The Time-Triggered Ethernet

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Overview

- Introduction
- Time-Triggered Ethernet
- Different configurations
- Related Work
- Conclusion

Introduction

- Embedded safety-critical real-time systems deploy time-triggered communication
- Time-triggered systems guarantee predictable and deterministic communication (achieved through a static TDMA scheme)
- Constant transmission latencies and bounded jitter
- Composable and simple
- Inflexible
- ASIC implementation of comm. controllers (TTP/C, FlexRay, TTCAN)

Requirements for flexible comm.

- Additional requirements flexible communication
- Examples
  - FlexRay and
  - DECOS integrated architecture (using TTP/C) implement that using a statically reserved resources for (flexible) event triggered messages – sometimes leading to communication resource wastage

Bandwidth requirements

- Existing time-triggered sollutions work with bandwidths
  - TTP/C – 25 Mbit/s,
  - FlexRay -10 Mbit/sec
  - TTCAN – 1 Mbit/sec
- All these are lower than those of most used network technology, like Ethernet.

Time-Triggered (TT) Ethernet

- A novel communication system, which integrates time-triggered and event-triggered traffic into a single hardware infrastructure
- Using inexpensive and commercially available components
- Bandwidth (100 Mbit/sec, 1000Mbit/sec)
- We call it: Time-Triggered Ethernet (TT Ethernet)
- Similar solutions exist – comparison with them is given latter.

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State / Event Messages

- State messages: periodic exchange of state information
- Event messages: sporadic exchange of event information
- State messages and event messages are two extremes of a spectrum of information type and transmission trigger combinations [Bauer 03]

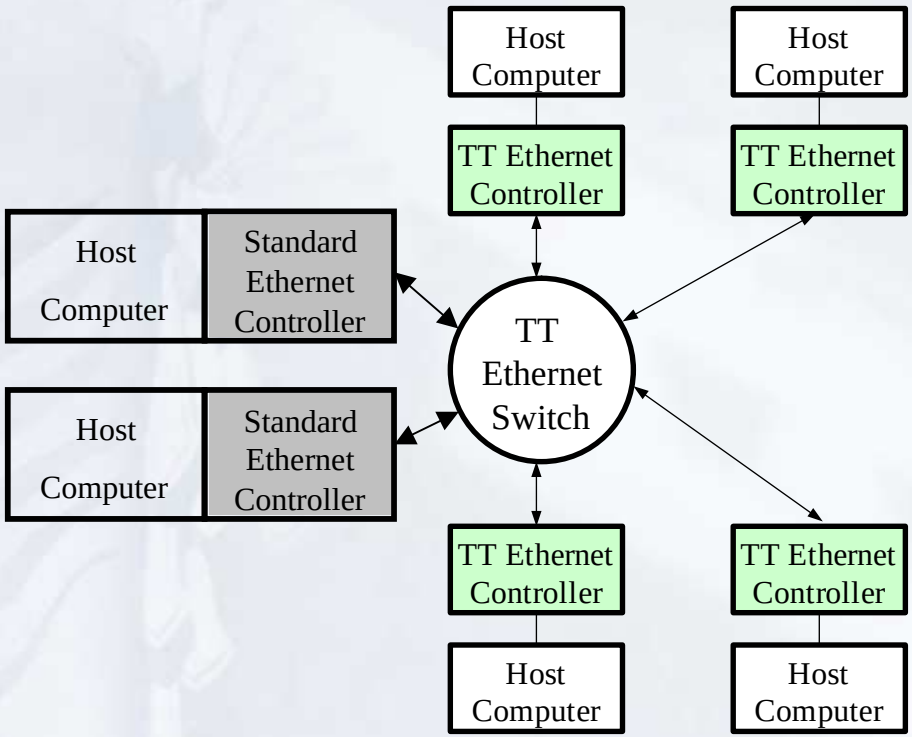
State Information

- At sender:
  - At-least-once transmission
  - Non-consuming sending, one can send the same status data many times.
- At Receiver:
  - Update in place
  - Non-consuming read (one can read the last valid message)

Event Information

- At sender:
  - Exactly-once transmission
  - Consuming sending
- At receiver:
  - Queuing
  - Consumed upon read

