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Middleware and Communication Protocols for Dependable Systems TI-MICO

"Time-Triggered Ethernet TT-Ethernet"

Version 3.12.2014

Time-Triggered Ethernet

Article:

"The Time-Triggered Ethernet (TTE) Design"

by

Hermann Kopetz; Astrit Ademaj; Petr Grillinger;
Klaus Steinhammer.

8th IEEE International Symposium on
Object-oriented Real-time Distributed Computing
Seattle, Washington, May 2005: page 22–33.

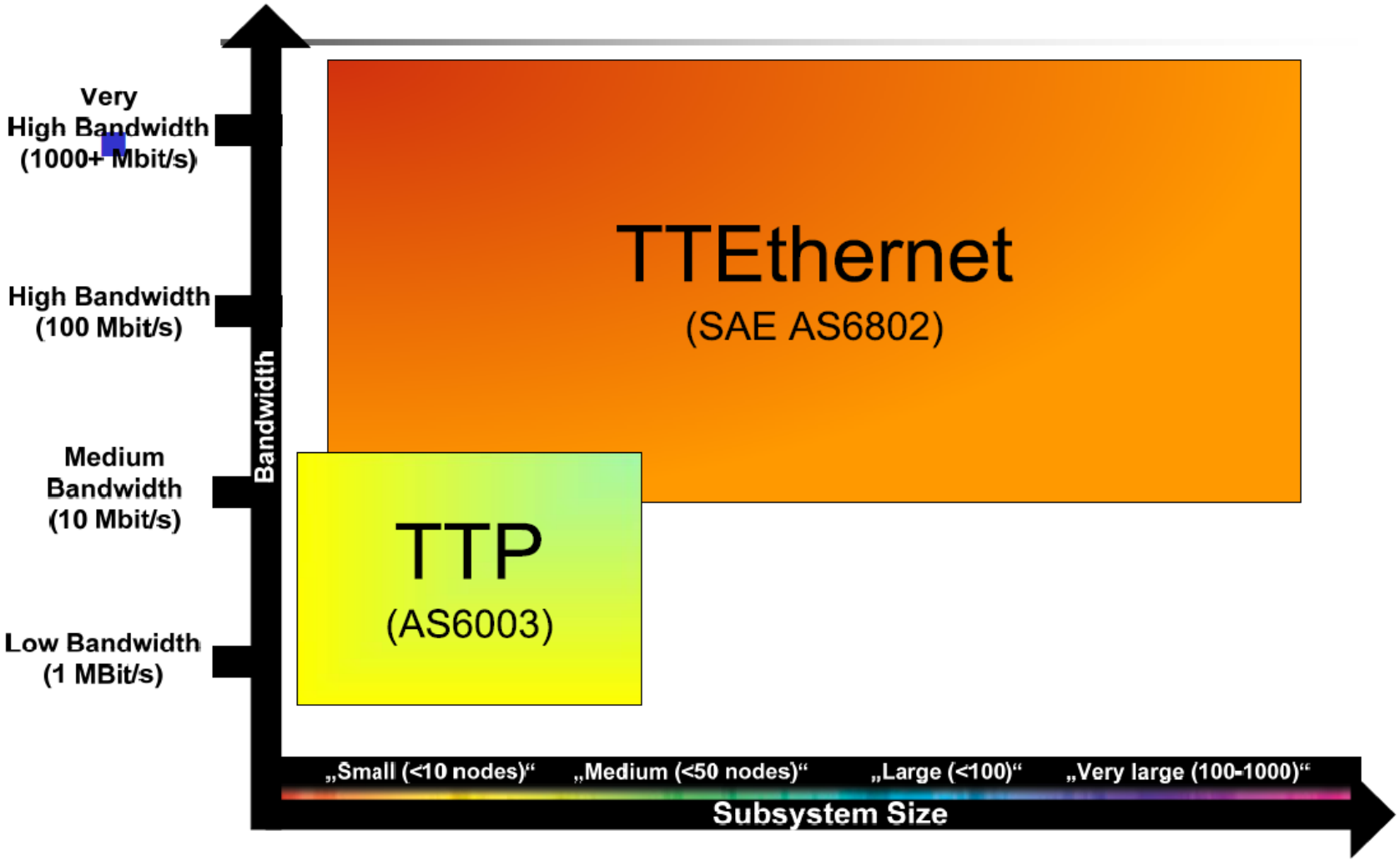
Abstract

1. Introduction to Time Triggered Ethernet
2. TT-Ethernet Switch
3. TT-Ethernet Protocol
4. Safety Critical TT-Ethernet Systems
5. TT-Ethernet and IEEE 1588
6. Summary

New Demands from Future Systems

- Deterministic and time-related behavior with lowest possible jitter
- One common network for all kinds of traffic
  - Control functions
  - Diagnostic information
  - Updates with loading of new programs
  - Multimedia applications i.e. voice and video have higher bandwidth requirements
  - High availability, safety and reliability
  - Integration of existing IP based diagnosis and update systems (i.e. legacy systems)

TTP and TT-Ethernet



Ref. SAE Aerospace

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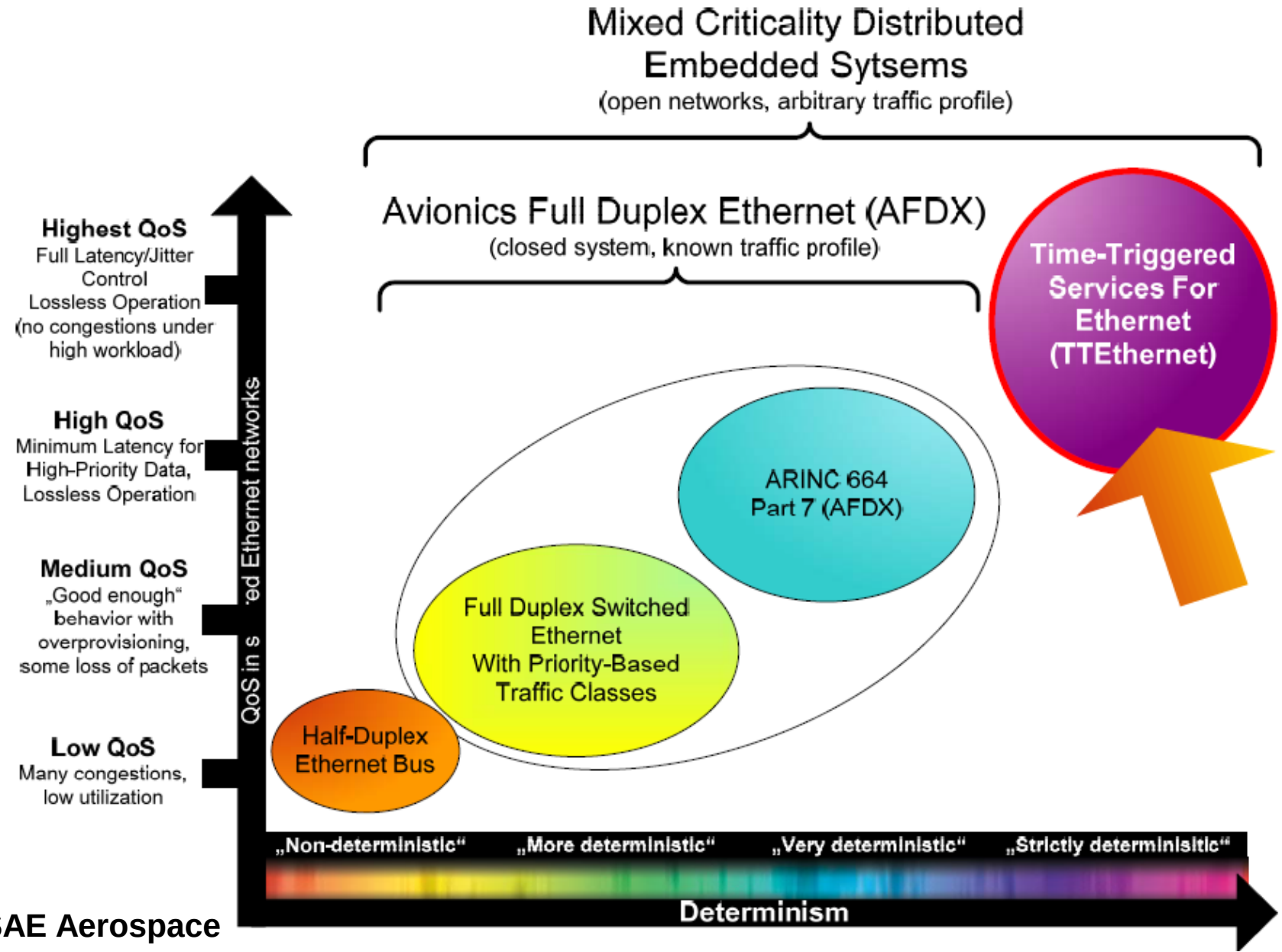
Deterministic Ethernet



