Automotive and highly dependable Networks

<u>**H. Kopetz, TU Wien (see references in the introduction)**</u>

Excellent surveys:

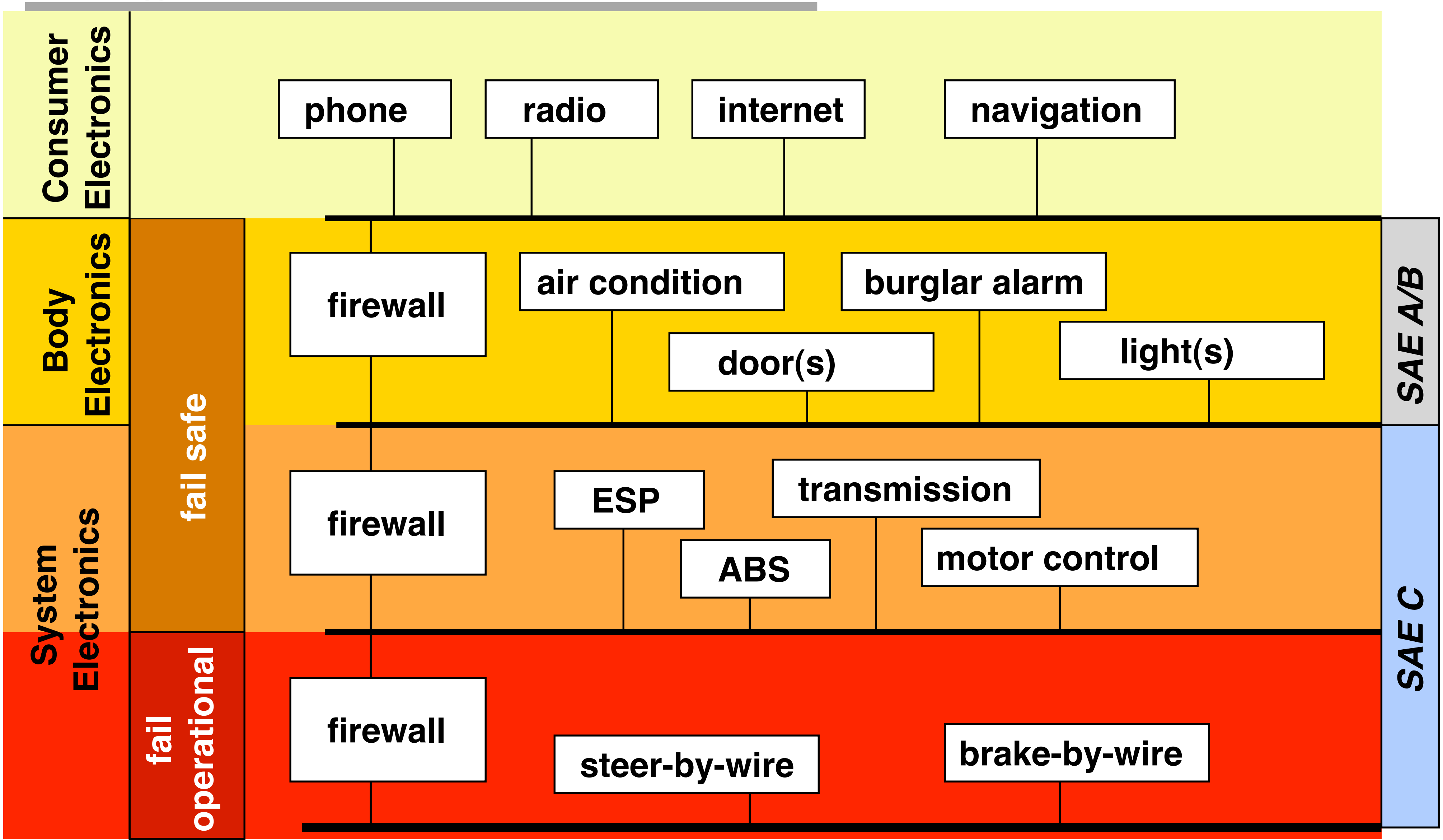
TTP:
Hermann Kopetz, Günther Bauer:
"The Time-Triggered Architecture"
http://www.tttech.com/technology/docs/history/HK_2002-10-TTA.pdf

Networks for safety critical applications in general:
John Rushby:
"Bus Architectures for Safety-Critical Embedded Systems"
http://www.csl.sri.com/users/rushby/papers/emsoft01.pdf

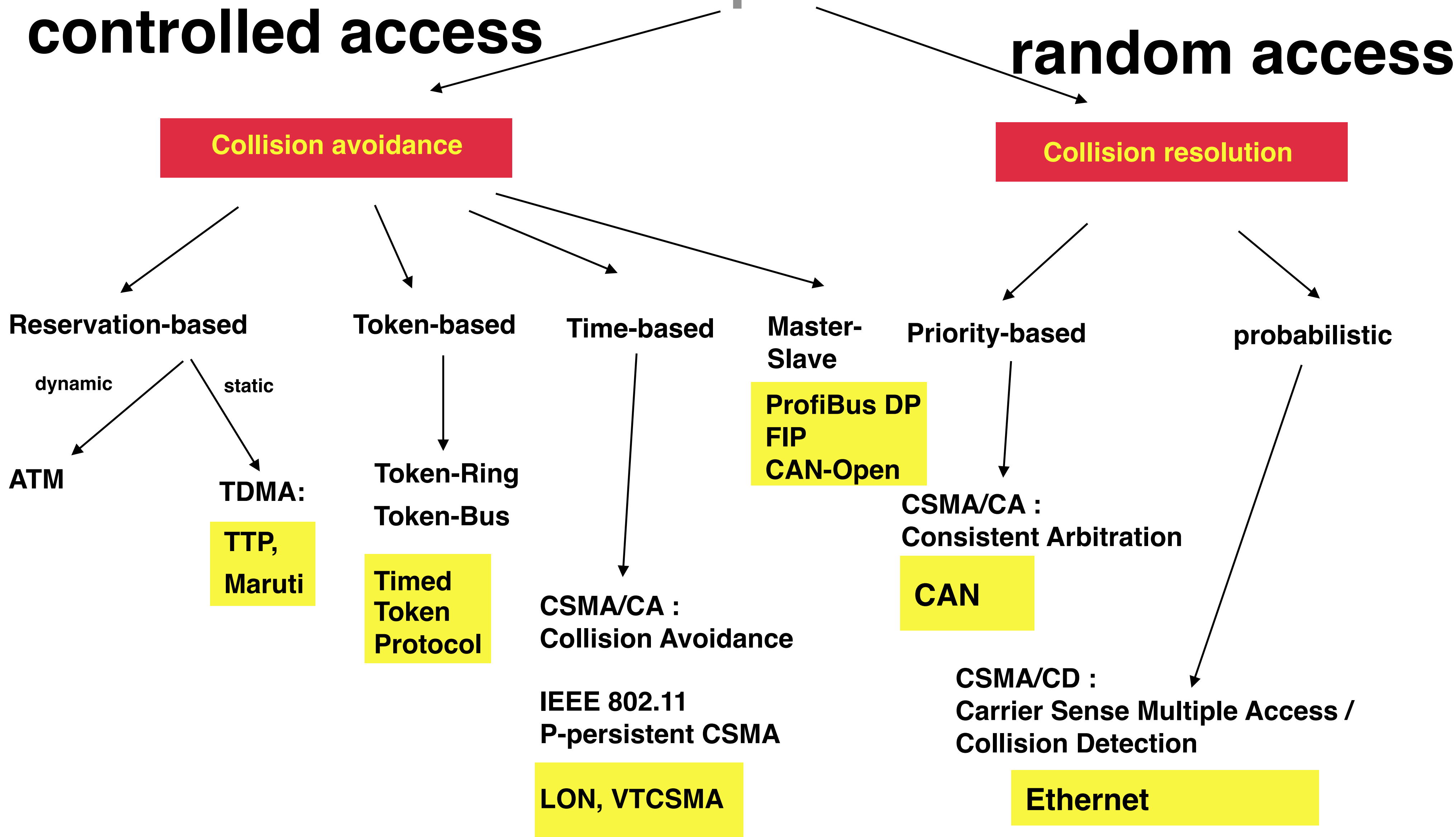
Products:
http://www.tttech.com/

Communication levels in a car

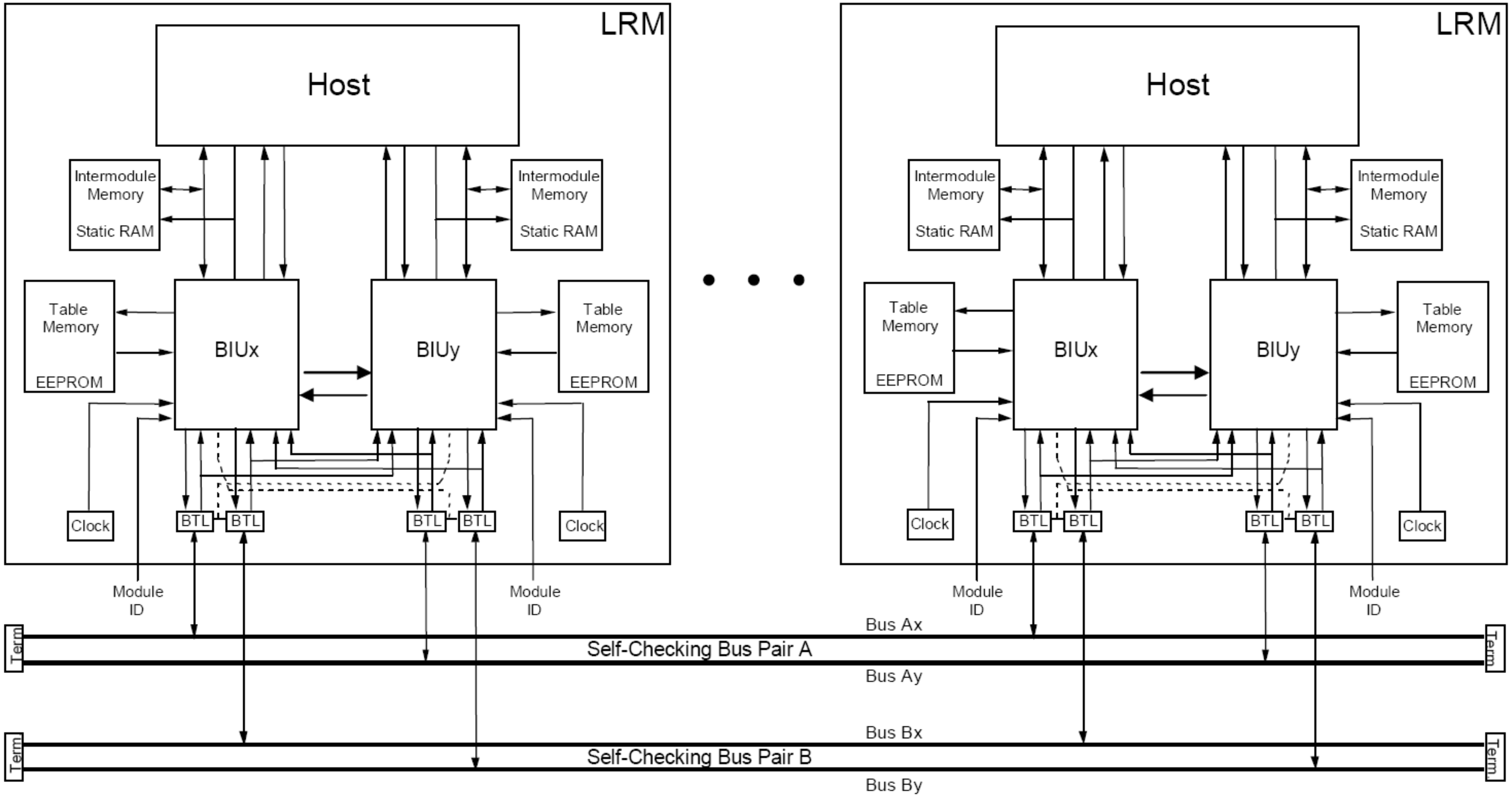
(T. Führer, B. Müller, W. Dieterle, F. Hartwich, R. Hugel, M. Walther:
„Time Triggered Communication on CAN“)



