



Space engineering

Time-Triggered Ethernet

Foreword

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering, product assurance and sustainability in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards. Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary without rewriting the standards.

This Standard has been prepared by the ECSS-E-ST-50-16C Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

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1

Scope

Using standard communication protocols for spacecraft communication links can provide interface compatibility between communication devices and components. Thus, it can improve the design and development process as well as integration and test activities at all levels and provide the potential of reusability across projects.

The aim of this space engineering standard is to define the interface services and to specify their corresponding network protocol elements for spacecraft using the Time-Triggered Ethernet data network. It also aims at defining requirements for the harmonisation of the physical interfaces and usage of the [IEEE 802.3] and [SAE AS6802] layer features.

This standard may be tailored for the specific characteristic and constraints of a space project in conformance with ECSS-S-ST-00.

Approach

The approach of the ECSS working group for defining this standard aims at identification of layers, services and functions of the typical Time-Triggered Ethernet communication network to ensure the use of the technology for various space projects. The standard aims at:

- Identifying Reference Architectures (Layers, Services, Functions and Elements of protocol) of typical Time-Triggered Ethernet communication network;
- Characterizing Services, Functions and Elements of Protocol of each Layer within identified Reference Architectures, using concrete project specifications;
- Define normative requirements rather than recommendations.

As far as possible, the defined communication requirements are extracted from the experience on existing spacecraft specifications.

2

Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revision of any of these publications do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

ECSS-S-ST-00-01	ECSS System - Glossary of terms
ARINC 664 part 7, 23 September 2009	Aircraft Data Network Part 2: Avionic Full-Duplex Switched Ethernet Network
IEEE 802.3, 28 December 2012	Ethernet Standard
SAE AS6802, November 2011	Time-Triggered Ethernet
RFC 768, 28 August 1980	User Datagram Protocol (UDP)
RFC 791, September 1981	Internet Protocol (IP)
RFC 792, September 1981	Internet Control Message Protocol (ICMP)
RFC 1157, May 1990	A simple network management protocol (for SNMPv1)
RFC 1350, July 1992	The TFTP Protocol (Revision 2)

3

Terms, definitions and abbreviated terms

3.1 Terms from other standards

For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply.

3.2 Terms specific to the present standard

3.2.1 acceptance window

timing interval in which the reception of the frame associated with a VL ID is expected

3.2.2 bandwidth allocation gap

minimum delay between two consecutive Rate-Constrained frames belonging to the same sending interval

[ARINC 664 part 7]

3.2.3 Best-Effort traffic

standard Ethernet frame which is neither **critical traffic** nor flow controlled traffic

NOTE A Best-Effort frame or traffic as specified by the standard [IEEE 802.3].

3.2.4 broadcast

transmission of an Ethernet frame from one sender to all receivers

3.2.5 cluster

Ethernet network composed of nodes synchronized to each other by the Time-Triggered Ethernet protocol

3.2.6 compression master

role of an element of the cluster that collects protocol control frames (PCFs) from the synchronization masters and uses them in a timing algorithm (compression) before sending them back to the configured synchronization masters and synchronization clients, to be used for synchronization purposes

3.2.7 critical traffic

flow of critical traffic frames, where each frame has the most significant 32 bits set to the critical traffic marker

NOTE Critical Traffic Marker is the value of the most significant 32 bits of the MAC Destination Address that identifies a frame as Critical Traffic.

3.2.8 device

element of an Ethernet network or an element connected to an Ethernet node

NOTE A device can be either a Switch or an **End-System** or a host computer. A device does not necessarily support RC or TT or BE traffic.

3.2.9 End-System

network component which provides the host device an interface to the network

NOTE Each host device uses an End-System interface to guarantee a secure and reliable data interchange with other host device.

3.2.10 flow controlled traffic

sequence of Ethernet packets from one sender to one or multiple receivers

NOTE A Flow controlled traffic as specified by [RFC 3697].

3.2.11 frame

part of a packet

NOTE 1 The following frame types are used throughout this document:

- Best-Effort frame: Basic Frame
- Critical Traffic frame: Rate-Constrained (RC) frame; Protocol Control Frame (is a RC frame); Time-Triggered (TT) frame

NOTE 2 Example of a packet is shown in Figure 3-1.

3.2.12 globally administered MAC

unique MAC address assigned to the network interface card by the manufacturer

3.2.13 link

physical connections between nodes in a network providing the means for transferring frames between them

3.2.14 locally administered MAC

unique MAC address assigned to the network interface card locally

3.2.15 multicast

transmission of an Ethernet frame from one sender to multiple receivers

3.2.16 node

element of an Ethernet network

NOTE A node can be either a Switch or an End-System. A node does not necessarily support RC and TT traffic but at least BE.

3.2.17 packet

complete Ethernet message including the header information consisting of the preamble and the start of frame delimiter

NOTE The Ethernet packet is specified in, 1000Base-X PCS, [IEEE 802.3] Clause 36 [2], section 1/section 3 "Media Access Control (MAC) frame and packet specifications". The structure is shown in Figure 3-1.

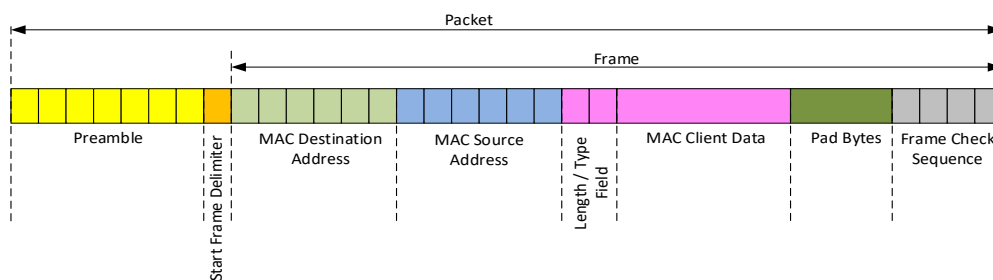


Figure 3-1: Structure of a Packet

3.2.18 protocol control frame

standard Ethernet frame whose Ethernet type field is set to 0x891D, which is used by the synchronization protocol [SAE AS6802]

3.2.19 raster granularity

timeline on which scheduling events are placed

3.2.20 Rate-Constrained

guaranteed bandwidth traffic as specified by the standard [ARINC 664 part 7]

3.2.21 schedule table

time schedule of transmission and reception events for critical traffic.

3.2.22 Switch

hardware device that connects multiple End-Systems or Switches to one network

NOTE A Switch works on Layer 2 of the Ethernet specification and has two different ways of packet switching between the different devices connected to its Ethernet ports which are static and dynamic switching. The static packet switching works according to a defined static switching table. Dynamic switching describes an automated forward path for a given MAC destination address based on the current network architecture.

3.2.23 synchronization client

role of an element of the cluster that consumes protocol control frames (PCFs) received from compression masters for synchronization purpose, without actively participating in the network synchronization process

3.2.24 synchronization master

role of an element of the cluster that generates protocol control frames (PCFs), transmits them to the compression masters, and consumes PCFs received from compression masters for synchronization purpose, actively participating in the network synchronization process

3.2.25 synchronization precision

worst-case Local Clocks offset between any two correctly synchronised End-Systems or Switches in the system

NOTE The calculation is given in [SAE AS6802] paragraph 3.2.

3.2.26 Time-Triggered frame

Critical Traffic (CT) frame which is sent over the network at predefined times and take precedence over all other frames types, except for Protocol Control Frames

3.2.27 unicast

transmission of an Ethernet frame from one sender to one receiver

3.2.28 virtual link

logical unidirectional connection path between one node towards one or more nodes

[ARINC 664 part 7]

3.2.29 virtual link identifier

least significant 16 bits of the MAC Destination Address of a Critical Traffic Frame

NOTE Per definition of the standard [ARINC 664 part 7], the VL ID uniquely identifies a multicast group with a dedicated sender of the message and a set of receivers.

3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms and symbols from ECSS-S-ST-00-01 and the following apply:

Abbreviation	Meaning
API	Application Programming Interface
ARINC	Aeronautical Radio Incorporated
BAG	Bandwidth Allocation Gap
BE	Best-Effort
CD	Collision Detection
CM	Compression Master
CRC	Cyclic redundancy check
CSMA	Carrier Sense Multiple Access
CT	Critical traffic
DLL	Data Link Layer
ECSS	European Cooperation for Space Standardization
EMC	Electromagnetic compatibility
ES	End-System
ESCC	European Space Components Coordination
FCS	Frame check sequence
FDIR	failure detection, isolation and recovery
FT	Fault Tolerant
Gbps	Giga bit per second
GMII	Gigabit media independent interface
GND	Ground
H/W	Hardware
IC	Integrity Checking
ICMP	Internet Control Message Protocol
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
IFG	Inter frame gap
IHL	Internet Header Length
IP	Internet protocol
IP	Intellectual Property
ISO	International Standard Organisation
LAN	Local Area Network
LLC	Logic Link Control
LVDS	Low Voltage Differential Signalling

Abbreviation	Meaning
MAC	Media access control
Mbps	Mega bit per second
MIB	Management Information Base
MII	Media independent interface
OSI	Open system interconnection
PCB	Printed circuit board
PCF	Protocol Control Frame
PCS	Physical Coding Sub-layer
PHY	Physical Layer
PLS	Physical Coding Sublayer
PMA	Physical Medium Attachment sub-layer
PMD	Physical Medium Dependent sub-layer
QoS	Quality of service
RC	Rate-Constrained
RM	Redundancy Management
SAE	Society of Automotive Engineers
SC	Synchronization Client
SFD	Start Frame Delimiter
SM	Synchronization Master
SN	Sequence number
SNMP	Simple Network Management Protocol
SW	Switch
TFTP	Trivial File Transfer Protocol
TT	Time-Triggered
TTE	Time-Triggered Ethernet
UDP	User Datagram Protocol
VL	Virtual Link
VL-ID	Virtual Link Identifier

3.4 Nomenclature

The following nomenclature applies throughout this document:

- The word “shall” is used in this Standard to express requirements. All the requirements are expressed with the word “shall”.
- The word “should” is used in this Standard to express recommendations. All the recommendations are expressed with the word “should”.

NOTE It is expected that, during tailoring, recommendations in this document are either converted into requirements or tailored out.

The words “may” and “need not” are used in this Standard to express positive and negative permissions, respectively. All the positive permissions are expressed with the word “may”. All the negative permissions are expressed with the words “need not”.

The word “can” is used in this Standard to express capabilities or possibilities, and therefore, if not accompanied by one of the previous words, it implies descriptive text.

NOTE In ECSS “may” and “can” have completely different meanings: “may” is normative (permission), and “can” is descriptive.

The present and past tenses are used in this Standard to express statements of fact, and therefore they imply descriptive text.

4 Overview

4.1 Reference Model

This Clause provides an overview of the Time-Triggered Ethernet Standard for the use of deterministic Ethernet in space applications. It covers the most important OSI model layers applicable for space applications and extensions providing useful features to the space community.

Time-Triggered Ethernet takes into consideration the [IEEE 802.3], as well as the [ARINC 664 part 7] and is specified in the Time-Triggered Ethernet Standard [SAE AS6802].

[SAE AS6802] Time-Triggered Ethernet standard is a Layer 2 Quality-of-Service (QoS) enhancement that defines Time-Triggered services for Ethernet networks. Time-Triggered Ethernet is designed for the development of highly dependable systems for applications in multiple industries, including integrated systems in aerospace, ground vehicles and industrial process control. It provides the capability for deterministic, synchronous, and congestion-free communication among distributed applications, unaffected by any asynchronous Ethernet traffic load. [SAE AS6802] is fully compatible with lower (1-2) and higher OSI layers (3-7) and is transparent to applications designed to use asynchronous Ethernet (Figure 4-1)

Time-Triggered Ethernet is a full-duplex, bidirectional, point-to-point data link. It encodes data according to [IEEE 802.3] with 10/100/1000Mbps speeds. It further encompasses different media types as copper and fibre.

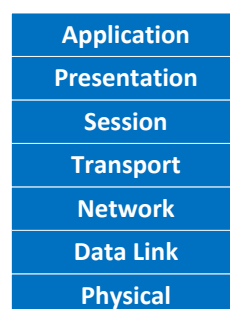


Figure 4-1: OSI Reference Model

4.2 Physical Layer

The physical level provides the actual interface between the network components including both the mechanical and electrical interface. This Clause covers:

- cable construction,
- connectors,
- cable assemblies, and
- PCB and backplane tracking.

Ethernet was developed to meet the EMC specifications of high reliable applications cross industry. However, since there are lots of space applications where power consumption is a key requirement, in some cases, the use of LVDS as physical layer provides advantages over the typical Ethernet physical layer. Since Ethernet specifies also the interface to the Ethernet physical layer transceiver, the media independent interface (MII), this interface can be used with LVDS transceivers to provide a solution for short distances with already available physical layer building block. As illustrated in Figure 4-2, Ethernet specifies the following three different functional layers within the physical layer:

- PCS (Physical Coding Sub-layer),
- PMA (Physical Medium Attachment sub-layer), and
- PMD (Physical Medium Dependent sub-layer)

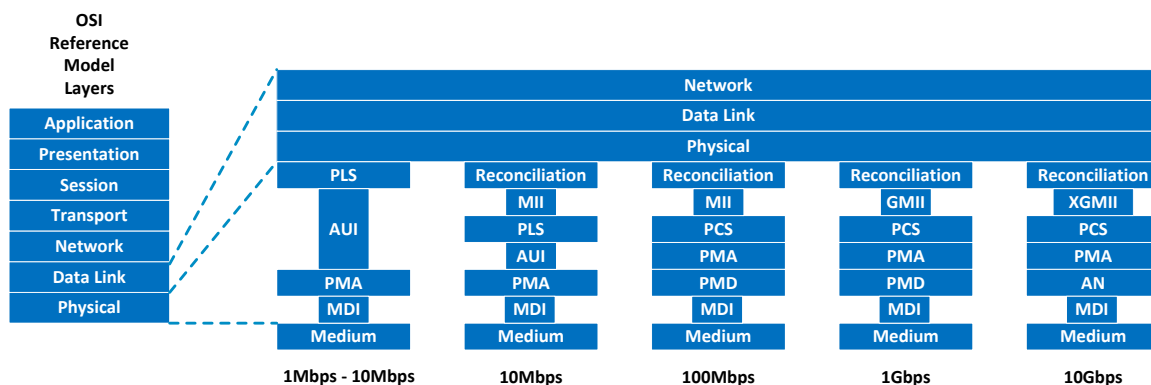


Figure 4-2: Physical Layer Model

4.3 Data Link Layer

4.3.1 Data Link Layer Overview

In a Local Area Network (LAN), the Data Link Layer consists of the Media Access Control (MAC) and the Logic Link Control (LLC) Sublayers as illustrated in Figure 4-3.

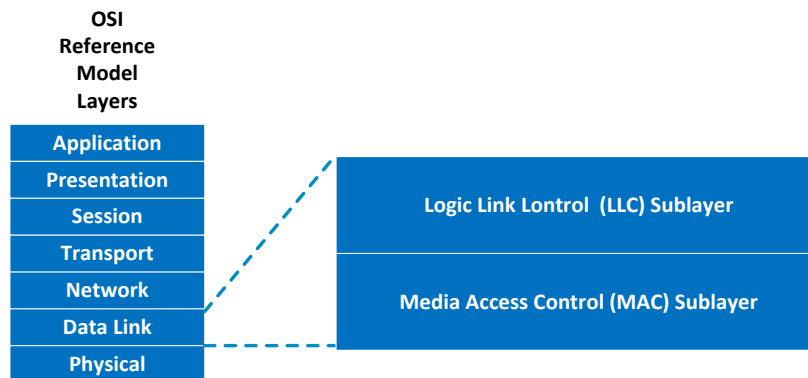


Figure 4-3: Data Link Layer

4.3.2 Data Link Layer Functionalities

The MAC sublayer defines a medium-independent facility, built on the medium-dependent physical facility provided by the Physical Layer, and under the access-layer-independent LAN LLC sublayer (or other MAC client). It is applicable to a general class of local area broadcast media suitable for use with the media access disciplines known as Time-Triggered Ethernet and Carrier Sense Multiple Access with Collision Detection (CSMA/CD).

The LLC sublayer and the MAC sublayer together are intended to have the same function as that described in the OSI model for the Data Link Layer alone. In a broadcast network, the notion of a data link between two network entities does not correspond directly to a distinct physical connection. Nevertheless, the partitioning of functions requires three main functions generally associated with a data link control procedure to be performed in the MAC sublayer. They are as follows:

- Data encapsulation (transmit and receive):
- Framing (frame boundary delimitation, frame synchronization)
- Addressing (handling of source and destination addresses)
- Virtual Link handling
- Error detection (detection of physical medium transmission errors)
- Media Access Management
- Medium allocation (collision avoidance)
- Contention resolution (collision handling)
- Network Synchronization
- Start-Up Service
- Restart Services
- Fault-Tolerant Clock Synchronization Service

The Media Access Management is not covered to a very large extent since this can be implemented as defined in the [IEEE 802.3]. For Time-Triggered traffic this is handled via the configurations of the devices in the network according to the global schedule created by the configuration tools. Also for Rate-Constrained traffic the flow-control of [IEEE 802.3] according to [ARINC 664 part 7] has to be disabled.

4.3.3 Time-Triggered Ethernet

Time-Triggered Ethernet specifies Time-Triggered services that are added to the standards for Ethernet established in [IEEE 802.3]. Figure 4-4 shows a parallel view of the Time-Triggered services and the common Open Systems Interconnection OSI model layers. A communication controller that implements the Time-Triggered services can synchronize its local clock with the local clocks of other communication controllers and Switches in the system. A system designer can define an offline schedule of frame transmission with respect to the synchronized time, and the Time-Triggered Ethernet devices can then dispatch frames according to this schedule. Such a transfer of a frame according to a synchronized time is called a “Time-Triggered transfer”. Offline scheduling tools can be used to guarantee that Time-Triggered transfers are conflict-free (i.e., no two Time-Triggered frames compete for transmission). Time-triggered communication is not priority-based and is driven only by time progression and frame schedule. This prevents network traffic congestion for Time-Triggered frames and enables communication with fixed latency in Ethernet networks, unaffected by any asynchronous Ethernet traffic load.

In addition to the Time-Triggered transfer service, a synchronized global time is used to specify temporal characteristics for intervals in which non-Time-Triggered communication can occur. This allows Time-Triggered Ethernet device implementations to support communication among applications with different real-time requirements over a single physical network. For example, in a particular Time-Triggered Ethernet system, there can be three different traffic classes (see Figure 4-4):

- Time-Triggered TT [SAE AS6802],
- Rate-Constrained RC [ARINC 664 part 7], and
- Best-Effort BE [IEEE 802.3].

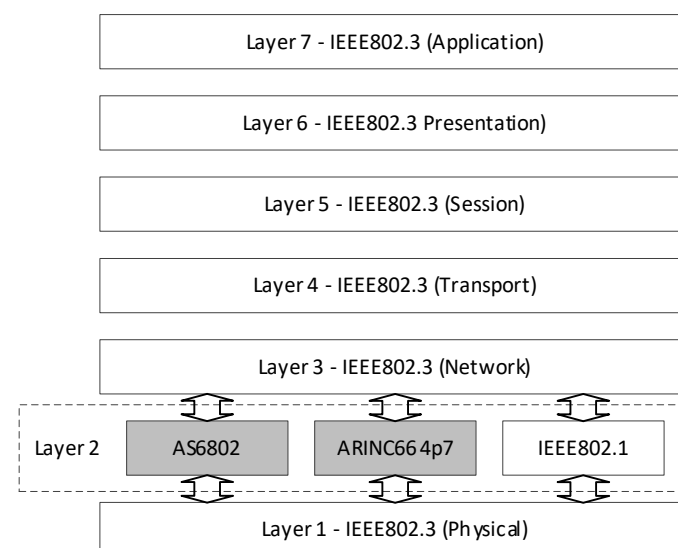


Figure 4-4: Time-Triggered Ethernet Services

Time-Triggered transfers (TT) best suit communications distributed in real-time systems. Tight latency, jitter, and determinism requirements can necessitate the use of TT transfers. All TT transfers are dispatched at predefined

times. In cases where an End-System decides not to use its assigned time slot (e.g., if there is no new data to send), the Switch recognizes the inactivity of the sender by not receiving the TT frame within the acceptance window and frees the bandwidth for the other traffic classes immediately afterwards.

Rate-Constrained transfers (RC) define the maximum allowed bandwidth use for a dedicated message to ensure bounded latency in complex networks. Successive transfers of RC frames belonging to the same Rate-Constrained dataflow are guaranteed to be offset by a minimum duration as specified offline. This is in contrast to TT communication, which in addition to the minimum duration also specifies a maximum duration for this interval. The RC communications paradigm is specified in the standard [ARINC 664 part 7]. A system designer can decide to use RC transfers when determinism and real-time operating requirements are less strict than those that drive the use of TT communication. RC transfers guarantee sufficient bandwidth allocation for each transmission, with defined limits for delays and temporal deviations. In contrast to TT transfers, RC transfers are not dispatched with respect to a system-wide synchronized time base. Hence, different communication controllers can dispatch RC-transferred frames at the same point in time. Consequently, the RC transferred frames can queue up in the network Switches, leading to increased transmission jitter and requiring increased buffer space. Given the known transmission rate of the RC transfers and the network Switch controls, it is possible to avoid frame loss by calculating the transmission latency offline.

Best-Effort transfers (BE) implement the classic Ethernet approach. There is no guarantee if and when these frames are transmitted, what delays can occur, or if BE-transferred frames arrive at the recipient location. BE transfers use the remaining bandwidth of the network and has a lower Quality of Service compared to TT and RC transfers.

TT services are concerned with configured frame transmission timing, not with the content of frames: as shown in Figure 4-4, frames from higher-layer protocols, such as IP or UDP, can easily become TT transfers without modification of the frames' content. TT services are concerned with configured frame transmission timing, not with the content of frames.

Other QoS protocols can be added to the Switch functionality and executed in a portion of bandwidth not used by TT transferred frames. Time-Triggered Ethernet Switch implementations contain in a minimum configuration the support for synchronous TT.

As depicted in Figure 4-5, the available bandwidth is shared by different QoS services due to robust bandwidth partitioning.

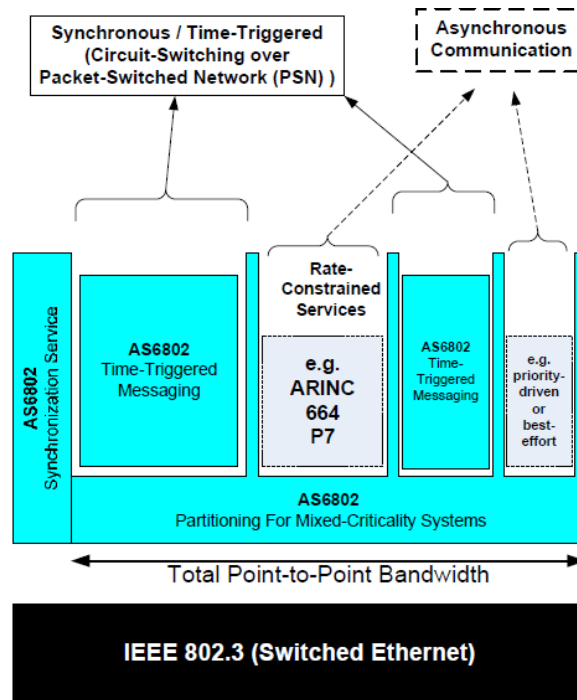


Figure 4-5: Traffic Partitioning

4.4 Network Level

4.4.1 Network Level Overview

A Time-Triggered Ethernet network is a Switch Ethernet based network - star topology - composed of End-Systems, Switches and links. End-Systems are the sources and destinations of the Ethernet packets and the Switch routes the packets according to a pre-established TTE configuration.

