Elastic Ethernet Networking for Industrial

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Background

➢ Industrial network has been discussed in IEEE 802.

- New Ethernet Applications – Industrial Networking Requirements (https://www.ieee802.org/3/ad_hoc/ngrates/public/18_03/woods_nea_01_0318.pdf) discussed smart factory challenges and corresponding networking requirements for **convergence**, **performance**,etc., stressing the need for controlling accumulated latency.

- IEEE 802 Nendica Report – Flexible Factory IoT: Use Cases and Communication Requirements for Wired and Wireless Bridged Networks (https://ieeexplore.ieee.org/document/9068511), presented communication requirements including **variable-type**, **variable-volume** production, and **rapid customization** in a factory.

- Low Latency Discussion for Ethernet Networking (https://mentor.ieee.org/802.1/dcn/21/1-21-0072-00-ICne-low-latency-discussion-for-ethernet-networking.pdf), discussed industrial scenarios with **low latency** requirements.

➢ As these contributions mentioned that the diverse demands of industrial production is the trend, and pushing Ethernet network down to device level of factory. Challenges and potential requirements were also discussed.

➢ This presentation starts discussion with current industrial networks, and proposes a way that Ethernet network moves forward.

1. To discuss the current silo industrial networks and corresponding disadvantages.
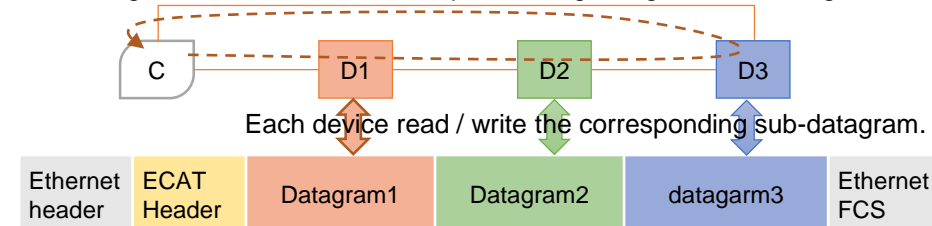2. Intends to propose some enhancement aspects for Ethernet network.

Now: Multiple Silo Industrial Ethernet Networks Coexist

➢ **Silo network:** specific industrial ethernet networks (evolved from industrial field bus) were built for specific vendor's controller / device and connects to IT network independently.

- **Evolve & extend independently** due to different technical mechanism including different topology / forwarding mode, etc.
- Independent & different management / control, it's **hard for overall schedule** according to global manufacturing operations, and **cannot quickly respond** to rapidly changing market conditions .
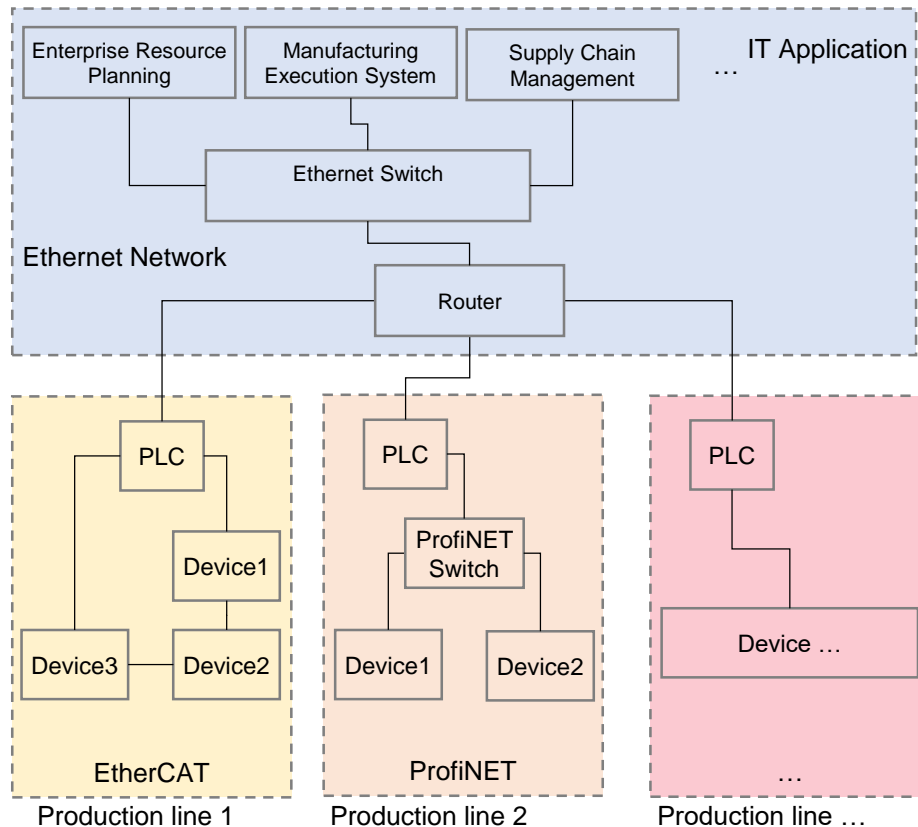
Main features of **EtherCAT** can be summarized as summation frame packaging, logical addressing.
1. **Summation frame packaging:** All device data is carried within one single summation datagram to optimize the bandwidth efficiency. So, in **one cycle**, only **one datagram** is refreshing on the fly.
2. **Logical addressing:** The Datagram from Controller is **passed through by devices one by one in a logical ring routing** and returning to Controller in the last hop according to logical addressing.

