

# Cut-Through Forwarding (CTF): Towards an IEEE 802.1 Standard

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# Introduction

# Proposed Activities

## 1) IEEE 802 Nendica: Already ongoing

- Discuss administrative and detailed technical aspects of potential lower layer modelling across IEEE 802.3 and IEEE 802.1 with support for CTF.
- Requires sufficient need/interest in IEEE WG 802.1 and IEEE WG 802.3 to work on such a modelling.

## 2) IEEE WG 802.1: Proposed

- Motion to develop PAR&CSD for an IEEE 802.1 project to standardize CTF as standalone IEEE 802.1 standard (not amendments to 802.1 Standards). Proposed items included in a scope:
  - Support for IEEE Std 802.3-2018 compatible *real implementations*.
  - Incorporate/standardize IEEE 802.1 aspects of a joint model across IEEE WG 802.1 and 802.3 with support for CTF, if such a *model* becomes available during the proposed IEEE 802.1 Stds development project.

## 3) IEEE 802 Nendica/IEEE WG 802.1: Now ... before the proposed motion in item 2)

- Discuss individual contributions that may support the aforementioned motion, and may be considered during development of the PAR&CSD [item 2)] by IEEE WG 802.1.

Note: IEEE 802 Nendica appears to be a good place for item 3), but this may be discussed due ongoing discussion on the processes between IEEE 802 Nendica and IEEE WG 802.1.

# A closer Look

A clear specification of CTF in the scope of IEEE WG 802.1 appears technically feasible.

## Proposal to IEEE WG 802.1

- Motion to develop PAR&CSD for an IEEE 802.1 project to standardize CTF as standalone IEEE 802.1 standard (not amendments to 802.1 Standards).
- Proposed items included in a PAR scope:
  1. Support for IEEE Std 802.3-2018 compatible **real implementations**.
  2. Incorporate/standardize IEEE 802.1 aspects of a joint model across IEEE WG 802.1 and 802.3 with support for CTF, if such a **model** becomes available during the proposed IEEE 802.1 Stds development project.

- Of course not the entire proposed scope...
- **Options** allowed by scope, although **not** pre-conditions/requirements for the suggested 802.1 Stds development project.

Difference may be small, but worth to talk about (figuratively):

***“A MAC ...”***

v.s.

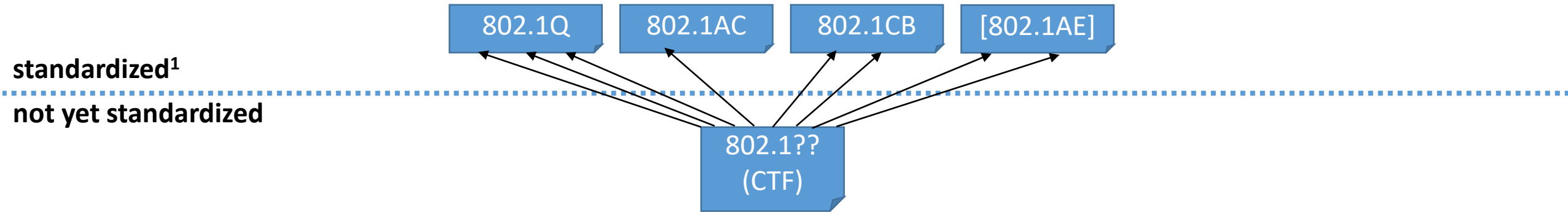
***“A MAC with the externally visible behavior perceived on network physical media and in managed objects as specified in IEEE Std 802.3-2018 ...”***

- If both WGs see the technical need to drive this, the model should become part of a running IEEE WG 802.1 project!
- The other way around, decisions documented in associated IEEE 802.1 Stds drafts could be helpful input for development of such a model.
- **IEEE 802 Nendica – contributions are welcome!**

# CTF as a standalone 802.1 Standard, not amendments to existing 802.1 standards

See also <https://mentor.ieee.org/802.1/dcn/21/1-21-0037-00-ICne-ieee-802-tutorial-cut-through-forwarding-ctf-among-ethernet-networks.pdf>

# Recap: Proposed Location in IEEE 802.1 Standards



## Separate stand alone IEEE 802.1 base standard for CTF

- **Single document**

Avoids distribution of CTF across existing standards (compared to multiple amendment projects).

- **Exclusion, inclusion/re-use and adjustment of existing protocols**

- Existing protocols not referred to are basically beyond specification.

- If no adjustments for CTF are needed:

Inclusion by reference (e.g., “*as specified in x.y.z of IEEE Std 802.1Xxx-20XX*”) can be sufficient.

- If adjustments for CTF are needed:

- Additional description of the differences can be sufficient.

- Adjustments apply for CTF only; no side effects on existing protocols in absence of CTF support.

<sup>1</sup>) The latest published base standards, corrigenda, and a subset of the published amendments.

# Recap: Proposed Content Categories and (some) Contents

## CTF in Networks

- Application and Limitations:
  - Quality of Service
  - Security Considerations
  - Resulting Network Requirements/Recommendations
- Usage/Performance aspects
- ...

