

Middleware and Communication Protocols for Dependable Systems TI-MICO

***“Time-Triggered Ethernet
TT-Ethernet”***

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.

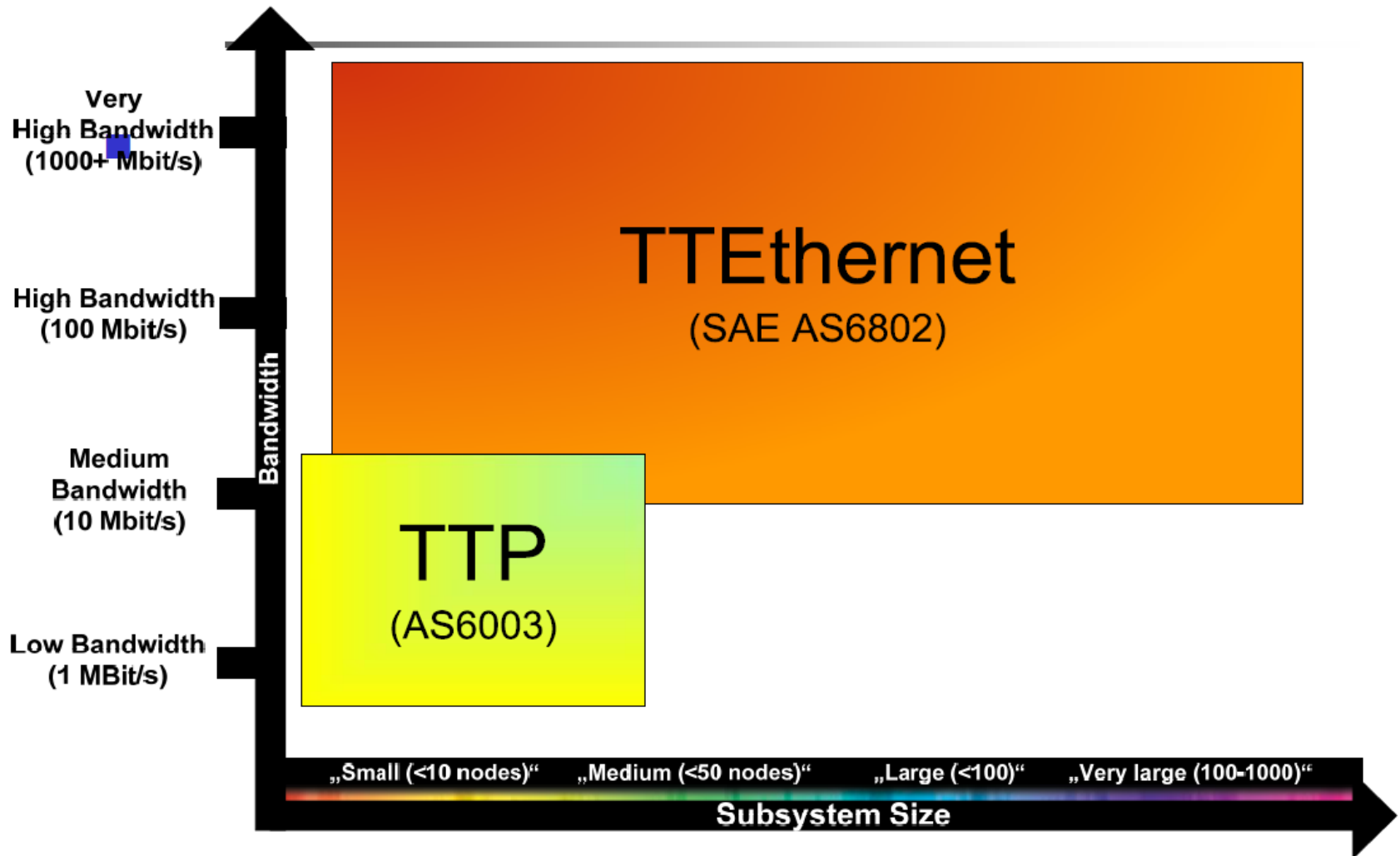
Abstract

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

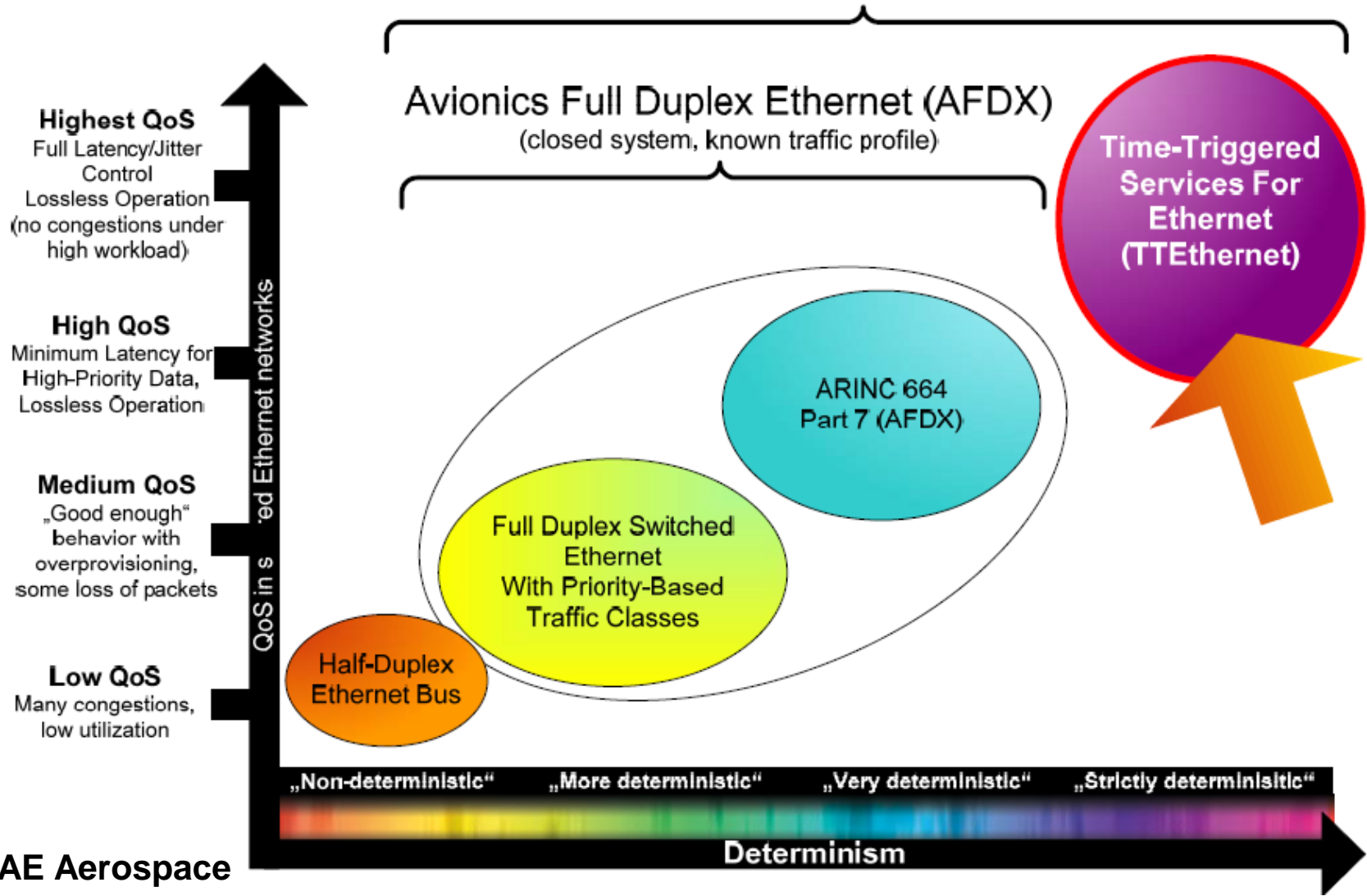
- Deterministic and time-related behavior with lowest possible jitter
- One common network for all kinds of traffic
 - Control functions
 - Diagnostic information
 - Updates with loading of new programs
 - Multimedia applications i.e. voice and video have higher bandwidth requirements
 - High availability,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

TTP and TT-Ethernet



Deterministic Ethernet

Mixed Criticality Distributed
 Embedded Systems
 (open networks, arbitrary traffic profile)



Closed and Open World Communication

Closed World Communication

Performance guarantees:
real-time, dependability, safety

Standards:

ARINC 664, ARINC 429, TTP,
MOST, FlexRay, CAN, LIN, ...

Applications:

Flight control, powertrain, chassis,
passive and active safety, ..

Validation & verification:

Certification, formal analysis, ...

High cost

Open World Communication

No performance guarantees:
best efforts

Standards:

Ethernet, TCP/IP, UDP, FTP,
Telnet, SSH, ...

Applications:

Multi-media, audio, video, phones,
PDAs, internet, web, ...

Validation & verification:

No certification, test, simulation, ...

