An example selection of standards, standard attributes and standard extensions to cover an use cases and requirements selection

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Basic idea

This contribution defines a selection of IEEE standards, standard features, protocols and procedures which are intended to fulfill selected use cases.

The use cases are selected in a way that all today provided features are either covered and/or additional customer expected features are provided.

The idea was to create a consistent set of selections as an example.

Particular the shown example of configuration model principles seems not to be covered by todays IEEE definitions.

Principle:

- List to be covered use cases
- List the standard selection
- List the protocol selection
- …

Selection of to be supported industrial use cases

http://www.ieee802.org/1/files/public/docs2018/60802-industrial-use-cases-0918-v13.pdf

- Interconnection of TSN Domains
- Universal Time Synchronization
- Working Clock Synchronization
- Use case 01: Sequence of events
- Bidirectional communication relations
- Control Loop Basic Model (Basic and Extended model only)
- Use case 02: Isochronous Control Loops with guaranteed low latency
- Use case 03: Non-Isochronous Control Loops with bounded latency
- Use case 04: Reduction ratio of network cycle
- Use case 06: Drives without common application cycle but common network cycle
- Use case 07: Redundant networks
- Use case 08: High Availability
- Use case 09: Wireless
- Use case 10: 10 Mbit/s end-stations (Ethernet sensors)
- Use case 11: Fieldbus gateway
- Use case 12: New machine with brownfield devices
- Use case 13: Mixed link speeds
- Use case 14: Multiple isochronous domains
- Use case 15: Auto domain protection
- Use case 16: Vast number of connected stations
- A representative example for VLAN requirements
- A representative example for data flow requirements
- Direct client access
- Field devices
- Bridge Resources

Selection of to be supported industrial use cases cont.

- Use case 17: Machine to Machine/Controller to Controller (M2M/C2C) Communication
- Use case 18: Pass-through Traffic
- Use case 19: Modular machine assembly
- Use case 20: Tool changer
- Use case 21: Dynamic plugging and unplugging of machines (subnets)
- Use case 22: Energy Saving
- Use case 23: Add machine, production cell or production line
- Use case 24: Multiple applications in a station using the TSN-IA profile
- Use case 25: Functional safety
- Use case 26: Machine cloning
- Use case 27: DCS Device level reconfiguration
- Use case 28: DCS System level reconfiguration
- Use case 29: Network monitoring and diagnostics
- Use case 30: Security
- Use case 31: Firmware update
- Use case 32: Virtualization
- Use case 33: Offline configuration
- Use case 34: Digital twin

Selection of to be supported industrial requirements

http://www.ieee802.org/1/files/public/docs2018/60802-industrial-requirements-1218-v12.pdf

All requirements bound to the selected use case need to be supported.

Next step

Select IEEE standards and protocols needed to fulfill the selected industrial use cases

IEEE standards
- Bridges and End-Stations -

Features from the following IEEE standards are selected

IEEE802.3-2018 - IEEE Standard for Ethernet

IEEE802.1Q-2018 - Bridges and Bridged Networks

IEEE802.1AB-2016 - Station and Media Access Control Connectivity Discovery

IEEE802.1AS-2019* - Timing and Synchronization for Time-Sensitive Applications

and optional if needed for security

IEEE802.1X-2010 - Port-based Network Access Control

and optional if needed for wireless

IEEE802.11-2016 - Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications
IEEE802.15.1-2005 - Wireless medium access control (MAC) and physical layer (PHY) specifications for wireless personal area networks (WPANs)

***Assumes that IEEE802.1AS will be updated in 2019**

Configuration
- Bridges and End-Stations -

The following protocols are selected to access a selection of managed objects for the selected standards and the access to this managed objects

Netconf

for the access of the selected managed objects using YANG models

and

Simple Network Management Protocol (SNMP)

for the access of the selected managed objects using MIBs

Next step

Select features from the selected IEEE standards needed to fulfill the selected industrial use cases

IEEE 802.3
- Bridges and End-Stations -

All MAU types which offers support of
- IEEE802.1AS,
- IEEE802.1AB,
- full-duplex mode operation,
- a link length of at least 100m,
- preemption (not needed for data rates >2,5Gbit/s), and
- 2000 octets frame size

may be used.

MAU types with data rates of
- 10Mbit/s,
- 100Mbit/s,
- 1Gbit/s,
- 2,5Gbit/s, and
- 10Gbit/s

shall be supported, others may be supported.