Each device read / write the corresponding sub-datagram.

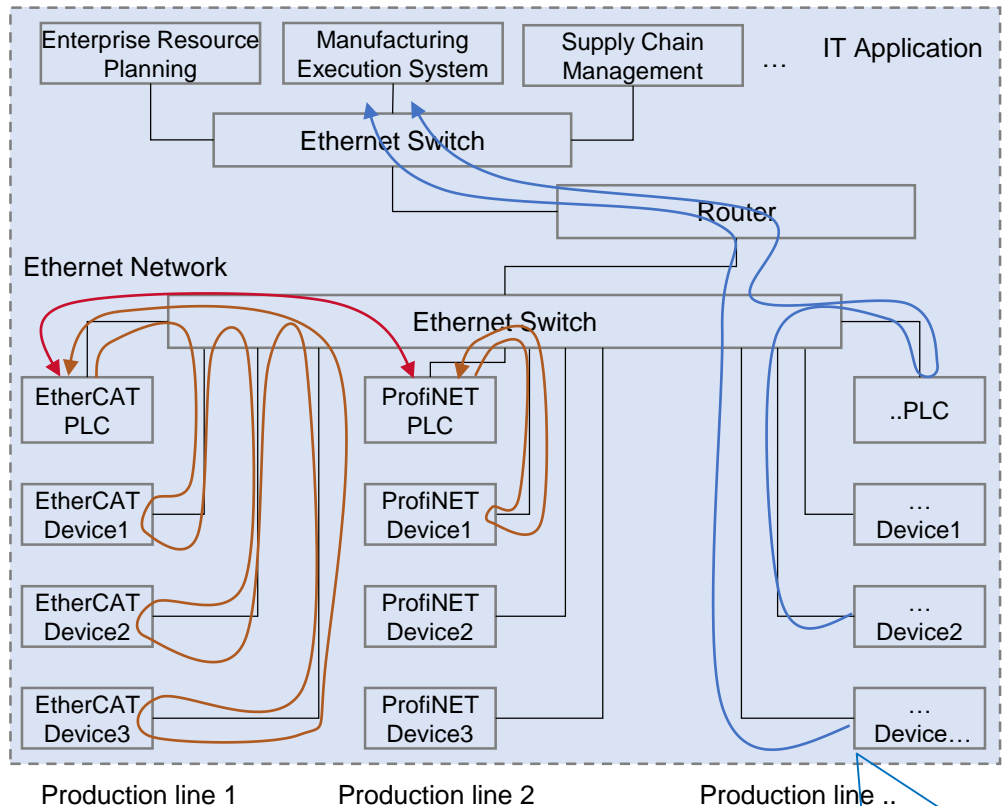| Ethernet header	ECAT Header	Datagram1	Datagram2	datagarm3	Ethernet FCS

Comparing to EtherCAT, **ProfiNET IRT** (Isochronous Real-Time, described with class number Real-Time Class 3) is the top performance class.
1. **Strict scheduling:** No delays can happen within this Real-Time class. Switches forward frames looking only at the time schedule, not MAC address. If a frame is missing, a dummy one is transmitted with "bad" status indication.
2. **Fast forwarding:** To shorten forwarding delays with rearranged frame structure by reducing the size of preamble section and copying Frame ID (2Bytes) to the destination MAC.