As an example, an on-board avionics computer composed of a micro-processor with a TTE communication controller interface is an End-System, the physical connections between the End-Systems are the links and the Switches provide the means for passing frames between the End-Systems. The links are connected to the communication ports of the End-Systems and Switches.

Figure 4-6 illustrates a basic switched communication network composed of two End-Systems and one Switch. The End-Systems have one full duplex communication port which is connected via a link to a communication port of the Switch. Depending on the fault tolerance needed, an End-System supports a given number of ports (up to three for dual fault-tolerance). The Switch in the example represented below has two communication ports.

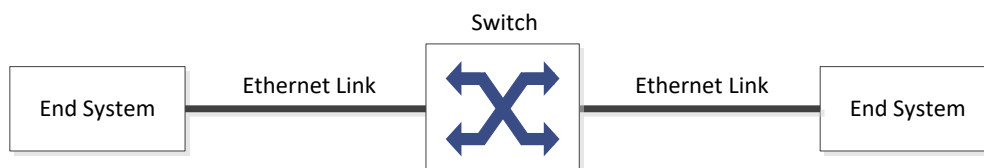


Figure 4-6: Network Communication Channel

An example network comprising several End-Systems and Switches is illustrated in Figure 4-6. Switches are connecting multiple End-Systems with each other and provide a means of switching packets from one End-System to one of many other possible End-Systems. Switches can also be cascaded to a larger network allowing the connection of much more End-Systems.

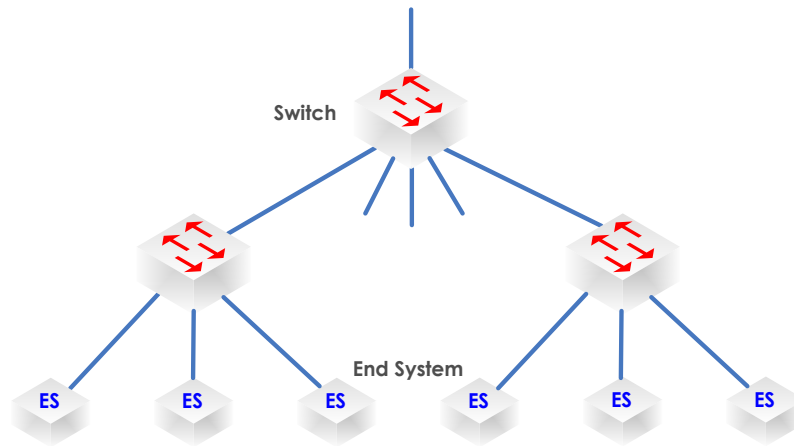


Figure 4-7: A TTE example network

Packets can be transferred from one End-System to another through one or more Switches. The frames exchanged by the End-Systems and forwarded by the Switches are fully compliant to the [IEEE 802.3] frame layout.

An example network comprising several End-Systems and Switches is illustrated in Figure 4-7. This figure is for illustrative purposes and does not show a practical network. Packets can be transferred from one End-System to another through one or more Switches.

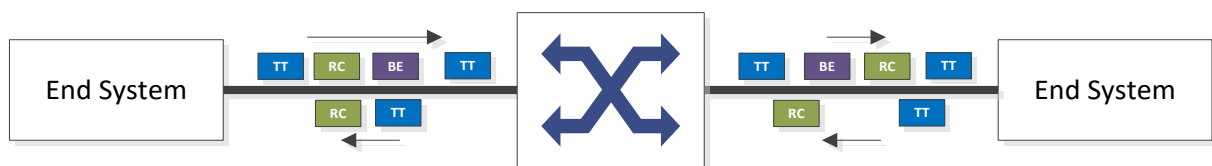


Figure 4-8: Full Duplex Links

In switched Time-Triggered Ethernet the links are full duplex which means that sending and receiving of all traffic classes (TT, RC and BE) is possible at the same time as illustrated in Figure 4-8.

The frames exchanged by the End-Systems and forwarded by the Switches are fully compliant to the [IEEE 802.3] frame layout as defined in Figure 4-4.

4.4.2 Message Processing at the Switch

TTEthernet uses store and forward switching which means that the messages are fully received by the Switch and are then be checked for consistency, timing, frame layout, CRC, ... until they are placed into the dedicated output queue.

A message conflict (whatever nature) can cause a delay of a message transmission until the transmission resource (port/link) becomes free. The pending messages are buffered, and their transmission is deferred. A message delay has different impacts on different traffic classes:

- Best-Effort (BE): does not have any timing guarantees
- Rate-Constrained: Introduce a jitter
- Time-Triggered: delays a frame, frame can be received outside the receive window

Possible scenarios are:

- Simultaneous TT-TT message conflict
 - Correct configuration schedules ensure that such message conflicts do not exist.
- Simultaneous RC-RC message conflict
 - Priority mechanisms resolve the conflict.
 - Among the same priority: internal priority level based on source port number.
- Simultaneous TT-RC message conflict
 - Priority mechanisms resolve the conflict.
- Simultaneous TT-BE or RC-BE message conflict
 - TT or RC over Best-Effort

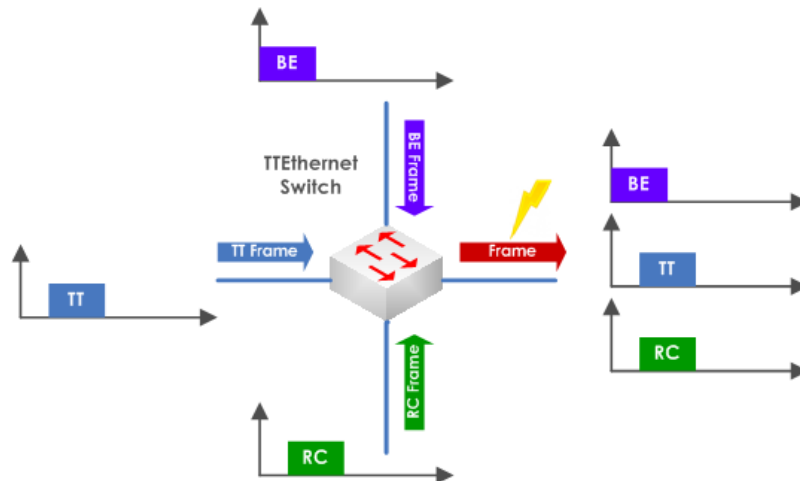


Figure 4-9: Message Processing at the Switch

In case an Ethernet frame is processed on the dedicated Switch port and a Time-Triggered send windows is dispatched as illustrated in Figure 4-9 there has to be a defined strategy for processing these two frames using the shared physical media.

The three different possible mechanisms are described below:

- Preemption
- Shuffling
- Media Reservation

Preemption

Preemption is one of the above-mentioned mechanisms to allow high-priority frames to preempt low-priority frames in order to reduce the delay of a message transmission (see Figure 4-10). These delays introduce a jitter at runtime, which can negatively affect the system behaviour. The resulting jitter value caused by lower priority frames is always have to be considered in the scheduling algorithm and system design.

If a Time-Triggered Ethernet device is busy with the transmission of an outgoing dataflow with a low-priority frame (Best-Effort frame), it can be necessary to abort the transmission of this low-priority frame. A key characteristic of the preemption policy is that aborted transmissions are discarded. The Switch abort the transmission of the low-priority frame and mark it as invalid that the receiver discards the frame after receiving.

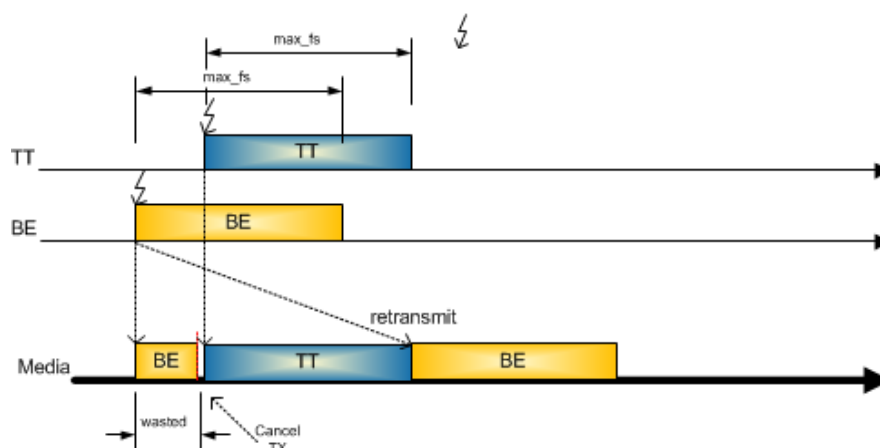


Figure 4-10: Preemption

Shuffling

The shuffling mechanism allows Best-Effort and Rate-Constrained frames passing the Switch also in case a Time-Triggered frame is scheduled (see Figure 4-11). In such a scenario the Time-Triggered frame can be delayed by a maximum Ethernet frame or rate constrained frame (1518 bytes @ 100 Mbps 124 μ s). This known delay adds to the jitter and is considered in the scheduling steps of the configuration tool. The latency of a Time-Triggered frame can get increased because of the shuffling mechanism, but the jitter gets bounded and is not accumulate over multiple Switches. The Switch where shuffling occurs then forwards the Time-Triggered frame to the next Switch where the Time-Triggered frame is sent according to the sending window of this frame. Therefore, the dynamic delay value of this Time-Triggered frame does not accumulate over multiple Switches. Due to known delay values on the physical link the shuffling method allows to properly schedule Time-Triggered frames and allocate bandwidth for Rate-Constrained frames beforehand. As a result, this ensures all traffic classes can coexist in a network but reduces the available bandwidth for Time-Triggered traffic.

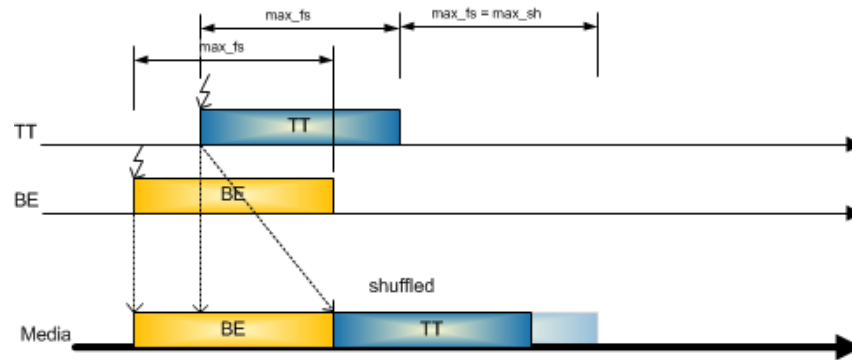


Figure 4-11: Shuffling

Media Reservation

Media reservation reserves a window of a maximum Ethernet frame (configurable) before a Time-Triggered frame is sent (see Figure 4-12). This mechanism does not allow frames with a lower priority to delay higher priority frames. Since the schedule point in time of the Time-Triggered frame is well known reserving a window in front of these frames is a matter of free scheduling resources which means that all media reservation windows need to have configured scheduling points. Depending on the used frame sizes this method can guarantee short latencies for Time-Triggered traffic but with implications to Best-Effort and Rate-Constrained traffic. By increasing the bandwidth utilization together with media reservation, the likelihood of losing low-priority frames gets increased.

Media reservation completely prevents the sending of low-priority frames delaying the scheduled Time-Triggered frame, but at the expense of bandwidth. The mechanism can be used to send scheduled Time-Triggered frames in a row, without lower-priority traffic interference.

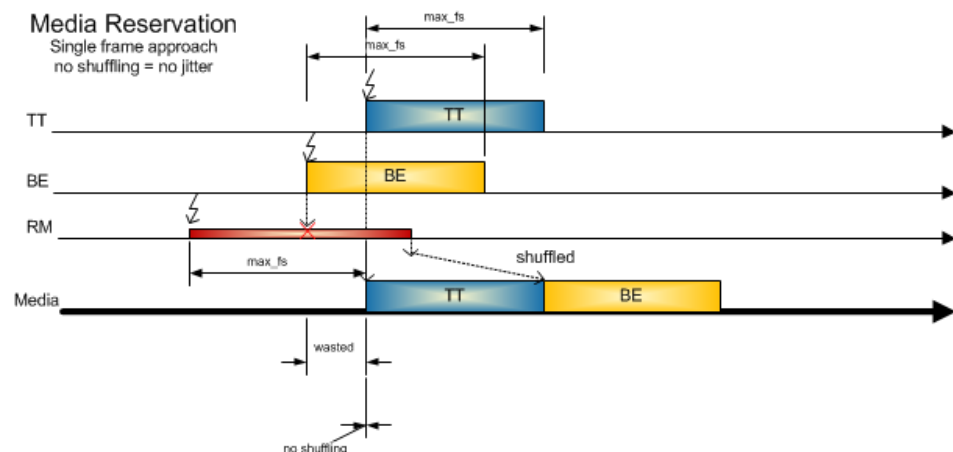


Figure 4-12: Media Reservation

In a summary, preemption is a mechanism that allows high-priority frames to preempt low-priority frames to reduce jitter of high-priority frames during runtime. A low priority preempt frame gets discarded by the receiver. Shuffling adds a bounded jitter to high-priority frames and is included in the scheduler algorithm, because of a maximum sized low-priority frames. The bounded jitter

is known and does not accumulate over multiple Switches. Media reservation is a mechanism to prevent low-priority frames delaying high-priority frames by reserving bandwidth just before scheduling windows of high-priority frames. This allows to send high-priority frames in a row without a low-priority frame interference.

4.4.3 Time-Triggered Ethernet Network Building Blocks

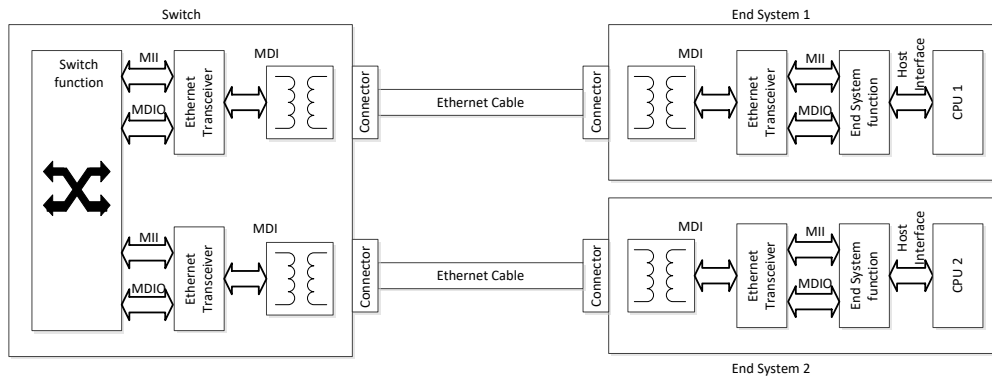


Figure 4-13: Network Building Blocks

A more detailed picture of the building blocks of a Time-Triggered Ethernet network is illustrated in Figure 4-13. The building blocks covered within this standard are:

- Switch consisting of:
 - Switch function (digital part)
 - Ethernet transceiver (mixed signal part)
 - Connectors
- End-System consisting of:
 - End-System function (digital part)
 - Ethernet Transceiver (mixed signal part)
 - Connectors
- Cabling/Harness:

As an example, a few pictures of the building blocks of a Time-Triggered Ethernet network is shown in Figure 4-14.

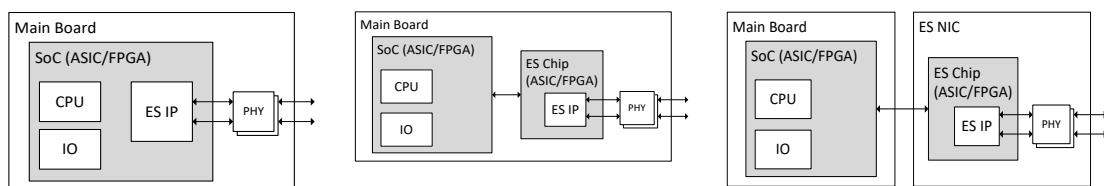


Figure 4-14: Network Building Blocks Examples

4.4.4 Virtual Link

The concept of virtual links is used for critical traffic which means Time-Triggered and Rate-Constrained.

A Virtual Link (VL) provides the possibility to partition one physical link into multiple virtual links providing some additional quality of service to standard Ethernet [IEEE 802.3] as defined in [ARINC 664 part 7]. Each transmit VL can only be assigned to 1 End-System (ES), and an End-System is only allowed to transmit on assigned VLs.

The same receive VLs, however, can be assigned to several ESs meaning that these can be eavesdropping on the same data.

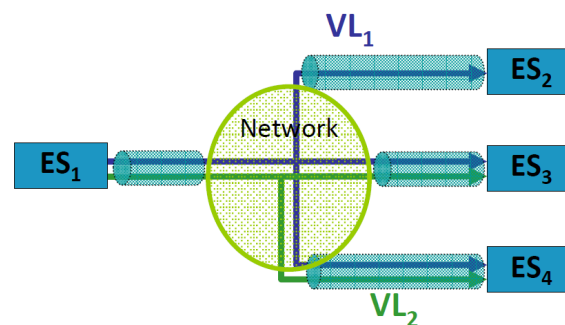


Figure 4-15: Virtual Link

A Virtual Link is a conceptual communication object, which has the following properties:

- A Virtual Link defines a logical unidirectional connection from one source End-System to one (unicast) or more (multicast) destination End-Systems, shown in Figure 4-15.
- Each Virtual Link has a dedicated maximum bandwidth. This bandwidth is allocated by the System Integrator by using the configuration tools.

The End-System should provide logical isolation with respect to available bandwidth among the Virtual Link(s) it supports. Regardless of the attempted utilization of a VL by an application, the available Bandwidth on any other VL is unaffected.

For each Virtual Link, the End-System should maintain the ordering of data as delivered by an application, for both transmission and reception (ordinal integrity).

The End-System communication stack should guarantee in transmission the allocated bandwidth of each Virtual Link regardless of the attempted use of Bandwidth by other Virtual Links, in order to preserve segregation between partitions at the network level.

Virtual Links are used for the Critical Traffic, which means Time-Triggered and Rate Constraint (this means also for PCFs).

4.4.5 Time-Triggered Traffic Policing

Time-Triggered traffic requires to schedule all messages in the network. These messages are defined off-line with a corresponding tool which assigns a transmitting period at the End-System and an Acceptance Window at the Switch to guarantee a well-defined latency and minimal jitter in the system.

At the output of the End-System, the flow of frames associated with a particular Virtual Link is characterized by the transmitting period.

The Switch checks for all incoming frames the acceptance window associated with a particular Virtual Link. A Switch forwards all received frames based on a per-port forwarding schedule to ensure at the receiving End-System and well defined latency and minimal jitter.

4.4.6 Rate-Constrained Traffic Policing

Rate-Constrained traffic works with bandwidth reservation for defined messages. These messages are defined off-line with a corresponding tool which assigns a bandwidth allocation gap (BAG) and a jitter for each of them.

At the output of the End-System, the flow of frames associated with a particular Virtual Link is characterized by the following two parameters:

- Bandwidth Allocation Gap (BAG) and
- Jitter.

If the frames experienced no jitter from the scheduler, the BAG represents the minimum time interval between the first bits of two consecutive frames from the same VL, as illustrated in Figure 4-16.

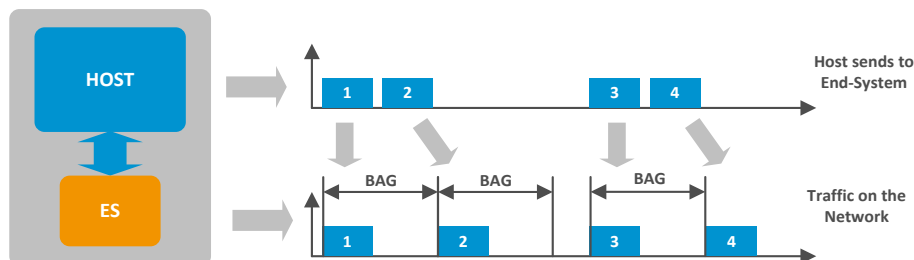


Figure 4-16: Bandwidth Reservation

Each frame has to wait until the dedicated BAG has been reached until it can be sent.

If the frames experience jitter from the scheduler, the jitter parameter is used to ensure the passing of the frames through the network. A description of this mechanism is given in [ARINC 664 part 7] § 4.1.1.3.

4.4.7 Clock Synchronization

Time-Triggered Ethernet is an extension of the traditional Ethernet standard, with additional services that guarantee reliable, deterministic delivery of time-critical messages.

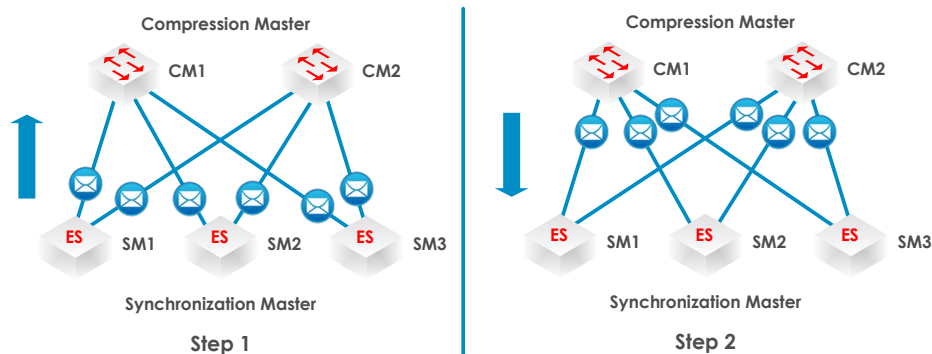


Figure 4-17: Time-Triggered Ethernet two step clock synchronization algorithm

End-System and Switches define physical components in the Time-Triggered Ethernet network and for the clock synchronization algorithm of Time-Triggered Ethernet three different roles are defined:

- Synchronization Master (SM),
- Compression Master (CM), and the
- Synchronization Client (SC).

For simplicity we assume a network consisting of three End-Systems, two Switches and two redundant channels, as shown in Figure 4-17. Furthermore, End-Systems implement the SM role and the CMs are realized in the Switches. SCs are only passively synchronizing to the time base as maintained by the SMs and CMs. In the clock synchronization algorithm SMs and CMs inform each other about their current state of their local clock by exchanging Protocol Control Frames (PCF).

In Time-Triggered Ethernet the clocks are synchronized in two steps. In the first step, the SMs send PCFs to the CMs. The CMs extract from the arrival points in time of the PCFs the current state of their local clocks and execute a first convergence function, the so-called compression function. The result of the convergence function is then delivered to the SMs in form of new PCFs (the compressed PCFs). In the second step the SMs collect the compressed PCFs from the CMs and execute a second convergence function.

Time-Triggered Ethernet requires an inconsistent-omission failure model for the CMs. This means that a faulty CM is able to arbitrarily accept and reject PCFs from the SMs and can also decide to which SMs it sends the compressed PCF and to which not. Babbling idiot failures of the CM are excluded by the design of the CM as self-checking pair and a CM cannot fail arbitrarily. The SMs, on the other hand, can fail arbitrarily, and in particular, they can start to babble PCFs. The CMs implement a central guardian functionality that ensures that only one PCF per SM is used per resynchronization cycle. Though, in the worst case, we assume that the clock value provided by a faulty SM can be arbitrary.