Low cost

Time-Triggered Protocols and Bandwidths

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

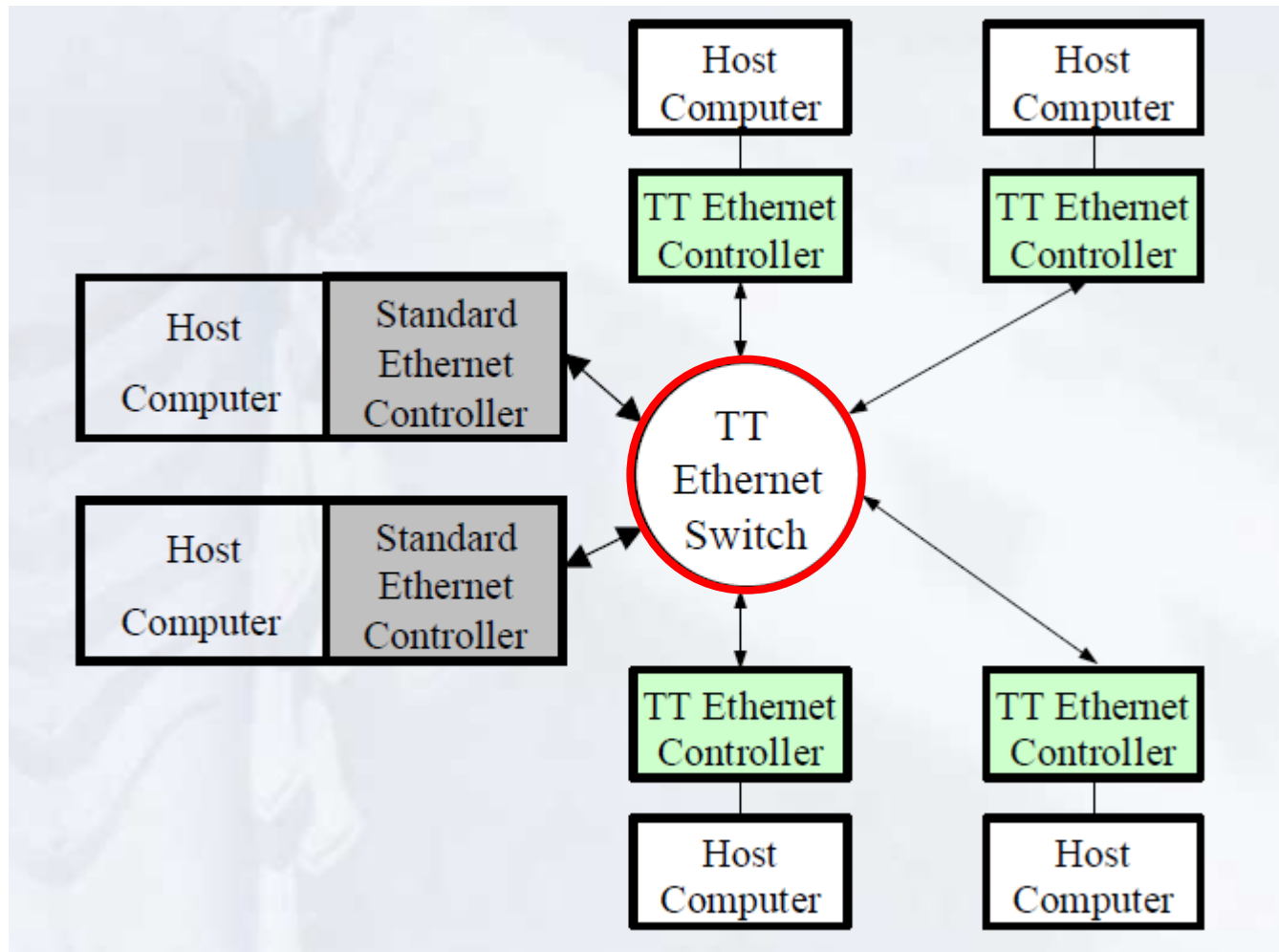
TT-Ethernet can be considered to be a unification of the best properties of standard Ethernet and TTP/C.