Preamble / SFD	DMAC	SMAC	EtherType	FrameID	IRT Datagram	FCS
8Bytes	6Bytes	6Bytes	2Bytes	2Bytes		4Bytes

ProfiNET V2.3 optimization with fast forwarding

2B	2B	4B	6B	2B	2B		4B

Future: Elastic Industrial Ethernet Network to be Shared by Different Industrial Production Lines / Systems

➢ **Elastic Industrial Ethernet Network:** A converged Ethernet network **serves different services**, provides **elastic adjustment** according to global coordination of manufacturing operation, and **quick responds** to rapidly changing market conditions .

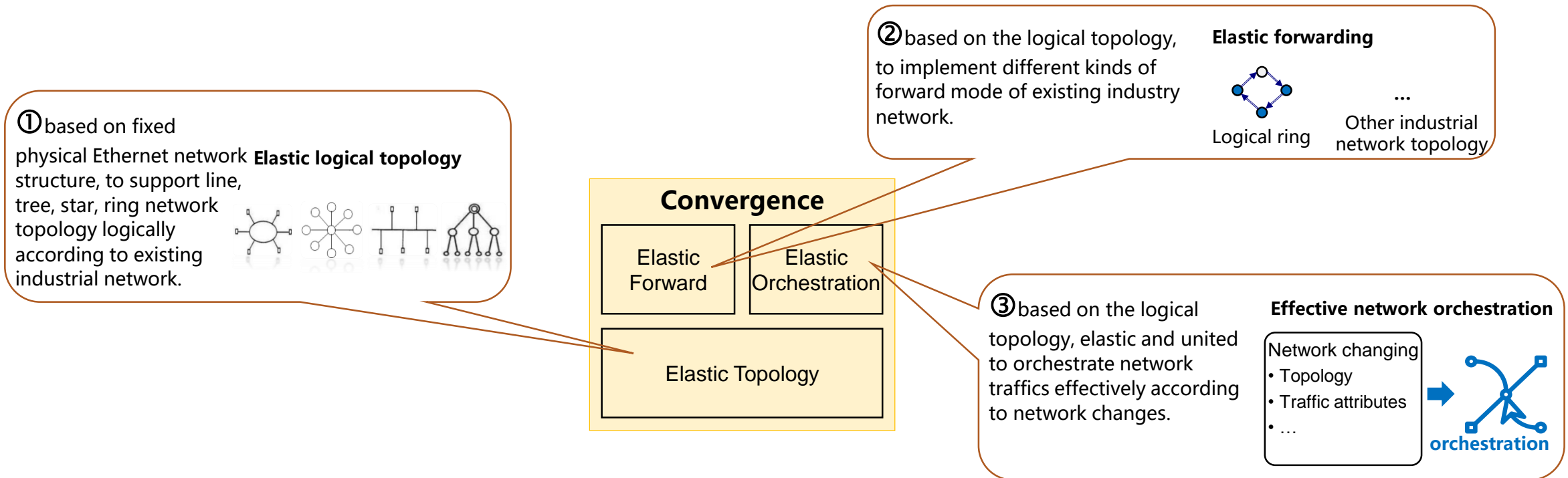|	
Compatible	One shared and convergent Ethernet network connects to all the production lines / devices and serves different services: • Compatible to existing service flow & technical mechanism • Network performance to satisfy the QoS of existing service
Elastic	The elastic Ethernet network supports agile adjustment: • Elastic Ethernet network orchestration to support global scheduling. • All devices connected as a whole pool to support global production line coordination & extension.
Efficient	One Ethernet network infrastructure fully connects to all systems, devices: • Quick network adjustment to rapidly changing market conditions. • Proper traffic path to improve overall network efficiency.

