Accessing the shared communication medium

Media
Access
Conntrol

Network-topologies

- Bus
- Ring
- Star
- Tree
- grid, mesh
- fully connected

assessment criteria:
Overhead, latency, tolerance of transmission errors and network partitions

What are the impairments of predicatbilty ?

Load

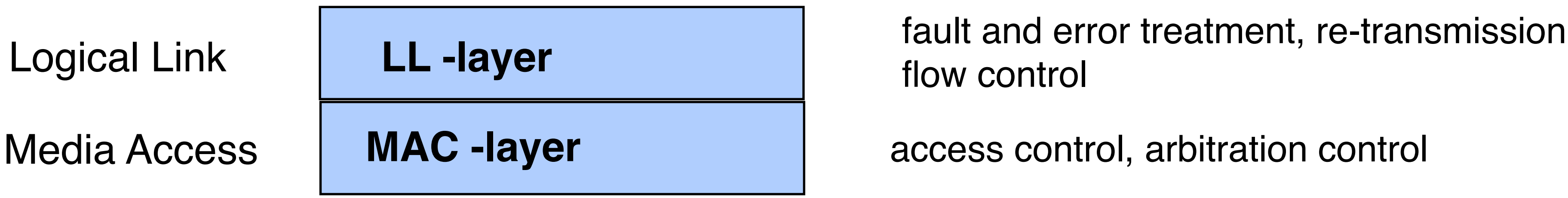
Failures

Network contention
Arbitration conflicts

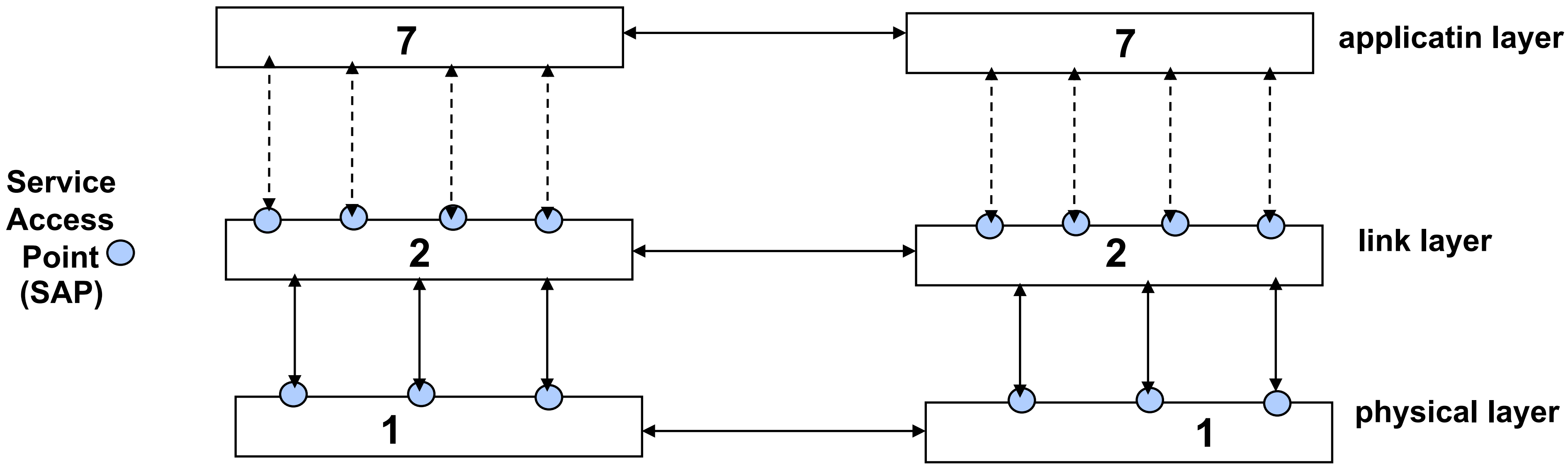
transmission errors,
lost messages

Media Access Control & Logical Link Layer

transfer of data blocks
flow control
fault and error handling
message re-transmissions



Common Layering in the fieldbus area



Assumption: homogeneous, closed system

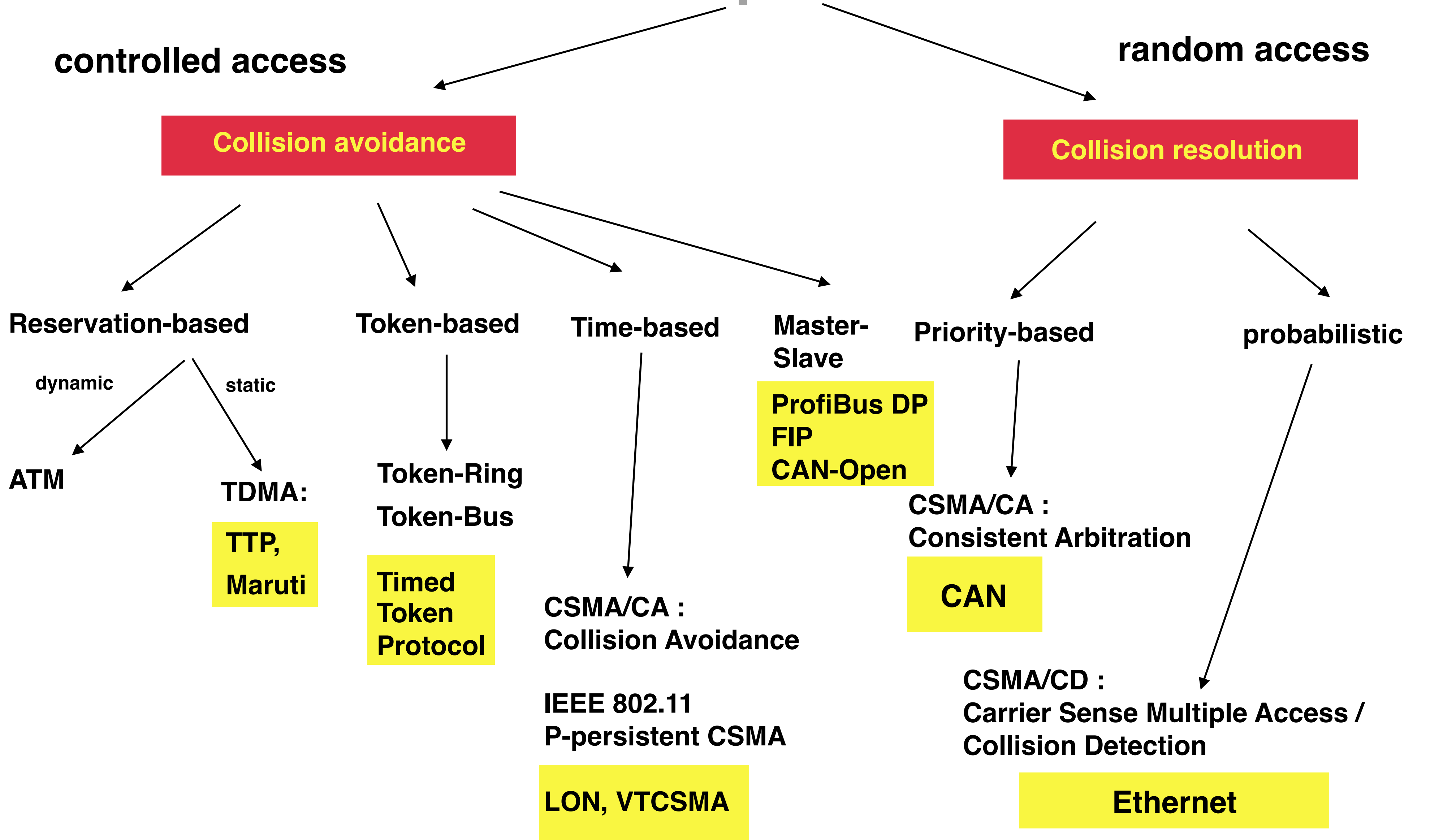
Not all layers are necessary (e.g. routing)
Empty layers in the ISO/OSI- model

Higher layers directly access the SAPs of lower layers.

Efficiency improvement

Direct mapping of layer 7 services to layer 2 functionality.

MAC-protocols



Predictability in random access networks:

probabilistic

very low overhead and latency in low load conditions
very flexible wrt. extensibility
thrashing in high load situations

Collsion avoidance

balances the latency against the collision probability

maintains a good average throughput in medium load situations

may adapt to high load conditions

Consistent arbitration with Collision Resolution

needs support from the physical layer

maintains a constant throughput in all load conditions

supports sophisticated fault handling

Controlled Access by Collision Exclusion:

Master/Slave

all control information in one place
maximum of control
easy to change

Global Time

Easy temporal co-ordination

Minimal communication overhead

Token-based

Decentralized mechanism

Integration of critical and non-critical messages

CAN-Bus
Controller Area Network

CAN Milestones

1983	Start of the Bosch internal project to develop an in-vehicle network
1986	Official introduction of CAN protocol
1987	First CAN controller chips from Intel and Philips Semiconductors
1991	Bosch's CAN specification 2.0 published
1991	CAN Kingdom CAN-based higher-layer protocol introduced by Kvaser
1992	CAN in Automation (CiA) international users and manufacturers group established
1992	CAN Application Layer (CAL) protocol published by CiA
1992	First cars from Mercedes-Benz used CAN network
1993	ISO 11898 standard published
1994	1st international CAN Conference (iCC) organized by CiA
1994	DeviceNet protocol introduction by Allen-Bradley
1995	ISO 11898 amendment (extended frame format) published
1995	CANopen protocol published by CiA
2000	Development of the time-triggered communication protocol for CAN (TTCAN)

http://www.can-cia.org/can/protocol/history/index.html

The CAN Standard

Developed by BOSCH, http://www.semiconductors.bosch.de/pdf/can2spec.pdf

CAN Specification 1.2
CAN Specification 2.0

Difference between the specifications mainly is:

- **the different lenth of message identifiers (CAN-ID)**
  - **Standard CAN: 11 Bit IDs (defined in CAN 2.0 A ← 1.2)**
  - **Extended CAN: 29 Bit IDs (defined in CAN 2.0 B)**

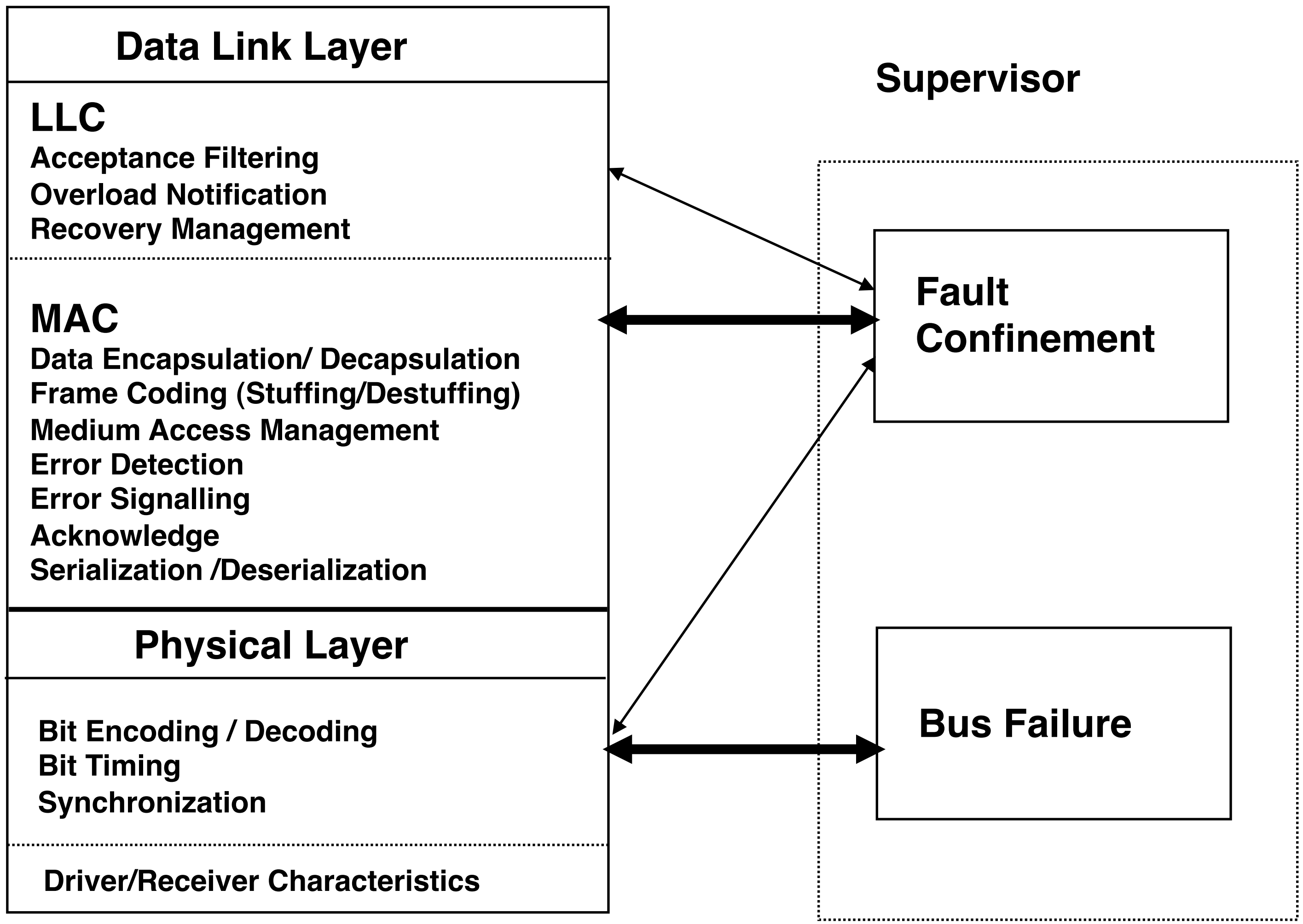
CAN-Controller Implementations:

- **Basic CAN: 1 Transmit + 1 Receive (Shadow) Buffer**
- **Extended CAN: 16 Configurable Transmit/Receive Buf.**

Basic CAN properties

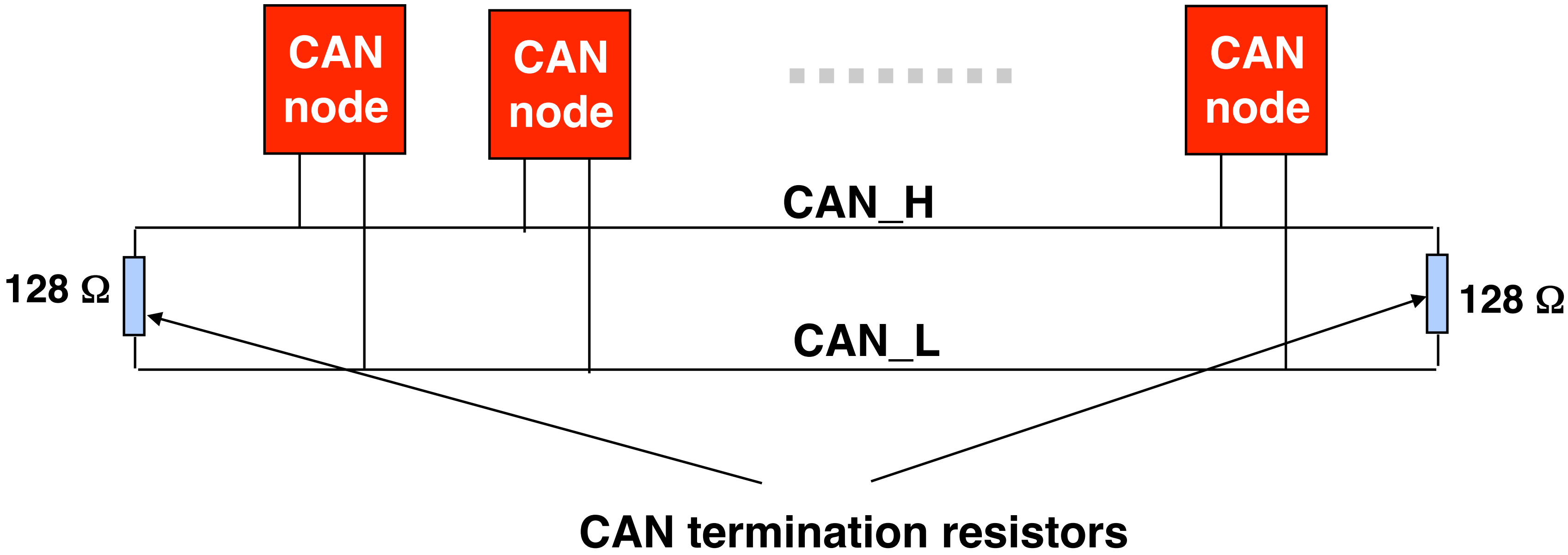
- Prioritised messages
- Bounded and guaranteed message delay for the highest priority message.
- Constant troughput in all load situations
- Error detection and signalling in the nodes.
- Automatic re-transmission.
- Fail silent behaviour of nodes.
- Consistent message delivery.
- Multicast with time synchronization.