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

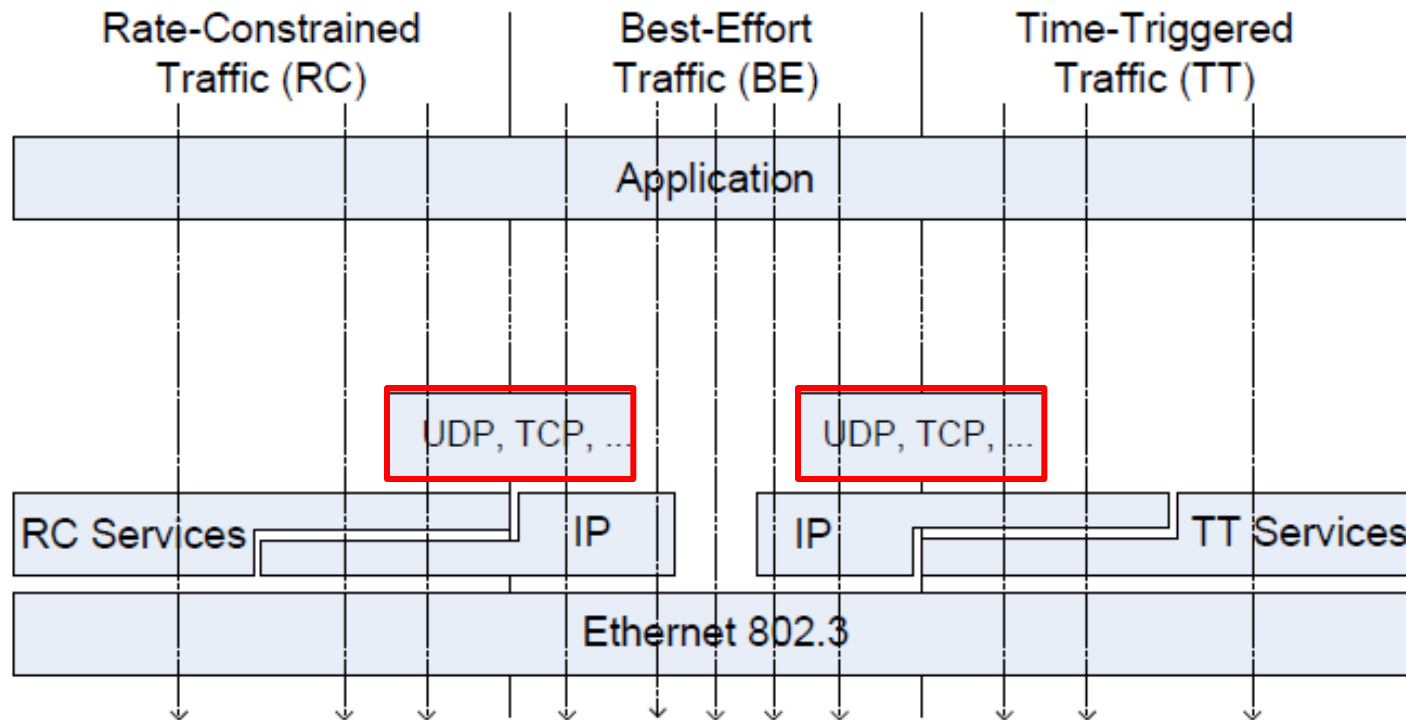


TT-Ethernet – Standard Configuration



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:

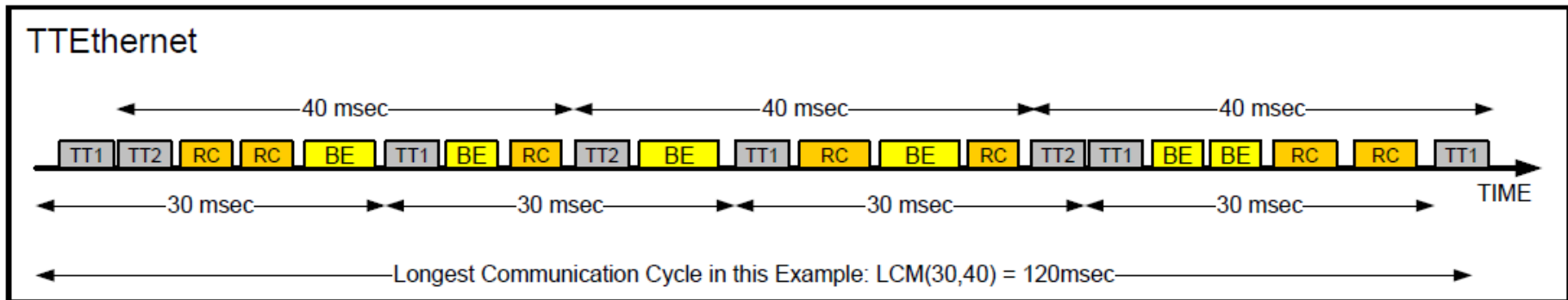
- dispatch messages according a predefined communication schedule

Rate-Constrained (RC) traffic:

- enforce minimum duration between two frames of the same stream

Best-Effort (BE) traffic:

- standard Ethernet communication paradigm – no temporal guarantees are given



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
- 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 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

Unprotected TT Message Types

- **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
- **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

Ethernet packet frame

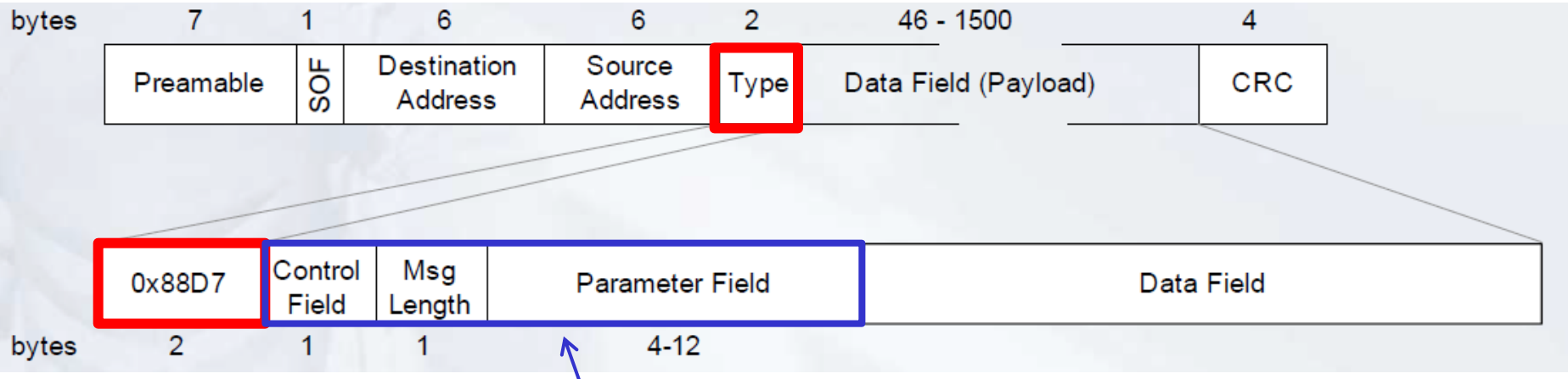
802.3 Ethernet packet and frame structure