First Step Convergence: Compression Master (CM)

The CMs collect the current states of the local clocks of the SMs. At the beginning of each convergence function the CM checks whether the number of bits set in the *pcf_membership_new* fields of unsynchronized PCF frames is above a configurable acceptance threshold. We denote these values by *SM_clock_i*, where $1 \leq i \leq |\mathbf{SM}|$ and assume that the *SM_clock_i* values are sorted in increasing order. To minimize the impact of the faulty SMs Time-Triggered Ethernet uses a variant of the fault-tolerant median to calculate the new "compressed" clock. Following rules define the compressed clock depending on the number of SM clock values received.

- One SM clock: $compressed_clock = SM_clock_1$
- Two SM clocks: $compressed_clock = \frac{SM_clock_1 + SM_clock_2}{2}$
- Three SM clocks: $compressed_clock = SM_clock_2$
- Four SM clocks: $compressed_clock = \frac{SM_clock_2 + SM_clock_3}{2}$
- Five SM clocks: $compressed_clock = SM_clock_3$
- More than five SM clocks: average of the $(k + 1)^{th}$ largest and the $(k + 1)^{th}$ smallest clocks, where k is the number of faulty SMs to be tolerated.

The compressed clock is delivered back to the SMs in a new "compressed" PCF and the SMs are able to read the compressed clock value from the arrival point in time of the compressed PCF. In addition to the compressed clock value, the CMs also generate a membership vector *pcf_membership_new*. Each position in this vector is assigned to one and only one SM. The CMs set the bit of a SM, if the respective SM_{*i*} has provided a local clock value *SM_clock_i* and clear the bit otherwise. The CMs transmit the *pcf_membership_new* vector in the payload of the compressed PCF. The self-checking pair design of the CM guarantees that the compressed clock and the *pcf_membership_new* vector are consistent. Hence, the design prevents a faulty CM to set an arbitrary number of bits in *pcf_membership_new*.

Second Step Convergence: Synchronization Master (SM)

In the second step of the clock synchronization algorithm, the SMs receive the compressed PCFs, extract the compressed clock values from them, and correct their local clocks. In the fault-free case each SM receives exactly one compressed PCF per CM from which it extracts the compressed clock values *CM_clock_j*, where $1 \leq j \leq |\mathbf{SM}|$ and we assume the *CM_clock_j* values sorted in increasing order. Under the assumption of one CM per channel and up to three channels maximum, the convergence function has to cover following three cases:

- One CM clock: $SM_clock = CM_clock_1$
- Two CM clocks: $SM_clock = \frac{CM_clock_1 + CM_clock_2}{2}$
- Three CM clocks: $SM_clock = CM_clock_2$

In the case of a faulty CM, a SM can receive at maximum one compressed PCF per CM (as the faulty CM can decide not to send its compressed PCF to some SMs). Furthermore, a SM only uses a compressed PCF in the convergence

function as described above if the *pcf_membership_new* field has at least accept threshold of bits set. Accept threshold is calculated as follows:

- Current max = maximum of bits set in the *pcf_membership_new* field of any compressed PCF
- Accept threshold = current max minus the allowed number of faulty SMs

The SM discards a compressed PCF that has less than accept threshold bits set in the *pcf_membership_new* field. This mechanism ensures that a SM excludes compressed PCFs that represent relative low numbers of SM clocks.

The *pcf_membership_new* vector is also used in other Time-Triggered Ethernet algorithms such as clique detection or start-up as well as in network configurations that use more than one CM per channel. For the analysis of the clock synchronization algorithm the description above is sufficient.

Unsynchronized Operation (Start-Up or Re-Start)

During unsynchronized operation, as for example during a coldstart or restart of the TTEthernet network, the Synchronization Masters transmit dedicated Protocol Control Frames, that are coldstart and coldstart acknowledge frames. The Compression Masters collect the coldstart and coldstart acknowledge frames and decide based on this input and their current state in the Compression Master protocol state machine whether to send coldstart or coldstart acknowledge frames themselves back to the Synchronization Masters and Synchronization Clients.

The Compression Master can be configured in two ways depending on whether the Synchronization Masters in a system are configured as high-integrity devices or not. When the Synchronization Masters are designed as high-integrity devices the Synchronization Master failure mode is restricted. TTEthernet allows then to tolerate a faulty Synchronization Master and a concurrent fault of a Compression Master at the same point in time. When the Synchronization Masters are designed as standard-integrity devices, the Synchronization Masters can fail in an arbitrary failure mode. In this case (standard integrity) TTEthernet tolerates either the failure of Synchronization Masters or the failure of Compression Masters, but not both at the same point in time.

A CM during start-up sequence with standard integrity synchronization masters dispatch coldstart frames when the compression master is in an unsynchronized state, and blocks coldstart frames in all other states.

A CM during start-up sequence with high-integrity synchronization masters, dispatch:

- All coldstart frames, only when the compression master is either in CM_UNSYNC state, CM_Wait_4_Cycle_Start, or CM_TENTATIVE_SYNC state and it discards coldstart frames received in other states as specified in [SAE AS6802] §9.4.
- All received coldstart acknowledge frames.
- All received integration frames as compressed integration frames.

An example of an integration PCF frame exchange between a compression master and two synchronization master is shown in Figure 4-18.

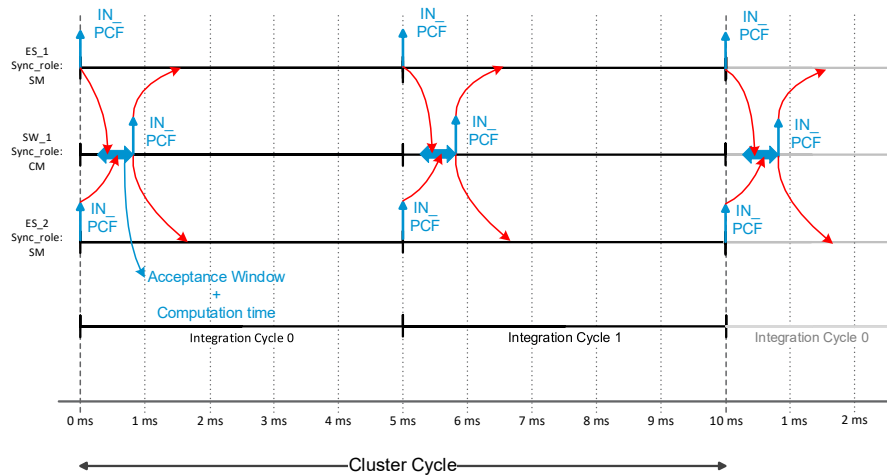


Figure 4-18: Example of an integration PCF Frame exchange

To tolerate a single Byzantine fault in the clocks of the synchronization masters there is a need for at least 4 SMs because of the Byzantine theorem. For two fault tolerance there is a minimum of 7 SMs needed since it allows to tolerate any Byzantine two faults of clocks of the synchronization masters.

More details about the clock synchronization can be found in the Time-Triggered Ethernet standard [SAE AS6802].

4.5 Redundancy Concept

4.5.1 Introduction

End-Systems communicate over multiple independent and redundant networks such that data flows are protected against the failure of any network component such as a link or a Switch. The effect of this is to protect communication between End-Systems against the loss of one complete network.

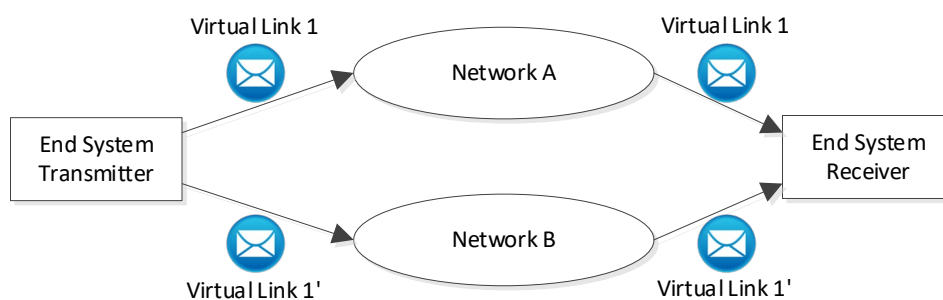


Figure 4-19: Redundancy Communication

The Figure 4-19 shows the basic concept for network redundancy. The redundancy scheme is operated on a per Virtual Link basis. A transmitting End-System and a receiving End-System communicate via a specific Virtual Link. This Virtual Link can be configured as TT or RC traffic. Depending on the

configuration of the End-System the Virtual Link is sent at a defined point in time if it is a TT Virtual Link or can be send immediately (depending on the priority sending buffer) if it is a RC-Virtual Link. Depending on the configured redundancy degree, the communication controller duplicates or triplicates the Virtual Link on the redundant channels.

For critical traffic the sending application is unaware of the underlying network redundancy, and a simple interface can be built between the communications controller and the host that utilize the network service.

The frame routing between the host and the physical ports can be configured so that frames can be send on one, two or all three ports. Upon reception, it is possible to configure no redundancy management or an algorithm in the communication controller which uses a “First Valid” policy. This means that the first frame to be received from either network is accepted and passed up to the receiving host.

As the flow of frames given in Figure 4-20 below indicates, RM (Redundancy Management) is placed after IC (Integrity Checking). Under fault-free network operation, the controller just passes on the frames that it has received from a network on to the RM. The redundancy management is merely to eliminate frames that are redundant copies of frames that it has already passed on to the host.

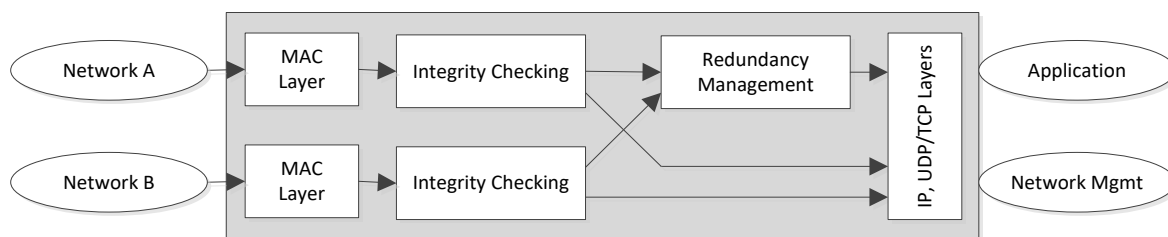


Figure 4-20: Redundancy Management at the Receiver

The Integrity Checking has the task of eliminating invalid frames. In case of RC traffic, it checks the incoming frames for any faults based on their sequence number to eliminate stuck frames or single abnormal frames and reducing the impact of a babbling Switch. A description of this mechanism is given in [ARINC 664 part 7] § 3.2.6.2.1.

4.5.2 TT traffic

The sending host prepares the data and passes it to the communication controller which, depending on the redundancy degree duplicates/triplicates the data and adds the Ethernet header information to it. A sequence number is not needed since the traffic is scheduled based on the global fault-tolerant time base and therefore the sending order cannot change.

4.5.3 RC traffic

The sending host prepares the data and passes it to the communications controller. Here a sequence number field is added to each frame, and the sequence numbers are incremented on each successive frame. The sequence

number is added to enable the receive function to reconstruct a single ordered stream of frames without duplication before delivery to the receiving application. The “First Valid” frame that is received from the network with the next valid sequence number gets passed up to the receiving host. If a frame with the same sequence number is received it is simply discarded.

4.6 Failure-modes

Time-Triggered Ethernet is designed to tolerate either the fail-arbitrary failure mode of an End-System or the fail-inconsistent-omission failure mode of a Switch. The Switches in Time-Triggered Ethernet network can be configured to execute a central bus guardian function. The central bus guardian function ensures that even if a set of End-Systems becomes arbitrarily faulty, it masks the system-wide impact of these faulty End-Systems by transforming the fail-arbitrary failure mode into an inconsistent-omission failure mode. The central bus guardian function is ensured by the traffic policing, specified in Clause 6.2.6 Switch Traffic Policing. The arbitrarily faulty failure mode also includes the babbling-idiot behaviour.

- Fail arbitrary failure mode:
 - A device that fails arbitrarily can generate messages with random contents at arbitrary points in time on arbitrary selection of outputs.
- Fail inconsistent-omission failure mode:
 - A faulty device can arbitrarily classify a subset of received messages as correct, while classifying the remaining messages (potentially correct) as incorrect

5

Network Architecture

5.1 Overview

5.1.1 Introduction

A TTE network architecture is a Switched-based implementation, or “star topology”, designed for real-time critical application, in which all End-System nodes (SM and SC) are individually connected to a central connection point: a TTE Switch (CM or SC).

This Clause defines the different types of architectures which can be implemented in a TTE network:

- Single Channel Network Topology
- Dual Channel Network Topology
- Triple Channel Network Topology
- Mixed Channel Network Topology
- Network Topology composed of Standard Ethernet node

5.1.2 Single Channel Network Topology

A TTE single network is a network in which only one channel is used for the data communication between the nodes of the network, as illustrated in the following example composed of two End-Systems.



Figure 5-1: Single Channel Network Topology

This network architecture involves a single point of failure of the devices over the network and the communication can be broken in case of event of a network failure (broken cable or connector, Switch or End-System failure).

Single network topology can be composed of one Switch or several cascaded Switches as illustrated on Figure 5-1 and Figure 5-3.

In case the network is composed of one Switch, the Switch takes the Compression Master role with regards to the synchronization while

Synchronization Masters can be supported by any of the End-Systems in the network. Single network topology requires that minimum one Synchronization Master is active within the TTE network.

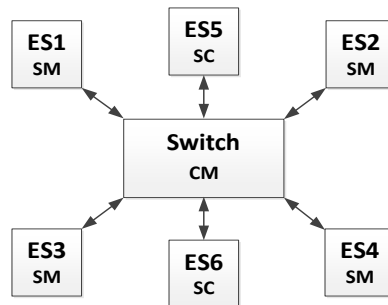


Figure 5-2: Single Channel Network Topology – without cascaded Switches

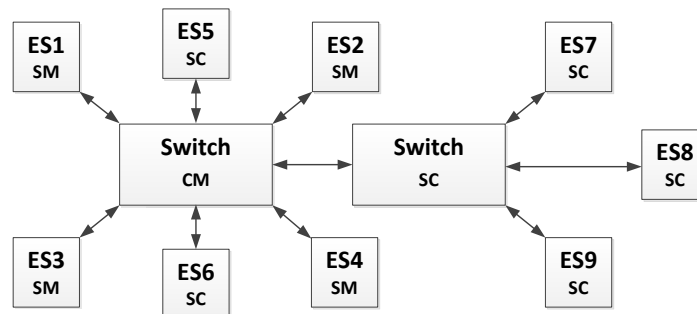


Figure 5-3: Single Channel Network Topology – with cascaded Switches

5.1.3 Dual Channel Network Topology

A TTE dual redundant network is a network composed of two redundant Links dedicated for the data communication between the nodes of the network as illustrated in the following example through an example composed of two End-Systems.



Figure 5-4: Dual Channel Network Topology

This TTE network architecture type enables covering space application requiring one-fault tolerant architecture (1FT) at system level. Each VL is transmitted in hot redundancy (at the same point in time) on both channels.

Dual network topology can be composed of one Switch or several cascaded Switches per channel. In case the network is composed of two redundant Switches, these Switches take the Compression Master role and Synchronization Masters can be performed by any of the End-Systems part of the network. Dual Redundant network with One Fault Tolerant requirement

requires that minimum four Synchronization Masters are active within the TTE network.

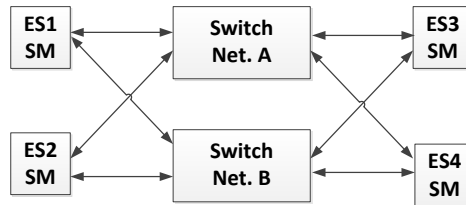


Figure 5-5: Dual Channel Network Redundancy without cascaded Switches

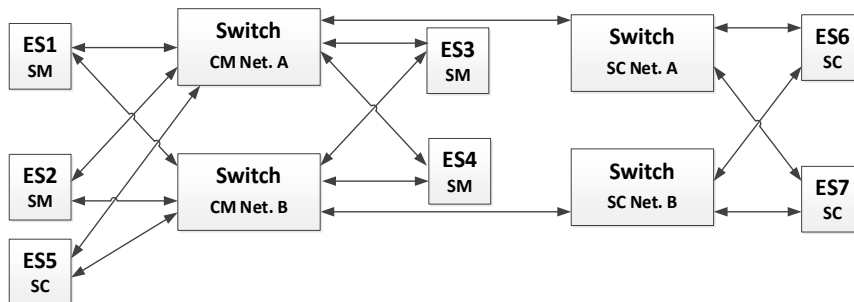


Figure 5-6: Dual Channel Network Redundancy with cascaded Switches

5.1.4 Triple Channel Network Topology

A TTE triple redundant network is a network composed of three redundant Links dedicated for the data communication between the nodes of the network. It is illustrated on the following figure through an example composed of two End-Systems.

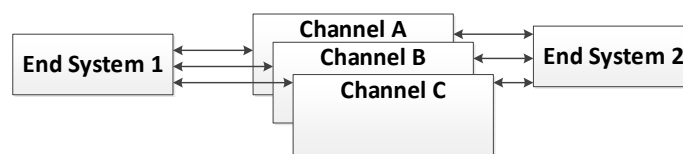


Figure 5-7: Triple Channel Redundant Network Topology

This TTE network architecture type enables covering space application requiring two-fault tolerant architecture (2FT) at system level. Each VL is transmitted in hot redundancy to the three networks.

Triple network topology can be composed of one Switch or several cascaded Switches per channel as illustrated here-after on figure 9 and figure 10. In case the network is composed of three redundant Switches, these Switches take the Compression Master role with regards to the synchronization while Synchronization Masters can be performed by any of the End-Systems part of the network. Triple Redundant network with Two Fault Tolerant requirement requires that minimum seven Synchronization Masters are active within the TTE network.

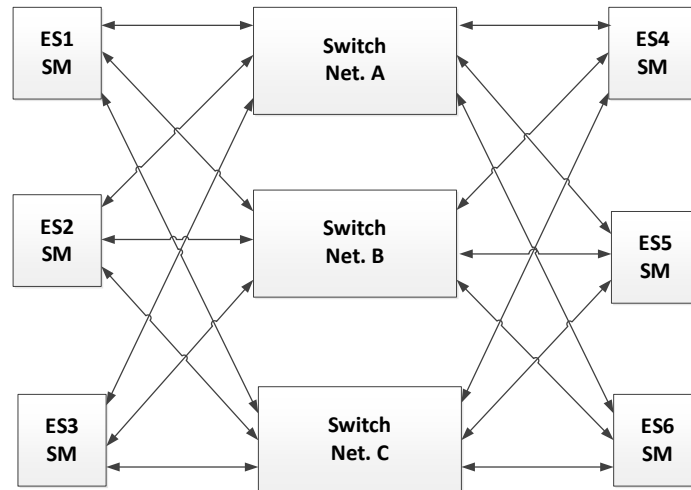


Figure 5-8: Triple Channel Network Redundancy without cascaded Switches

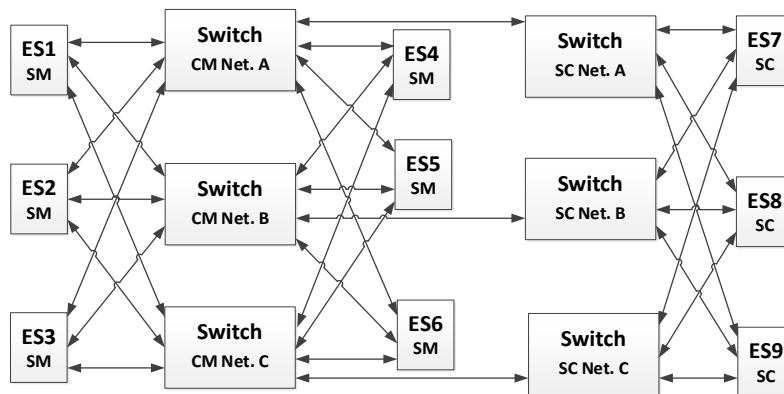


Figure 5-9: Triple Channel Network Redundancy with cascaded Switches

5.1.5 Mixed Network Topology

A TTE mixed network topology is a network composed of redundant or single Links dedicated for the data communication between the nodes of the network. It is illustrated on the following figure through an example composed of multiple End-Systems.

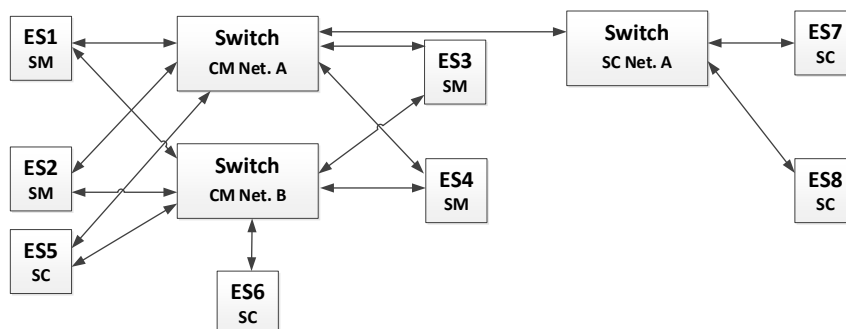


Figure 5-10: Mixed Architecture

This TTE network architecture type allows to combine applications where redundancy is needed as well as non-redundant ones. This means that the synchronization in the redundant part can be configured to be single fault-tolerant with e.g. 4 SMs as illustrated in this example connected to a non-redundant part of the cluster which is synchronized to the same time-domain but only support a single channel non-redundant architecture. This setup illustrates the configurability of the TTE network allowing to support different kind of architectures.

5.1.6 Multiple Networks Topology

Multiple Network topologies are combined clusters consisting of two or more individual networks. Each of these clusters is able to work self-sustained but in a combination with others the clusters are able to provide an extended functionality. A cluster is defined as an independent distributed avionics system which is self-sustained and provides a defined interface to the outside world.

This Clause describes the multiple networks topology approach combining multiple independent cluster based on TTEthernet to a single network. It further describes the cluster concept, the TTEthernet technology features provided to support these applications and how such an integration can be implemented.

In this Clause we assume that each of the cluster is based on a TTEthernet network or at least offers a TTEthernet interface allowing to interface to another system.

The multiple networks topology is defined such as different independent cluster having their own communication network with use-cases integrate into one cluster to fulfil their mission requirements. This means that two independent data network handling different control- or management-data join and leverage the function from each other at least partly by exchanging data over the joint links.

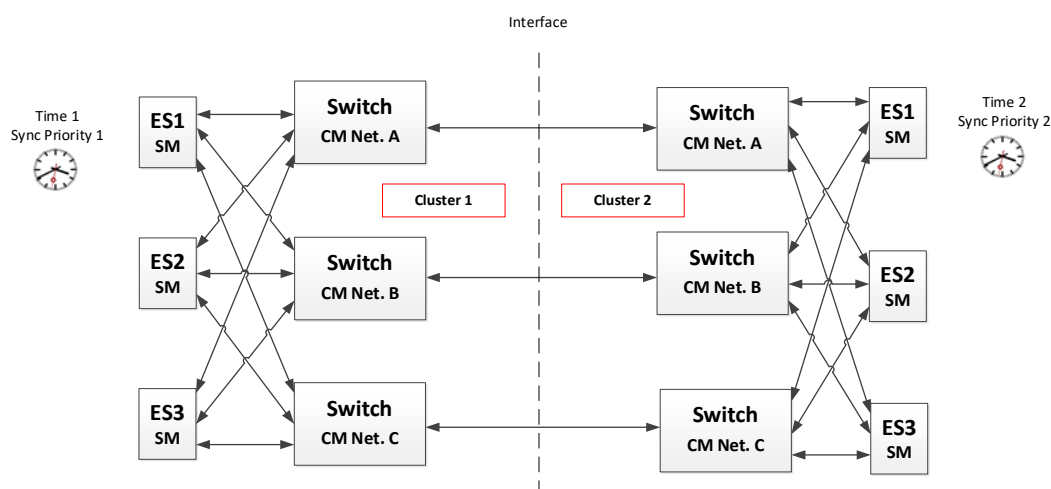


Figure 5-11: Multiple Networks Topology

Each of the above described cluster has a data network providing different quality of services to the application like fault-tolerant global time base, deterministic data transfer, redundancy management, network diagnostics and network management.

