Initial solution for Nendica Study Item Forwarding of Fieldbus CPF 12 on 802.1 Bridges

Huajie Bao (baohuajie@huawei.com, Huawei)
Jiang Li (lijiang3@huawei.com, Huawei)
Guanhua Zhuang (zhuangguanhua@huawei.com, Huawei)

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Objective

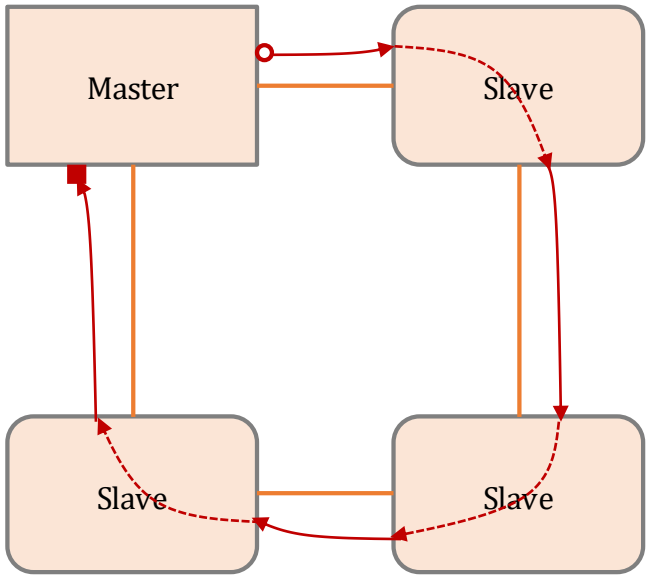
- According to the proposal for Nendica Study Item (Forwarding of Fieldbus CPF 12 on 802.1 Bridges) and comments of last Nendica meeting, this presentation is to present the following points:
  - Detail use case and practical requirements for this Study Item
  - Feasibility of operation and corresponding impact
- Any comments are welcomed.

Contents

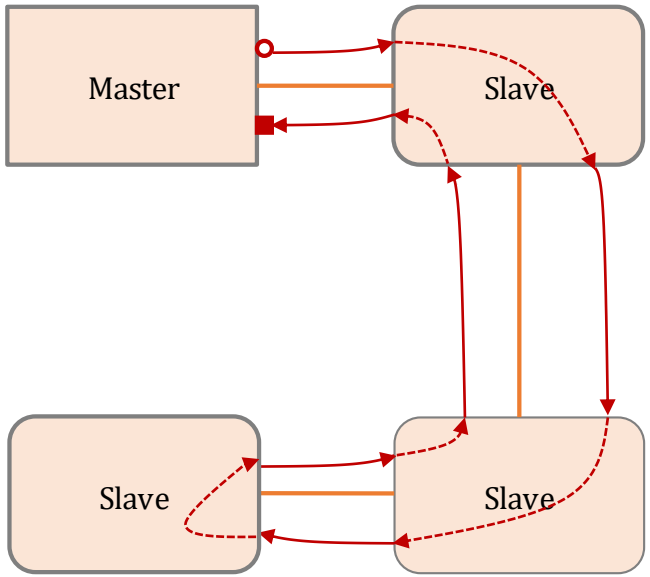
1. Detail use case and practical requirements for intermixed EtherCAT and Ethernet forwarding
2. Feasibility of operation
3. Impact on functionality, including latency, compared to independent networks

EtherCAT Logical-Ring Forwarding

The Type 12 fieldbus in IEC 61158-3/4/5/6-12 is also known as EtherCAT. An EtherCAT network can be understood as a railway network where slave devices are treated as stations, data are treated as passengers, and EtherCAT frames are treated as trains. While the EtherCAT frames move through the slave devices, the slave devices can off-load and re-load data into EtherCAT frames.



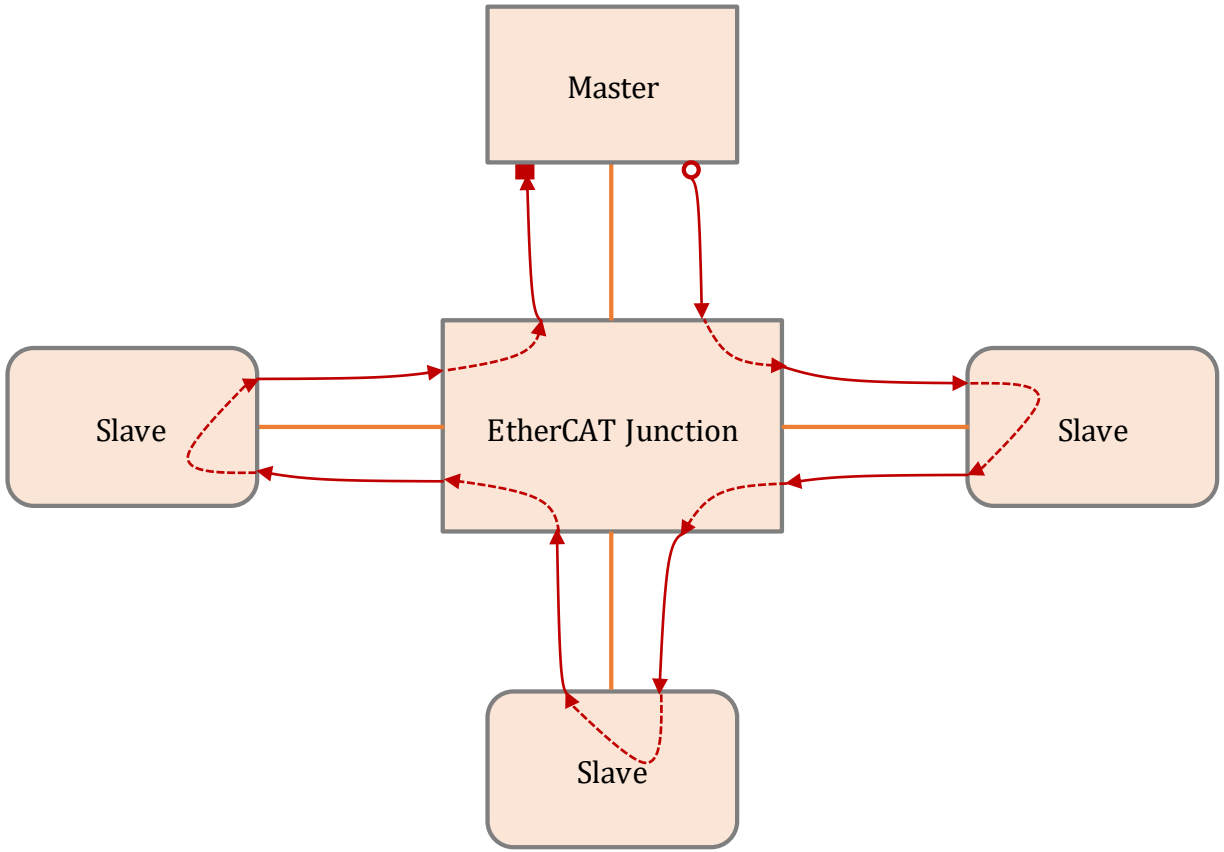
(a)



(b)

- EtherCAT frame MAC & PHY follow Ethernet specs
  - with distinct EtherType
- Frame originates at master, passes each slave (which may modify it) and is returned to master
- Logical topology is a ring
  a) physical ring topology
  b) physical line topology
     - ✓ Single-port slave forwards frame back to sender

