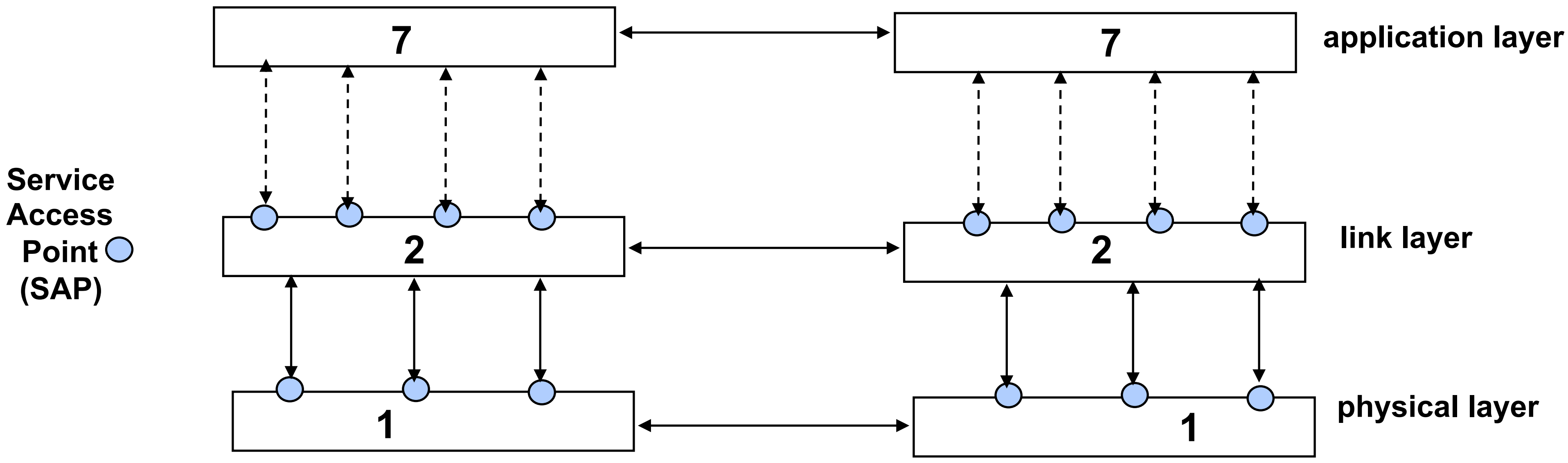
# Accessing the shared communication medium