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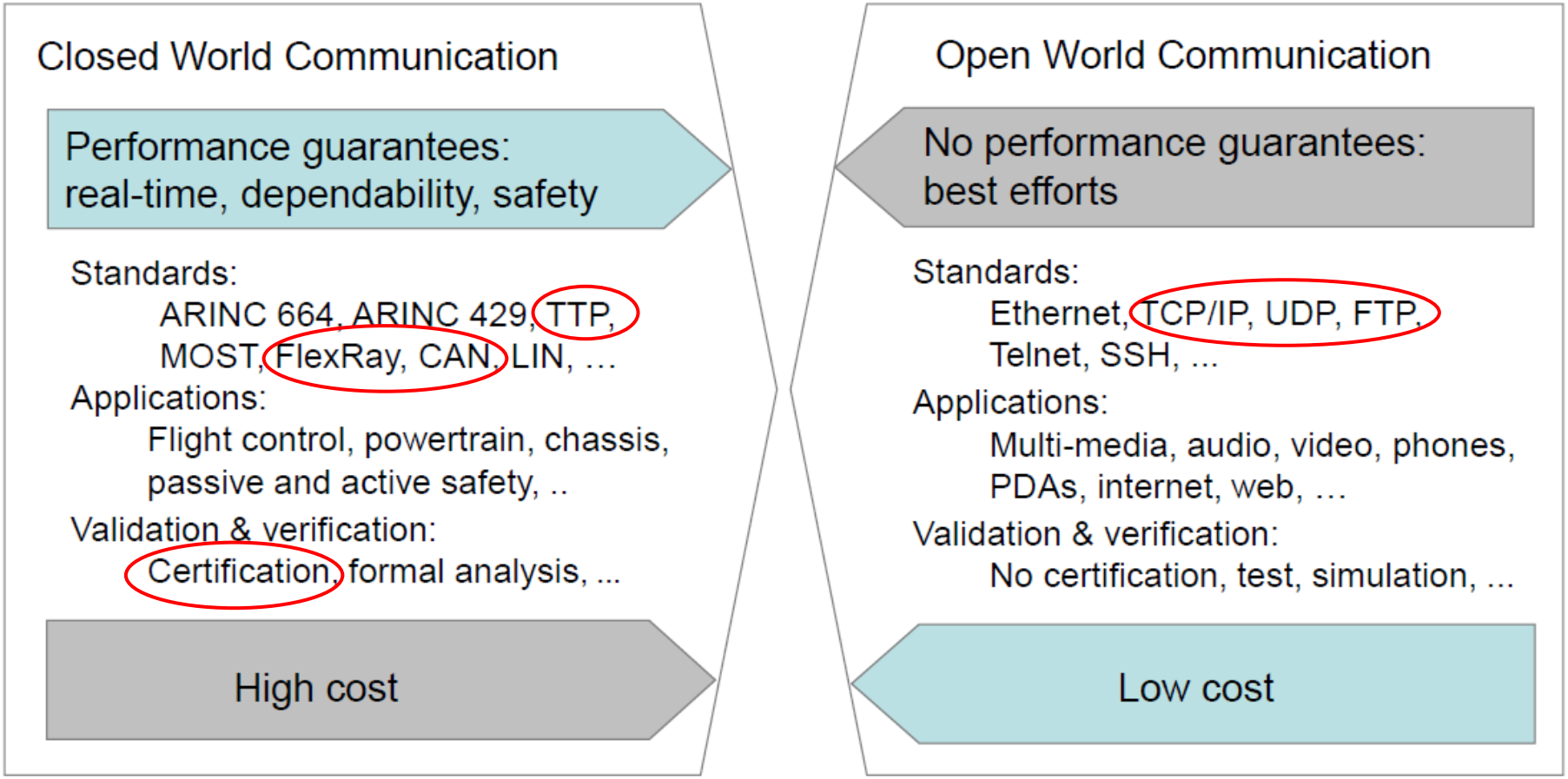
Closed and Open World Communication