## CTF in Bridges

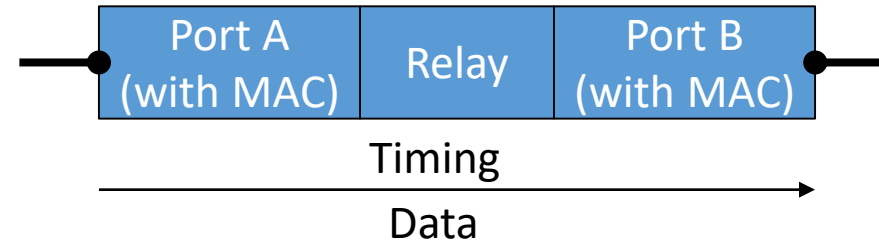
- Bridge relay behavior
  - MAC Relay Entity/Forwarding Process
  - Bridge Port Transmit and Receive
- Managed Objects/YANG
- ...

See <https://mentor.ieee.org/802.1/dcn/21/1-21-0037-00-ICne-ieee-802-tutorial-cut-through-forwarding-ctf-among-ethernet-networks.pdf>

On the next slides

# Aspects of externally visible Behavior

(on the relevant path from frame reception to frame transmission)



Two types of aspects define the externally visible behavior of a bridge

## 1. Data

- What data goes into a bridge, and comes out of the bridge?
  - Ports: What data in frames is transmitted by a Port B, as a result of data in frames received on a Port A?
  - Management: What are the management interfaces, and how can management parameters change/be set?

## 2. Timing

- When are frames transmitted at a Port B as a result of frame reception at a Port A?



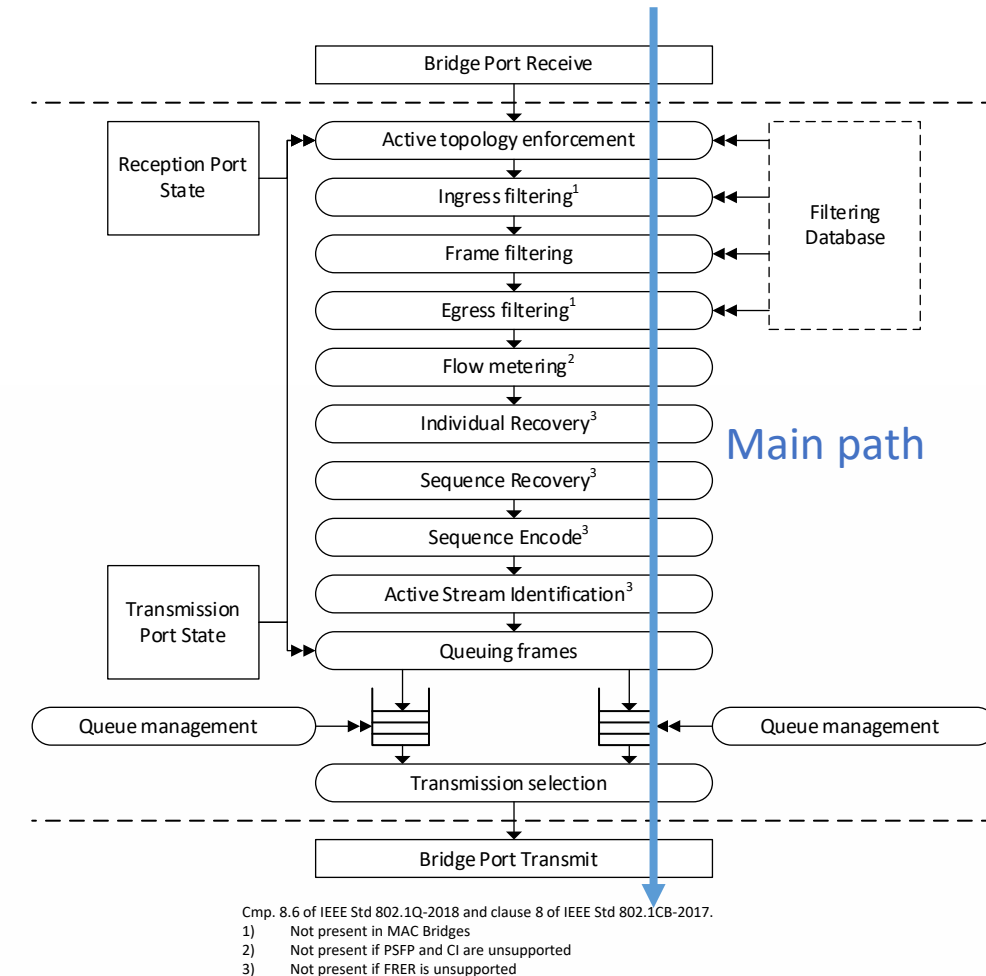
# Recap: CTF in Bridges - Relay with CTF Support

## Coexistence of CTF & S&F

- **Traffic separation**
  - Decoded priority (VLAN-Tags, IPV assignment)
  - Ports/traffic classes (FDB & decoded priority)
- **Enabling/disabling CTF**
  - Per reception port (the entire port)
  - Per transmission port per traffic class