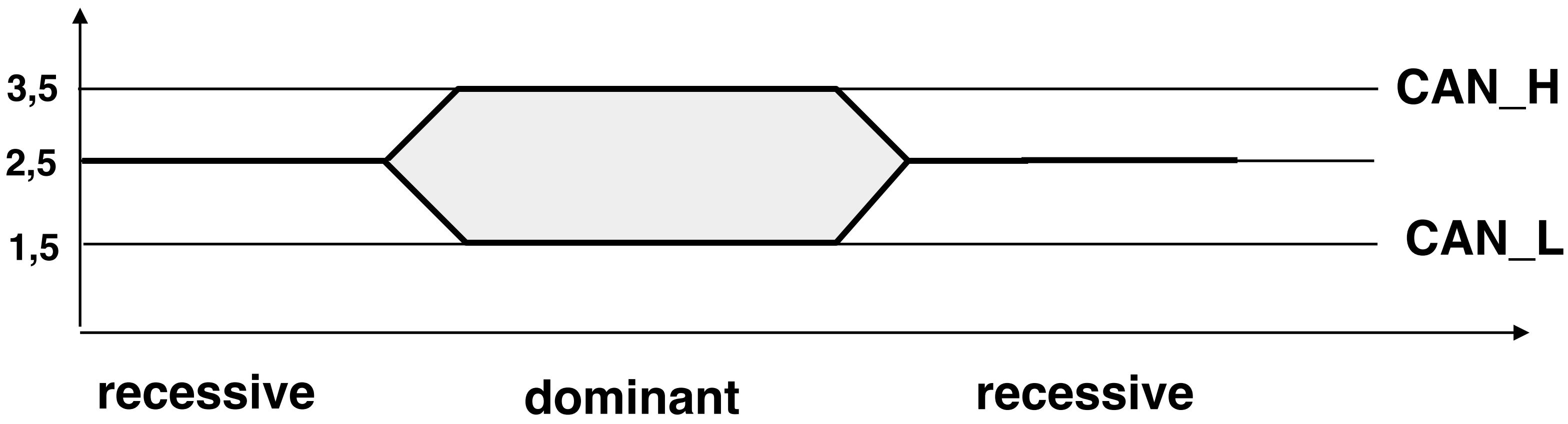
Layers defined by the CAN standard



LLC = Logical Link Control
MAC = Medium Access Control

CAN differential transmission scheme

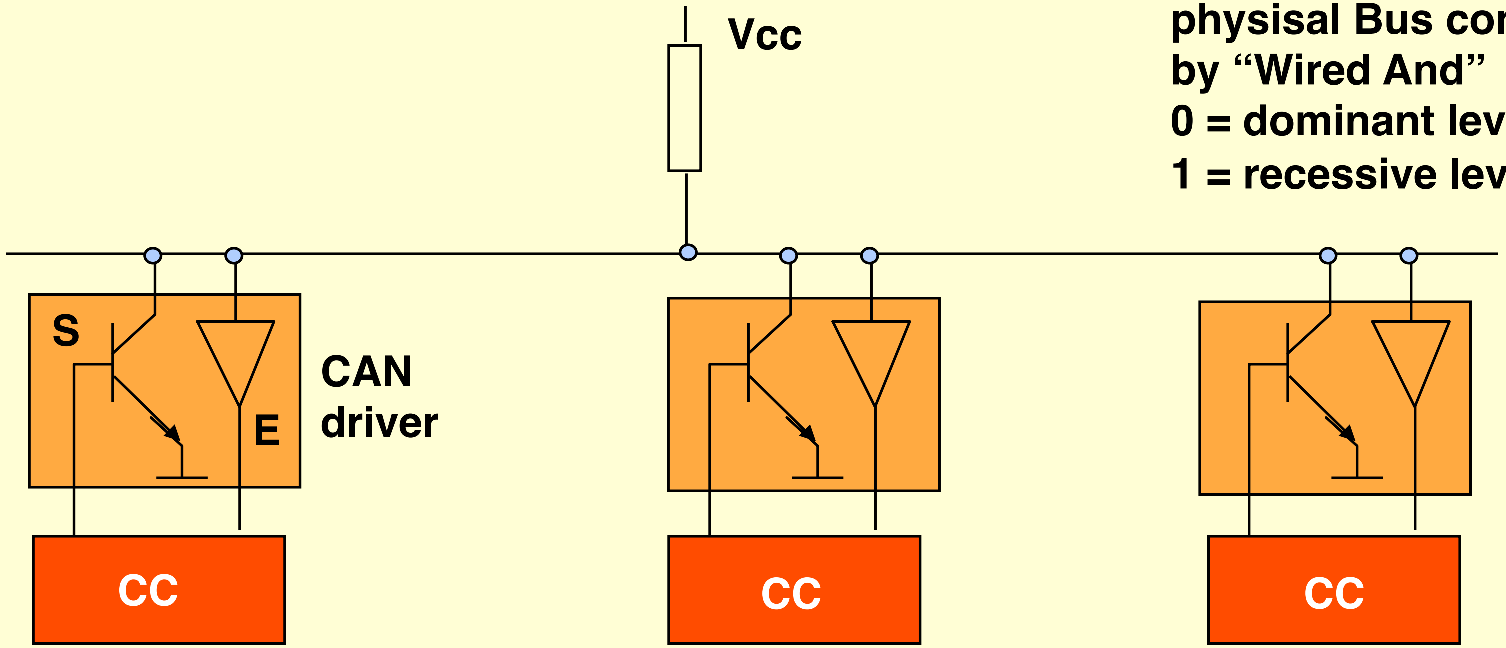




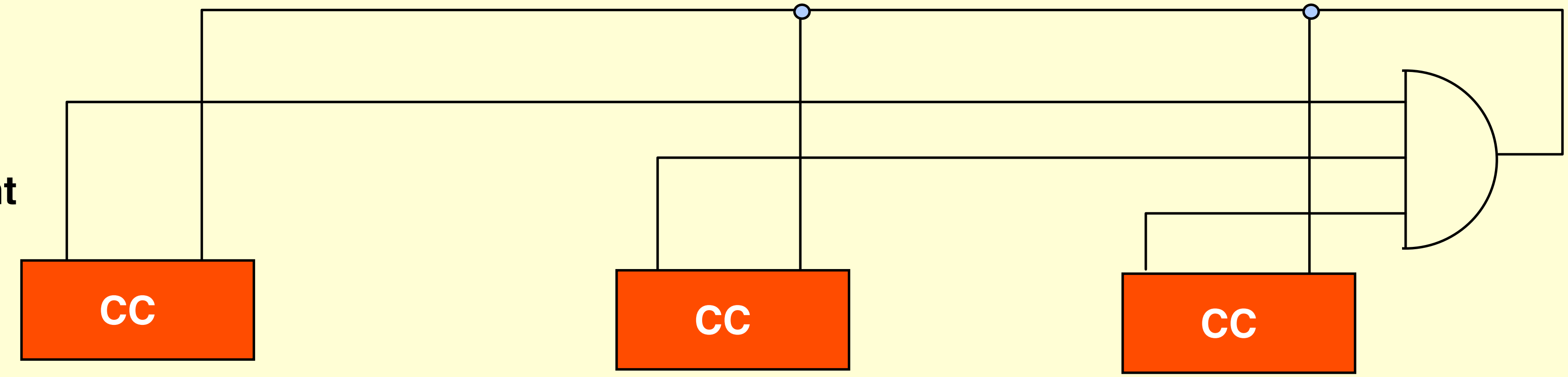
The CAN physical layer

physisal Bus connection by “Wired And”
0 = dominant level
1 = recessive level

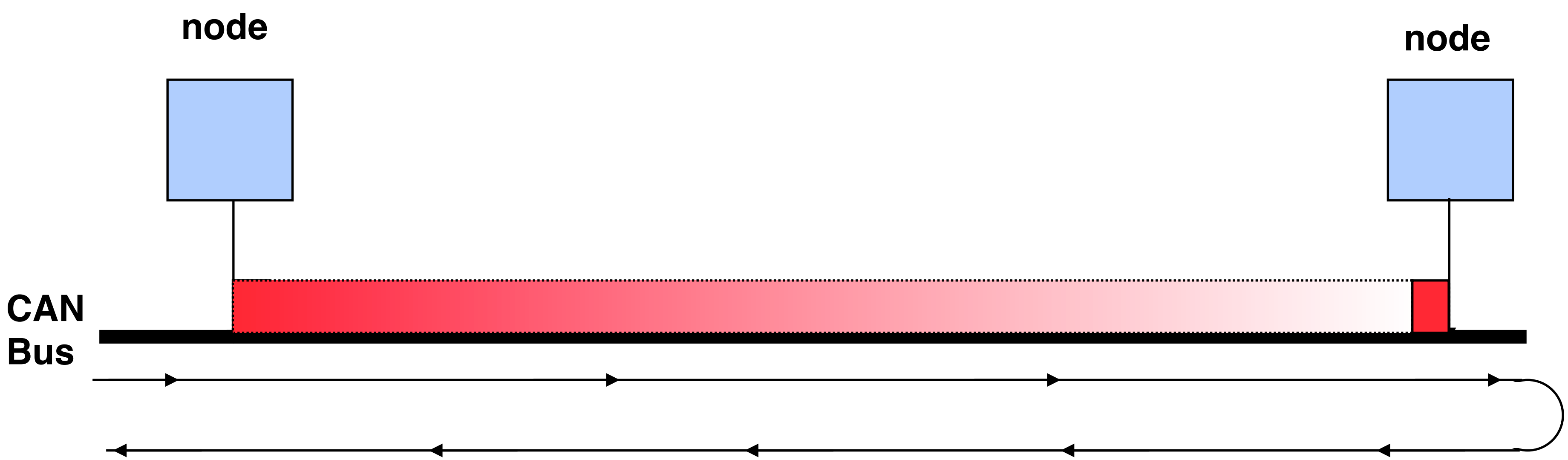
physisal connection



logic equivalent



CAN Bit Synchronisation

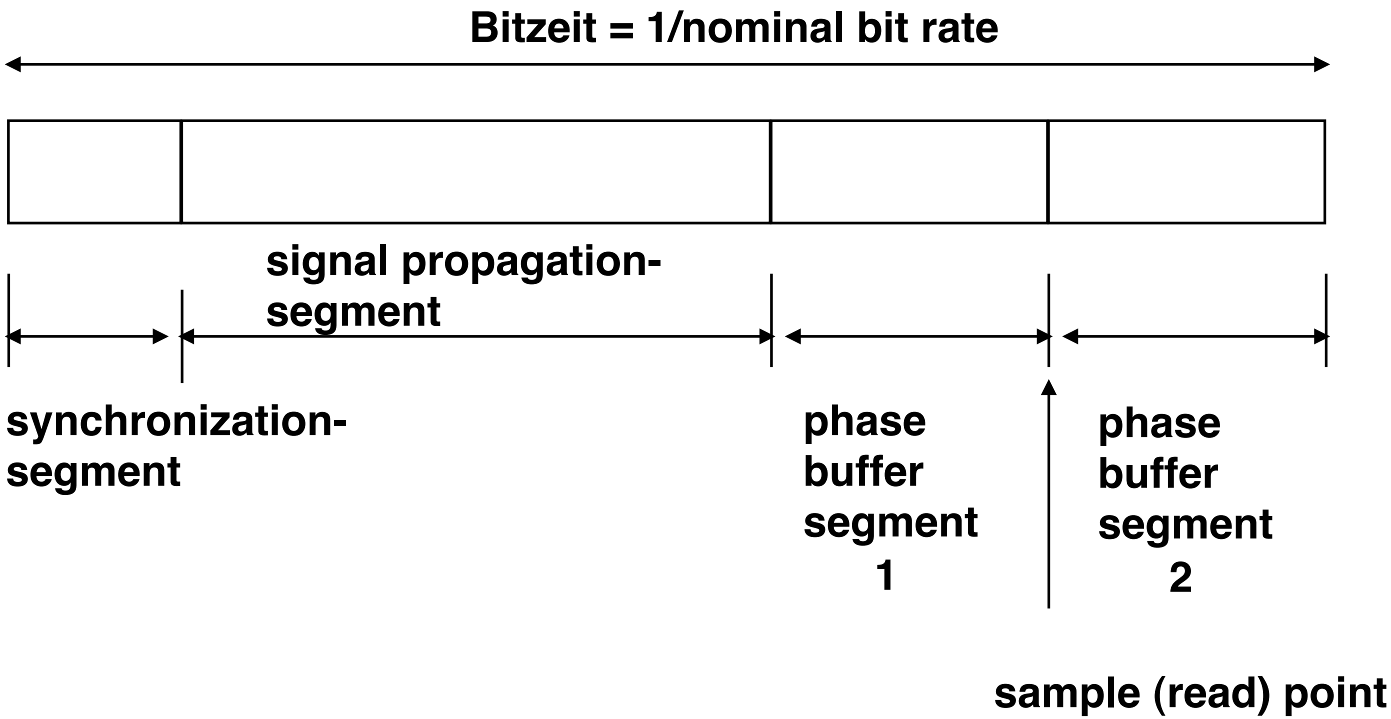


After a certain time, all nodes have seen the value of a bit

Bit rate dependend on the length of the bus

Bit Monitoring

Bit-timing and bit synchronization



Länge der Zeitsegmente werden in Vielfachen einer aus der Oszillatorperiode abgeleiteten Zeiteinheit (time quantum) spezifiziert:

synch.-segment	1	time quanta
sig. propag. seg.	1...8	time quantas
phase buffer seg. 1	1...8	time quantas
phase buffer seg. 2	1...8	time quantas

CAN transfer rates in relation to the bus length

$$T_d = T_{TT\text{-}delay} + T_{line\ delay}$$

$T_{TT\text{-}delay}$ ~ 100 ns

(driver, transceiver, comparator logic, etc.)