Ref. www.tttech.com

Time-Triggered Protocols and Bandwidths

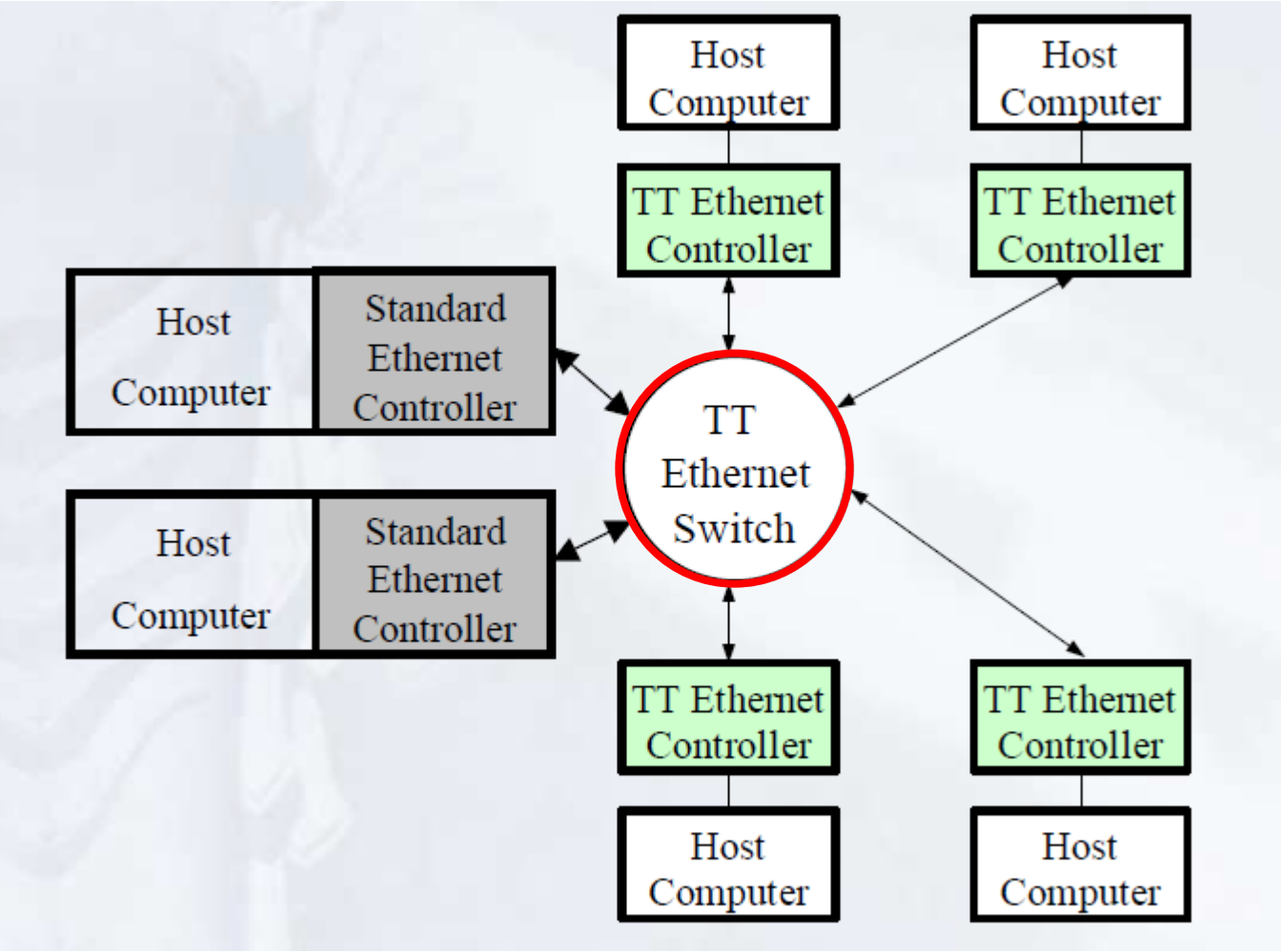
- TTP/C 25 Mbit/s,
- FlexRay 10 Mbit/s
- TTCAN 1 Mbit/s
- TT-Ethernet 100 Mbit/s (future 1 Gbit/s)

TT-Ethernet can be considered to be a unification of the best properties of standard Ethernet and TTP/C.

TT-Ethernet Usage Example

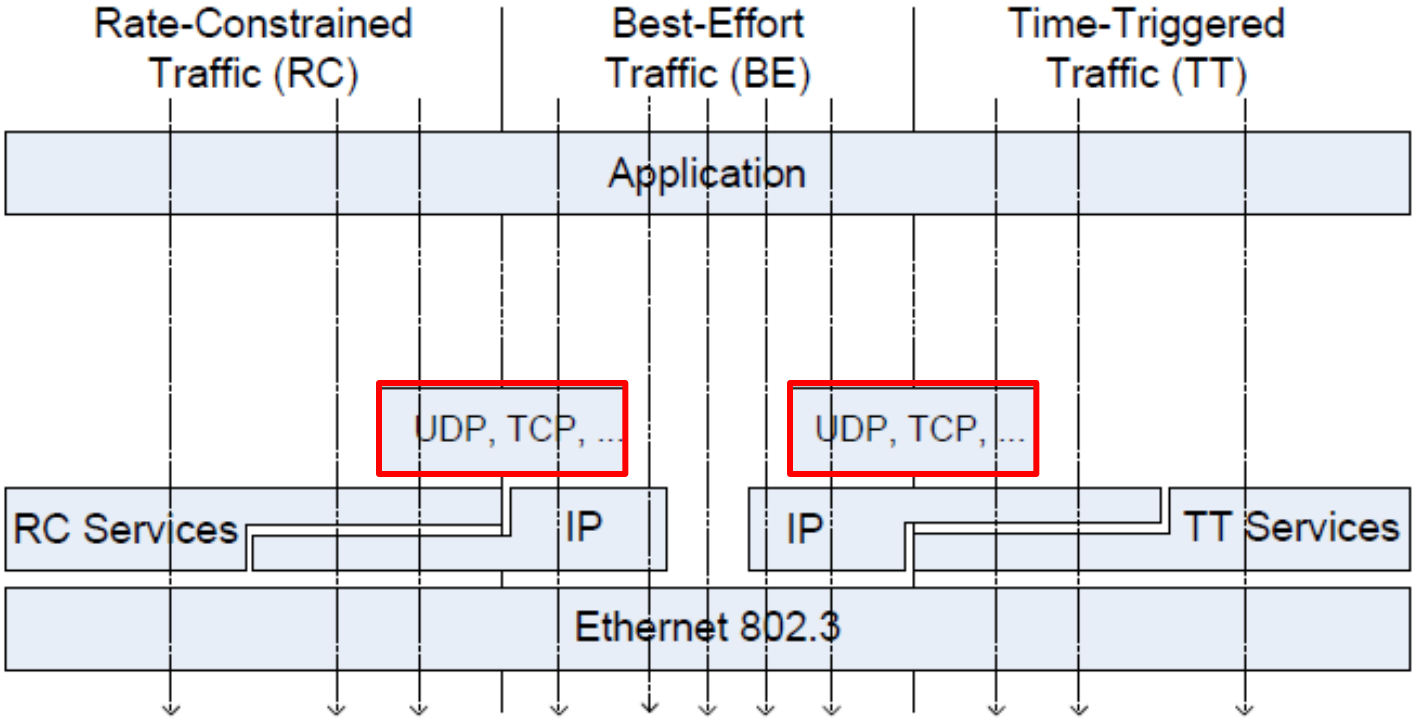
- TT-Ethernet is used as backbone network in NASA's new **Orion Spacecraft**.
  - News April 28, 2014: NASA Orion Avionics System Ready for First Test Flight

TT-Ethernet – Standard Configuration



3 Traffic Classes Supported by TTE

- Time-Triggered Traffic (TT)
- Rate-Constrained Traffic (RC)
- Best-Effort Traffic (BE)



TT-Ethernet Traffic Classes

Time-Triggered (TT) traffic:

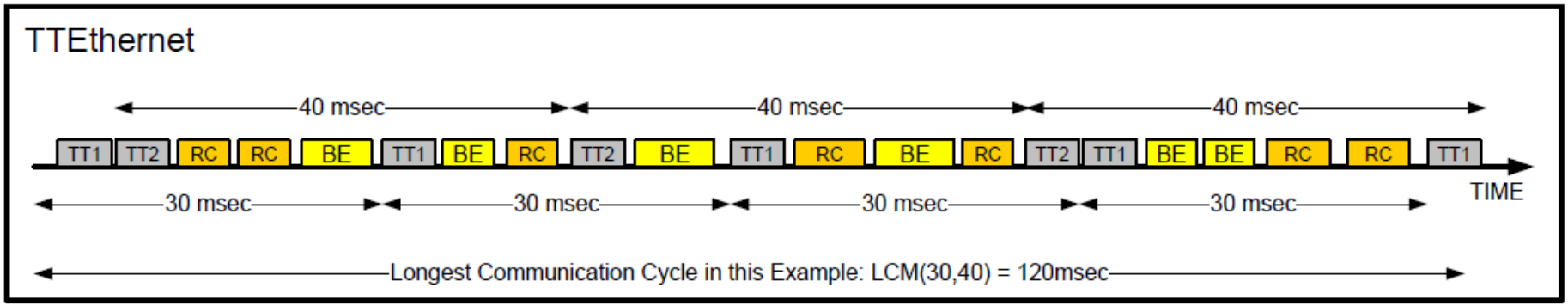
- dispatch messages according to a predefined communication schedule