If these networks are connected, the goal is to keep as much services as possible available to allow an operation of the resulting coupled system without decrease of the quality of service or even increase the capability of some functions by combining the two data networks. This allows to have multiple clusters which are able to be controlled or use services from another cluster. The data of one cluster can selectively be used in the other cluster and therefore the interface between these clusters needs to be specified according to the services needed.

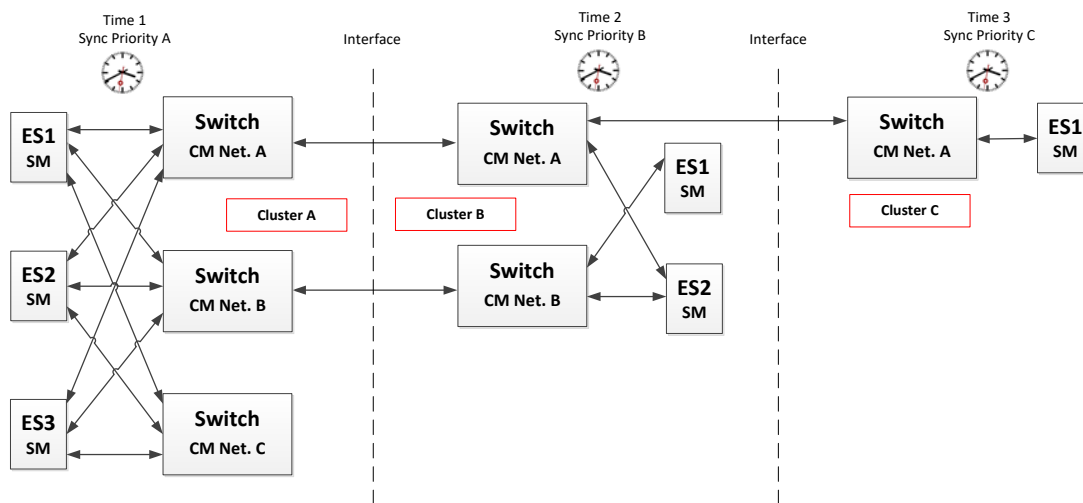


Figure 5-12: Synchronization priority assignment recommendation

5.1.7 Compatibility with standard Ethernet Network

The TTE cluster topologies are Ethernet compatible and therefore interoperable with Best-Effort nodes where Best-Effort traffic class is used for the communication as illustrated in Figure 5-13 composed of seven nodes:

- 3 Standard-Ethernet End-Systems
- 3 TTEthernet End-Systems
- 1 TTEthernet Switch

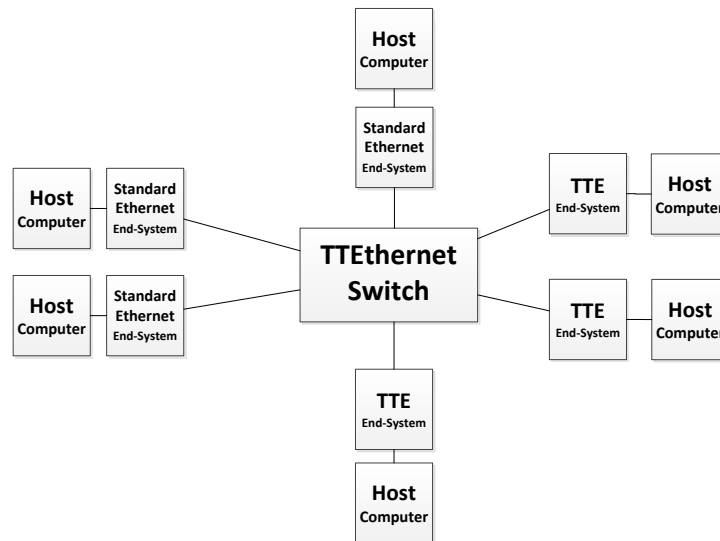


Figure 5-13: Time-Triggered Ethernet topology composed of standard Ethernet nodes

Time-Triggered Ethernet End-Systems are connected via Time-Triggered Ethernet Switches for Time-Triggered, Rate-Constrained and Best-Effort communication. Standard-Ethernet nodes can be connected to both Time-Triggered Ethernet End-Systems and Time-Triggered Ethernet Switches. TTEthernet End-Systems can communicate by using the Best-Effort traffic class and therefore be connected to Ethernet or TTEthernet Switches or End-Systems.

5.2 Network Topology Requirements

5.2.1 Single Network Topology

ECSS-E-ST-50-16_1490001

- a. TTEthernet network topology shall be at least one of the following types:
 1. Single channel
 2. Dual channel
 3. Triple channel
 4. Mixed

ECSS-E-ST-50-16_1490002

- b. All Time-Triggered End-System shall be of either SM or SC type as specified in [SAE AS6802].

ECSS-E-ST-50-16_1490003

- c. All Time-Triggered Switches shall be of either CM or SC type as specified in [SAE AS6802].

ECSS-E-ST-50-16_1490004

- d. An End-System of SC type shall implement the synchronization client functionality as specified in the [SAE AS6802] standard §9.3.

ECSS-E-ST-50-16_1490005

- e. An End-System of SM type shall implement the synchronization master functionality as specified in the [SAE AS6802] standard §9.2.

ECSS-E-ST-50-16_1490006

- f. A Switch of CM type shall implement the compression master functionality as specified in the [SAE AS6802] standard §9.4 & §9.5.

ECSS-E-ST-50-16_1490007

- g. A Switch of SC type shall implement the synchronization client functionality [SAE AS6802] standard §9.3.

ECSS-E-ST-50-16_1490008

- h. A TTEthernet network shall be composed of at least (as specified in [SAE AS6802] §4.2):
- 1 SM and 1 CM for Single network Topology (No Fault Tolerant)
 - 4 SM and 2 CM for Duplex network Topology (Single Fault Tolerant architecture)
 - 7 SM and 3 CM for Triplex network Topology (Dual Fault Tolerant architecture)

NOTE In order to tolerate F Byzantine faults in a distributed system $N \leq 3F + 1$ Nodes are required.

ECSS-E-ST-50-16_1490009

- i. The TTE network shall be usable as a conventional [IEEE 802.3] Ethernet network at least at MAC level.

NOTE Without the need of synchronization.

ECSS-E-ST-50-16_1490010

- j. In all fault-tolerant network setups the respective fault hypothesis shall remain valid so that:
1. For 1FT the network is able to tolerate a single fault of any TTE network element in the network.
 2. For 2FT the network is able to tolerate any 2 faults of any TTE network element in the network.

NOTE 1 Since the reliability depends typically on the mission/application, different hybrid models are possible. However, the basic fault-tolerance which is also described in the [SAE AS6802]

standard §3.3.1 is 0FT, 1FT and 2FT with a certain configuration of the parameters. This requirement covers arbitrary faults of any End-System as well as inconsistent *omissive* faults of any Switch in the network.

NOTE 2 Inconsistent *omissive* faults is when a node arbitrarily classifies a subset of received messages as correct while classifying the remaining messages, potentially correct, as incorrect.

ECSS-E-ST-50-16_1490011

- k. If the SM is connected to the CM via a TT Switch, then this Switch shall be transparent with regards to PCF frames.

NOTE Transparent means, that the TT Switch needs to update its transparent clock in PCF frames passing this Switch as described in [SAE AS6802] §5.1.

5.2.2 Multiple Networks Topology

ECSS-E-ST-50-16_1490012

- a. A TTEthernet multiple network topology shall at least contain two separate networks of the following topologies:
1. Single channel topology
 2. Dual channel topology
 3. Triple channel topology

ECSS-E-ST-50-16_1490013

- b. In a multiple network topology, the following clock synchronization parameters shall be equal between separate cluster:
1. Integration Cycle Duration
 2. Cluster Cycle Duration

ECSS-E-ST-50-16_1490014

- c. In a multiple networks topology, for rate constrained traffic the following parameters shall be equal between separate clusters for each VL:
1. BAG
 2. Jitter

ECSS-E-ST-50-16_1490015

- d. In a multiple network topology, each cluster shall have a unique synchronization priority.

NOTE The synchronization priority assignment is depending on the network topology of each cluster. It is recommended that clusters with three channels have higher priority than clusters with two channels as illustrated in Figure 5-12.

ECSS-E-ST-50-16_1490016

- e. If separate clusters are joined together, the synchronization master and client shall realize the host-interactive and autonomous modes of PCF filtering as specified in [SAE AS6802] §10.1.

ECSS-E-ST-50-16_1490017

- f. If separate clusters are joined together, the compression masters shall automatically synchronize to the higher priority PCFs received from the synchronization master.

ECSS-E-ST-50-16_1490018

- g. The transparent clock granularity between joined clusters shall be equal.

ECSS-E-ST-50-16_1490019

- h. The network synchronization precision between joined clusters shall be equal.

ECSS-E-ST-50-16_1490020

- i. The CT-Marker between joined clusters shall be equal.

ECSS-E-ST-50-16_1490021

- j. The Max Transparent Clock value between joined clusters shall be equal.

NOTE The Max Transparent Clock calculation includes all clusters

6 Device Services

6.1 Overview

This Clause specifies the requirements applicable to the Switch and End-System devices.

In this Clause the following OSI Layer Services are specified (see Figure 6-1):

- Application Layer:
 - TFTP: for data loading and file transfer
 - SNMP: for network management
- Transport Layer:
 - UDP: required for application layers TFTP, SNMP, and communication ports
 - TCP: is considered optional and not covered in this document.
- Network Layer:
 - IP: IPv4 required by transport/application layers
 - ICMP: to be used for diagnostic and monitoring purposes or generated in response to errors in IP operations
- Data Link:
 - [SAE AS6802]: as a Layer 2 Quality-of-Service (QoS) enhancement for TTE and for time synchronization
 - Ethernet MAC: based on [IEEE 802.3] and the [ARINC 664 part 2]

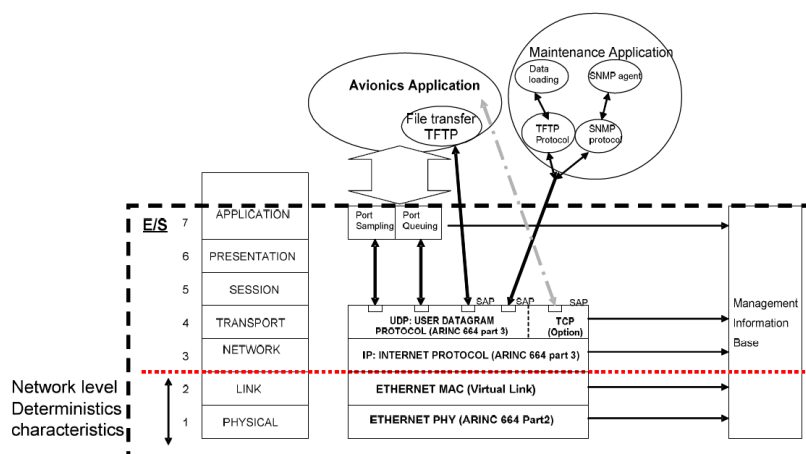


Figure 6-1: OSI Layer Services

6.2 Media Access Control (MAC) Sublayer

6.2.1 MAC sublayer functions

ECSS-E-ST-50-16_1490022

- a. The MAC sublayer functions shall be implemented according to [IEEE 802.3] § 1 4.2.3.

6.2.2 MAC Addressing

ECSS-E-ST-50-16_1490023

- a. A MAC destination address of a Critical Traffic frame shall have a unique 32-bit configurable Critical Traffic (CT-Marker) field for critical traffic (TT and RC) in a Time-Triggered Network.

NOTE In order to be compliant with the Ethernet standard, MAC group addresses is used to send frames from End-System to End-System(s). The CT-Marker field should follow the formatting as illustrated in Figure 6-2.

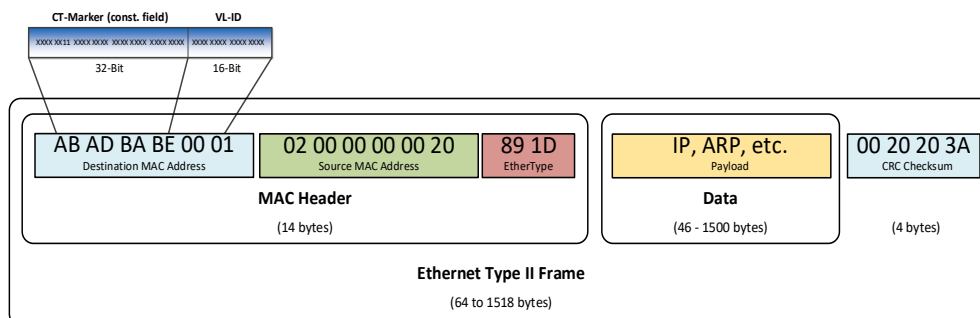


Figure 6-2: Destination MAC Address

ECSS-E-ST-50-16_1490024

- b. A Virtual Link shall be identified by the MAC destination address with a network unique CT-Marker and a Virtual Link Identifier (VL ID).

NOTE Illustration is given in Figure 6-2.

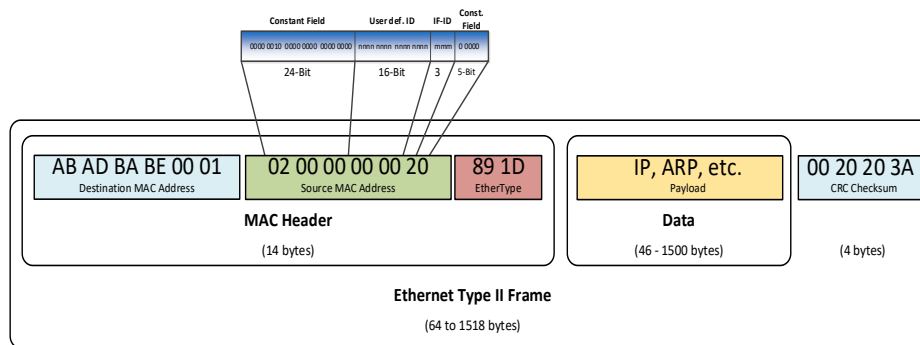


Figure 6-3: Source MAC Address

ECSS-E-ST-50-16_1490025

- c. The Constant field (24-Bit) of the source MAC address shall be set to “0000 0010 0000 0000 0000 0000”.

ECSS-E-ST-50-16_1490026

- d. The MAC Source address shall be an Individual and Locally Administered address compliant with [IEEE 802.3] § 3.2.4.

NOTE As illustrated in Figure 6-3.

ECSS-E-ST-50-16_1490027

- e. The Const. Field (5-Bit) of the source MAC address shall be set to “0 0000”.

NOTE As illustrated in Figure 6-3.

ECSS-E-ST-50-16_1490028

- f. The User defined ID (User def. ID) is a single 16-bit field that shall be used to give each addressable host on the network a unique MAC address.

NOTE This is defined by the network integrator who creates the configurations for the network. It provides additional information on the source of the message.

ECSS-E-ST-50-16_1490029

- g. The redundant frames transmitted on all ports shall always be the same except the MAC source address where different interface ID fields are assigned at each port and the FCS.

ECSS-E-ST-50-16_1490030

- h. The network on which a frame is transmitted shall be identified according to the Interface ID (IF-ID) field of the Ethernet MAC source address as defined in Table 6-1.

NOTE The Interface ID defined in Table 6-1 indicates to which redundant Time-Triggered Ethernet

network the Ethernet MAC frame is transmitted.

ECSS-E-ST-50-16_1490031

Table 6-1: Interface ID

Interface ID	Description
0 0 1	The Ethernet MAC frame is transmitted to network A
0 1 0	The Ethernet MAC frame is transmitted to network B
0 1 1	Not used
1 0 0	The Ethernet MAC frame is transmitted to network C
1 0 1	Not used
1 1 0	Not used
1 1 1	Not used

6.2.3 Traffic Classes

ECSS-E-ST-50-16_1490032

- a. Each network element supporting this standard shall implement the three traffic classes: Time-Triggered, Rate-Constrained and Best-Effort.

ECSS-E-ST-50-16_1490033

- b. The priorities of traffic classes shall be as following:
1. Protocol control frame (PCF) has highest priority
 2. Time-triggered traffic (TT) has the second highest priority
 3. Rate-Constrained traffic (RC) has priority(s) in between TT and BE
 4. Best-Effort (BE) has the lowest priority

ECSS-E-ST-50-16_1490034

- c. PCF, TT, RC and BE traffic shall be sent according to their priority.

ECSS-E-ST-50-16_1490035

- d. In reception each network element should have at least two independent memory partitions one for Best-Effort and one for Critical Traffic.

NOTE This is an optional requirement to separate input memory partitions and allow in case of a babbling idiot behaviour to receive critical traffic on a faulty node.

ECSS-E-ST-50-16_1490036

- e. In transmission, each network element should have at least two independent memory partitions one for Best-Effort and one for Critical Traffic.

NOTE This is an optional requirement to separate output memory partitions allow in case of a babbling idiot behaviour to transmit critical traffic on a faulty node.

6.2.4 MAC Transmit**ECSS-E-ST-50-16_1490037**

- a. Switch function without a compression master role shall not be able to generate PCF frames.

NOTE A Switch without a compression master role is only able to relay PCF frames.

ECSS-E-ST-50-16_1490038

- b. If a frame is discarded, a dedicated diagnostics counter shall be incremented to provide this information to the upper layers.

NOTE This counter allows to distinguish between sporadic or permanent errors

ECSS-E-ST-50-16_1490039

- c. A TT traffic shall be sent at defined scheduled points according to the synchronized time.

ECSS-E-ST-50-16_1490040

- d. If the End-System is not synchronized, only rate constrained frames and Best-Effort frames shall be transmitted.

ECSS-E-ST-50-16_1490041

- e. In case the MAC performs a clock correction, it shall adjust the time interval between the current schedule point and the next schedule point, by adding the clock correction value to this time interval.

ECSS-E-ST-50-16_1490042

- f. Frames shall be sent on the redundant ports simultaneously.

NOTE The delay between transmissions of the redundant frames is not specified but has an impact on the synchronization precision (refer to Clause 7.4).

ECSS-E-ST-50-16_1490043

- g. Redundant RC frames shall have the same sequence number.

6.2.5 MAC Receive

6.2.5.1 General

ECSS-E-ST-50-16_1490044

- a. At the successful receive of a MAC Frame, the MAC shall treat a valid MAC frame as specified in [IEEE 802.3].

6.2.5.2 Critical Traffic

ECSS-E-ST-50-16_1490045

- a. The MAC shall treat a valid MAC frame as Critical Traffic if the CT-Marker matches the CT-Marker entry of the Table 7-9.

ECSS-E-ST-50-16_1490046

- b. The MAC shall discard a valid MAC frame belonging to Critical Traffic if the VL ID does not match any entry of the Table 7-6.

ECSS-E-ST-50-16_1490047

- c. The MAC shall discard a valid Critical Traffic frame if the MAC Frame Length is greater than the value configured for the maximum frame size.

NOTE If larger frames are sent, the bandwidth restrictions can be violated.

ECSS-E-ST-50-16_1490048

- d. Redundant TT frames shall be identified according to their destination MAC address (CT-Marker, VL-ID) and the respective receive window.

ECSS-E-ST-50-16_1490049

- e. The time-skew between the redundant instances of the TT frames shall be configurable.

ECSS-E-ST-50-16_1490050

- f. Redundant RC frames shall be identified according to their destination MAC address and the respective sequence number.

ECSS-E-ST-50-16_1490051

- g. The time-skew between the redundant instances of the RC frames shall be configurable.

ECSS-E-ST-50-16_1490052

- h. Depending on the configuration parameter, a configurable redundancy management unit shall forward the first valid frames to the host or forward all redundant frames to the host.

6.2.6 Switch Traffic Policing

ECSS-E-ST-50-16_1490053

- a. If the Switch is not synchronized, it shall discard all received Time-Triggered frames.

ECSS-E-ST-50-16_1490054

- b. The Switch shall discard a received frame which is policed to be Time-Triggered if the Switch holds a previous frame of the same VL ID.

ECSS-E-ST-50-16_1490055

- c. In reception, if a TT frame is received outside its scheduled time window, the frame shall be discarded.

NOTE For the calculation of the acceptance window duration, refer to guidelines provided in Clause 7.5.8.

ECSS-E-ST-50-16_1490056

- d. The Switch shall discard all valid Time-Triggered frames stored inside the Switch and waiting for transmission in case of a Synchronization Loss.

ECSS-E-ST-50-16_1490057

- e. The Switch shall discard any valid Time-Triggered frames which frame length is greater than the MaxLength entry defined in Table 7-11.

NOTE The related diagnostics and status information counter are described in Clause 8.4.3.

ECSS-E-ST-50-16_1490058

- f. Traffic policing for RC traffic shall be in accordance with requirements specified in [ARINC 664 part 7] §4.1.1 and §4.2.2.

ECSS-E-ST-50-16_1490059

- g. In reception, if on a given port the Switch receives a frame with a VL-ID not consistent with the VL-IDs expected on this port, the frame shall be discarded.

NOTE The related diagnostics and status information counter are described in Clause 8.4.3

ECSS-E-ST-50-16_1490060

- h. If a PCF frame does not have a payload length of exactly 46 bytes, the frame shall be discarded as specified in [SAE AS6802] §4.6.

ECSS-E-ST-50-16_1490061

- i. A PCF frame shall include the actual integration cycle number as specified in [SAE AS6802] §4.6.

ECSS-E-ST-50-16_1490062

- j. A PCF frame shall include a membership vector of all synchronization master contributing to the synchronization protocol as specified in [SAE AS6802] §4.6.

ECSS-E-ST-50-16_1490063

- k. A PCF frame shall include the synchronization priority and synchronization domain as specified in [SAE AS6802] §4.6.

ECSS-E-ST-50-16_1490064

- l. A PCF frame shall include the transparent clock value as specified in [SAE AS6802] §4.6.

ECSS-E-ST-50-16_1490065

- m. In case the Switch is forwarding PCF's, a PCF frame shall be discarded if the time interval between two consecutive PCF of the same VL-ID is outside the limit specified by the entries BAG and Jitter in the Output VL Table associated to this VL-ID.

NOTE 1 The value for jitter depends on the precision.

NOTE 2 The Switch Output VL Table is defined in Table 7-11.

ECSS-E-ST-50-16_1490066

- n. In case the Switch is forwarding PCF's, the values for BAG shall be equal to the integration cycle.

ECSS-E-ST-50-16_1490067

- o. In reception, if a MAC frame is not correct, as specified in [IEEE 802.3], the frame shall be discarded.

6.2.7 Switch Transmit

ECSS-E-ST-50-16_1490068

- a. The Switch shall allow reserving the sending media for a defined CT-frame.

NOTE This is needed to ensure that TT frames are not delayed by other frames which are in the sending process when a TT frame is sent. The reservation of a window in front of a TT frame does not allow to process other frames within this window.

ECSS-E-ST-50-16_1490069

- b. If the following conditions are both true, the Switch shall start at a defined point in the Schedule Table:
1. The Switch adjusts its local clock to the network time received via an integration PCF frame,
 2. The Switch adjusts its local integration cycle number with the integration cycle number contained in the integration PCF frame.

ECSS-E-ST-50-16_1490070

- c. When the Switch finishes executing the last entry of the Schedule Table, the Switch shall restart with the first entry of the Schedule Table.

