Deterministic Ethernet

Interoperability Specification for Per-Flow Time-Triggered Communication

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Approval

Name	Function	Signature

Revision Chart

A revision is a new edition of the document and affects all sections of this document.

Version	Date	Responsible Person	Modification
0.1	26.04.2013	Wilfried Steiner	Initial Version
0.2	05.06.2013	Wilfried Steiner	Several updates, mostly in the Bridge and clock sync sections.
0.3	19.02.2014	Wilfried Steiner	Updates in WST-404 – WST-406
1.0	30.11.2015	Stefan Rebernig	Release

Contents

1 Overview

2 General Requirements

WST-001: All end stations and switches that transmit, forward, or receive a given time-triggered flow shall have access to a synchronized timebase with precision CLOCK_SYNC_PRECISION.

> Note: The synchronized timebase can be accomplished by different protocols, examples are listed in the SAE AS6802 standard, the IEEE 1588 standards or within IEEE 802.1AS.

SRE-001: End stations and switches shall discard time-triggered flows if the precision of the synchronized timebase is worse than CLOCK_SYNC_PRECISION.

> Note: Time-aware devices which are not synchronized are not allowed to transmit based on their local notion of time since this leads to arbitrary, non-deterministic communication patterns.

WST-002: A flow shall be identifiable as a time-triggered flow by a generic traffic classification engine implemented in end stations and switches.

Note: The intent of this requirement is to identify flows in a switch by making use of higher-layer protocol information, such as UDP/IP or Profinet headers. However, to comply with TSN, it is also required to classify on sole layer-2 header information as well.

3 Interface Description of a Time-Triggered Flow-Aware End Station

An end station may act as the source and/or the sink of one or many time-triggered flows. It is the aim of this section to specify the transmission interface and the reception interface of an end station in the value domain as well as in the time domain.

3.1 End Station Transmission

WST-103: An end station shall identify a flow for transmission as a time-triggered flow by executing a traffic classification function mapping the frame to an internal flow identifier.

Note: The intent of this requirement is to make it clear that the end station operates time-triggered communication on a per-flow basis.

WST-104: An end station shall associate each time-triggered flow it transmits with a ES_TT_TX_LENGTH, a ES_TT_TX_PERIOD, and a ES_TT_TX_PHASE.

Note: a scheduler for time-triggered flows will typically take the ES_TT_TX _LENGTH and ES_TT_TX_PERIOD values of all frames as an input and return a value for ES_TT_TX_PHASE for each time-triggered flow as an output.

WST-105: ES_TT_TX _LENGTH is the allowed length of an Ethernet frame including IFG and preamble:

Minimum(ES_TT_TX _LENGTH) = 84 Bytes
Maximum(ES_TT_TX _LENGTH) = 1542 Bytes

WST-106: ES_TT_TX_PERIOD is the transmission period with which the end system will dispatch the respective time-triggered flow.

WST-107: ES_TT_TX_PHASE is a value given by:

ES_TT_TX_PHASE = K * ES_SCHEDULE_GRANULARITY, where ES_SCHEDULE_GRANULARITY is the granularity of the schedule and K is a natural number such that ES_TT_TX_PHASE <= ES_TT_TX_PERIOD holds.

WST-108: An end station shall specify ES_SCHEDULE_GRANULARITY the granularity of ES_TT_TX_PERIOD at which the end system accepts values of ES_TT_TX_PHASE from the scheduler.

Note: An example would be ES_TT_TX_PERIOD=20ms, ES_SCHEDULE_GRANULARITY 20us; which means that ES_TT_TX_PHASE may take any value between 0 and 20ms in 20us increments.

WST-109: An end station shall specify its minimum duration, ES_MIN_TT_TX_GAP between two consecutive transmit triggers for time-triggered flows.

WST-110: An end station shall specify the maximum duration ES_TT_TX_MAX_JITTER that it takes starting from the synchronized timebase reaching the phase ES_TT_TX_PHASE in the period ES_TT_TX_PERIOD of a time-triggered flow until the first bit of the Preamble of the frame is placed on the transmit communication line.

WST-111: An end station shall be able to transmit at minimum ES_MIN_TT_TX_FLOWS time-triggered flows.

WST-112: An end station shall specify the number of ES_ TT_TX_FLOWS time-triggered flows it is capable to transmit.

WST-113: An end station shall specify the different ES_TT_TX_PERIOD it supports.