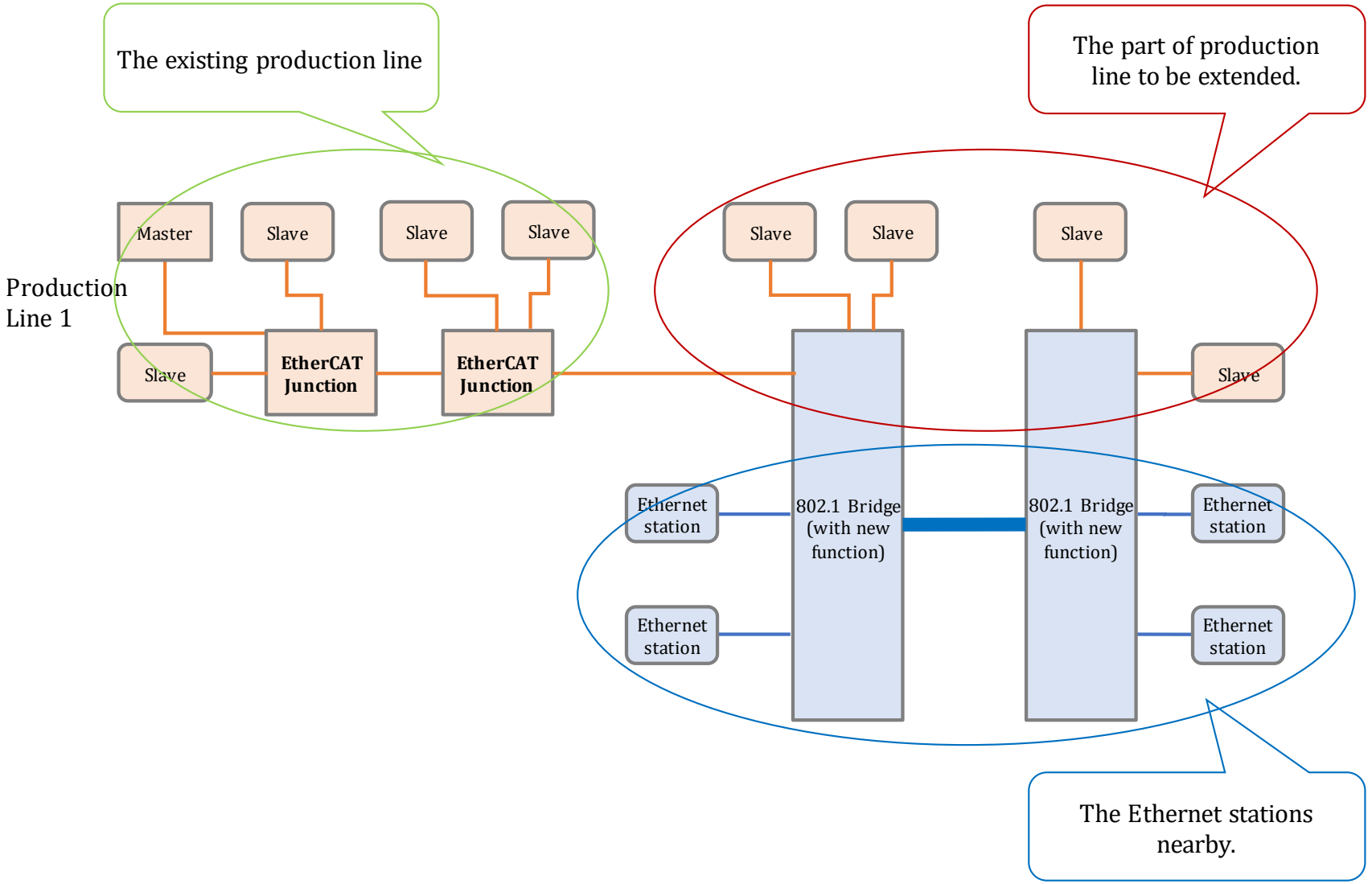
EtherCAT Junction



- EtherCAT Junction operates something like a switch
- Forwarding port is statically determined based on ingress port alone
  - Frames are cut-through forwarded to next port
- EtherCAT Junction is not a bridge

The EtherCAT Junction, as a reference, there are requirements that would request 802.1 bridges to serve as both an EtherCAT Junction and an Ethernet bridge.

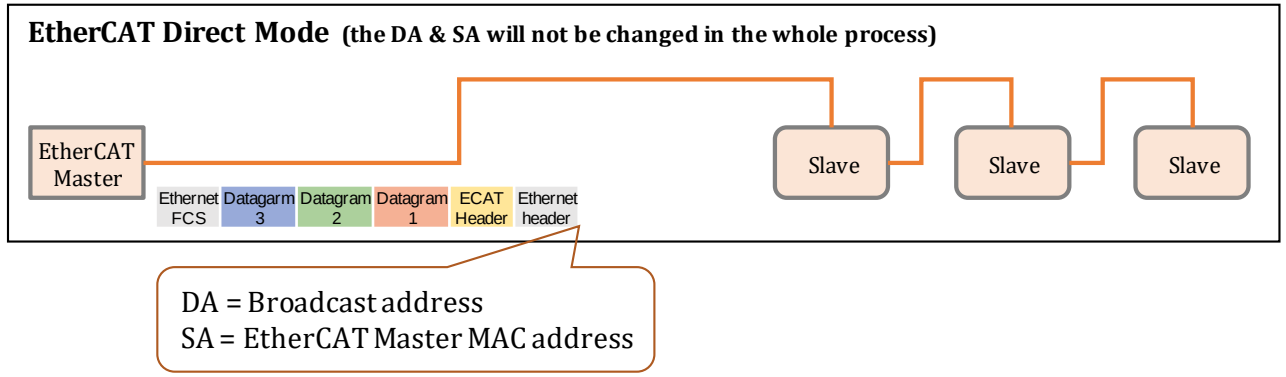
Use Case for 802.1 Bridge to Forward EtherCAT & Ethernet Frames Simultaneously



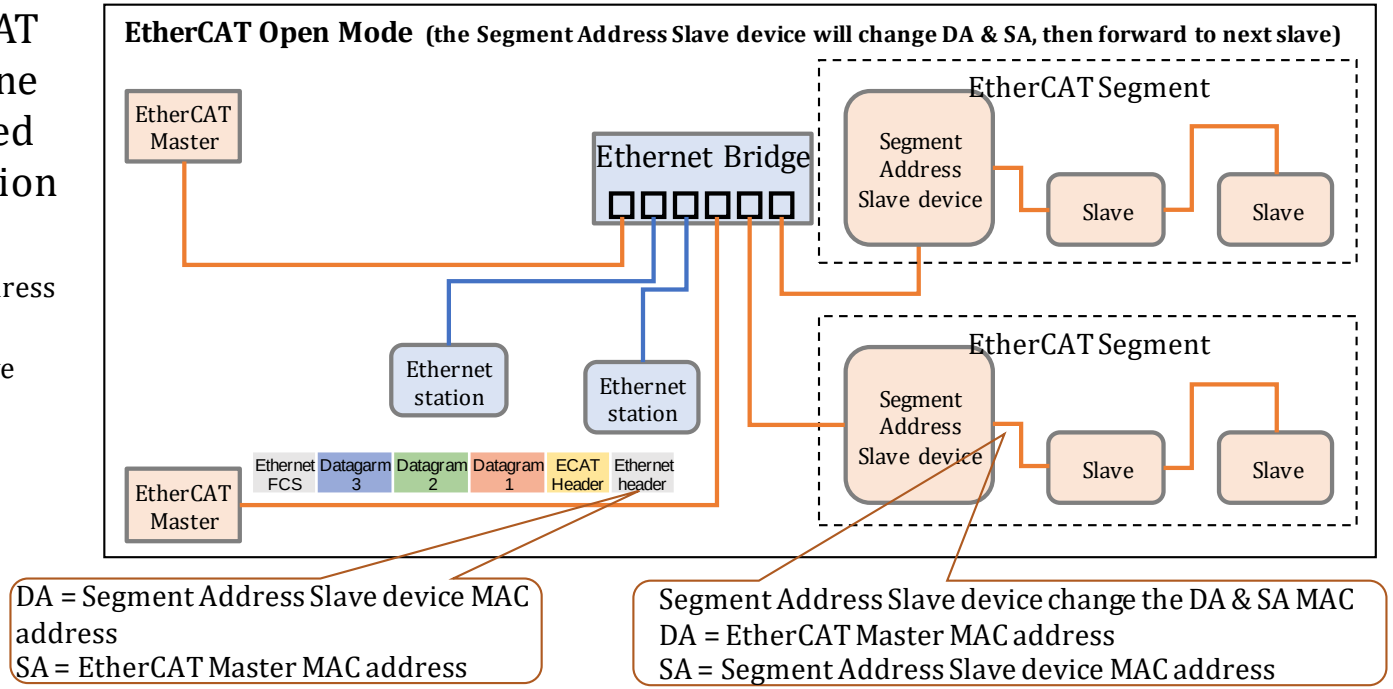
- Production line network requirement: cycle time 4ms, jitter < 10%
- Considering the space and cost, the factory seeks 802.1 Bridges to support to forward EtherCAT frames and Ethernet frames from the same link.