**M**edia
**A**ccess
**C**onntrol

# 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.

# Media Access Control & Logical Link Layer

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

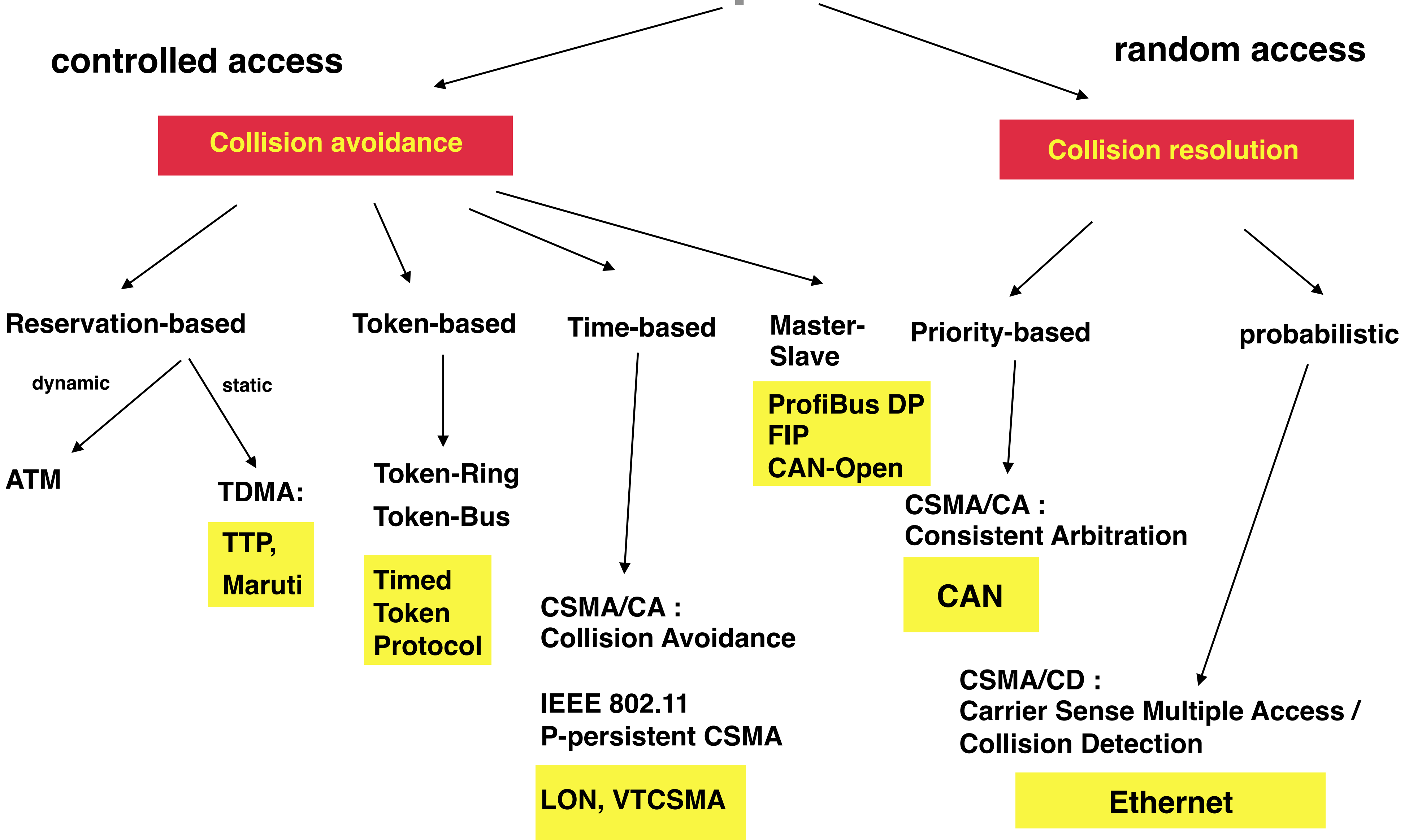
| | | |
|---|---|---|
| Logical Link | **LL -layer** | fault and error treatment, re-transmission<br>flow control |
| Media Access | **MAC -layer** | access control, arbitration control |

# What are the impairments of predicatbilty ?


Network contention
Arbitration conflicts

transmission errors,
lost messages

# 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

# CSMA access modes

**1-persistent**

**Sender checks medium continuously. If medium is free, sender starts sending. In case of collision, sender waits random period of time.**

**Non-persistent**

**Sender senses the medium. If medium is free, sender starts transmitting the data. If the channel is busy, sender waits for a certain (random or specified) amount of time and then repeats the procedure.**

**P-persistent**

**Sender checks the medium continuously . If the medium is free, the sender transmits a frame with a probability p.**

***Unslotted variant:*** **With probability 1-p the sender waits for a specified period of time. It again checks the availability of the channel and repeats the procedure.**

***Slotted variant:*** **With probability 1-p the sender waits until the next available time slot. It again checks the availability of the channel and repeats the procedure.**