$T_{line\ delay}$ ~ 0,2 m / ns twisted pair

Bitrate (kBits/s)	max. network extension (m)
1000	40
500	112
300	200
200	310
100	640
50	1300

CAN payload

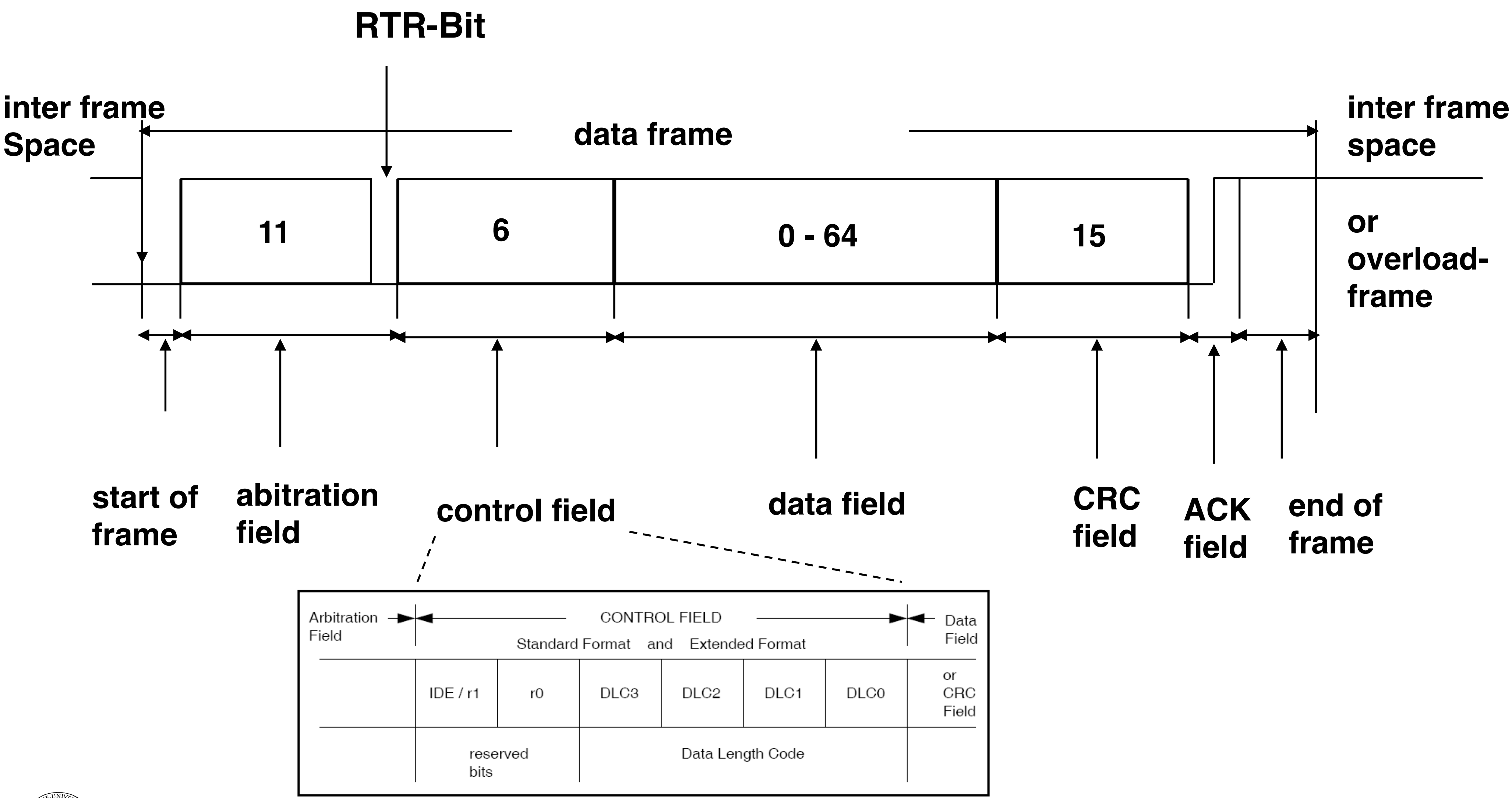
payload # of bytes	Std. frame kbits/sec	extended frame kbits/sec
0	--	--
1	71,1	61,1
2	144,1	122,1
3	216,2	183,2
4	288,3	244,3
5	360,4	305,3
6	432,4	366,4
7	504,5	427,5
8	576,6	488,5

The CAN MAC and Logical Link Control (LLC) levels

Frame types and formats:

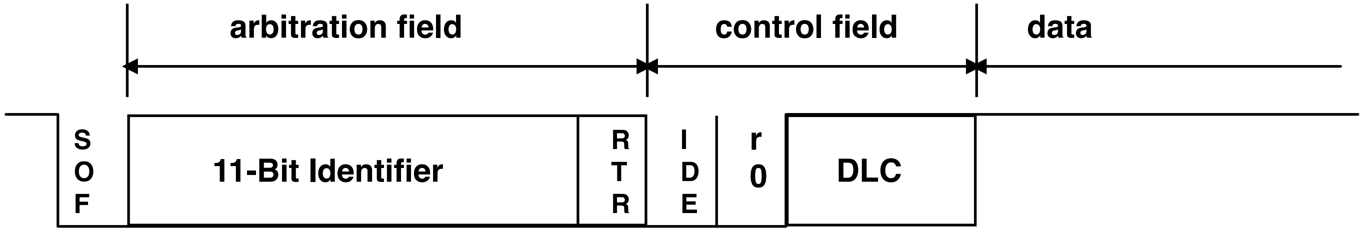
- **Data Frame** normal data transmision initiated by the sender
- **Remote Frame** participant requests frame which is sent with the identical frame ID from some other participant.
- **Error Frame** participant signals an error which it has detected
- **Overload Frame** used for flow control. Results in a delayed sending of the subsequent frame.

CAN Standard Data Frame

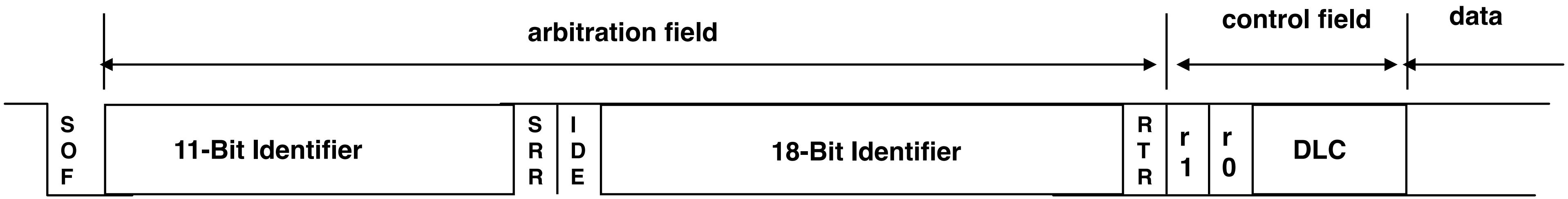


Compatibility between standard and extended frames

Standard Format SF (compatible to CAN Spezifikation 1.2)

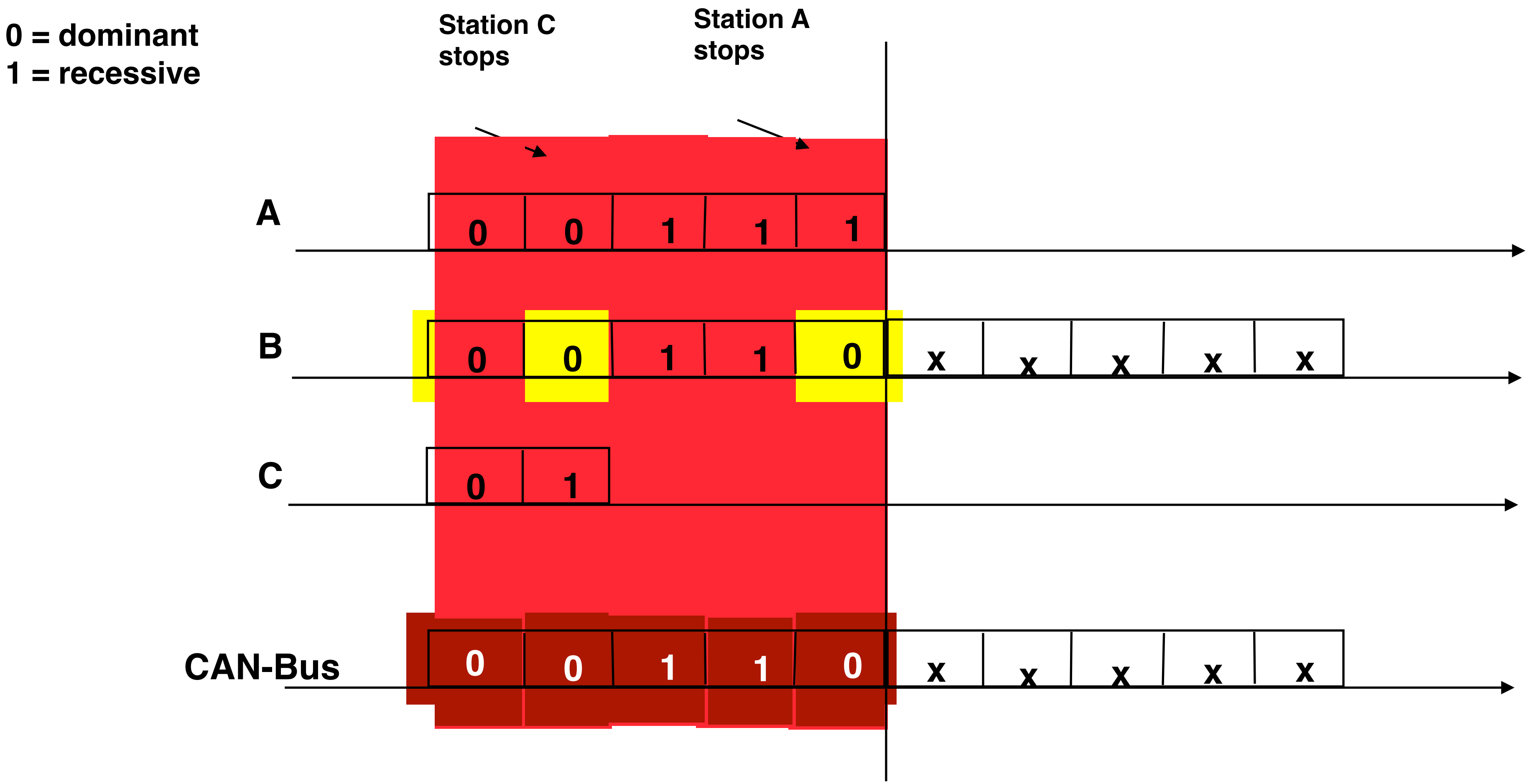


Extended Format EF (CAN Spezifikation 2.0)



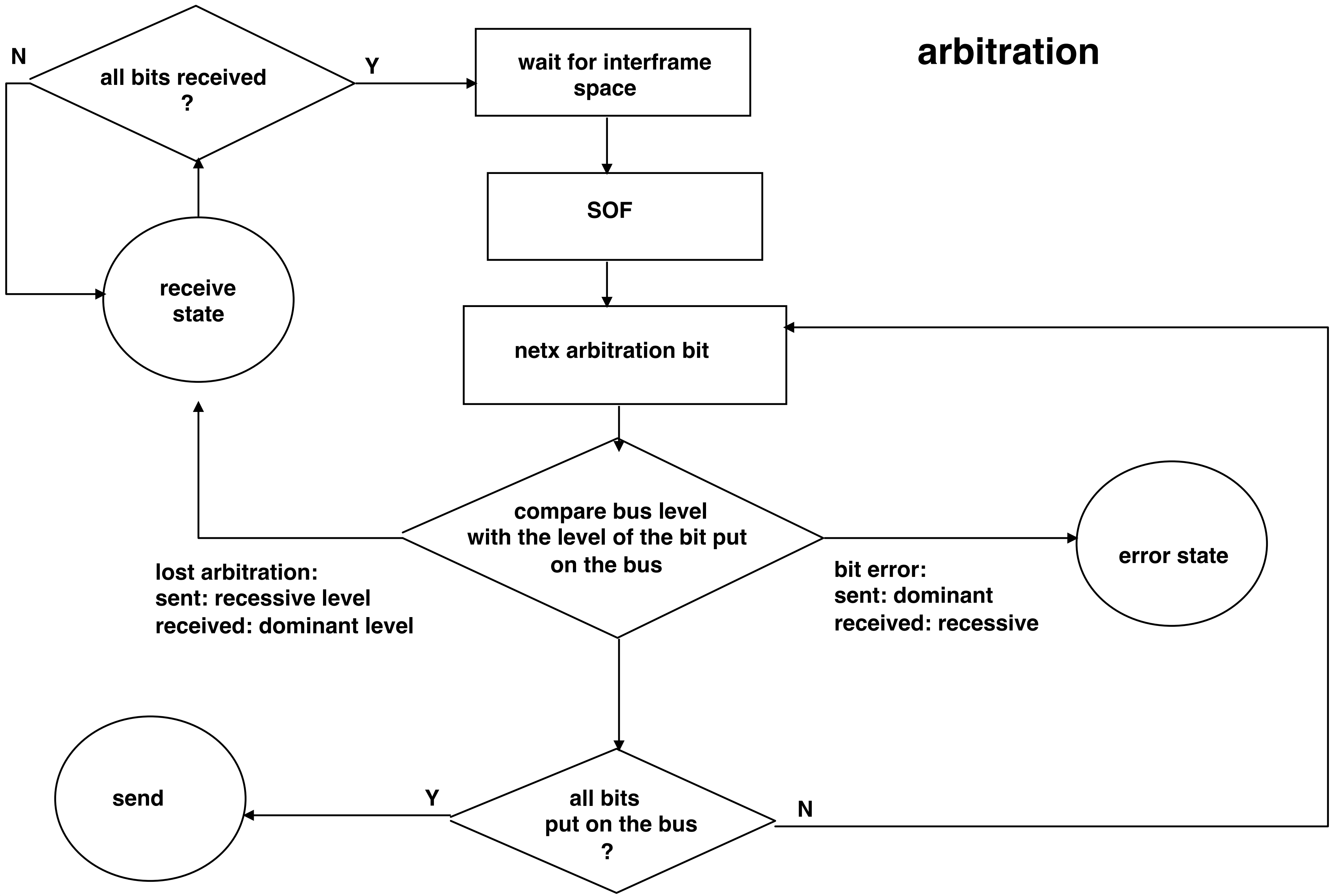
RTR:	Remote Transmissin Request. In Data Frame: RTR = dominant. In Remote Frame: RTR = recessive. In the EF, the SSR-Bit has the funktion or the RTR-Bit
IDE:	Identifier Extension. In the SF this is part of the control field, has a dominant value but is not interpreted. In the EF it is part of the addressing field, has a recessive value and causes the format to be recognized as EF.
SRR:	Subsitute Remote Request. Recessive, replaces RTR in the EF for compatibility reasons.
DLC:	Data Length Control. 0-8 Byte.
r0, r1:	reserved

Arbitration on a CAN-Bus



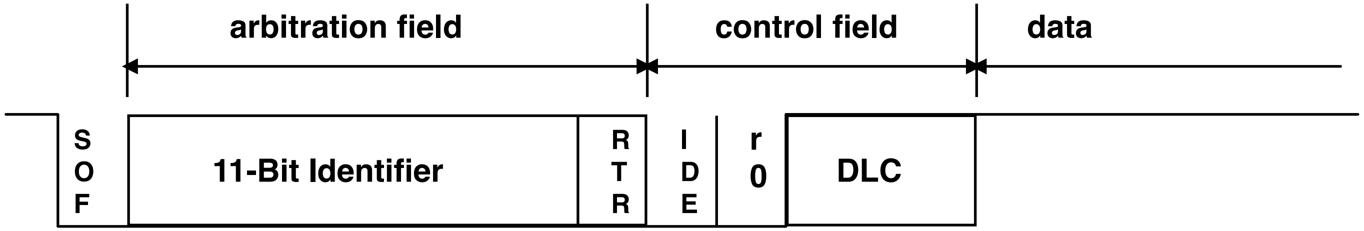
CAN enforces a global priority-based message scheduling

arbitration



CAN Data Frame

Standard Format SF (compatible to CAN Spezifikation 1.2)



