Excerpt by Hermann Härtig
The Rationale for
Time-Triggered (TT) Ethernet

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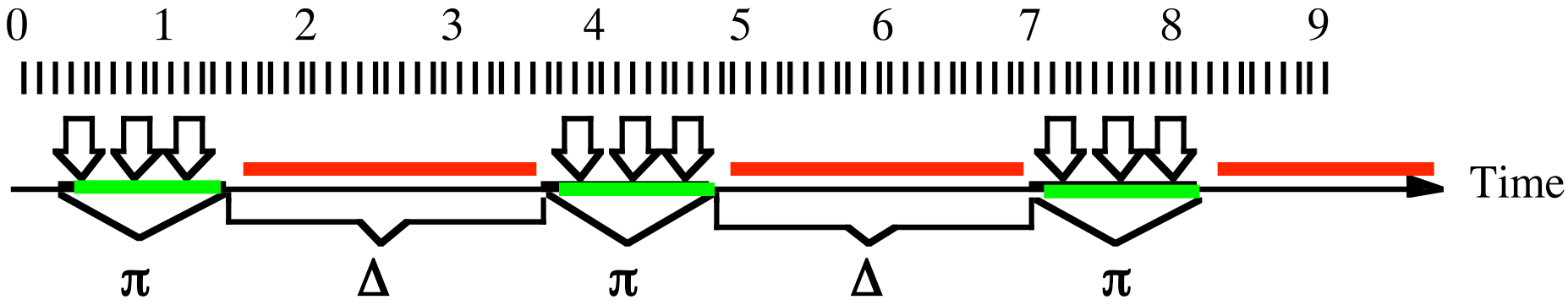
Time

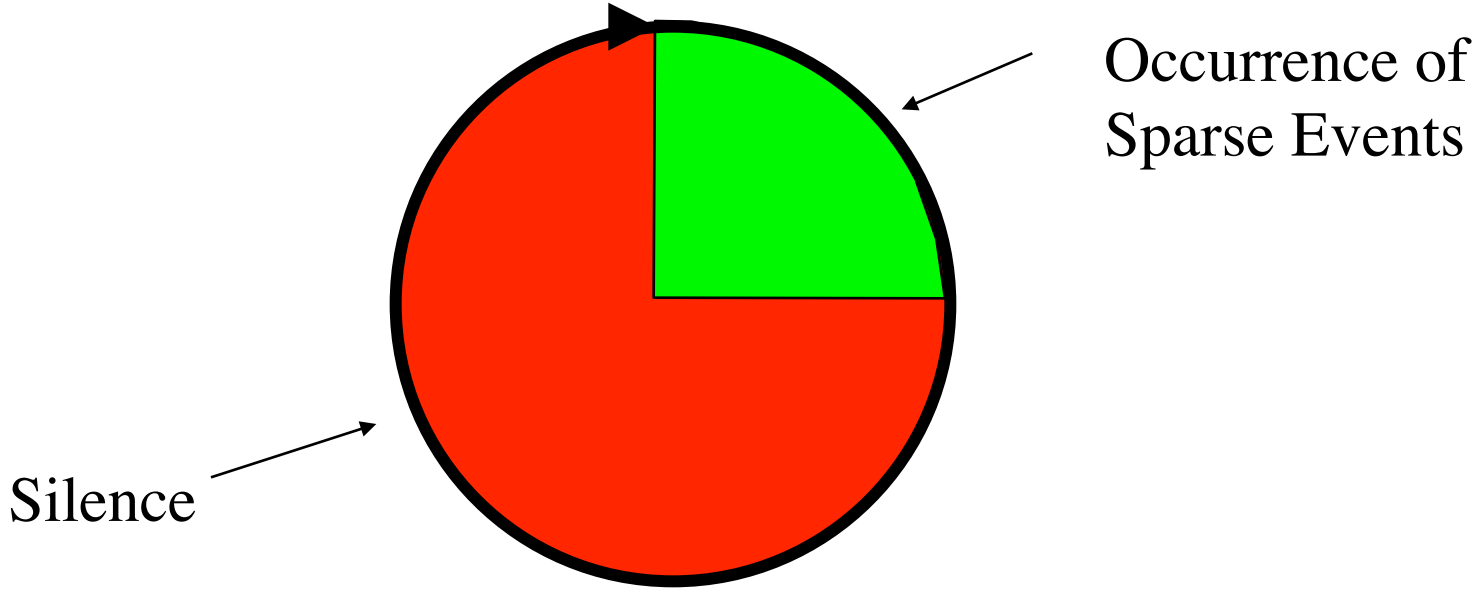
Whenever we use the term *time* we mean *physical time* as defined by the international standard of time TAI.