IEEE 801.Q
- Bridges and End-Stations -

Feature selection
- Five VLANs, one default and four for streams
- Eight queues, two for streams
- Strict priority queue based traffic shaping algorithm
- Ingress rate limiter support / Flow classification and metering
- Priority remapping
- VLAN stripping
- VLAN adding
- Individual VLAN learning
- 2048 entries for the default VLAN FDB
- 4096 entries for the stream VLAN FDB
- Preemption support
- TAS support (for data rates <= 1Gbit/s and three gates; use only intended for 100Mbit/s based systems)
- Synchronized network access

and additional
- Minimum bridging resources to protect stream and non-stream traffic for a well-defined traffic model from dropping due to missing resources
- Cut through support (for data rates <= 1Gbit/s)

IEEE 801.Q
- Bridges and End-Stations – Cut through / Preemption / TAS

The need for Cut through, Preemption and TAS depends on the used data rate. Thus, the following assumption is used for hardware and feature selection.
Usage of TAS together with mixed data rates (e.g. 1 Gbit/s <-> 100 Mbit/s) is not intended.
Yes/No means „may or may not be used“

Data rate	Cut through	Preemption	TAS	Comment
10 Mbit/s	Yes	Yes	Yes	Sensor network, particular process automation
100 Mbit/s	Yes	Yes	Yes	Standard for todays industrial fieldbuses
1 Gbit/s	Yes	Yes	Yes/No	Expected new standard for industrial fieldbuses
2,5 Gbit/s	Yes/No	Yes/No	Not needed	Backbone for industrial fieldbuses
5 Gbit/s	Not needed	Not needed	Not needed	---
10 Gbit/s (and higher)	Not needed	Not needed	Not needed	Line level backbone

IEEE 801.Q
- Bridges and End-Stations – Traffic classes – Default setup

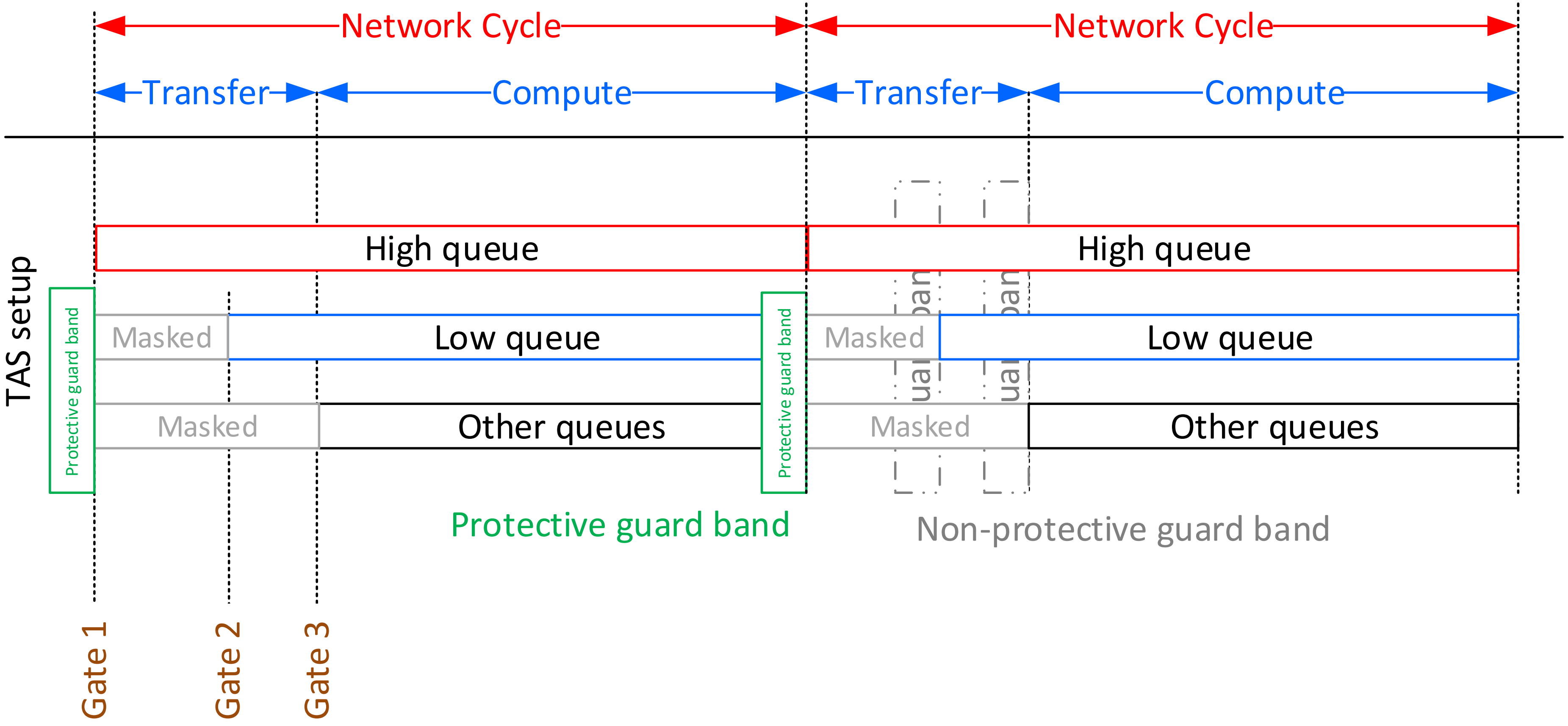
Queue	TCI.PCP	Stream	Preemption	Mask [Group]	QBTSA	Cut through	Comment
0	0	—	Preemptable	—	Strict priority	—	Inter region traffic, passing by - Other protocols
1	1	—	Preemptable	—	Strict priority	—	Inter region traffic, passing by - Other protocols
2	2	—	Preemptable	—	Strict priority	—	Frames used for connection establishment, records and control - Domain internal traffic
3	3	—	Preemptable	—	Strict priority	—	Cyclic and acyclic transmitted frames for nodes outside of the time aware domain - “Brownfield”
4	4	—	Preemptable	—	Strict priority	—	Acyclic transmitted frames rated by as alarm
5	7	—	Preemptable	—	Strict priority	—	Synchronization (never preempted) - Network Management
6	5	Low	Preemptable	—	Strict priority	—	Stream “cyclic real-time” Cyclic transmitted frames rated as Control Data LOW
7	6	High	Preemptive	—	Strict priority	Yes	Stream “isochronous cyclic real-time” Cyclic transmitted frames rated as Control Data HIGH