MAC-protocols



Hardware-Structure of the SAFEbus



Brendan Hall, Kevin Driscoll, Michael Paulitsch, Samar Dajani-Brown, "Ringing out Fault Tolerance. A New Ring Network for Superior Low-Cost Dependability," dsn, pp. 298-307, 2005 International Conference on Dependable Systems and Networks (DSN'05), 2005

Automotive and highly dependable Networks

TTP/C
Byteflight
FlexRay
Braided Ring

Time Triggered CAN (TTCAN)
TTP/A
LIN

Time Triggred Protocol (TTP)

Objectives:

- **Predictable, guaranteed message delay**
- **No single fault should lead to a total network failure**
- **Fault-Tolerance**
  - **Fault detection on the sender and the receiver side**
  - **Forward error recocery**
  - **Treating massive temporary faults (Black-out)**
  - **Distributed redundancy management**

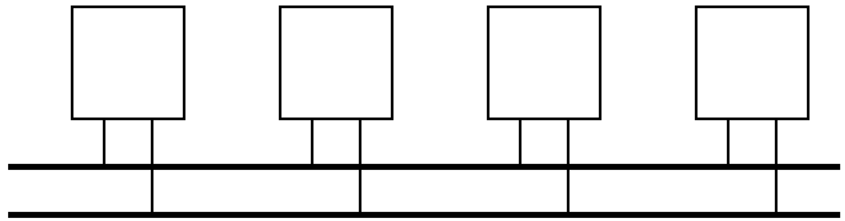
- **Clock synchronization**
- **Membership-service (basis for atomic multicast)**
- **Support for fast consistent mode changes**
- **Minimal protocol overhead**
- **Flexibility without sacrifycing predictability**

Design principles

- Exploiting a priori knowledge (static message schedule)
- Implicit flow control
- Fail silence
- Continuous supervision and consistent view of system state

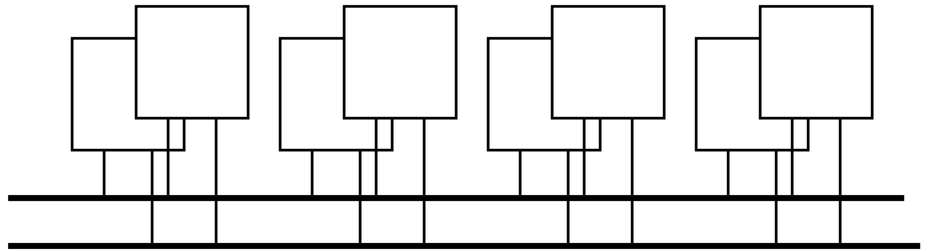
Fault-Tolerant Network Configurations

Class 1:
1 node/FTU
2 frames/FTU

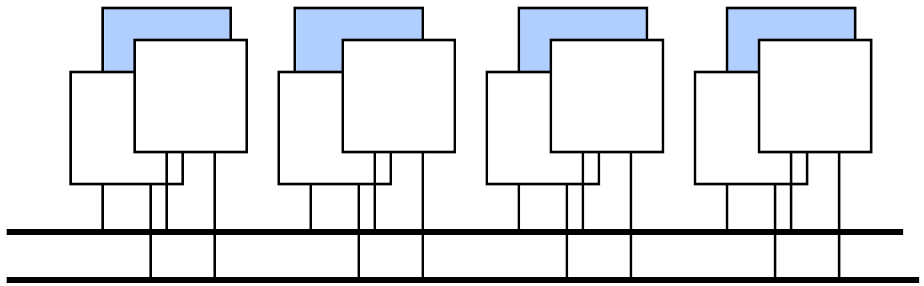


Class 2:
2 active node/FTU
2 frames/FTU

Class 3:
2 active nodes/FTU
4 frames/FTU



Class 4:
2 active nodes/FTU
+ 1 spare/FTU
4 frames/FTU



component redundancy + time redundancy

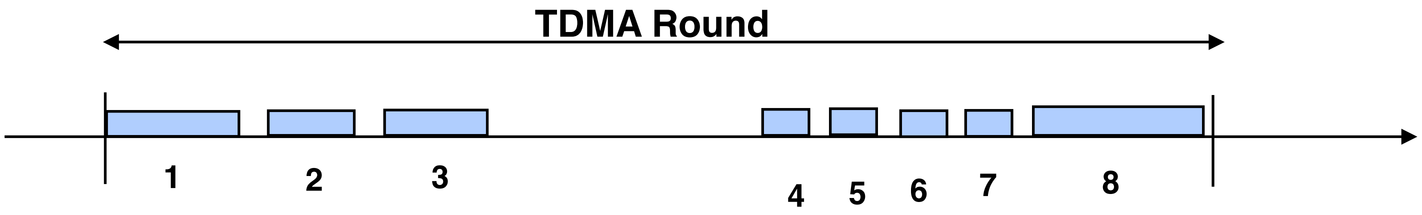
Fault-tolerance parameters

failure type	failure probability/h
permanent node failure	10^{-6}/h
permanent channel failure	10^{-5}/h
transient node failure	10^{-4}/h
transient channel failure	10^{-3}/h

what is the relation: faulty messages / overall number of messages ?

type of failures	Class 1	Class 2	Class 3	Class 4
Perm. node failure	0	1	1	2
Perm. comm. failure	1	1	1	1
Trans. node failure	0	1/Rec.interv.	1/Rec. interv.	1/TDMA-round
Trans. comm. failure	1 of 2	1 of 2	3 of 4	3 of 4

Exploit a priori knowledge: Off-line Scheduling



		Attributes			
	time	address	D	L	I	A
1						
2						
3						
4						
5						
6						
7						
8						

Message
Description
List

MEDL

time: defines the point in time when the message has to be transmitted

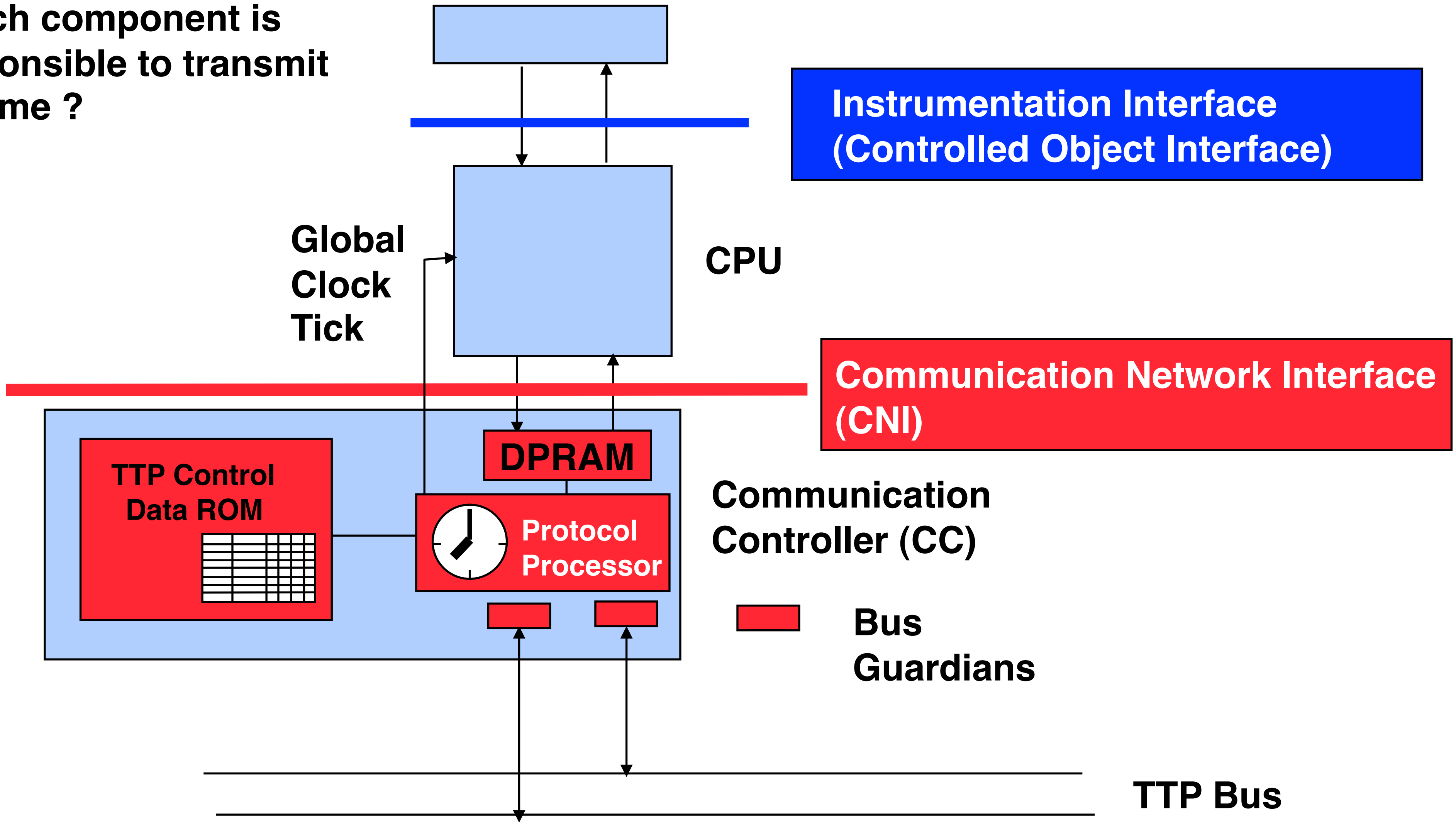
Address: Defines the local address where the messages to be transmitted/ received are stored in the node's memory

D: Direction Input or Output
L: frame length
I: Init or normal message
A: “Additional” Parameter Field

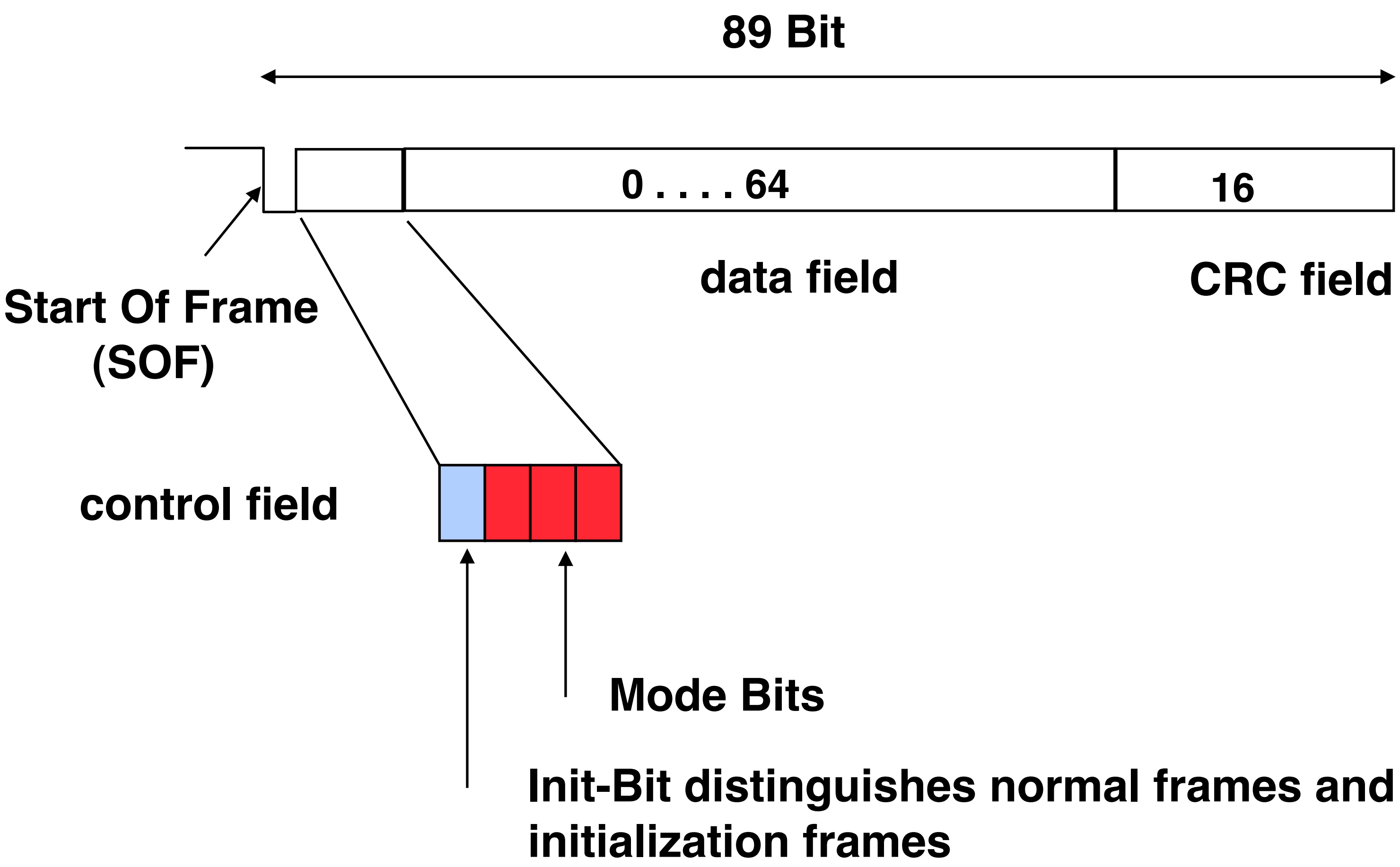
TDMA Round (Cluster Cycle): Every FTU has at least transmitted once in a round.