# 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)**

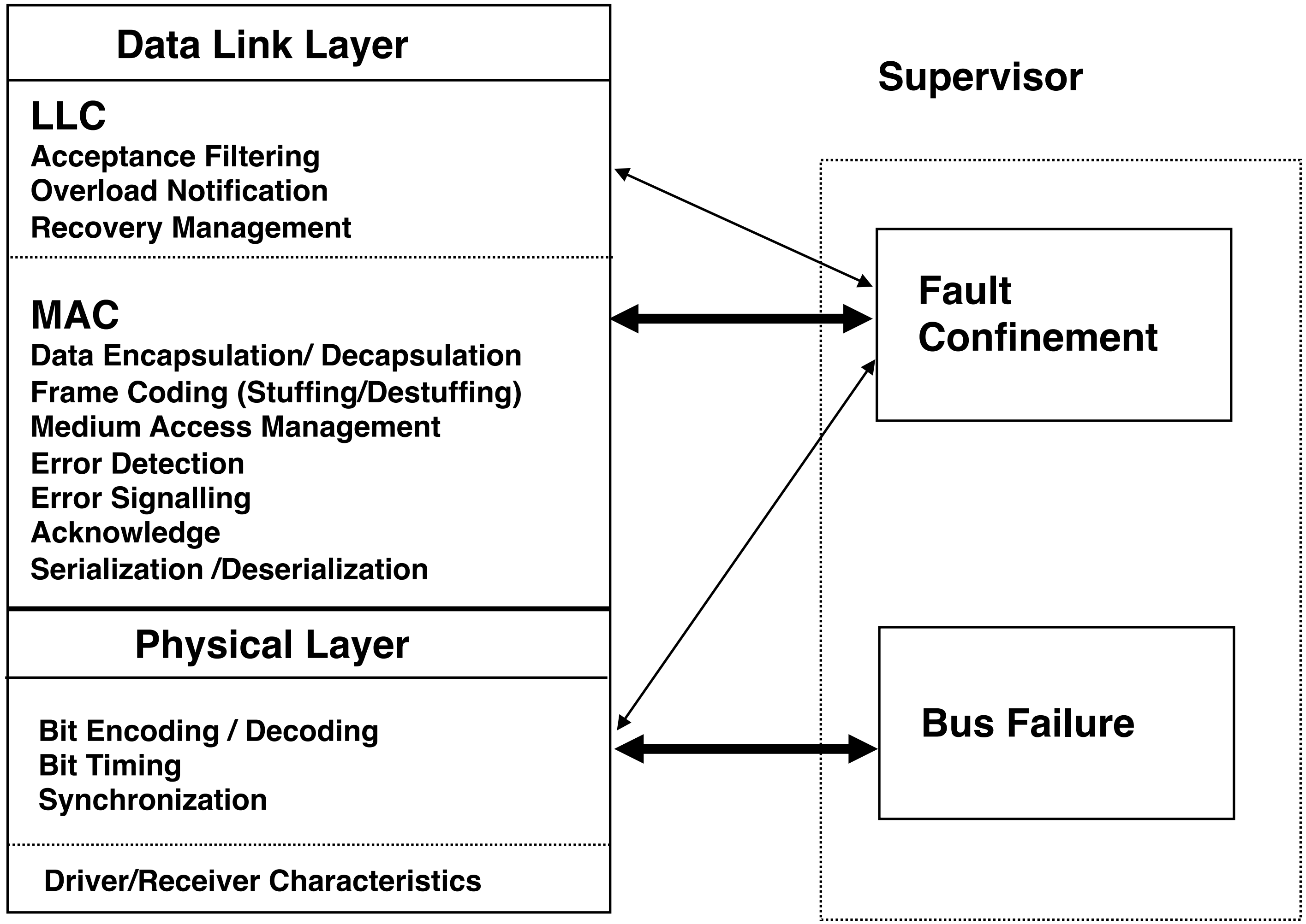
**CAN-Controller Implementations:**

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

# Basic CAN properties

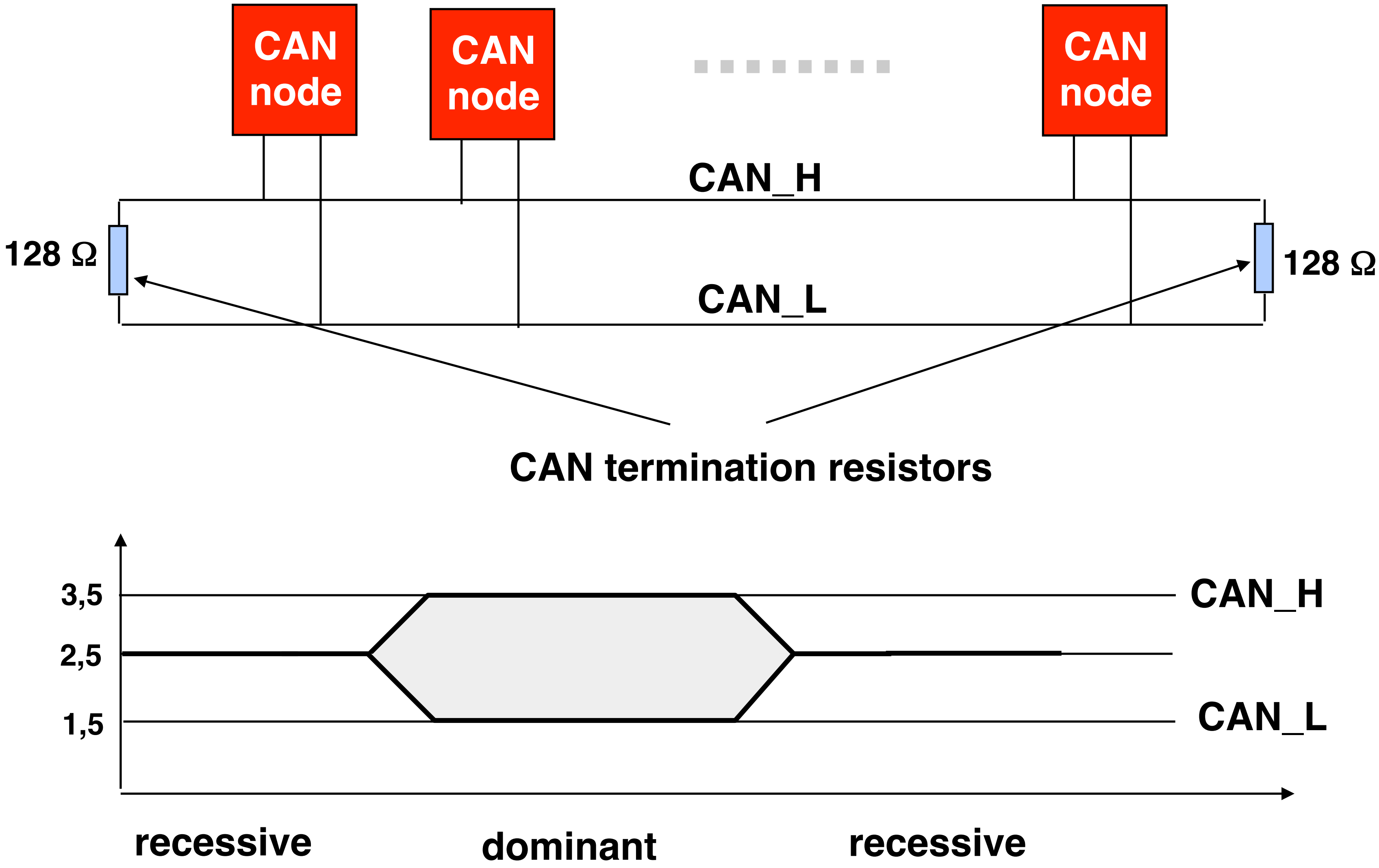
- Prioritised messages
- Bounded and guaranteed message delay for the highest priority message.
- Constant troughput in all load situations
- Error detection and signalling in the nodes.
- Automatic re-transmission.
- Fail silent behaviour of nodes.
- Consistent message delivery.
- Multicast with time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