IEEE 801.Q
- Bridges and End-Stations – Traffic classes – With queue masking (TAS)

Queue	TCI.PCP	Stream	Preemption	Mask [Group]	QBTSA	Cut through	Comment
0	0	—	Preemptable	Other	Strict priority	—	Inter region traffic, passing by - Other protocols
1	1	—	Preemptable	Other	Strict priority	—	Inter region traffic, passing by - Other protocols
2	2	—	Preemptable	Other	Strict priority	—	Frames used for connection establishment, records and control - Domain internal traffic
3	3	—	Preemptable	Other	Strict priority	—	Cyclic and acyclic transmitted frames for nodes outside of the time aware domain - “Brownfield”
4	4	—	Preemptable	Other	Strict priority	—	Acyclic transmitted frames rated by as alarm
5	7	—	Preemptable	Other	Strict priority	—	Synchronization (never preempted) - Network Management
6	5	Low	Preemptable	Low	Strict priority	—	Stream “cyclic real-time” Cyclic transmitted frames rated as Control Data LOW
7	6	High	Preemptive	High	Strict priority	Yes	Stream “isochronous cyclic real-time” Cyclic transmitted frames rated as Control Data HIGH

IEEE 801.Q
- Bridges and End-Stations – TAS setup

Friendly neighborhood based time aware shaper model used for a TSN domain which assumes synchronized network access only!



IEEE 801.Q
- Bridges and End-Stations - Domain boundary support

Priority remapping

To protect the TSN domain each node shall support “Priority remapping” and “VLAN assignment and stripping”.
Both shall work with line speed and should not increase the bridge delay.
Priority remapping adds, updates or strips a TCI.PCP tag of an ingress or egress packet.

VLAN assignment and stripping

To protect the TSN domain each node shall support “Priority remapping” and “VLAN assignment and stripping”.
Both shall work with line speed and should not increase the bridge delay.
VLAN assignment and stripping adds, updates or strips a VLAN tag of an ingress or egress packet.

IEEE 801.Q
- Bridges and End-Stations – Ingress rate limiter

Each boundary port shall support rate limiting for ingress traffic.
- Limiter for Unicast
- Limiter for Multicast/Broadcast

Both limiters are independent parameterized.

Working principle:
Limiting the bandwidth with an observation interval of 1 ms.
Burst breaking may be supported.

Network control (e.g. IEEE 802.1AS or IEEE 802.1AB) shall not be affected by rate limiting.

This ingress rate limiter supports protection of switching and application resources of devices inside the TSN domain (outside of the TSN domain is assumed hostile).

No “Denial of Service” protection intended.