## The standardized model extended

- **Flow**  
(Incomplete) frames pass through processing stages, remain visible to earlier stages.
- **Stalls (incomplete frames)**  
Waiting for more data of an incomplete frame before passing it to the next stage.
- **Stall until completed (incomplete frames)**  
Stalling incomplete frames until completed before passing it to the next stage → Fallback to S&F
- **Late errors (incomplete frames)**
  - Causes (earlier stage)
  - Handling (same or later stage)



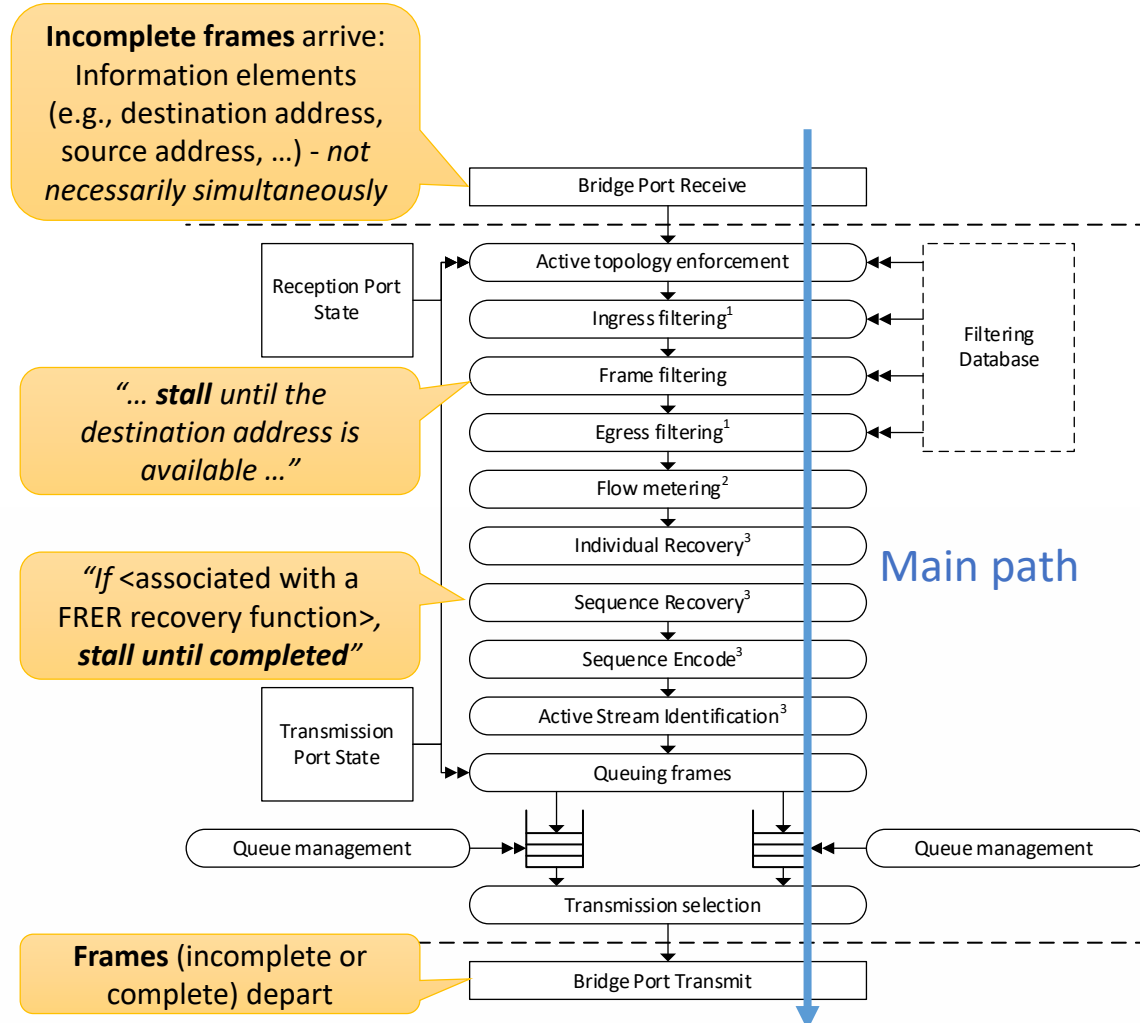
# CTF in Bridges: Data and Flow of the Model Illustrated

Upfront: Relevant implications of an IEEE 802.1 standalone Standard for CTF

- **No (full)** conformance with IEEE Stds 802.1Q, 802.1AC, etc. required.
- **Partial** re-use of elements from existing IEEE 802.1 Stds is reasonable (e.g., individual data transformations), omitting others is possible (e.g., MAC service definition without ISO/IEC 10731 service primitives, handle information elements in frames individually, both)

## Resolution of Information Elements

- Information elements of (incomplete) frames at the resolution necessary for the behavior in stages.  
→ Keep definitions at a minimum.
- It may be discussed in detail if higher resolution (e.g., octets) are helpful/needed ...
- ... it likewise appears that such detailed discussions can/should happen during a potential IEEE 802.1 Stds development project according to the defined process.