EtherCAT Open Mode & Direct Mode

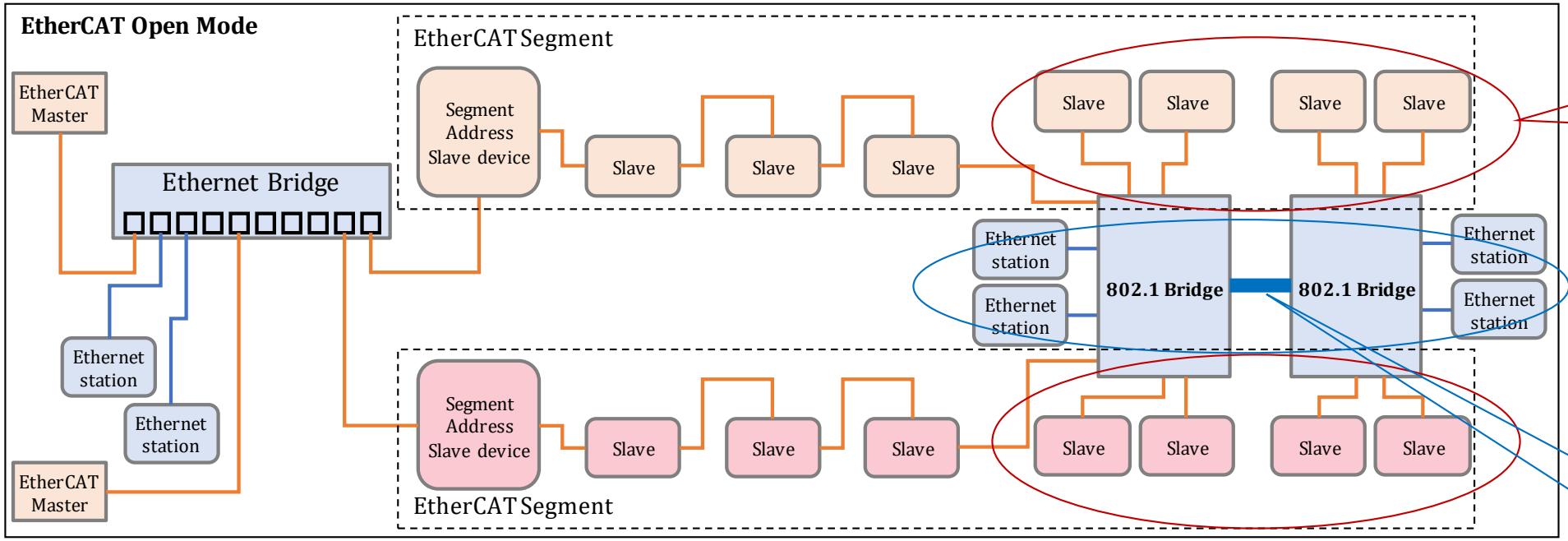
- The previous slides indicated EtherCAT direct mode. In the direct mode, the EtherCAT master and the slave devices are connected one by one, and the frames are forwarded in a logical ring, and the MAC address fields of the EtherCAT frames are not checked (the SA is the EtherCAT master address, and the DA is the broadcast address).

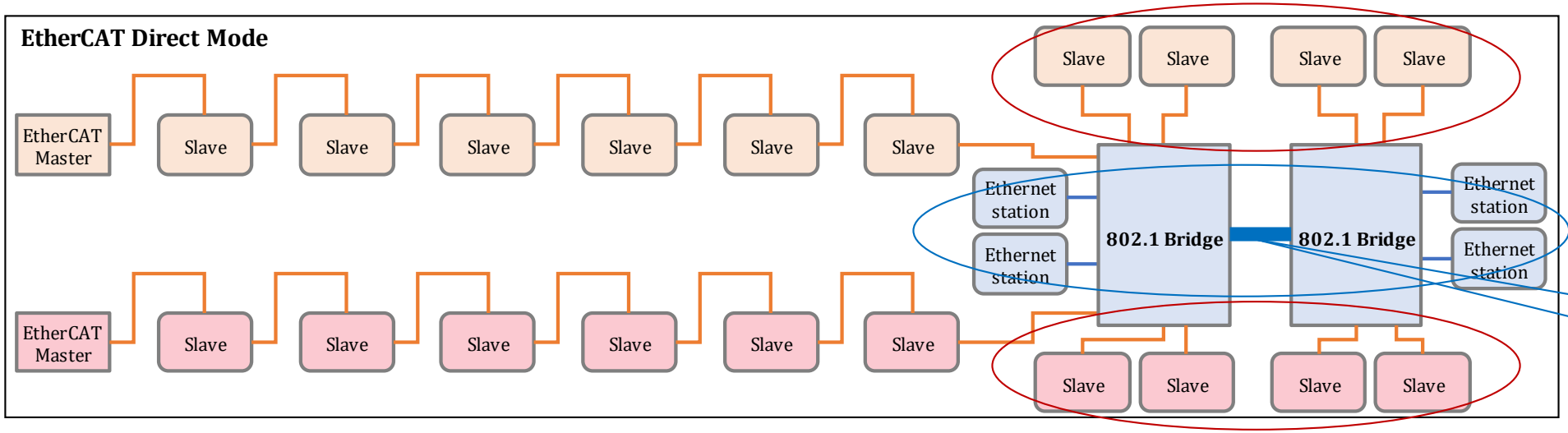


- Using the EtherCAT open mode, one or several EtherCAT segments can be connected via Ethernet bridge with one or more Master devices. Each segment can be addressed using a “Segment Address Slave” device (the head station of the segment).
  - The EtherCAT master sends the EtherCAT frame, and the DA is the MAC address of the Segment Address Slave device.
  - The Ethernet bridge forwards the EtherCAT frame to Segment Address slave device.
  - This Segment Address Slave device replaces the DA with the SA (address of master) and replaces the SA with its own MAC address.
  - The EtherCAT frame loops as the rule of EtherCAT in the segment network.
  - Finally, the EtherCAT frame is forwarded to master by the Ethernet bridge.



Extension Use Case based on 802.1 Bridges According to EtherCAT Open Mode & Direct Mode





The part of production line to be extended.

The Ethernet stations nearby.

Frame identification requires study; should be identifiable by EtherType, DA, SA.

