



**BSI Standards Publication**

## **Space engineering — Time triggered Ethernet**

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## National foreword

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English version

## Space engineering - Time triggered Ethernet

Ingénierie spatiale - Ethernet à déclenchement temporel (TTE)

Raumfahrttechnik - Zeitgesteuertes Ethernet

This European Standard was approved by CEN on 5 December 2021.

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## European Foreword

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This document (EN 16603-50-16:2021) has been prepared by Technical Committee CEN-CENELEC/TC 5 “Space”, the secretariat of which is held by DIN.

This standard (EN 16603-50-16:2021) originates from ECSS-E-ST-50-16C.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2022, and conflicting national standards shall be withdrawn at the latest by June 2022.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a standardization request given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any EN covering the same scope but with a wider domain of applicability (e.g. : aerospace).

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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.

## Normative references

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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.

| EN reference   | Reference in text                      | Title                                                                       |
|----------------|----------------------------------------|-----------------------------------------------------------------------------|
| EN 16601-00-01 | ECSS-S-ST-00-01                        | ECSS System - Glossary of terms                                             |
|                | ARINC 664 part 7,<br>23 September 2009 | Aircraft Data Network Part 2: Avionic Full-Duplex Switched Ethernet Network |
|                | IEEE 802.3,<br>28 December 2012        | Ethernet Standard                                                           |
|                | SAE AS6802,<br>November 2011           | Time-Triggered Ethernet                                                     |
|                | RFC 768,<br>28 August 1980             | User Datagram Protocol (UDP)                                                |
|                | RFC 791, September<br>1981             | Internet Protocol (IP)                                                      |
|                | RFC 792, September<br>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)                                              |