Fail silence und strict enforcement of transmit times

Which component is responsible to transmit a frame ?

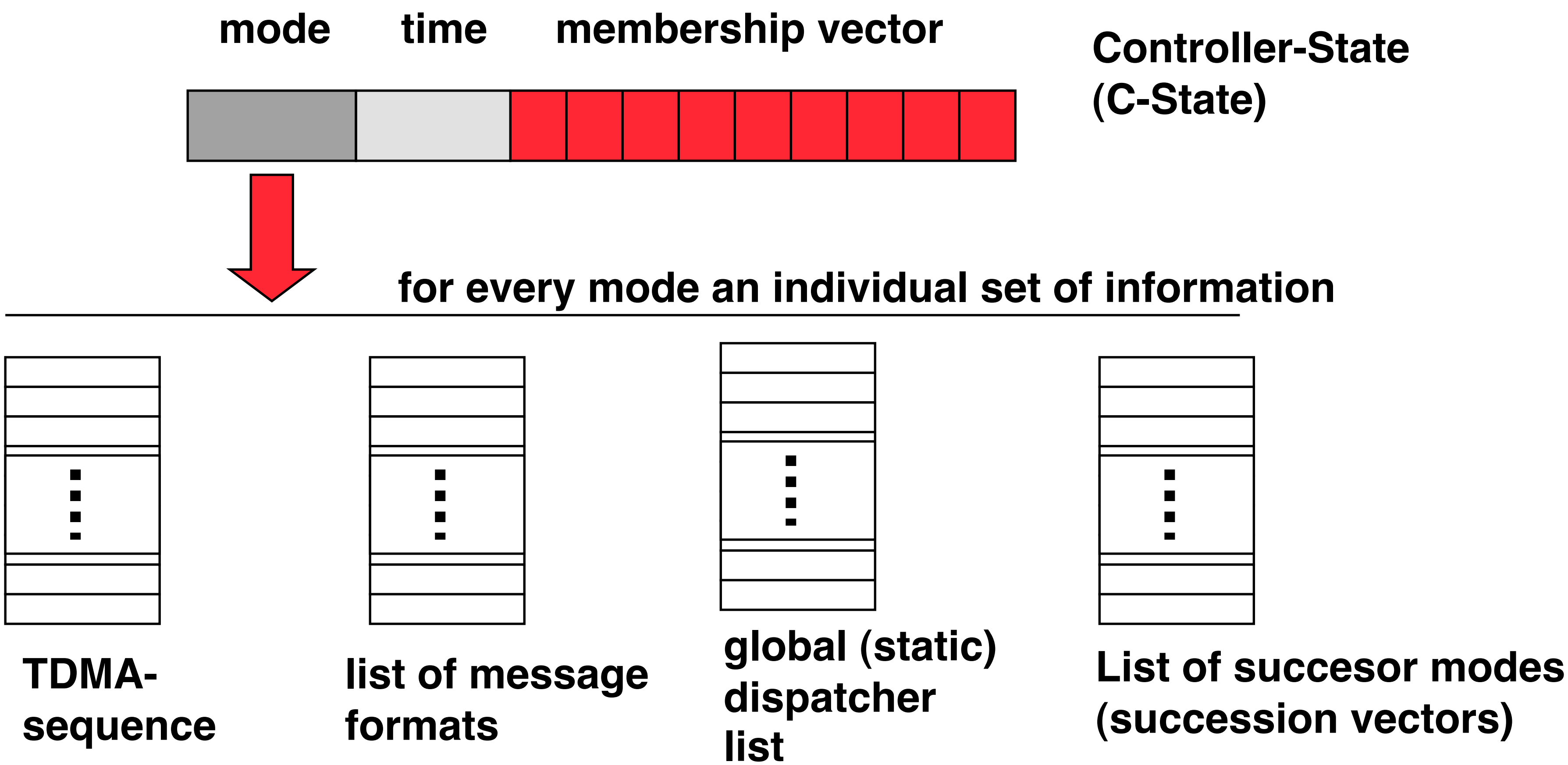


Format of a TTP frame

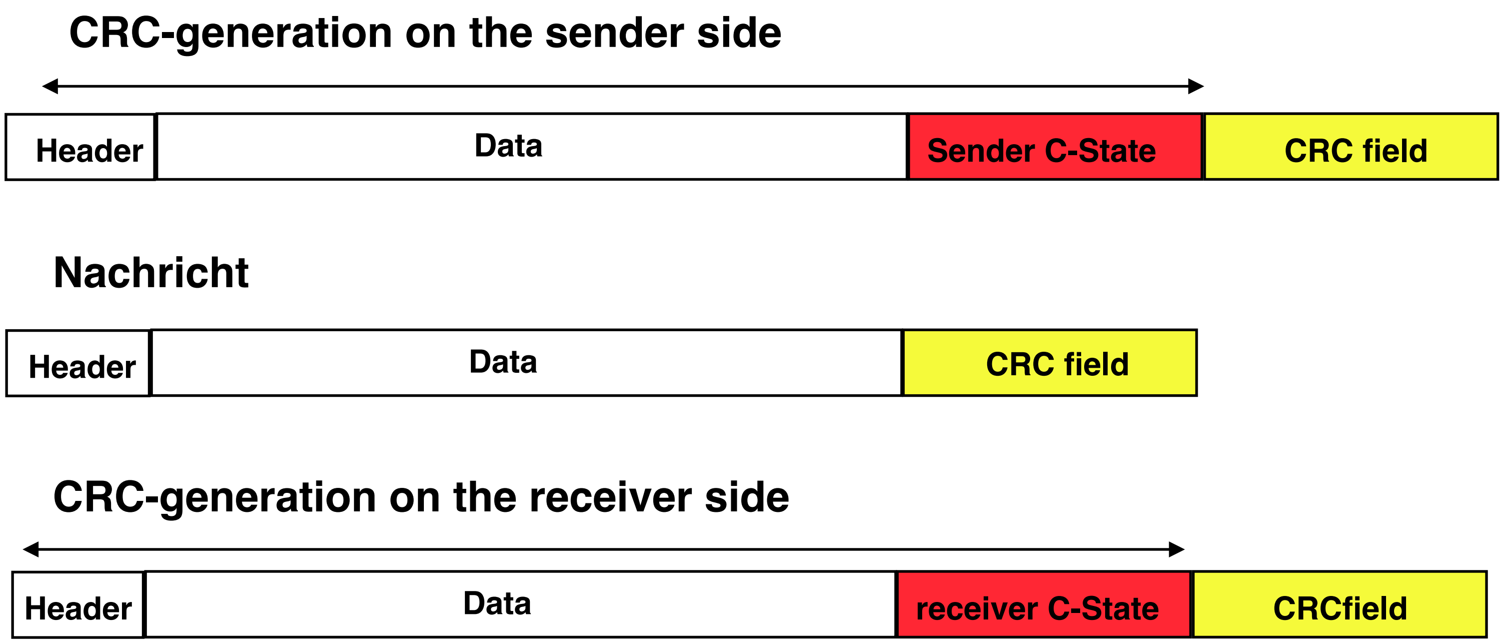


MFM Coding: Constant frame length (not data dependent)

Continuous supervision of the global state



Continuous supervision of the global state



Handling mode changes

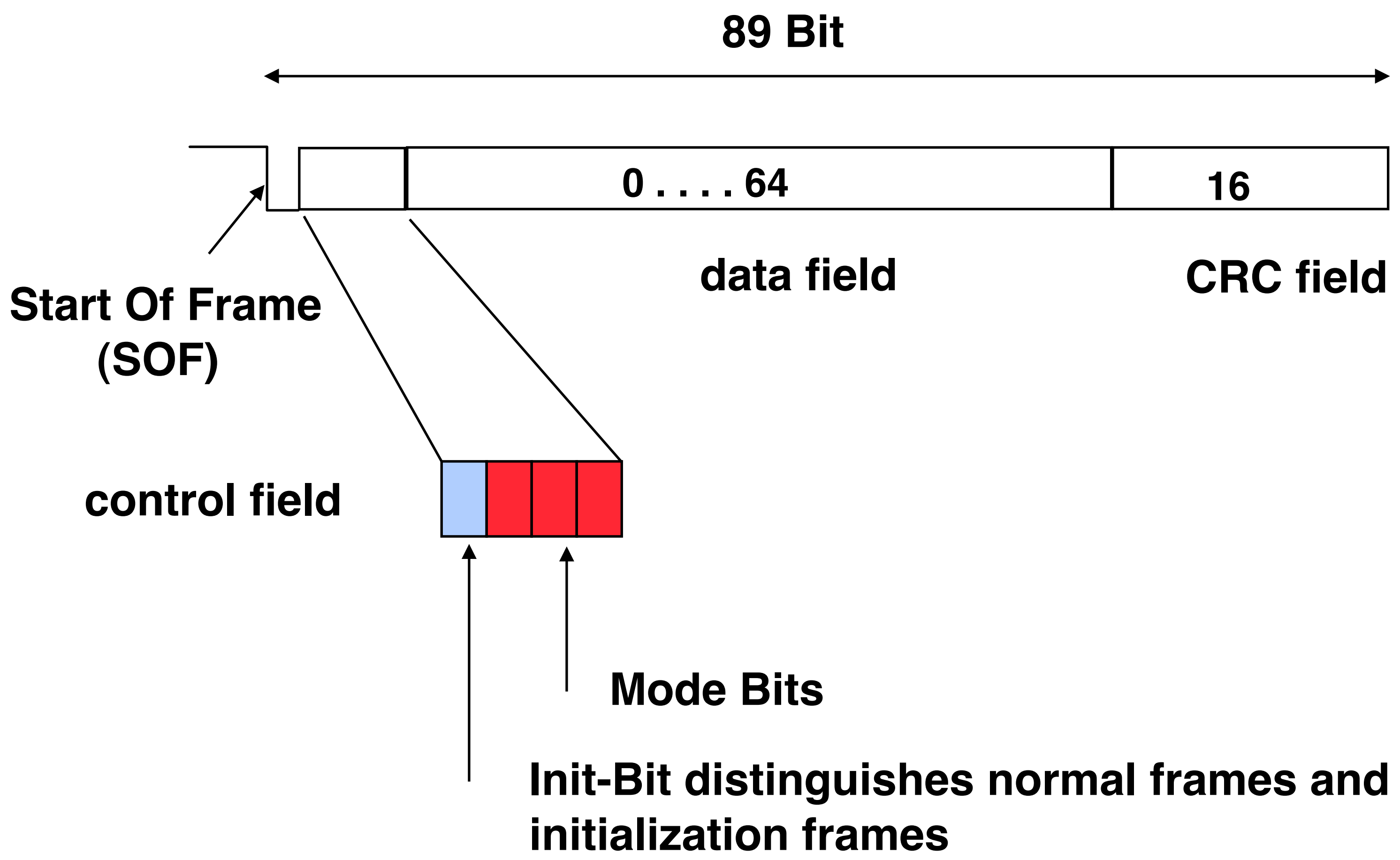
At every point in time, all nodes are in a specific mode.