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)

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

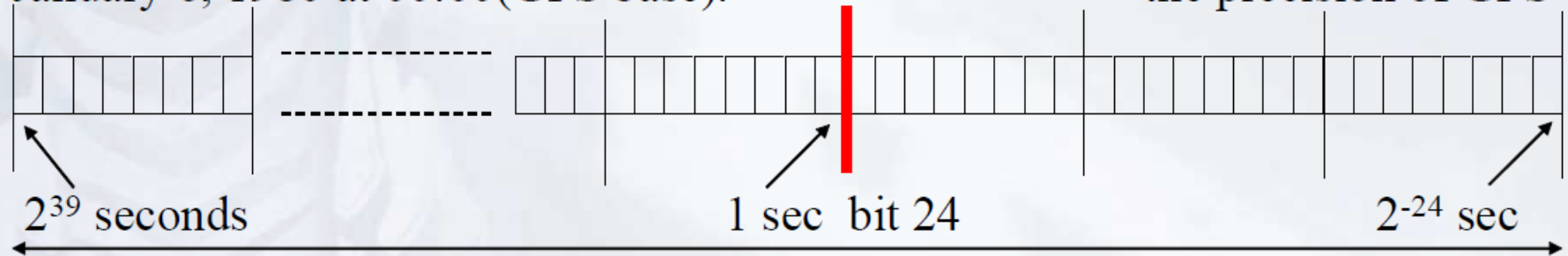
TT-Ethernet Time Format

Time horizon

about 30 000 years,
elapsed seconds since
January 6, 1980 at 00:00(GPS base).

Time granularity

about 60 nanoseconds
determined by
the precision of GPS



TT Ethernet time format (8 bytes)

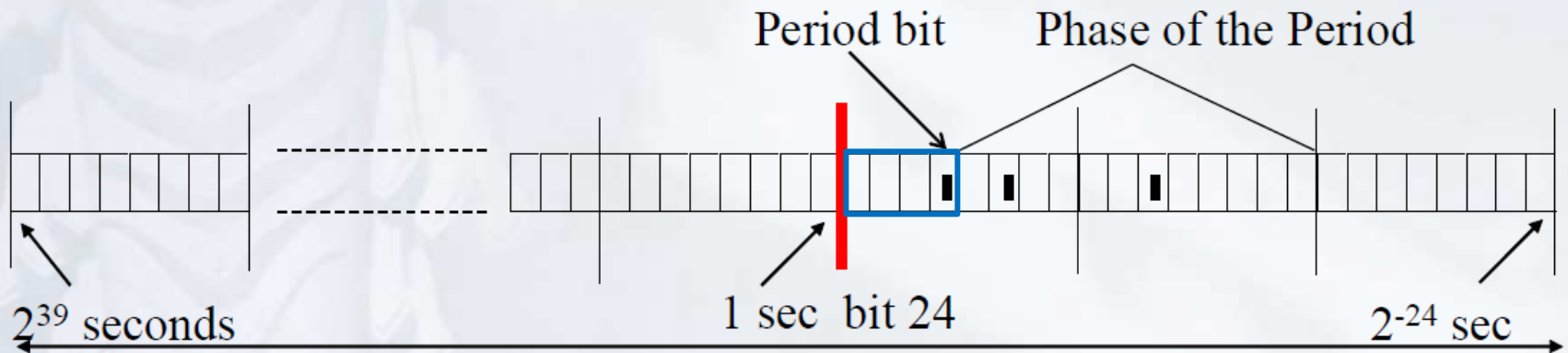
Time Format: Period ID (=Msg ID)

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)