Rate-Constrained (RC) traffic:

- enforce minimum duration between two frames of the same stream (e.g. used for multimedia traffic)

Best-Effort (BE) traffic:

- standard Ethernet communication paradigm – no temporal guarantees are given



Ref. www.tttech.com

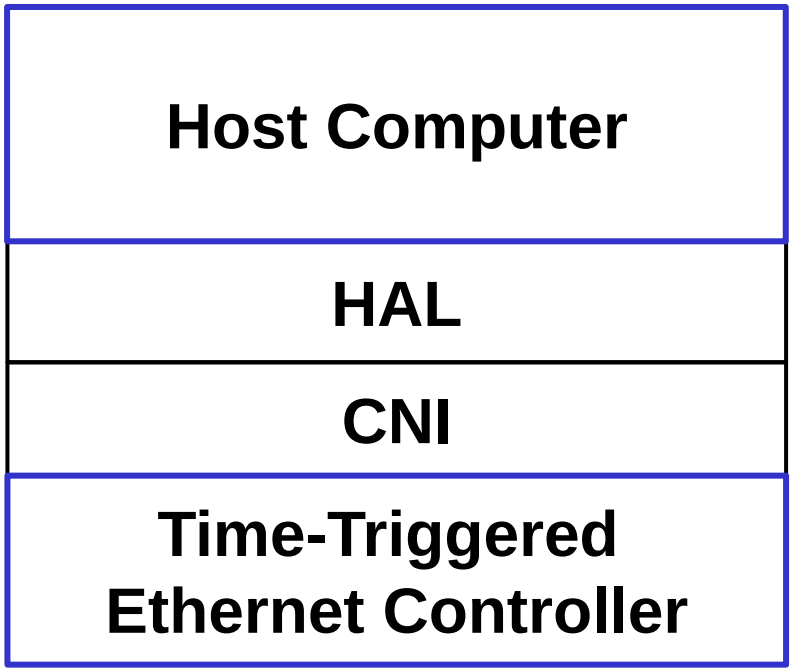
2. TT-Ethernet Switch

- Standard Ethernet switches use the **store-and-forward** paradigm
  - Entire packets buffered and checksum verified
  - Corrupted packets dropped
- TT-Ethernet switches uses the **cut-through** paradigm for TT-messages
  - Reads only **up to the type field** before forwarding
  - A constant delay, before forwarding
  - Forwards also corrupted packets as the checksum is not verified by the switch
- TT-Ethernet switches uses the **store-and-forward** paradigm for ET-messages (BE)

TT-Ethernet Switch Principles

- TT Ethernet switch - transmits TT messages with a constant delay
- ET messages is preempted during transmission, when a Time-Triggered message arrives at a switch port
  - The ET message is retransmitted after the TT message
- If during the transmission of TT message an ET message arrives at a port of the switch,
  - the ET message is stored in the buffer of the switch and transmitted after the transmission of the TT message is finished

TT Ethernet Node Structure



1. Standard TT-Controller
2. Safety Critical TT-Controller

TT-Ethernet Controller

- A specific TT-Ethernet Controller is needed in each node who sends TT-traffic
- All TT-Ethernet Controller is synchronized to a common time base
- Each TT-Ethernet Controller has its reserved timeslots for sending frames onto the network
- This secures that TT-messages are not received at the same time at a given switch

3. TT-Ethernet Protocol

- TT-Ethernet standardized in 2011 by SAE
  - **SAE AS6802: Time-Triggered Ethernet, Standard** Version 1.11.2011.
  - SAE: Society of Automotive and Airspace Engineers

Basic Message Categories

1. Event -Triggered (ET) messages
   - Normal Ethernet event messages
2. Free Form Time-Triggered (FFTT) messages
   - Send with TT priority, can preempt ET in the switch
3. **Unprotected** Start-up messages
   - Used for initial synchronization in start-up phase
4. **Unprotected** Synchronization messages
   - Maintain the clock synchronization during normal op.
5. **Unprotected** TT messages (UTTM)
   - Transport user messages with state semantic from a sender to one or more receivers

Two Unprotected TT Message Types

1. **Unprotected periodic** TT Messages
   - Periodic, always sent, until the ***last message bit*** is set
   - Message length is variable
   - *Information pull mode* interface to the host
2. **Unprotected sporadic** TT Messages
   - Periodic
   - Message length is variable
   - Only sent when the host updates the message
   - *Information push mode* interface to the host

Standard Ethernet Frame

L2 Ethernet packet frame

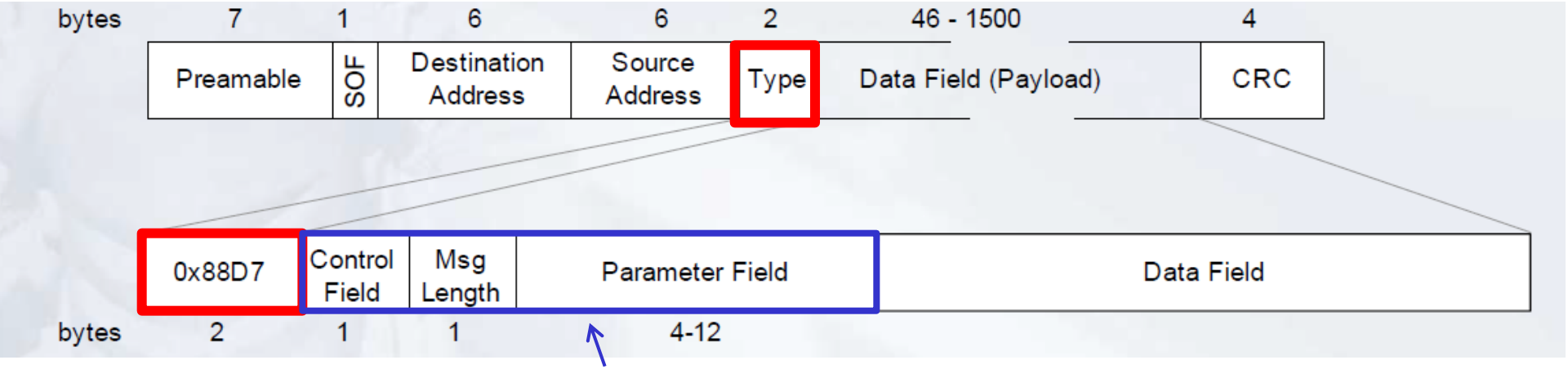
802.3 Ethernet packet and frame structure

Layer	Preamble	Start of frame delimiter	MAC destination	MAC source	802.1Q tag (optional)	Ethertype (Ethernet II) or length (IEEE 802.3)	Payload	Frame check sequence (32-bit CRC)	Interpacket gap
	7 octets	1 octet	6 octets	6 octets	(4 octets)	2 octets	46(42)[b]–1500 octets	4 octets	12 octets
Layer 2 Ethernet frame	← 64–1518(1522) octets →								
Layer 1 Ethernet packet	← 72–1526(1530) octets →								

(Source wikipedia)

- L2 Header= 14 bytes (standard, optional 18 bytes)
- Trailer CRC= 4 bytes
- L2 Overhead= 18 bytes (standard, optional 22 bytes)
- A minimum L2 frame must be at least 64 bytes long
- User data < 46 bytes are padded up to 46 bytes