Frame identification requires further study.

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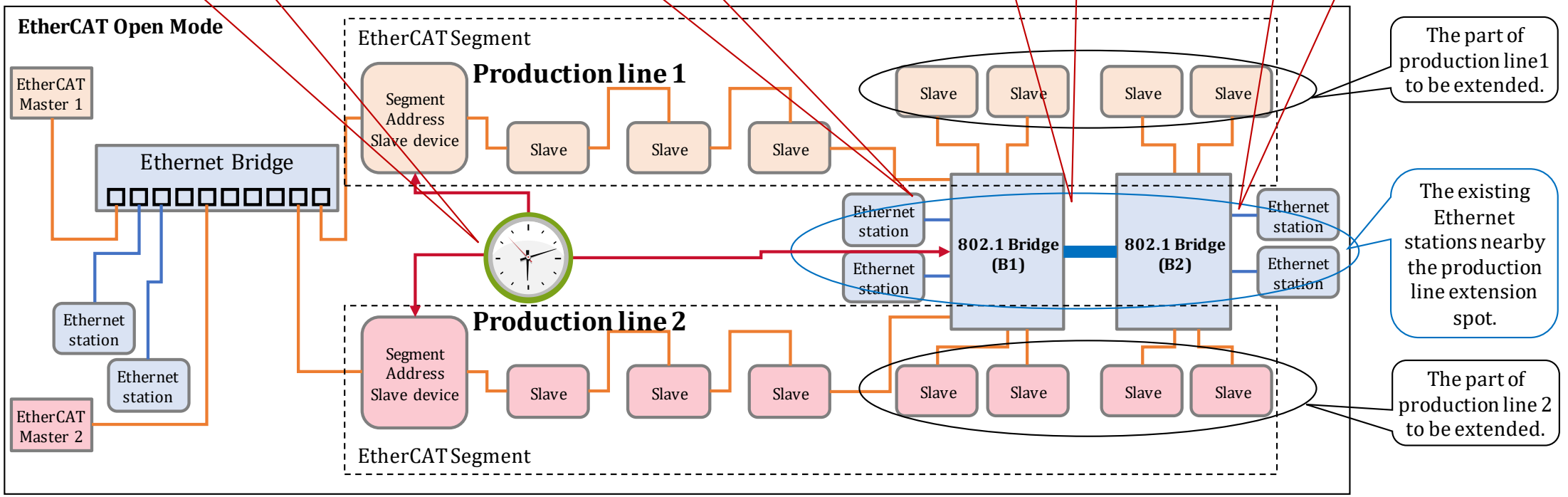
Initial Solution Points for the Use Case of EtherCAT Production Line Extension

① **Clock Synchronization**: clock synchronized to all of the two production lines and the 802.1 Bridges based on the current clock synchronization solution. (outside of current study item)

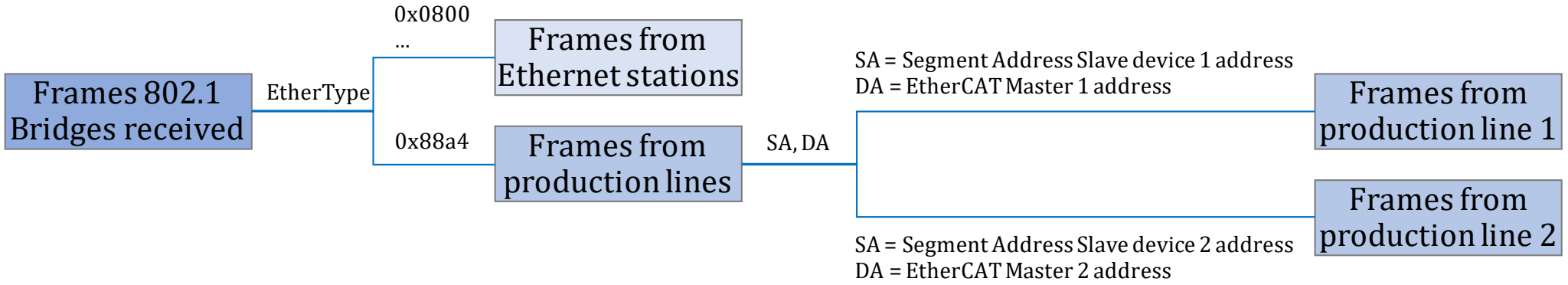
② **Identify different kinds frames, and forward to specific ports or devices according to EtherCAT**

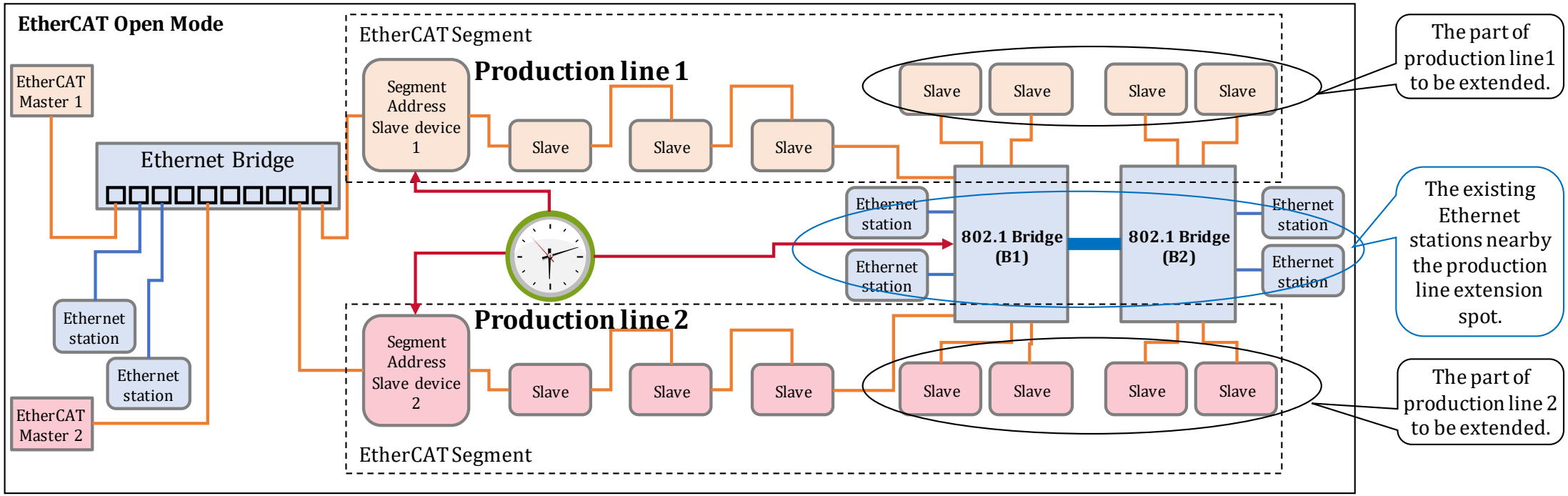
③ **Improve the latency / jitter, assure the low latency / jitter according to independent of EtherCAT network**

④ **Build reliable capability, assure the high reliability according to independent of EtherCAT network**