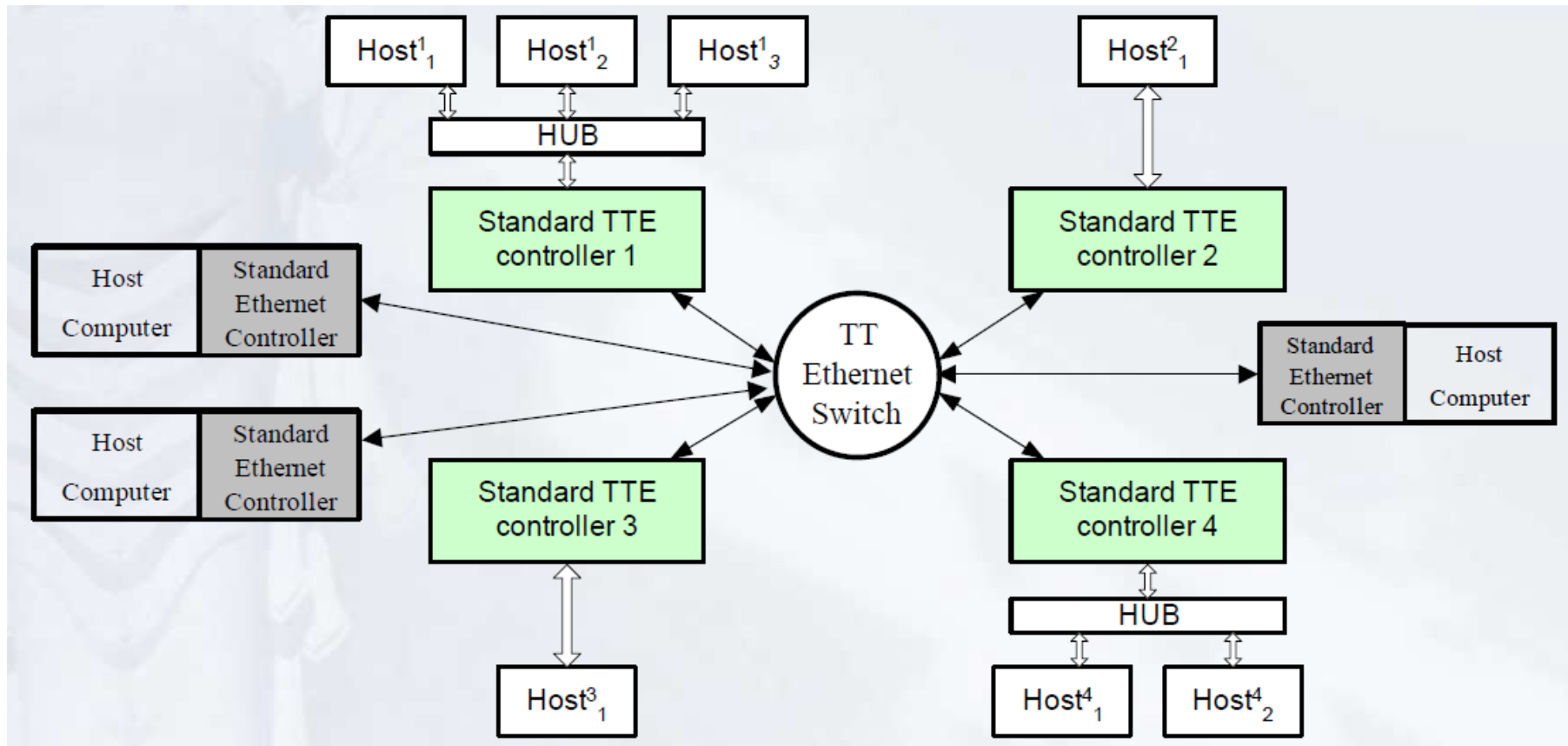
Phase of $1/2^6 + 1/2^{11} = 16113$ sec.