Cmp. 8.6 of IEEE Std 802.1Q-2018 and clause 8 of IEEE Std 802.1CB-2017.  
 1) Not present in MAC Bridges  
 2) Not present if PSFP and CI are unsupported  
 3) Not present if FRER is unsupported

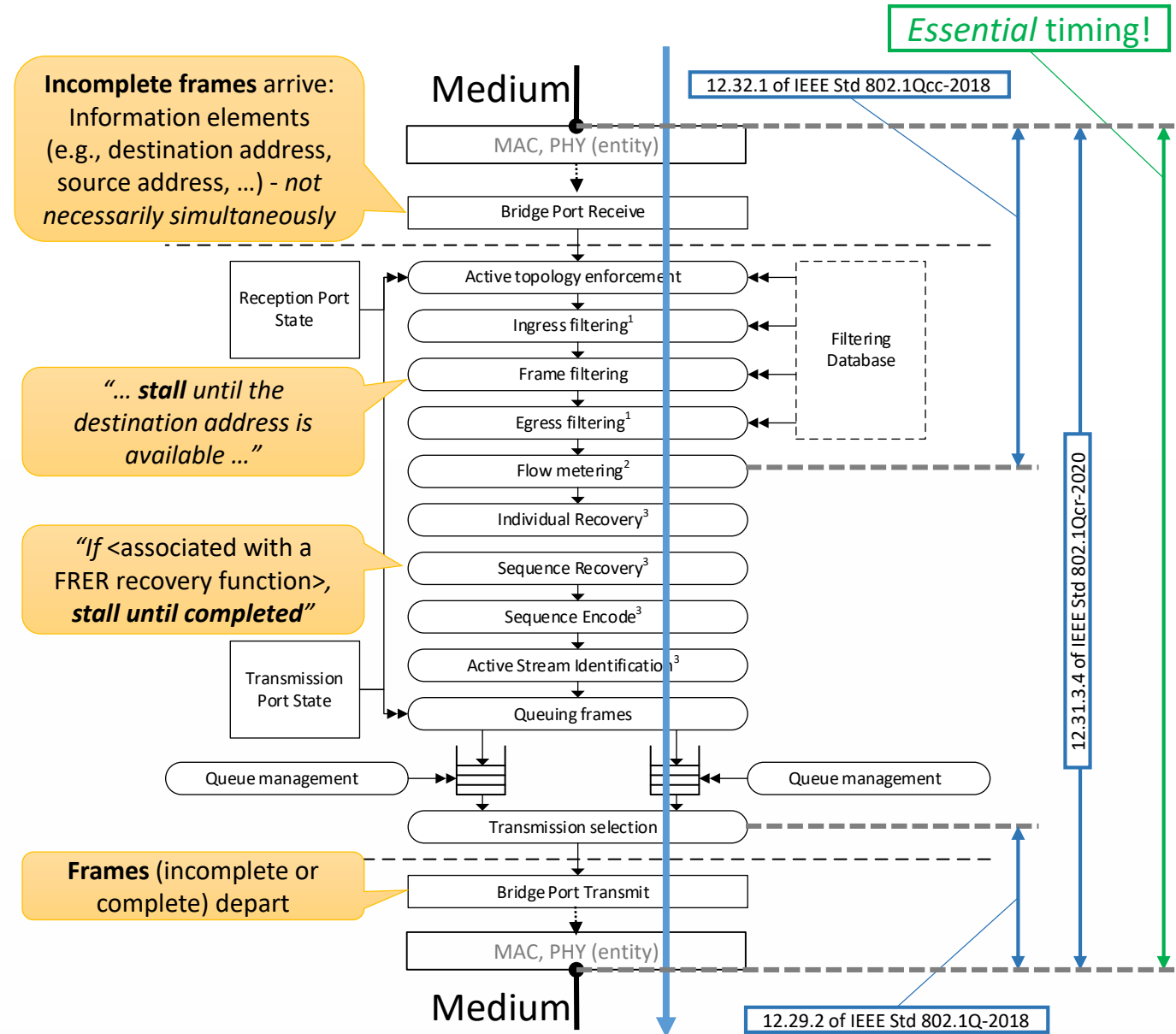
# Timing

## Essential Timing

- Required for clear specification of the externally visible behavior on the path *medium* → *bridge* → *medium* with CTF.

## Can it be specified in an IEEE 802.1 Std?

- An IEEE 802.1 Std is the right place to do this:
  - A perception of this timing only exists if there is “*something*” (i.e., bridge) between the network media.
  - For S&F Bridges, the essential timing (and more) is found in existing 802.1 standards.