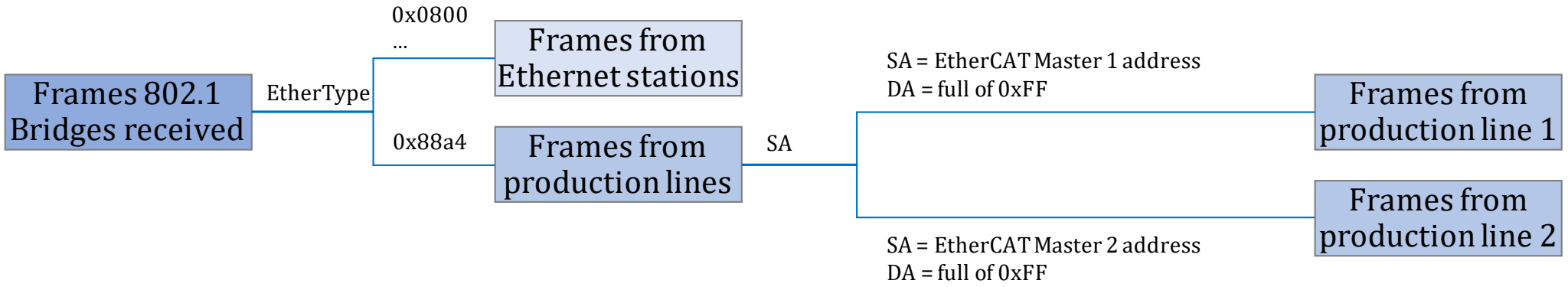


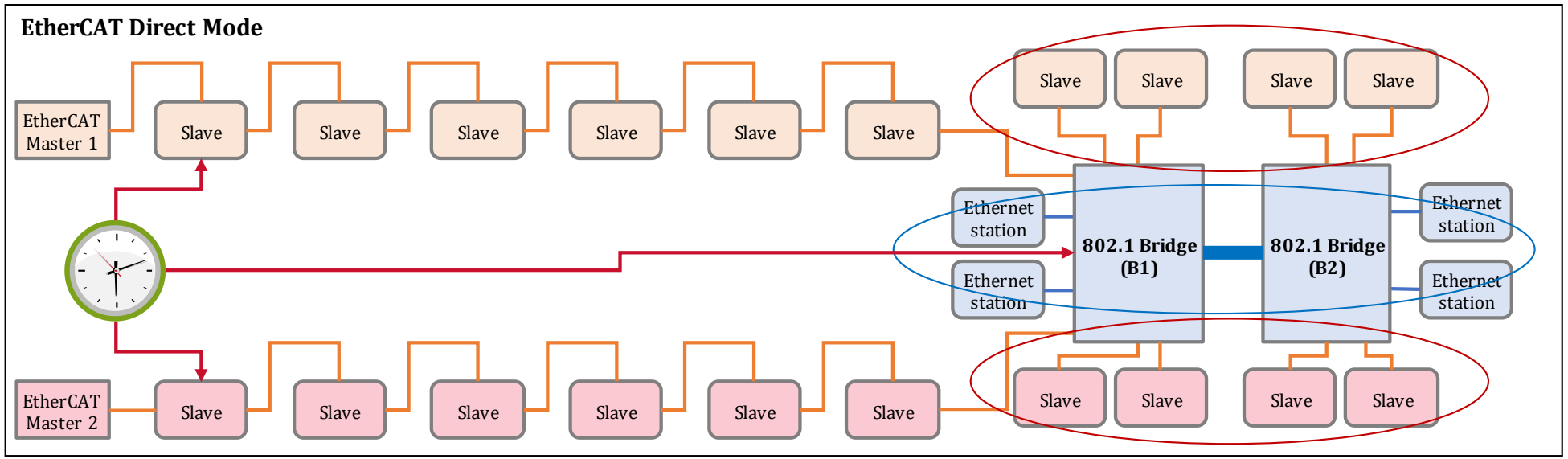
Identify Different Kinds Frames in EtherCAT Open Mode



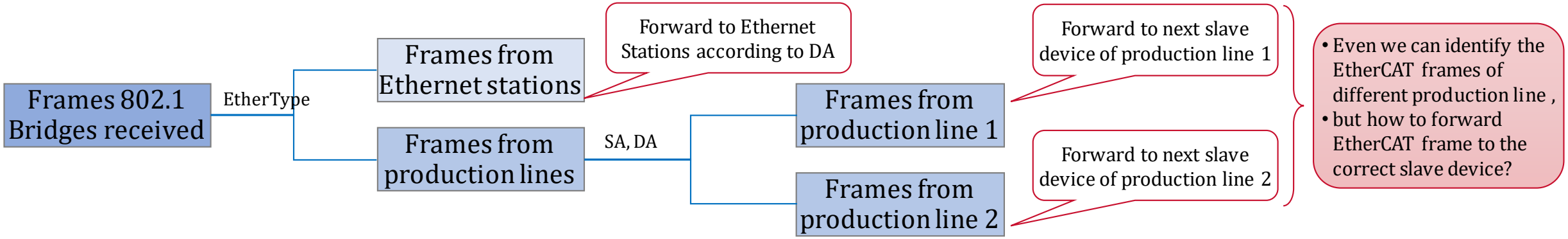


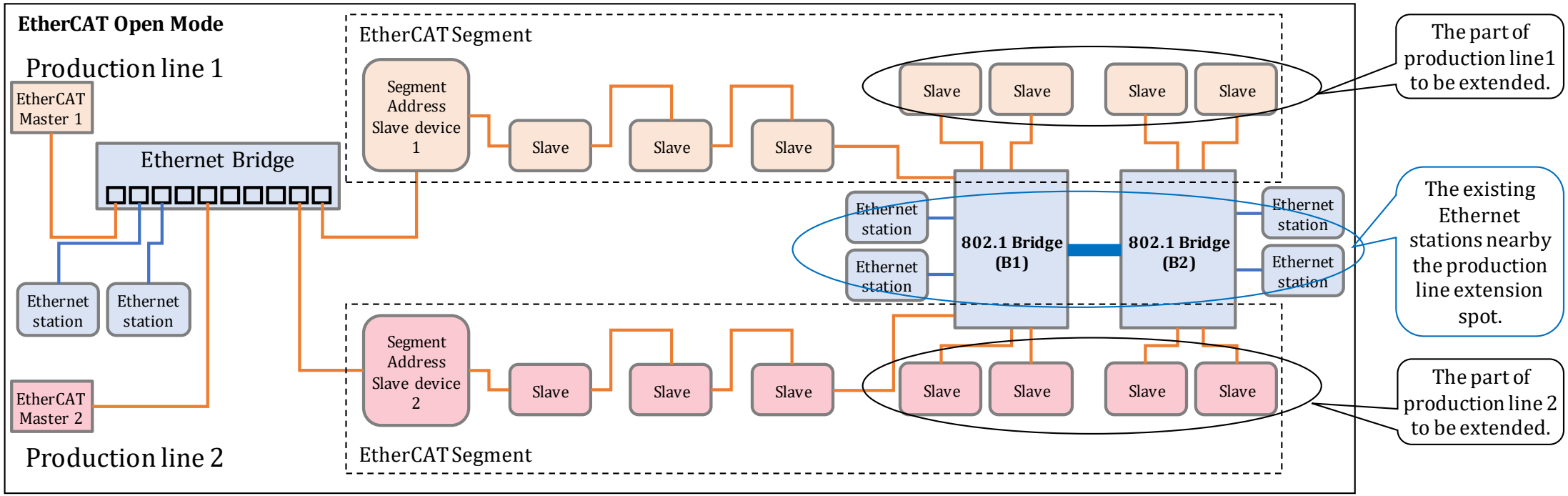
Identify Different Kinds Frames in EtherCAT Direct Mode