Time-Triggered Ethernet – Standard Configuration



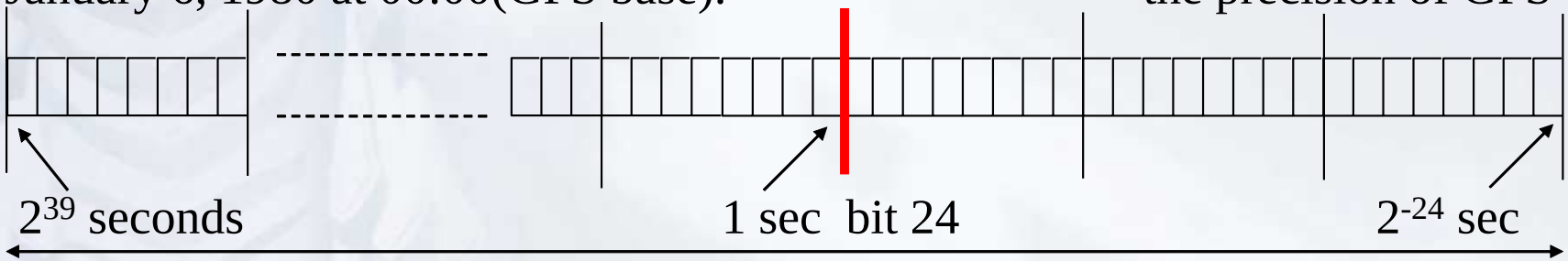
Principle of Operation

- TT Ethernet switch - transmits TT msg. with a constant delay
- Transmission of ET msg. is preempted,
  - if during the transmission a TT msg. arrives at a switch port, ET msg. is stored in the buffer of the switch, and retransmitted as soon as the transmission of the TT msg. is finished
- If during the transmission of TT msg. an ET msg. arrives in a port of the switch, the ET msg. is stored in the buffer of the switch and transmitted after the transmission of TT msg. is finished

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)

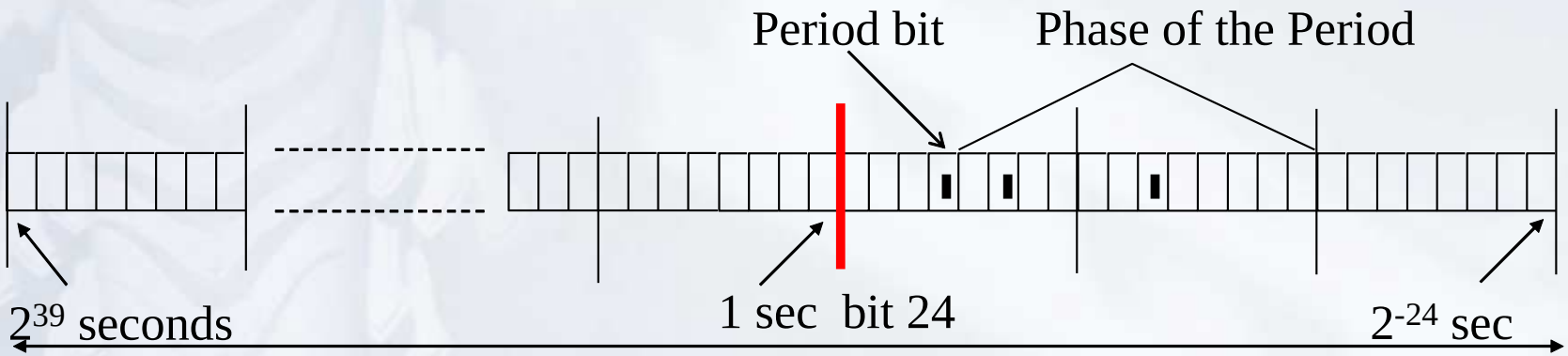
TT Ethernet - Time Format (2)

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)