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

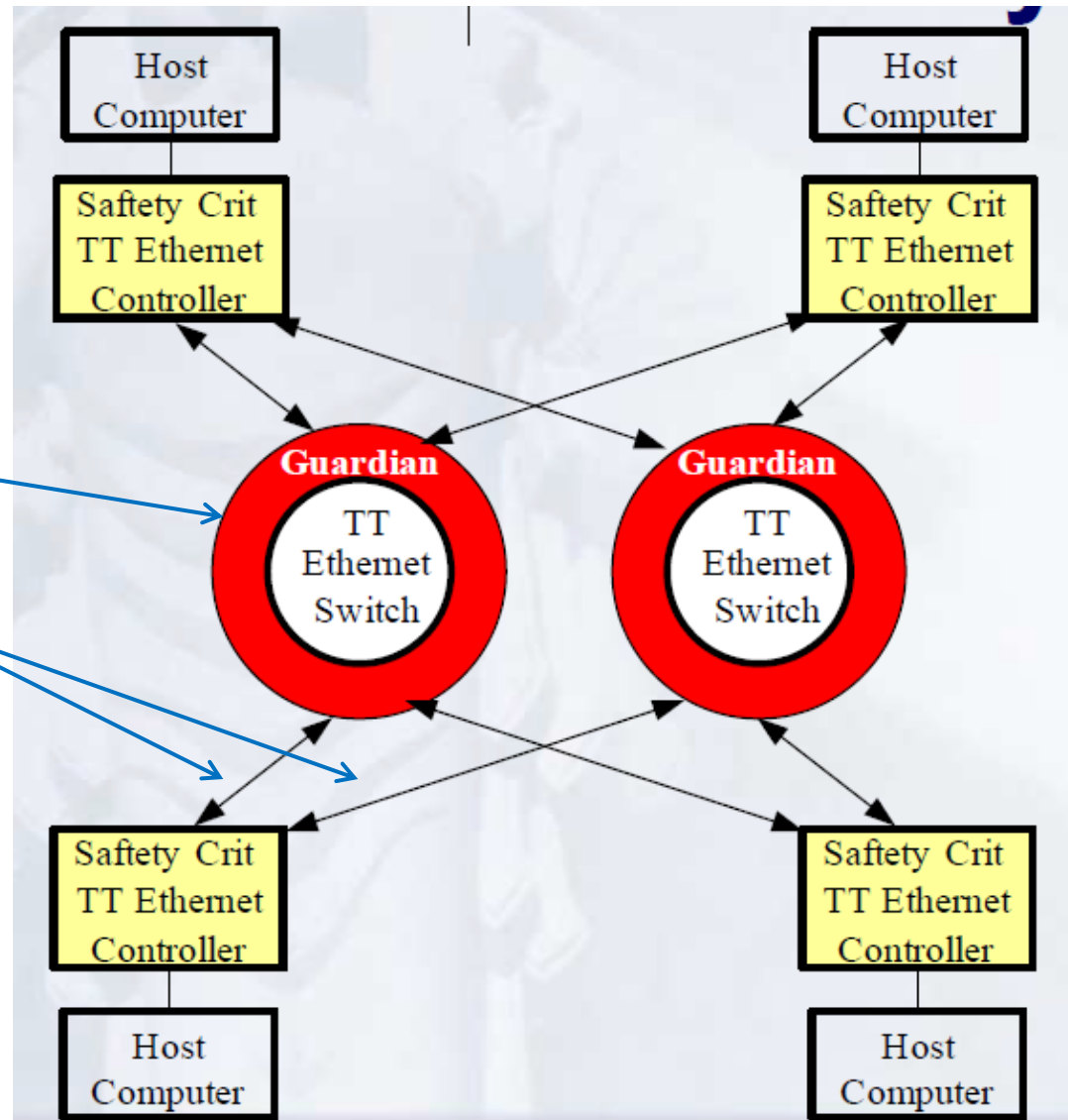


4. Safety Critical TT-Ethernet

Requires:

- Safety critical TT-Ethernet controllers
- Minimum two TT-Ethernet switches
- Bus Guardians for switch/bus protection
- Two communication busses