6.2.8 Switch Frame Routing

ECSS-E-ST-50-16_1490071

- a. The Switch shall support both of the following routing scheme:
1. Static Best-Effort routing according to a static Best-Effort routing table as part of the configuration
 2. Dynamic Best-Effort routing according to a dynamic Best-Effort routing table created via address learning according to RFC 826

ECSS-E-ST-50-16_1490072

- b. CT-Frames shall be routed according to their VL-ID

ECSS-E-ST-50-16_1490073

- c. In case preemption is not used, a Switch shall not cause sending of incomplete frames because of a priority conflict on a sending port.

NOTE If a higher priority frame is sent at a dedicated port where a lower priority frame is in process, the low priority frame sending process cannot be interrupted.

ECSS-E-ST-50-16_1490074

- d. The Switch shall be able to perform independent frame routing on all ports at the same time with full line rate.

ECSS-E-ST-50-16_1490075

- e. The order of Rate-Constrained frames received on the same reception port and belonging to the same VL ID shall be preserved on the transmission port.

7

Interoperability Specification

7.1 Overview

This Clause specifies the parameters of the implementation which are needed to achieve interoperability between the Switches and End-Systems developed according to this standard. This Clause specifies it for the implementation e.g. IP level and allows together with the Network Configuration Clause an integration of devices from different vendors into a complete network.

It further defines the network configuration parameters which are needed to create a configuration of the network and each device specifying e.g. senders, receivers, messages, time-constraints and redundancy constraints.

All these parameters are taken by the configuration tools as an input to derive the device specific configurations. Since not every device needs to be aware of the whole network configuration, these configurations only need to define the device related parameters to ensure the interoperability with the network. However, the network related device parameters need to be consistent to ensure a correct behaviour of the TT and RC traffic flows.

This Clause aims at specifying the parameters needed on the different layers (network and device) to ensure the interoperability within a network.

Figure 7-1 shows the interface between the tool creating the device specific configuration out of the network level specification which are used by the IP to perform the operation.

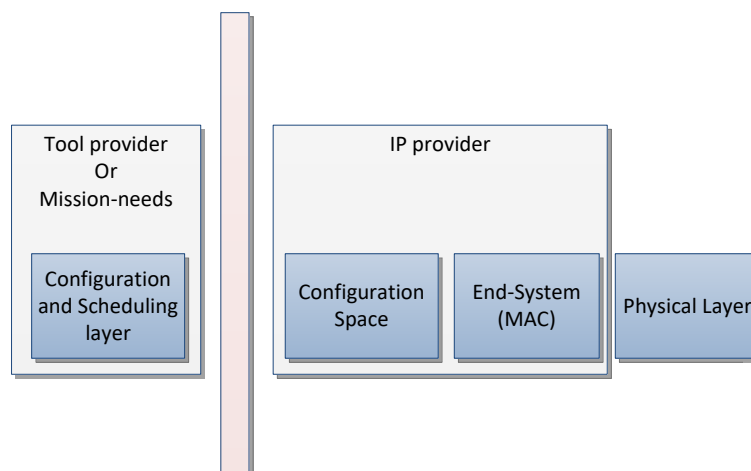


Figure 7-1: Configuration Interface Tool – IP

7.2 Device Specification

7.2.1 Device Parameters Description

ECSS-E-ST-50-16_1490076

- a. The parameters which are used to ensure the interoperability between the nodes in the network for the Switch and the function shall be defined as per Table 7-1, Table 7-2 and Table 7-3.

NOTE These parameters are essential inputs for the creation of the configuration for the devices since it defines the performances of each of them within the network.

ECSS-E-ST-50-16_1490077

Table 7-1: General Interoperability Parameter Table

Parameter	Description
CLOCK_SYNC_PRECISION	Clock synchronization precision

ECSS-E-ST-50-16_1490078

Table 7-2: Switch Interoperability Parameter Table

Parameter	Description
SW_TT_TX_LENGTH	Frame length of the Time-Triggered frame to be sent
SW_TT_TX_PERIOD	Period of the Time-Triggered frame to be sent
SW_TT_TX_PHASE	Phase of the Time-Triggered frame to be sent
SW_SCHEDULE_GRANULARITY	Raster granularity in which the Time-Triggered frames can be placed for sending
SW_MIN_TT_TX_GAP	The minimum gap between two consecutive Time-Triggered frames to be transmitted
SW_TT_TX_MAX_JITTER	Maximum duration from synchronized state to the first bit placed onto the transmit line
SW_TT_TX_FRAMES	Number of Time-Triggered frames the Switch is able to transmit
SW_NUM_TT_TX_PERIOD	Maximum number of different Time-Triggered periods a Switch supports for transmit
SW_LIST_TT_TX_PERIOD	List of Time-Triggered frame periods the Switch supports
SW_TT_RX_WINDOW_CHECK	Input policing for Time-Triggered frames supported by the Switch
SW_TT_RX_EXPECT_ARR_TIME	Expected arrival time of a certain Time-Triggered frame

Parameter	Description
SW_TT_RX_ACT_ARR_TIME_EARLY	Earliest point in time for a Time-Triggered frame to be accepted at the input port of the Switch
SW_TT_RX_ACT_ARR_TIME_LATE	Latest point in time for a Time-Triggered frame to be accepted at the input port of the Switch
SW_MAX_NUM_TT_FRAMES	Maximum number of Time-Triggered frames a Switch can buffer at any time
SW_MAX_TT_BUFFER_SIZE	Maximum buffer size for Time-Triggered frames
SW_MAX_FORWARD_DELAY	Maximum forward delay of the Switch for Time-Triggered frames

ECSS-E-ST-50-16_1490079

Table 7-3: End-System Interoperability Parameter Table

Parameter	Description
ES_TT_TX_LENGTH	Frame length of the Time-Triggered frame to be sent
ES_TT_TX_PERIOD	Period of the Time-Triggered frame to be sent
ES_TT_TX_PHASE	Phase of the Time-Triggered frame to be sent
ES_SCHEDULE_GRANULARITY	Raster granularity in which the Time-Triggered frames can be placed for sending
ES_MIN_TT_TX_GAP	The minimum gap between two consecutive Time-Triggered frames to be transmitted
ES_TT_TX_MAX_JITTER	Maximum duration from synchronized state to the first bit placed onto the transmit line
ES_NUM_TT_TX_PERIOD	Maximum number of different Time-Triggered periods an End-System supports for transmit
ES_LIST_TT_TX_PERIOD	List of Time-Triggered frame periods the End-System supports
ES_TT_RX_WINDOW_CHECK	Input policing for Time-Triggered frames supported by the End-System
ES_TT_RX_EXPECT_ARR_TIME	Expected arrival time of a certain Time-Triggered frame
ES_TT_RX_ACT_ARR_TIME_EARLY	Earliest point in time for a Time-Triggered frame to be accepted at the input port of the End-System
ES_TT_RX_ACT_ARR_TIME_LATE	Latest point in time for a Time-Triggered frame to be accepted at the input port of the End-System

7.2.2 General Requirements

ECSS-E-ST-50-16_1490080

- a. All End-System and Switches that transmit, forward or receive a given Time-Triggered frame shall have access to a synchronized timebase with precision CLOCK_SYNC_PRECISION.

7.2.3 Switch Level Specification

7.2.3.1 General

ECSS-E-ST-50-16_1490081

- a. The Switch forwarding and Switch reception requirements shall be equivalent to the End-System transmission and End-System reception requirements.

7.2.3.2 Switch Forwarding

ECSS-E-ST-50-16_1490082

- a. A Switch shall associate each Time-Triggered frame it forwards with a `SW_TT_TX_LENGTH`, a `SW_TT_TX_PERIOD`, and a `SW_TT_TX_PHASE`.

NOTE A scheduler for Time-Triggered frames typically takes the `SW_TT_TX_LENGTH` and `SW_TT_TX_PERIOD` values of all frames as an input and returns a value for `SW_TT_TX_PHASE` for each Time-Triggered frame as an output.

`SW_TT_TX_LENGTH` is the allowed length of an Ethernet frame including IFG and preamble:

- $\text{Minimum}(\text{SW_TT_TX_LENGTH}) = \text{IFG (12 bytes)} + \text{preamble (7 bytes)} + \text{start of frame delimiter (1 bytes)} + \text{frame (64 bytes)}$
- $\text{Maximum}(\text{SW_TT_TX_LENGTH}) = \text{IFG (12 bytes)} + \text{preamble (7 bytes)} + \text{start of frame delimiter (1 bytes)} + \text{frame (1518 bytes)}$

`SW_TT_TX_PERIOD` is the transmission period with which the Switch dispatches the respective Time-Triggered frame.

`SW_TT_TX_PHASE` is a value given by:

$$\text{SW_TT_TX_PHASE} = K * \text{SW_SCHEDULE_GRANULARITY}$$

where:

`SW_SCHEDULE_GRANULARITY` is the granularity of the schedule

`K` is a natural number such that $\text{SW_TT_TX_PHASE} \leq \text{SW_TT_TX_PERIOD}$ holds.

ECSS-E-ST-50-16_1490083

- b. A Switch shall specify `SW_SCHEDULE_GRANULARITY` the granularity of `SW_TT_TX_PERIOD` at which the Switch accepts values of `SW_TT_TX_PHASE` from the scheduler.

NOTE An example is SW_TT_TX_PERIOD = 20ms, SW_SCHEDULE_GRANULARITY 20us; which means that SW_TT_TX_PHASE takes any value between 0 and 20ms in 20us increments.

ECSS-E-ST-50-16_1490084

- c. A Switch shall specify the maximum duration SW_TT_TX_MAX_JITTER that it takes starting from the synchronized timebase reaching the phase SW_TT_TX_PHASE in the period SW_TT_TX_PERIOD of a Time-Triggered frame until the first bit of the frame is placed on the transmit communication line.

NOTE There can be two jitter values, one in case media reservation is set and another one if media reservation is not set.

ECSS-E-ST-50-16_1490085

- d. A Switch shall specify the number of SW_TT_TX_FRAMES Time-Triggered frames it is capable to transmit.

ECSS-E-ST-50-16_1490086

- e. A Switch shall specify the different SW_TT_TX_PERIOD it supports.

ECSS-E-ST-50-16_1490087

- f. A Switch shall specify the number SW_NUM_TT_TX_PERIOD of different SW_TT_TX_PERIOD it can support during operation.

NOTE SW_TT_TX_PERIOD is the value, e.g. 5 ms period for TT frames, of the period the Switch supports and SW_NUM_TT_TX_PERIOD defines the maximum number of different frame periods that a Switch supports during operation.

ECSS-E-ST-50-16_1490088

- g. A Switch shall specify a list SW_LIST_TT_TX_PERIOD of different SW_TT_TX_PERIOD it can support during operation.

NOTE This is an implementation constraint which reduces the number of theoretically possible periods to a list limited by the implementation e.g. Switch supports 3 periods from 1ms to 100ms but cannot support all of them simultaneously.

ECSS-E-ST-50-16_1490089

- h. A Switch shall support during operation any selection of size SW_NUM_TT_TX_PERIOD of the SW_TT_TX_PERIOD which the Switch supports, if it does not explicitly specify SW_LIST_TT_TX_PERIOD.

ECSS-E-ST-50-16_1490090

- i. A Switch shall provide a port mirroring function.

NOTE This functionality is needed to allow traffic monitoring.

7.2.3.3 Switch Reception**ECSS-E-ST-50-16_1490091**

- a. A Switch shall identify a frame it receives as a Time-Triggered frame by a lookup in an internal table.

NOTE The intent of this requirement is to make clear that the Switch operates Time-Triggered communication on a per-frame basis.

ECSS-E-ST-50-16_1490092

- b. A Switch shall implement an incoming function SW_TT_RX_WINDOW_CHECK.

ECSS-E-ST-50-16_1490093

- c. A Switch shall locally store for each Time-Triggered frame where the SW_TT_RX_WINDOW_CHECK is executed, an expected arrival time SW_TT_RX_EXPECT_ARR_TIME(x).

NOTE The list of SW_TT_RX_EXPECT_ARR_TIME(x) is an output of the scheduler.

ECSS-E-ST-50-16_1490094

- d. A Switch shall accept an incoming Time-Triggered frame where the SW_TT_RX_WINDOW_CHECK is executed, only if the first bit of the incoming frame is received no earlier than SW_TT_RX_ACT_ARR_TIME_EARLY and not later than SW_TT_RX_ACT_ARR_TIME_LATE.

ECSS-E-ST-50-16_1490095

- e. A Switch shall specify the number of SW_TT_RX_FRAMES Time-Triggered frames it is capable to receive.

ECSS-E-ST-50-16_1490096

- f. A Switch shall specify the number SW_NUM_TT_RX_PERIOD of different SW_TT_RX_PERIOD it can support concurrently during operation.

ECSS-E-ST-50-16_1490097

- g. A Switch shall specify a list SW_LIST_TT_RX_PERIOD of different SW_TT_RX_PERIOD it can support during operation.

ECSS-E-ST-50-16_1490098

- h. A Switch shall support during operation any selection of size SW_NUM_TT_RX_PERIOD of the SW_TT_RX_PERIOD that the Switch supports, if it does not explicitly specify SW_LIST_TT_RX_PERIOD.

7.2.3.4 Buffering**ECSS-E-ST-50-16_1490099**

- a. A Switch shall specify the maximum number SW_MAX_NUM_TT_FRAMES of different Time-Triggered frames it can buffer at any point in time.

ECSS-E-ST-50-16_1490100

- b. A Switch shall specify its maximum buffer size SW_MAX_TT_BUFFER_SIZE for Time-Triggered frames.

ECSS-E-ST-50-16_1490101

- c. If a Switch has additional constraints on the number and size of Time-Triggered frames it supports, it shall be explicitly specified.

7.2.3.5 Forwarding Delay**ECSS-E-ST-50-16_1490102**

- a. A Switch shall specify the duration SW_MAX_FORWARD_DELAY as the maximum time elapsed between the complete reception of a TT frame and the start of its retransmission through any of its output Switch ports under the assumption that all outgoing queues are empty and the clocks in the network are synchronized.

NOTE 1 SW_MAX_FORWARD_DELAY specifies the maximum implementation specific delay from the reception of a TT frame to the latest possible point in time when the frame is ready to forward. A scheduler takes the SW_MAX_FORWARD_DELAY and the CLOCK_SYNC_PRECISION into account when calculating the SW_TT_TX_PHASE of a TT frame.

NOTE 2 SW_MAX_FORWARD_DELAY is a Switch-internal parameter. SW_TT_TX_PHASE, CLOCK_SYNC_PRECISION, and SW_TT_TX_MAX_JITTER need also to be taken into account when calculating the complete, externally observable, delay through the Switch.

7.2.4 End-System Level Specification

7.2.4.1 Introduction

An End-System acts as the source or destination of one or many Time-Triggered messages. It is the aim of this Clause to specify the transmission interface and the reception interface of an End-System in the value domain as well as in the time domain.

7.2.4.2 End-System Transmission

ECSS-E-ST-50-16_1490103

- a. An End-System shall identify a frame for transmission as a Time-Triggered frame by a lookup in an internal table.

NOTE The intent of this requirement is to make clear that the End-System operates Time-Triggered communication on a per-frame basis.

ECSS-E-ST-50-16_1490104

- b. An End-System shall associate each Time-Triggered frame it transmits with an ES_TT_TX_LENGTH, an ES_TT_TX_PERIOD, and an ES_TT_TX_PHASE.

NOTE A scheduler for Time-Triggered frames typically takes 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 frame as an output.

ES_TT_TX_LENGTH is the allowed length of an Ethernet frame including IFG and preamble:

- Minimum(ES_TT_TX_LENGTH) = IFG (12 bytes) + preamble (7 bytes) + start of frame delimiter (1 bytes) + payload (64 bytes)
- Maximum(ES_TT_TX_LENGTH) = IFG (12 bytes) + preamble (7 bytes) + start of frame delimiter (1 bytes) + payload (1518 bytes)

ES_TT_TX_PERIOD is the transmission period with which the End-System dispatches the respective Time-Triggered frame.

ES_TT_TX_PHASE is a value given by the formula:

$$ES_TT_TX_PHASE = K * ES_SCHEDULE_GRANULARITY$$

where

ES_SCHEDULE_GRANULARITY is the granularity of the schedule, and

K is a natural number such that
 $ES_TT_TX_PHASE \leq ES_TT_TX_PERIOD$
holds.

ECSS-E-ST-50-16_1490105

- c. An End-System 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 is `ES_TT_TX_PERIOD=20ms`,
`ES_SCHEDULE_GRANULARITY 20us`; which means that `ES_TT_TX_PHASE` can take any value between 0 and 20ms in 20us increments.

ECSS-E-ST-50-16_1490106

- d. An End-System shall specify its minimum duration, `ES_MIN_TT_TX_GAP`, between two consecutive Time-Triggered frames.

ECSS-E-ST-50-16_1490107

- e. An End-System shall specify the maximum duration `ES_TT_TX_MAX_JITTER` that it takes starting from the synchronized time base reaching the phase `ES_TT_TX_PHASE` in the period `ES_TT_TX_PERIOD` of a Time-Triggered frame until the first bit of the frame is placed on the transmit communication line.

ECSS-E-ST-50-16_1490108

- f. An End-System shall be able to transmit at minimum `ES_MIN_TT_TX_FRAMES` Time-Triggered frames.

ECSS-E-ST-50-16_1490109

- g. An End-System shall specify the number of `ES_TT_TX_FRAMES` Time-Triggered frames it is capable to transmit.

ECSS-E-ST-50-16_1490110

- h. An End-System shall specify the different `ES_TT_TX_PERIOD` it supports.

ECSS-E-ST-50-16_1490111

- i. An End-System shall specify the number `ES_NUM_TT_TX_PERIOD` of different `ES_TT_TX_PERIOD` it can support concurrently during operation.

ECSS-E-ST-50-16_1490112

- j. An End-System shall specify a list `ES_LIST_TT_TX_PERIOD` of different `ES_TT_TX_PERIOD` it can support during operation.

ECSS-E-ST-50-16_1490113

- k. 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.

7.2.4.3 End-System Reception**ECSS-E-ST-50-16_1490114**

- a. An End-System shall accept all incoming valid Ethernet frames.

ECSS-E-ST-50-16_1490115

- b. In case redundancy management is enabled, the End-System shall accept the first received valid Time-Triggered frame and discard all following Time-Triggered frames which are inside the configured time skew and contain the same VL ID.

ECSS-E-ST-50-16_1490116

- c. In reception, if the VL ID does not match the entry in Table 7-6, the frame shall be discarded.

7.2.5 Clock Synchronization**ECSS-E-ST-50-16_1490117**

- a. The clock synchronization shall be implemented as specified in [SAE AS6802] §7.

7.3 Configuration Parameters**7.3.1 Device Level and Clock Synchronization Parameters****7.3.1.1 Overview**

This Clause specifies the minimum set of device level parameters needed to ensure the interoperability of a TTEthernet device to be able to communicate within a TTEthernet network. These parameters can be divided into the parameters needed for the message exchange of Best-Effort, Rate-Constrained, Time-Triggered messages and parameters needed for the establishment and maintenance of the clock-synchronization.

7.3.1.2 End-System Parameters

ECSS-E-ST-50-16_1490118

- a. The scheduling parameters of an End-System device shall be configured as defined in Table 7-4.

ECSS-E-ST-50-16_1490119

Table 7-4: End-System Schedule Parameters

Parameter	Description
VL-ID	This parameter specifies the identifier of the VL to be configured.
Trigger	This parameter specifies the time when the message is scheduled to be transmitted.
ReserveMedia	This parameter specifies a trigger to reserve the media for a VL trigger.
TxEnable	This parameter specifies a trigger to send the respective VL.

ECSS-E-ST-50-16_1490120

- b. The Output VL parameters of an End-System device shall be configured as defined in Table 7-5.

ECSS-E-ST-50-16_1490121

Table 7-5: End-System Output VL Parameters

Parameter	Description
VL-ID	This parameter specifies the identifier of the VL to be configured.
Priority	This field contains the output priority of the respective VL
MaxLength	This field specifies the maximum length of frames for the respective sub VL in bytes including Ethernet header but not including Ethernet CRC checksum or an optional [ARINC 664 part 7] sequence number.
DestPort	This field specifies the ports the respective sub VL is output to.
BAG	This field specifies the BAG of the VL according to the definitions of [ARINC 664 part 7].
SN	This flag indicates whether a sequence number is to be added to frames of the respective VL.

ECSS-E-ST-50-16_1490122

- c. The Input VL parameters of an End-System device shall be configured as defined in Table 7-6.

ECSS-E-ST-50-16_1490123

Table 7-6: End-System Input VL Parameters

Parameter	Description
VL-ID	This parameter specifies the identifier of the VL to be configured.

ECSS-E-ST-50-16_1490124

- d. The Best-Effort filtering parameters of an End-System device shall be configured as defined in Table 7-7.

ECSS-E-ST-50-16_1490125

Table 7-7: End-System Best-Effort Filtering Parameters

Parameter	Description
MacAddr	This field contains the value the Ethernet destination address of input non-critical traffic frames is compared against after applying the mask provided by the MacFilter field of the entry.
MacFilter	This field contains a bit-masked to be applied (in a bit-wise-and operation) to the Ethernet destination MAC address of input non-critical traffic frames before checking them against the content of the MacAddr field of the same entry.

ECSS-E-ST-50-16_1490126

- e. The clock synchronization parameters of an End-System device shall be configured as defined in Table 7-8.

ECSS-E-ST-50-16_1490127

Table 7-8: End-System Clock Synchronization Parameters

Parameter	Description
THRESHOLDS	
IntegrateToSyncThreshold	See [SAE AS6802]
IntegrateToWaitThreshold	See [SAE AS6802]
WaitTresholdAsync	See [SAE AS6802]
UnsyncToTentativeThreshold	See [SAE AS6802]
UnsyncToSyncThreshold	See [SAE AS6802]
TentativeToSyncThreshold	See [SAE AS6802]

Parameter	Description
TentativeSyncThresholdSync	See [SAE AS6802]
TentativeSyncThresholdAsync	See [SAE AS6802]
SyncThresholdSync	See [SAE AS6802]
SyncThresholdAsync	See [SAE AS6802]
StableThresholdSync	See [SAE AS6802]
StableThresholdAsync	See [SAE AS6802]
SyncToStableEnabled	See [SAE AS6802]
CLOCK SYNC GENERAL	
IntegrationCycleDuration	See [SAE AS6802]
InitialIntegrationCycle	See [SAE AS6802]
SyncDomain	See [SAE AS6802]
ObservationWindow	See [SAE AS6802]
MembershipPosition	See [SAE AS6802]
MaxTransparentClock	See [SAE AS6802]
MaxIntegrationCycle	See [SAE AS6802]
MaxExtCorrValue	See [SAE AS6802]
ExpectedArrival	See [SAE AS6802]
AcceptanceWindowHalf	See [SAE AS6802]
SyncMaster	See [SAE AS6802]
HighIntegrity	See [SAE AS6802]
CompressionEnabled	See [SAE AS6802]
AvgMode	See [SAE AS6802]
SYNC PRIORITY	
PriorityFallbackCycles	See [SAE AS6802]
STARTUP AND RESTART	
SMListenTimeout	See [SAE AS6802]
SMColdstartTimeout	See [SAE AS6802]
SMCsOffset	See [SAE AS6802]
SMCaOffset	See [SAE AS6802]
SMRestartTimeoutSync	See [SAE AS6802]
SMRestartTimeoutAsync	See [SAE AS6802]
NumUnstableCycles	See [SAE AS6802]
NumStableCycles	See [SAE AS6802]
CaAcceptanceWindowHalf	See [SAE AS6802]
IgnoreCaInStable	See [SAE AS6802]
PCF	
PcfSize	See [SAE AS6802]

Parameter	Description
PcFldOut	See [SAE AS6802]
PcFldInMin	See [SAE AS6802]
PcFldInMax	See [SAE AS6802]
PcPriorityFilter	See [SAE AS6802]
EthSrcPCF	This parameter defines the Ethernet source MAC address that is used for output protocol control frames.
OutDelay	This field provides the initial value for the transparent clock field of output protocol control frames. It is used to compensate for the delay introduced by circuitry outside of the IP, the PHY, and potentially also the transport delay on the wire.
InDelay	This field provides a correction value that is added to the transparent clock field of input protocol control frames. It is used to compensate for the delay introduced by circuitry outside of the IP, the PHY, and potentially also the transport delay on the wire.