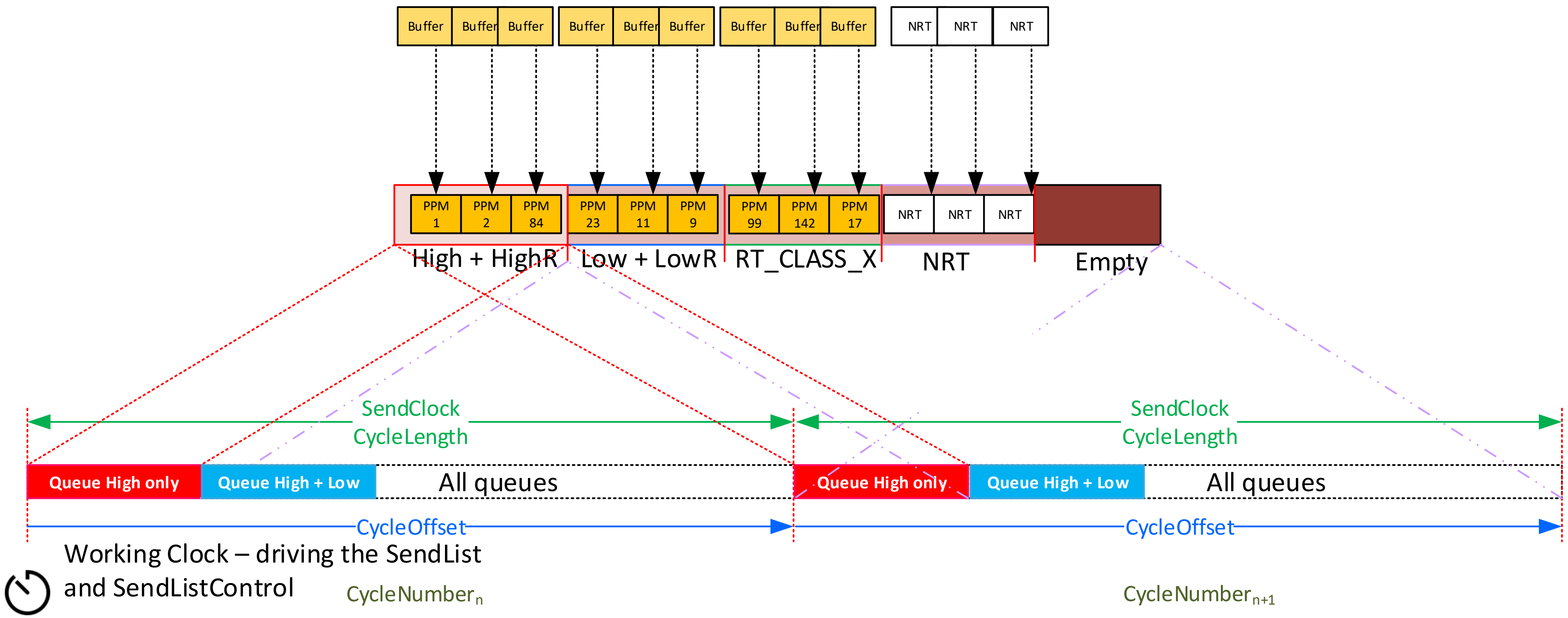
IEEE 801.Q
- Bridges and End-Stations – Network access

Network access is always synchronized to the working clock to support todays network loads for real-time traffic together with reduction ration, phase and sequence.

<table>
<tr><th>Level</th><th colspan="2">Isochronous Application</th><th colspan="2">Non-isochronous Application</th></tr>
<tr><td>Application</td><td colspan="2">Synchronized to network access</td><td colspan="2">Synchronized to local timescale</td></tr>
<tr><td>Network access</td><td colspan="4">Synchronized to working clock,
Stream Class based scheduling, Preemption</td></tr>
<tr><td rowspan="2">Network/Bridges</td><td>Synchronized to working clock</td><td>Free running</td><td>Synchronized to working clock</td><td>Free running</td></tr>
<tr><td>Scheduled traffic + Strict Priority + Preemption</td><td>Strict Priority or other Shaper + Preemption</td><td>Scheduled traffic + Strict Priority + Preemption</td><td>Strict Priority or other Shaper + Preemption</td></tr>
</table>

IEEE 801.Q
- Bridges and End-Stations – Network access model

Well defined behavior of the network access of each end-station allows load calculation which provides much better values than undefined network access und thus better network utilization.