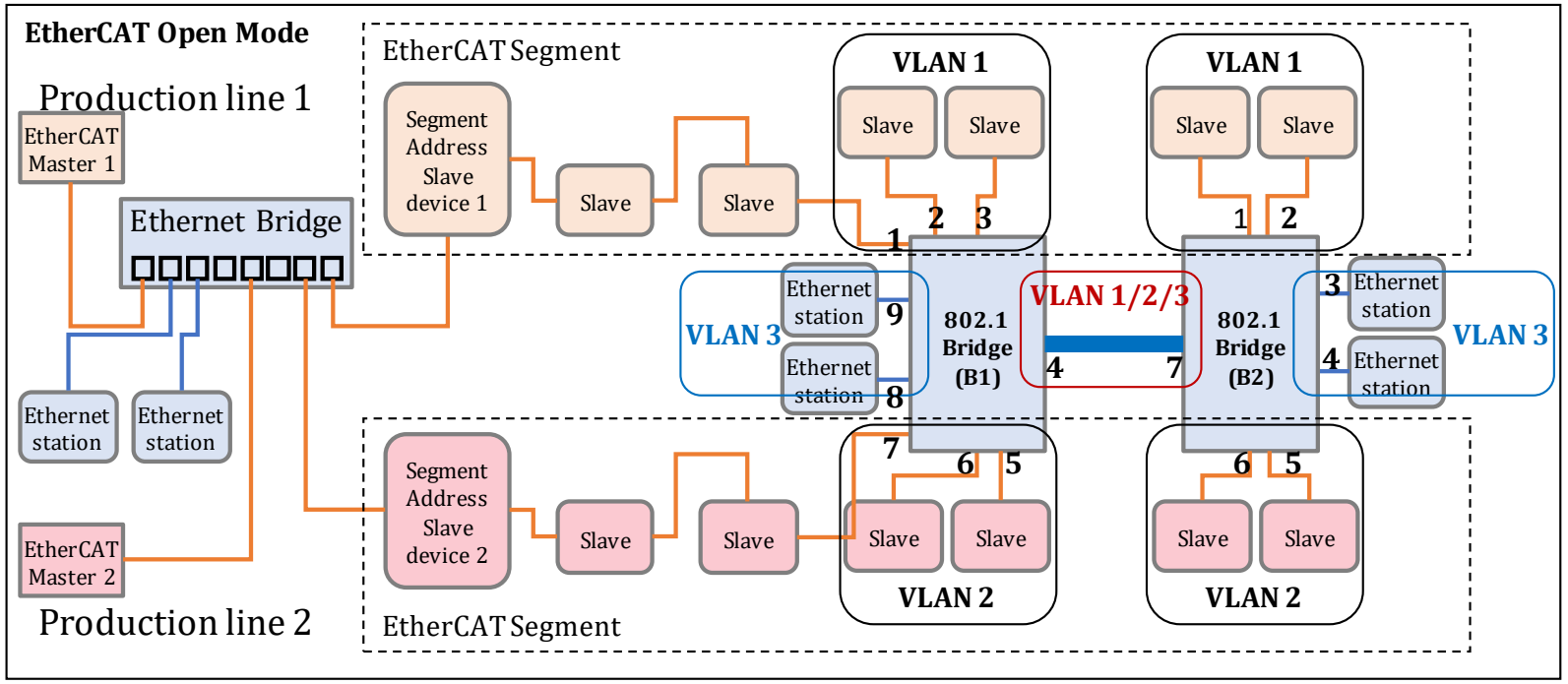
Forward the EtherCAT Frame to Specific Port





Identify the Next Slave Device of the Current Production Line in EtherCAT Open Mode

- Set 3 VLANs for 802.1 bridges B1 & B2
  - Set the ports connecting production line 1 devices into VLAN 1 as access type
  - Set the ports connecting production line 2 devices into VLAN 2 as access type
  - Set the ports connecting Ethernet stations into VLAN 3 as access type
  - Set the ports inter-connecting the 802.1 Bridges into VLAN 1 / 2 / 3 as trunk type
- The frames received from the port connecting to production line devices will be forwarded to next port as the right table.

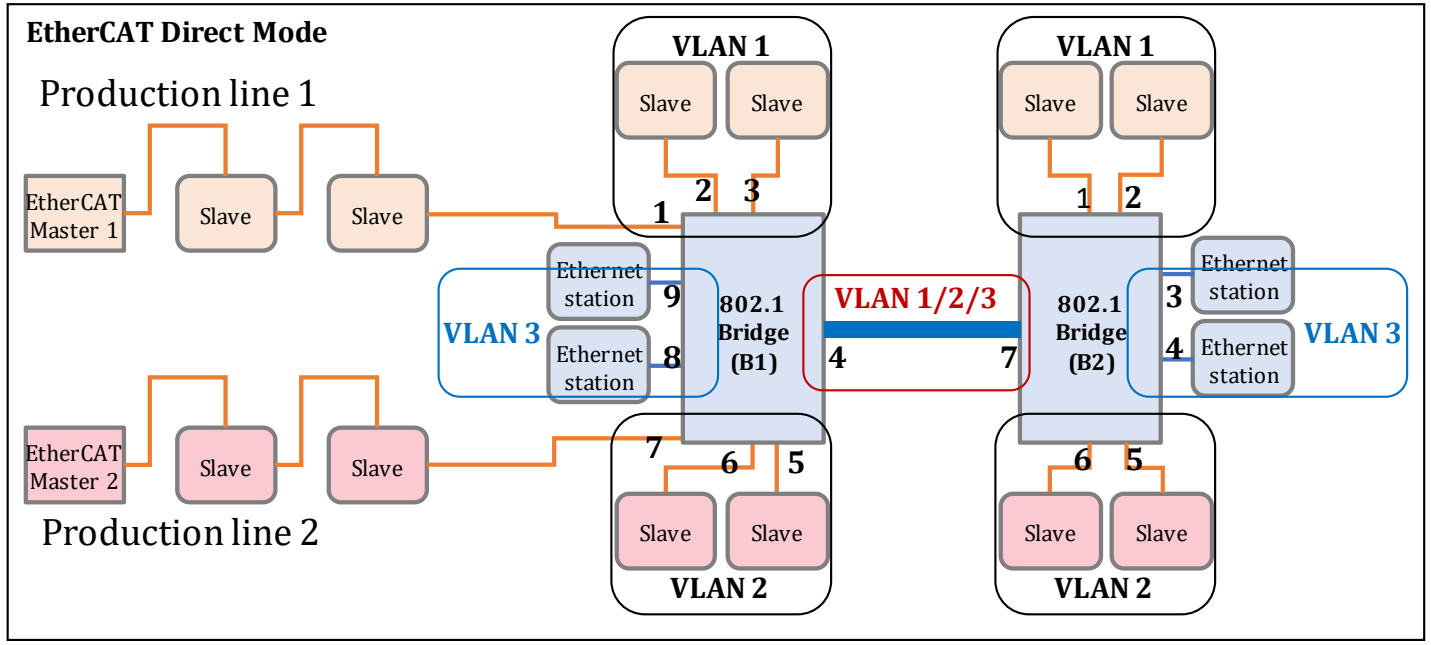


Bridge	Frames Received from	Frames Tagged VLAN	Frames Forwarded to Port
B1	Port 1	VLAN1	Port 2
	Port 2	VLAN1	Port 3
	Port 3	VLAN1	Port 4
	Port 4	VLAN1	Port 1
	Port 7	VLAN2	Port 6
	Port 6	VLAN2	Port 5
	Port 5	VLAN2	Port 4
	Port 4	VLAN2	Port 7
	Port 4	VLAN3	According to DA
	Port 8	VLAN3	
	Port 9	VLAN3	
B2	Port 7	VLAN1	Port 1
	Port 1	VLAN1	Port 2
	Port 2	VLAN1	Port 7
	Port 7	VLAN2	Port 6
	Port 6	VLAN2	Port 5
	Port 5	VLAN2	Port 7
	Port 7	VLAN3	According to DA
	Port 3	VLAN3	
	Port 4	VLAN3	

The table background color represents the frame type corresponding to the figure left.