# 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.

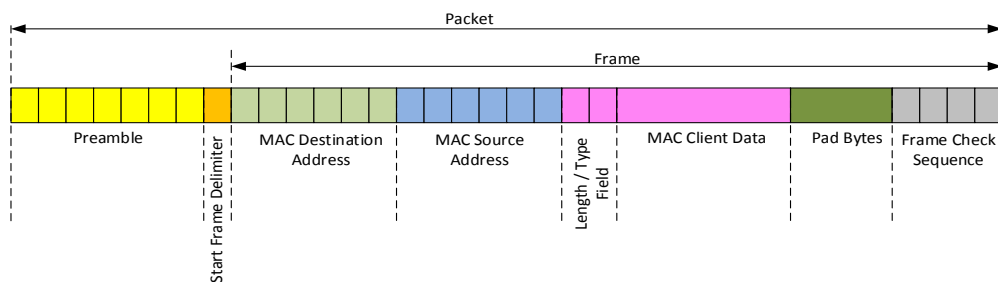


**Figure 3-1: Structure of a Packet**

**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)

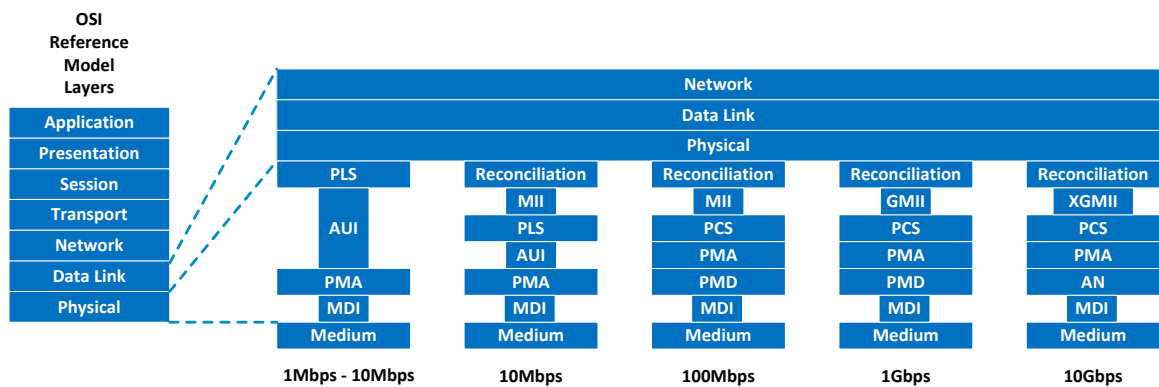


Figure 4-2: Physical Layer Model

## 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.

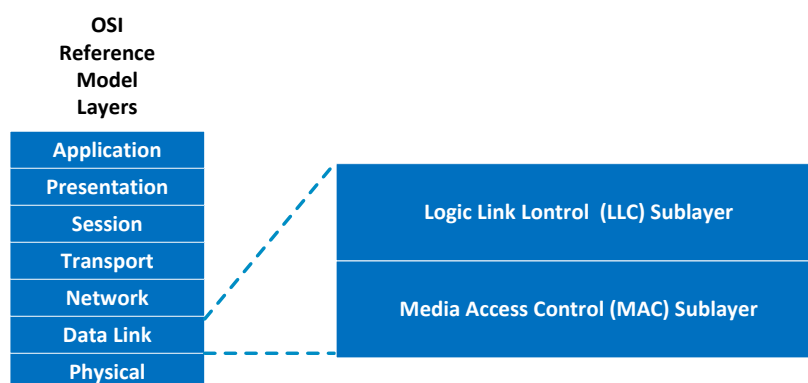


Figure 4-3: Data Link Layer

### 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].

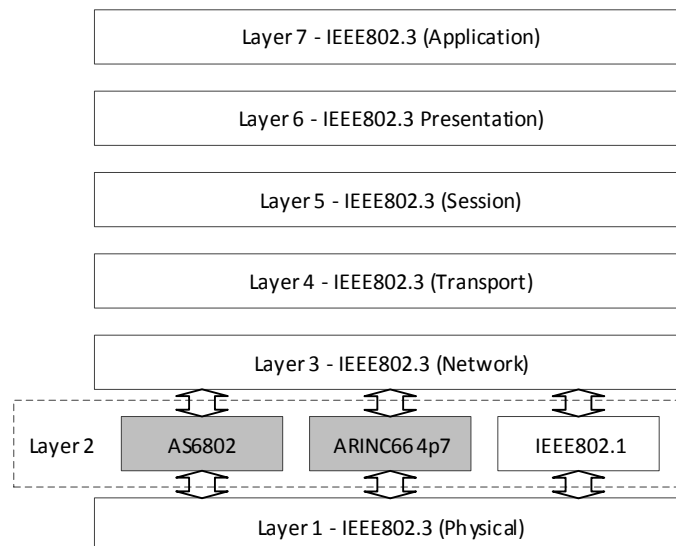


**Figure 4-4: Time-Triggered Ethernet Services**

**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.

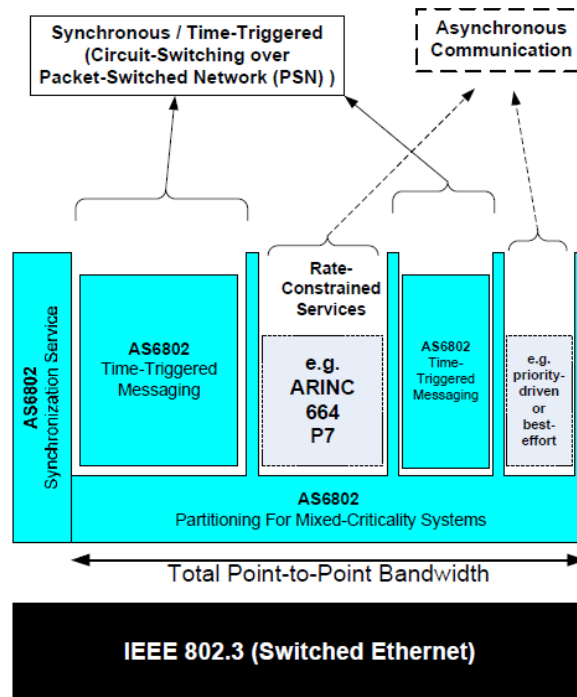