If the occurrence of events is restricted to some active intervals on the timeline with duration π with an interval of silence of duration Δ between any two active intervals, then we call the time base π/Δ-sparse, or ***sparse*** for short, and events that occur during the active intervals ***sparse events***.



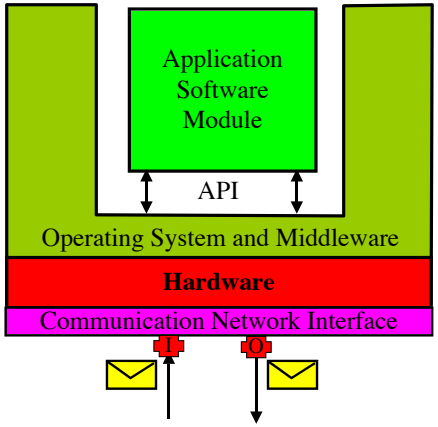
Cyclic Representation of the *Sparse Time*

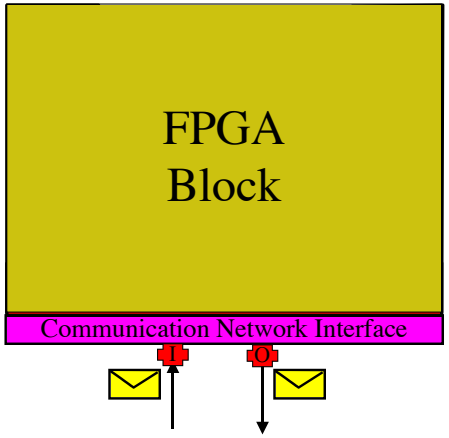
Real-Time

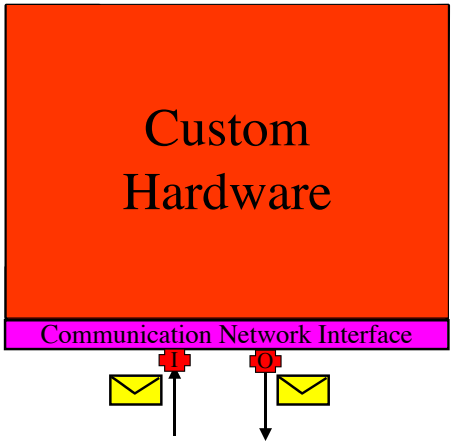


Component

A *component* is a hardware/software unit that accepts input messages, provides a useful service, maintains internal state, and produces after some *elapsed time* output messages containing the results. A component is thus an identifiable functional unit of data transformation and comprehension and forms an abstract high-level concept in the mental model of system behavior.