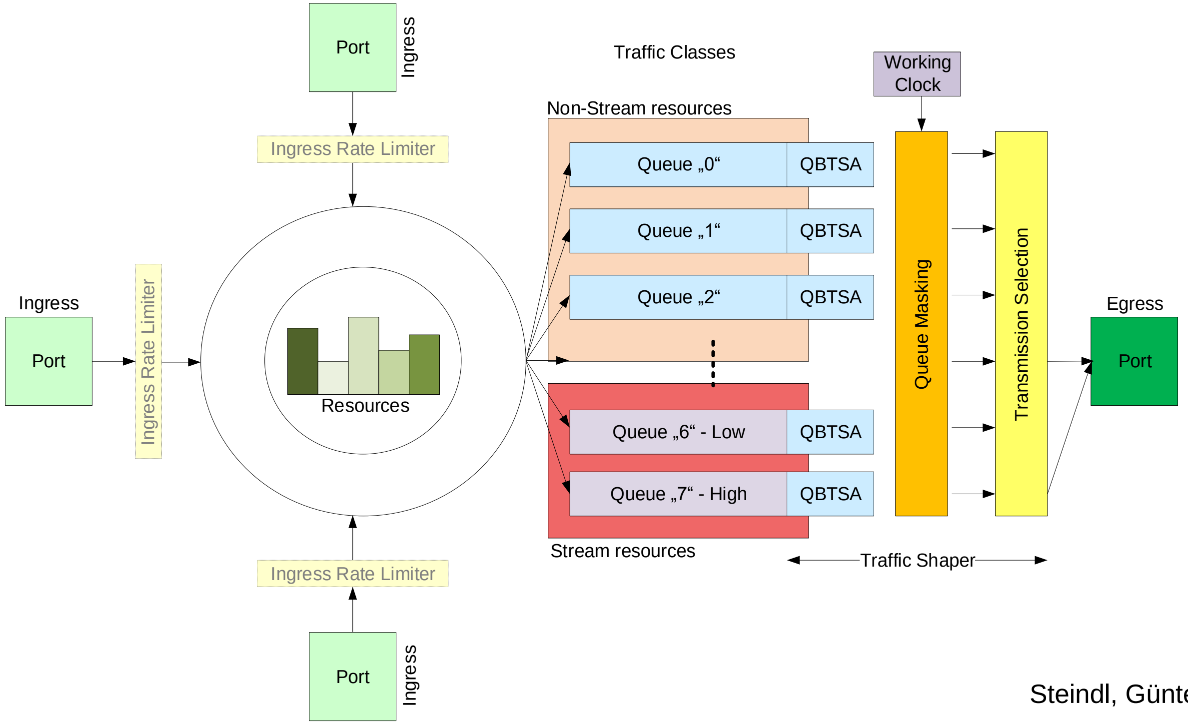


IEEE 801.Q
- Bridges and End-Stations – Guaranteed resources

Industrial networks use different protocols, often not TCP based, to fulfill the industrial requirements. The controlled process relays on the timeliness of all of this needed protocols.
The bandwidth used for this protocols is well defined and these frames shall not be dropped when streams are transmitted.
Thus, bridges shall guarantee these switching resources to avoid process disturbance due to dropped frames.

Non-Stream resources need to be as big as the maximum blocking time of a port with streams.

Stream resources need to be as big as the in class interference of the high class.



IEEE 802.1AB
- Bridges and End-Stations – Neighborhood discovery

TSN domain discovery

LLDP based neighborhood discovery allow the TSN domain network management entity to work w/o topology engineering.

TSN domain

Auto domain protection uses LLDP exchanged TSN domain information to identify whether a connected device will extend the TSN domain or this port is a boundary.

A TSN domain name is user friendly, a TSN domain ID protects the maximum frame size of a LLDP frame.

Cloning of a machine needs to creates at least a unique TSN domain name which is unique compared to its neighborhood domains.

Working Clock domain

Auto domain protection needs to cover this, too in case of cloning or independent TSN domain engineering.

IEEE 802.1AB
- Bridges and End-Stations – Network diagnostics

Topology discovery together with selected readable management objects allow network diagnostics. Particular already defined 802.3 and 802.1Q objects support peer to peer detection of deviations.

Additional diagnostic mean will be defined together with the selection of further supported management objects.

Todays network diagnostic features need to be available.

IEEE 802.1AS
- Bridges and End-Stations – Synchronization

DomainNumber

Four domain numbers are defined

0: time

1: time redundant tree

20: working clock

21: working clock redundant tree

Universal Time domain

Clock master redundancy with zero failover time is optional and if needed will be supported by engineered sync trees.

Working Clock domain

Clock master redundancy with zero failover time will be supported by engineered sync trees.

IEEE 802.1AS
- Bridges and End-Stations – Diagnostics

802.1AS defined managed objects will be used to create diagnostic information for the customer.

Additional diagnostic mean will be defined together with the selection of further supported management objects.

Todays synchronization diagnostic features need to be available.