TTE-Ethernet Frame



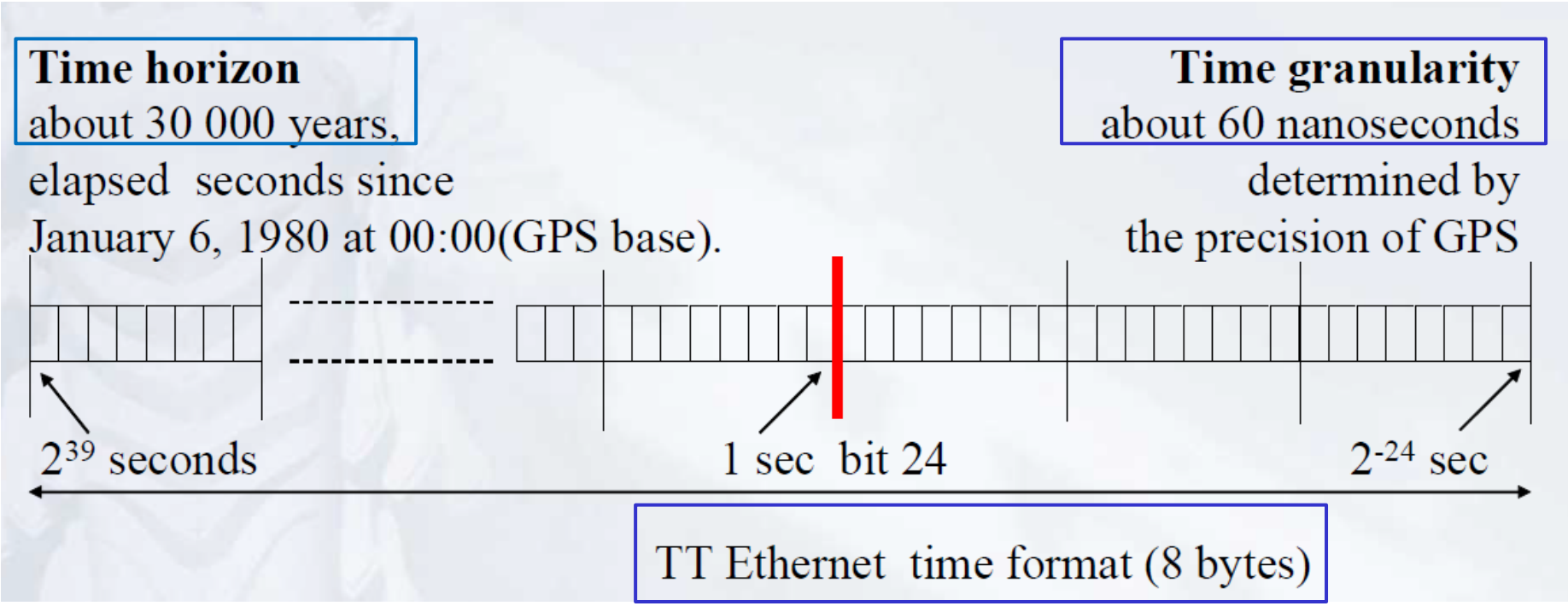
TT-Ethernet Header

- Included in a Standard Ethernet frame
- Standardized frame type field **0x88D7= TTE**
- Ethernet data field contains the **TT-Ethernet Header** and the data fields of different TT Ethernet frames

TT Ethernet Header

- Control field (1 byte)
  - Identify the message category
- Msg Length (1 byte)
  - Number of 8 bytes data blocks
- Parameter Field (4-12 bytes)
  - Message ID (2 bytes) = period (4 bits) and phase (12 bits)
  - Node identification (1 byte)
  - Schedule identification (1 byte)
  - Membership data (8 bytes, 64 bits) – one bit for each safety critical TT-node in a cluster

TT-Ethernet Time Format



Time Format: Period ID (=Msg ID)

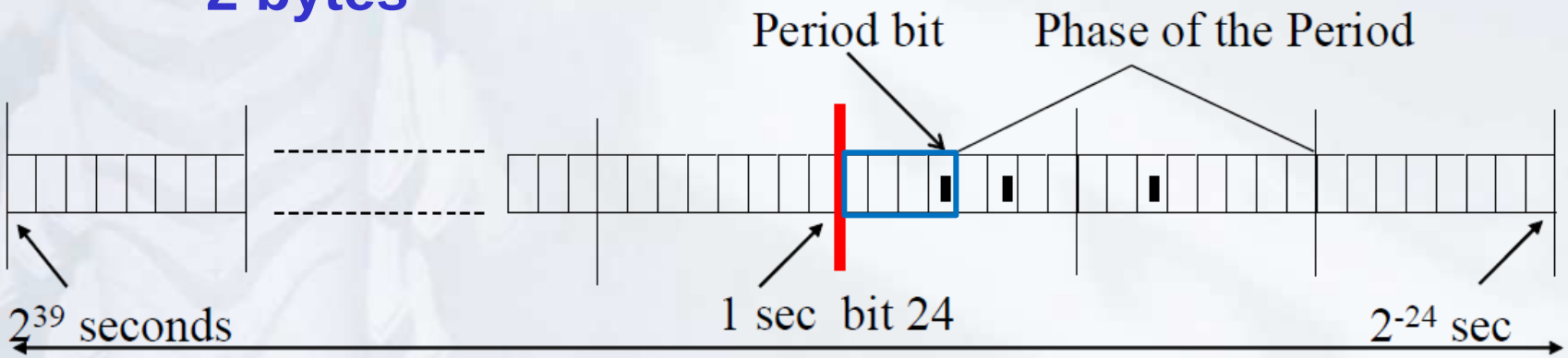
Period ID (Msg ID)

Period bit				Phase bit											
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Period of $1/2^4$ (i.e 1/16)

Phase of $1/2^6 + 1/2^{11}$ = 16113 sec.