# Layers defined by the CAN standard

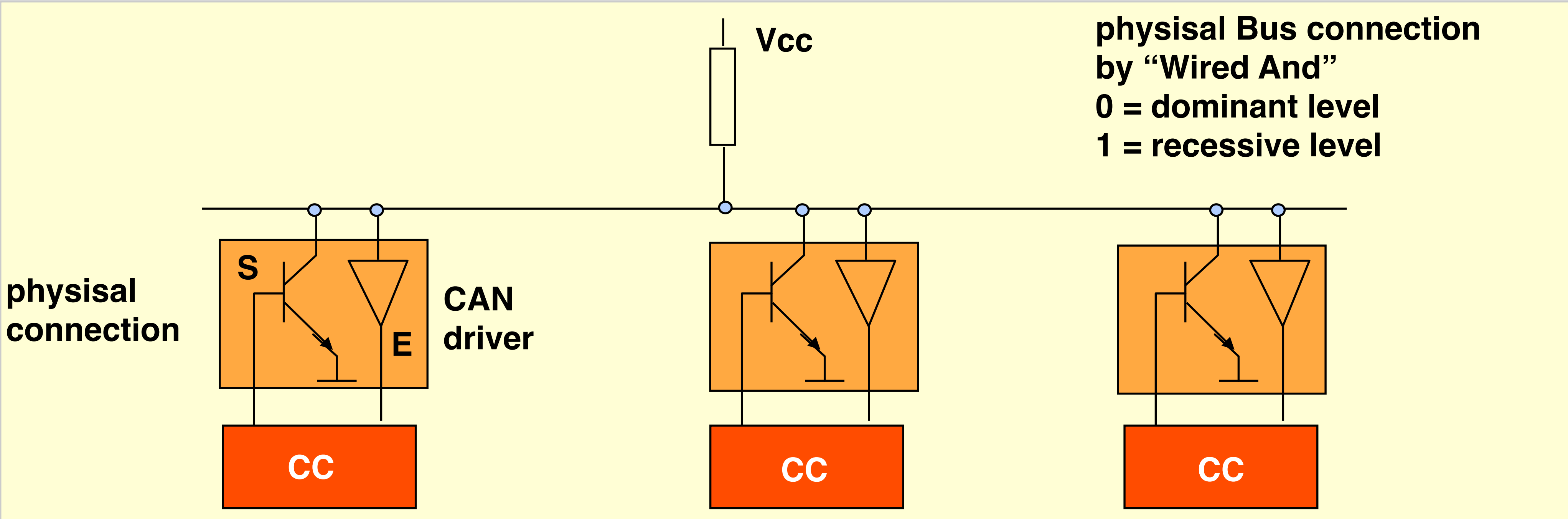


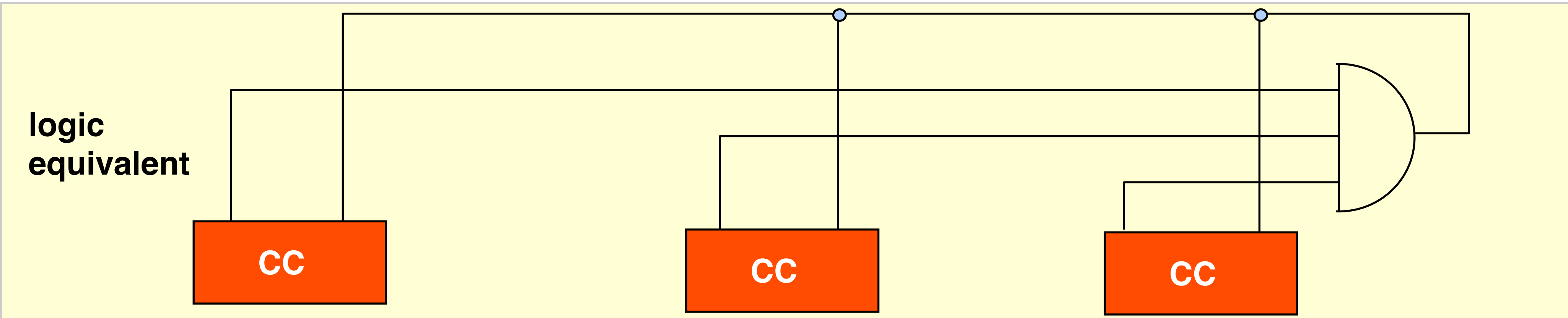

**LLC = Logical Link Control**
**MAC = Medium Access Control**

# CAN differential transmission scheme

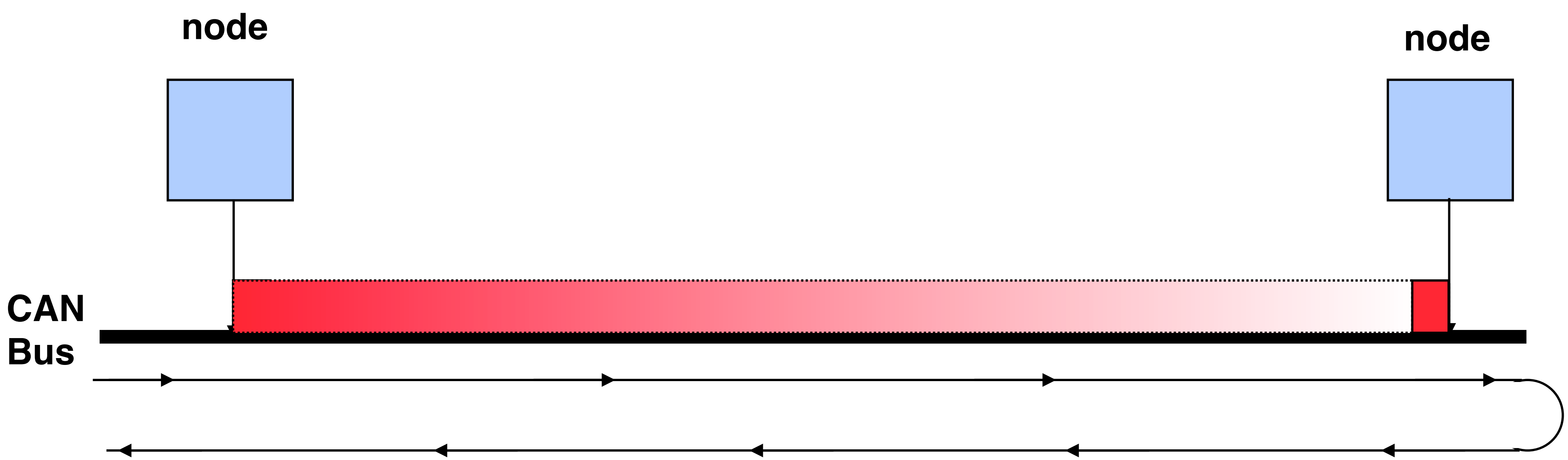


# The CAN physical layer



# CAN Bit Synchronisation

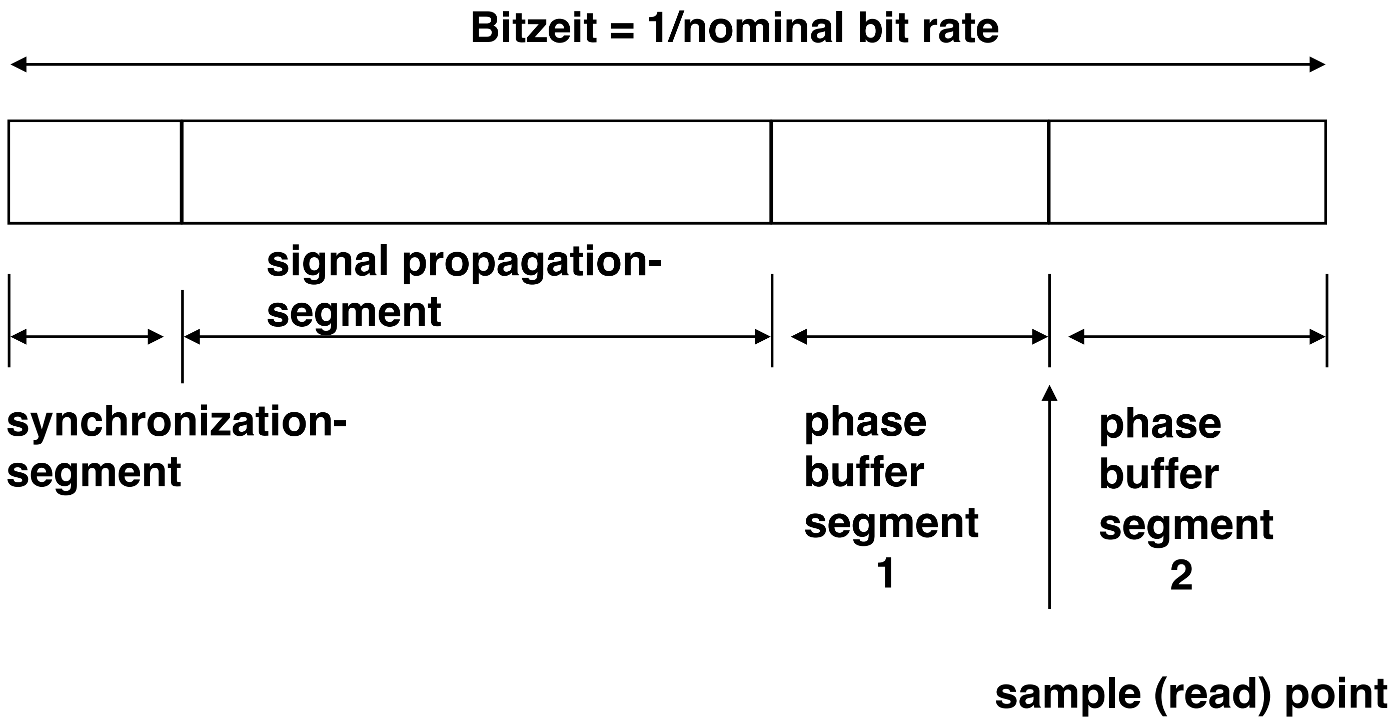