WST-114: An end station shall specify the number ES_NUM_TT_TX_PERIOD of different ES_TT_TX_PERIOD it can support during operation.

Note: not all possible values that an end station can be configured to TT_TX_PERIOD may necessarily be able to run concurrently. ES_NUM_TT_TX_PERIOD, thus defines the maximum number of different frame periods that an end station supports during operation.

WST-115: An end station may specify a list ES_LIST_TT_TX_PERIOD of different ES_TT_TX_PERIOD it can support during operation.

WST-116: An end system shall support during operation any selection of size ES_NUM_TT_TX_PERIOD of the ES_TT_TX_PERIOD which the end system supports, if it does not explicitly specify ES_LIST_TT_TX_PERIOD.

3.2 End Station Reception

WST-117: An end station shall identify a flow it receives as a time-triggered flow by executing a traffic classification function mapping the frame to an internal flow identifier.

Note: The intent of this requirement is to make it clear that the end station operates time-triggered communication on a per-flow basis.

WST-118: An end station may implement an ingress policy function ES_TT_RX_WINDOW_CHECK.

WST-119: An end system that implements the ES_TT_RX_WINDOW_CHECK shall locally store, for each time-triggered flow x for which the ES_TT_RX_WINDOW_CHECK is to be executed, an expected arrival time interval ES_TT_RX_EXPECT_ARR_TIME_INT(x).

> Note: The list of ES_TT_RX_EXPECT_ ARR_TIME_INT(x) will be an output of the scheduler.

WST-120: An end system that implements the ES_TT_RX_WINDOW_CHECK shall accept an incoming frame belonging to the time-triggered flow x only if the Start of Frame Delimiter of the frame is received within ES_TT_RX_EXPECT_ ARR_TIME_INT(x).

3.3 Dynamic reconfiguration during runtime

SRE-121: An end station shall support dynamic updates to the following configuration parameters, for each flow:

- ES_TT_TX_LENGTH
- ES_TT_TX_PERIOD
- ES_TT_TX_PHASE
- ES_TT_RX_EXPECT_ARR_TIME_INT

> Note: In order to ensure seamless operation of the system, dynamic updates to this parameters should not have an impact to unaffected traffic flows.

SRE-122: An end station shall support dynamic updates to ES_TT_RX_WINDOW_CHECK.

4 Interface Description of a Time-Triggered Flow-Aware Bridge

Editor's note: the bridge forwarding and bridge reception requirements are analogously to the end station transmission and end station reception requirements.

4.1 Bridge Forwarding

WST-203: A bridge shall identify a flow it forwards as a time-triggered flow by executing a traffic classification function mapping the frame to an internal flow identifier.

> Note: The intent of this requirement is to make it clear that the bridge operates time-triggered communication on a per-flow basis.

SRE-200: A bridge shall determine the egress port map for each flow x based on the configuration value B_EGRESS_PORTS(x).

> Note: The set of egress ports is statically configured for each flow by traffic engineering.

WST-204: A bridge shall associate each time-triggered flow it forwards with a B_TT_TX_LENGTH, a B_TT_TX_PERIOD, and a B_TT_TX_PHASE.

Note: a scheduler for time-triggered flows will typically take the B_TT_TX_LENGTH and B_TT_TX_PERIOD values of all frames as an input and return a value for B_TT_TX_PHASE for each time-triggered flow as an output.

WST-205: B_TT_TX_LENGTH is the allowed length of an Ethernet frame including IFG and preamble:

Minimum(B_TT_TX_LENGTH) = 84 Bytes
Maximum(B_TT_TX_LENGTH) = 1542 Bytes

WST-206: B_TT_TX_PERIOD(x) is the transmission period with which the bridge will dispatch the respective time-triggered flow x.

Note: For each flow, the bridge supports one transmission period, e.g., flow 1 gets forwarded every 10ms, flow 2 every 5ms. The transmission period is typically an input from the network design engineer to the scheduling tool.

WST-207: B_TT_TX_PHASE(x, p) is a value given by:

B_TT_TX_PHASE(x, p) = K(p) * B_SCHEDULE_GRANULARITY, where B_SCHEDULE_GRANULARITY is the granularity of the schedule and K(p) is a natural number such that B_TT_TX_PHASE <= B_TT_TX_PERIOD(x) for flow x and port p holds.