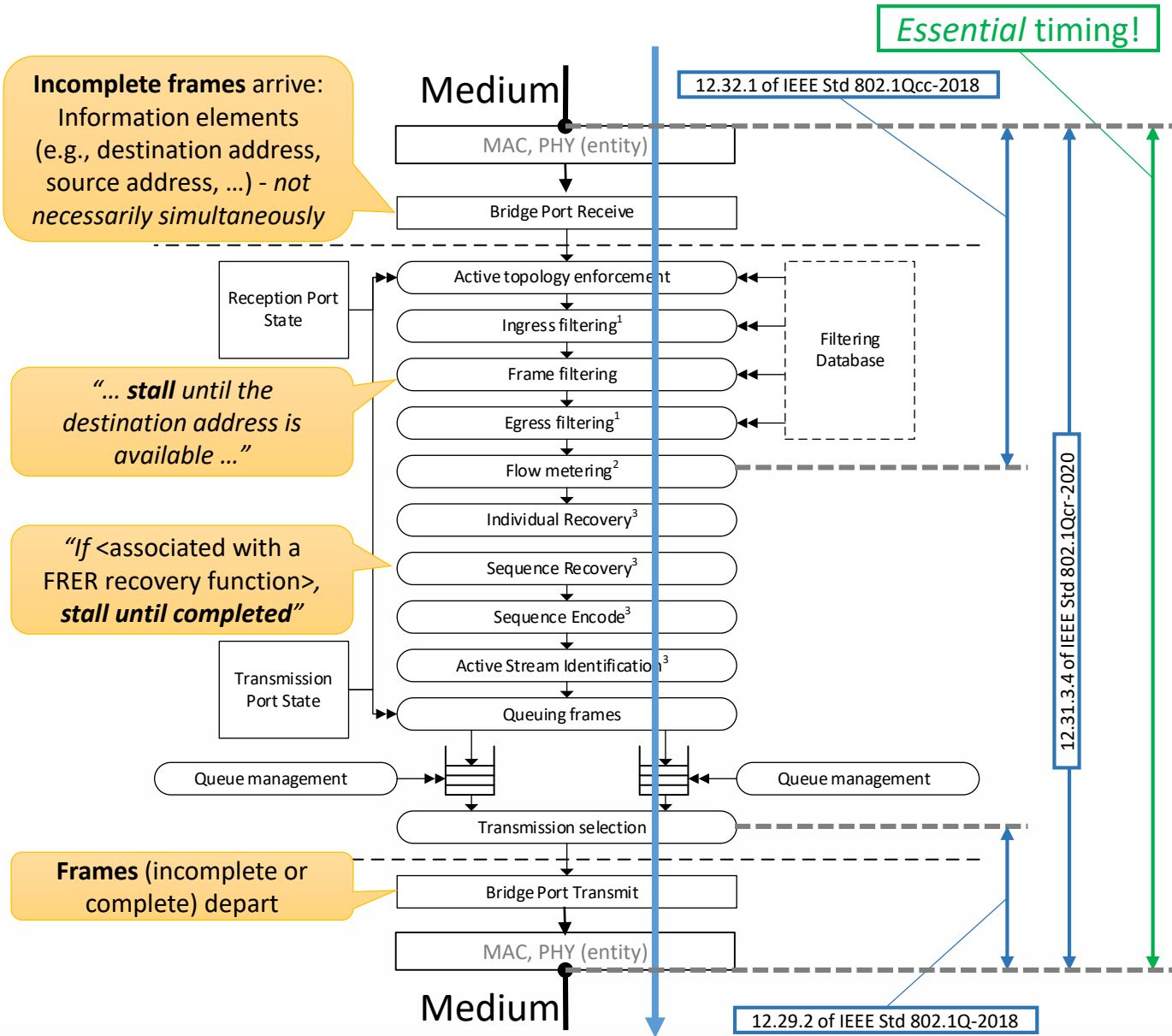
# Intermediate Discussion

## Technical questions

- Fundamentally missing elements that prevent clear specification of the behavior of a bridge with support for CTF?
- Items beyond the scope of IEEE WG 802.1?

## Non-technical questions

- Comments for getting a better impression about the “for and against” of standardizing CTF?
- Other non-technical aspects?



# How could core elements of PAR&CSD look like?

## **Important:**

**This slide set is an individual contribution, not an official statement of IEEE 802 or IEEE 802.1. At the date of this slide set, IEEE WG 802.1 is not authorized to develop PAR&CSD for the proposed project. In the case such authorization becomes available, IEEE WG 802.1 may or may not consider individual contributions for development.**

# Individually contributed PAR&CSD proposals (1)

**PAR/Approximate number of people expected to be actively involved in the development of this project [5.1]**

30

**PAR/Scope [5.2]**

This project specifies protocols, procedures and managed objects of Bridges with support for Cut-Through Forwarding (CTF), termed CTF Bridges, that interconnect individual Local Area Networks (LANs) connected by different or identical media access control (MAC) methods.

This project also specifies requirements and recommendations for the usage of CTF in bridged networks.

The project allows integration of a detailed model for internal interaction between CTF Bridges and 802 MAC Standards, although completion of this project does not depend on such a model.

# Individually contributed PAR&CSD proposals (2)

**PAR/Is the completion of this standard dependent upon the completion of another standard? [5.3]**

No.

**PAR/Purpose [5.4]**

CTF Bridges, as specified by this project, allow the compatible interconnection of information technology equipment attached to separate individual LANs.