**After a certain time, all nodes have seen the value of a bit**

**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

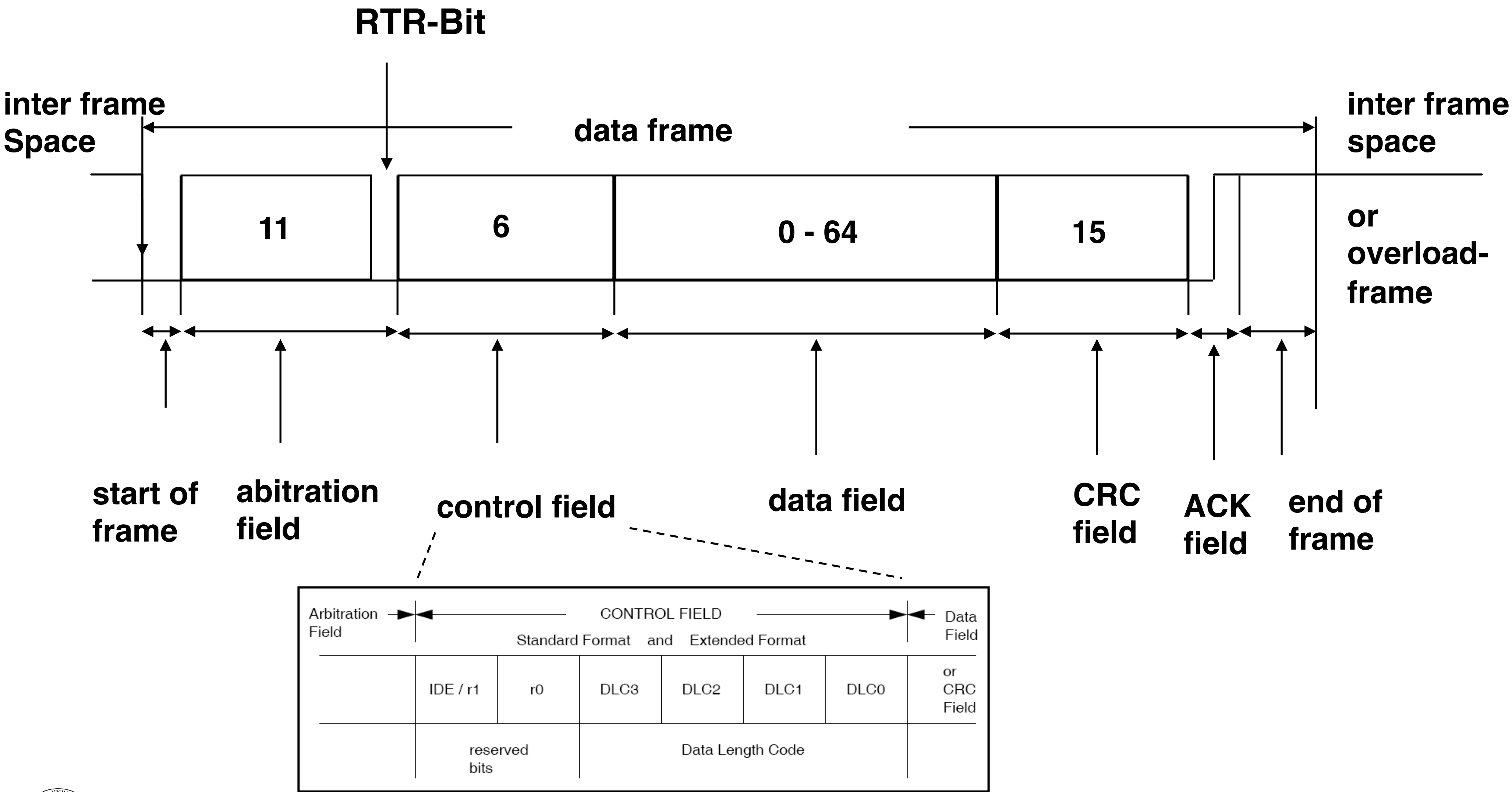
| payload # of bytes | Std. frame kbits/sec | extended frame kbits/sec |
|---|---|---|
| 0 | -- | -- |
| 1 | 71,1 | 61,1 |