ECSS-E-ST-50-16_1490128

- f. The general parameters of an End-System device shall be configured as defined in Table 7-9.

ECSS-E-ST-50-16_1490129

Table 7-9: End-System General Parameters

Parameter	Description
CTMarker	Provides the upper 32 bits of the Ethernet destination MAC address of frames considered critical traffic.
SourceMacAddress	Provides the Ethernet source address used by frames sent through any data port type.

7.3.1.3 Switch Parameters

ECSS-E-ST-50-16_1490130

- a. The scheduling parameters of a Switch device shall be configured as defined in Table 7-10.

Table 7-10: Switch Scheduling Parameters

Parameter	Description
WindowStart	Indicates that the reception window of the entry of the VL starts here.
WindowEnd	Indicates that the reception window of the entry of the VL ends here.
DestPort	Defines the ports the respective VL is routed to.
VL-ID	This parameter specifies the identifier of the VL to be configured.
Trigger	This parameter defines the time when the message is scheduled to be transmitted.
ReserveMedia	This parameter identifies a trigger to reserve the media for a VL trigger.
TxEnable	This parameter identifies a trigger to send the respective VL.

ECSS-E-ST-50-16_1490132

- b. The output VL parameters of a Switch device shall be configured as defined in Table 7-11.

ECSS-E-ST-50-16_1490133

Table 7-11: Switch Output VL Parameters

Parameter	Description
VL-ID	This parameter specifies the identifier of the VL to be configured.
EntryType	This parameter defines if the VL is Time-Triggered or Rate-Constrained.
MaxLength	This field defines the maximum length of frames for the respective sub VL in bytes including Ethernet header but not including Ethernet CRC checksum or an optional [ARINC 664 part 7] sequence number.
Jitter	The bandwidth allocation gap (BAG) jitter value to be used for this entry.
BAG	The bandwidth allocation gap (BAG) value to be used for this entry.

ECSS-E-ST-50-16_1490134

- c. The input VL parameters of a Switch device shall be configured as defined in Table 7-12.

ECSS-E-ST-50-16_1490135

Table 7-12: Switch Input VL Parameters

Parameter	Description
VL-ID	This parameter specifies the identifier of the VL to be configured.
Port	This field contains the number of the port the respective VL ID is allowed at.

ECSS-E-ST-50-16_1490136

- d. The Best-Effort filtering parameters of a Switch device shall be configured as defined in Table 7-13.

ECSS-E-ST-50-16_1490137

Table 7-13: Switch Best-Effort Filtering Parameters

Parameter	Description
MacAddr	This field contains the value of one Ethernet destination address of input non-critical traffic frames.
DestPort	Defines the ports to which frames carrying MacAddr as destination MAC address is routed to.

ECSS-E-ST-50-16_1490138

- e. The clock synchronization parameters of a Switch device shall be configured as defined in Table 7-14.

ECSS-E-ST-50-16_1490139

Table 7-14: Switch Clock Synchronization Parameters

Parameter	Description
THRESHOLDS	
IntegrateToSyncThreshold	See [SAE AS6802]
WaitTresholdSync	See [SAE AS6802]
UnsyncToTentativeThreshold	See [SAE AS6802]
UnsyncToSyncThreshold	See [SAE AS6802]
TentativeToSyncThreshold	See [SAE AS6802]
TentativeSyncThresholdSync	See [SAE AS6802]

Parameter	Description
TentativeSyncThresholdAsync	See [SAE AS6802]
SyncThresholdSync	See [SAE AS6802]
SyncThresholdAsync	See [SAE AS6802]
StableThresholdSync	See [SAE AS6802]
StableThresholdAsync	See [SAE AS6802]
IntegrateToTentativeThreshold	See [SAE AS6802]
IntegrateToSyncThreshold	See [SAE AS6802]
CLOCK SYNC GENERAL	
IntegrationCycleDuration	See [SAE AS6802]
InitialIntegrationCycle	See [SAE AS6802]
SyncDomain	See [SAE AS6802]
ObservationWindow	See [SAE AS6802]
MembershipSrcPort(N)	See [SAE AS6802]
MembershipSrcPort (...)	See [SAE AS6802]
MembershipSrcPort(0)	See [SAE AS6802]
MaxTransparentClock	See [SAE AS6802]
MaxIntegrationCycle	See [SAE AS6802]
TentativeSyncRelayEnabled	See [SAE AS6802]
TentativeSyncMembershipAsyncEnabled	See [SAE AS6802]
SyncToStableEnabled	See [SAE AS6802]
SyncRelayEnabled	See [SAE AS6802]
SyncMembershipSyncEnabled	See [SAE AS6802]
SyncMembershipAsyncEnabled	See [SAE AS6802]
StableMembershipAsyncEnabled	See [SAE AS6802]
AcceptanceWindowHalf	See [SAE AS6802]
CmMaster	See [SAE AS6802]
FullCbg	See [SAE AS6802]
SYNC PRIORITY	
PriorityFallbackCycles	See [SAE AS6802]
TIMEOUTS	
ListenTimeout	See [SAE AS6802]
CaEnabledTimeout	See [SAE AS6802]
Wait4In0Timeout	See [SAE AS6802]
NumStableCycles	See [SAE AS6802]
NumUnstableCycles	See [SAE AS6802]
PCF	
PcfSize	See [SAE AS6802]

Parameter	Description
PcfPriority	See [SAE AS6802]
PcfIdOut	See [SAE AS6802]
PcfIdInMin	See [SAE AS6802]
PcfIdInMax	See [SAE AS6802]
PcfPriorityFilter	See [SAE AS6802]
EthSrcPCF	This parameter defines the Ethernet source MAC address for output protocol control frames.
OutDelay	This field provides the initial value for the transparent clock field of output protocol control frames. It is used to compensate for the delay introduced by circuitry outside of the IP, the PHY, and potentially also the transport delay on the wire.
InDelay	This field provides a correction value added to the transparent clock field of input protocol control frames. It is used to compensate for the delay introduced by circuitry outside of the IP, the PHY, and potentially also the transport delay on the wire.

ECSS-E-ST-50-16_1490140

- f. The CT-Marker parameter of a Switch device shall be configured as defined in Table 7-15.

ECSS-E-ST-50-16_1490141

Table 7-15: Switch General Parameter

Parameter	Description
CTMarker	Provides the upper 32 bits of the Ethernet destination MAC address of frames considered critical traffic.

7.4 Configuration and Scheduling guideline

7.4.1 Overview

This Clause provides additional guidelines for configuration regarding delays, latencies, synchronization and scheduling topics. A proper configuration of the network devices is important to ensure an appropriate synchronization precision of the network schedule when implementing Time-Triggered Ethernet at system level.

7.4.2 Delays

First of all, the different delays introduced by hardware are presented.

In a TTE network, the different delays introduced by the hardware have an impact on:

- PCF transmissions and so the synchronization between devices (synchronization precision):
 - o Drift between ground clock (perfect clock) and board clock along the entire mission,
 - o Drift between devices of the same network during each integration cycle,
 - o Timestamp accuracy.
- TT frames transmissions and so the definition of the scheduling:
- Maximum propagation delay for one node to another,
- Size of receive windows.

At system level, a first list of delays can be defined as illustrated in Figure 7-2:

- Wrapper delays
- PHY delays
- Media delays (cable delays)
- Forward delays (switching delays)

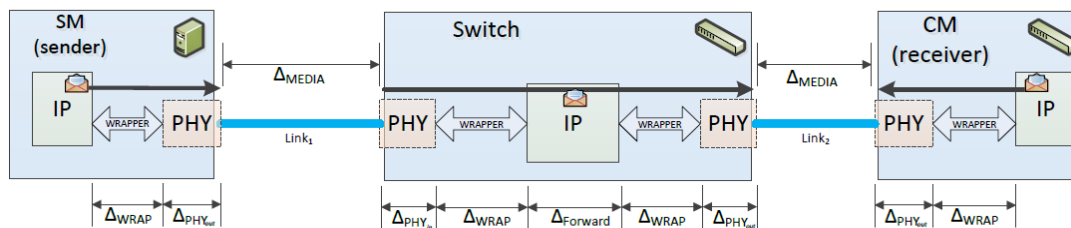


Figure 7-2: Example of delays at system level

After that, going more deep in a typical IP, refinements can be made and additional delay types can be added as illustrated in Figure 7-3:

- Controller schedule delays
- Controller synchronization delays
- Controller interface delays

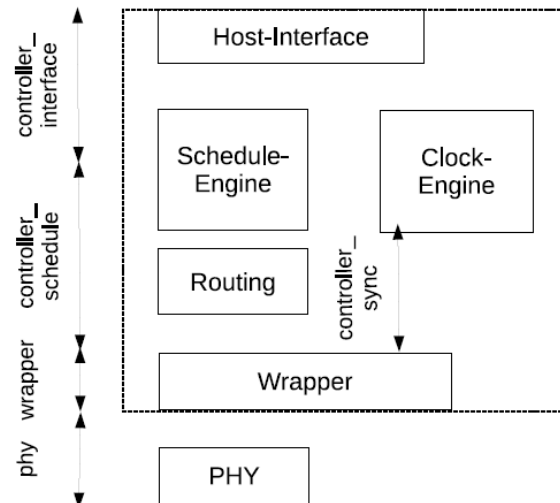


Figure 7-3: Example of delays related to a device

Regarding that, as presented in the following Figure 7-4, additional errors can be propagated on the synchronization precision of the network because of the variability of the propagation delays (internal and external).

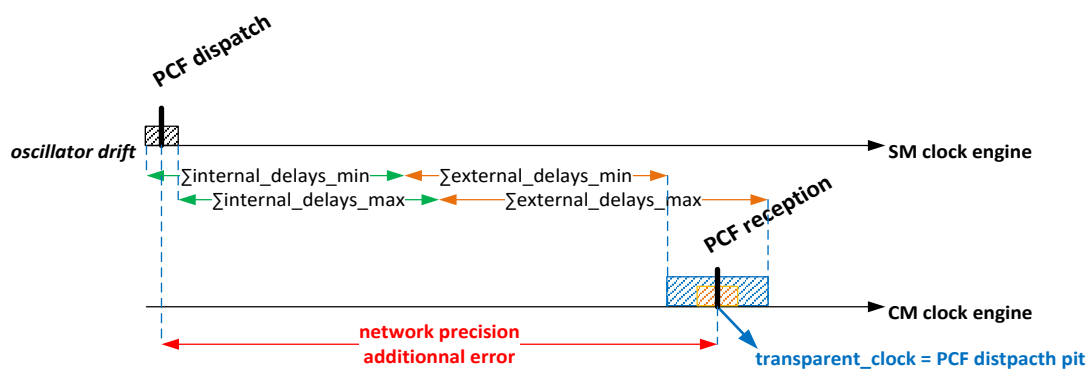


Figure 7-4: Impact of delays on synchronization precision

To increase the synchronization precision of the network and fulfil the precision target, internal and external delays should be compensated (see following Clauses for the precision calculation).

7.4.3 Latencies

The latency of the path for any given PCF, $T_DELTA(PCF_i)$, in a contention-free scenario (i.e. without interference of other network traffic) is computed as the time it takes from a given PCF_i originated at a SM to reach the destination CM, or the other way round, to reach the corresponding SM when originated at the CM.

The worst-case latency, $T_DELTA_MAX(PCF_i)$, accounts for the propagation delay through physical links at their respective media speed, the transmission delay of the PCF frame itself at each hop, in addition to the maximum value for all other delays encountered along the path at each ingress or egress port (e.g.

PHY latency, Wrapper, Controller, ...), as well as the forwarding latency of each Switch traversed along the path.

The best-case latency, $T_DELTA_MIN(PCF_i)$, is defined analogously by taking the same delays but with minimum values instead.

7.4.4 Transparent clock

The transparent clock is defined by the sum of the delays on a path from the sender (of a PCF) to the receiver which are taken into account by the transparent clock update function of each device.

$T_DELTA_MAX_NC(PCF_i)$ is defined as $T_DELTA_MAX(PCF_i)$ but taking into account only delays which are not compensated in the `pcf_transparent_clock` field in PCF (external delays).

The same apply to $T_DELTA_MIN_NC(PCF_i)$ regarding $T_DELTA_MIN(PCF_i)$.

To obtain the maximum transparent clock in a network, it is necessary to calculate the sum of the delays for each path from ES to Switch CM and from Switch CM to ES.

7.5 Scheduling requirements

7.5.1 Delays to be identified

ECSS-E-ST-50-16_1490142

- a. The static delays, which depend on the physical conditions, shall be identified with minimum and maximum values defined for each use case.

NOTE For example, static delays that can be induced by wrappers, transceivers or cables.

ECSS-E-ST-50-16_1490143

- b. The dynamic delays, which depend on the load in the network, shall be identified with minimum and maximum values defined for each use case.

NOTE For example, dynamic delays due to buffering or computation.

7.5.2 Delays compensation

ECSS-E-ST-50-16_1490144

- a. Each node should update the `pcf_transparent_clock` field of PCF with the accumulated internal delays (as defined in [SAE AS6802] §5.3).

NOTE That allows to reduce the uncertainty on the PCF reception as presented in Figure 7-5.

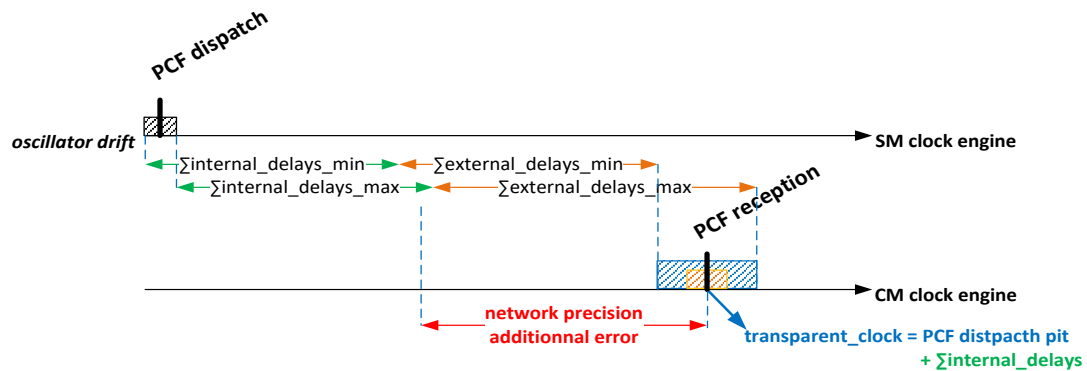


Figure 7-5: Impact of delays on synchronization precision

ECSS-E-ST-50-16_1490145

- b. Regarding external delays, each node should allow to configure an external delay value for each physical port in both ways (Rx/Tx).

ECSS-E-ST-50-16_1490146

- c. External delay configurable values should be set to the mean value of the related delay range (average between minimum and maximum value).

ECSS-E-ST-50-16_1490147

- d. Each node should update the `pcf_transparent_clock` field of PCF with the appropriate (regarding the physical port used and the way of the transmission) configurable value of external delay (as defined in [SAE AS6802] §5.3).

NOTE That allows to reduce again the uncertainty on the PCF reception as presented in Figure 7-6.

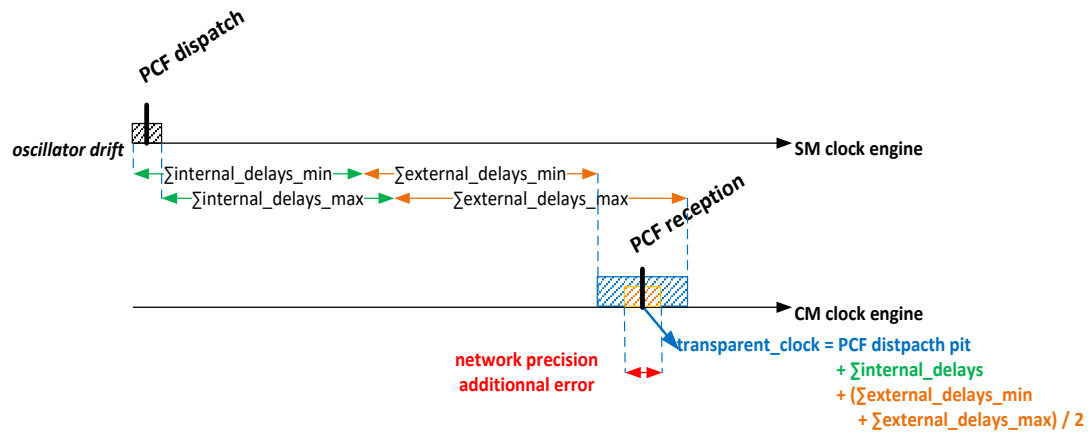


Figure 7-6: Impact of delays on synchronization precision

7.5.3 PCF latency

ECSS-E-ST-50-16_1490148

- a. The maximum PCF latency among all PCFs should be defined according to the following formula:

$$\text{MAX_PCF_LATENCY} = \max(T_DELTA_MAX(\text{PCF}_j) : \text{for all } j)$$

NOTE This value is the minimum bound to be used in the computation of the maximum transparent clock (see below). Any larger value is possible, although the parameter has a relation to the minimum integration cycle duration and indirectly affects the precision quality.

7.5.4 Maximum transparent clock

ECSS-E-ST-50-16_1490149

- a. The global maximum transparent clock of the network should be defined according to the following formula:

$$\begin{aligned} \text{max_transparent_clock} &= \text{MAX_PCF_LATENCY} \\ &+ (\text{MAX_BE_SHUFFLING} + \text{PCF_SHUFFLING}) \times \text{PCF_num_hops} \\ &+ T_PCF_reception \end{aligned}$$

NOTE 1 Refer to Table 7-16 for parameters description.

NOTE 2 This value is an upper bound for the worst-case latency of any PCF. Any value larger than this bound is possible, although the parameter has a relation to the minimum integration cycle.

Table 7-16: Max Transparent Clock parameter table

Parameter	Description
MAX_BE_SHUFFLING = $1538 \times 8 / \text{SPEED}$	assuming the largest possible frame-size in case of Shuffling (null if shuffling is not used)
PCF_SHUFFLING = $84 \times 8 / \text{SPEED}$	if the size of the PCF is configured to be a min-size Ethernet frame
PCF_num_hops	is the maximum number of links in the path of a PCF
T_PCF_reception	is the necessary residual time for a PCF on reception (a PCF must be received with at least this margin till the end of the max_transparent_clock to be considered in time) – This time is implementation dependent.

7.5.5 PCF transparent clock jitter

ECSS-E-ST-50-16_1490150

- a. The maximum jitter bound for PCFs in a contention-free scenario should be the maximum difference between best- and worst-case latency among all PCFs as per the following formula:

$$MAX_PCF_JITTER = \max([T_DELTA_MAX_NC(PCF_j) - F_j] \Delta_MAX_NC(PCF_j)] : \text{forall } j)$$

NOTE This value is the minimum bound to be used in the computation of the precision parameter (see below). Any larger value is possible, although the parameter has a relation to the minimum integration cycle duration and directly affects the precision quality.

7.5.6 Precision parameter

ECSS-E-ST-50-16_1490151

- a. The precision parameter should include the oscillator drifts impacts and the non-compensated part of the static delays (PCF transparent clock jitter) as per the following formula:

$$Precision = FACTOR \times (DRIFT_INT + 2 \times MAX_PCF_JITTER) + 2 \times DRIFT_INT \times nEsNumUnstableCycles$$

NOTE 1 Refer to Table 7-17 for parameters description.

NOTE 2 This value is the minimum bound to be used. Any larger value is possible, although the parameter has a relation to the acceptance windows size (PCF and TT frames).

Table 7-17: Precision parameter Table

Parameter	Description
FACTOR	With 1FT hypothesis → FACTOR = 8/3 With 2FT hypothesis → FACTOR = 12/3 = 4
DRIFT_INT = OSC_PPM × T_INT	maximum drift of a local clock during one integration cycle
MAX_PCF_JITTER	This term is multiplied by 2 to take into account the unknowns on the delays (as margins).
nEsNumUnstableCycles	Configurable IP parameter related to how many integration cycles may be tolerated without enough PCFs being received (see [SAE AS6802] standard).

7.5.7 Time-Triggered minimum gap

ECSS-E-ST-50-16_1490152

- a. The minimum gap between two scheduled virtual links (VL1, VL2) sent by the same End-System should be defined according to the following formula:

$$\text{min_gap} = \text{vl2_tx_pit} - \text{vl1_tx_pit} = \text{vl1_duration} + \text{IFG} + \text{Preamble} + \text{SFD}$$

NOTE This value is the minimum bound to be used. Any larger value is possible well but the bandwidth usable for TT messages on the related links is decreased. Overlapping Tx windows causes frames to queue on egress if the distance between scheduled send events is less than the min_gap.

7.5.8 Time-Triggered Switch receive window

ECSS-E-ST-50-16_1490153

- a. For each TT frames received by a Switch, the receive window, acceptance window, should be defined by a start time and an end time respecting the two formulas provided on Table 7-18.

ECSS-E-ST-50-16_1490154

Table 7-18: TT Switch Receive Window start and end time

$$\begin{aligned} \text{receive_window_start} &= \text{vl_tx_pit} \\ &+ \text{es_tx_external_delay_min} \\ &+ \text{es_tx_internal_delay_min} \\ &+ \text{cable_delay_min} \\ &+ \text{sw_rx_external_delay_min} \\ &+ \text{sw_rx_internal_delay_min} \end{aligned}$$

+ <i>min_frame</i> - <i>Precision</i>
$receive_window_end = vl_tx_pit$ + <i>es_tx_external_delay_max</i> + <i>es_tx_internal_delay_max</i> + <i>cable_delay_max</i> + <i>sw_rx_external_delay_max</i> + <i>sw_rx_internal_delay_max</i> + <i>max_vl_duration</i> + $PCF_SHUFFLING \times NB_MAX_PCF_ON_LINK$ + $MAX_BE_SHUFFLING$ + <i>Precision</i>

- NOTE 1 Refer to Table 7-19 for parameters description
- NOTE 2 The calculated window with these formulae's is the smallest possible one. Any larger values are possible but the determinism of the reception will then decrease.
- NOTE 3 Overlapping Rx windows are not an issue since an Rx window is necessarily larger than Tx window for the same frame (due to e.g. the clock domain offset between sender and receiver makes the Rx window 2 x precision larger –to cover the two extreme situations in which the sender is 1 precision ahead of time with respect to the receiver as well as 1 precision behind).

Table 7-19: Time-Triggered Switch receive window Table

Parameter	Description
$MAX_BE_SHUFFLING = 1538 \times 8 \div SPEED$	assuming the largest possible frame-size in case of Shuffling (null if shuffling is not used)
$PCF_SHUFFLING = 84 \times 8 \div SPEED$	if the size of the PCF is configured to be a min-size Ethernet frame
$NB_MAX_PCF_ON_LINK$	is the maximum number of PCF transmitted on the link (depends on the topology)
$sw_rx_to_wnd_min$	is an IP implementation dependent value defining the time until the rx evaluation point within the IP.
min_frame	is the time of a minimum frame size for the VL at the given network speed. A generic value corresponding to the minimum Ethernet frame size can be used: $min_frame = 84 \times 8 \div SPEED$

7.5.9 Time-Triggered Switch minimum transmission

ECSS-E-ST-50-16_1490155

- a. The minimum gap between a `receive_window_end` of a virtual link and the `vl_tx_pit` of the same virtual link should be: `sw_min_transmission = 0`

NOTE The end of the Rx window (as computed above) includes the worst-case scenario (maximum delays, maximum interference, maximum clock offset between sender and receiver) until the frame is in the buffer and ready to be triggered for transmission.