The device with IP capability will send the report data to IT application directly, otherwise it has to be passed through PLC.

→ Automation Control Inside Production Line
→ Automation Control Cross Production Line
→ Device Data Report Datagram

Requirement Category 1: Elastic Forwarding & Orchestration to Support Different Industrial Ethernet Running On Shared/Converged Ethernet Network

➢ **Convergent** industrial network for multi-service & **elastic** adjustment to changes and overall coordination

① **Elastic logical topology** based on fixed physical Ethernet network topology to support different kinds topology of existing industrial networks

② **Elastic forwarding** to simulate and be compatible with existing forwarding mode of current industrial networks

③ **Elastic orchestration** via adjusting and scheduling to quickly match the industrial network changes.

② based on the logical topology, to implement different kinds of forward mode of existing industry network.

Elastic forwarding

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Logical ring | Other industrial network topology

① based on fixed physical Ethernet network structure, to support line, tree, star, ring network topology logically according to existing industrial network.

Elastic logical topology

Convergence

| Elastic Forward | Elastic Orchestration |

Elastic Topology

③ based on the logical topology, elastic and united to orchestrate network traffics effectively according to network changes.

Effective network orchestration

Network changing
• Topology
• Traffic attributes
• …

orchestration

Requirement Category 2: Extreme Performance to Match Industrial Scenarios

➢ **Performance**: extreme low latency / jitter to satisfy industry scenarios, and extreme low recovery delay to keep service available.

As increasing of control complexity and precision of the control system, the real-time performance is also increasing.
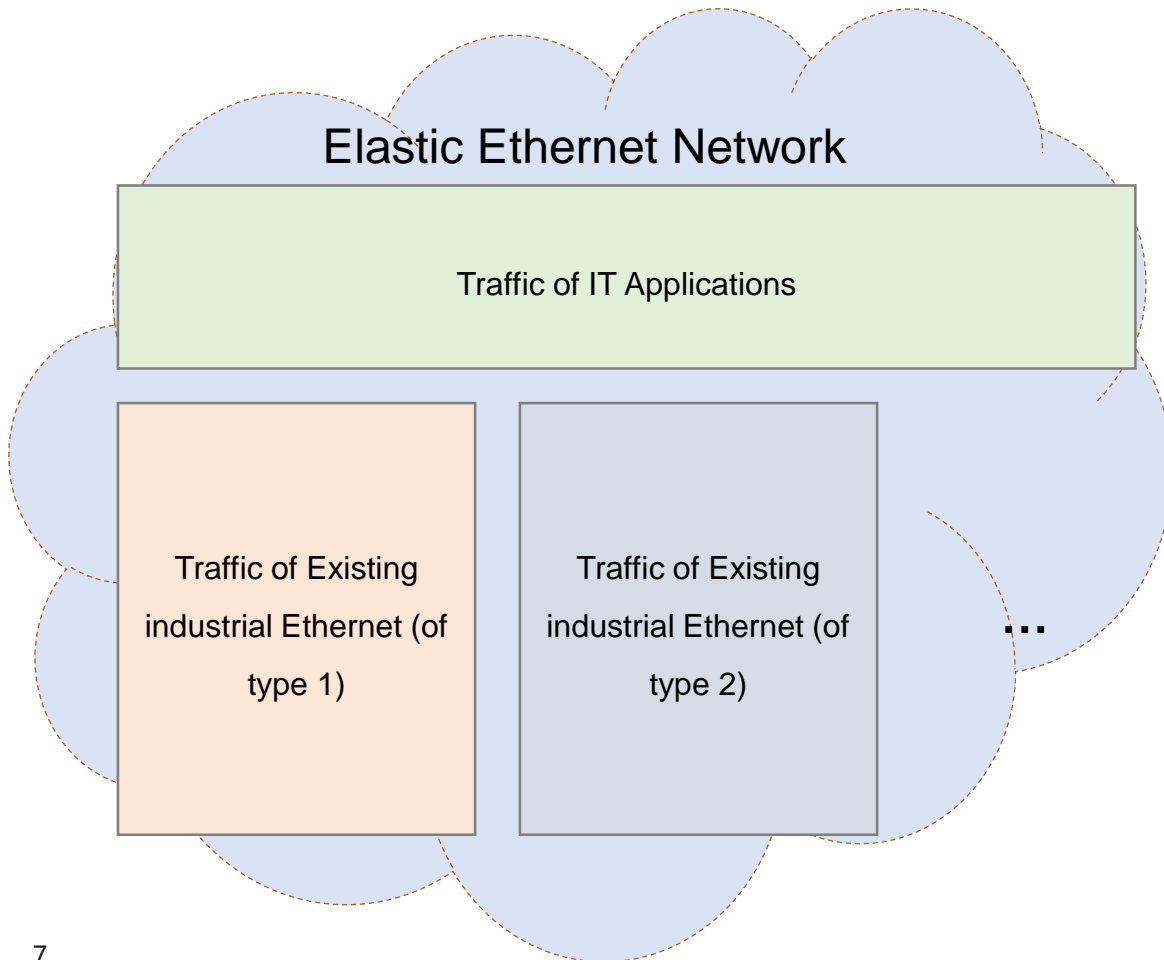
Real-time level

