745	$3,555	31.1%

Source: Hyperion Research, November 2020

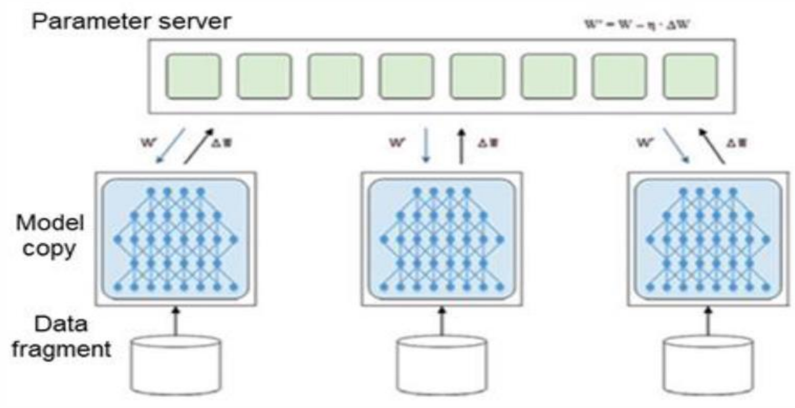


Latency is Critical in Data Center Networks (1)

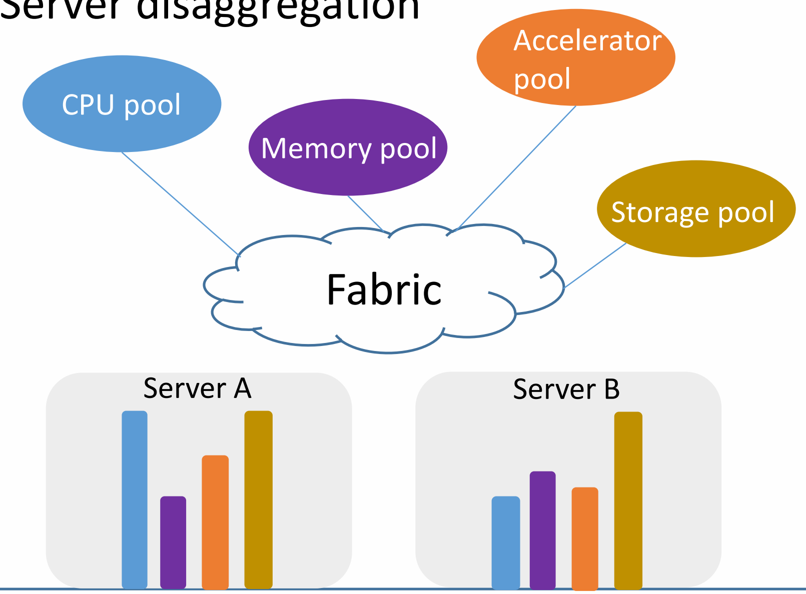
High performance applications are driving change in data center, putting pressure on end-to-end latency.

- System scale is increasing significantly, with much more end points and a larger network.
- Synchronization in large parallel applications is critical to job completion time.
- New hardware architectures, such as server disaggregation, require extremely low-latency fabric.

Parallel AI software



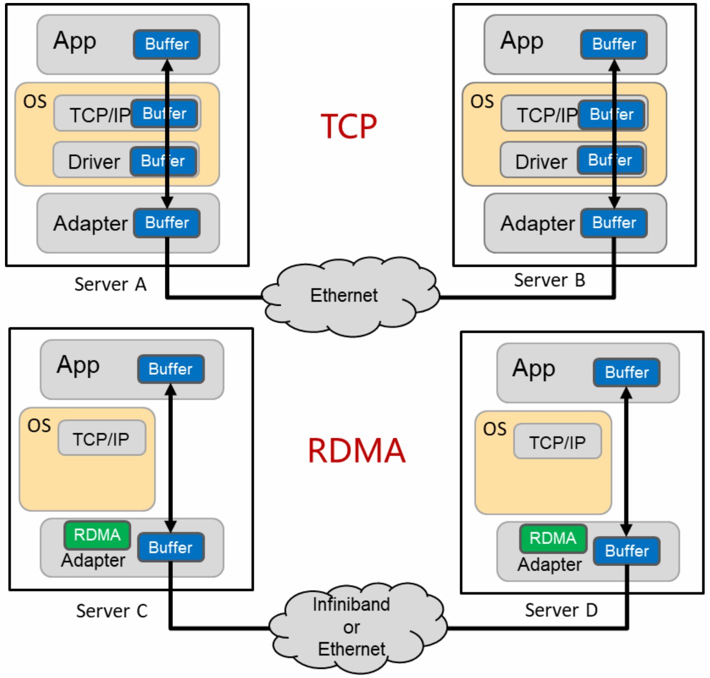
Server disaggregation

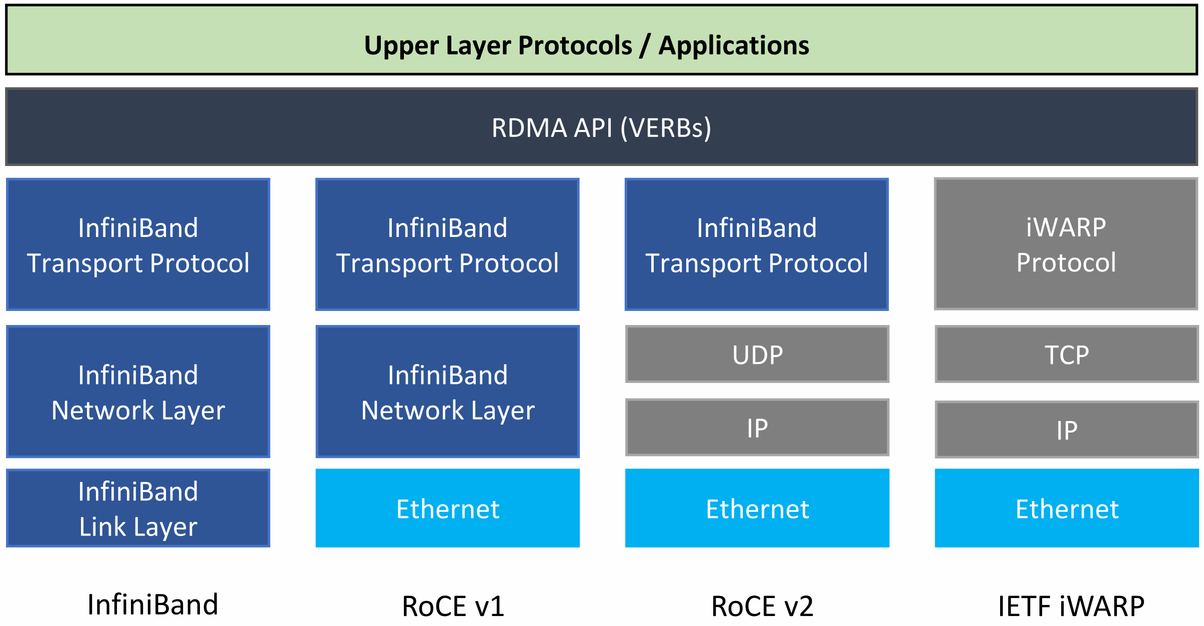


Latency is Critical in Data Center Networks (2)

New technologies are emerging to reduce system latency.