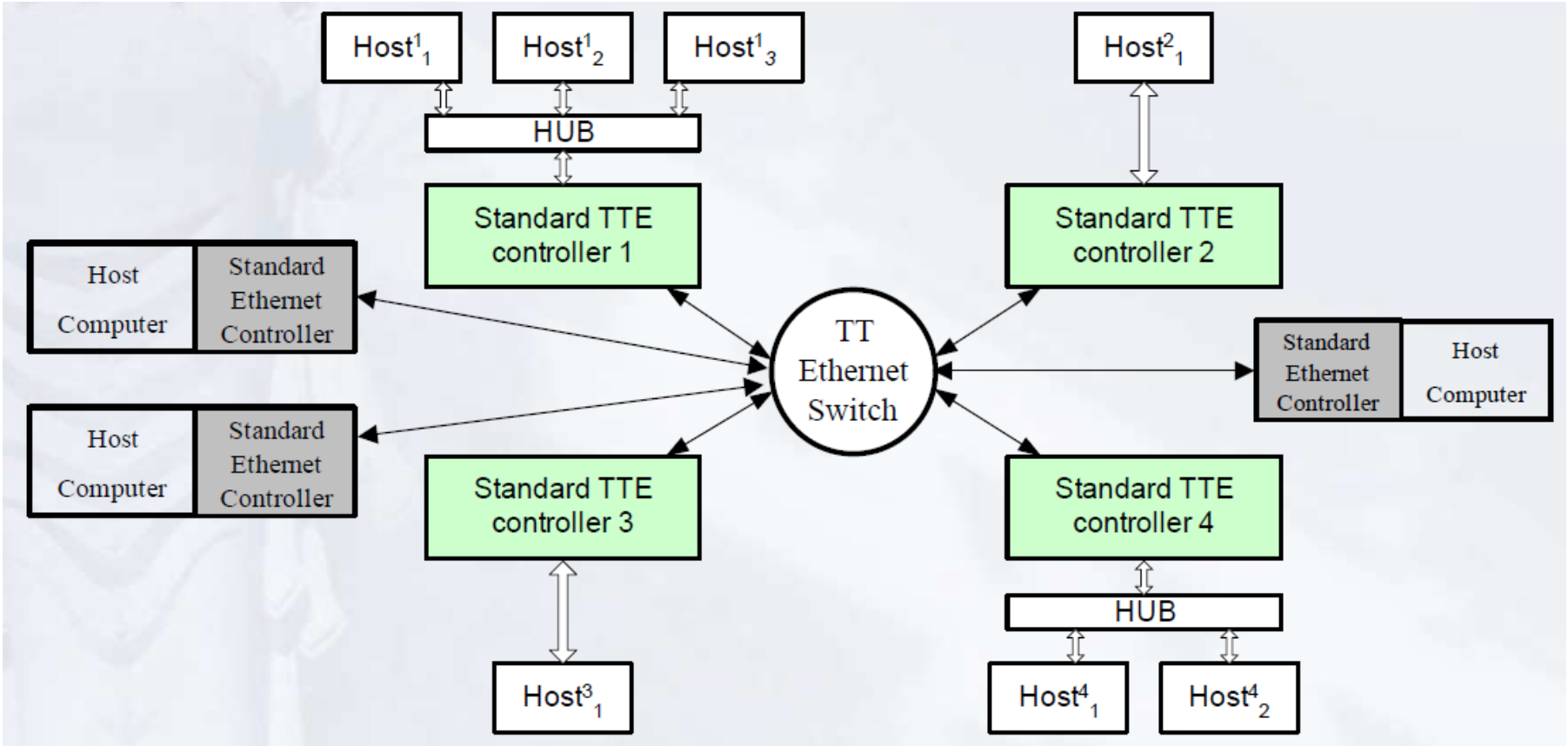
2 bytes



Message Naming

- The two bytes Period ID is used as the **message type name** (unique for a given node)
- A particular **message instance** can be identified by the concatenation of the message type name (= Period ID) with the send instant of the message

Standard Configuration with HUB's



4. Safety Critical TT-Ethernet

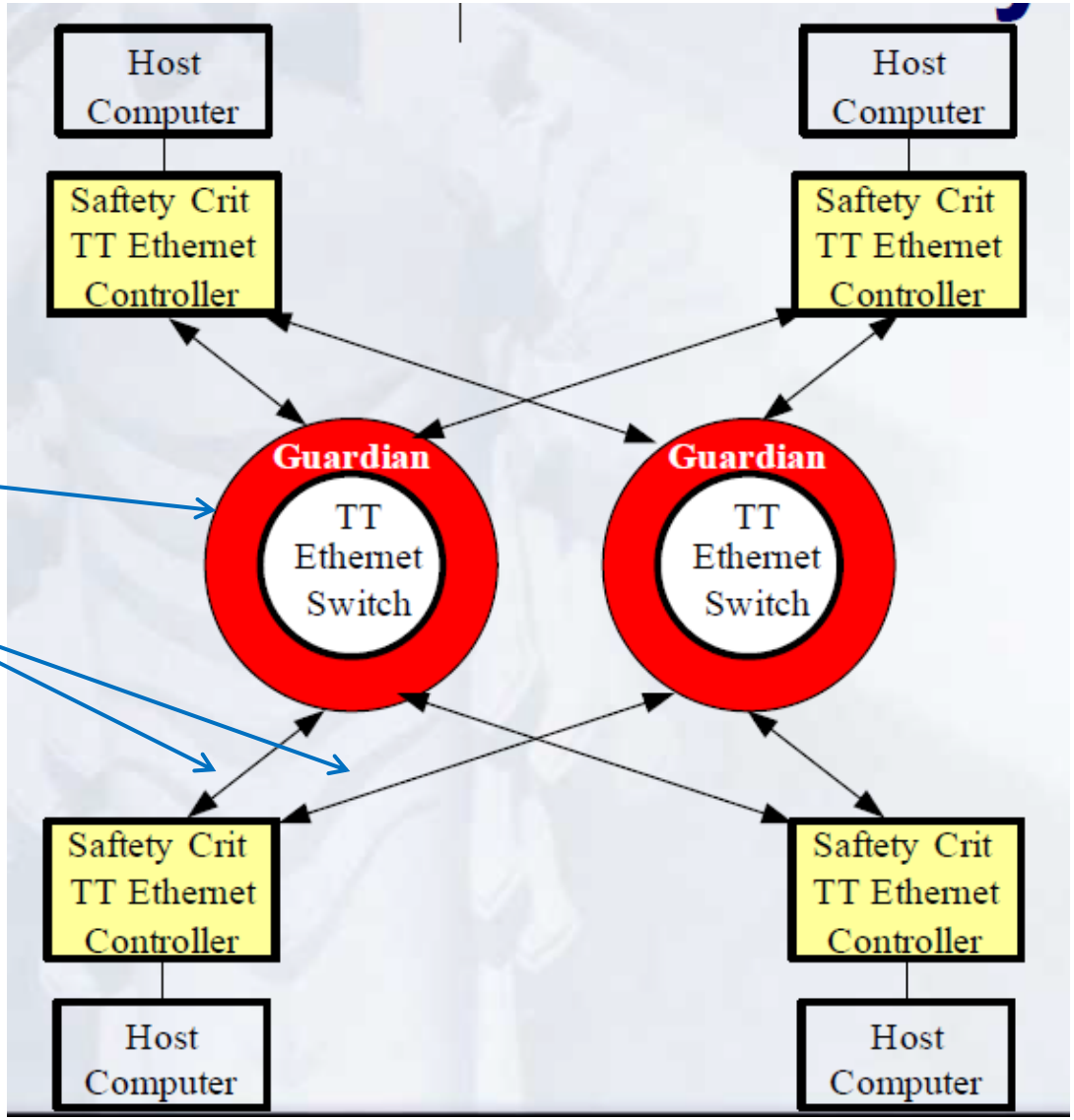
Requires:

- Safety critical TT-Ethernet controllers
- Minimum two TT-Ethernet switches
- Guardians for switch/bus protection
- Two communication busses
- Redundant Fail Tolerant Units (Host + TTE Controller)