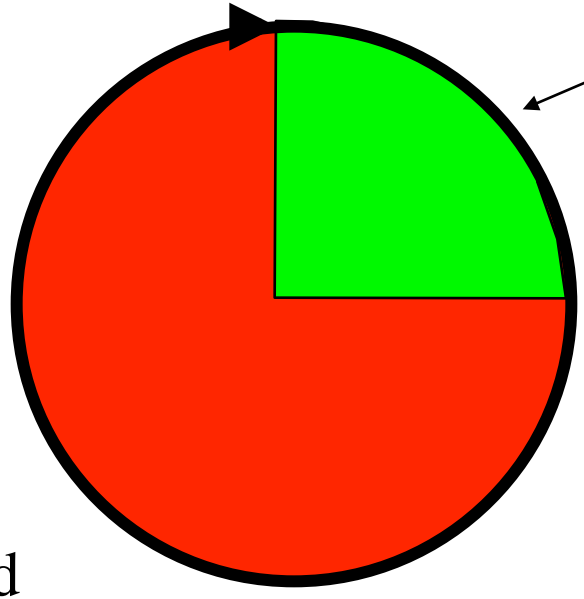






Sparse Time and *State*

Real-Time

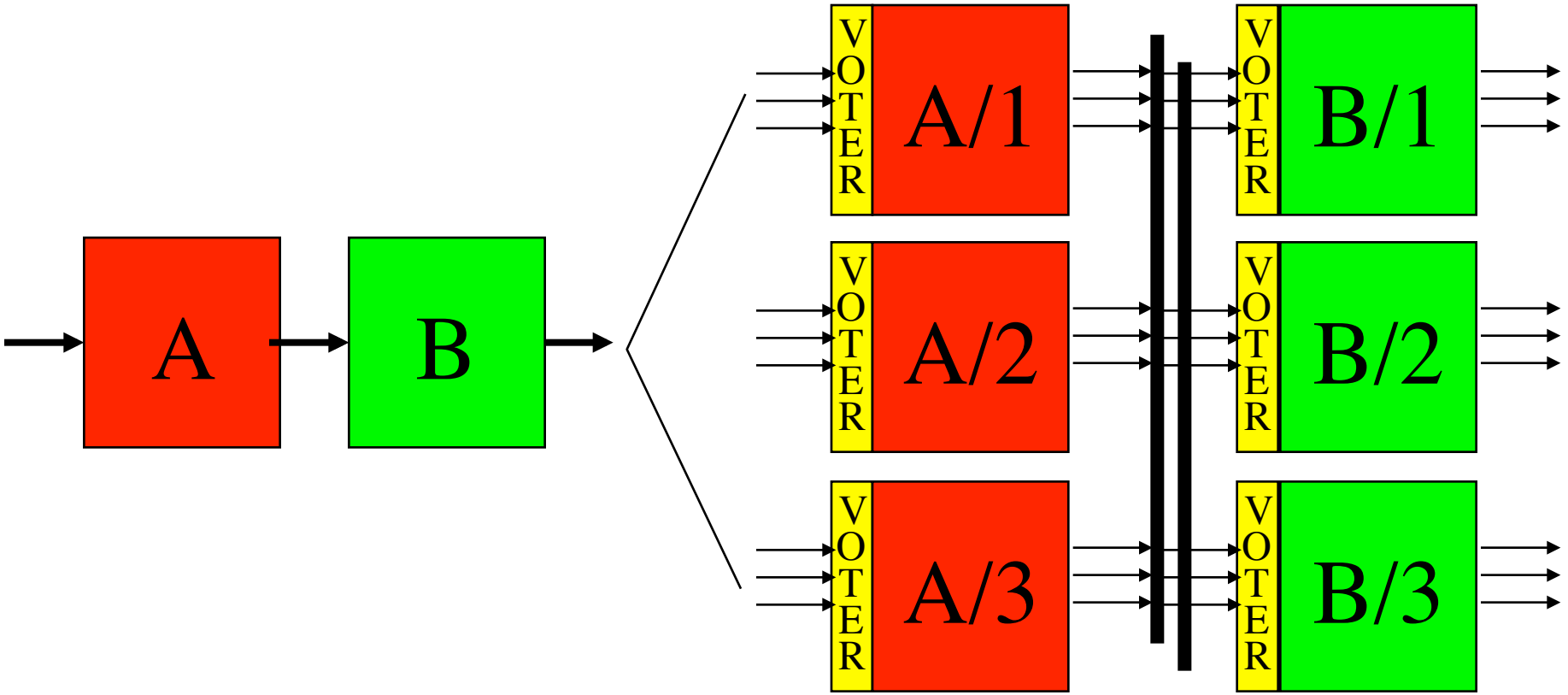


Occurrence of
Sparse Events

Silence, when
State is defined

Fault-Handling at the Architectural Level: TMR

Triple Modular Redundancy (TMR) is the *generally accepted technique* for the mitigation of component failures at the system level:



Purpose of TT Ethernet

The *purpose* of TT Ethernet is to provide a *uniform* communication system for all types of distributed non-real-time and real-time applications, from very simple uncritical data acquisition tasks, to multimedia systems and *up to safety-critical control applications*, such as *fly-by-wire* or *drive-by wire*.

It should be possible to upgrade an application from standard TT- Ethernet to a safety-critical configuration with minimal changes to the application software.