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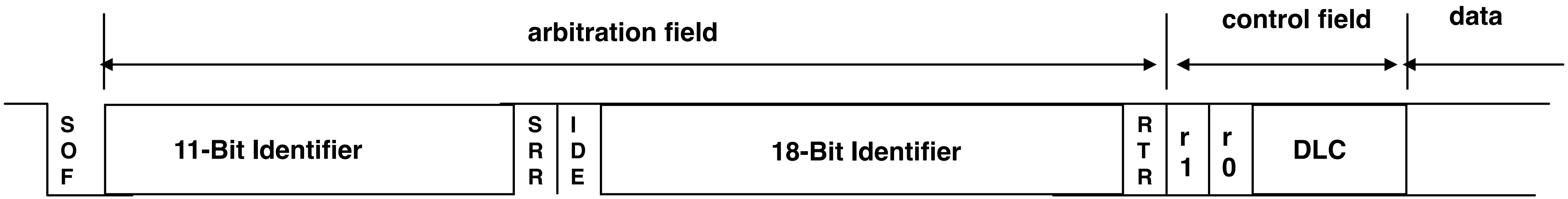

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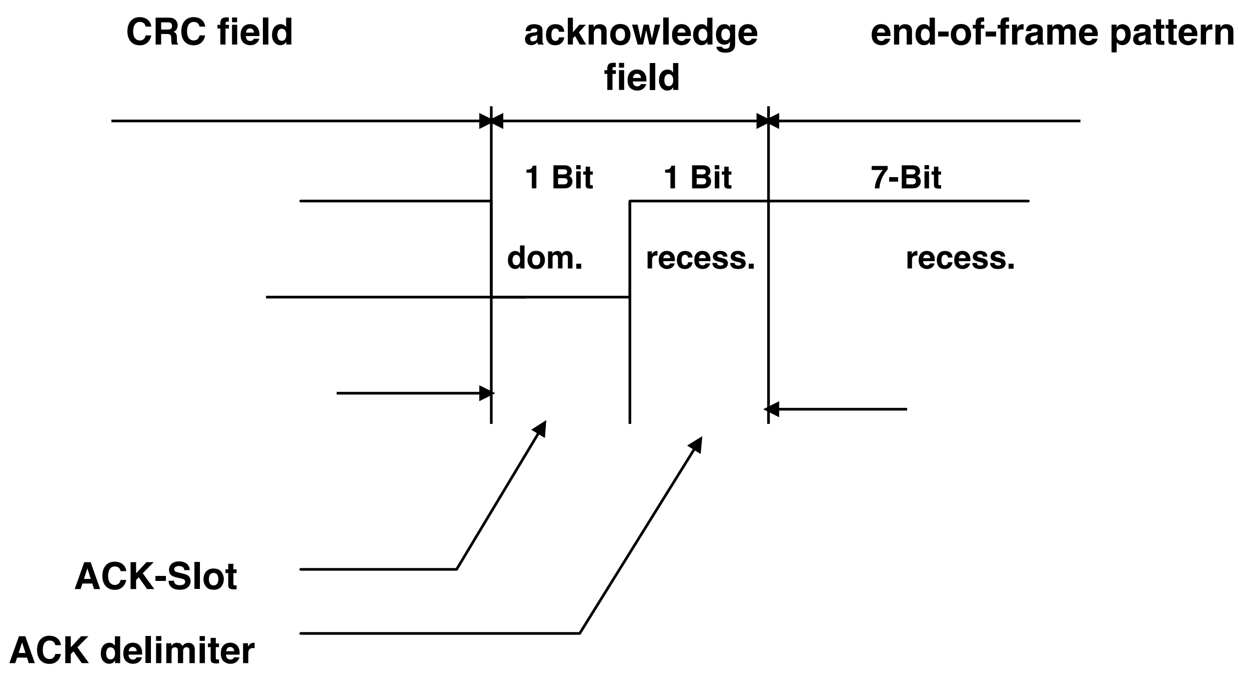
r0, r1:	**reserved**

Anonymous acknowledgement of a CAN message

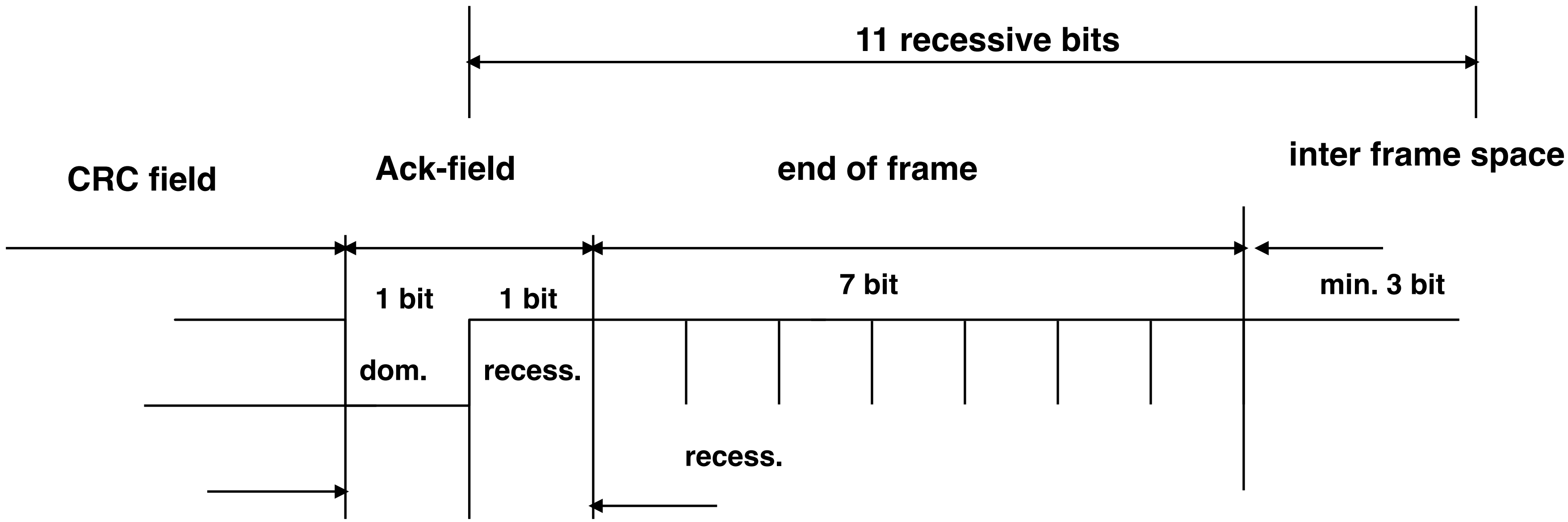


positive anonymous acknowledgement (Broadcast !)

receivers that correctly received a message(a matching CRC sequence) report this in the ack-slot by superscibing the recessive bit of the sender by a dominat bit. The sender switches to a recessive level.

- **Message is acknowledged by a single correct reception on a correct node.**
- **Systemwide data consistency requires additional signalling of local faults.**

Termination sequence of a frame



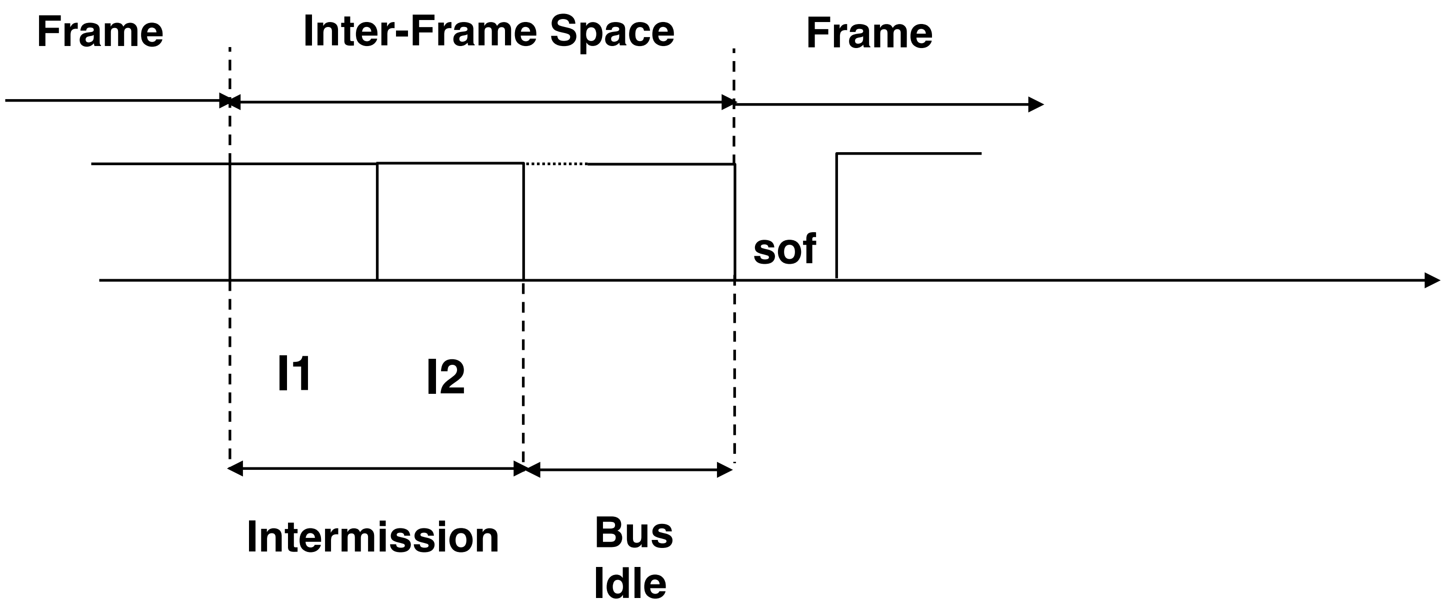
Goals:

1. Detecting AND signalling the error within the actual fame in which it occured
2. Identifying the node which may have caused the error.
3. Creating a systemwide view on the reception state of the message.

Approach: End of frame pattern consisting of 7 recessive bits.

1. Any error detection is signalled by putting a dominant bit on the bus.
2. An out-of-sync node, not being aware of the EOF sequence will signal an error at position "6".

Interframe Space

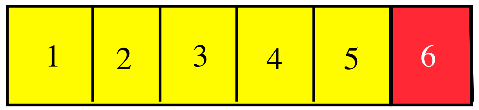


Intermission: no data- or remote Frame may be started

Intermission 1: active overload Frame may be started
Intermission 2: re-active overload frame (after detecting a dominant bit in I1)

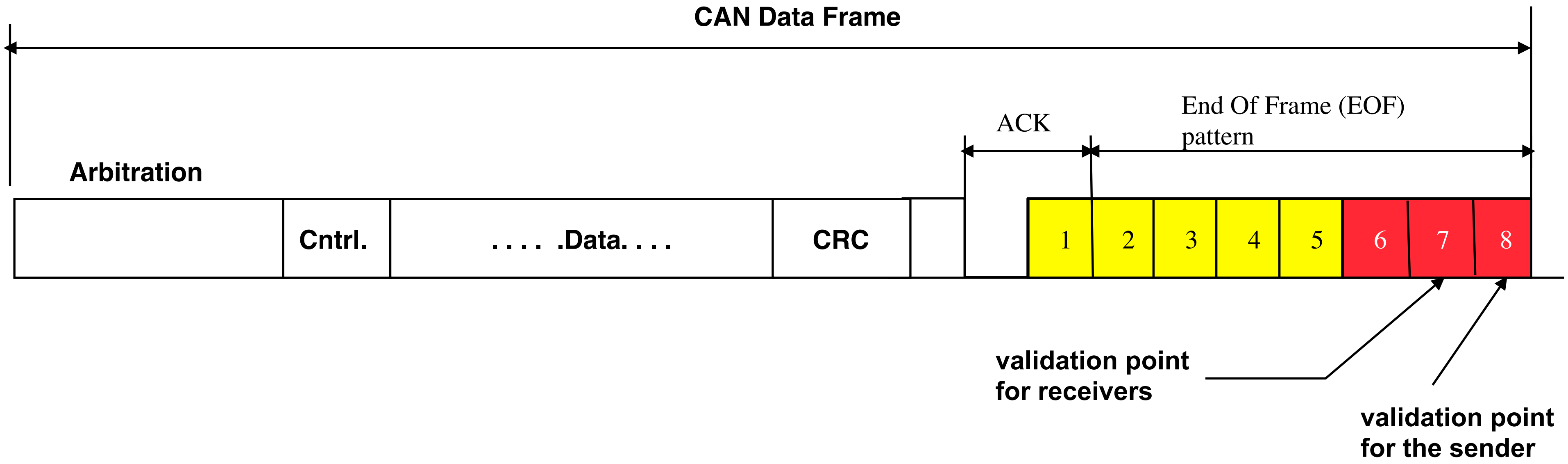
Error Detection and Error Signalling in CAN

Violation of the Bit-Stuffing Rule:
Used for Error Detection and Signalling



Bit-Stuffing enforces the following rule:

A sequence of 5 identical bit levels is followed by a complementary bit level



Error detection

1.) **Monitoring: Sender compares the bit sent with the bit actually on the bus.**
Type of faults: local sender faults
Error detection: sender based

2.) **Cyclic Redundancy Check:**
Type of faults: 5 arbitrarily distributed faults in the code word, burst error max. length 15.
Error detection: receiver based

3.) **Bitstuffing:**
Type of faults: transient faults, stuck-at-faults in the sender
Error detection: receiver based

4.) **Format control:**
Type of faults: the specified sequence of fields is violated.
Error detection: receiver based

5.) **Acknowledgment:**
Type of faults: no acknowledge
Error detection: sender based, sender assumes local fault.

Risk of undetected errors

Bit monitoring: An error will not be detected if
- the sender is correct and monitoring doesn't detect an error
- all other nodes receive the same bit pattern which is different from that of the sender and contains a non-detectable error.

Bit-stuffing: double errors within 6 bits will not be detected

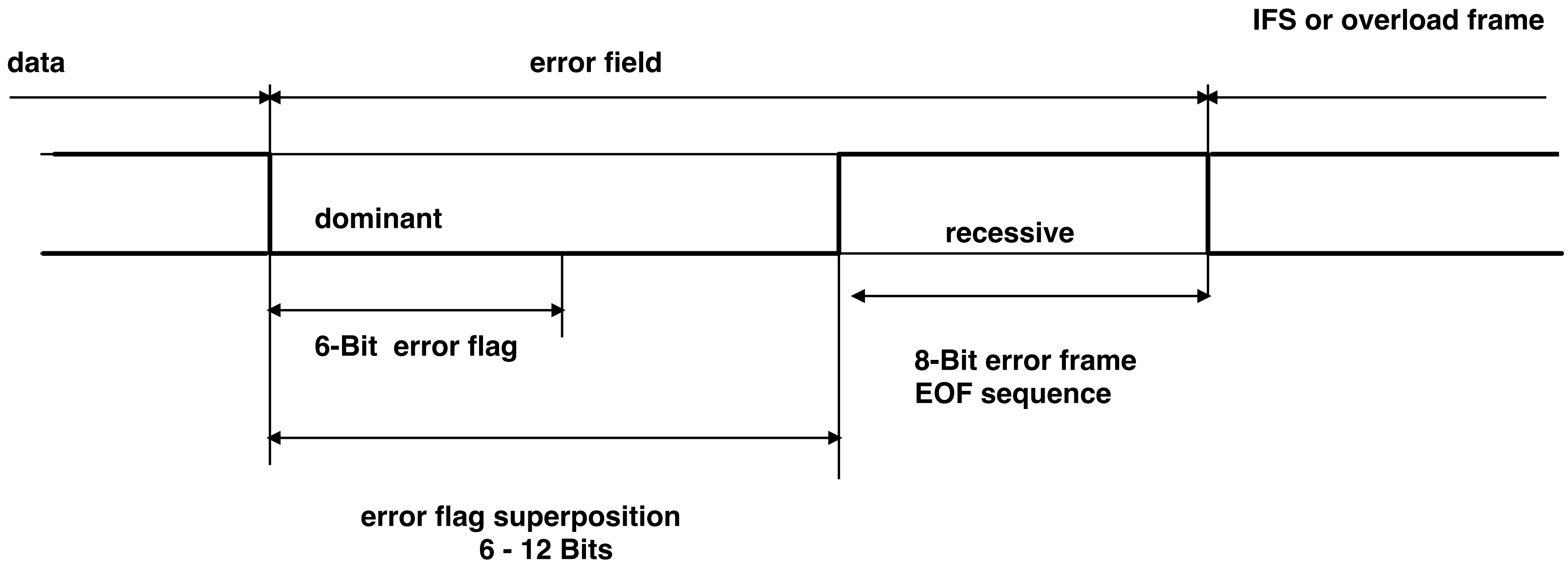
CRC: difference between frame sent and received is a multiple of the generator polynome.