7.5.10 Time-Triggered End-System reception

ECSS-E-ST-50-16_1490156

- a. A Switch connected to an End-System configured to receive a TT frame at `T_es_receive` should send the frame at `T_sw_send`.

NOTE Even if there is no timing filtering in reception on End-System part, it is still important to well define the sending time of the connected Switch to respect receive time constraint

ECSS-E-ST-50-16_1490157

- b. The maximum value for `T_sw_send` should be defined by the formula:

$$T_{sw_send} \leq T_{es_receive}$$

- `sw_tx_internal_max`
- `sw_tx_external_delay_max`
- `cable_delay_max`
- `es_rx_external_delay_max`
- `es_rx_internal_delay_max`
- `PCF_SHUFFLING` × `NB_MAX_PCF_ON_LINK`
- `MAX_BE_SHUFFLING`
- *Precision*

NOTE This value is the maximum bound to be used. Any lower value is possible to respect the receive time constraint. In case of media reservation usage, the parameter `MAX_BE_SHUFFLING` can be omitted.

8

Network Setup and Services

8.1 Overview

This Clause specifies how the network setup is performed by means of loading the configurations onto the network, how the network is monitored and how error management is handled.

It also describes diagnostics and monitoring mechanisms which are provided by the network components. Such mechanisms aim at collecting raw data, organize them and make them available so that the end user (application or operator) is able to perform the spacecraft FDIR.

To operate a Time-Triggered Ethernet network all components communicating via critical traffic need to be configured in a consistent manner. Moreover, the system needs to be aware of the health status of these components for the overall system FDIR.

The related management services is described within this Clause:

- The Dataloading of the application- and the configuration-data via TFTP
- The Diagnostic and Status-Information of the network via SNMP
- The required Error management functionalities of and End-System and Switch

Since spacecraft networks consist of low complex End-Systems on the network, these services are optional because for e.g. sensor and actuator nodes dataloading via the TFTP protocol is not needed because the configuration could also be hard coded directly into the device. Also, the diagnostics and status information can be transmitted via standard (TT, RC or BE) messages without using the SNMP protocol.

This standard lists the data to be collected but not how to interpret them. Interpretation and analysis of those data are use case and topology specific and can't be covered in such documentation.

When designing the network architecture, the diagnostics and monitoring mechanism can be tailored to cover the application specificity (see Figure 8-1).

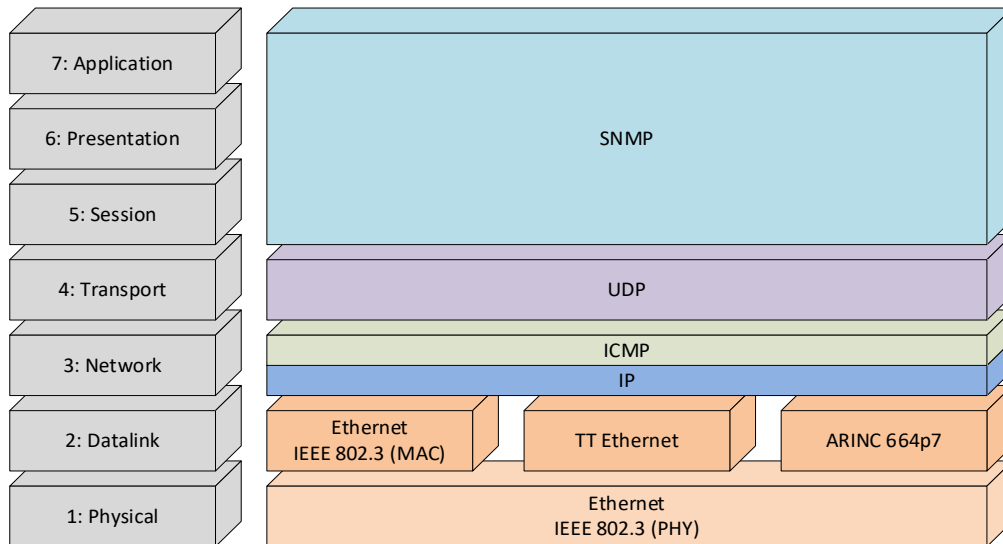


Figure 8-1: Network Diagnostic and Monitoring Service Layers

8.2 General Requirements

8.2.1 Overview

This Clause specifies the protocol support that is needed to support upper layer functionalities which are used to ensure the interoperability between the nodes in the network.

8.2.2 Internet Protocol (IP)

ECSS-E-ST-50-16_1490158

- a. In transmission, the IPv4 packet structure shall be compliant with [RFC 791] 13 fields defined as follow:
 1. Version: 4 bits (0100)
 2. Header Length: 4 bits (0101)
 3. Type of Service: 1 byte (0x00)
 4. Total Length: 2 bytes
 5. Fragment Identification: 2 bytes
 6. Control Flags: 3 bits
 7. Fragment Offset: 13 bits
 8. Time to Live: 1 byte
 9. Protocol: 1 byte
 10. Header Checksum: 2 bytes
 11. Source IP Address: 4 bytes
 12. Destination IP Address: 4 bytes
 13. IP Payload: 1-1479 bytes

ECSS-E-ST-50-16_1490159

- b. In transmission, in the IPv4 packet structure, the Version field shall be equal to 4 in decimal notation to indicate IP version 4.

ECSS-E-ST-50-16_1490160

- c. In reception, in the IP layer, if a check of the Version field is performed and fails, the frame shall be discarded.

NOTE It is not required to check of the Version field in reception.

ECSS-E-ST-50-16_1490161

- d. In transmission, In the IPv4 packet structure, the Internet Header Length (IHL) field shall be equal to 5 in decimal notation.

ECSS-E-ST-50-16_1490162

- e. In reception, in the IP layer, if a check of the Internet Header Length (IHL) is performed and fails, the frame shall be discarded.

NOTE It is not required to check the Internet Header Length (IHL) in reception.

ECSS-E-ST-50-16_1490163

- f. In transmission, without fragmentation, in the IPv4 packet structure, the IP length shall be equal to the UDP length + 20 bytes.

ECSS-E-ST-50-16_1490164

- g. In reception, if the IP datagram is not fragmented, and if the IP length is not equal to the UDP length + 20 bytes, the frame shall be discarded.

ECSS-E-ST-50-16_1490165

- h. In transmission, in the IPv4 packet structure, the Time to Live field shall be equal to 1.

NOTE To avoid propagation through routers.

ECSS-E-ST-50-16_1490166

- i. In reception, in the IP layer, the Time to live field shall not be checked.

NOTE This constant field does not need to be checked. All fields in the IP layer are filled in emission according to IPv4. Moreover, in reception, the receiver does not use these fields to take decision: if such fields are corrupted, it is fully transparent for the application.

ECSS-E-ST-50-16_1490167

- j. In reception, the frame shall be deleted if the Protocol Type Field of the IP layer is not supported by the End-System.

ECSS-E-ST-50-16_1490168

- k. In the IPv4 packet structure, the header checksum field shall be the 16 bit's one's complement of the one's complement sum of all 16 bit words in the header.

ECSS-E-ST-50-16_1490169

- l. In reception, if a check of the IP Header Checksum is performed and fails, the frame shall be discarded.

NOTE It is not required to check the IP Header Checksum in reception.

8.2.3 UDP

ECSS-E-ST-50-16_1490170

- a. In transmission, the UDP packet structure shall be compliant with [RFC 768] with 5 fields defined as follow
1. Source Port: 16 bits
 2. Destination Port: 16 bits
 3. Length: 16 bits
 4. Checksum: 16 bits
 5. UDP Payload: 1-8 Kbytes

ECSS-E-ST-50-16_1490171

- b. In transmission, the Length field shall be the length in bytes of the User Datagram including the header and the data.

ECSS-E-ST-50-16_1490172

- c. In reception, if the UDP length - 8 bytes is greater than the buffer size, the frame shall be discarded and the MIB counter "UDPInError" be incremented.

ECSS-E-ST-50-16_1490173

- d. In transmission, in the UDP structure, the Checksum field shall be set to 0.

NOTE The checksum field is not used in UDP.

ECSS-E-ST-50-16_1490174

- e. In reception, if a check of the UDP Checksum field is performed and fails, the frame shall be discarded.

NOTE It is not required to check the UDP Checksum in reception.

8.2.4 ICMP

ECSS-E-ST-50-16_1490175

- a. Switches and End-Systems shall support ICMP using BE traffic class.

NOTE Since RC traffic class is optional, the BE traffic class is used for ICMP.

ECSS-E-ST-50-16_1490176

- b. A Switch shall be able to reply to an ICMP echo or echo reply request as specified in [RFC 792] version 1.

ECSS-E-ST-50-16_1490177

- c. An End-System shall be able to reply to an ICMP echo request as specified in [RFC 792] version 1.

ECSS-E-ST-50-16_1490178

- d. In the ICMP structure, the Type field shall be: 8 for an echo message, 0 for an echo reply message.

NOTE Most relevant types for space applications.

ECSS-E-ST-50-16_1490179

- e. In reception, if the ICMP Type field is not supported, the frame shall be discarded and the MIB counter "ProtocolInError" be incremented.

ECSS-E-ST-50-16_1490180

- f. In reception, in the ICMP structure, if a check of the Checksum is performed and fails, the frame shall be discarded.

NOTE It is not required to check the ICMP Checksum in reception.

ECSS-E-ST-50-16_1490181

- g. In reception, in the ICMP structure, if the data field is not in the range 1 to 64 bytes, the frame shall be discarded.

ECSS-E-ST-50-16_1490182

- h. If ICMP is implemented, it shall be available after power on of the network interface.

NOTE For factory, test, validation application.

ECSS-E-ST-50-16_1490183

- i. If an ICMP frame carries an ICMP service type different from 0, 3, 8 or 11, the frame shall be discarded and the MIB counter ICMPProtocolInError be incremented.

NOTE They are the 4 allowed ICMP services.

8.3 Dataloading via TFTP

8.3.1 Trivial File Transfer Protocol (TFTP) Overview

This service is optional: when implemented, all requirements defined in clause 8.3.2 are applicable.

TFTP is a simple protocol to transfer files. It is implemented on top of the Internet User Datagram protocol (UDP or Datagram). It is designed with low complexity and therefore the implementation can be done with very low effort. It reads and writes files from/to a remote server. In common with other Internet protocols, it passes 8bit bytes of data.

Any transfer begins with a request to read or write a file, which also serves to request a connection. If the server grants the request, the connection is opened, and the file is sent in fixed length blocks of 512 bytes. Each data packet contains one block of data and is acknowledged by an acknowledgment packet before the next packet can be sent. A data packet of less than 512 bytes signals termination of a transfer. If a packet gets lost in the network, the intended recipient timeouts and can retransmit his last packet (which can be data or an acknowledgment), thus causing the sender of the lost packet to retransmit that lost packet. The sender has to keep just one packet on hand for retransmission, since the lock step acknowledgment guarantees that all older packets have been received. Notice that both machines involved in a transfer are considered senders and receivers. One sends data and receives acknowledgments; the other sends acknowledgments and receives data.

The TFTP protocol has basically 5 types of messages as given in Figure 8-2 below:

- The RRQ and WRQ messages are used by the client to request the server to start reading or writing a file respectively. Both these messages send the file name and transfer mode (ASCII or binary) as additional parameters.
- The DATA messages carry the actual file blocks, with each message carrying a block of data. Each block has a sequence number field indicating the block number.
- The ACK message is used to acknowledge successfully received data blocks. It has the sequence number as the additional parameter, indicating the block number that was successfully received. Whenever a block is received error free (indicated by the UDP checksum), then the receiving TFTP node immediately acknowledges the block to the peer, by sending an ACK message.
- The ERROR message is sent to the peer whenever some operation could not be performed (e.g. invalid file name, file does not have read/write permissions etc.).
- TFTP protocol has been enhanced to allow for additional option negotiations like initial sequence number, block size etc.

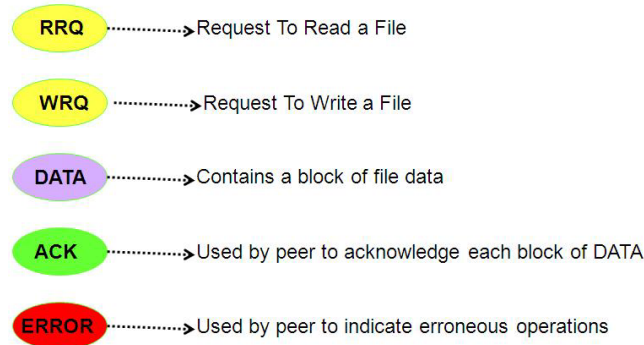


Figure 8-2: FTP Message Types

8.3.2 Dataloading requirements

ECSS-E-ST-50-16_1490184

- a. The Switches should use the TFTP client according to [RFC 1350] and [RFC 768] functionality for downloading and uploading of configuration and firmware.

ECSS-E-ST-50-16_1490185

- b. The End-Systems should use the TFTP client according to [RFC 1350] and [RFC 768] functionality for downloading and uploading of configuration and firmware.

ECSS-E-ST-50-16_1490186

- c. A TFTP server according to [RFC 1350] and [RFC 768] should be used to provide the configuration and application data to the network.

ECSS-E-ST-50-16_1490187

- d. In the UDP port, if a buffer overflow occurs in reception, an ERROR packet (opcode 5) should be sent to the client and the frame be discarded.

ECSS-E-ST-50-16_1490188

- e. Each TFTP client and server should support the following configurable parameters:
 1. Default Timeout: sets the packet timeout.
 2. Retry Count: sets the retry limit.

NOTE The use of [RFC 2349] (TFTP Timeout Interval and Transfer Size Options) to define the Timeout as a negotiated parameter under the framework defined by [RFC 1782] (TFTP Option Extension) is not considered in this standard.

8.4 Diagnostics and Status-Information via SNMP

8.4.1 Simple Network Management Protocol (SNMP) Overview

This service is optional: when implemented, all requirements defined in clauses 8.4.2, 8.4.3 and 8.4.4 are applicable.

Simple Network Management Protocol (SNMP) is mainly used in network management systems to monitor network-attached devices for conditions that warrant administrative attention. It is the most popular network management protocol in the TCP/IP protocol suite.

SNMP is a request/response protocol that communicates management information between two types of SNMP software entities: SNMP managers and SNMP agents. The following picture in Figure 8-3 shows an exemplary setup:

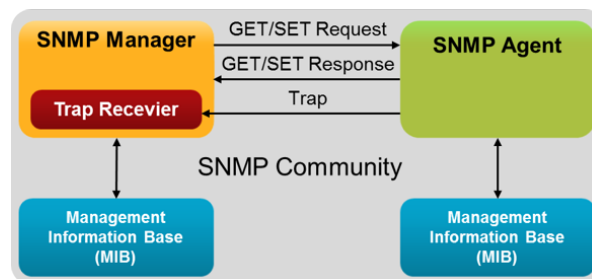


Figure 8-3: Simple Network Management Protocol (SNMP)

For space application it has been decided to use the SNMPv1 which has been judged as sufficient to cover the technical needs. There is no backward compatibility between SNMPv2 and after with SNMPv1.

In summary, SNMP performs the following operations:

- The GET operation receives a specific value about a managed object, such as the available hard disk space from the agent's MIB.
- The GET-NEXT operation returns the "next" value by traversing the MIB tree of managed object variables.
- The SET operation changes the value of a managed object's variable. Only variables whose object definition allows read/write access can be changed.
- The Trap operation sends a message to the Management Station when a change occurs in a managed object, and that change is important enough to send an alert message.

The SNMP Agent validates each request from a SNMP manager before responding to the request, by verifying that the manager belongs to a SNMP community with access privileges to the agent. A SNMP community is a logical relationship between a SNMP agent and one or more SNMP managers. The community has a name, and all members of a community have the same access privileges: either read-only or read-write.

The data base controlled by the SNMP Agent is referred to as the SNMP Management Information Base (MIB). It is a standard set of statistical and control values. SNMP allows the extension of these standard values with values specific to a particular agent through the use of private MIBs.

The goals of the SNMP protocol are:

- Monitor the global status of equipment (active, inactive, partially operational);
- Manage exceptional events such as the loss of a link network or an abrupt shutdown of an equipment;
- Analyse different metrics to anticipate future problems such as network congestion;
- Act on some elements of the configuration of the equipment.

The different elements that can be identified with the SNMP protocol are summarized by the diagram at Figure 8-4 in which:

- The SNMP agent is the application embedded in the equipment to supervise.
- The SNMP supervisor is a central machine from which an operator can supervise its entire infrastructure in real-time, diagnose problems to help troubleshooting.
- The SNMP protocol is the protocol used by SNMP agents and their supervisors to communicate with each other.
- The MIB is the information Dynamics instantiated by the various SNMP agents and lifts in real-time to the supervisor.
- The SNMP tools are the different utilities used by the supervisor to help diagnose a problem. These tools are also used when you set up the supervisor to take into account the specificities of the infrastructure.

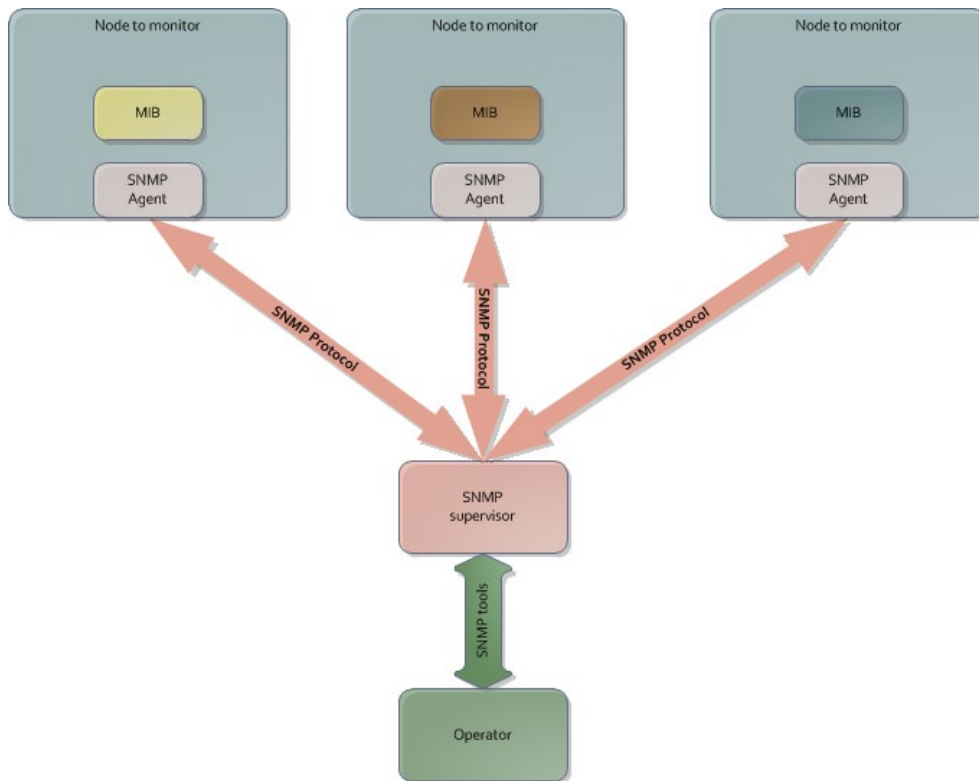


Figure 8-4: Global SNMP architecture

8.4.2 SNMP requirements

ECSS-E-ST-50-16_1490189

- a. The Switch should use the SNMP Agent functionality according to [RFC 1157] to provide its diagnostics and status information from the Switch.

ECSS-E-ST-50-16_1490190

- b. A host connected to an End-System should implement the SNMP Agent functionality according to [RFC 1157] to provide its diagnostics and status information from the Switch.

ECSS-E-ST-50-16_1490191

- c. An SNMP Manager according to [RFC 1157] should be used on a host connected to the network to perform the network management tasks needed.

8.4.3 Diagnostic and Status-Information requirements

8.4.3.1 End-System Management Information Database (MIB) requirements

ECSS-E-ST-50-16_1490192

- a. In reception, if a frame of the End-System does not have a correct length, the MIB counter `MACRxFramesErrors` should be incremented.

NOTE Ethernet II MAC Length:

- For MAC length=64 bytes, if the IP length (in bytes) + K1 bytes is greater than 64 bytes.
- For MAC length>64 bytes, if the MAC length (in bytes) is not equal to IP length (in bytes) + K1 bytes.

K1 is equal to 18 bytes if SN is not used and equal to 19 if SN is used, MAC length does not include the FCS length (4 bytes).

[IEEE 802.3] MAC Length:

- For MAC length=64 bytes, if the Ethernet length (in bytes) + 18 bytes is greater than 64 bytes.
- For MAC length>64 bytes, if the MAC length (in bytes) is not equal to Ethernet length (in bytes) + 18 bytes.

MAC length does not include the FCS length (4 bytes).

ECSS-E-ST-50-16_1490193

- b. In reception, if the End-System is designed to handle new frame although the interframe gap has been smaller than 11 bytes, the MIB counter `tteIFGErr` should be incremented.

ECSS-E-ST-50-16_1490194

- c. In reception, if a frame is discarded due to invalid size, the MIB counter `tteEsEthPortNoLossLengthError` should be incremented.

ECSS-E-ST-50-16_1490195

- d. In reception, if a frame has to be discarded because the receiving buffer was full, the MIB counter `tteDropNoMem` counter should be incremented.

ECSS-E-ST-50-16_1490196

- e. In an End-System, when a MIB is implemented, it should at least contain the following fields at the root:
1. tteSyncState - containing the TTE clock synchronization state
 2. tteSyncLoss - counter of the number of transitions to from SYNC or STABLE state to any other state

ECSS-E-ST-50-16_1490197

- f. In an End-System, when a MIB is implemented, it should have an entry called "configuration".

ECSS-E-ST-50-16_1490198

- g. In an End-System, when a MIB is implemented, the entry called "configuration" should at least contains the following fields:
1. tteDevId - containing the End-System device ID
 2. tteDevRev - containing the End-System device revision
 3. tteDevItfRev - containing the End-System interface revision

NOTE To allow identifying an End-System.

ECSS-E-ST-50-16_1490199

- h. In an End-System tteEsCfgSignature should containing the signature of the configuration file.

ECSS-E-ST-50-16_1490200

- i. If a check of the ICMP Header Checksum of the End-System is performed and fails, the frame should be discarded and the MIB counter ICMPProtocolInError be incremented.

ECSS-E-ST-50-16_1490201

- j. If the structure of an ICMP frame is checked and fails, the frame should be discarded and the MIB counter ICMPProtocolInError be incremented.

ECSS-E-ST-50-16_1490202

- k. If an ICMP frame length of the End-System is smaller than 1 bytes, the frame should be discarded and the MIB counter ICMPProtocolInError be incremented.

ECSS-E-ST-50-16_1490203

- l. If an ICMP frame length of the End-System is greater than 64 bytes, the frame should be discarded and the MIB counter ICMPProtocolInError be incremented.

8.4.3.2 Switch Management Information Database (MIB) requirements

ECSS-E-ST-50-16_1490204

- a. In reception, if a frame of the Switch does not have a correct length, the MIB counter MACRxFramesErrors should be incremented.