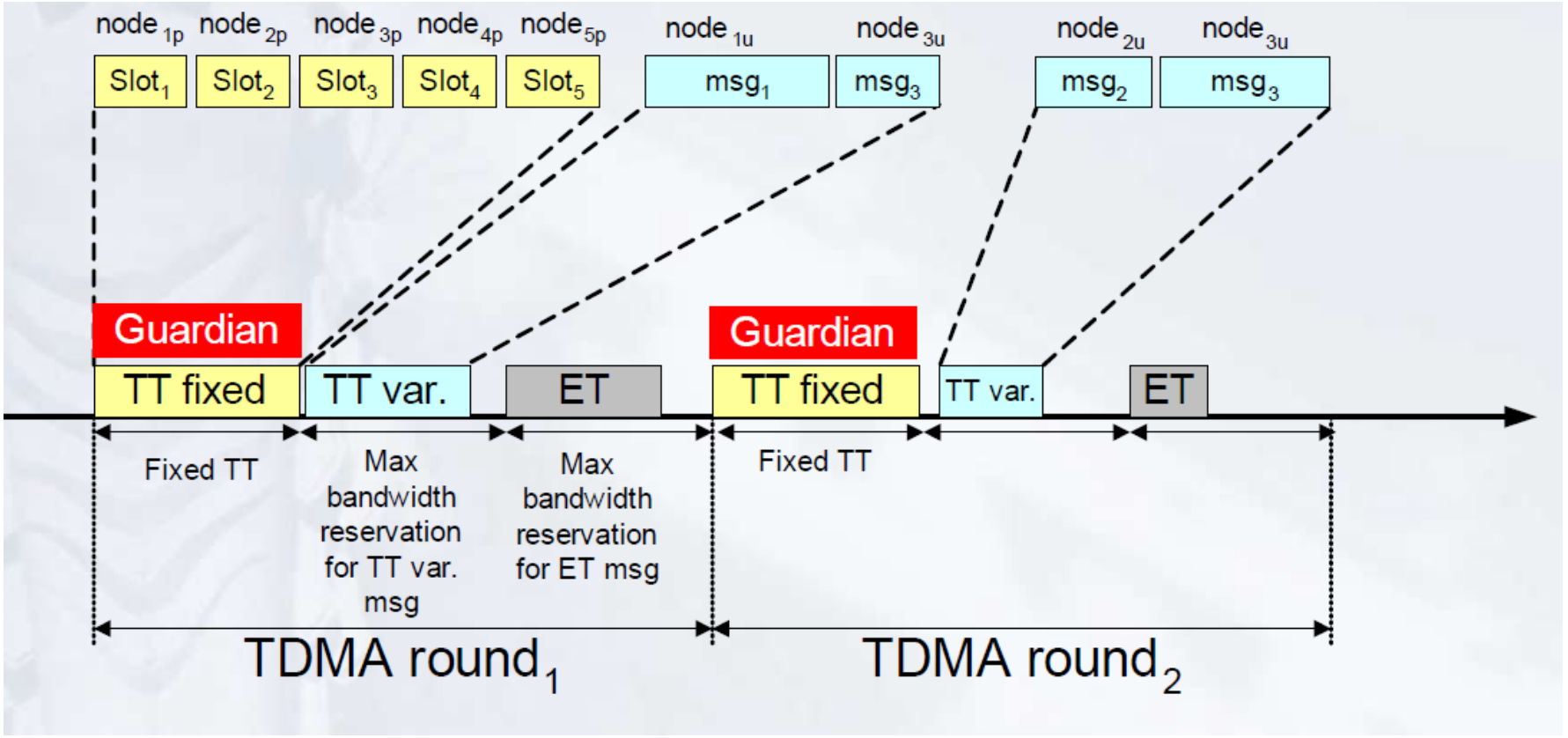
TTE Safety Critical Configuration

Guardian

Two Busses



Communication Schedule Example



New Protected Message Categories

1. **Protected** Start-up message
2. **Protected** Synchronization message
3. **Protected** TT message

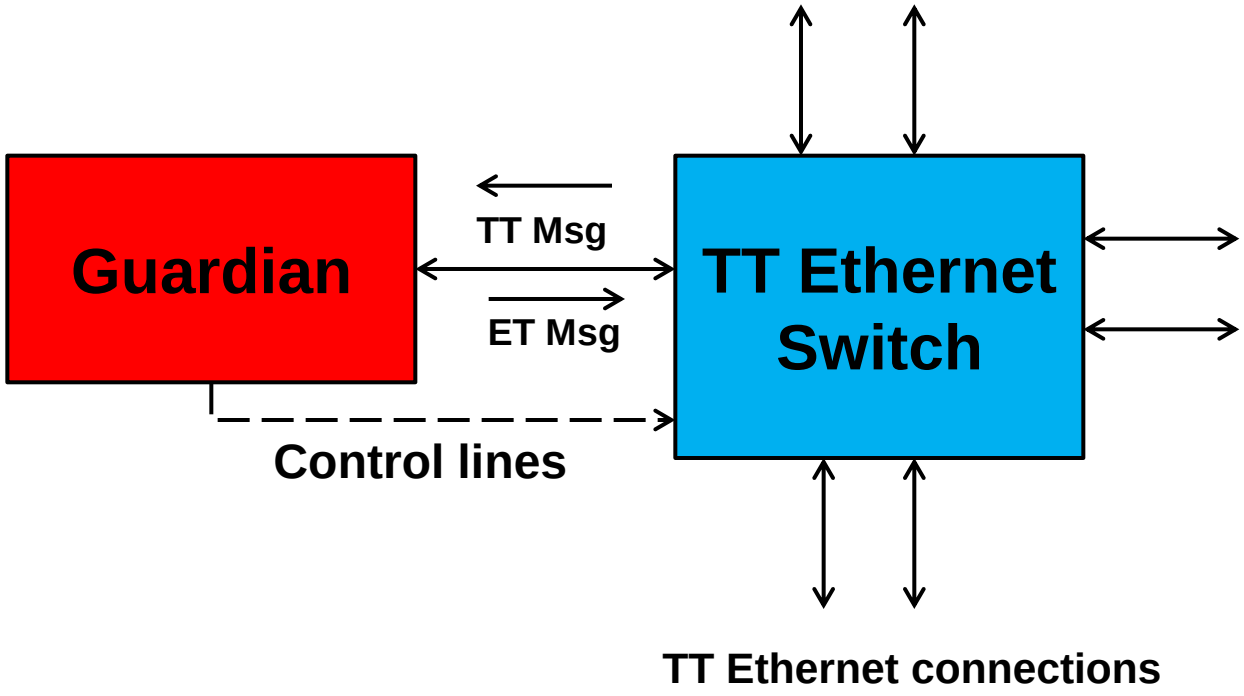
Common properties for Protected messages:

- Use **TDMA scheme**, TDMA rounds divided into time slots for each msg.
- **Message length is fixed**
- Sent through **two redundant channels**
- **Protected TT messages are always sent** (no message last bit)
- **Protected by the guardians**