Frame errors: the frame is shortened or additional bits are added. At the same time a correct end-of-frame sequence is generated.

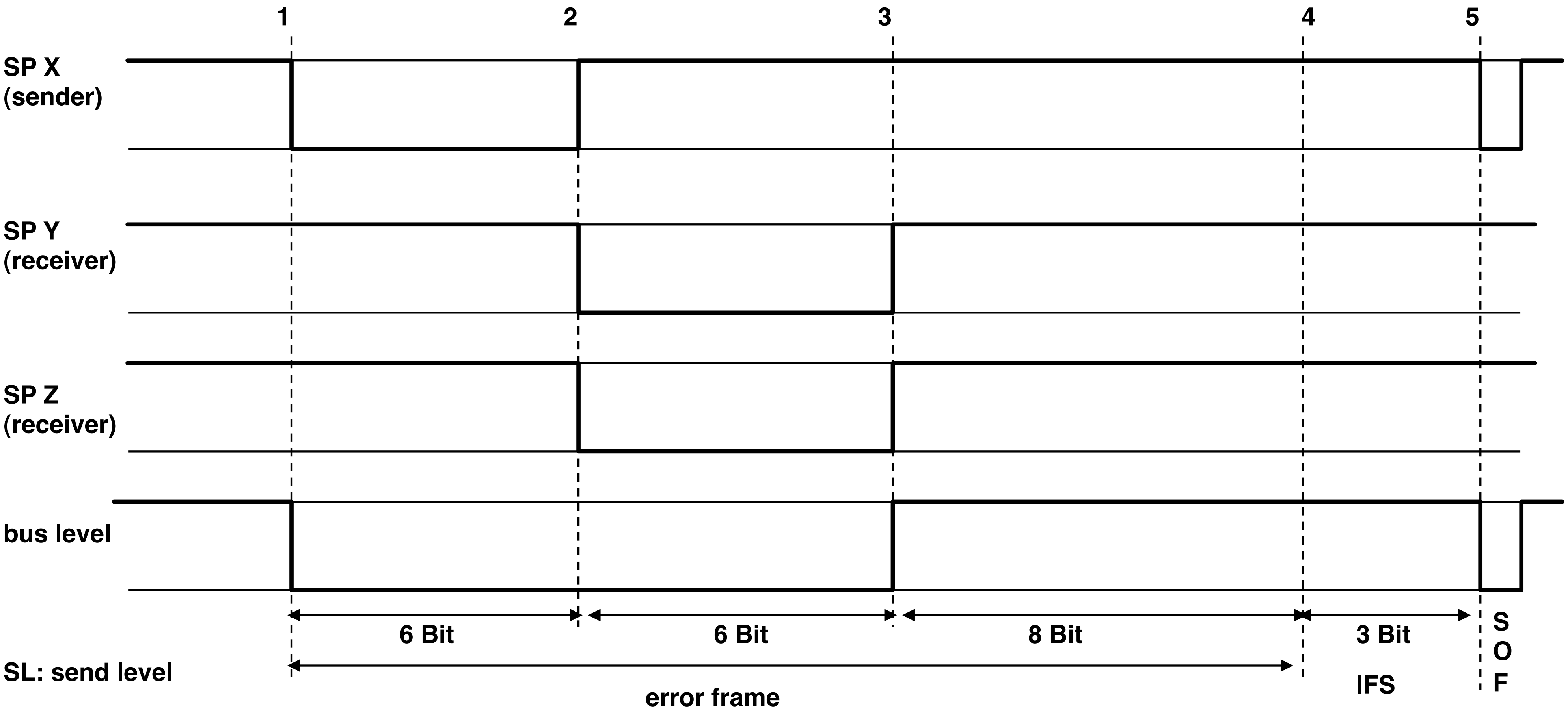
Unruh, Mathony und Kaiser:"Error Detection Analysis of Automotive Communication Protocols", SAE International Congress, Nr. 900699, Detroit, USA, 1990

Scenario:
nodes: 10, Bit error rate: $2 \cdot 10^{-2}$, message error rate: 10^{-3}
risk of undetected errors: $4{,}7 \cdot 10^{-14}$
When the number of nodes increase, the probability of undetected errors decreases.

CAN error frame

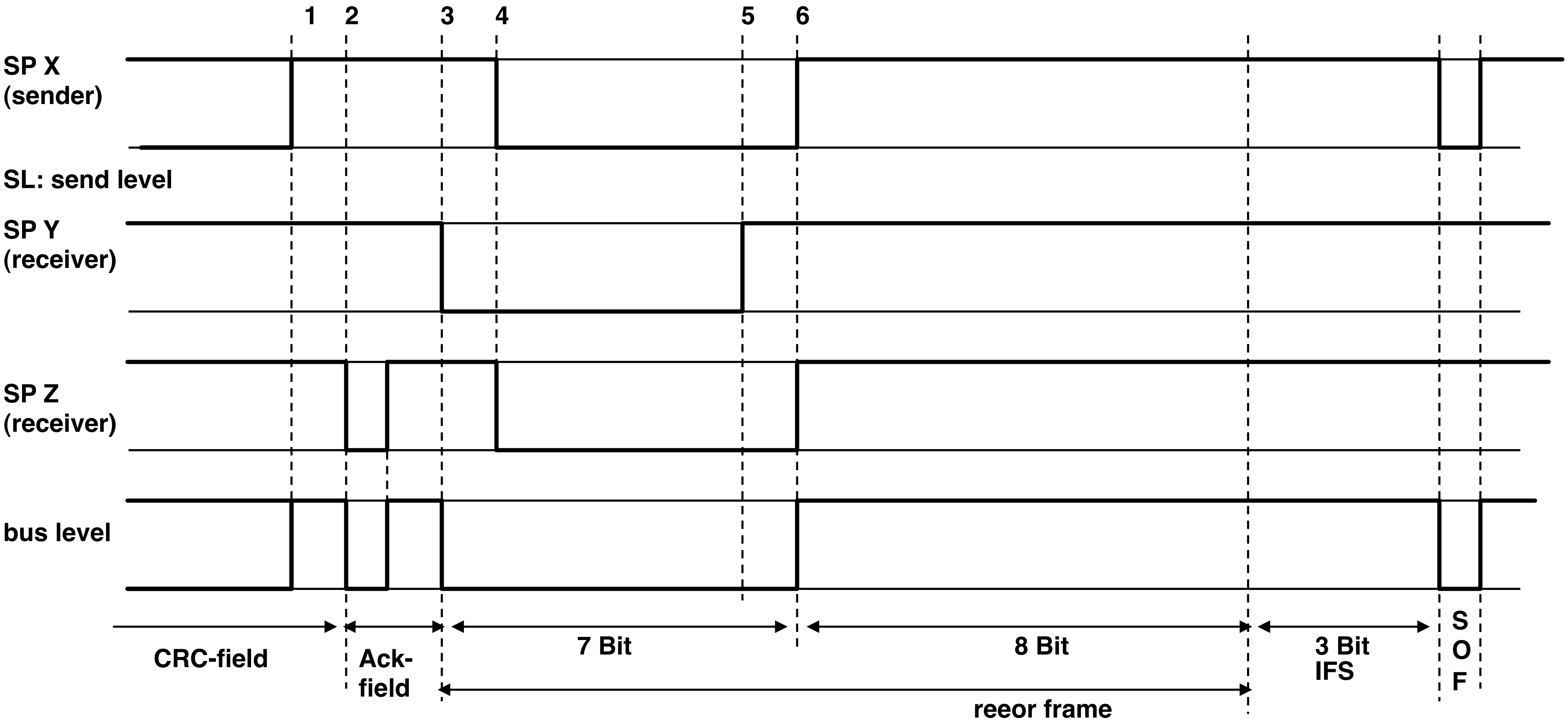


Error frame resulting from a sender fault



time to re-transmit a faulty message frame: min. error recovery time: 23 bit times

Error frame resulting from a receiver fault



time to re-transmit: min. error recovery time: 20 bit times

Enforcing fault confinement and a “Fail Silent” behaviour

Problem: Faulty component may block the entire message transfer on the CAN-Bus.

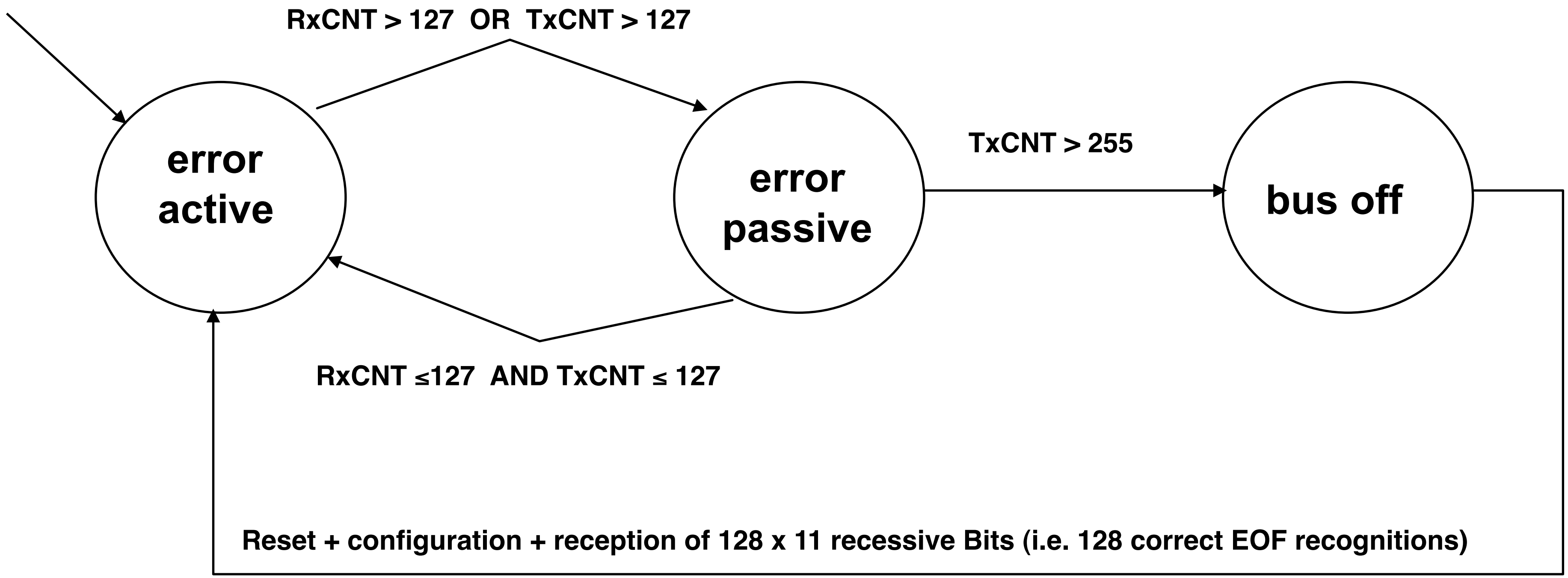
Assumption:
1. A faulty node detects the error first.
2. frequently being the first which detects an error --> local fault in the node

approach: error counter for receive and transmit errors. If error was first detected by the node, the counter is increased by 8-9.

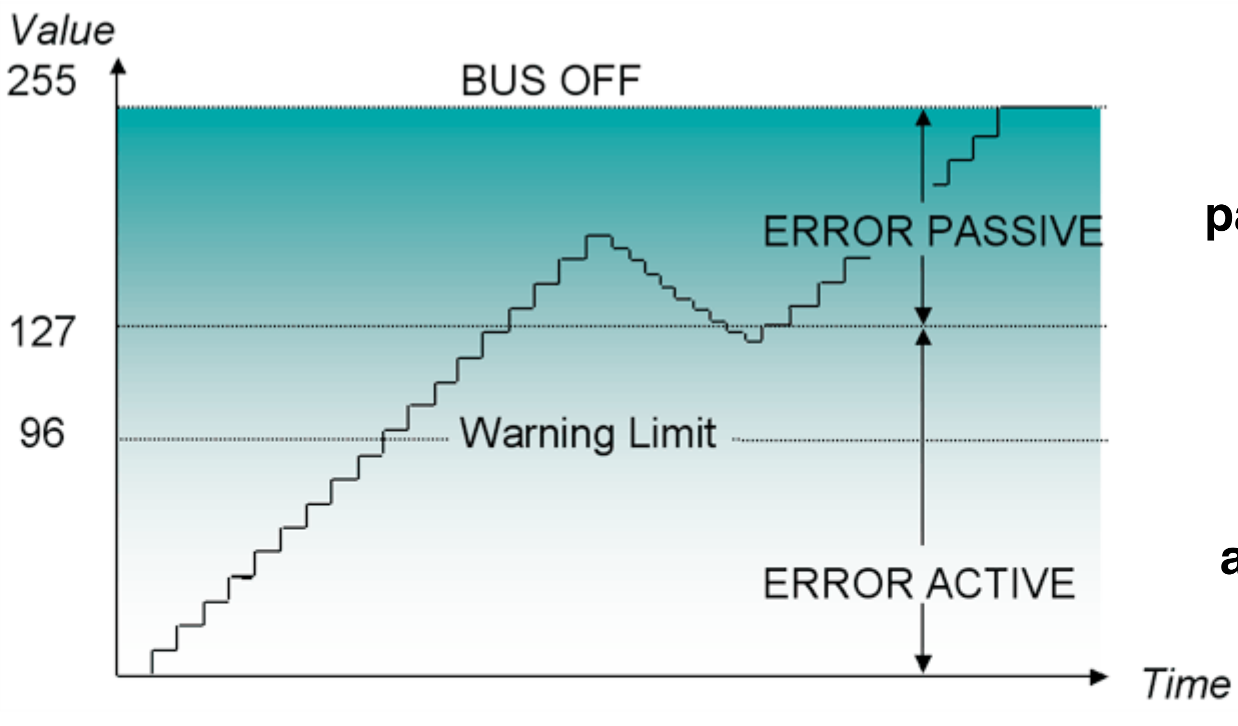
Enforcing fault confinement and a “Fail Silent” behaviour