→ needs consensus

Mode changes:
FTU signals mode changes in the control field by setting the position of the succession vector (index into the respective table).

→ Flexibility: Succession vector can be changed.

Format of a TTP frame



MFM Coding: Constant frame length (not data dependent)

Critical functions:

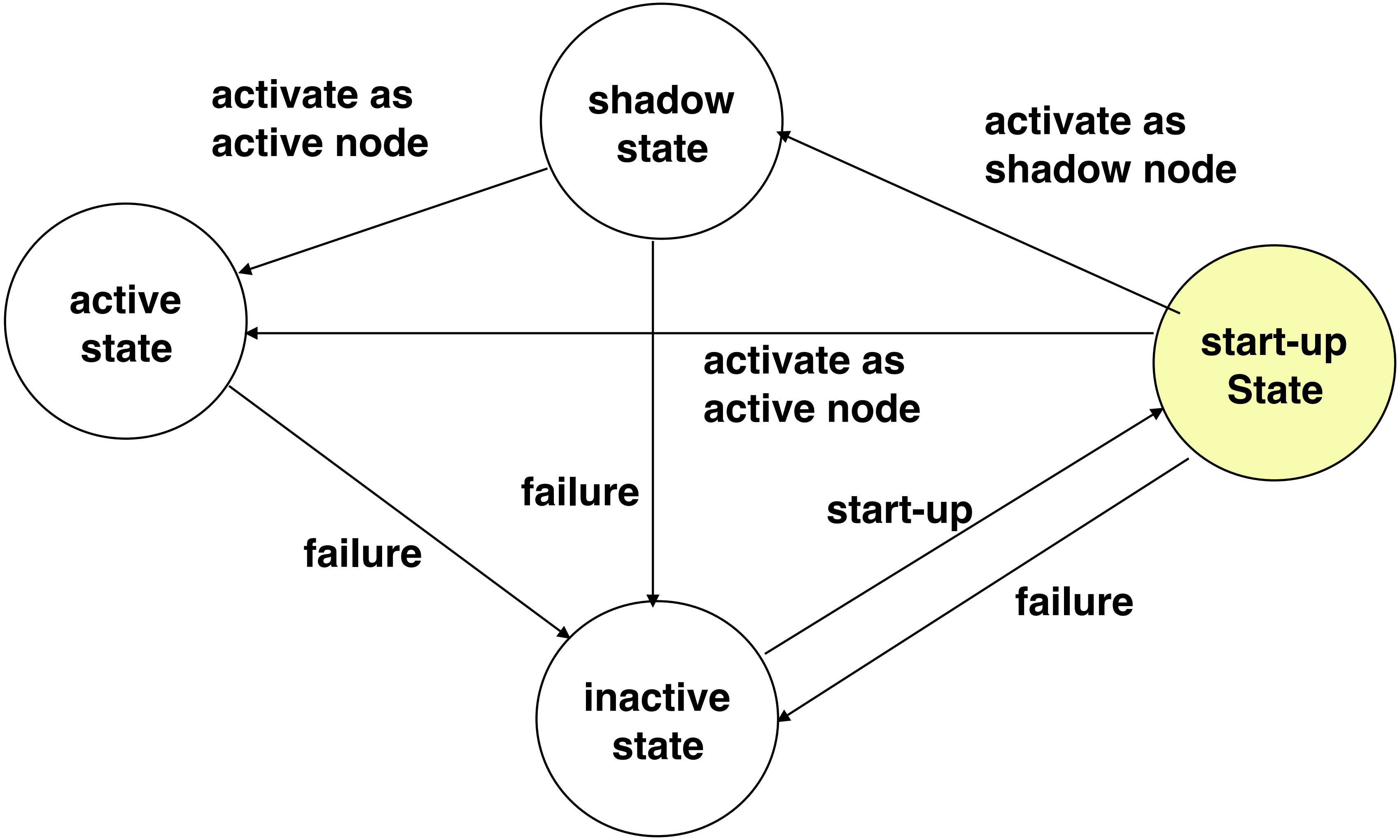
- Initialization
- Membership
- Black-out Handling

Redundancy management and initialization

- **Every node has a unique name that defines its position in the TDMA round.**
- **Some special nodes are enabled to send initialization frames (I-frame).**
- **Initialization frames comprise the complete state of the entire system.**
- **The longest interval between two I-frames determines the minimal waiting time for a node before it can be re-integrated.**

Redundancy management and initialization

Local states of an FTU:



Redundancy management and initialization

- Reset local clock.

- Monitoring the bus for I_1 (I_1 > longest TDMA round)
An I-frame will be sent during this time if the network is initialized.

in case of message traffic, wait for an I-frame

in case of NO message traffic, wait specified time I_2
(I_2 is a node specific delay to ommit collisions)

After I_2 send I-frame with C-state in the init-mode

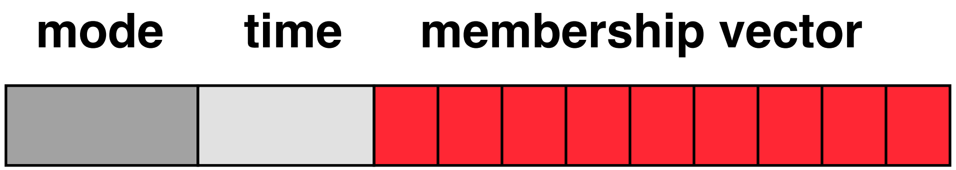
Membership Service

Sender sets membership bit (MB) to "1"

All receivers set MB to "1"

If no correct frame is received, all receivers set MB = 0 directly after the TDMA-slot

When reaching the membership-point (an a priori known point in time, when the FTU sends a message), the sender checks whether it still is member in the group.



Controller-State (C-State)

Membership Service

A node is member if:

1. the internal check is ok.

2. at least one frame which has been sent during the round has been acknowledged from one of the FTUs, i.e. the physical connection is ok.

3. the number of correct frames which were accepted by the FTU during the last TDMA round is bigger than the number of discarded frames.

If this is not the case, then the local C-state is not in compliance with the majority of other nodes and the node looses its membership. This avoids the formation of cliques, which have different views on the whole group.

Black-out handling

"Black-out" denotes a global distortion, e.g. if the physical communication channel is distorted by external electromagnetic fields.

Black-out detection:

A node continuously monitors the membership field.
If membership dramatically decreases a mode change is triggered to black-out handling.

↓

Black-out mode: nodes only send I-Frames and monitor the bus

↓

When external distortion vanishes, membership will stabilize again.

↓

Return to "normal mode"

Discussion

Synchrony (Jitter, Steadyness, Thightness)

Automatic clock synchronization

Fault masking

Monopolization- (Babbling Idiot-) faults are omitted

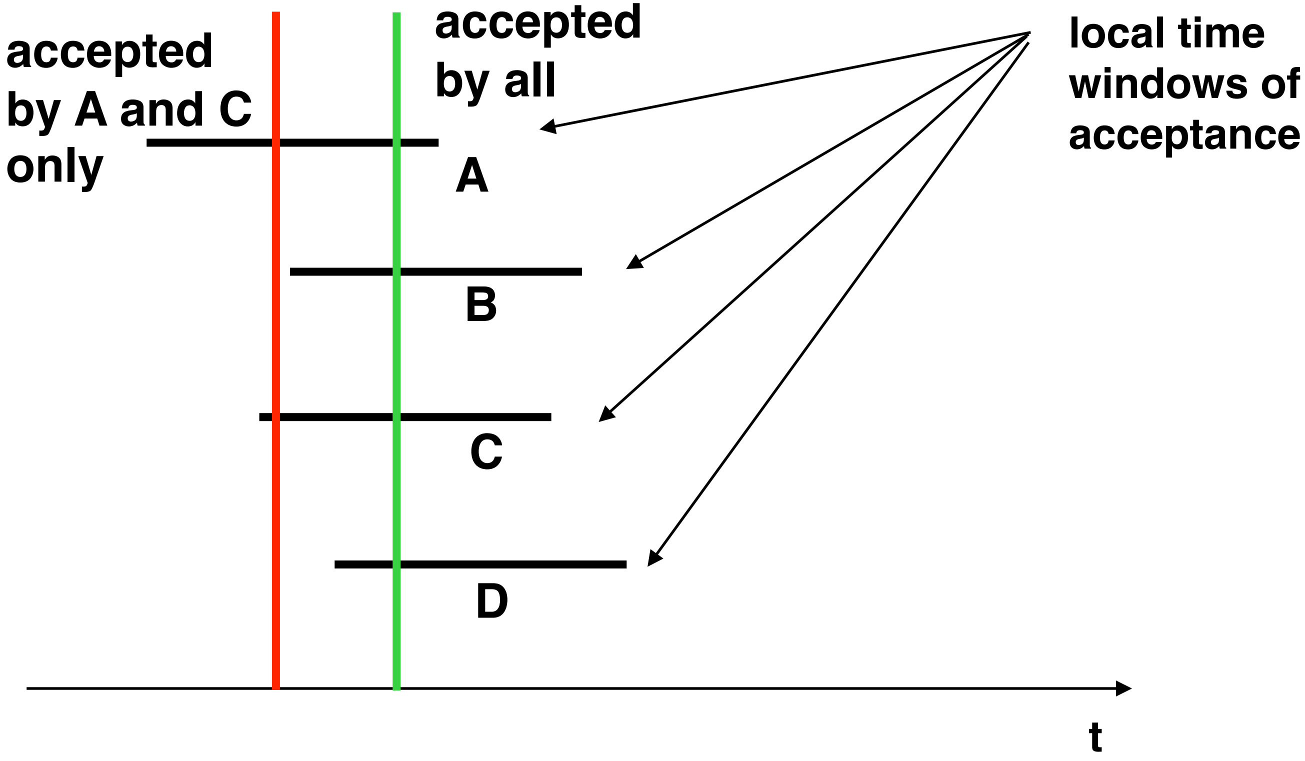
Replica Determinism

Composability and extensibility

Problems with a Bus Topology

- **Monopolization failures**
- **Common mode & spatial proximity failures**
- **Synchronization between nodes and SOS failures**