- **RDMA (Remote Direct Memory Access)**
  - RDMA enables direct memory access from one server to another, bypassing the TCP/IP stack handling in OS.
  - RDMA runs over InfiniBand or Ethernet.
    - InfiniBand, like Ethernet, is a networking technology, but customized for high throughput and low latency.
  - RDMA improves message transfer time by 5x compared with TCP/IP.

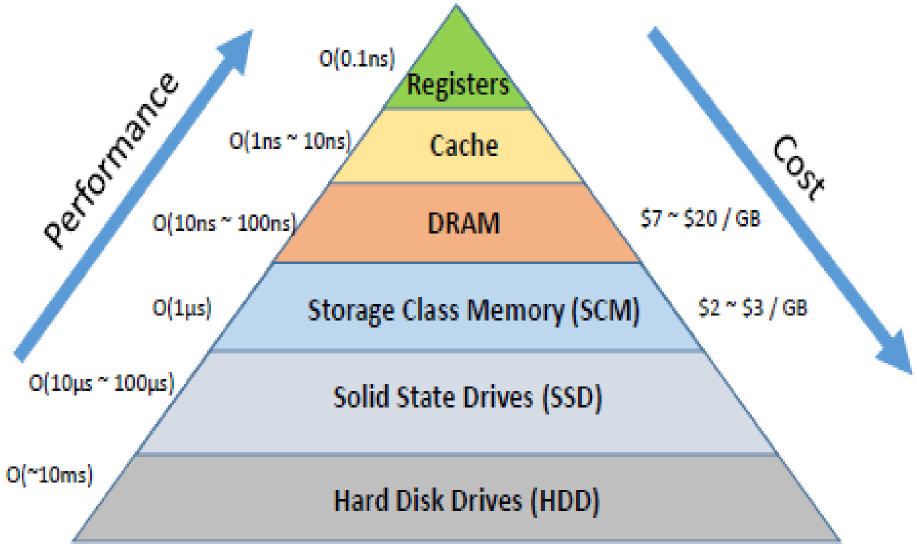




Latency is Critical in Data Center Networks (3)

New technologies are emerging to reduce storage latency.

- **Faster storage media**
  - Persistent storage latencies are approaching memory latencies with the latest Storage Class Memory (SCM) technology.
- **NVMe (Non-Volatile Memory express)**
  - NVMe is a storage interface specification defining communication between host software and PCIe SSD.
  - “The NVMe specification was designed from the ground up for SSDs. It is a much more efficient interface, providing lower latency, and is more scalable for SSDs than legacy interfaces, like serial ATA (SATA). ” (https://nvmexpress.org/)
  - NVMeoF (NVMe over Fabrics) enables “networked” fast storage (SSD/SCM) however without networking enhancements, the network becomes the largest part of end-to-end latency.



Network latency becomes the bottleneck!

Latency is Critical in Data Center Networks (4)

Types of latency in data center networks: dynamic and static

Dynamic latency = queuing delay + retransmission delay

- Mainly caused by congestion
  - In-cast congestion from parallel applications.
  - In-network congestion from ineffective load balancing.

- Mainly cause by packet loss due to congestion
  - Priority-based Flow Control (PFC) guarantees no loss
  - PFC has deployment challenges: configuration, deadlocks, head-of-line blocking, congestion spreading

Static latency = switch forwarding + packet processing + link latency

- Impacted by forwarding table lookup delay, frame reception delay (if store and forwarding) and switching delay

- Impacted by header processing and packet modification

- Propagation delay impacted by distance and speed

- Dynamic latency is the major component and attracts a lot of the industry's attention: See
  - 802 Nendica - The Lossless Network for Data Centers - https://mentor.ieee.org/802.1/dcn/18/1-18-0042-00-ICne.pdf
  - 802 Nendica - Intelligent Lossless Data Center Networks - https://mentor.ieee.org/802.1/dcn/20/1-21-0004-00.pdf
- However, Static latency becomes significant in high performance scenarios, such as HPC.

Benefits of Cut-Through Forwarding in the HPC Networks

HPC network operates at the nanosecond level

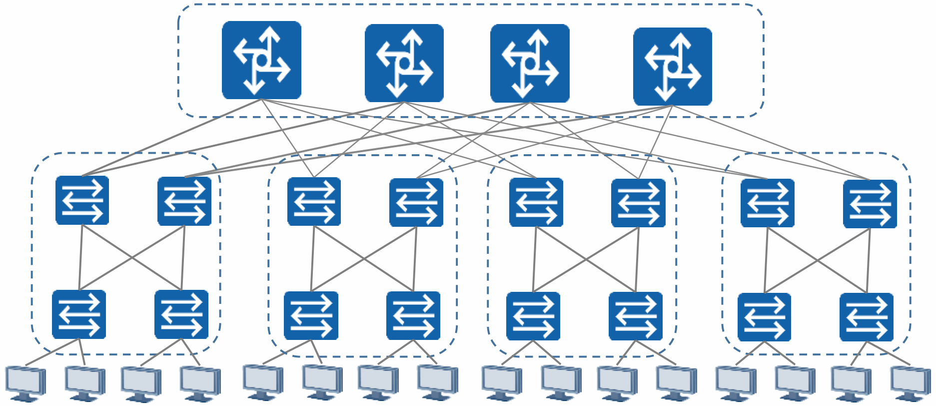
- E2E network latency is only several micro-seconds.
- Per hop latency is required as low as possible, hundreds of nano seconds, or even lower.