Identify the next slave device of the current production line in EtherCAT Direct Mode

- Set 3 VLANs for 802.1 bridges B1 & B2
  - Set the ports connecting production line 1 devices into VLAN 1 as access type
  - Set the ports connecting production line 2 devices into VLAN 2 as access type
  - Set the ports connecting Ethernet stations into VLAN 3 as access type
  - Set the ports inter-connecting the 802.1 Bridges into VLAN 1 / 2 / 3 as trunk type
- The frames received from the port connecting to production line devices will be forwarded to next port as the right table.



Bridge	Frames Received from	Frames Tagged VLAN	Frames Forwarded to Port
B1	Port 1	VLAN1	Port 2
	Port 2	VLAN1	Port 3
	Port 3	VLAN1	Port 4
	Port 4	VLAN1	Port 1
	Port 7	VLAN2	Port 6
	Port 6	VLAN2	Port 5
	Port 5	VLAN2	Port 4
	Port 4	VLAN2	Port 7
	Port 4	VLAN3	According to DA
	Port 8	VLAN3	
	Port 9	VLAN3	
B2	Port 7	VLAN1	Port 1
	Port 1	VLAN1	Port 2
	Port 2	VLAN1	Port 7
	Port 7	VLAN2	Port 6
	Port 6	VLAN2	Port 5
	Port 5	VLAN2	Port 7
	Port 7	VLAN3	According to DA
	Port 3	VLAN3	
	Port 4	VLAN3	

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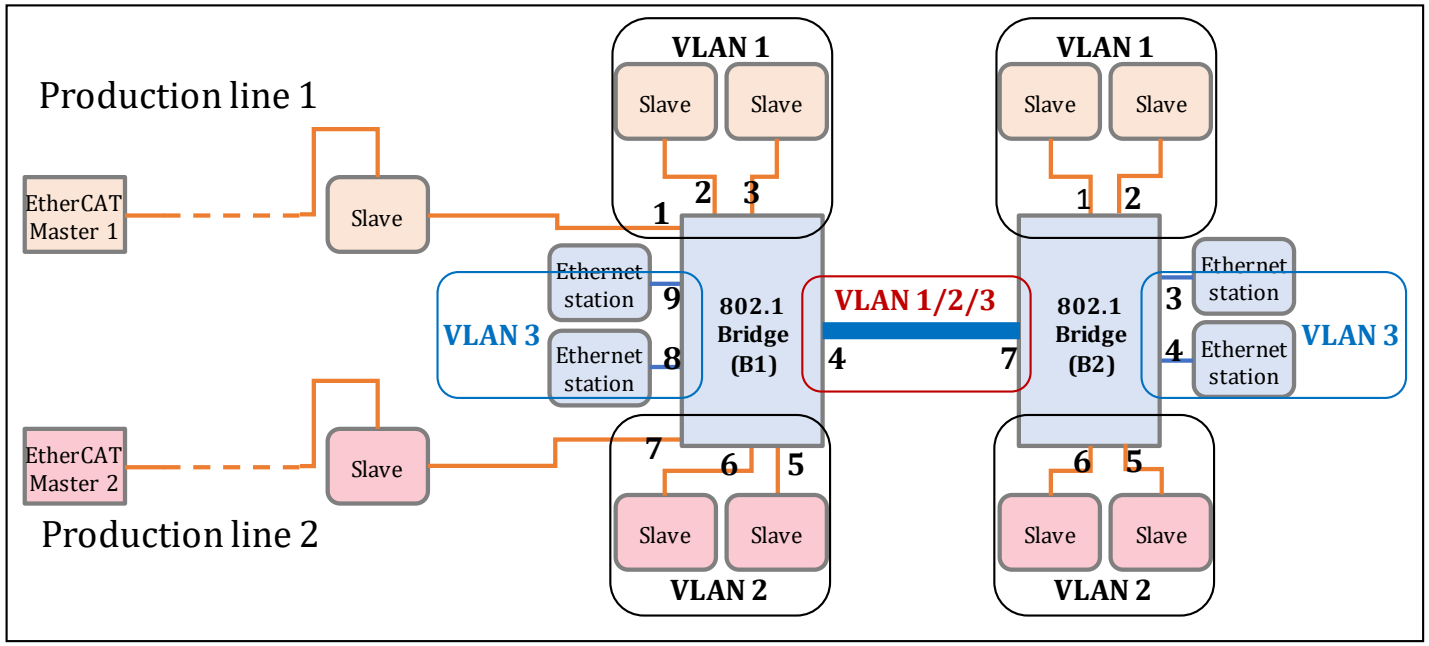
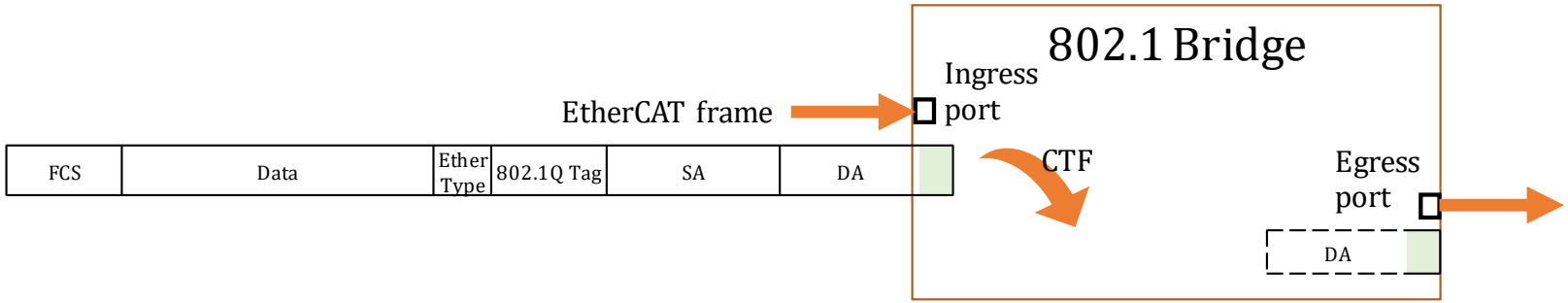
The Main Latency Related with 802.1 Bridges

- The main latency related with 802.1 bridges includes three parts:
  1. Forwarding latency
     - ✓ The delay to query the specific table get the egress port via ingress port & VLAN ID, it's fixed delay and hard to reduce.
     - ✓ The delay to forward the frame to egress port, it's possible to reduce the delay via cut-through forwarding.
  2. Schedule latency (mixed inter-link between 802.1 bridges)
     - ✓ The streams from different EtherCAT master will be mix-transferred in the inter-link, so it's should be orchestrated based on application cycle, inter-link bandwidth and application frame size, and to avoid frame lost and get the bounded latency.
     - ✓ The send queue for the egress port of the inter-link should be scheduled according to the orchestration results.
  3. Interface / cable latency
     - ✓ The latency is related with rate of interfaces and the corresponding interface connected. It's fixed delay and hard to reduce.



Cut-Through Forwarding to Reduce Forwarding Delay

- In order to minimize the forwarding delay, it's necessary to apply the cut-through forwarding.
- As for EtherCAT open mode or direct mode, it's necessary to get a common mechanism to query the table to get the egress port, and then trigger the cut-through forwarding immediately.
- The 802.1 bridges are configured to indicate that the EtherCAT frame from each ingress port will be forward to specific egress port, according to this forwarding rule configured, the cut-through forwarding could be applied.