**PAR/Need for the Project [5.5]**

Support for CTF is found in existing Bridge implementations, but it is not standardized by an IEEE 802.1 Standard. Existing IEEE 802.1 Standards do not permit support for CTF. This project complements the existing IEEE 802.1 Standards and allows interoperability of CTF Bridge implementations.

# Individually contributed PAR&CSD proposals (3)

## PAR/Stakeholders for the Standard? [5.6]

Developers, providers, and users of networking services and equipment for industrial automation, professional Audio-Video (pro AV), data centers and other systems requiring decreased latency over store and forward bridging operations, including networking integrated circuit (IC) developers, Bridge and network interface card (NIC) vendors, and users.



# Individually contributed PAR&CSD proposals (4)

## CSD/Managed objects [1.1.1]

Describe the plan for developing a definition of managed objects. The plan shall specify one of the following:

- a) The definitions will be part of this project.
- b) The definitions will be part of a different project and provide the plan for that project or anticipated future project.
- c) The definitions will not be developed and explain why such definitions are not needed.

This project will use method a).

# Individually contributed PAR&CSD proposals (5)

## CSD/Coexistence [1.1.2]

A WG proposing a wireless project shall prepare a Coexistence Assessment (CA) document unless it is not applicable.

a) Will the WG create a CA document as part of the WG balloting process as described in Clause 13? (yes/no)

b) If not, explain why the CA document is not applicable.

This project is not a wireless project; therefore, the CA document is not applicable.

# Individually contributed PAR&CSD proposals (6)

## CSD/Broad Market Potential CSD/Broad Market Potential [1.2.1]

Each proposed IEEE 802 LMSC standard shall have broad market potential. At a minimum, address the following areas:

### a) Broad sets of applicability.

CTF is already widely used in industrial automation installations and data center networks. Standardizing CTF can be an enabling technology for a wide range of pro A/V applications.

### b) Multiple vendors and numerous users

Existing products of multiple Bridge vendors support CTF, but interoperability is limited. Standardizing CTF is an opportunity for deployment of IEEE 802 technology in existing and new use cases in industrial automation systems, data centers, and pro A/V applications such as concert venues, theatres, conference centers, corporate buildings, casinos, hotels, theme parks, cruise ships, sport venues and beyond.

Additional material: <https://mentor.ieee.org/802.1/dcn/21/1-21-0037-00-ICne-ieee-802-tutorial-cut-through-forwarding-ctf-among-ethernet-networks.pdf>.

# Individually contributed PAR&CSD proposals (7)

**CSD/Compatibility/Will the proposed standard comply with IEEE Std 802, IEEE Std 802.1AC and IEEE Std 802.1Q? [item a) in 1.2.2]**

Each proposed IEEE 802 LMSC standard should be in conformance with IEEE Std 802, IEEE 802.1AC, and IEEE 802.1Q. If any variances in conformance emerge, they shall be thoroughly disclosed and reviewed with IEEE 802.1 WG prior to submitting a PAR to the Sponsor.

**a)Will the proposed standard comply with IEEE Std 802, IEEE Std 802.1AC and IEEE Std 802.1Q?**

No, there will be variances in conformance, as disclosed in <https://mentor.ieee.org/802.1/dcn/21/1-21-0051-02-ICne-ctf-discussing-next-steps.pdf> for reviewing with IEEE 802.1 WG.

This project will not modify the definitions of IEEE Std 802.1AC, as used by various IEEE 802 MAC standards. Conformance of existing implementations complying to IEEE Std 802, IEEE Std 802.1AC and IEEE Std 802.1Q remains unaffected.

**b)If the answer to a) is no, supply the response from the IEEE 802.1 WG.**

*<TBD: Response from IEEE WG 802.1>*

The review and response is not required if the proposed standard is an amendment or revision to an existing standard for which it has been previously determined that compliance with the above IEEE 802 standards is not possible. In this case, the CSD statement shall state that this is the case.

# Individually contributed PAR&CSD proposals (8)

## CSD/Distinct Identity [1.2.3]

Each proposed IEEE 802 LMSC standard shall provide evidence of a distinct identity. Identify standards and standards projects with similar scopes and for each one describe why the proposed project is substantially different.

No other IEEE 802 standard or project defines support for CTF in Bridges and Bridged Networks.

# Individually contributed PAR&CSD proposals (9)

## CSD/Technical Feasibility [1.2.4]

Each proposed IEEE 802 LMSC standard shall provide evidence that the project is technically feasible within the time frame of the project. At a minimum, address the following items to demonstrate technical feasibility:

a) Demonstrated system feasibility.

System feasibility is demonstrated by existing industrial automation installations and data center networks based on similar non-IEEE 802 technologies.

b) Proven similar technology via testing, modeling, simulation, etc.

CTF in Bridges is proven by existence of products implementing similar non-IEEE 802 technology.