CTF is applicable in the HPC network

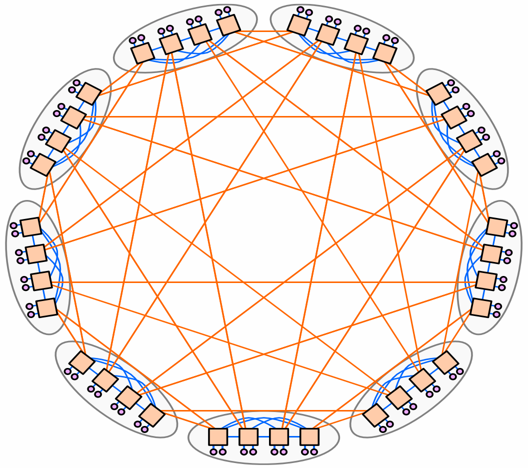
- Traffic loads can be predictable, leading to congestion avoidance techniques in switches.
- Data center topologies are well structured with similar type of switches.

Regular Topologies: Two typical HPC networks

Fat Tree is a rearrangeably non-blocking structure, which provides an oversubscription ratio of 1:1 to all servers.

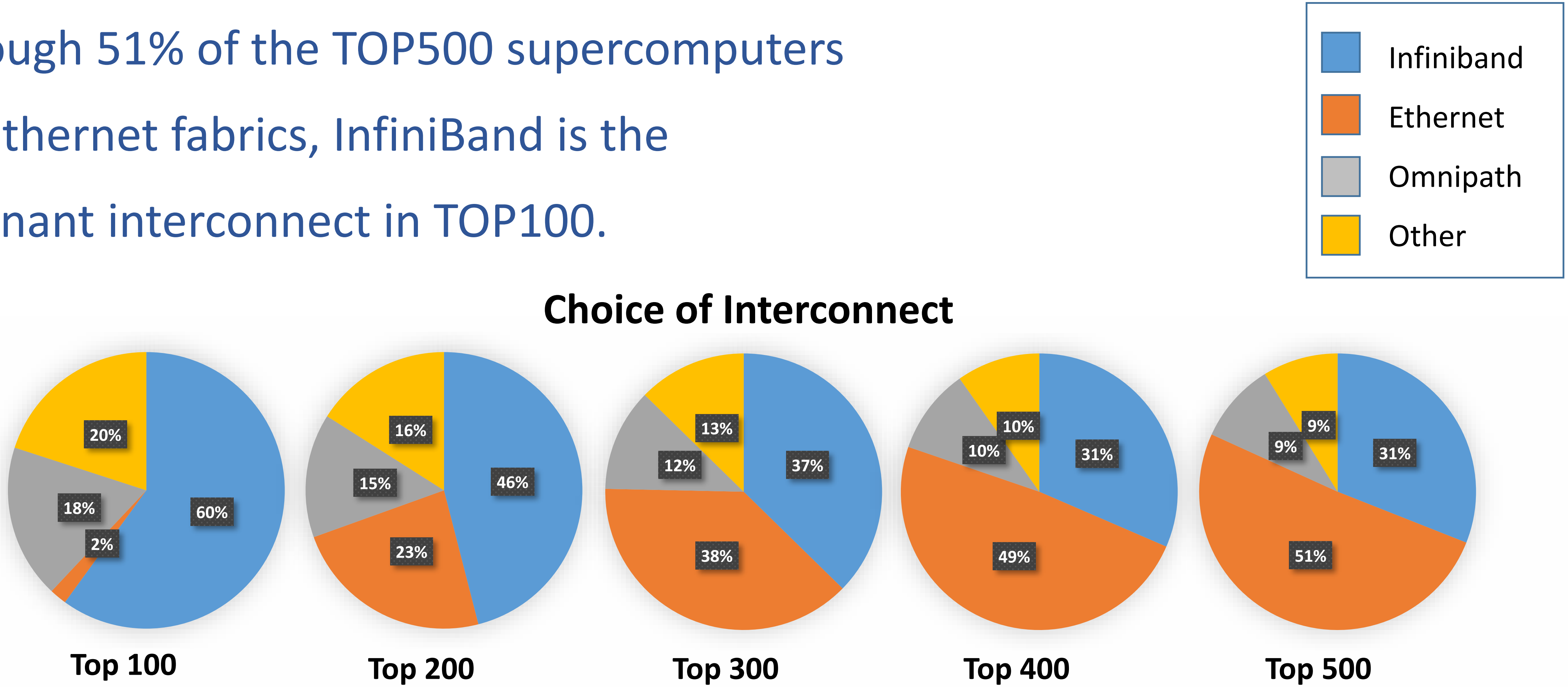


Dragonfly is a well-balanced network with no oversubscription.



InfiniBand is the ‘first-choice’ in HPC Today (1)

Although 51% of the TOP500 supercomputers use Ethernet fabrics, InfiniBand is the dominant interconnect in TOP100.



InfiniBand is the ‘first-choice’ in HPC Today (2)

InfiniBand switch per hop latency is much lower than Ethernet

- Ethernet switching chipset latency can be greater than 100s of ns.
- Latency increases with frame size using store-and-forward.
- InfiniBand switching chipset latency can be less than 100ns.
- Cut-through is an important feature for InfiniBand to keep per hop latency low.

Ethernet (non-CT)

	BRCM THK
Port	128*25G

One 25GbE Port to One 25GbE Port Test

Frame Size(Bytes)	64	128	256	512	1024	1280	1518	2176	4096	9216
Latency(ns)	511	528	556	567	717	793	872	1082	1694	3334

Source: Tolly, February 2016

IB (with CT)

	MLNX Switch-IB	**MLNX Switch-IB2**
Port	144*25G	144*25G
Latency	90ns	90ns

Source: https://www.mellanox.com/news/press_release/

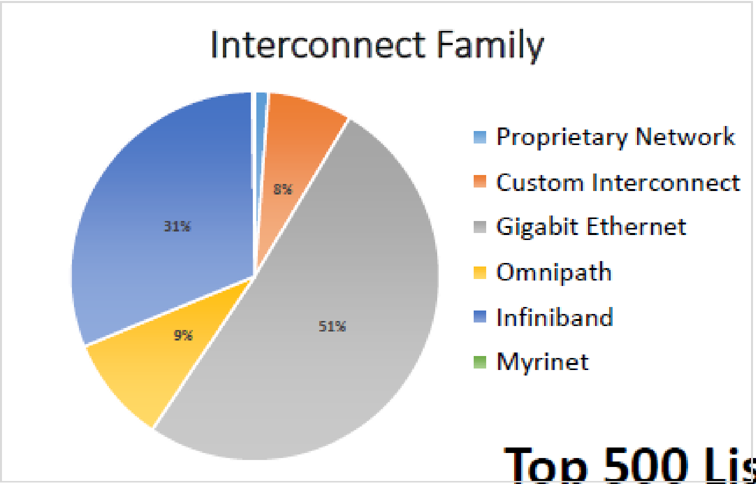
Ethernet needs CTF to further penetrate HPC

Ethernet has great opportunity to become more competitive in HPC market.