Slightly-off-specification failures

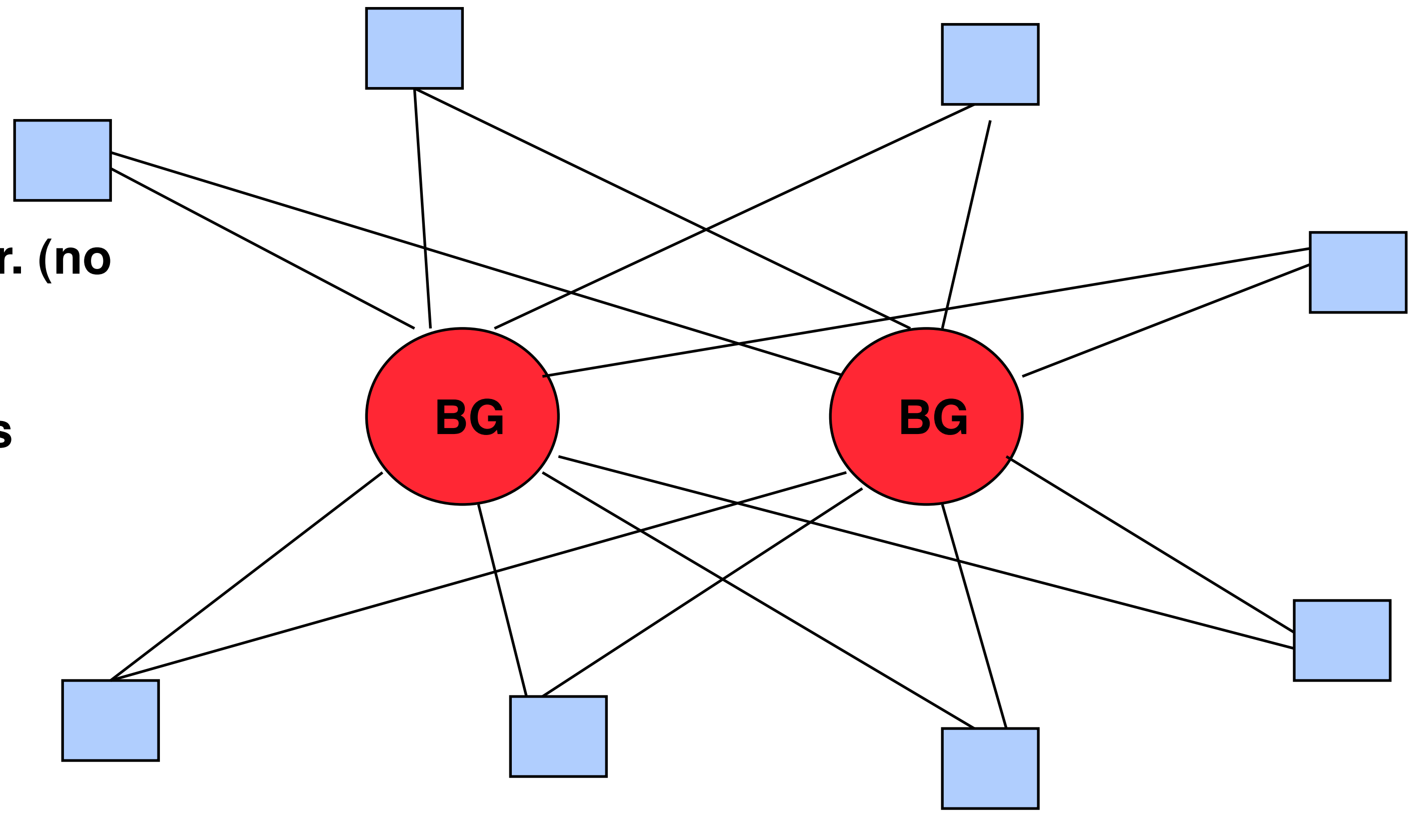


Slightly-off-specification failures can occur at the interface between the analog and the digital world. They may occur in the value (signal level) and in the time domain.

Migration of Bus-Guardians: Star-Topology

Motivation:

- Re-shaping and synchr. (no SOS failures)
- Isolation of faulty FTUs
- Physical separation of Bus guardians from hosts (less common mode failures)



BUT: needs careful design!
Jennifer Morris, Daniel Kroening, Philip Koopman: Fault Tolerance Tradeoffs in Moving from Decentralized to Centralized Embedded Systems, DSN-2004

FTU

BG: Bus Guardian

Summary TTP

- Protocol execution is initiated by the progression of global time.
  The sending point in time for every message is a priori know by all receivers.

- The maximum execution time corresponds to the average execution time (with a small deviation only)

- Error detection is possible for the recievers because they know when a message can be expected.

- The protocol is unidirectional. No acknowledgements are required.

- Implicit flow control is needed.

- No arbitration conflicts can occur.

Desirable Features

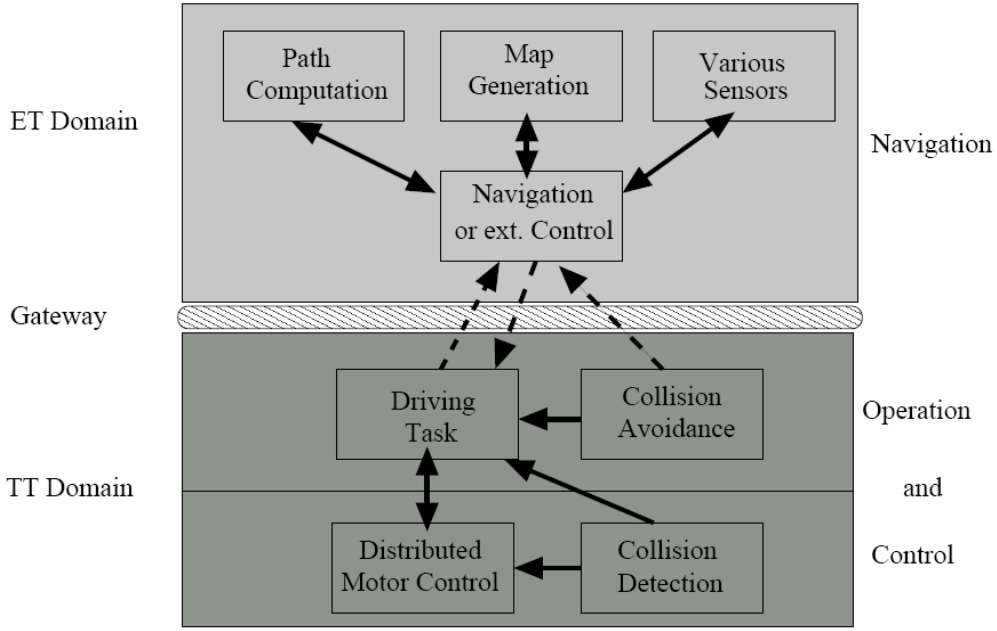
More Flexibility:

- Accomodating a range of criticality requirements
- Accomodating more messages than slots
- Dynamic assigment of transmission slots
- Event-triggered message dissemination

What will be the price to pay?

More Flexibility ?

Federating networks with different properties.



byteflight –

A New High-Performance Data Bus System for Safety-Related Applications

By Josef Berwanger, Martin Peller and Robert Griessbach

BMW AG, EE-211 Development Safety Systems Electronics,
Knorrstrasse 147, 80788 Munich, Germany

http://www.byteflight.com/presentations/atz_sonderausgabe.pdf byteflight

Flexible protocol supports synchronous and asynchronous messages

supports high data rates

availability of integrated communications-controller (e.g. Motorola 68HC912BD32)

integral part of FlexRay

Principles:

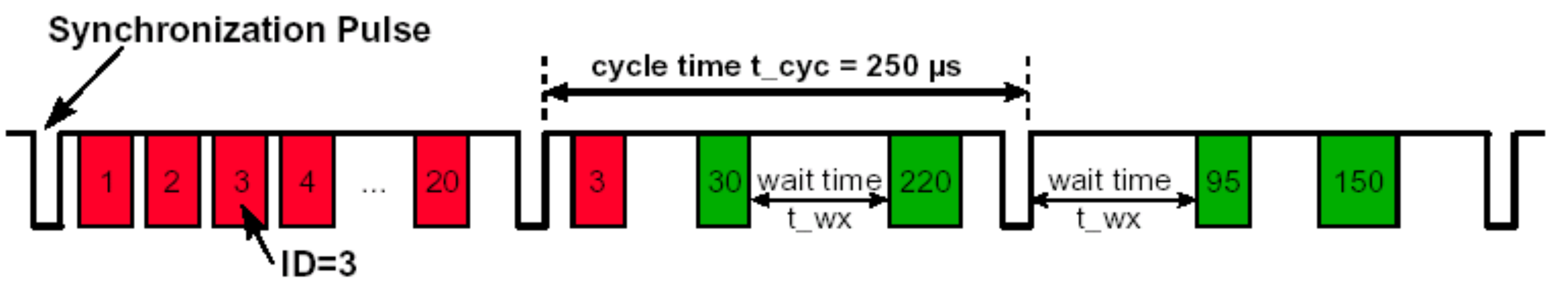
- **message priorities are associated with node-IDs**
- **time slots, which correspond to certain priorities**
- **priority is enforced by waiting times**

Assumptions

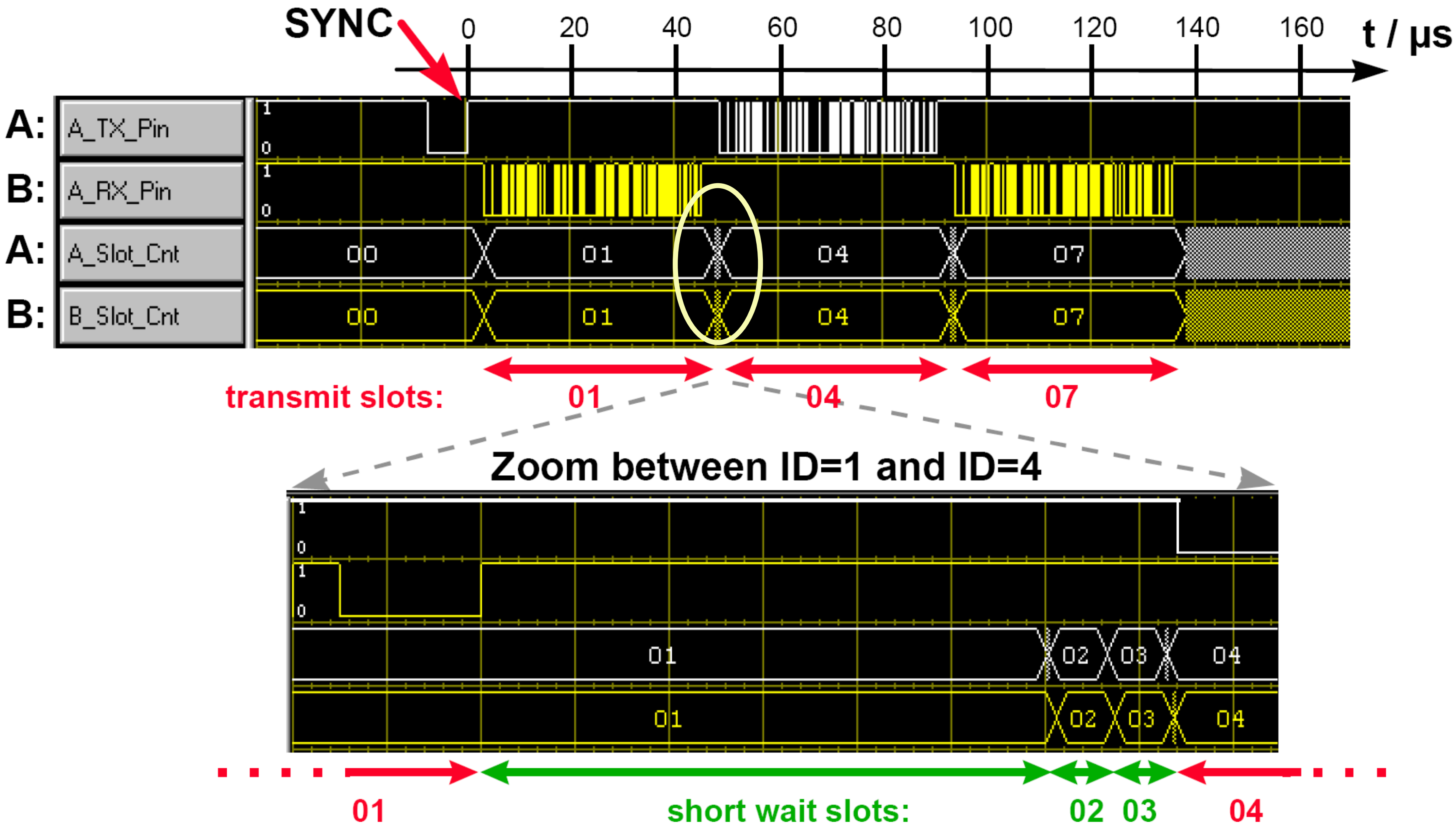
- Communication is organized in rounds or cycles respectively.
- Clock synchronization between nodes is assumed to be better than 100ns.
- One (fault-tolerant) sync master responsible to indicate the start of a round by sending a sync pulse.
- The interval between two sync pulses determines the cycle time (250 μs @ 10 Mbps)

Byteflight: Flexible TDMA

- **SyncMaster sends the synchronization pulse to init the cycle.**
- **The interval between two sync pulses determines the cycle time (250 μs @ 10 Mbps)**
- **Every node has a number of identifiers assigned that define message priorities. The system must ensure that the message IDs are unique.**
- **Every communication controller has a counter which counts message slots.**
- **The counter is stopped on an ongoing message transfer and will be started again when the transfer has completed.**
- **If the counter value corresponds to the priority of a message, this message can be transmitted.**