# Support for real implementations of IEEE Std 802.3-2018 possible?

Considerations with the focus on externally visible behavior

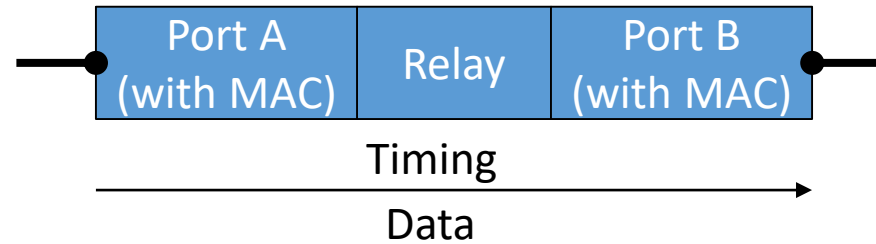
# Model v.s. Implementations (1)

*It is important to distinguish, however, between the model and a real implementation. The **model** is **optimized for simplicity and clarity** of presentation, while any realistic **implementation** shall place heavier **emphasis on** such constraints as **efficiency and suitability** to a particular implementation technology or computer architecture. [4A.2.2 of IEEE Std 802.3-2018, “Overview of the Procedural Model”]*

*... it is the **behavior of any MAC sublayer implementations** that shall match the standard, not their internal structure. The internal details of the procedural model are useful only to the extent that they help specify that behavior clearly and precisely. [item b) in 4A.2.2.1 of IEEE Std 802.3-2018, “Ground rules for the procedural model”]*



# Model v.s. Implementations (2)



## Model

*The handling of incoming and outgoing frames is rather stylized in the procedural model, in the sense that **frames are handled as single entities** by most of the MAC sublayer and are only serialized for presentation to the Physical Layer. [item c) in 4A.2.2.1 of IEEE Std 802.3-2018, “Ground rules for the procedural model”]*

## Implementations

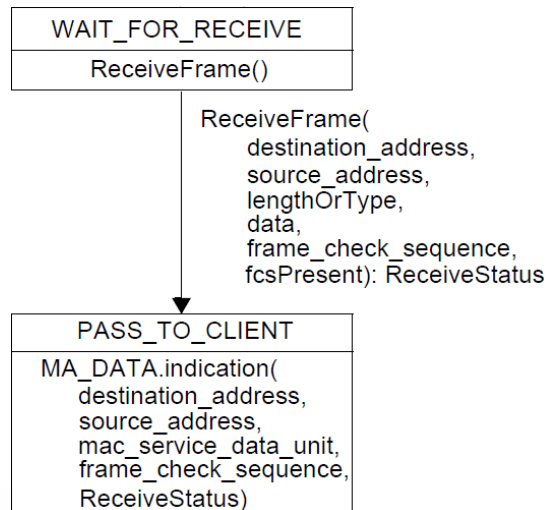
*In reality, **many implementations will instead handle frames serially on a bit, octet or word basis**. This approach has not been reflected in the procedural model, since this only complicates the description of the functions without changing them in any way. [item c) in 4A.2.2.1 of IEEE Std 802.3-2018, “Ground rules for the procedural model”]*

## Observations & Considerations

- MAC *implementations* that handle frames serially appear conformant to IEEE Std 802.3-2018.
- Serial handling fits well to the concept around “incomplete frames” proposed on earlier slides.
- Aspects of the data behavioral that appear important to look at (only “fast path” in a bridge):
  1. Port A: Is it possible to access frame contents in the relay in presence FCS errors?
  2. Port B: Is it possible to send FCS errors forwarded by the relay (i.e., no unintended “repair”)?

Note: Less than minFrameSize octets appears likewise important, but is not in focus of this slide set (see also <https://mentor.ieee.org/802.1/dcn/21/1-21-0058-01-ICne-ctf-forwarding-timing-in-industrial-automation.pdf>).

# Data: Receive Path



Source: Figure 4A-4 of IEEE Std 802.1-2018

## From 4A.2.9 of IEEE Std 802.3-2018

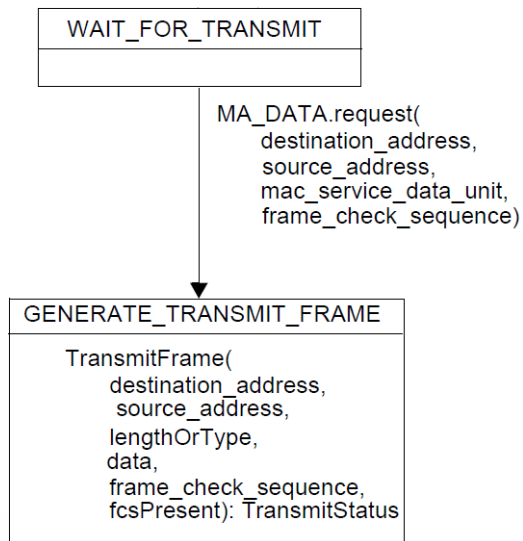
```
procedure ReceiveLinkMgmt;  
begin  
  repeat  
    StartReceive;  
    while receiving do nothing; {Wait for frame to finish arriving}  
    excessBits := frameSize mod 8;  
    frameSize := frameSize - excessBits; {Truncate to octet boundary}  
    receiveSucceeding := (frameSize ≥ minFrameSize) {Reject frames too small}  
  until receiveSucceeding  
end; {ReceiveLinkMgmt}
```