- Level 1 — Non real-time process
- Level 2 — Simple close-loop control
- **Extreme Low Latency**
- Level 3 — **High speed process control**, CNC, industrial robots
- Level 4 — **High performance sync process**, multi-axis motion sync

Application latency (transmission + process)

1μs 10μs 100μs 1ms 10ms 100ms 1s 10s

Source: "Research on Collaborative Scheduling and Optimization in Reliable Real-time EPA Network"
From China National Knowledge Infrastructure

Performance

Extreme low latency / jitter

Extreme low recovery delay

- **Extreme low latency / jitter:** The industrial scenarios of Extremely Low Latency is a challenge for Ethernet networks to achieve.

- Application cycle time down to 25 ~ 31.25μs
- Jitter <1μs
- Fault recovery delay no more than one cycle
  * Ring network fault recovery via ring loop

- **Extreme low recovery delay:** based on ring topology, ring network fault affects one cycle of service at most. The fault recovery delay is no more than one application cyle.

Refer to : Low Latency Discussion for Ethernet Networking (https://mentor.ieee.org/802.1/dcn/21/1-21-0072-00-ICne-low-latency-discussion-for-ethernet-networking.pdf)

Requirement Category 3: Adaptive to Different Traffics Sharing the Network

➢ **Adaptability**: adaptive to different traffic of industrial services and IT applications sharing the network.

Elastic Ethernet Network

Traffic of IT Applications

Traffic of Existing industrial Ethernet (of type 1)
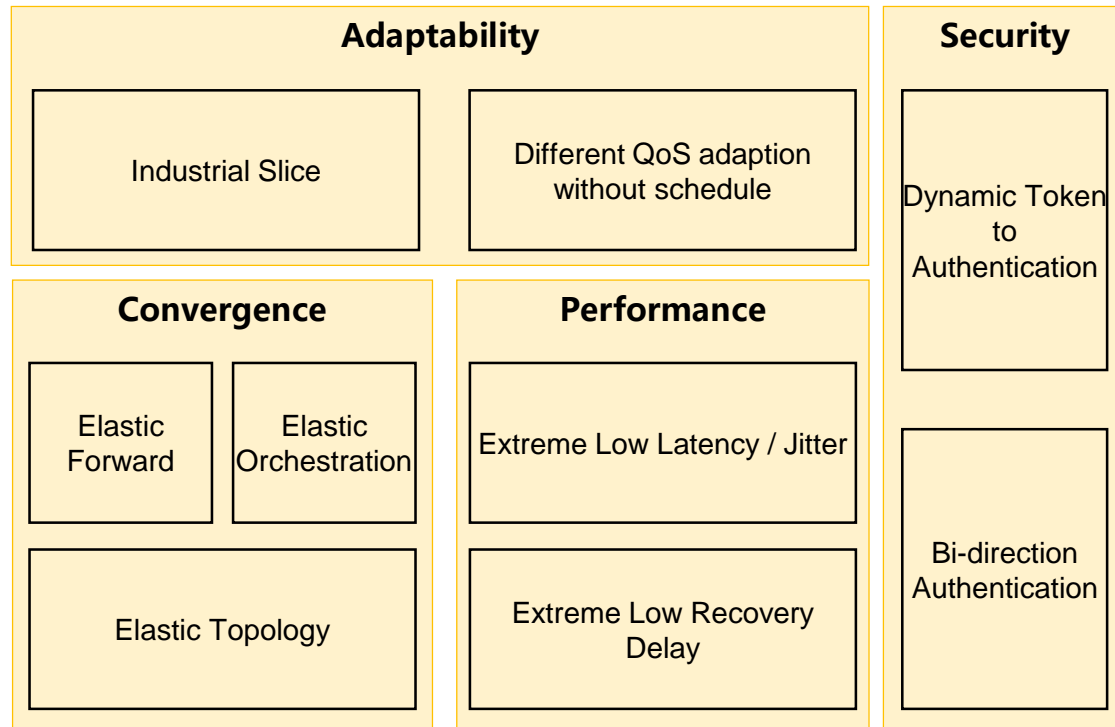
Traffic of Existing industrial Ethernet (of type 2)