Note: B_TT_TX_PHASE(x, p) is the actual point in time within the transmission period B_TT_TX_PERIOD(x) at which a frame belonging to flow x gets forwarded on port p. E.g., flow 1 gets forwarded every 10ms, at an offset of 1.5ms on port 1 and at an offset of 3.4ms on port 4. The intention is, that each port has an individual point in time on which a specific time-triggered frame gets forwarded.

WST-208: A bridge shall specify B_SCHEDULE_GRANULARITY the granularity of B_TT_TX_PERIOD at which the bridge accepts values of B_TT_TX_PHASE from the scheduler.

Note: An example would be B_TT_TX_PERIOD(x) = 20ms, B_SCHEDULE_GRANULARITY = 20us; which means that B_TT_TX_PHASE(x, p) may take any value between 0 and 20ms in 20us increments on each port p.

WST-209: A bridge shall specify its minimum duration, B_MIN_TT_TX_GAP between two consecutive transmit triggers for time-triggered flows.

WST-210: A bridge shall specify the maximum duration B_TT_TX_MAX_JITTER that it takes starting from the synchronized timebase reaching the phase B_TT_TX_PHASE in the period B_TT_TX_PERIOD of a time-triggered flow until the first bit of the preamble of the frame is placed on the transmit communication line.

Note: this parameter specifies the worst case deviation of the actual transmission time vs. the scheduled transmission time (B_TT_TX_PHASE) and is typically impacted by the following effects:

- The physical medium is busy transmitting an interfering best-effort frame, this can be compensated by using explicit media reservation or frame preemption mechanisms.
- The design of the egress stage of the switch introduces jitter.

Note: Network devices connected to the switch need to take this jitter value into account if they execute any TT_RX_WINDOW_CHECK.

WST-211: A bridge shall be able to forward at minimum B_MIN_TT_TX_FLOWS time-triggered flows.

WST-212: A bridge shall specify the number of B_ TT_TX_FLOWS time-triggered flows it is capable to transmit.

WST-213: A bridge shall specify the different B_TT_TX_PERIOD it supports.

WST-214: A bridge shall specify the number B_NUM_TT_TX_PERIOD of different B_TT_TX_PERIOD it can support during operation.

Note: not all possible values that a bridge can be configured to B_TT_TX_PERIOD may necessarily be able to run concurrently. B_NUM_TT_TX_PERIOD, thus defines the maximum number of different frame periods that a bridge supports during operation.

WST-215: A bridge may specify a list B_LIST_TT_TX_PERIOD of different B_TT_TX_PERIOD it can support during operation.

WST-216: A bridge shall support during operation any selection of size B_NUM_TT_TX_PERIOD of the B_TT_TX_PERIOD which the bridge supports, if it does not explicitly specify B_LIST_TT_TX_PERIOD.

4.2 Bridge Reception

WST-217: A bridge shall identify a flow it receives as a time-triggered flow by a lookup in an internal table.

Note: The intent of this requirement is to make it clear that the bridge operates time-triggered communication on a per-flow basis. *(Editor's note: However, if people feel this is not needed, but follows from the context, the requirement can be removed.)*

WST-218: A bridge may implement an ingress policy function B_TT_RX_WINDOW_CHECK.

WST-219: A bridge that implements the B_TT_RX_WINDOW_CHECK shall locally store, for each time-triggered flow x, on port p, for which the B_TT_RX_WINDOW_CHECK is to be executed, an expected arrival time B_TT_RX_EXPECT_ARR_TIME_INT(x, p).

> Note: The list of B_TT_RX_EXPECT_ARR_TIME_INT(x, p) specifies, for each ingress port, a time interval within B_TT_RX_PERIOD, the reception period associated to this flow and will be an output of the scheduler.
> E.g., Flow 1, received every 20ms, is accepted on port 1 with an offset of 1ms and 1.5ms.

WST-220: A bridge that implements the B_TT_RX_WINDOW_CHECK shall accept an incoming frame belonging to the time-triggered flow x, on port p, only if the Start of Frame Delimiter of the frame is received within B_TT_RX_EXPECT_ ARR_TIME_INT(x, p).

WST-221: A bridge that implements the B_TT_RX_WINDOW_CHECK shall specify the number of B_ TT_RX_FLOWS time-triggered flows it is capable to receive.

WST-222: A bridge that implements the B_TT_RX_WINDOW_CHECK shall specify the different B_TT_RX_PERIOD it supports.