Figure 4-5: Traffic Partitioning

## 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.

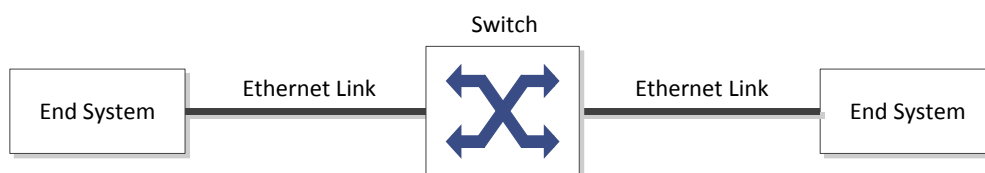


Figure 4-6: Network Communication Channel

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.

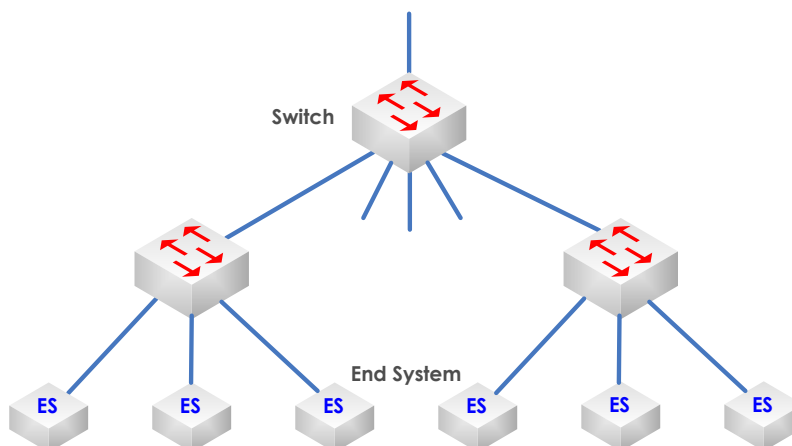


**Figure 4-7: A TTE example network**

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.

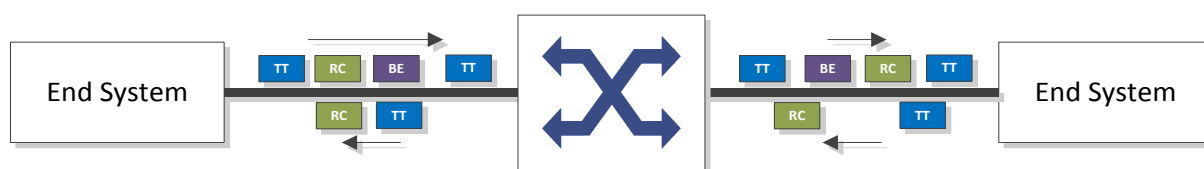


**Figure 4-8: Full Duplex Links**

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

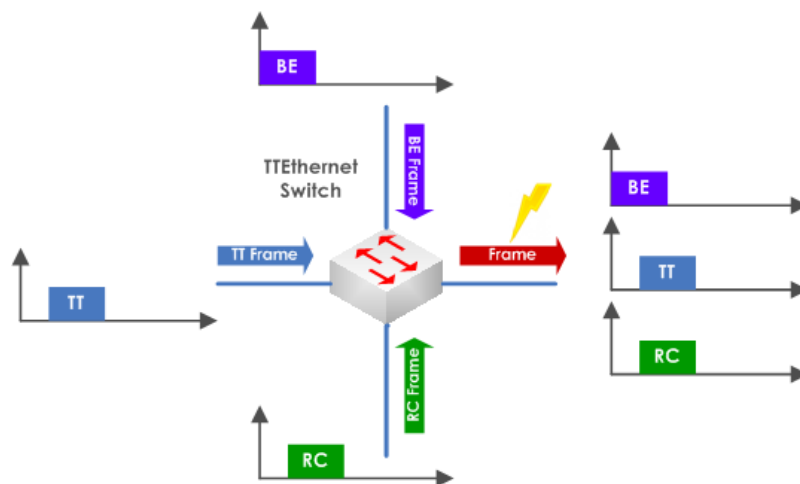


**Figure 4-9: Message Processing at the Switch**

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.