Guardian properties

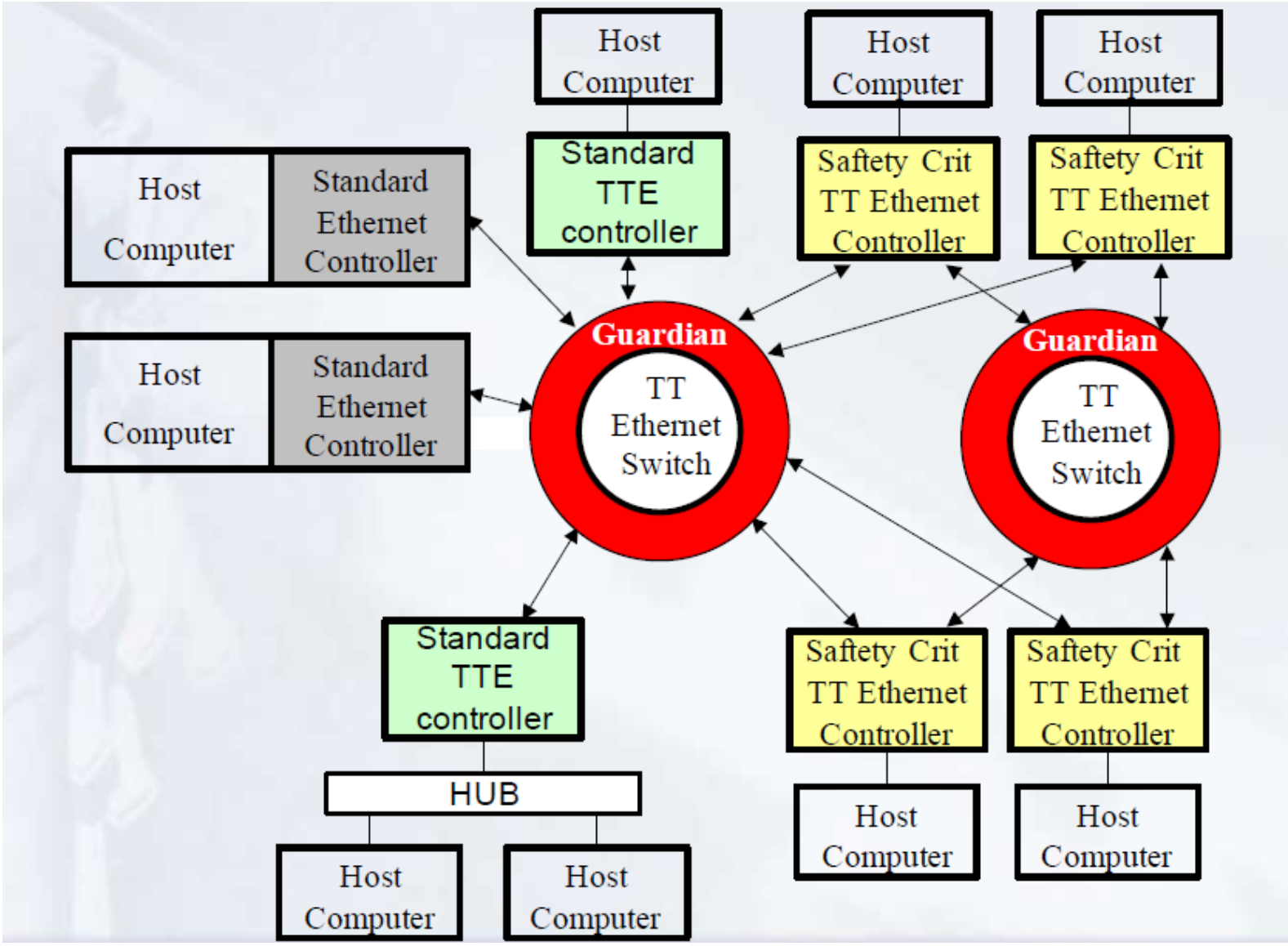
- A safety critical TT-Switch is monitored and controlled by its own dedicated guardian
- A guardian can disable the inputs and outputs of the switch through control lines
- A guardian has its own fault-tolerant clock synchronization system
- A guardian has knowledge of the schedule for protected TT messages
- A guardian controls how a switch delays outgoing messages to reshape the start of frame transmission

Guardian and Switch



An example of an ET message from a Guardian is a diagnostic message

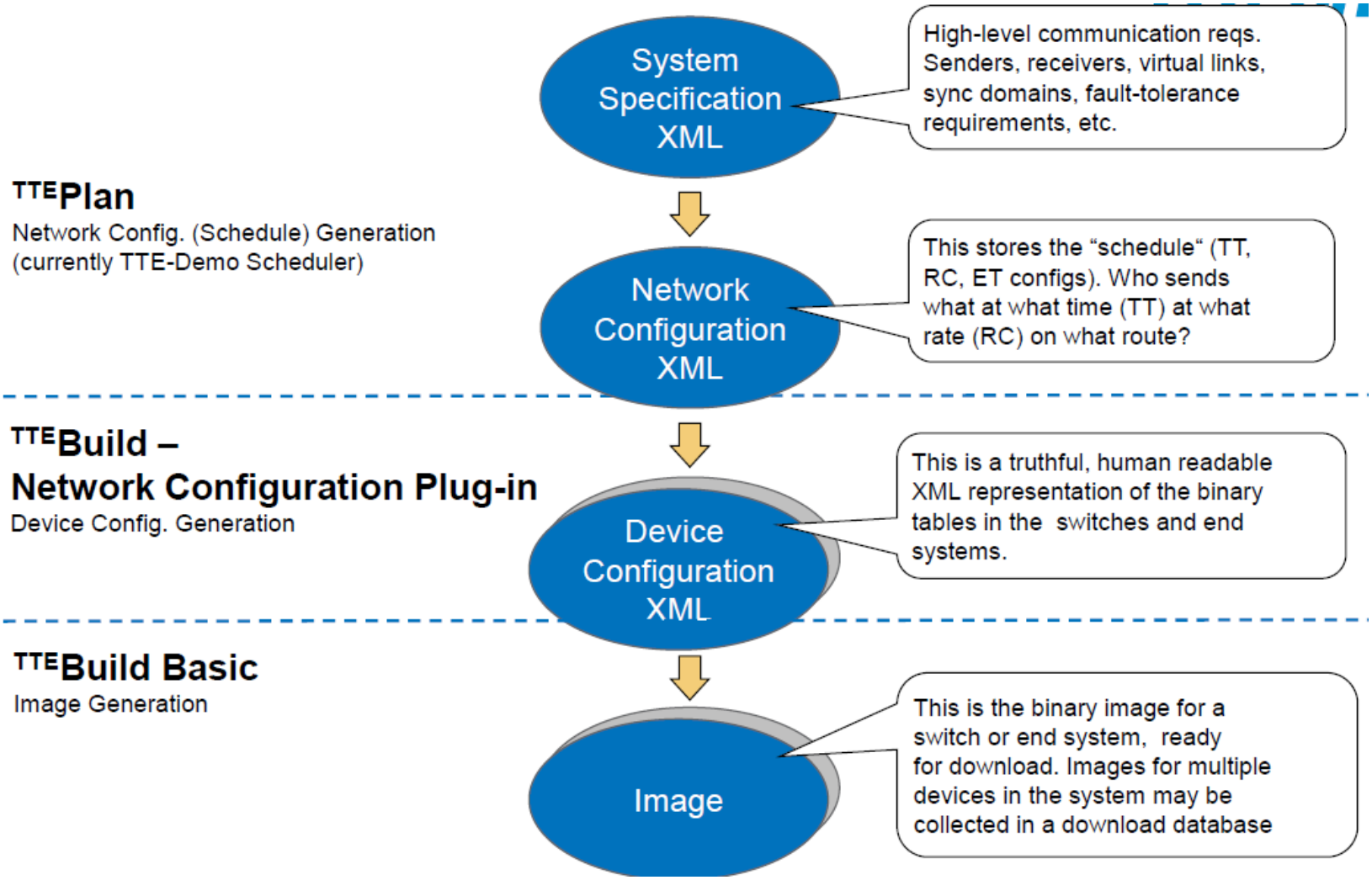
Safety Critical Configuration Example



5. TT-Ethernet and IEEE 1588

- IEEE 1588 – a standard for clock synchronizations in distributed Ethernet switched based networks

TT-Ethernet Tool Suite from TTTech



Ref. www.tttech.com

Summary

- Builds upon many years of research and experiences with TTA/TTP
- Use a switch based Ethernet configuration
- Supports high data rates 100 Mbit/s (currently)
- Integration of Time Triggered and Event Triggered communication in the same network
- Use standard Ethernet frames
- Use dedicated TT-Ethernet switches and TT-Ethernet controllers

References

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Hermann Kopetz; Astrit Ademaj; Petr Grillinger; Klaus Steinhammer. *"The Time-Triggered Ethernet (TTE) Design"*. 8th IEEE International Symposium on Object-oriented Real-time distributed Computing (Seattle, Washington: TU Wien), May 2005, page 22–33.

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