ECSS-E-ST-50-16_1490205

- b. In a Switch, the MIB should contain the following fields at the root:
1. tteSweSyncState - containing the TTE clock synchronization state
 2. tteSweNumberOfSyncLoss - counter of the number of transitions to from SYNC or STABLE state to any other state

ECSS-E-ST-50-16_1490206

- c. In a Switch, the MIB should have an entry called "configuration".

ECSS-E-ST-50-16_1490207

- d. In a Switch, the entry called "configuration" should at least contains the following fields:
1. tteSweDevId - containing the Switch device ID
 2. tteSweDevRev - containing the Switch device revision
 3. tteSweDevItfRev - containing the Switch interface revision
 4. tteSweCfgSignature - containing the signature of the configuration file

NOTE 1 To allow identifying a Switch and its content.

NOTE 2 In a Switch, the MIB should have an entry called "Ports".

ECSS-E-ST-50-16_1490208

- e. In a Switch, the entry called "Ports" should at least contains following fields
1. numberOfPorts - containing the number of functional ports in the Switch
 2. lowestPort - containing the number of the port having the lowest number

NOTE It is possible that a Switch doesn't use all its ports. Port numbering can start from 0 or any value depending on the implementation.

ECSS-E-ST-50-16_1490209

- f. In a Switch, the entry called "Ports" should contain 1 sub-entry for each port in use.

ECSS-E-ST-50-16_1490210

- g. In a Switch sub-entries should be named "PortN", where N is the number of the port.

ECSS-E-ST-50-16_1490211

- h. In a Switch, each sub-entry called "PortN" should at least contain the following fields:
1. tteSweEthPortName - containing the name of the port
 2. tteSweEthPortTxBytes - containing the amount of bytes sent through this port
 3. tteSweEthPortTxFrames - containing the amount of frames sent through this port
 4. tteSweEthPortRxBytes - containing the amount of bytes received through this port
 5. tteSweEthPortRxFrames - containing the amount of frames received through this port
 6. tteSweEthPortNoLossBePolicing
 7. tteSweEthPortNoLossCtPolicing
 8. tteSweEthPortNoLossUnknownVI
 9. tteSweEthPortNoLossCrcError
 10. tteSweEthPortNoLossLengthError
 11. tteSweEthPortNoLossSofError
 12. tteSweEthPortNoLossAlignmentError

NOTE See Clause 8.4.3 for details.

ECSS-E-ST-50-16_1490212

- i. In a Switch, the MIB should have an entry called "Statistics".

ECSS-E-ST-50-16_1490213

- j. In a Switch, the entry called "Statistics" should at least contains following fields
1. numberOfErrReport - containing the number of error reports

ECSS-E-ST-50-16_1490214

- k. In a Switch, the entry called "Statistics" should contain 1 sub-entry for each for each error report.

ECSS-E-ST-50-16_1490215

1. In a Switch sub-entries should be named "ErrorN", where N is the number of the error report.

ECSS-E-ST-50-16_1490216

- m. In a Switch, the sub-entry called "ErrorN" should contain at least the following fields to describe the error it is reporting:
1. ErrorType - containing the type of error
 2. ErrorField - containing the value of the field identified as faulty
 3. ErrorOrigin - containing the MAC address of the originator of the faulty frame
 4. ErrorTimeStamp - containing the date of the failure

ECSS-E-ST-50-16_1490217

- n. If a check of the ICMP Header Checksum of the Switch is performed and fails, the frame should be discarded and the MIB counter ICMPProtocolInError be incremented.

ECSS-E-ST-50-16_1490218

- o. If a check of the structure of an ICMP frame is performed and fails, the frame should be discarded and the MIB counter ICMPProtocolInError be incremented.

ECSS-E-ST-50-16_1490219

- p. If an ICMP frame length of the Switch is smaller than 1 bytes, the frame should be discarded and the MIB counter ICMPProtocolInError be incremented.

ECSS-E-ST-50-16_1490220

- q. If an ICMP frame length of the Switch is greater than 64 bytes, the frame should be discarded and the MIB counter ICMPProtocolInError be incremented.

ECSS-E-ST-50-16_1490221

- r. In reception, if the Switch receives a frame with an incorrect CRC, the frame should be discarded and the tteSweEthPortNoLossCrcError counter of the relevant port entry be incremented.

ECSS-E-ST-50-16_1490222

- s. In reception, if the Switch receives a frame with an incorrect CRC, the tteSweEthPortNoLossCrcError counter of the relevant port entry should be incremented.

ECSS-E-ST-50-16_1490223

- t. In reception, if the Switch receives a frame with a VL number not consistent with the port number it is received through, the tteSweEthPortNoLossUnknownVl counter of the relevant port entry should be incremented.

ECSS-E-ST-50-16_1490224

- u. In reception, if a TT frame is received outside its scheduled time window, the `tteSweEthPortNoLossCtPolicing` counter of the relevant port entry should be incremented.

ECSS-E-ST-50-16_1490225

- v. In reception, if a frame is received has an inconsistent length, the `tteSweEthPortNoLossLengthError` counter of the relevant port entry should be incremented.

ECSS-E-ST-50-16_1490226

- w. In reception, if a frame has an invalid preamble or Start Frame Delimiter, `tteSweEthPortNoLossSofError` counter of the relevant port entry should be incremented.

ECSS-E-ST-50-16_1490227

- x. In reception, if a frame has a length which is not a multiple of 8 bits, the frame should be discarded and a `tteSweEthPortNoLossAlignmentError` counter of the relevant port entry be incremented.

ECSS-E-ST-50-16_1490228

- y. In reception, if a BE frame is received and the MAC source address does not match the configured MAC source address, the frame should be discarded and the `tteSweEthPortNoLossBePolicing` counter of the relevant port entry be incremented.

8.4.4 Monitoring Mode

ECSS-E-ST-50-16_1490229

- a. Each Switch of a TTEthernet network should provide a port for Spy mode.

NOTE It can be a port temporarily allocated (configurable) or a physically isolated port.

ECSS-E-ST-50-16_1490230

- b. If a Switch of a TTEthernet network provides a physically isolated Spy mode port, it should use a dedicated communication interface.

8.5 Error management in End-System and Switch

ECSS-E-ST-50-16_1490231

- a. An error shall be characterized by at least:
 - 1. The type of error
 - 2. The node or the component which is affected by the error

ECSS-E-ST-50-16_1490232

- b. An error report shall contain at least:
 - 1. The type of failure
 - 2. The node or the component which is affected by the failure
 - 3. A time reference to locate the failure in the timeline
 - 4. The cause of the failure

NOTE The time reference can be absolute (date) or relative (number of integration cycle).

ECSS-E-ST-50-16_1490233

- c. An error report shall be emitted if the diagnostics process failed.
 - NOTE** This can occur when one of the elements to be reported can't be retrieved (type, node, time or cause).

ECSS-E-ST-50-16_1490234

- d. When defining a failure state, the reset condition of this state shall be defined. The allowed condition types are:
 - 1. Event-driven
 - 2. Time-driven
 - 3. Persistent (i.e. cannot be reset)

ECSS-E-ST-50-16_1490235

- e. A failure reset condition shall be an adjustable parameter.
 - NOTE** The resiliency of a subsystem to error is implementation dependent.

ECSS-E-ST-50-16_1490236

- f. A monitoring process shall be characterized by:
 - 1. The elements to be observed
 - 2. The frequency of observation

ECSS-E-ST-50-16_1490237

- g. A monitoring process shall be characterized by a parameter.

NOTE They can be adjusted according to the need of the implementation or the operational phase.

ECSS-E-ST-50-16_1490238

- h. In a TTEthernet network each of the parameters shall be retrievable individually.

9

Test and verification

9.1 Test Specification

ECSS-E-ST-50-16_1490239

- a. All the elements that belong to the same network, for a given system, shall be tested against the same system's test specification.

NOTE Using a common test specification ensures the compatibility of the different elements of the network, even those that have not been specifically developed for the corresponding mission.

ECSS-E-ST-50-16_1490240

- b. The test specification shall contain specific chapters for the different elements of the network.

NOTE Examples of different elements of network are End-System, Switch.

ECSS-E-ST-50-16_1490241

- c. The test specification shall cover at least the most demanding condition that the system requires to each of its elements.

ECSS-E-ST-50-16_1490242

- d. In case an element of the network has its own test specification, a compliance matrix against the system test specification shall be prepared.

9.2 Test references

9.2.1 Overview

Time-Triggered networks can have very different architectures and degrees of complexity. This is the reason why this standard does not provide detailed verification requirements, since they are tightly dependent on the implementation.

There are many commercial products available aimed at testing Ethernet's physical layers, on all of its standard variants.

9.2.2 Requirements for implementation at system level

ECSS-E-ST-50-16_1490243

- a. The physical layer of each element of the TTEthernet network shall be tested to verify their compliance with the corresponding Ethernet standard (10 Mbit/s, 100 Mbit/s, 1 Gbit/s...) applicable for this network.

ECSS-E-ST-50-16_1490244

- b. For Network synchronization, it shall be checked that all the elements that form the TTEthernet network are correctly synchronized after applying the same procedure that is conducted to set the network in Flight configuration.

ECSS-E-ST-50-16_1490245

- c. The network shall be configured and monitored using the same procedures that is applied to set the network in Flight configuration.

NOTE This includes the use of the foreseen services (TFTP, SNMP...).

ECSS-E-ST-50-16_1490246

- d. The worst cases in terms of Best-Effort and Rate-Constrained traffics shall be tested to check the consistency of the configuration of the network.

ECSS-E-ST-50-16_1490247

- e. It shall be checked that the network's redundancy management works as foreseen in the System's specification.

10 Tailoring

10.1 Scope

Tailoring is a process by which individual requirements or specifications, standards and related documents are evaluated and made applicable to a specific project, by selection of requirements.

This Clause provides recommendations, guidelines and templates for tailoring according to project requirements. Tailoring information and general policy is described in ECSS-S-ST-00.

10.2 Tailoring options and parameters

10.2.1 Overview

Most of the services requirements defined in this standard are not configurable. However, there are options identified as well as different levels of performance depending on the value assigned to services managed parameters. It is necessary to specify those parameters for a given project in accordance with user's communication requirements.

It is recommended to perform tailoring in the two steps described in 10.2.2 and 10.2.3.

10.2.2 Step 1: Function and service selection

First level of tailoring is the selection of the functions and services that are applicable to the project; the Table 10-1 provides a requirement applicability matrix template.

10.2.3 Step 2: Services configuration

Second level of tailoring is the configuration of the services management parameters which are defined within the user service requirements normative Clauses as stated in Table 10-1. This configuration adapts the services characteristics and performance according to the project requirements. Table 10-2 and Table 10-3 provide a template for the configuration of the managed parameters for the functions and services listed in the Table 10-1.

Table 10-1: Requirements selection

Function/service	Clauses	Applicability
Physical layer	4.2	Not part of this standard.
Data link layer	4.3	Always applicable.
Service definition	6	Optional. If selected for a mission the requirements are normative for the Switch. If selected for a mission the requirements are normative for the End-System.
Clock Synchronization	7.2.5	Always applicable.
Redundancy and Fault Tolerance	5, 6	Optional. If selected for a mission the requirements are normative for the End-System and the Switch.

10.3 IEEE 802.3 Tailoring

The tailoring to [IEEE 802.3] - Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications is provided within this Clause and defined in Table 10-2.

Table 10-2: Tailoring to [IEEE 802.3] - Part 3

Standard Tag	Requirement	Applicability
3.2	The Ethernet frame shall be composed of the following fields: <ul style="list-style-type: none"> • preamble • start frame delimiter (SFD) • destination address • source address • length/type • MAC client data • pad • Frame Check Sequence (FCS) 	Always applicable
3.2.1	Preamble Field The preamble field is a 7-octet field that is used to allow the PLS circuitry to reach its steady-state synchronization with the received frame timing (see 4.2.5).	Always applicable
3.2.2	Start Frame Delimiter (SFD) field The SFD field is the sequence 10101011. It immediately follows the preamble pattern and indicates the start of a frame.	Always applicable

Standard Tag	Requirement	Applicability
3.2.3	<p>Address fields</p> <p>Each MAC frame shall contain two address fields: the Destination Address field and the Source Address field, in that order. The Destination Address field shall specify the destination addressee(s) for which the frame is intended. The Source Address field shall identify the station from which frame was initiated.</p>	Always applicable
3.2.4	The MAC frame format shall maintain a destination address field.	Always applicable
3.2.5	The MAC frame format shall maintain a source address field.	Always applicable
3.2.6	The MAC frame format shall maintain a length/type field.	Always applicable
3.2.7	<p>The MAC frame format shall maintain a data field.</p> <p>NOTE: Data: Is a sequence of n bytes of any value, where n is less than or equal to 1500. If the length of actual useful data carried by this field is less than 46, the useful data is actually padded up to the 46 bytes with an arbitrary byte value.</p>	Always applicable
3.2.8	For Frame Check Sequence Field a CRC value shall be calculated based on Destination Address, Source Address, Length/Type and Data fields.	Always applicable
3.4	<p>A frame that meets at least one of the following conditions shall be considered as invalid MAC frame and discarded:</p> <p>The frame length is inconsistent with a length value specified in the length/type field. If the length/type field contains a type value, then the frame length is assumed to be consistent with this field and should not be considered an invalid frame on this basis.</p> <p>It is not an integral number of octets in length.</p> <p>The bits of the incoming frame (exclusive of the FCS field itself) do not generate a CRC value identical to the one received.</p>	Always applicable
4.2.3.1	The MAC sublayer shall provide capability for encapsulation of transmits data.	Always applicable

Standard Tag	Requirement	Applicability
4.2.3.2.1	<p>Full duplex mode</p> <p>In full duplex mode, the CSMA/CD MAC does not defer pending transmissions based on the carrierSense signal from the PLS. Instead, it uses the internal variable transmitting to maintain proper MAC state while the transmission is in progress. After the last bit of a transmitted frame, (that is, when transmitting changes from true to false), the MAC continues to defer for a proper inter-FrameSpacing.</p>	Always applicable
4.2.3.2.2	<p>MAC sublayer shall start the transmission of a frame at least interFrameGap time after the previous frame has been transmitted.</p>	Always applicable
4.2.4.1	<p>The MAC sublayer shall provide capability for decapsulation of received data.</p>	Always applicable
4.2.4.1.2	<p>The frame shall be identified as invalid if the frames bits, excluding the FCS field, do not generate a CRC value identical to the one received in the FCS field.</p>	Always applicable
4.2.4.2	<p>Upon reception of a receiveData-Valid signal provided by the Physical Layer in MII/GMII interfaces, MAC sublayer indicates a length error if one of the following:</p> <p>the length on the frame is greater than max FrameSize</p> <p>the number of octets in the frame is not an integer multiple of 8 bits.</p>	Always applicable
4.2.4.2	<p>When operating in Full Duplex mode the MAC sublayer shall discard any frame having the length less than minFrameSize.</p>	Always applicable
4.4.2.4	<p>A frame that meets at least one of the following conditions shall be considered as invalid MAC frame and discarded:</p> <p>frame length less than 64 octets</p> <p>basic frame length greater than 1522 octets, including VLAN</p> <p>inter packet gap less than 96 bits</p>	Always applicable
4.2.5	<p>The value of preamble shall be a 7-byte field of alternating "10" patterns.</p>	Always applicable
4.2.6	<p>The Start-of-frame delimiter (SFD) field shall:</p> <p>immediately follow the preamble pattern</p> <p>have the sequence "10101011"</p>	Always applicable

Standard Tag	Requirement	Applicability
35.2.2	<p>The GMII interface shall consist of the following signals:</p> <ul style="list-style-type: none"> • GTX_CLK (1000 Mb/s transmit clock) • RX_CLK (receive clock) • TX_EN (transmit enable) • TXD (transmit data) • TX_ER (transmit coding error) • RX_DV (receive data valid) • RXD (receive data) • RX_ER (receive error) • CRS (carrier sense - only for half duplex mode) • COL (collision detected - only for half duplex mode) 	Always applicable
40	The transceiver shall implement the Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 1000 BASE-T.	Optional. If 1000 Base-T implemented it is required.
Annex 31B.1	<p>A MAC control pause frame, used for inhibiting transmission of the BE data frames from another station on the network shall have the following fields set to the specified values:</p> <p>The globally assigned 48-bit multicast address 01-80-C2-00-00-01,</p> <p>The PAUSE opcode,</p> <p>A request_operand indicating the length of time for which it wishes to inhibit data frame transmission.</p>	Always applicable
Annex 31B.1	<p>The PAUSE frames shall be generated regardless the received PAUSE operations.</p> <p>Guideline: The PAUSE operation cannot be used to inhibit transmission of MAC Control frames, TT frames and RC frames.</p>	Always applicable
Annex 31B.1	The bridge shall discard the frames sent to the PAUSE multicast destination address, regardless of the state of the bridge's ports.	Always applicable

10.4 SAE AS6802 Tailoring

All requirements of the [SAE AS6802] standard are applicable except the following one (see Table 10-3).

Table 10-3: Tailoring to [SAE AS6802]

Standard Tag	Requirement	Applicability
4.6	The Time-Triggered Ethernet device, when acting as a synchronization master or synchronization client, shall be configurable to also accept PCFs with a priority other than their own.	Optional. If multiple sync domains are implemented it is required.

Annex A (informative)

Patent licensing

A.1 Scope

The Time-Triggered Ethernet technology specified within this standard is based on patents from the following parties:

- Airbus for AFDX
- TTTech for patents listed in A.2

With respect to the patents owned by TTTech and the ones owned jointly with Honeywell, the patent licensing described below in section A.2 applies.

A license agreement on usage of these patents for implementing a product compliant to this ECSS standard in a space project can be obtained from ESA. The TTE Patent licence request forms to be filled are provided in Annex A.3.

A.2 Time-Triggered Ethernet Patent Overview

Table A-1: Clock Synchronization

Short	Patent #	Description
F30	WO 2009/146472	Method for synchronizing local clocks in a distributed computer network*
F31	EP 2 148 474	Multirouter for time-controlled communication systems*
F9	WO 2001/84286	Multi-master Clock-Synchronization*
T32/F31	WO 2009/146471	Method for Synchronizing Local Clocks**
F37	WO 2011/123877	Method and Device for Fault-tolerant Time-Triggered Real-Time Communication*
NOTES: * Solely owned by TTTech ** Jointly owned by TTTech and Honeywell and joint right of disposal		

Table A-2: Time-Triggered Communication

Short	Patent #	Description
F12	WO 2002/075557	Realization of Event-Channels in a TT Communication System*
F14	WO 2003/107609	Time-Triggered Ethernet*
F16	WO 2004/107670	Transmission of Messages in a TT System*
F23	WO 2008/124854	Communication Method and Device for Efficient and Secure Transmission of TT Ethernet Messages*
F28	WO2009/121087	Method for Secure Dynamic Bandwidth Allocation in TT Ethernet*
F53	WO2013/170285	Method and Device for Relaying TT and ET Messages*
NOTES:		
* Solely owned by TTTech		

Table A-3: Dependability

Short	Patent #	Description
F41	WO 2009/146472	Method for synchronizing local clocks in a distributed computer network*
F15	WO 2004/023302	Error Detection Method*
S06	EP 1 222 542	Method for Enforcing the Fail-Silent Property in a Distributed Computer System and Distributor Unit of Such a System*
T10	WO 2007/000007	Safe start-up of a network**
F23	EP 2 145 431	Procedure and Architecture for the protection of real time data*
F56	WO 2014/134652	Method for Increasing the Reliability in a TT System*
NOTES:		
* Solely owned by TTTech		
** Jointly owned by TTTech and Honeywell and joint right of disposal		

A.3 TTE Patent licence request form

Licensee	
Entity Complete Name and Legal Nature ⁽¹⁾	
Entity Address of its Seat (or Business Unit, if applicable)	
Post code	
City	
Country (ISO Code)	
Contact person to whom all communication related to the request should be addressed	
Name:	
Telephone no.:	
Fax no.:	
Email address:	
Licensor	
Entity Complete Name and Legal Nature ⁽¹⁾	TTTech Computertechnik AG (TTTech)
Entity Address of its Seat (or Business Unit, if applicable)	Schoenbrunner Strasse 7
Post code	1040
City	Vienna
Country (ISO Alpha 3 Code)	Austria (AUT)
Contact person to whom all communication related to the request should be addressed	
Name:	
Telephone no.:	
Fax no.:	
Email address:	XXXXXX@tttech.com
(1) Specify here the type of business entity to which the company belongs (e.g. Limited Company, Société Anonyme, AG etc.).	

Licensed TTE Patents		
Short	Patent #	Description
F30	WO 2009/146472	Method for synchronizing local clocks in a distributed computer network
F31	EP 2 148 474	Multirouter for time-controlled communication systems
F9	WO 2001/84286	Multi-master Clock-Synchronization
....

Licensed Patents information

The **Licensee** hereby requests from the **Licensor** the authorisation to use the **Licensed TTE Patents** according to the terms and conditions of the Agreement between ESA, acting on behalf of the members of the European Cooperation for Space Standardization (ECSS), and TTTech on the use of the TTE Patents and TTE Products, reference ..., dated ... (hereinafter referred to as Agreement).

The Licensee confirms that the licence and the Licensed TTE Patents shall be used solely for space applications based on the ECSS TTE Standard (ECSS-E-ST-50-16C) in line with the terms and conditions of the Agreement.

(if applicable)

The licence and the Licensed TTE Patents shall be used for a limited period, starting from [...] and ending on [...].

Date:

Signature:

Name and title of the signatory: *(Full name and function)* duly authorized to commit the requesting entity for this purpose.

Bibliography

ECSS-S-ST-00	ECSS system – Description, implementation and general requirements
ECSS-E-ST-70-41	Space engineering - Telemetry and Telecommand packet utilization
ARINC 664	Available from ARINC, 2551 Riva Road, Annapolis, MD 21401. www.arinc.com
ARINC 664 part 2, 24 October 2018	Aircraft Data Network Part 2: Ethernet Physical and Data Link Layer Specification
ARINC 653	Available from ARINC, 2551 Riva Road, Annapolis, MD 21401. www.arinc.com
IEEE 802.3	Ethernet Standard, available from the Institute of Electrical and Electronics Engineers (IEEE), 445 Hoes Lane, Piscataway, NJ 08854-1331, Tel: 732-981-0060, www.ieee.org
RFC 826	Ethernet Address Resolution Protocol
[SAE AS6802]	Time-Triggered Ethernet, Available from the Society of Automotive Engineers (SAE) International, SAE International Headquarters, 400 Commonwealth Dr., Warrendale, Pennsylvania, USA, standards.sae.org
ESCC	ESCC publications: https://escies.org ESCC 3902/003 and ESCC 3401/071 are also posted at http://www.estec.esa.nl/tech/spacewire/literature
CCSDS 702.1-B-1	IP over CCSDS space links, CCSDS Secretariat Space Communications and Navigation Office, 7L70, Space Operations Mission Directorate, NASA Headquarters Washington, DC 20546-0001, USA
CCSDS 850.0-G-2	Spacecraft Onboard Interface Services Informational Report, December 2013
RFC 768	User Datagram Protocol
RFC 791	Internet Protocol
RFC 792	Internet Control Message Protocol (ICMP)
RFC 1157	A simple network management protocol (for SNMPv1)
RFC 1350	The TFTP Protocol (Revision 2)
RFC 1441	Introduction to version 2 of the Internet-standard Network Management Framework (for SNMP V2)
RFC 3411	An Architecture for Describing Simple Network Management Protocol Management Frameworks (for SNMP V3)
RFC 2349	TFTP Timeout Interval and Transfer Size Options
RFC 3697	IPv6 Flow Label Specification