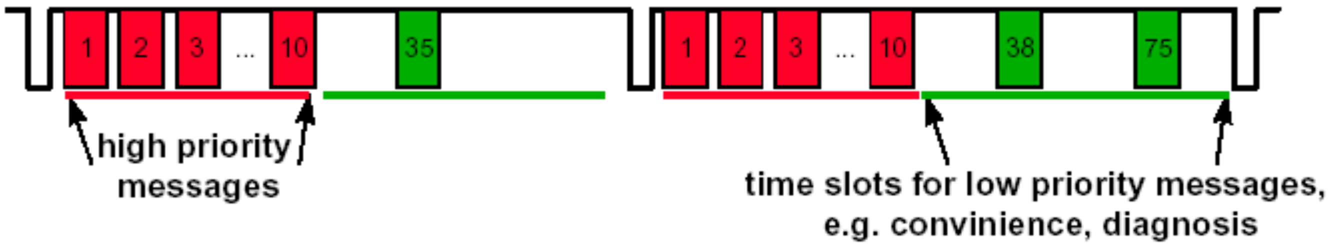


Distributed synchronized "Slot-" counter



Waiting period $t\_wait = t\_0 + t\_delta * (ID - ID_{t-1})$

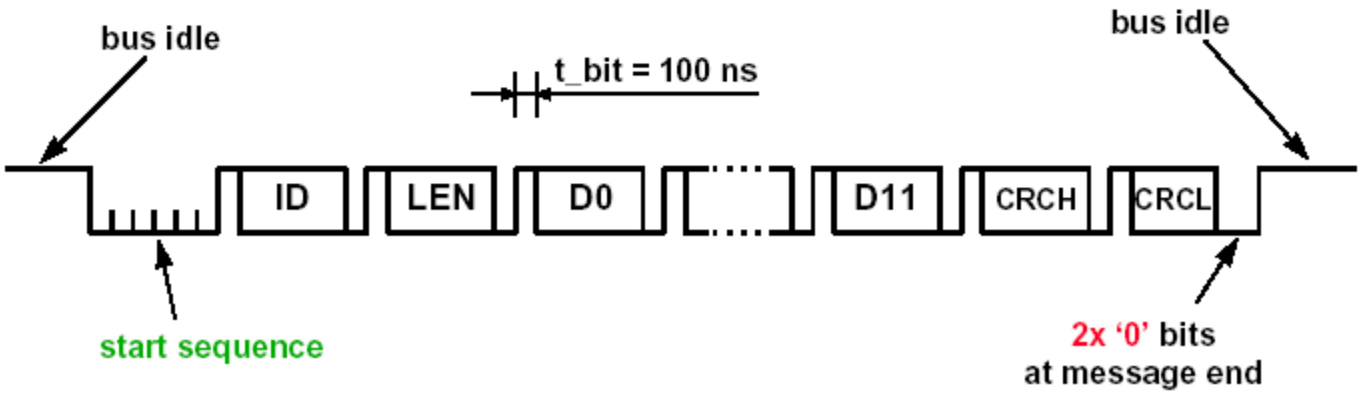
Synchronous and asynchronous data transmission



Slots with fixed priorities are reserved for synchronous messages. These slots are assigned in every cycle (1-10) and allow a deterministic analysis of message latencies.

Asynchronous messages have lower priorities. These are dynamically assigned and enforced by the waiting mechanism. To determine message latencies, only probabilistic analysis is possible.

ByteFlight message format



Start sequnence:	**6 Bits**
ID:	**8 Bits (1 Byte)**
Length:	**8 Bits (1 Byte)**
Data:	**96 Bits (12 Bytes)**
CRC:	**16 Bits (Hamming distance = 6)**

Fault handling in the Byteflight Protocol

Alarm state:

The master can send a special synchronization signal that is recognized by all stations. This signal has no influence on the protocol but the nodes can detect a specific situation locally.

Fault treatment:

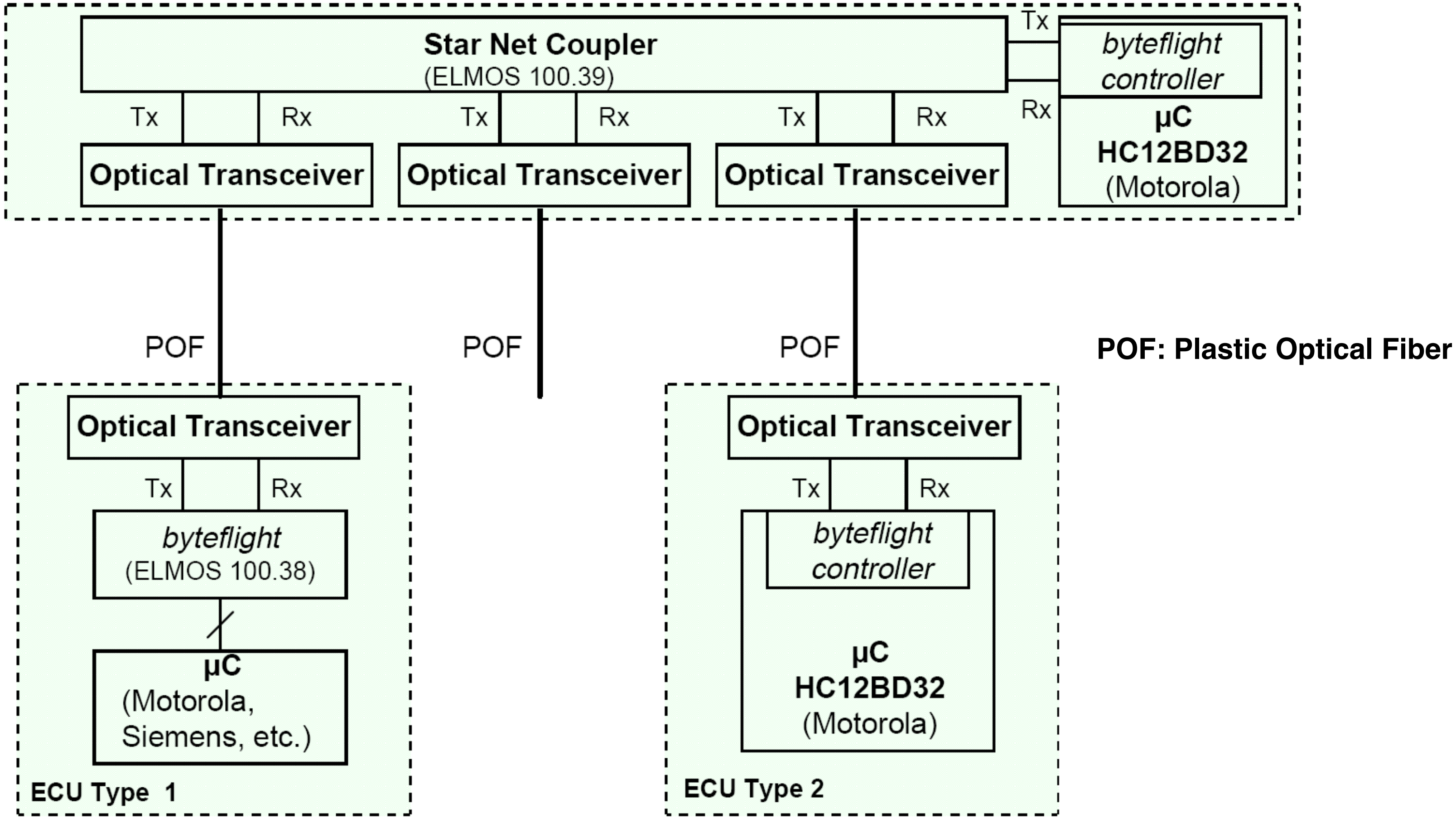
Transient transmission faults are not specially treated and no re-transmission is initiated. It is assumed that with the next cyclic transmission this fault is gone.

Timing errors are handled by the star coupler.

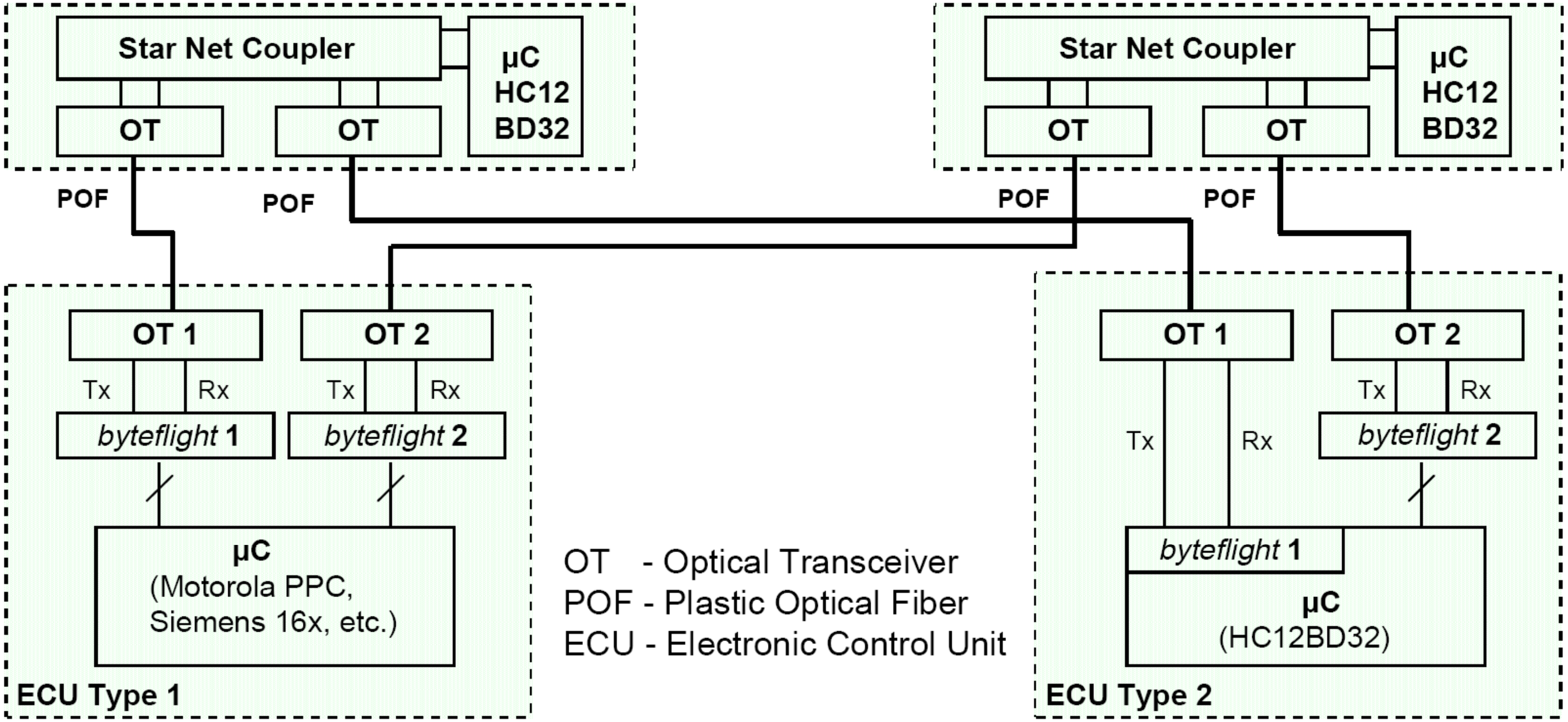
In a bus structured network, bus guardians are used to enforce a fail silent behaviour. Here the protocol exploits the strict timing discipline.

Replacements for a failing sync master are determined a priori.