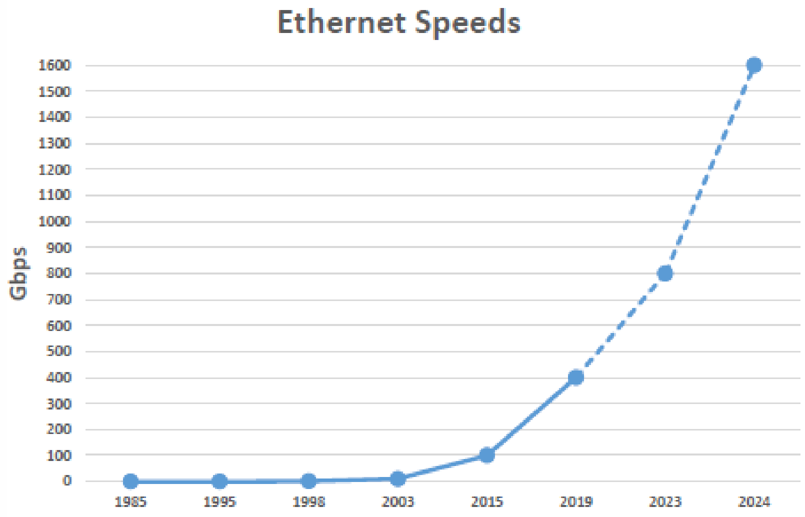
- TOP 500 shows Ethernet Interconnects already takes the largest share (51%)
- Ethernet has its own advantages
  - Ethernet is ubiquitous technology.
    - Cost-effective solution
    - Relatively easy to deploy and manage
    - Leading technology development
  - Ethernet provides large bandwidth connectivity
    - up to 400G, 100G for single lane
    - towards 800G, 200G for single lane

The obvious gap of Ethernet is latency

- Per hop latency gap is significant compared with InfiniBand
- CTF is a good method to improve per hop latency



Top 500 List



Use-Cases: Professional Audio/Video

Henning Kaltheuner

Possible integration into IEEE 802.1: General

Johannes Specht

Location in IEEE 802.1 Standards

Dedicated IEEE 802.1 Standard for CTF

- Not one or more amendment[s] to existing IEEE 802.1 Standards.

Reference Usage

- Select/import and adjust existing protocols and protocol procedures from other IEEE 802.1 Standards:
  1. IEEE Std 802.1Q-20xx
  2. IEEE Std 802.1CB-20xx
  3. IEEE Std 802.1AC-20xx

Some Implications

- At least some of the implications:
  1. No distribution of CTF across multiple IEEE 802.1 Standards documents
  2. Existing protocols and protocol procedures not addressed are basically “beyond specification”
  3. A simple way for inclusion without adjustment is basically *“as specified in x.y.z of IEEE Std 802.1A.B.C”*

Main Contents

Requirements for CTF in Bridges

CTF in Networks

- Structure and elements (e.g., “CTF Bridge”)
- QoS Maintenance/Requirements[1]
- Usage/Performance aspects[2]

CTF in Bridges

- Bridge data plane behavior and managed objects (YANG)
  - MAC Relay Entity/Forwarding Process
  - Bridge Port Transmit and Receive[3]

“Features” for QoS Maintenance and usage

1) Issues introduced by CTF (cmp. 6.5 of IEEE Std 802.1Q-20xx)
2) See earlier slides in this slide set
3) To the extent possible in IEEE 802.1

Possible integration into IEEE 802.1: CTF in Bridges

Johannes Specht

CTF in Bridges: Feature Set

- Required:
  1. IEEE Std 802.1Q-20xx: “Basic” VLAN/MAC Bridge Operations
  2. New for CTF: Fallbacks from CTF to S&F (i.e., to behavior from existing IEEE 802.1 Stds)
  3. New for CTF: Late error handling
- Options/within specification:
  1. IEEE Std 802.1Q-20xx: Per-Stream Filtering and Policing (PSFP)
  2. IEEE Std 802.1Q-20xx: Congestion Isolation (CI)
  3. IEEE Std 802.1Q-20xx: Enhancements for Scheduled Traffic (EST)
  4. IEEE Std 802.1Q-20xx: Enhanced Transmission Selection (ETS)
  5. IEEE Std 802.1CB-20xx: Frame Replication and Elimination for Reliability (FRER)
  6. IEEE Std 802.1Q-20xx: Preemption
- For later discussion in IEEE WG 802.1:
  1. New for CTF: Header check sequences[1]

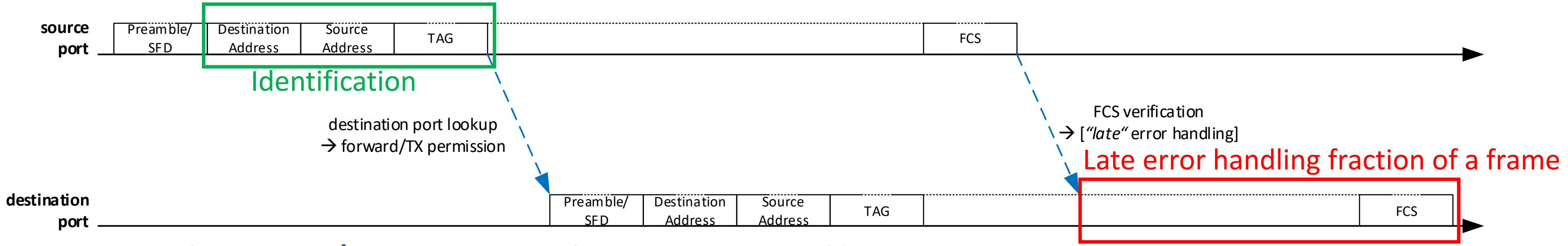
Common Elements (Superset)
- Stream Filters
- Maximum SDU size filtering
- Stream Gates
- MEF 10.3 Flow Meters

Common Element
- Transmission Gates

1) Not necessarily required - header check sequences imply several challenges (interoperability with non-CTF Bridges, loose definition of headers, etc.). This topic can be considered thoroughly during a IEEE 802.1 standards development project.