Concurrent Audio and Video
- IEEE802.1BA constraints

IEEE802.1BA require as max interference one maximum frame for its highest class. Which means that this profile could not be used together with TSN-IA if the Control Data (High and Low) is above Audio/Video.

But Audio/Video could easily be integrated into TSN-IA if these devices use CD High/CD Low instead – in short are TSN-IA profile devices, too.

Following this approach allows the combination of video with control loops, even integrate video image recognition to the control loop itself.

Thus, even the combination of Video and functional safety should work from the TSN-IA point of view.

Next step

Select an engineering model which fulfills the selected industrial use cases

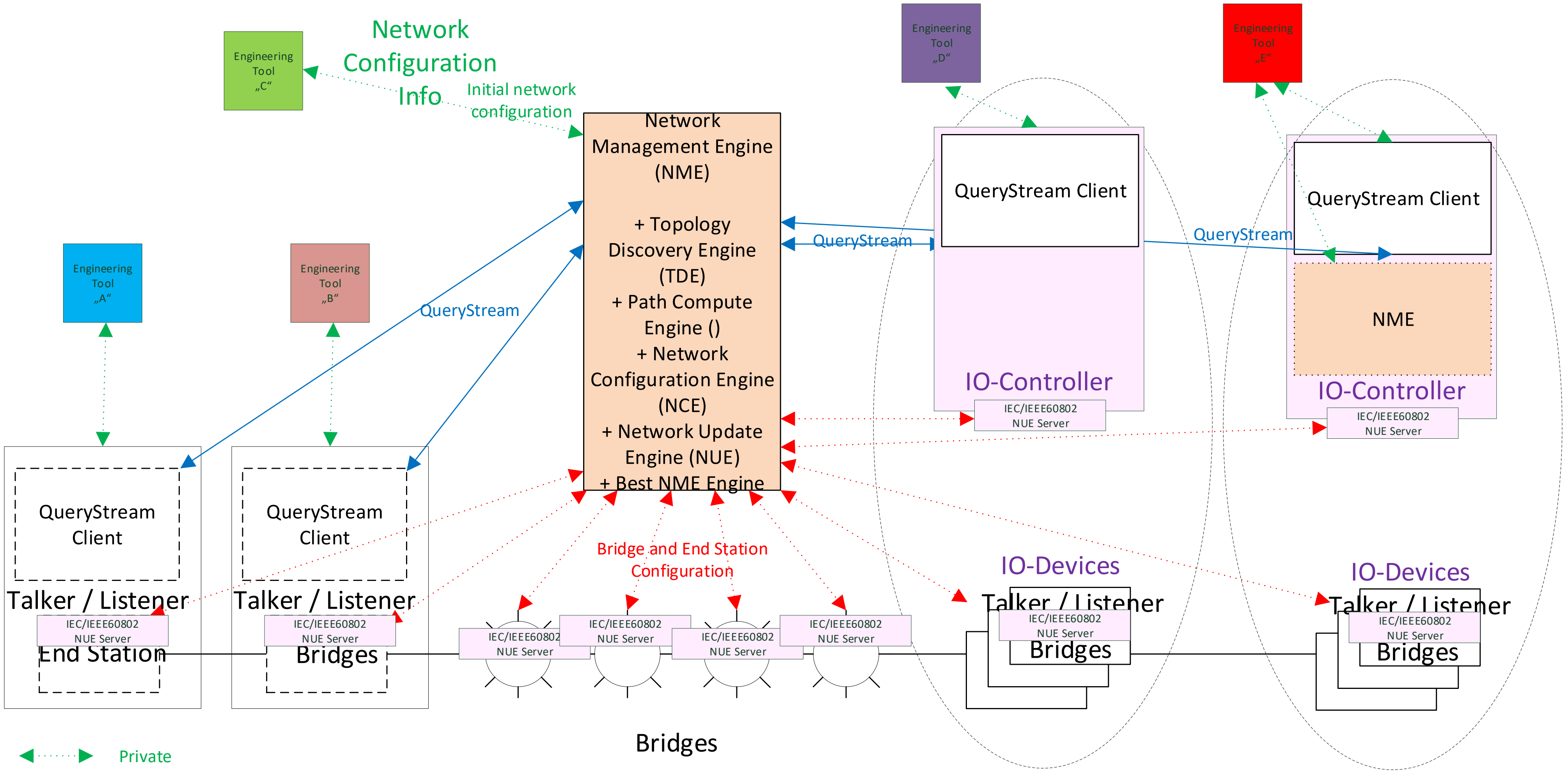
Engineering model
- Bridges and End-Stations

An engineering model covering all selected use cases is needed.