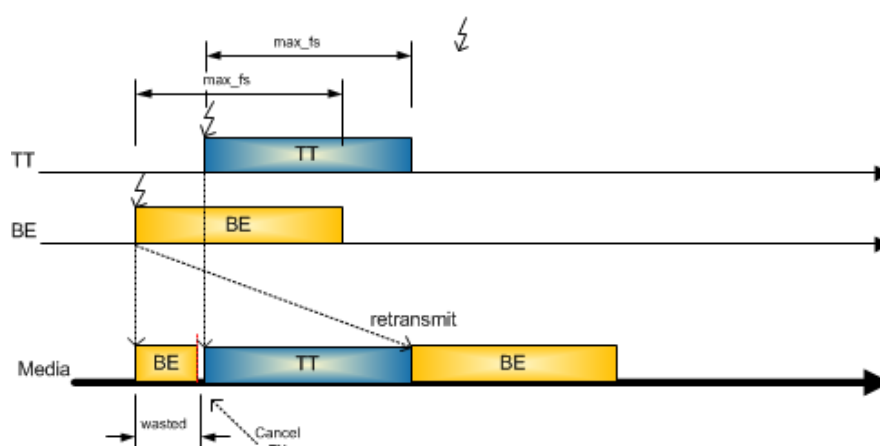


Figure 4-10: Preemption

### 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  $\mu$ 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.

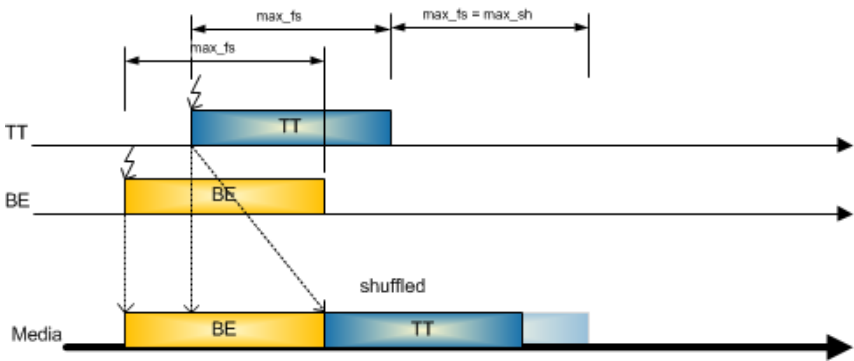


Figure 4-11: Shuffling

### 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.

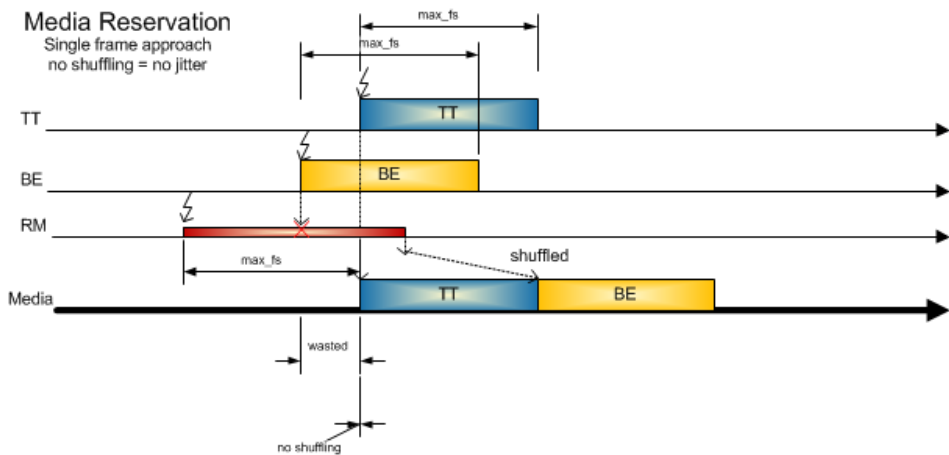


Figure 4-12: Media Reservation

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

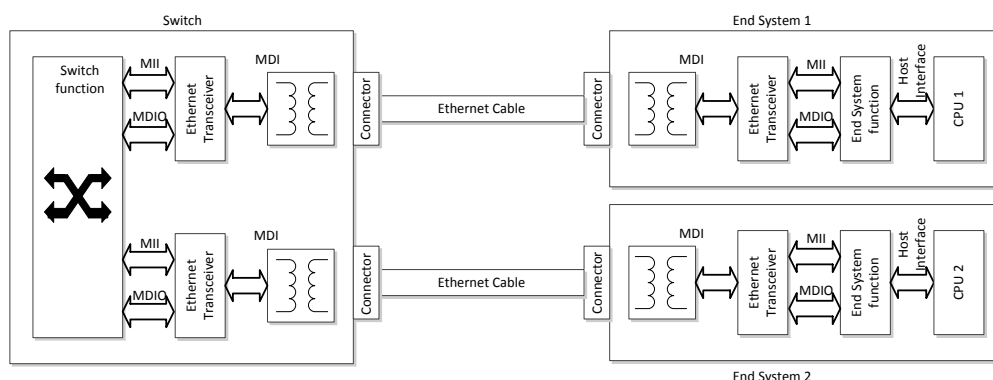