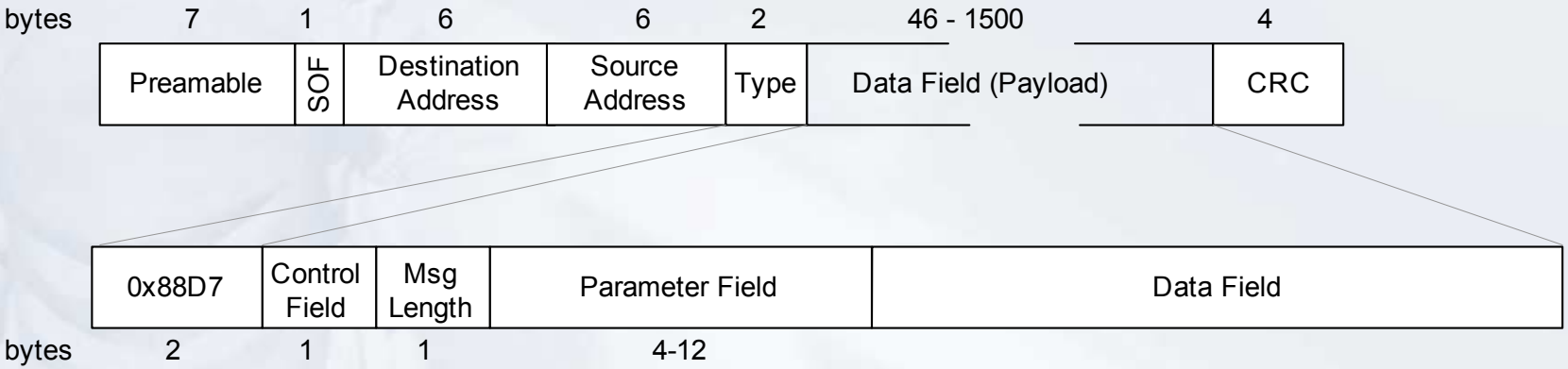
Phase of $1/2^6 + 1/2^{11}$ = 16113 sec.



Message Naming

- Naming scheme for messages to support the identification of a message type (in the literature this is often called a message name) and a message instance.
- The message type name denotes a sequence of messages of the same type.
- Two bytes period ID as the message type name.
- A particular message instance can be identified by
  - the concatenation of the message type name (the period ID)
  - with the send instant of the message

TTE Frames



- Standard Ethernet frames
- Standard frame type field 0x88D7
- Ethernet data field contains the header and the data fields of different TT Ethernet frames

Message Categories

1. Event -Triggered (ET) messages
2. Free Form Time-Triggered (FFTT) messages
3. Unprotected Start-up messages
4. Unprotected Synchronization messages
5. Unprotected periodic TT messages
6. Unprotected sporadic TT messages

} unprotected TT msg

Event –Triggered (ET) message

- ET messages - are handled in conformance with the IEEE Ethernet e.g., IP, UDP, IPX, Appletalk etc.
- Message queue (event semantics)

Free Form Time-Triggered (FFTT) message

- FFTM are handled similar as ET, with a small difference.
- Sent with TT priority (for the switch), can preempt ET messages
- Message queue (event semantics)

Unprotected Start-up message

- The TT startup messages establish an initial synchronization
- After this initial synchronization has been achieved, the *startup phase* is terminated → operational phase

Unprotected Synchronization message

- maintain the clock synchronization during the operational phase, they are sent periodically
- The length of the period (the resynchronization period) is determined by the quality of oscillators and the required precision of the global time

Unprotected TT message

- Unprotected TT messages (UTTM) transport user data from a sender to one or a set of receivers
- Messages with state semantics
- In case of a *non-silent failure* of a node, an UTTM of one node might be corrupted by a TT message from another node.
- UTTMs are intended for multimedia applications
- In TT Ethernet, we distinguish between two kinds of UTTMs, the *periodic UTTMs* and the *sporadic UTTMs*.