The following feature shall be supported

- no topology engineering needed
- topology engineering together with topology checking possible
- application engineering doesn’t need to engineer “pure” bridges
- network policy based network engineering – only basic customer decision need
- multiple independent application projects needs to be supported
- industrial controller and device roles shall still be possible
- adding and removing of communication relations, devices, networks and TSN domains shall be supported without influencing not direct affected devices
- device replacement without engineering tool
- inter TSN domain streams
- high utilization of the bandwidth reserved for streams supporting reduction ratio, phase and sequence
- establishment of sync trees, redundant and non redundant

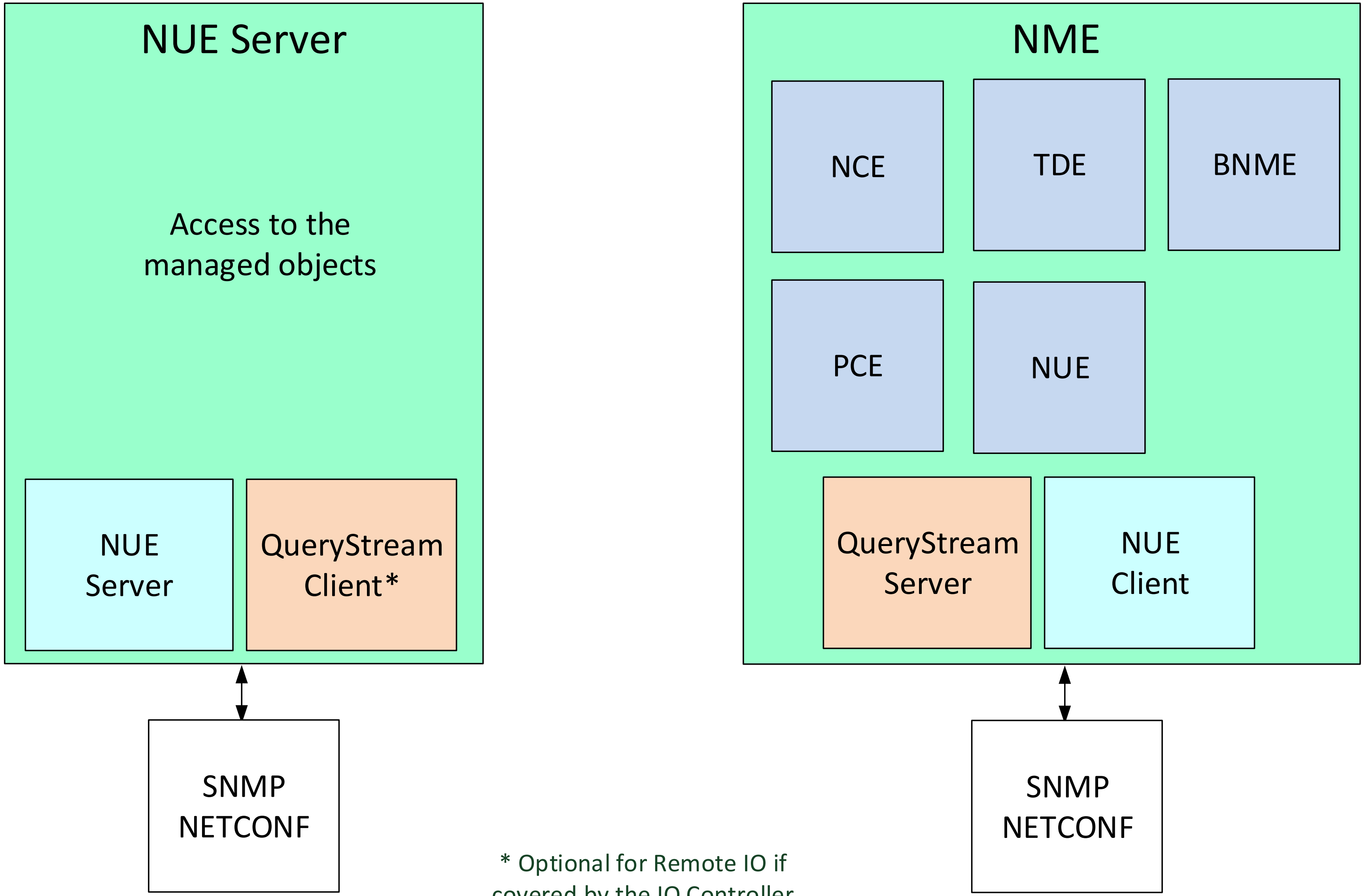
Engineering model - Principle



Selected „NME“ - Multiple „QueryStream Clients“

IO-Controller := End-Station or bridged End-Station with the application role „Controller“
IO-Device := End-Station or bridged End-Station with the application role „Remote IO“