CTF in Bridges: Basic path of Frames through Bridges

Cut-Through Forwarding (CTF)
Not standardized in IEEE 802.1 and IEEE 802.3



1. Reception: Initial Identification/separation from S&F Traffic

Reception on a Port for which CTF has been enabled
AND (

Priority decoded from VLAN-TAG (6.9 and 6.20 of IEEE Std 802.1Q-20xx)
OR
Stream Identification (IEEE Std 802.1CB-20xx),
used by stream filters followed by stream gates for Internal Priority Value assignments[1] (IEEE Std 802.1Q-20xx)

)

New Management Parameter(s)
- CTFReceiveEnable
  (Boolean, RW, default False)
- Per-Port

2. Queuing

Queuing in traffic classes (8.6.6 of IEEE Std 802.1Q-20xx) for which CTF is supported **AND** enabled

New Management Parameter(s)
- CTFTransmitEnable
  (Boolean, RW, default False)
- CTFTransmitSupported
  (Boolean, RO)
- Per-Port per traffic class

3. Transmission

- Strict priority transmission selection algorithm **OR** enhanced transmission section algorithm (if supported),
- followed by transmission gates (if supported)
- Late error handling, in case of late errors

1) The Mask-and-Match stream identification, as currently under development in IEEE P802.1CBdb, effectively enables a priority to be determined by at least the Destination Address. As one result, there are different (potentially co-existing) perceptions of a "header".

CTF in Bridges: Late Errors

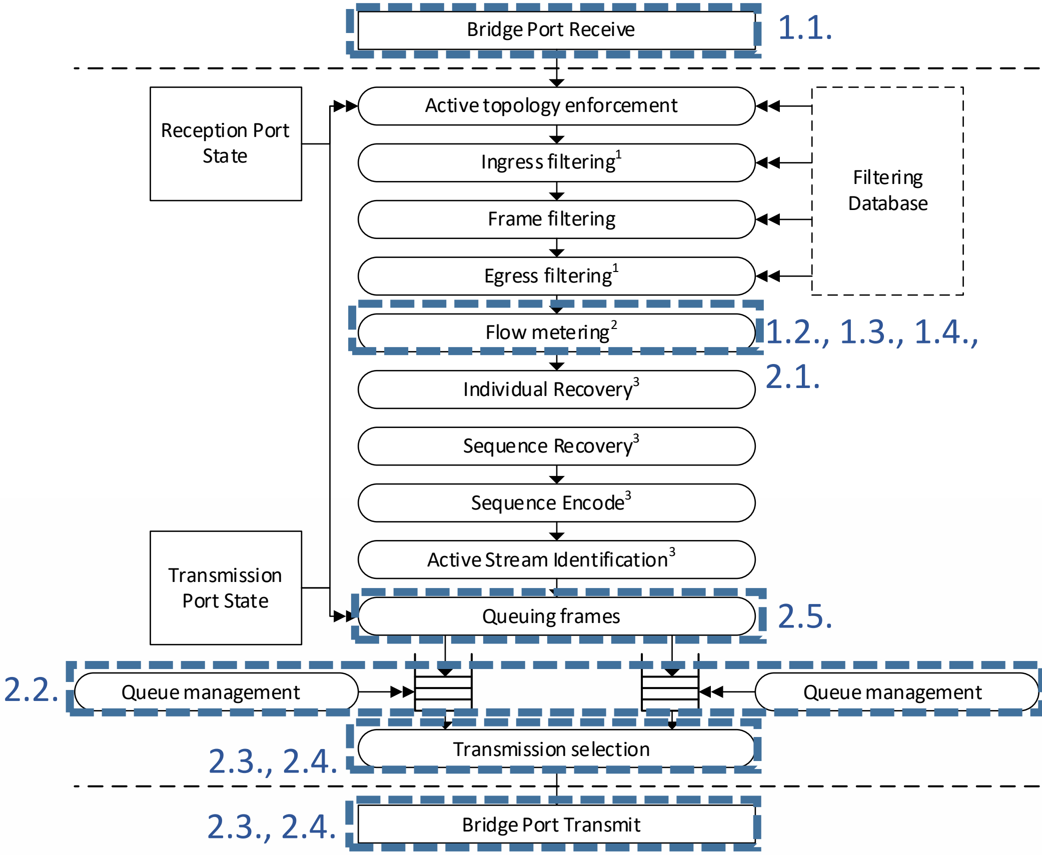
1. Causes

1. Errors discovered by FCS verification
2. Maximum SDU size filtering limit reached during reception
3. Stream gates transition to closed state[1]
4. Color of flow meters (MEF 10.3) transitions to red
5. The per traffic class maximum SDU size of transmission gates is exceeded

2. Handling

1. Treat the frame end by PSFP's maximum SDU size filtering, stream gates and flow meters (MEF 10.3)
2. Remove the frame from all queues
3. Shorten the end of frame by an implementation-specific amount
4. Erroneous frame marking (end of frame)

New Management Parameter(s)
- CTFTransmitShorteningMin (Integer, RO, nanoseconds)
- Per-Port



Cmp. 8.6 of IEEE Std 802.1Q-20xx and clause 8 of IEEE Std 802.1CB-20xx.
1) Not present in MAC Bridges
2) Not present if PSFP or CI is unsupported
3) Not present if FRER is unsupported

New Management Parameter(s)
- CTFReceivedErroneousMarked (Counter, RW)
- CTFReceivedErroneousUnmarked (Counter, RW)
- Per-Port

1) In contrast to stream gates, it is not intended to involve late error handling if EST transmission gates transition to a closed state during transmission for compatibility (see 8.6.8.4 of IEEE Std 802.1Q-20xx)