States of a CAN node:
- **error active**
- **error passive**
- **bus off**

RxCNT: Value of the receive counter
TxCNT: Value of the transmit counter



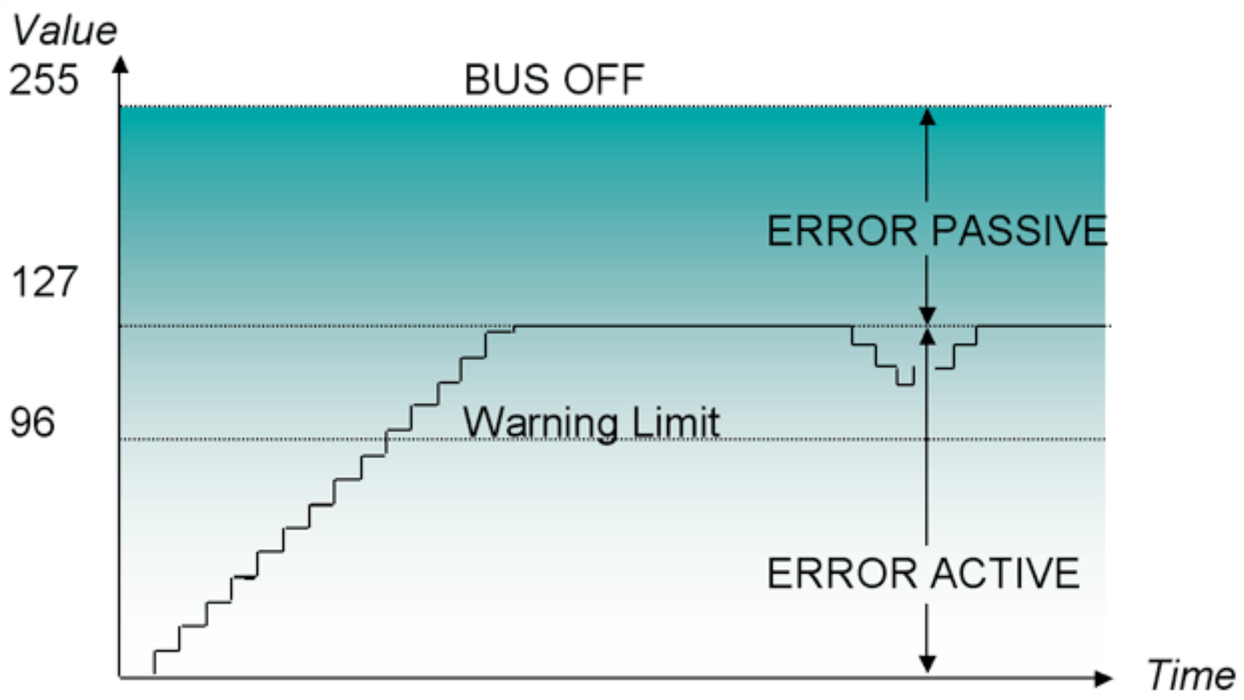
CAN bus Error Handling - Transmit Error Counter



passive error frame

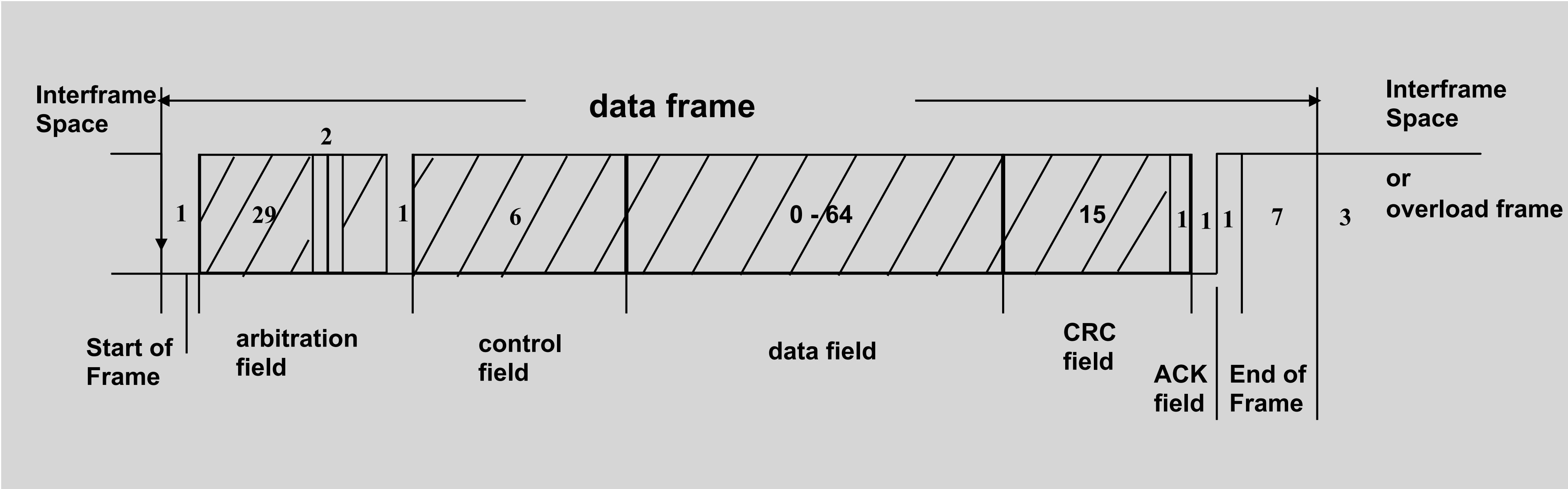
active error frame

CAN bus Error Handling - Receive Error Counter



Analysis of CAN inaccessibility

CAN Data Frame



longest possible message:

Format-Overhead:	67 bit times
Data:	64 bit times
Bitstuffing (max):	23 bit times
total:	154 bit times

CAN Inaccessibility Times*

Data Rate 1 Mbps , Standard Format

Scenario	t_{inacc} (µs)	
Bit Errors	155.0	← worst case single
Bit Stuffing Errors	145.0	
CRC Errors	148.0	
Form Errors	154.0	
Ack. Errors	147.0	
Overload Errors	40.0	
Reactive Overload Errors	23.0	
Overload Form Errors	60.0	
Transmitter Failure	2480.0	← worst case multiple
Receiver Failure	2325.0	

P. Verissimo, J. Ruffino, L. Ming:" How hard is hard real-time communication on field-busses?"

Predictability of various Networks*

Worst Case Times of Inaccessibility*	t_{inacc} (ms)	
ISO 8002/4 Token Bus (5 Mbps)	139.99	Token-based Protocols
ISO 8002/5 Token Ring (4 Mbps)	28278.30	
ISO 9314 FDDI (100 Mbps)	9457.33	
Profibus (500 kbps)	74.80	
CSMA/CD	unbounded	CSMA Protocols
CSMA/CA	stochastic	
CAN-Bus (1Mbps)	2.48	

The worst-case-delay of the Timed-Token-Protocol is 2•TTRT (Target Token Rotating Time)**

* P. Verissimo, J. Ruffino, L. Ming:" How hard is hard real-time communication on field-busses?"
** J.N. Ulm: "A Timed Token Ring Local Area Network and its Performance Characteristics"
R.M. Grow: " A Timed Token Protocol for local Area Networks"

CAN-Bus Properties (summary)

- Event-triggered communication with low latency
- Priority-based arbitration with collision resolution for guaranteed throughput
- error handling:
  - anonymous positive acknowledge
  - negative ack. in case of an error (systemwide messaging)
  - identification of faulty nodes
  - immediate synchronisation and retratnsmission
- content-based addressing with a high flexibilitx (system elasticity)

High level issues

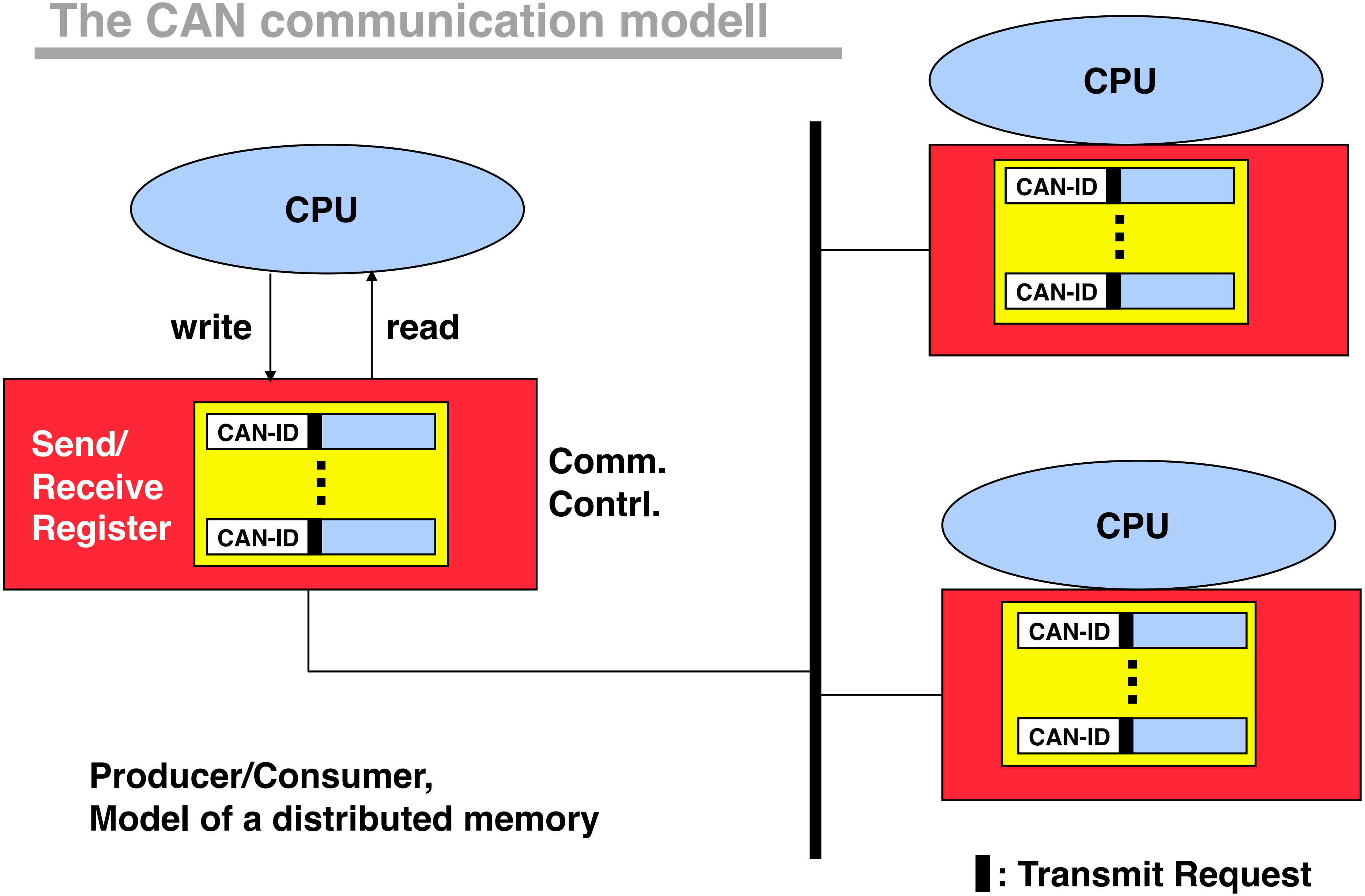
Routing: How does a message reach a receiver ?

CAN: Broadcast, message subjects

Filtering: How can the receiver only receive those messages selectively in which it is interested in ?