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- Adaptive to different kind of existing service traffic for normal running
  ① **Network slicing** with logical isolation to avoid interfering and make full use of the bandwidth.
  ② Different kinds of traffics with different low / jitter requirements are running in the same Ethernet network, it's necessary to assure these traffics' QoS without scheduling.
    - Application cycle 1ms, jitter < 1%
    - ....
    - Application cycle 100ms jitter < 15%

Adaptability

Industrial Slice

Different QoS adaption without schedule
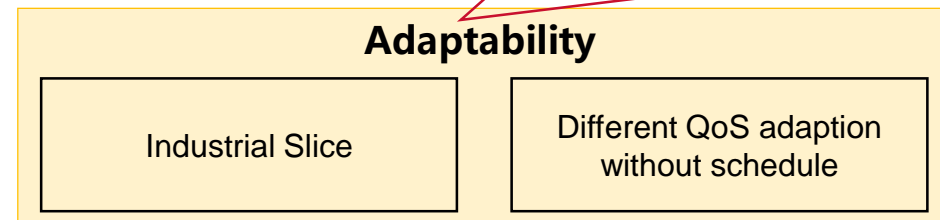
Framework of Elastic Ethernet Networking for Industry Sharing one Network

Elastic Industrial Ethernet Network supports to **Full Coverage** industrial scenarios.

Adaptability

Industrial Slice	Different QoS adaption without schedule

Convergence

Elastic Forward	Elastic Orchestration

Elastic Topology

Performance

Extreme Low Latency / Jitter

Extreme Low Recovery Delay

Security

Dynamic Token to Authentication

Bi-direction Authentication

1. **Implement network convergence**
   - ✓ Share the same network infrastructure
   - ✓ Elastic topology & forwarding mode logically
   - ✓ Ease to orchestrate based on a fixed physical network

2. **Assure network performance**
   - ✓ Extreme low latency & jitter
   - ✓ Extreme low recovery delay of ring network fault

3. **Build service adaptability**
   - ✓ Industrial slicing to avoid interfering
   - ✓ Different QoS adaption without schedule

4. **Security mechanism**
   - ✓ Dynamic token & bi-direction to authentication to assure security

Next Steps

➢ Consider to initiate a new study item for further discussion toward possible work item.

➢ Potential topics include:

- Explore detailed requirements & use case according to 3 aspects (convergence, performance, adaptability)

- Explore related technologies to be leveraged or gaps to be addressed

- Explore the framework of elastic industrial Ethernet networks

- Explore potential technology points

  ✓ Elastic topology / forwarding based on fixed physical topology

  ✓ Elastic and united orchestration for different networks

  ✓ High performance making use of full Ethernet network bandwidth

  ✓ Support QoS and other service requirements of existing services

Thank you.