**Figure 4-13: Network Building Blocks**

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.

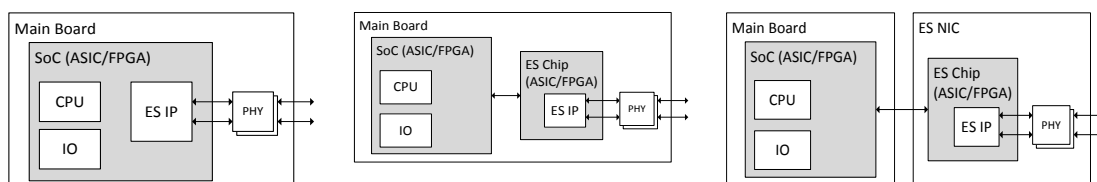


**Figure 4-14: Network Building Blocks Examples**

#### 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.

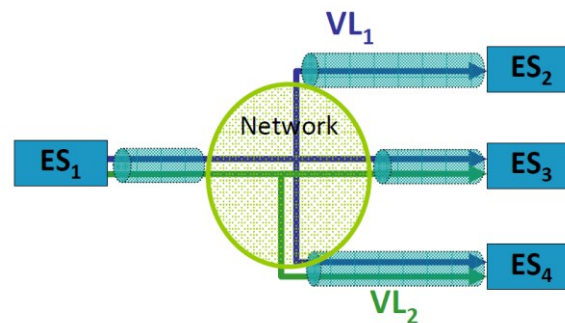


Figure 4-15: Virtual Link

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.

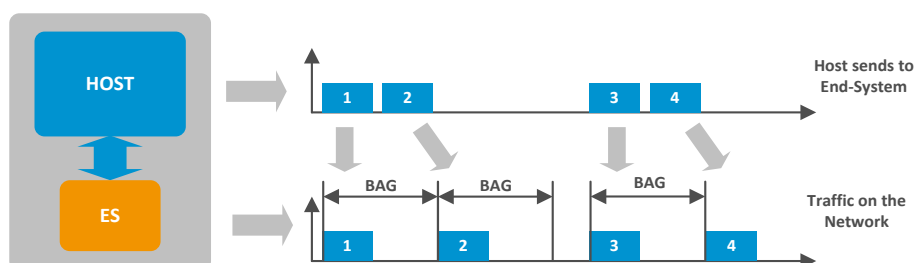


**Figure 4-16: Bandwidth Reservation**

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.