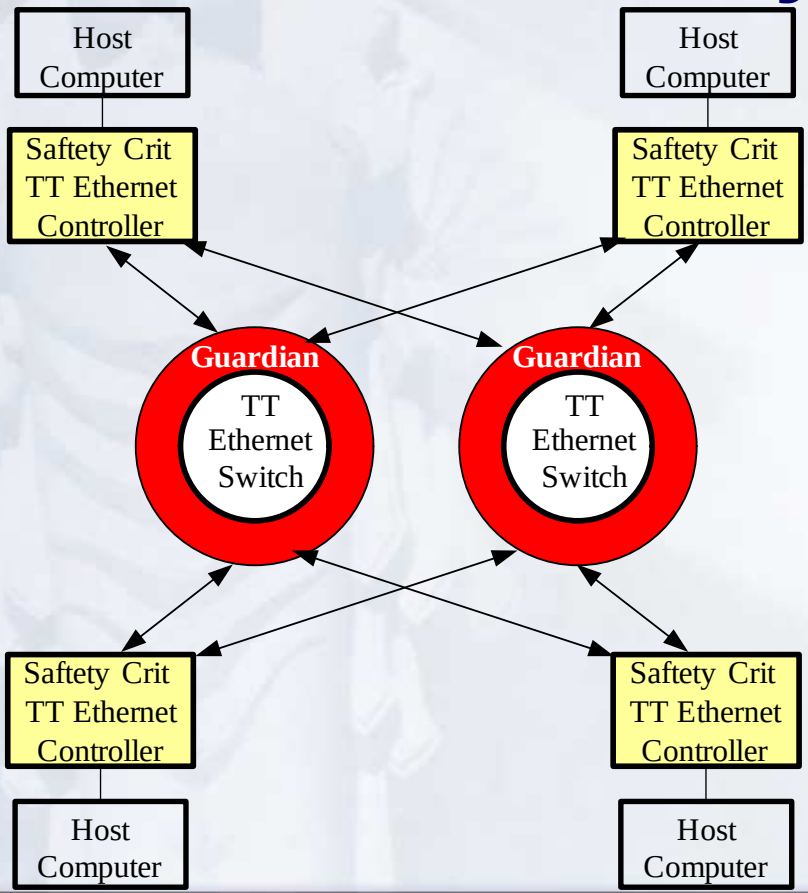
Unprotected periodic TT message

- Periodic, always sent, until the ***last message bit*** is set
- *Message length is variable*
- *Information pull mode* interface to the host

Unprotected sporadic TT message

- Periodic
- *Message length is variable*
- Only sent when the host updates the message
- *Information push mode* interface to the host

TT Ethernet Safety-Critical Config.



- The Guardian
- Two busses

New Message Categories

1. protected Start-up message
2. protected Synchronization message
3. protected TT message

- 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
- Nodes that suffers from faults within the fault hypothesis cannot affect the transmission of protected TT traffic

Fault hypothesis

- Unit of failure: fault containment region (FCR)
  - node: communication controller + host computer
  - TT Ethernet switch + Guardian
  - One communication channel (channel 0, channel 1)
- One arbitrary failure of one FCR at a time
- Never give-up (faults outside fault hypothesis are detected)