Example of a Byteflight topology



Byteflight star topology & redundancy concept



OT - Optical Transceiver
POF - Plastic Optical Fiber
ECU - Electronic Control Unit

Comparison between Byteflight and TTP

byteflight: a new high-performce data bus system for safety related applications,
J. Berwanger, M. Peller, J. Griessbach, BMW-AG, EE211 Development Safety Systems Electronic

Feature	CAN	TTP [10]	*byteflight*
Message transmission	asynchronous	synchronous	asynchronous and synchronous
Message identification	message identifier	time slot	message identifier
Data rate	1 Mbps gross	2 Mbps gross	10 Mbps gross
Bit encoding	NRZ with bit stuffing	modified frequency modulation (MFM)	NRZ with start/stop bits
Physical layer	transceivers up to 1 Mbps	not defined	optical transceiver up to 10 Mbps
Latency jitter	bus load dependent	constant for all messages	constant for high priority messages according t_cyc
Clock synchronization	not provided	distributed, in µs range	by master, in 100 ns range
Temporal composability	not supported	supported	supported for high priority messages
Error containment (physical layer)	partially provided	provided with special physical transceiver	provided by optical fiber and transceiver chip
Babbling idiot avoidance	not provided	possible by independent bus guardian	provided via star coupler
Extensibility	excellent	only if extension planned in original design	extension possible for high priority messages with affect on asynchronous bandwidth
Flexibility	flexible bandwidth for each node	only one message per node and TDMA cycle	flexible bandwidth for each node
Availability of components	several µC families and transceiver chips	microcoded RISC chip available, physical transceiver and independent bus guardian not available	HC12BD32, E100.38 *byteflight* standalone controller, E100.39 star coupler ASIC, optical transceiver available

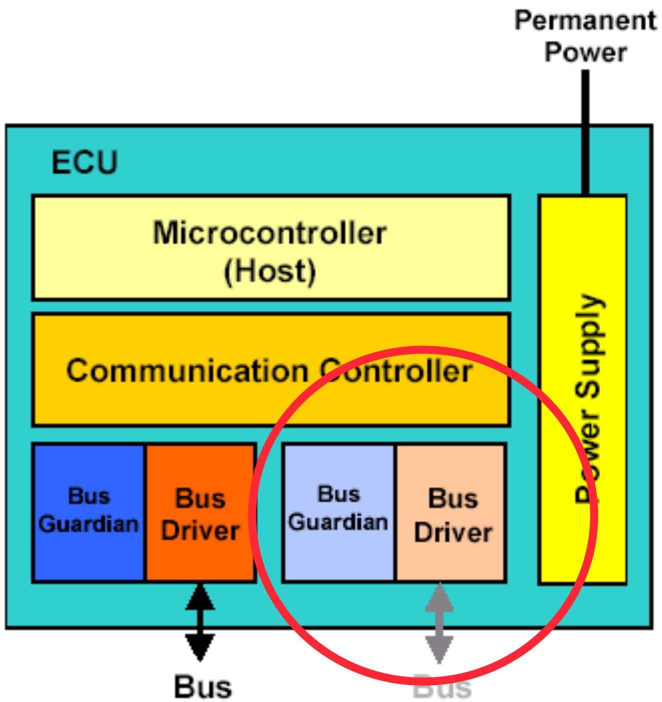
Combination of TDMA and Byteflight

Belschner et al. : Anforderungen an ein zukünftiges Bussystem für fehlertolerante Anwendungen aus Sicht Kfz-Hersteller

Requirements of the Protocol

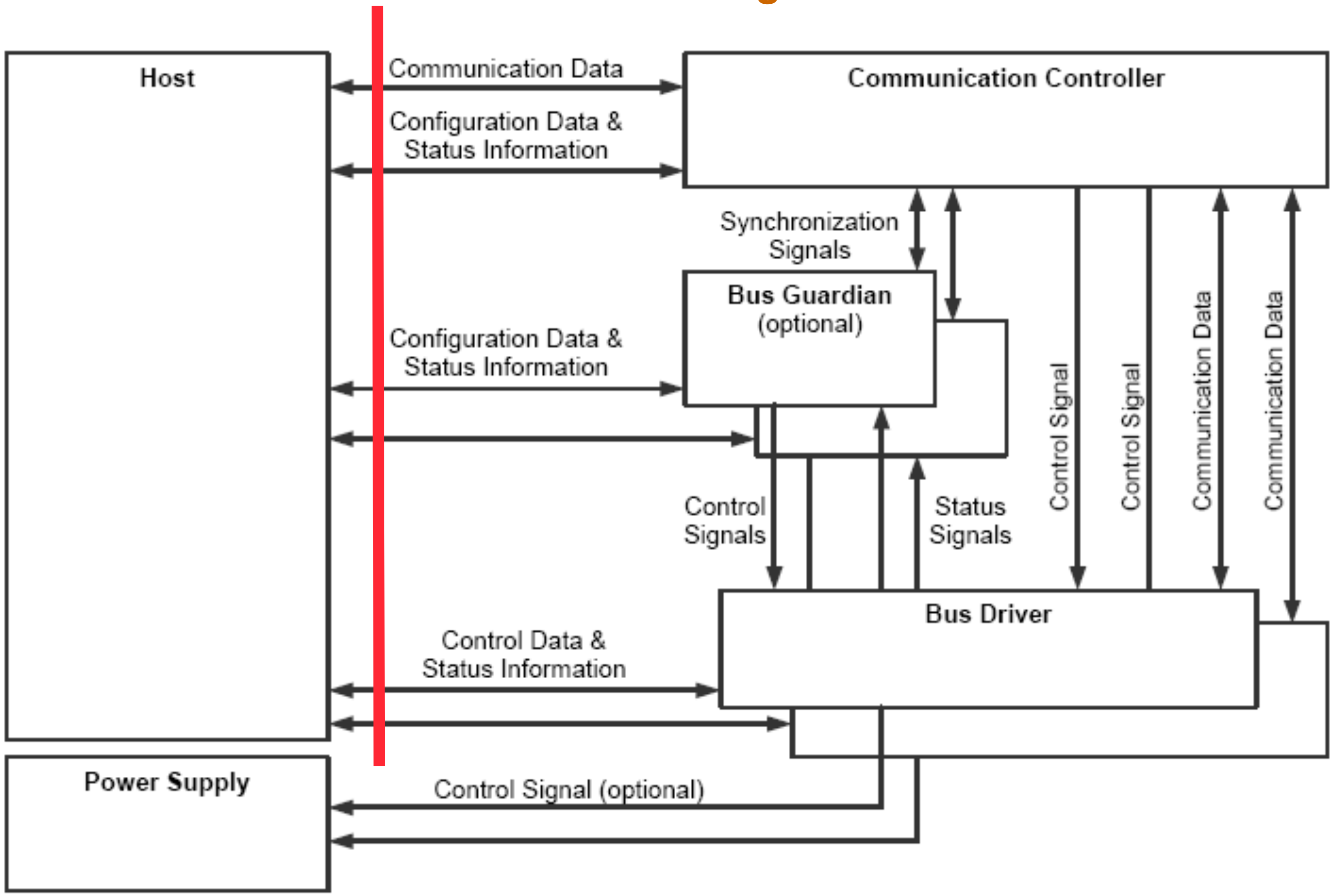
- Synchronous and asynchronous data transmission (scalable)
- Deterministic data transmission, guaranteed message latency
- Fault-tolerant, synchronized global time
- Redundant transmission channels (configurable)
- Flexibility (expandability, bandwidth usage, ...)
- Different topologies (bus, star and multi-star)
- Electrical and optical physical layer
- Communication protocol independent of the baud rate

Architecture of a FlexRay node (ECU: Electronic Control Unit)



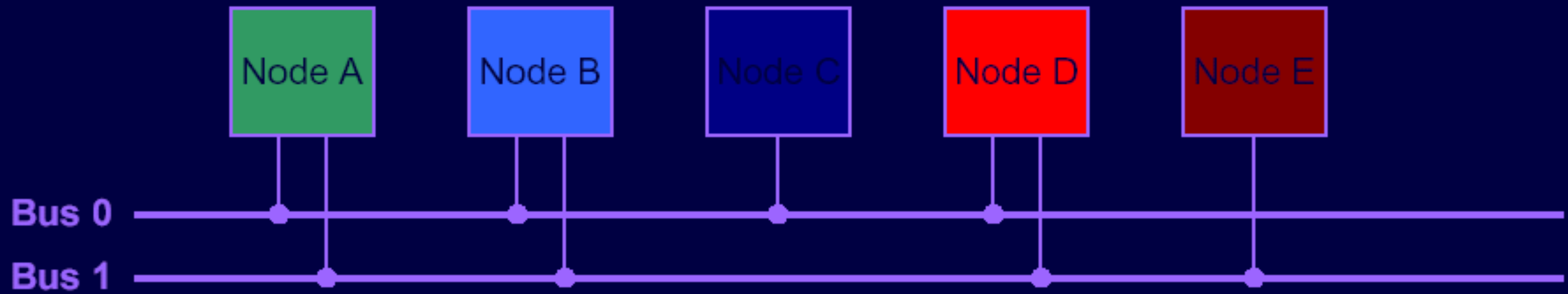
Interfacing the communication controller

CNI: no control signals



Data- und control flow between Host and CC

FlexRay Basic Concepts



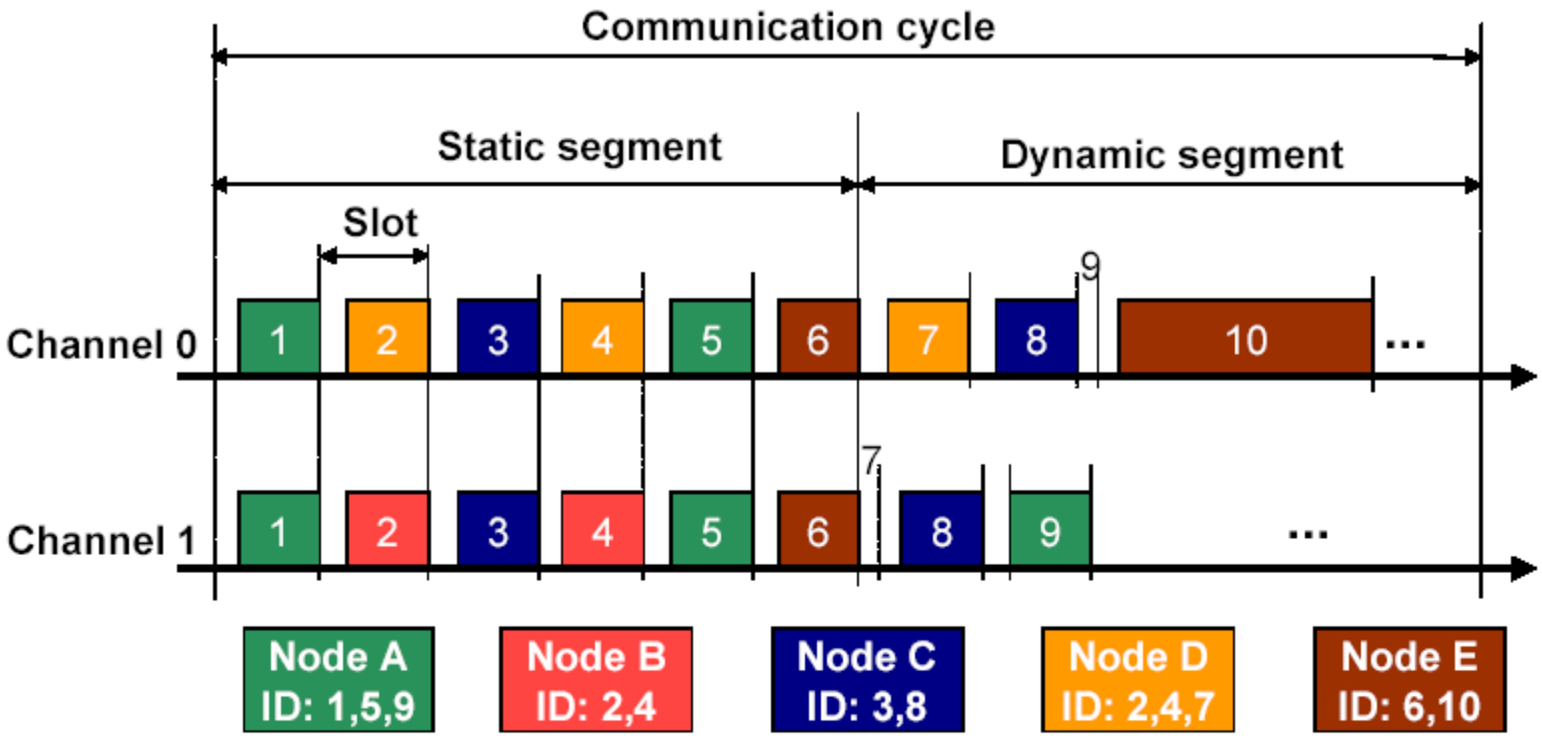
Redundancy

- The protocol supports two serial busses
- A node can either be connected to both or only one of the busses