Legacy Integration

TT-Ethernet is required to be fully compatible with existing Ethernet systems in hardware and software:

- Message format in full conformance with Ethernet standard
- Standard Ethernet traffic must be supported in all configurations
- Existing Ethernet controller hardware must support TT Ethernet traffic.
- IEEE 1588 standard for global time representation is supported

Distinguish between two Categories of Messages

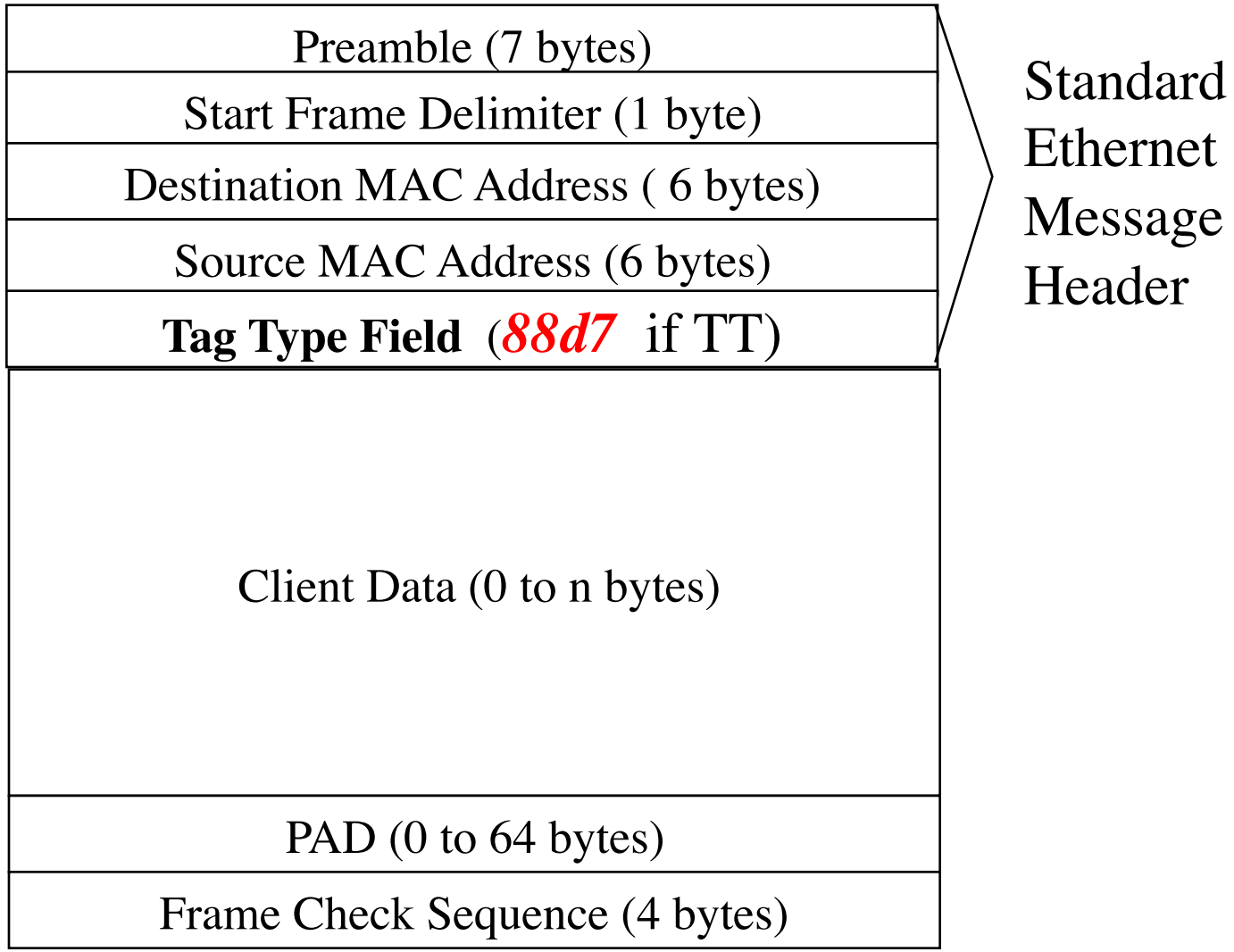
ET-Messages:

- Standard Ethernet Messages
- Open World Assumption
- No Guarantee of Timeliness and No Determinism

TT-Messages:

- Scheduled Time-Triggered Messages
- Closed World Assumption
- Guaranteed *a priori* known latency
- Determinism

TT and ET Ethernet Message Formats are Alike



Conflict Resolution in TT Ethernet

- **TT versus ET:** TT message wins, ET message is interrupted (preempted). The switch will retransmit the preempted ET message autonomously
- **TT versus TT**: Failure, since TT messages assumed to be properly scheduled (closed world system)
- **ET versus ET:** One has to wait until the other is finished (standard Ethernet policy).