CTF in Bridges: Fallbacks to S&F

1. On the main relay path

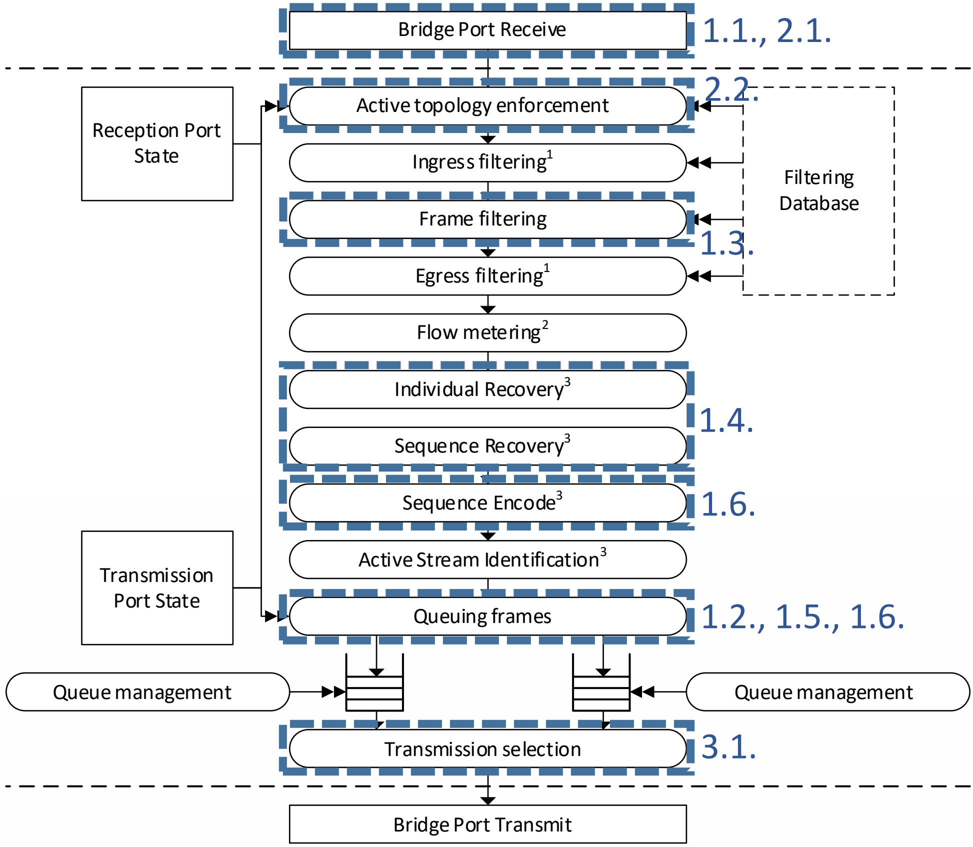
1. CTF reception is disabled on a Bridge Port
2. CTF is disabled/unsupported by a traffic class on a Bridge Port
3. No matching filtering entry in the FDB (i.e., flooding)
4. Association of a frame under reception with a FRER recovery function
5. Different link speed between reception-transmission port pairs
6. Frame length changes (e.g., TAG removal)

2. Leaving the relay path

1. To Higher Layer Entities
2. FDB for learning

3. Implicit

1. Interfering frames during transmission



Cmp. 8.6 of IEEE Std 802.1Q-20xx and clause 8 of IEEE Std 802.1CB-20xx.
1) Not present in MAC Bridges
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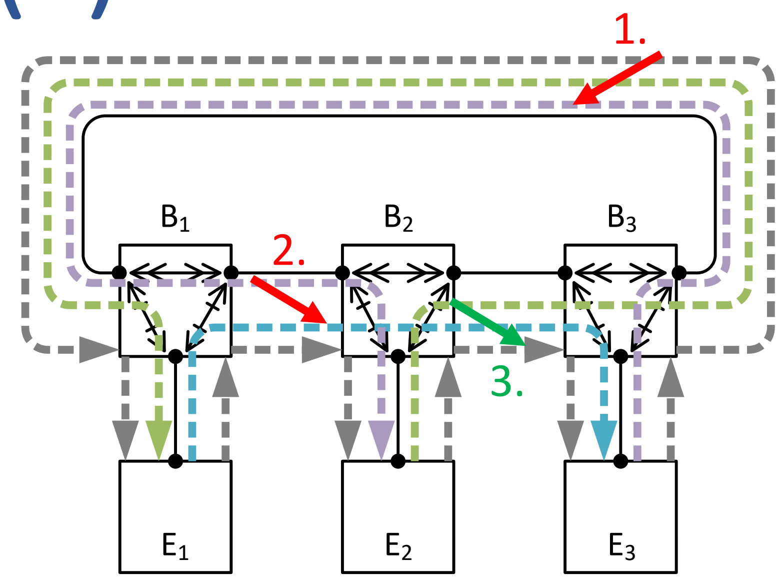
Possible integration into IEEE 802.1: CTF in Networks

Johannes Specht

CTF in Networks: Circulating frames (1)



Problem Description

- Erroneous frame under reception by CTF Bridge are classified for CTF, and are transmitted by unintended Bridge Ports before FCS verification.
- The issue affects networks/network segments with topological loops, in which such frames can circulate for "a while".

Observation

- It does not matter whether erroneous frames were intended for CTF or S&F
    1. Frames intended for S&F can be misclassified by the receiving CTF Bridge as CTF frames.
    2. Frames intended for CTF can remain classified for CTF, but match a wrong FDB entry (i.e., wrong port map).
    3. Frames misclassified as S&F frames are no issue (i.e., FCS verification prior to transmission).

Goal Definition

Frame removal after at most one round, if FCS verification can discover the error.