PHY Bit Coding

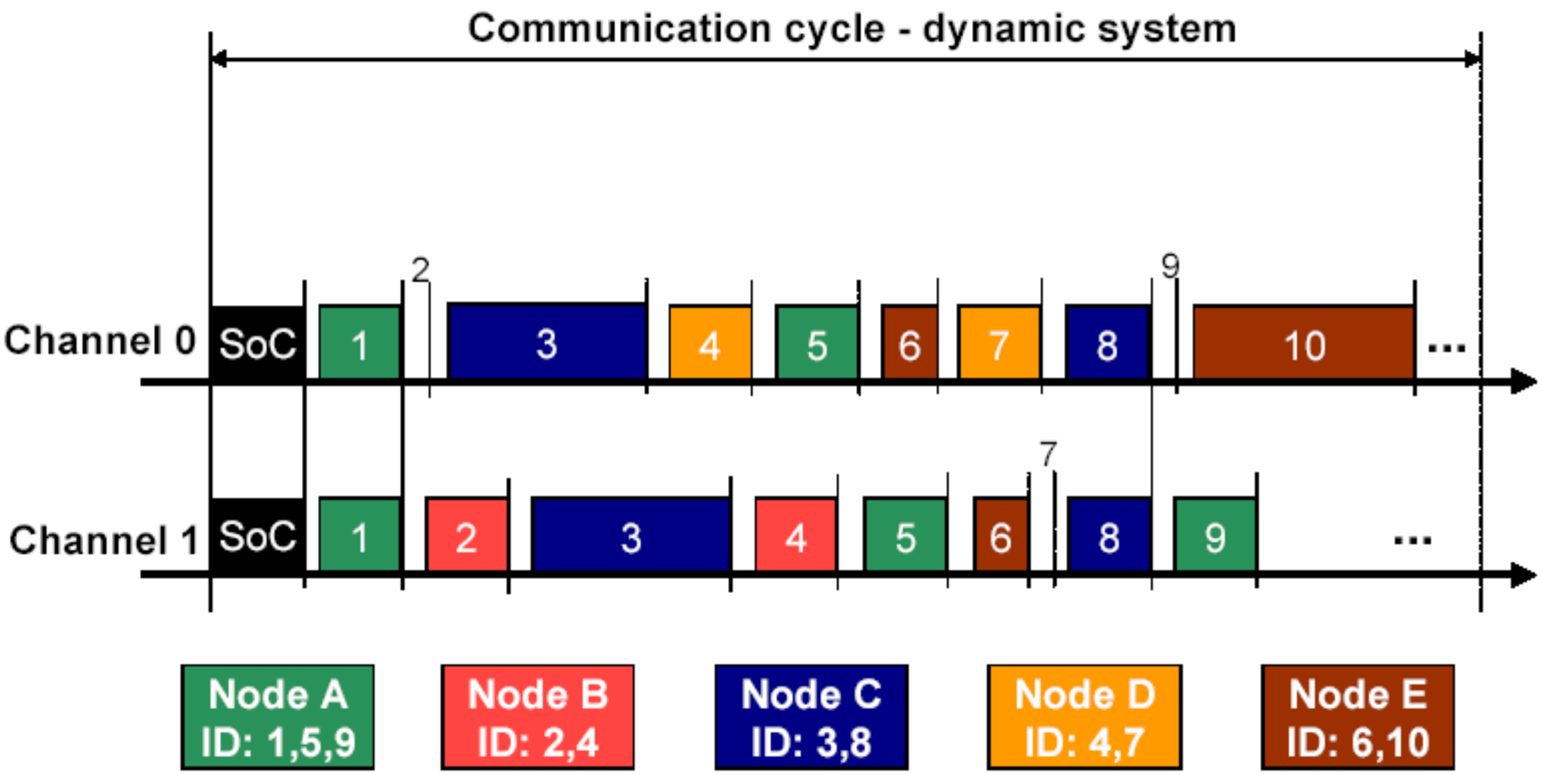
- transmission speed up to 10 Mbit/s (gross, optical)
- NRZ 8N1 for optical transmission
- Xerxes (MFM extension) coding for electrical transmission

The FlexRay Communication Cycle



Cycle with static and dynamic segment

The FlexRay Communication Cycle



Cycle with dynamic segment only

Format of a FlexRay frame

ID	MUX	SYNC	LEN	CYCLE	DATA	CRC	0
10 bit	1 bit	1 bit	4 bit	8 bit	0...11 byte	15 bit	1 bit

ID: Identifier, 10 Bit, value range: (1 ... 1023), defines the slot position in the static segment and the priority in the dynamic segment. A low ID defines a high priority. ID = 0 is reserved for the SYNC-symbol. An identifier must be unique in the network, i.e. two identical IDs would lead to a collision. Every node may use one or more identifiers in the static and the dynamic segment.

MUX: Multiplex-field, 1 Bit. This bit enables to send multiple data under the same ID..

SYNC: SYNC-field, 1 Bit. This bit indicates whether the message is used for clock synchronization and whether the first byte contains the sync counter (SYNC = “1”: message with Frame-Counter and clock synchronization, SYNC = “0”: message without counter)

LEN: Length field, 4 Bit, number of data bytes (0 ... 12). Any value > 12 will be interpreted as LEN=12. If the cycle counter (in the first byte) is used (SYNC=1) any value >11 is set to LEN=11.

CYCLE: The CYCLE-Field can be used to transmit the cycle counter or data. The cycle counter is synchronously incremented at the start of every communication cycle by all communication controllers.

D0-11: Data bytes, 0 – 12 bytes

CRC: 15 Bit Cyclic Redundancy Check.

Topology Options

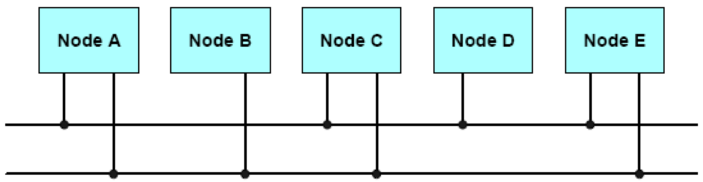


Figure 1-1: Dual channel bus configuration.

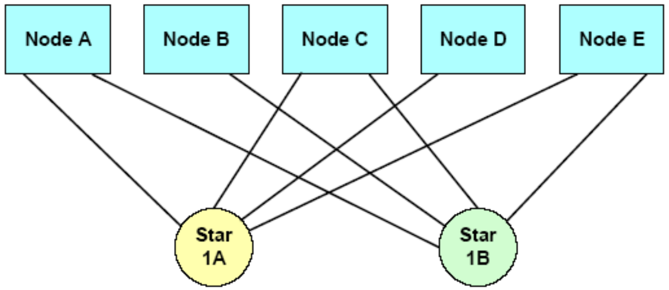


Figure 1-2: Dual channel single star configuration.

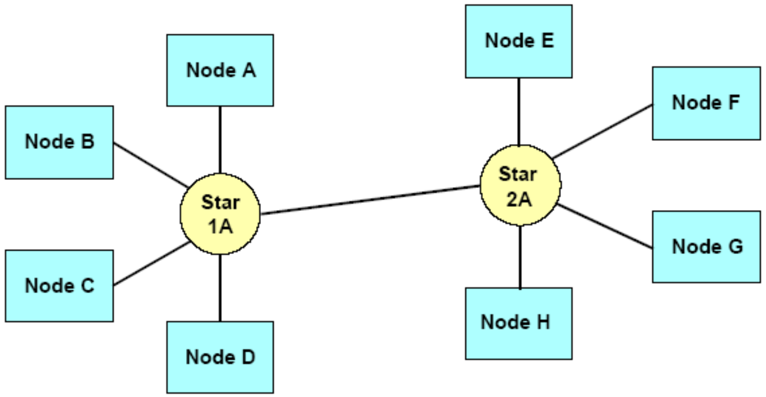


Figure 1-3: Single channel cascaded star configuration.

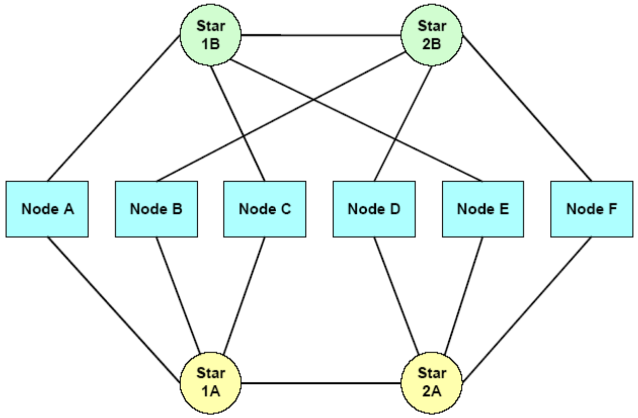


Figure 1-4: Dual channel cascaded star configuration.

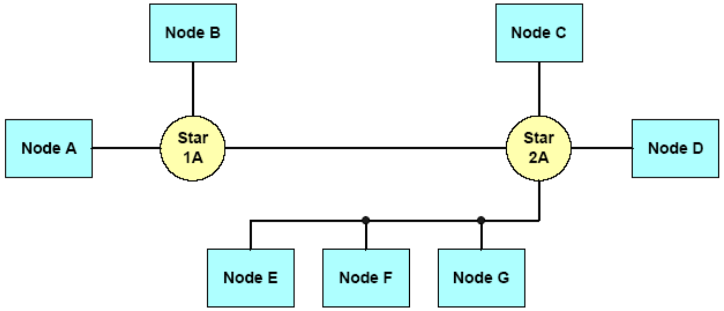


Figure 1-5: Single channel hybrid example.

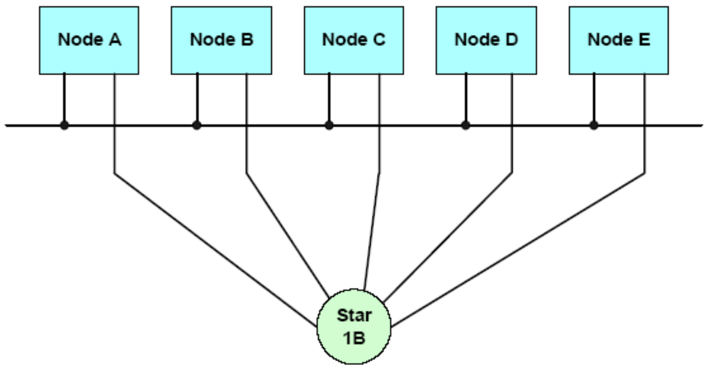


Figure 1-6: Dual channel hybrid example.

Comparison

H. Kopetz

A Comparison of TTP/C and FlexRay
Research Report 10/2001

hk@vmars.tuwien.ac.at
Institut für Technische Informatik
Technische Universität Wien, Austria
May 9, 2001

Characteristic	TTP/C	FlexRay
Designed to meet automotive requirements	yes	yes
Priority in the "safety versus flexibility" conflict	safety	flexibility
Specification in the public domain	yes	no
Composability (precise interface specification in the value domain and in the temporal domain)	yes	no
Fault-tolerant clock synchronization	yes	yes
Replicated communication channels	yes	yes
Time-triggered message channels	yes	yes
Bus guardians to avoid babbling idiots	yes	yes
Bus guardian and protected node in different fault-containment regions	yes	no
Dynamic asynchronous message channels	yes, local	yes, global
Membership service	yes	no
Fault-hypothesis specified	yes	no
Never-give-up (NGU) strategy specified	yes	no
Critical algorithms formally analyzed	yes	no
Handling of outgoing link failures	yes	?
Handling of SOS failures	yes	?
Handling of Spatial Proximity failures	yes	?
Handling of Masquerading failures	yes	?
Handling of babbling idiot failures	yes	?
Transmission speed planned up to	25 Mbits/sec	10 Mbits/sec
Message data field length up to	236 bytes	12 bytes
Physical layer	copper/fiber	copper/fiber
CRC field length	3 bytes	2 bytes
Maximum achievable data efficiency for time-triggered messages in a 10Mbit/second system, interframe gap 5 microseconds.	95.8 %	45.7 %
Scalability: Maximum achievable data efficiency for time-triggered messages in a 100Mbit/second system, interframe gap 5 microseconds.	78 %	14.5%
Number of oscillators in a system with 10 ECUs	12	30
First system available on the market	1998	planned 2002
Architecture validated by fault injection	yes	no
Architecture viable for aerospace applications	yes	?