There is no guarantee of timeliness and determinism for ET messages!

Global Time

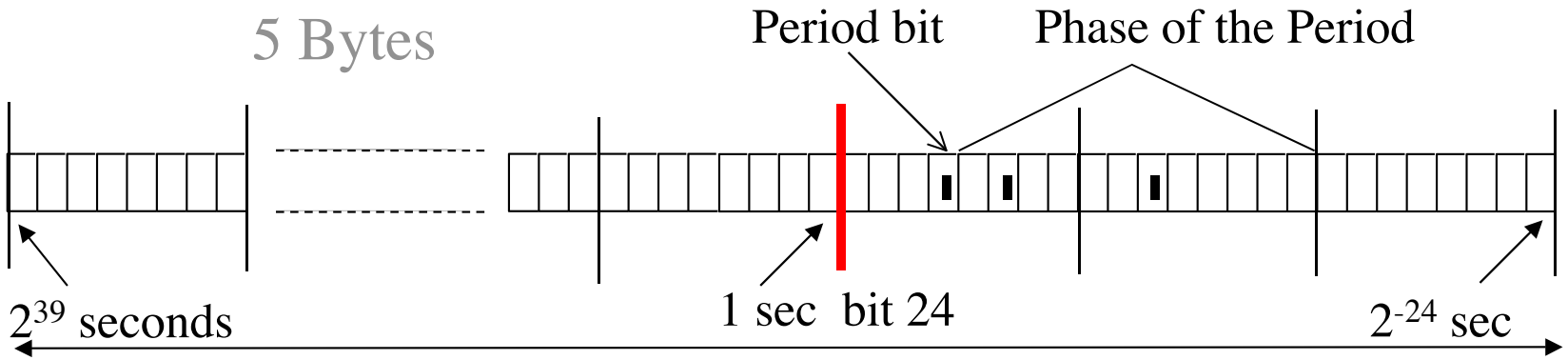
- TT Messages are used to build a global time base
- TT Ethernet time format is a *sparse binary time format.* Fractions of a second are represented as 24 negative powers of two (down to about 60 nanoseconds), and full seconds are presented in 40 positive powers of two (up to about 30 000 years) of the physical second.
- This binary time-format has been standardized by the OMG and IEEE 1588.
- TT Ethernet gives the user the option to make a tradeoff between dependability and cost of the global time.

TT Ethernet Periods

- The TT Ethernet *recommends* to restrict the period durations to the positive and negative *powers of two* of the second, i.e. a period can be either 1 second, 2 seconds, 4 seconds, and so forth, or 1/2 second, 1/4 second, 1/8 second and so forth.
- The duration of each period can then be characterized by the corresponding bit (*period bit*) in the binary time format.
- The *phase of a period,* i.e. the *offset* to the start instant of the selected duration in the global time format, is designated by the specification of a pattern of twelve bits (*the phase bits*) to the right of the *period bit*.

  We then can represent a cycle with two Bytes (*four period bits* i.e. 16 periods, and *twelve phase bits*).

TT Ethernet Periods--Example



Specification of a period of $1/2^4$ (i.e 1/16) second with a phase (i.e. the offset from the periodic 1/16 second instant) of $1/2^6+1/2^{11}$ = 16113 μseconds.

Integrity-Level of Application Domains

Application	System MTTF w.r.t. permanent failures (in years)	System MTTF w.r.t transient failures (in years)	Data-integrity requirement	Market volume	Examples
Low-Integrity	> 10	> 1	low	huge	Consumer Electronics
Moderate-Integrity	> 100	> 10	moderate	large	Present-day automotive
High-Integrity	> 1000	> 100	very high	moderate	Enterprise server
Safety-Critical	> 100 000	> 100 000	very high	small	Flight control

Conclusions

TT Ethernet

- provides a uniform communication infrastructure for all types of real-time and non real-time applications--from simple data acquisition systems, to multimedia systems up to safety-critical control applications.
- is based on sound theoretical concepts concerning time and determinism
- is fully compatible with the existing Ethernet standard.
- can be introduced in a modular fashion, integrating existing Ethernet hardware and software with modules that support the new services.