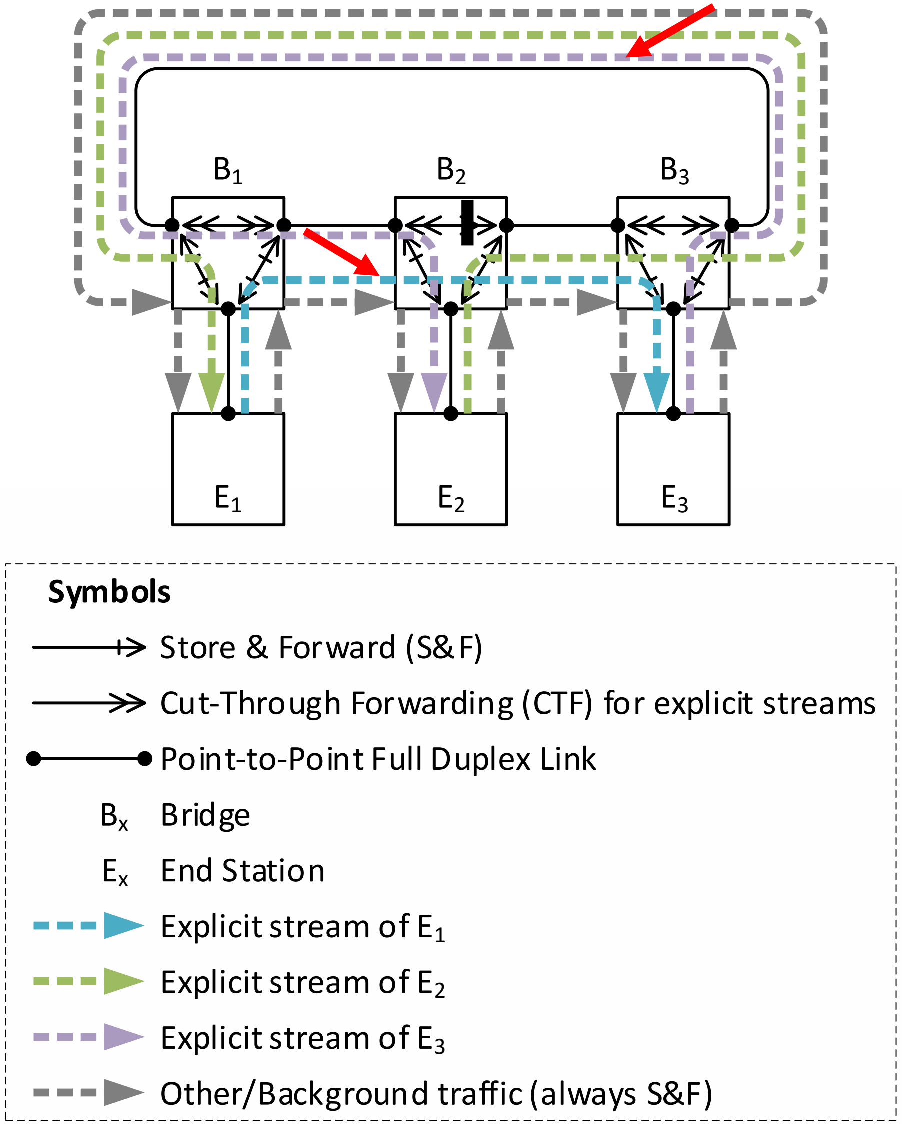
Symbols

- Store & Forward (S&F)
- Cut-Through Forwarding (CTF) for explicit streams
- Point-to-Point Full Duplex Link
- B_x Bridge
- E_x End Station
- Explicit stream of E_1
- Explicit stream of E_2
- Explicit stream of E_3
- Other/Background traffic (always S&F)

CTF in Networks: Circulating frames (2)

Network Requirements

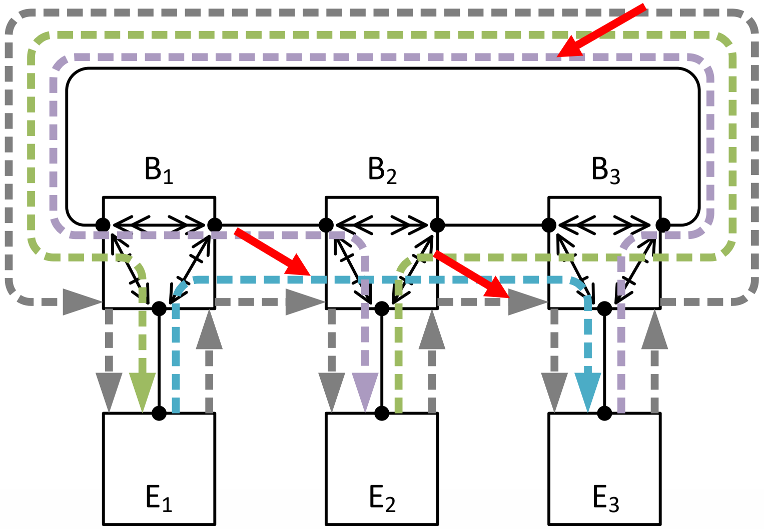
- **Default**
  At least one S&F-only hop in each topological loop.
- **Potential Alternative**
  Only explicit FDB filtering entries for all traffic in all CTF Bridges in a loop
  AND
  the probability of errors affecting the same frame on two or more different links is negligible low.
- **Potential Alternative**
  The topological loop contains sufficient links(hops),
  AND
  all Bridges in the loop limit frame lengths of CTF traffic,
  AND
  the sum of the minimum frame shorting in all Bridges in the loop is greater than the frame length limit.



CTF in Networks: Bandwidth loss (1)

Problem Description

- Erroneous frame under reception by CTF Bridge are classified for CTF, and transmitted before FCS verification by
  - unintended Bridge Ports **AND/OR**
  - in the wrong traffic class.
- Such frames in the affected traffic class in Bridge transmission Ports can cause unplanned interferences in this traffic class or any higher priority traffic classes (oversized frames) and reduce the bandwidth available for lower priority traffic classes.
- The issue affects every traffic class in Bridge transmission Ports if CTF reception in at least one other Bridge Port is enabled.



Symbols
- Store & Forward (S&F)
- Cut-Through Forwarding (CTF) for explicit streams
- Point-to-Point Full Duplex Link
- B_x Bridge
- E_x End Station
- Explicit stream of E_1
- Explicit stream of E_2
- Explicit stream of E_3
- Other/Background traffic (always S&F)

1) The planning required to properly configure PSFP can be inacceptable for some systems.
2) See the introduction of this slide set.