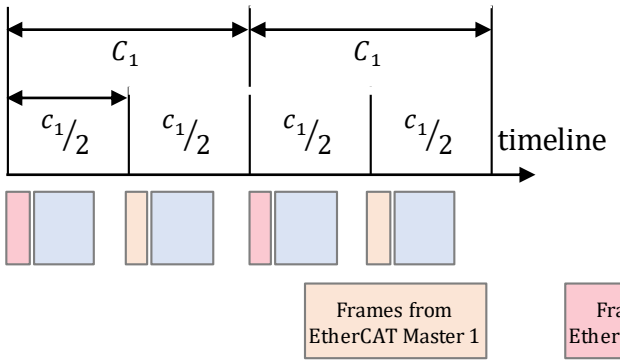
- Generally, there are different transmission speed between the port connecting to slave device and port connecting to another 802.1 bridge, store and forward might be mandatory and cause additional latency in the mixed link.
- Next Step
  - Evaluate the latency of the EtherCAT frame forwarded by 802.1 Bridges, and check the feasibility of latency.

Orchestrate to Achieve Bounded Latency

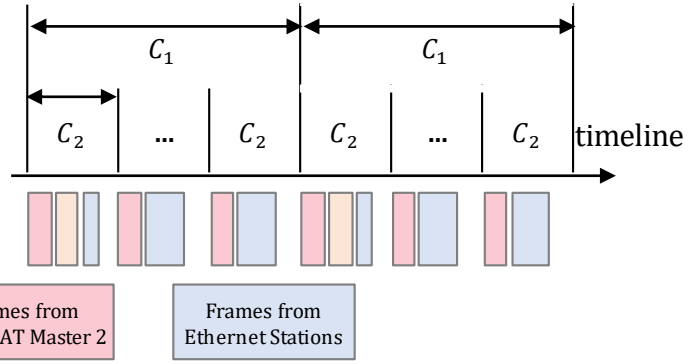
- Based on the clock synchronization to two production lines and the 802.1 bridges, the frames from EtherCAT master 1 / EtherCAT master 2 and the Ethernet stations will be mix-forwarded in the inter-link between the 802.1 bridges.
  - The inter-connection bandwidth between the 802.1 bridges should be evaluated according the EtherCAT frame size and application cycle.
  - The transfer delay from the EtherCAT master to 802.1 bridges should be evaluated based on the frame size and bandwidth.
  - All these parameters and evaluation results will be input as per 802.1Qbv, and orchestrate the streams to get the specific timeline.
  - Along the whole routine, the EtherCAT frames should be sent to and arrived at the nodes (slave devices or 802.1 bridges) as per the timeline.
  - Even if the frames of the two EtherCAT masters arrive at the egress port of inter-link simultaneously, one of them has to be delayed as the timeline.

- C_1 = Cycle of EtherCAT master 1, C_2 = Cycle of EtherCAT master 2, $C_1 \geq C_2$

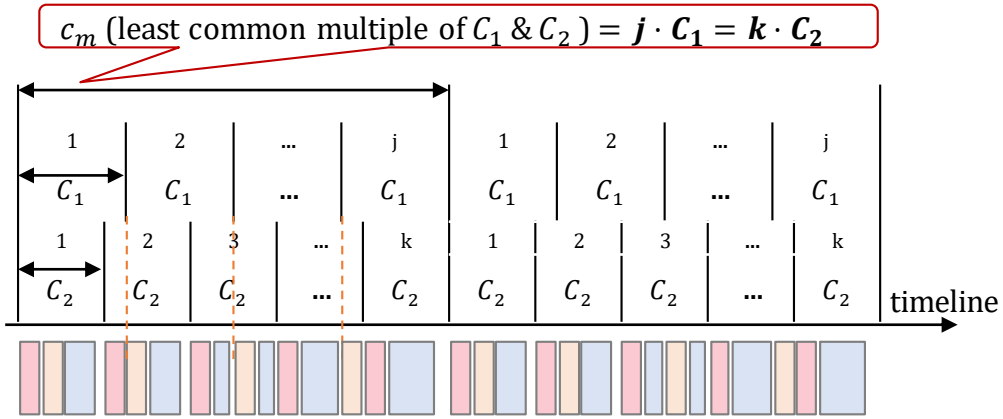
1. $\boldsymbol{C_1 = C_2}$



2. $\boldsymbol{C_1 = nC_2}$ **(n > 1 is an integer)**



3. $\boldsymbol{C_1 = mC_2}$ **(m > 1 is not an integer)**



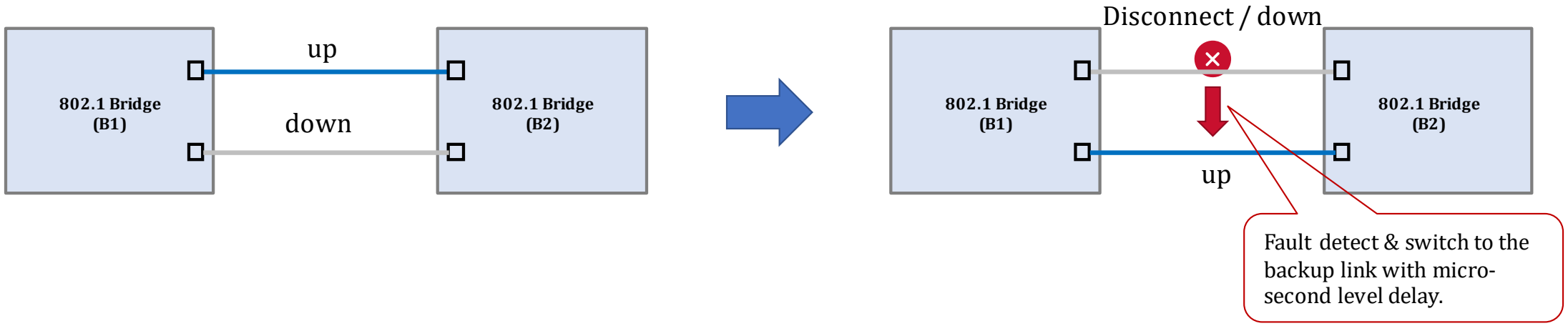
Frames from EtherCAT Master 1

Frames from EtherCAT Master 2

Frames from Ethernet Stations

High Reliability of the Inter-Connection between the 802.1 Bridges

- According to EtherCAT application cycle requirements (the redundancy recovery time is no more than a application cycle as specified in IEC 61784-2), the inter-link between the 802.1 bridges should support , micro-second level to detect and notify the Bridges to switch to the backup link.
- Next step:
  - To study the possible high reliability solution according to EtherCAT application requirements (micro-second level).



Thank you.

Proposal for Nendica Study Item

- For Nendica to initiate a study item on **Forwarding of Fieldbus CPF 12 on 802.1 Bridges**

To be studied	• Detail use case and practical requirements for intermixed EtherCAT and Ethernet forwarding • Feasibility of operation • Impact on functionality, including latency, compared to independent networks • Feasibility of assuring QoS for EtherCAT and Ethernet • **This study item excludes aspects that are covered by project IEC/IEEE 60802**
Deliverable	An informal report documenting • Summary requirements according to industrial scenarios • Potential benefits • Summary of feasibility issues • Impact & optimization of evolving technologies • Possible standardization needs • Possible recommendation to initiate a work item
Leader	• Huajie Bao (Huawei), or other volunteers
Timeline	• Start in June 2022, finish in Nov 2022 • Draft version Aug 2022 • Call for comments Sept 2022 • Complete Study Item Report Nov 2022
Work schema	• Weekly meeting or on-demand meeting • Encourage all contributions • Provide ongoing reporting to IEC/IEEE 60802