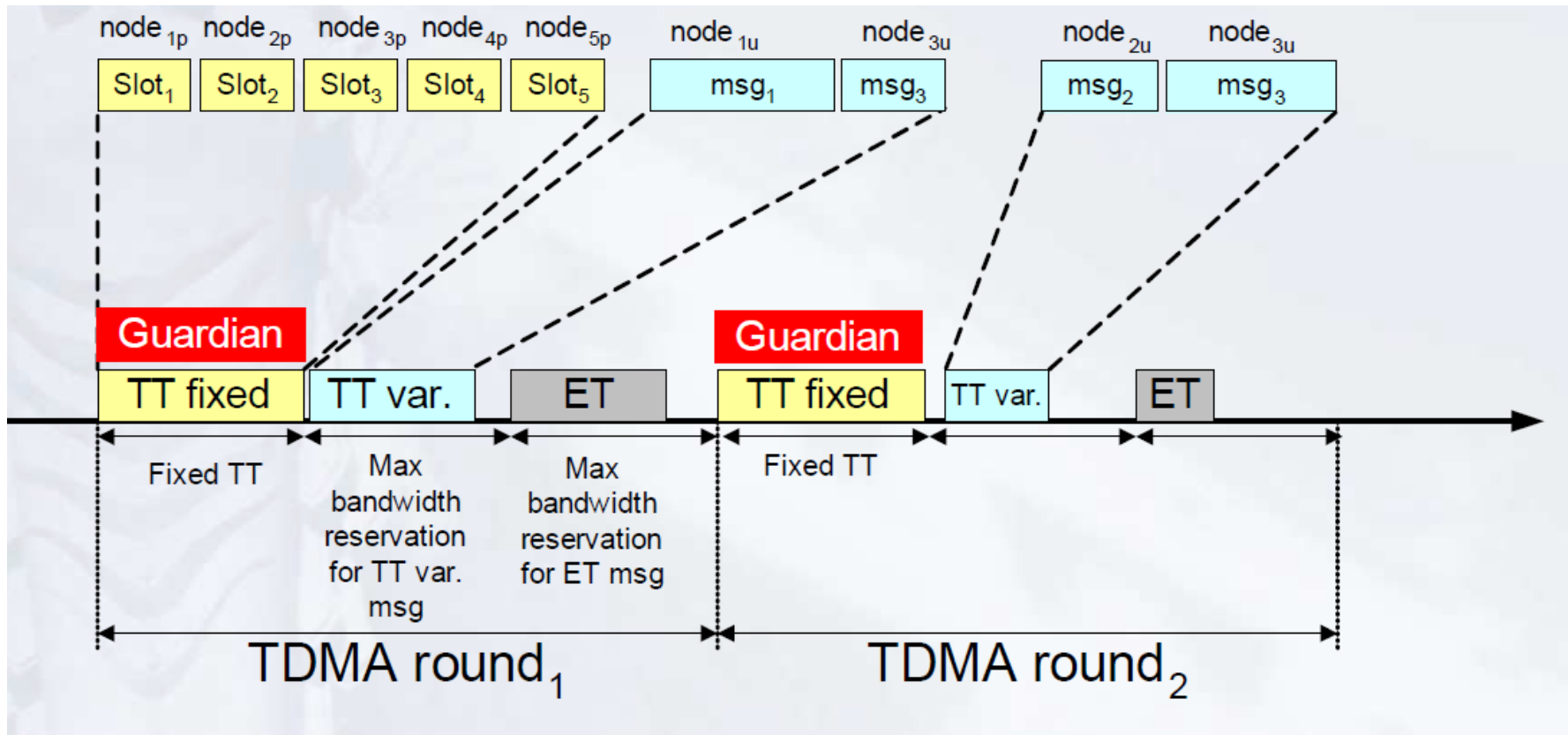
TTE Safety Critical Configuration



Bus Guardian

Two Busses

Communication Schedule Example



New Protected Message Categories

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

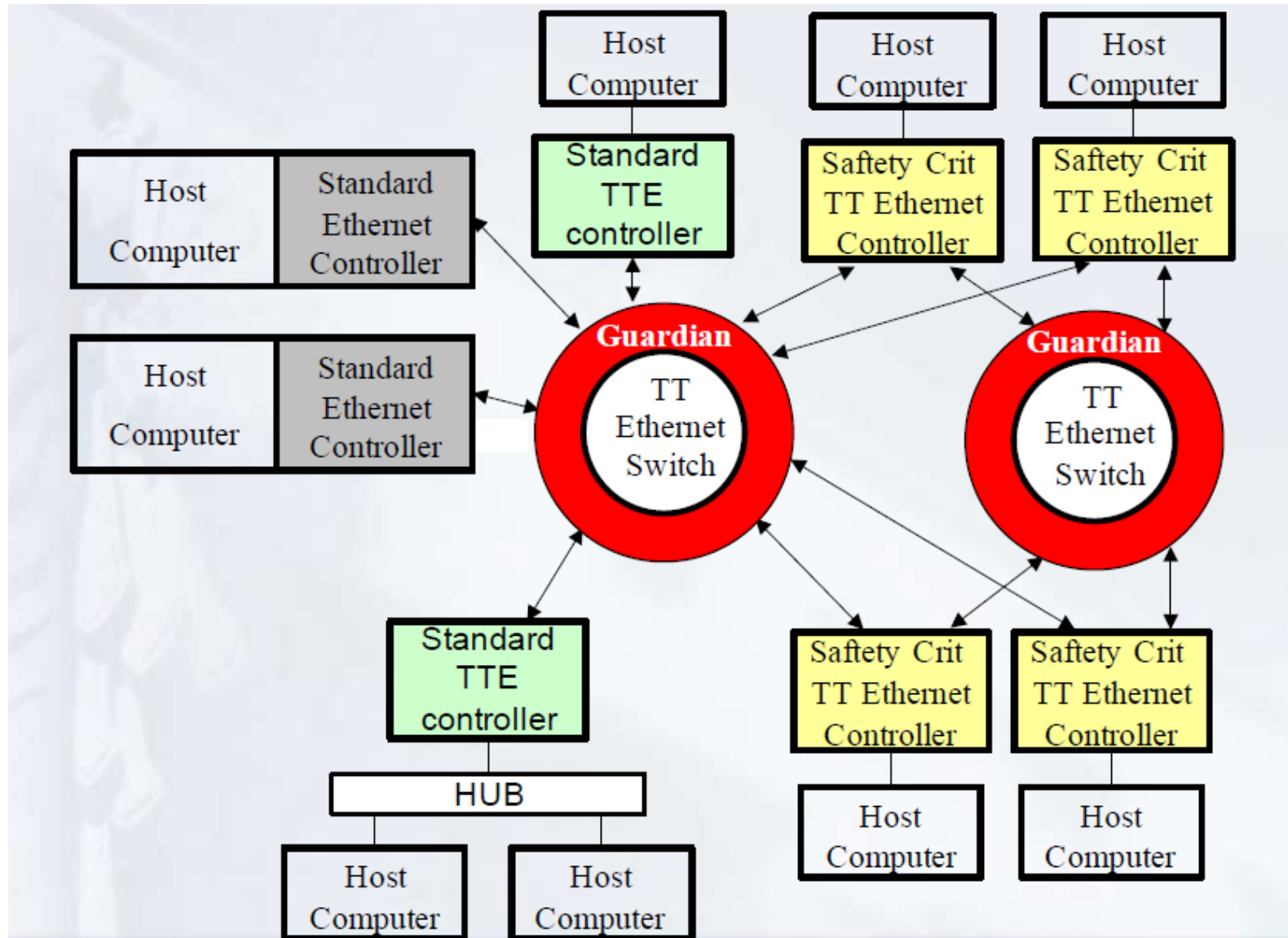
Common properties for Protected messages:

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

Bus Guardian properties

- A safety critical TT-Switch is monitored and controlled by its dedicated bus guardian
- A guardian can disable the inputs and outputs of the switch
- 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

Safety Critical Configuration Example



5. TT-Ethernet and IEEE 1588

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

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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