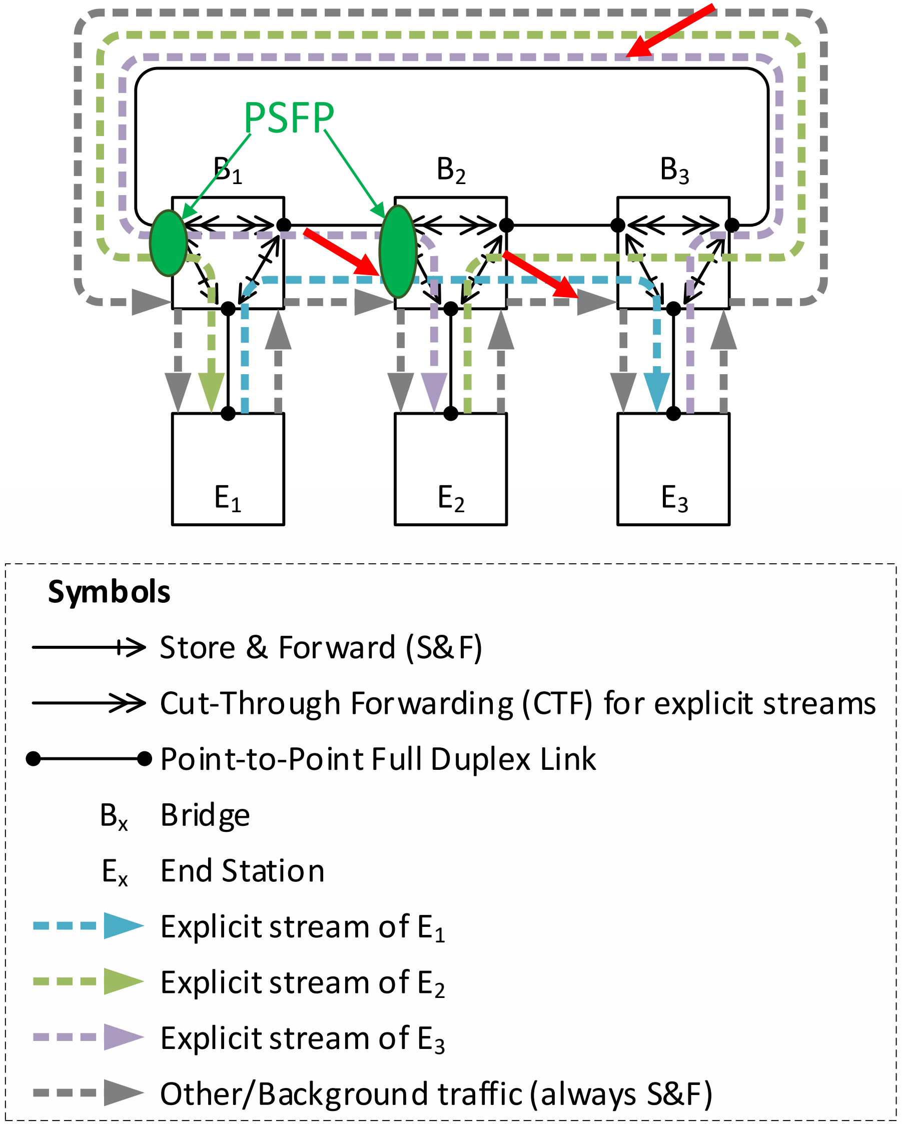
CTF in Networks: Bandwidth loss (2)

Network Recommendations

- Plan for additional interference/bandwidth usage
- If applicable[1], use disjoint redundant paths via FRER
- If applicable[2], use PSFP
  - Max. SDU size filtering can limit the effect of oversized frames
  - Proper usage of flow meters and/or stream gates depends on the traffic characteristics - for example[3]:
    - Flow meters (MEF 10.3) can limit the bandwidth of uncoordinated traffic
    - Stream gates can be used for TDM traffic

Implicit, but still present

- Frame shorting (limits the propagation/impact)



1) Disjoint paths are inacceptable for some systems (e.g., due to cost reasons).
2) The planning required to properly configure PSFP can be inacceptable for some systems.
3) See the introduction of this slide set.

Problem Statements

Johannes Specht

Problem Statements: Introduction

Background

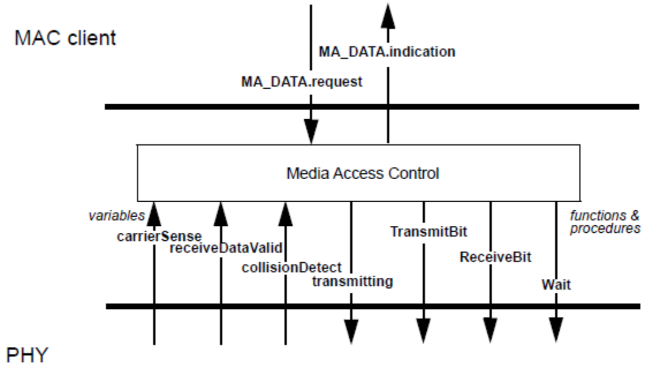
- It is intended to standardize CTF for Bridges and Bridged Networks in IEEE WG 802.1. A proposal on how this can be done has been outlined before.
- The lower layers in this proposal were intentionally left out. In particular, details on the interface between IEEE 802.1 Bridges and IEEE 802.3 MACs were omitted: *The MAC Service Interface.*

Problem Summary

- The standardized *MAC Service Interface* treats frame transfers between MAC and Bridge as atomic operations that transfer entire frames (from destination address to frame check sequence) as a whole:
  - *MA_DATA.request* (frame transmission)
  - *MA_DATA.indication* (frame reception)
- Due to the atomic property of these operations, the MAC Service Interface cannot support CTF.
- IEEE WG 802.1 and IEEE WG 802.3 are asked to collaborate on a <u>*solution*</u> that allows CTF in Bridges.

Refinement

- The subsequent content details the problem further.
- **Remarks:**
  - **None of the subsequent contents shall imply a requirement to change the standardized MAC Service Interface!**
  - **It is not intended to shift present and potential future functions from IEEE 802.3 to IEEE 802.1 or vice versa!**



MA_DATA.request (
destination_address,
source_address,
mac_service_data_unit,
frame_check_sequence
)

MA_DATA.indication (
destination_address,
source_address,
mac_service_data_unit,
frame_check_sequence,
reception_status
)

Source: Clause 2 of IEEE Std 802.3-2018

Questions & Answers

Table of Contents

Call for Actions

Johannes Specht

Call for Actions

Proposal for IEEE 802.1

Authorize IEEE 802.1 to craft PAR/CSD for an IEEE 802.1 Standard for CTF in Bridges and Bridged Networks

- CTF is technically feasible
- Market Potential for CTF exists
- A way to integrate CTF into the 802.1 Standards environment has been shown
- How QoS challenges can be addressed has been shown

Thank you for your Attention!

Questions, Opinions, Ideas?