WST-223: A bridge that implements the B_TT_RX_WINDOW_CHECK shall specify the number B_NUM_TT_RX_PERIOD of different B_TT_RX_PERIOD it can support during operation.

> Note: not all possible values that a bridge can be configured to B_TT_RX_PERIOD may necessarily be able to run concurrently. B_NUM_TT_RX_PERIOD, thus defines the maximum number of different frame periods that a bridge supports during operation.

WST-224: A bridge that implements the B_TT_RX_WINDOW_CHECK may specify a list B_LIST_TT_RX_PERIOD of different B_TT_RX_PERIOD it can support during operation.

WST-225: A bridge that implements the B_TT_RX_WINDOW_CHECK shall support during operation any selection of size B_NUM_TT_RX_PERIOD of the B_TT_RX_PERIOD which the bridge supports, if it does not explicitly specify B_LIST_TT_RX_PERIOD.

4.3 Buffering

WST-226: A bridge shall specify the maximum number SW_MAX_NUM_TT_FLOWS of different time-triggered flows it can buffer at any point in time.

WST-227: A bridge shall specify its maximum buffer size SW_MAX_TT_BUFFER_SIZE for time-triggered flows.

WST-228: A bridge may specify additional constraints on the number and size of time-triggered flows it supports.

> Note: Bridges that do not specify other constraints than maximum number of time-triggered flows and maximum buffer size must support all combinations of frames that meet the number and size constraints. In other words, if a bridge has additional constraints, these

constraints must be made explicit. This is information is required for the scheduling tool in order to compute correct message schedules.

4.4 Forwarding Delay

WST-229: A bridge shall specify the duration B_MAX_FORWARD_DELAY as the maximum time it takes a bridge starting with the complete reception of a TT flow until the TT flow is ready to transmit on any outgoing port of the bridge under the assumption that all outgoing queues are empty and the clocks in the network are perfectly synchronized.

Note: B_MAX_FORWARD_DELAY specifies the maximum implementation specific delay from the reception of a TT flow to the latest possible point in time when the frame will be ready to forward. A scheduler will take the B_MAX_FORWARD_DELAY and the CLOCK_SYNC_PRECISION into account when calculating the B_TT_TX_PHASE of a TT flow.

Note: B_MAX_FORWARD_DELAY is a bridge-internal parameter. B_TT_TX_PHASE , CLOCK_SYNC_PRECISION, and B_TT_TX_MAX_JITTER need also to be taken into account when calculating the complete, externally observable, delay through the bridge.

4.5 Redundancy Management

WST-230: A bridge shall be able to receive up to three redundant copies of the same time-triggered flow and forward only one of these redundant copies.

- Note: A bridge is capable of distinguishing between redundant copies of a single packet associated with a single data flow. Protocols achieving this are for instance PRP/HSR or the upcoming IEEE 802.1CB standard. In parallel, the same mechanism can also be achieved using the mechanisms described in Bridge Reception by explicitly scheduling the arrival times of the different redundant copies to be in the same B_TT_RX_EXPECT_ARR_TIME_INT.

4.6 Dynamic reconfiguration during runtime

SRE-221: A bridge shall support dynamic updates to the following configuration parameters, for each flow:

- B_TT_TX_LENGTH
- B_TT_TX_PERIOD
- B_TT_TX_PHASE
- B_LIST_TT_TX_PERIOD
- B_TT_RX_EXPECT_ARR_TIME_INT

Note: In order to ensure seamless operation of the system, dynamic updates to this parameters should not have an impact to unaffected traffic flows.

SRE-222: A bridge shall support dynamic updates to B_TT_RX_WINDOW_CHECK.

5 Clock Synchronization

WST-401: An end station shall implement the synchronization client functionality as described in the SAE AS6802 standard.

WST-402: An end station should implement the synchronization master functionality as described in the SAE AS6802 standard.

WST-403: An end station may implement the compression master functionality as described in the SAE AS6802 standard.

WST-404: A bridge shall implement the compression master functionality as described in the SAE AS6802 standard.

WST-405: A bridge shall implement the synchronization client functionality as described in the SAE AS6802 standard.

WST-406: A bridge may implement the synchronization master functionality as described in the SAE AS6802 standard.

6 Abbreviation and Glossary

Acronym / Term	Meaning

7 References

- SAE AS6802, published 2011-11-01