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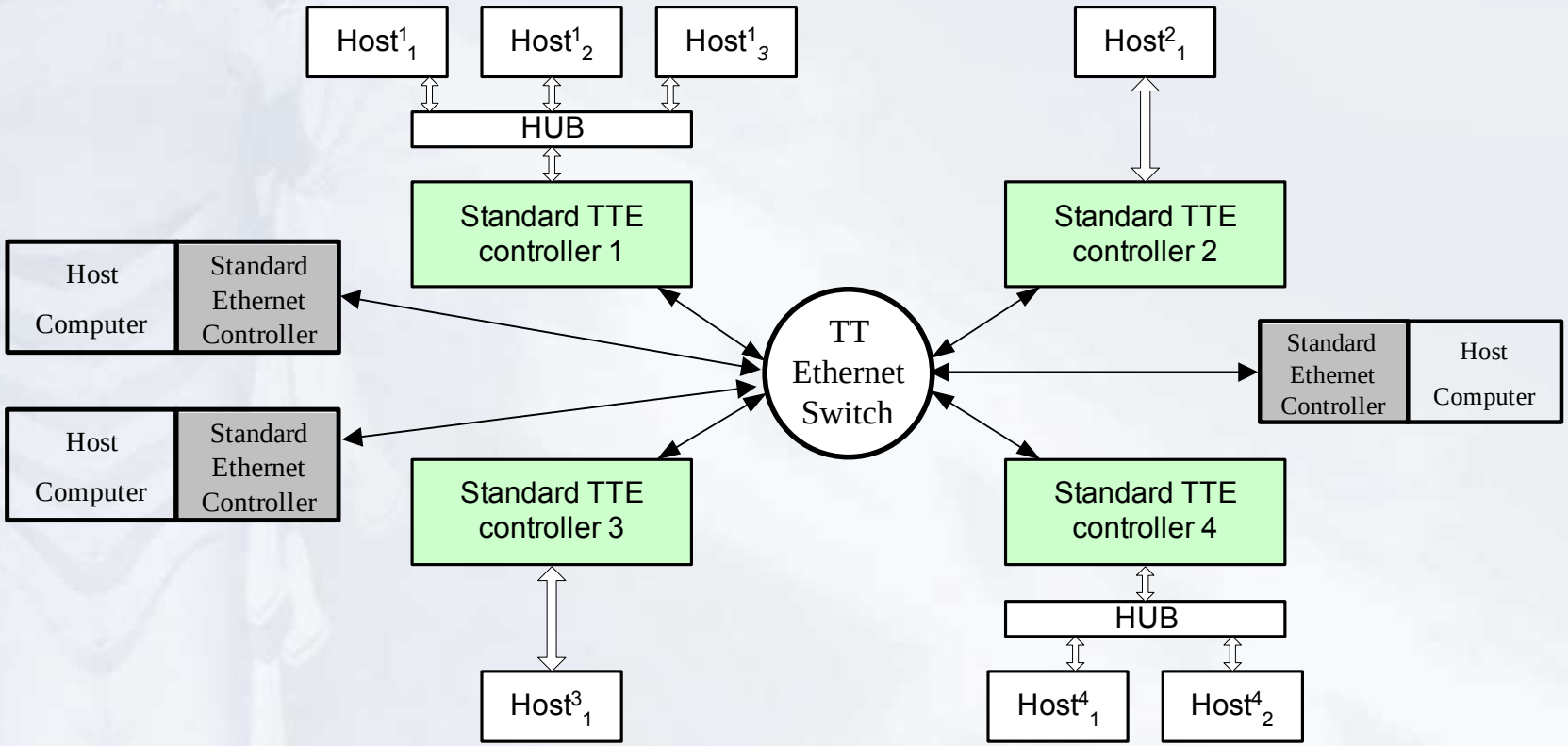
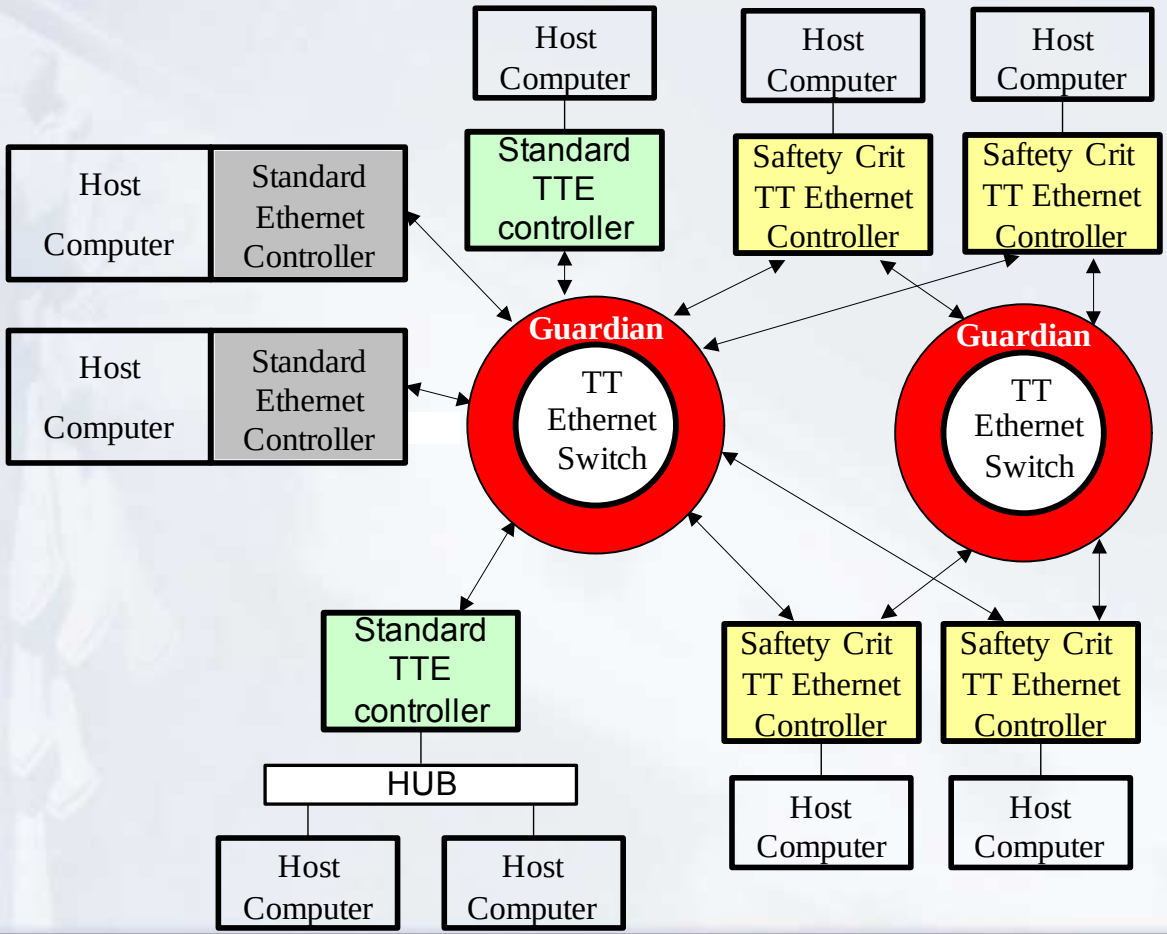
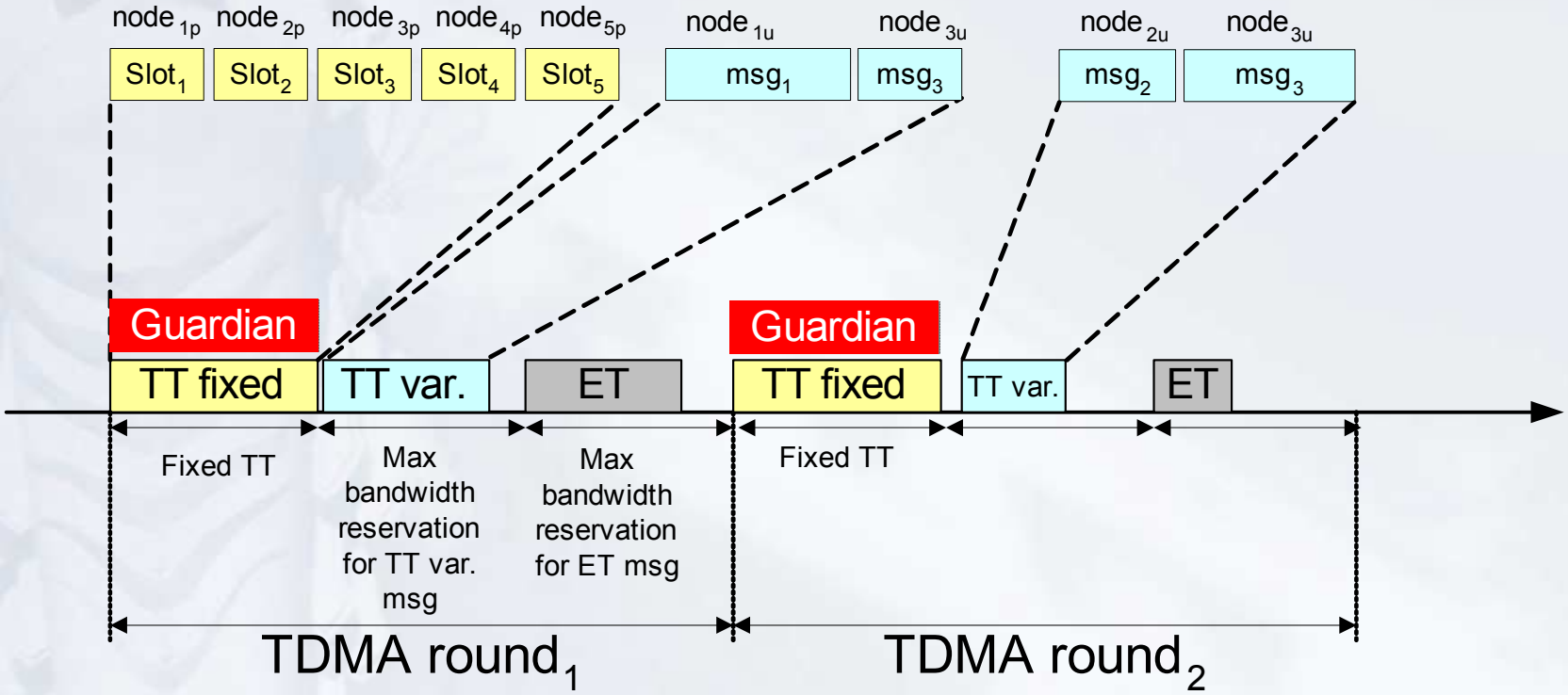
Different configurations : standard



Different configurations: safety-critical



Communication Schedule Example



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Related Work

- **RTnet,** timed UDP, RTAI OS (Hannover University)
- **PROFInet** SW and HW implementation(PSB, Siemens)
- **ETHERNET Powerlink** (B&R Industrie-Elektronik)
- **Switch with Time-Server** (Ontime Networks)
- **AFDX** (Condor Electronics)
- **…**
- **…**
- **Overview**: (http://www.real-time-ethernet.de)

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Conclusion

- A comm. infrastructure for integration of real-time and non real-time traffic
- Compatible with Ethernet standard
- Different application of different level of criticality
- Currently working in two implementations in Vienna
  - Linux RTAI based implementation
  - Network adaptor with PCMCIA interface (FPGA)
- Main difference with existing real-time Ethernet solutions is **interrupt mechanisms of TT Ethernet Switch**