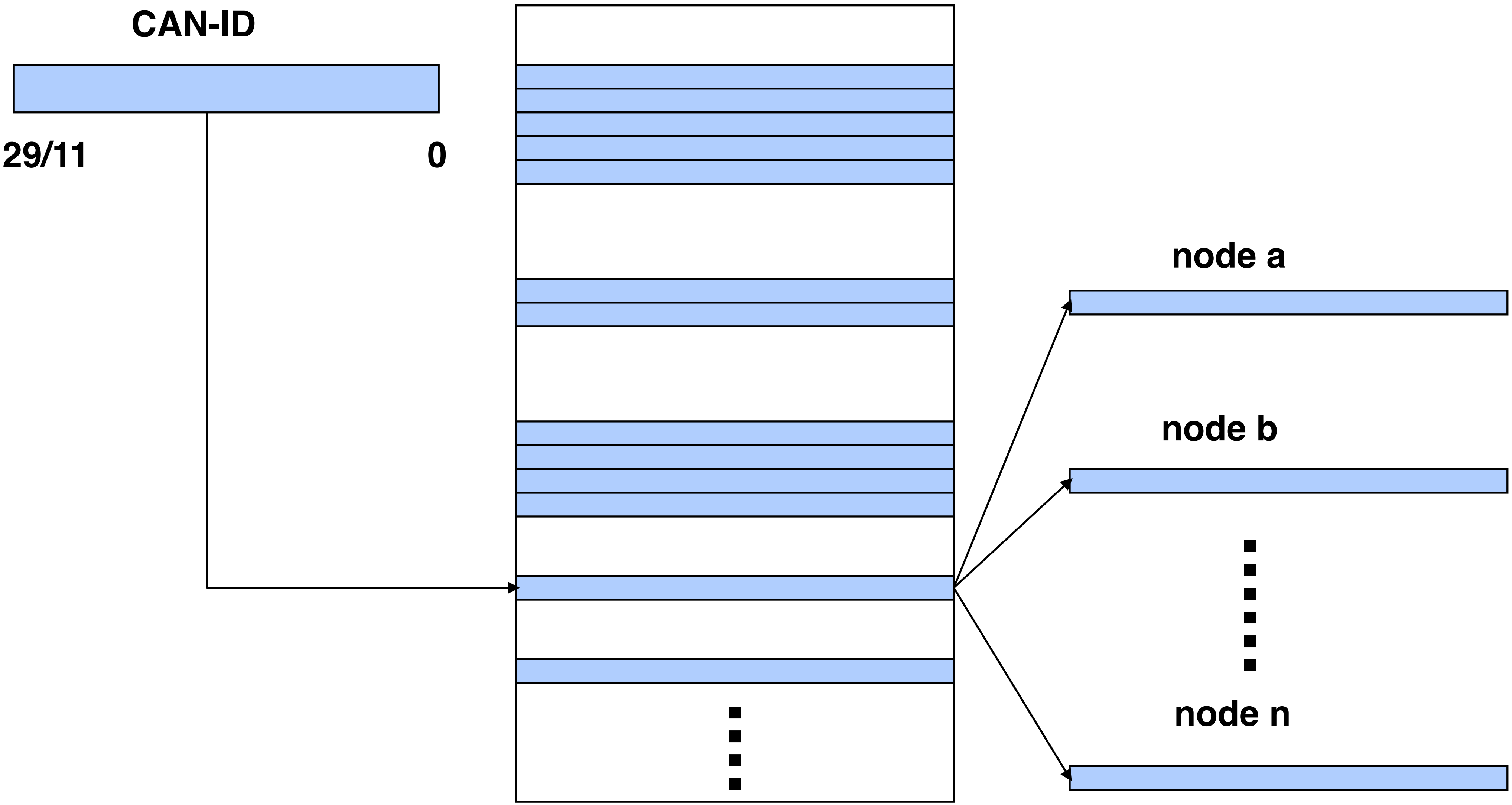
CAN: message filters

The CAN communication modell

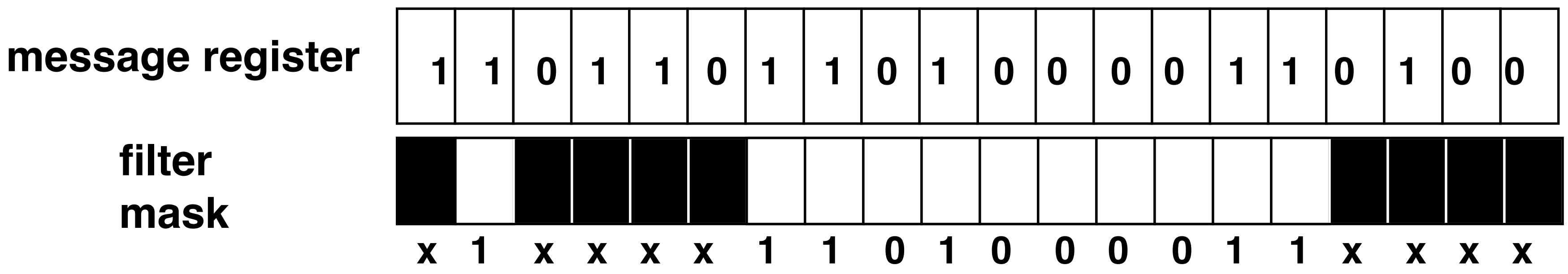


Producer/Consumer,
Model of a distributed memory

The CAN communication modell

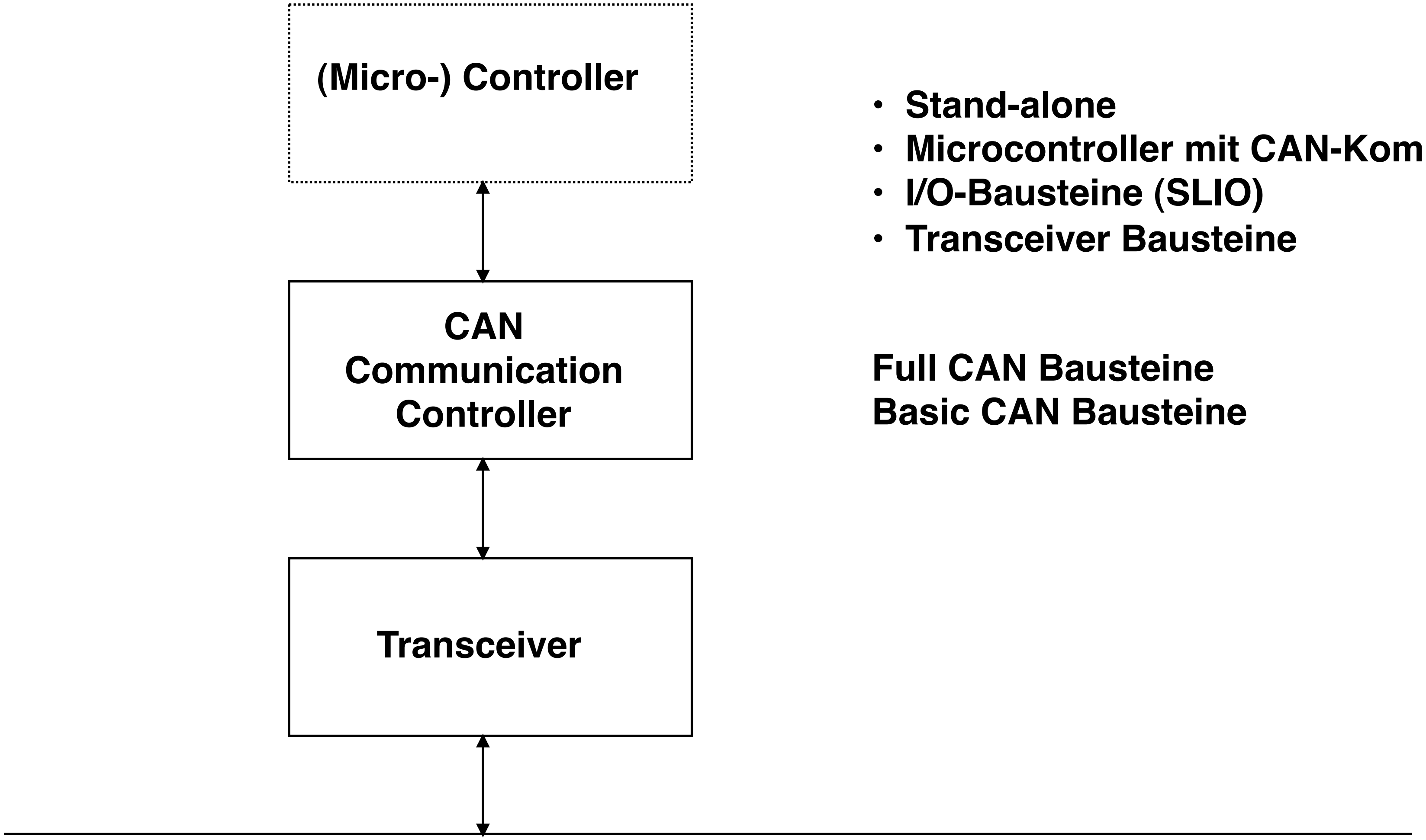


message filtering



Anzahl der Nachrichtenregister, Konfigurationsmöglichkeiten und Möglichkeiten der Nachrichtenfilterung sind abhängig vom verwendeten Kommunikationskontroller.

CAN Bausteine



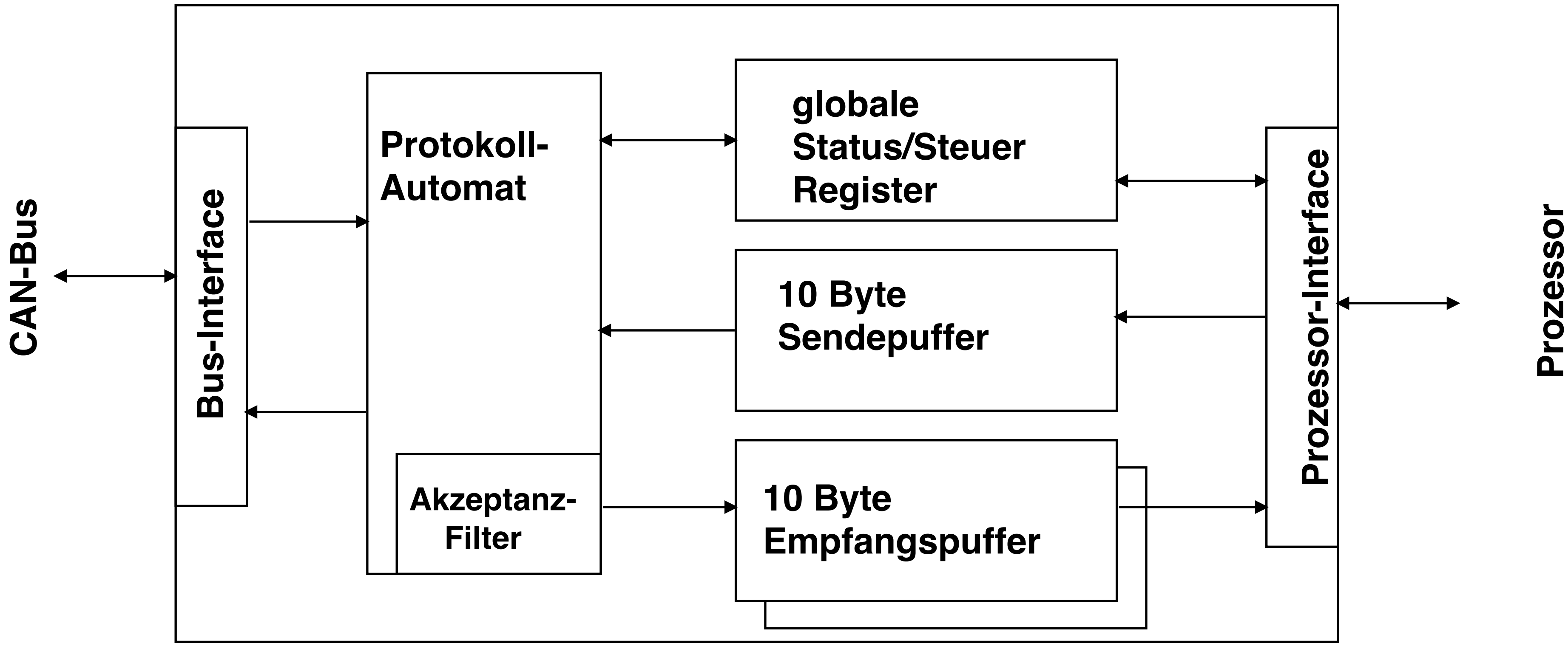
- Stand-alone
- Microcontroller mit CAN-Komponente
- I/O-Bausteine (SLIO)
- Transceiver Bausteine

Full CAN Bausteine
Basic CAN Bausteine

Aufgaben des CAN Controllers

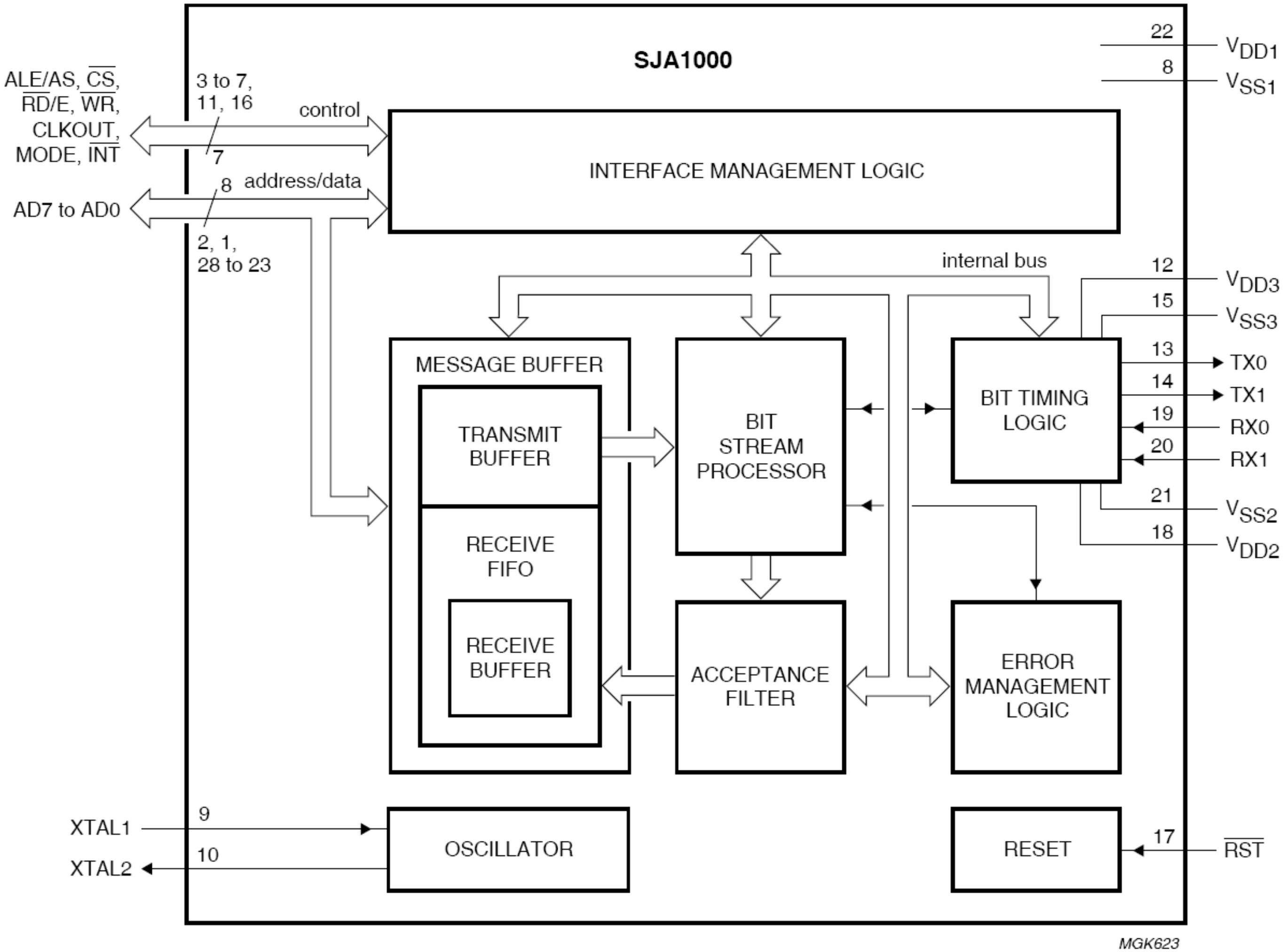
- Busarbitrierung
- Serialisierung der zu sendenden Telegramme
- Assemblierung der empfangenen Telegramme
- Berechnung bzw. Überprüfung der Checksumme
- Fehlererkennung und Fehlersignalisierung
- Bildung der CAN-Nachrichtenformate
- Einfügen bzw. Entfernen der zusätzlichen Bits beim Bit-Stuffing
- Erzeugen bzw. Überprüfen des Acknowledge-Bits
- Synchronisation des empfangenen Bitstroms

Basic CAN

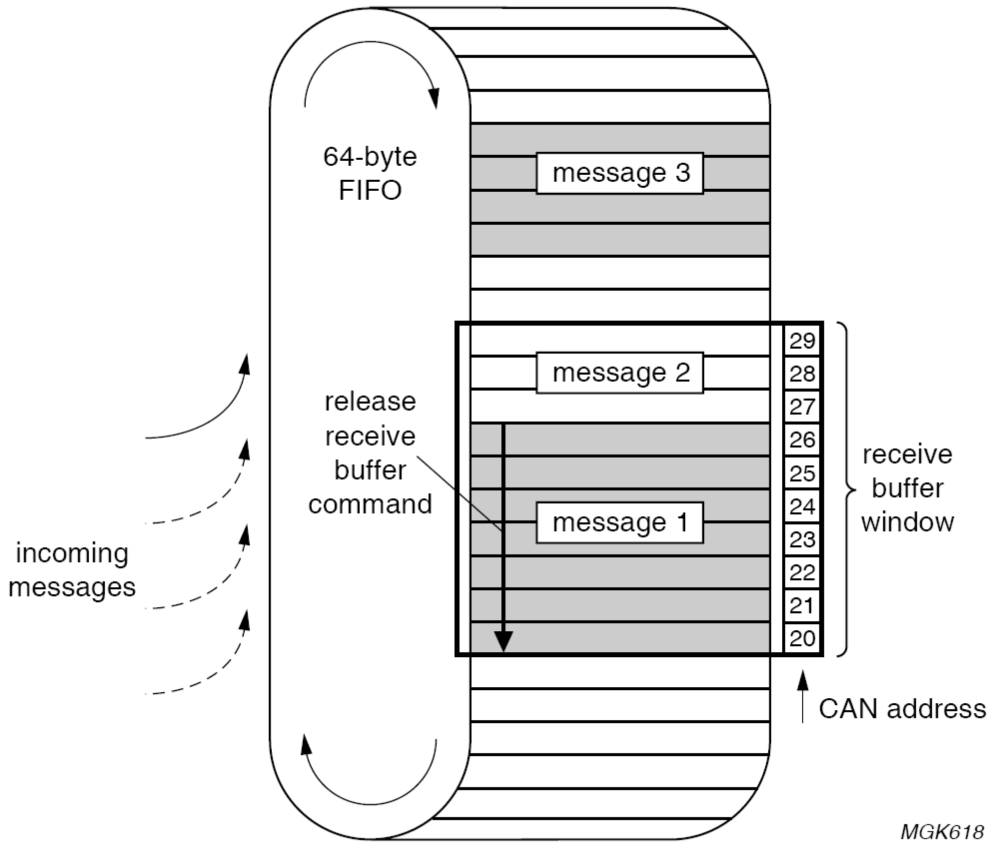


CAN-Bus
Bus-Interface
Protokoll-
Automat
Akzeptanz-
Filter
globale
Status/Steuer
Register
10 Byte
Sendepuffer
10 Byte
Empfangspuffer
Prozessor-Interface
Prozessor