Engineering model
- Components



* Optional for Remote IO if covered by the IO Controller

Engineering model
- Terms

NME (Network Management Engine)

The network management engine is responsible for
- the policy based network configuration using Network Configuration Engine (NCE) and Network Update Engine (NUE)
- the topology based path computing using Path Compute Engine (PCE) and Network Update Engine (NUE)
- the topology discovery using the Topology Discovery Engine (TDE)
- the NME negotiation in case of multiple NMEs in one TSN domain using the Best NME Engine (BNME)

based on IEC/IEEE 60802 defined/selected interfaces and protocols.

It provides an interface (defined/selected by IEC/IEEE 60802) to request a Stream for any device of the TSN domain and for cross domain streams. For optimization purpose it shall allow to query a bunch of streams at once to optimize the PLC / Controller / Remote Io use case.

The NME may be locate in a dedicated device or integrated into any PLC or IO-controller.

Thus, its configuration interface is defined vendor specific and may only work with the NME vendors engineering tool.

Engineering model
- Terms

NCE (Network Configuration Engine)

The network configuration engine is responsible for

- the policy based network configuration using Network Configuration Engine (NCE) and Network Update Engine (NUE)

based on engineering loaded policy based network configuration and the discovered topology provided by the Topology discovery engine.

The policy based network configuration is loaded by the vendor specific engineering tool using private means.

The network configuration is loaded into any device in the TSN domain using IEC/IEEE 60802 defined/selected interfaces and protocols.

TSN-IA profile based devices need to be fully configurable using only the IEC/IEEE 60802 defined/selected interfaces, protocols and managed objects.

Engineering model
- Terms

TDE (Topology Discovery Engine)

The topology discovery engine is responsible for

- the topology discovery and device identification
- the topology comparism if a expected topology is provide by the vendor specific engineering

based on IEC/IEEE 60802 defined/selected interfaces, protocols and managed objects.

The internal provided topology database is used by the NCE, NUE and PCE for their work.

The TDE detects added or remove devices and triggers internal the NCE, NUE or PCE if needed.

Engineering model
- Terms

PCE (Path Compute Engine)

The path compute engine is responsible for

- the management of the stream MAC addresses
- the calculation of paths through the TSN domain based on the topology database and the used network configuration
- the expected maximum latency calculation
- the check of the bridge resource at the path against the IEC / IEEE 60802 defined limits

based on IEC/IEEE 60802 defined/selected interfaces and protocols.

The NUE is used to update the device on the path using IEC/IEEE 60802 defined/selected interfaces and protocols.

All calculated paths may be stored persistent and reestablished during startup for performance reasons.

Engineering model
- Terms

BNME (Best NME Engine)

The best NME engine is responsible for
- the management of the active NME
based on IEC/IEEE 60802 defined/selected interfaces and protocols.

If multiple NME are detected, one is selected. This process shall be reproduceable to make sure that unnecessary switches between NMEs are avoided.

A device with a deselected NME is handled like a device without an NME.

Engineering model
- Terms

NUE (Network Update Engine)

The network update engine is responsible for
- the update of the managed objects in the devices when request by NCE or PCE

based on IEC/IEEE 60802 defined/selected interfaces and protocols.

NUE Server (Network Update Engine server)

The network update engine server is responsible for
- the handling of the update requests for the managed objects in the devices

based on IEC/IEEE 60802 defined/selected interfaces and protocols.

Engineering model
- Terms

QueryStream (Interface to request a stream or multiple streams)

Client

Any node in the TSN domain is able to request streams from the NME using an IEC/IEEE 60802 defined/selected interface and protocol.

Server

The network management engine server is responsible for

- the handling of the QueryStream request
- the forwarding to its PCE
- providing the feedback from the PCE
- the establishment of the paths

based on IEC/IEEE 60802 defined/selected interfaces and protocols.

Next step

Check what is missing to fulfills the selected industrial use cases based on this example selection

Verifying selection

Best way to verify such a selection is the implementation and testing with real devices.

Replacing the missing definitions with available and well defined interfaces, protocols and managed objects.

Thus, feedback from real implementation together with real TSN hardware will be available.

Next step

Conclusion

Conclusion

The provided example selection provides a solution which solves the selected use cases and requirements.

Missing means, like the definition of an interface for QueryStreams or Best NME or managed objects for LLDP need to identified.

Ways how to solve such opens need to be defined.

The author suggests to continue with such an approach for the TSN-IA profile work.

Thank you

Questions?