## From 4A.2.9 of IEEE Std 802.3-2018

```
function ReceiveFrame (  
  ...  
  function ReceiveDataDecap: ReceiveStatus; {Nested function; see body below}  
  ...  
  function ReceiveDataDecap: ReceiveStatus;  
  ...  
  receiveSucceeding := LayerMgmtRecognizeAddress(destinationField);  
  if receiveSucceeding then  
    begin {Disassemble MAC frame}  
      destinationParam := destinationField;  
      sourceParam := sourceField;  
      lengthOrTypeParam := lengthOrTypeField;  
      dataParam := RemovePad(lengthOrTypeField, dataField);  
      fcsParamValue := fcsField;  
      fcsParamPresent := passReceiveFCSMode;  
      ...  
      if exceedsMaxLength then status := frameTooLong  
      else if fcsField = CRC32(incomingFrame) then  
        if validLength then status := receiveOK else status := lengthError  
        else if excessBits = 0 then status := frameCheckError  
        else status := alignmentError;  
      ...  
      ReceiveDataDecap := status  
    end; {ReceiveDataDecap}
```

→ It seems that contents of valid and **several types of invalid frames including frames with invalid FCS**, are transferred to MAC clients (e.g., Relay) other than MAC control and LLC (see also 3.4 of IEEE Std 802.3-2018).

# Data: Transmit Path



Source: Figure 4A-3 of IEEE Std 802.1-2018

## From 4A.2.8 of IEEE Std 802.3-2018

```
process BitTransmitter;
begin {Inner loop}
...
while transmitting do
begin
TransmitBit(outgoingFrame[currentTransmitBit]);
currentTransmitBit := currentTransmitBit + 1;
transmitting := (currentTransmitBit ≤ lastTransmitBit)
end
...
```

## From 4A.2.8 of IEEE Std 802.3-2018

```
function TransmitFrame (
destinationParam: AddressValue;
sourceParam: AddressValue;
lengthOrTypeParam: LengthOrTypeValue;
dataParam: DataValue;
fcsParamValue: CRCValue;
fcsParamPresent: Bit): TransmitStatus;
procedure TransmitDataEncap; {Nested procedure; see body below}
begin
if transmitEnabled then
begin
TransmitDataEncap;
TransmitFrame := TransmitLinkMgmt
...

```

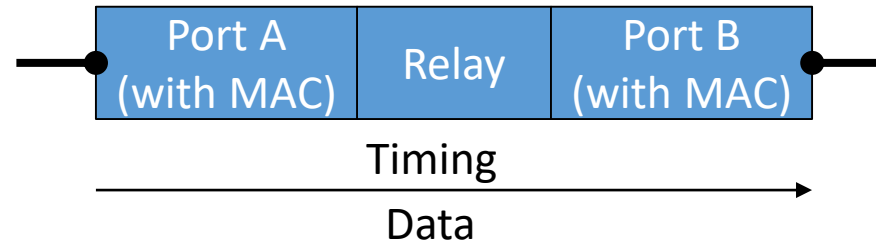
## From 4A.2.8 of IEEE Std 802.3-2018

```
procedure TransmitDataEncap;
begin
with outgoingFrame do
...
destinationField := destinationParam;
sourceField := sourceParam;
lengthOrTypeField := lengthOrTypeParam;
if fcsParamPresent then
begin
dataField := dataParam; {No need to generate pad if the FCS is passed from MAC client}
fcsField := fcsParamValue {Use the FCS passed from MAC client}
...

```

→ It seems that contents of frames from a MAC client, including frames with invalid FCS, are transmitted.

# Intermediate Discussion



## Discussion

- It seems both, the transmit and the receive path of IEEE 802.3 Std conformant MAC implementations allow exchange of frames with invalid FCS between a MAC client (relay) and a PHY entity.
- The simplified MAC (clause 4A of IEEE Std 802.3-2018) has been considered, but the same observation appears valid for the CSMA/CD MAC (clause 4 of IEEE Std 802.3-2018).
- Not mentioned in the slides before were error counters on the receive path (this is nothing new) ...
- ... but there may be other implications, for example, during transmission.
- Should IEEE WG 802.3 be asked for having a look at invalid FCS'?

# Summary & Conclusions

# Summary & Conclusion

## Proposed to IEEE WG 802.1

- Motion to develop PAR&CSD for an IEEE 802.1 project to standardize CTF as standalone IEEE 802.1 standard (not amendments to existing 802.1 Standards).

## Technical Contents in this Slide Set

- An approach for clear specification of bridge behavior with support for CTF appears feasible and in scope of IEEE WG 802.1.
- Considerations on the option to refer to implementations of IEEE Std 802.3-2018 in a potential IEEE 802.1 standard for CTF.

## Contributions related to PAR&CSD

- If appropriate, the author is happy to prepare and present individual contributions, independent of whether IEEE 802.1 would consider such contributions during a potential future PAR&CSD development or not.

# Thank you for your Attention!

## *Questions, Opinions, Ideas?*

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