SJA1000 (Philips)

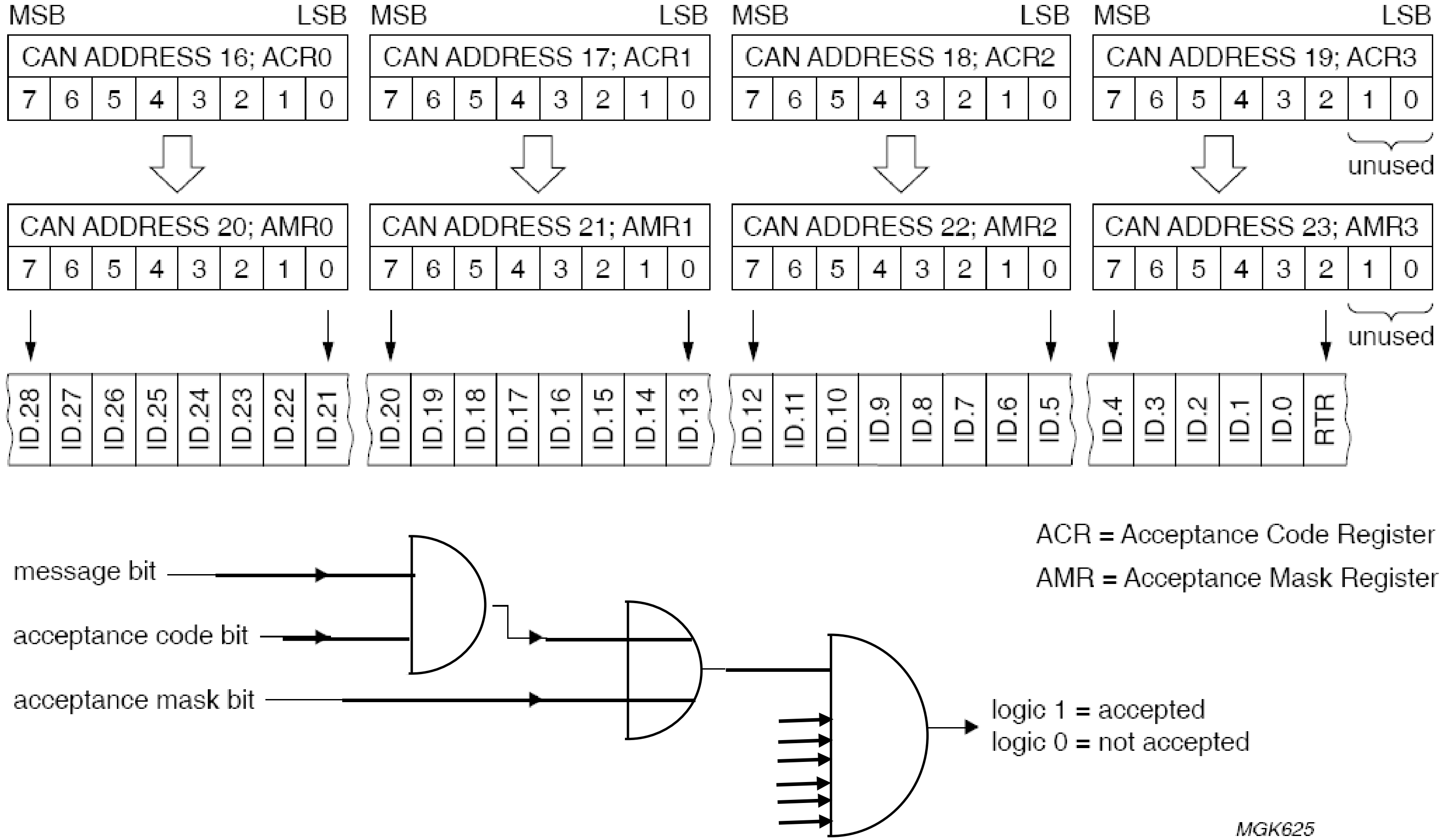


SJA1000 (Philips)



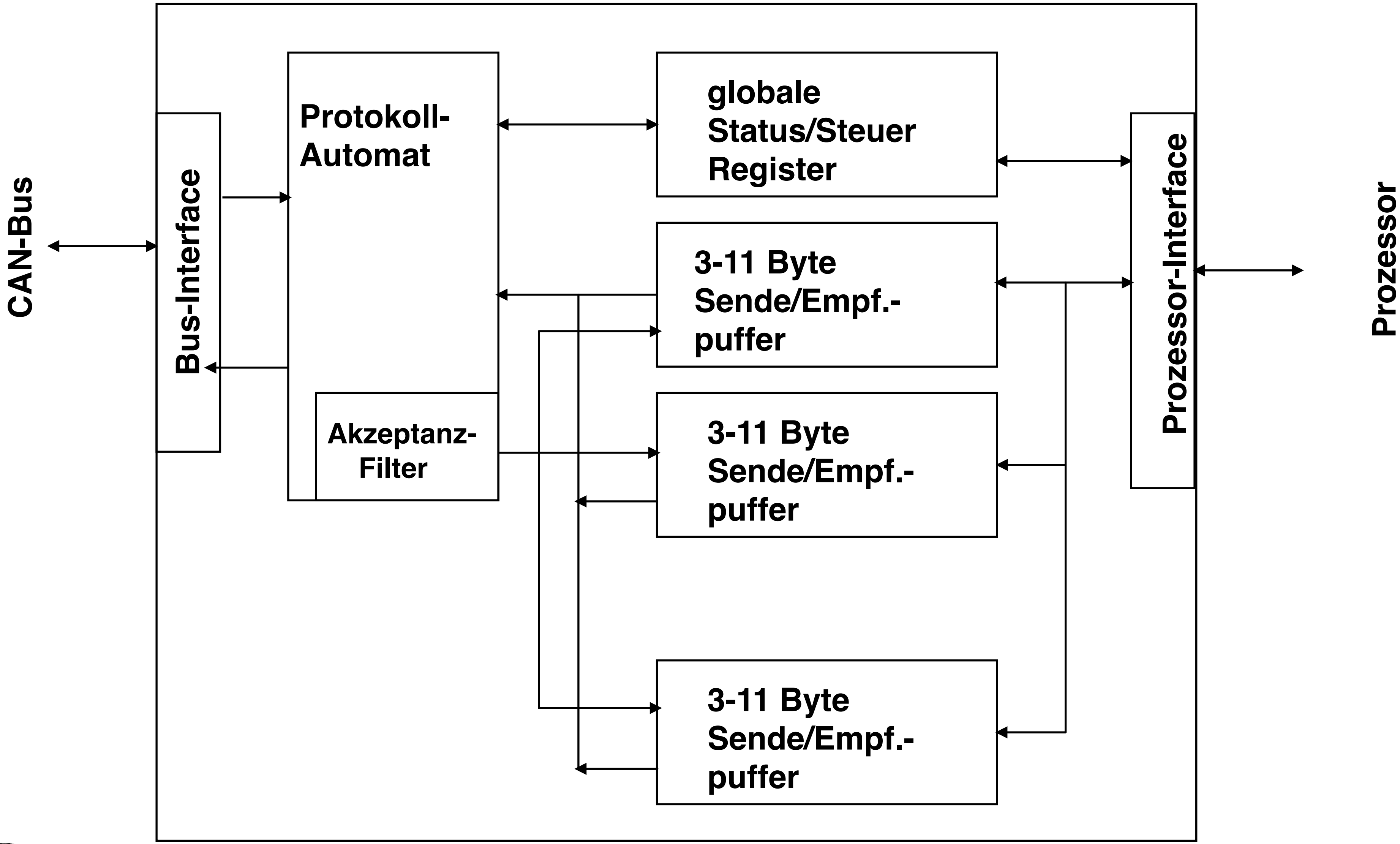
SJA1000 (Philips)

single mask option



ACR: defines the pattern of CAN message IDs which are accepted.
AMR: defines a mask of "don't care" positions.

Full CAN

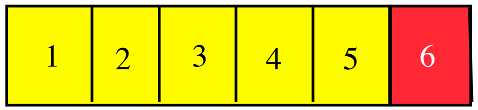

CAN-Bus
Bus-Interface
Protokoll-
Automat
Akzeptanz-
Filter
globale
Status/Steuer
Register
3-11 Byte
Sende/Empf.-
puffer
3-11 Byte
Sende/Empf.-
puffer
3-11 Byte
Sende/Empf.-
puffer
Prozessor-Interface
Prozessor

What CAN can't

- All-or-nothing property under all single (crash/omission) fault conditions
- Temporal guarantees for message transmissions
- Consistent order of messages

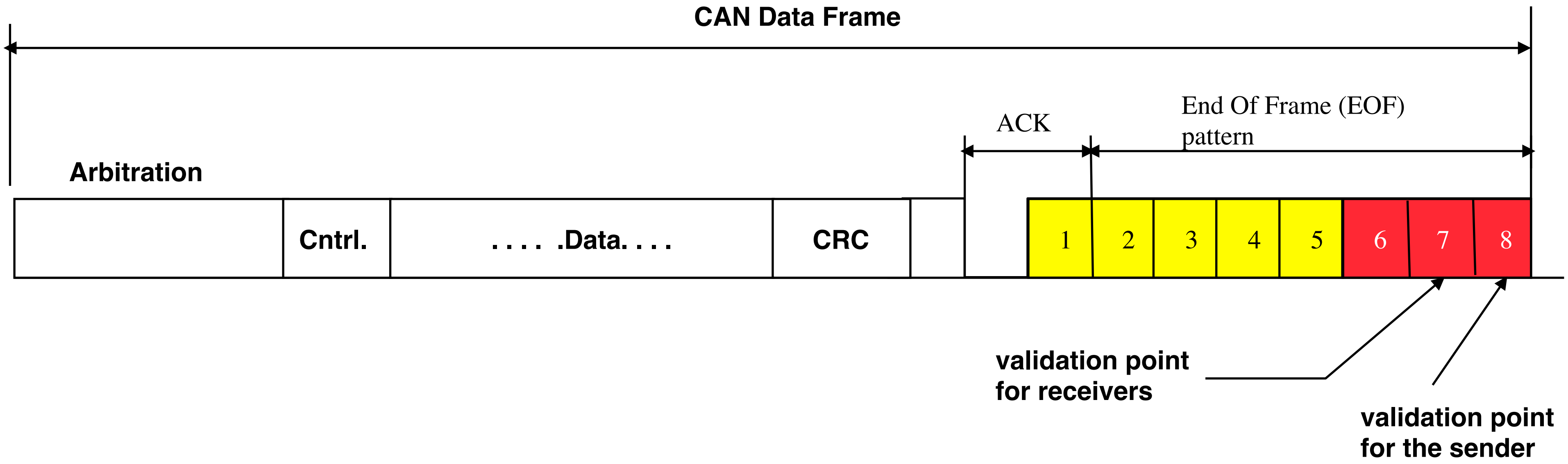
Error Detection and Error Signalling in CAN
The Case for Inconsistencies

Violation of the Bit-Stuffing Rule:
Used for Error Detection and Signalling



Bit-Stuffing enforces the following rule:

A sequence of 5 identical bit levels
is followed by a complementary bit level



Konsequenzen aus dem Validierungsprotokoll

J. Rufino, P. Veríssimo, C. Almeida , L. Rodrigues: „Fault-Tolerant Broadcasts in CAN“, *Proc. FTCS-28, Munich, Germany, June 1998.*

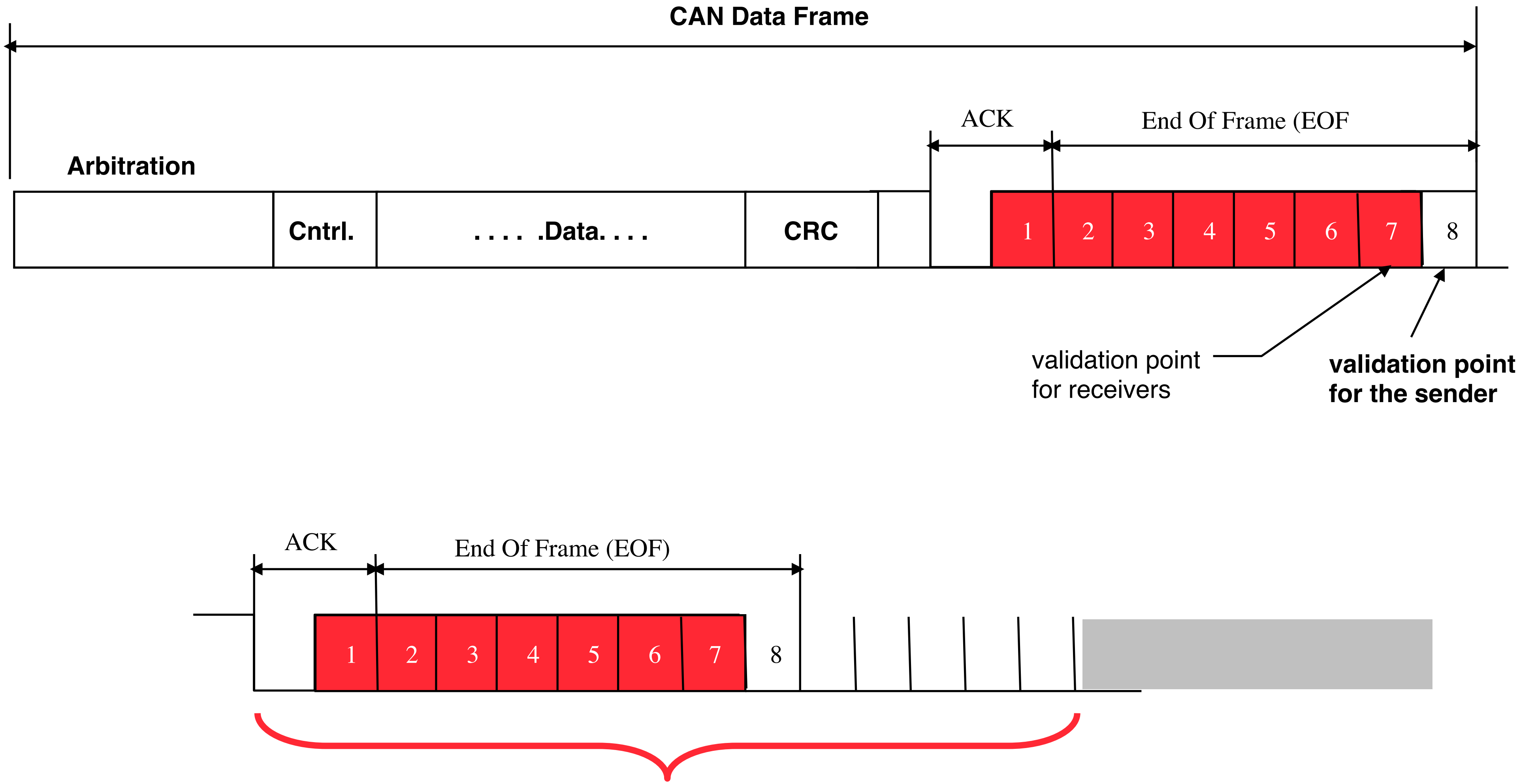
J. Kaiser, Mohammad Ali Livani: "Achieving Fault-Tolerant Ordered Broadcasts in CAN" *Proc. of the 3rd European Dependable Computing Conference, (EDCC-3), Prague, Sept. 1999*

➡ **Inkonsistente Nachrichten-Duplikate**

➡ **Inkonsistente Omission-Fehler**

➡ **(Potentiell) Unbeschränkte zeitliche Verzögerungen**

The Case for SHARE: Inconsistent Omissions



unique pattern : 1 dominant, 7 recessive, 6 dominant !

The Architecture of SHARE