| 2 | 144,1 | 122,1 |
| 3 | 216,2 | 183,2 |
| 4 | 288,3 | 244,3 |
| 5 | 360,4 | 305,3 |
| 6 | 432,4 | 366,4 |
| 7 | 504,5 | 427,5 |
| 8 | 576,6 | 488,5 |

# The CAN MAC and Logical Link Control (LLC) levels

**Frame types and formats:**

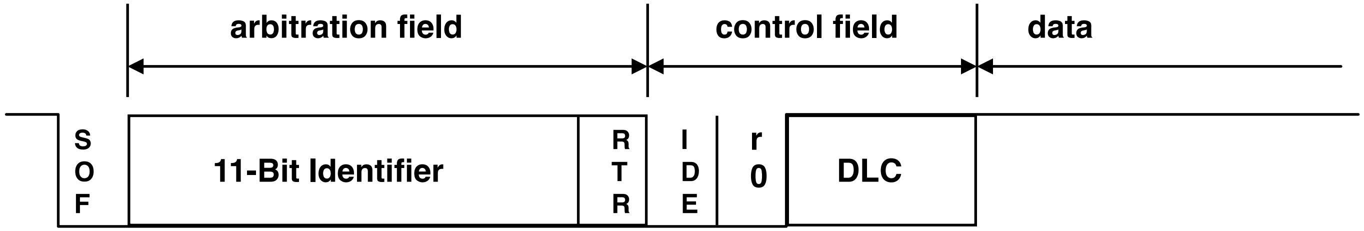
- **Data Frame** — **normal data transmision initiated by the sender**
- **Remote Frame** — **participant requests frame which is sent with the identical frame ID from some other participant.**
- **Error Frame** — **participant signals an error which it has detected**
- **Overload Frame** — **used for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

# CAN Standard Data Frame

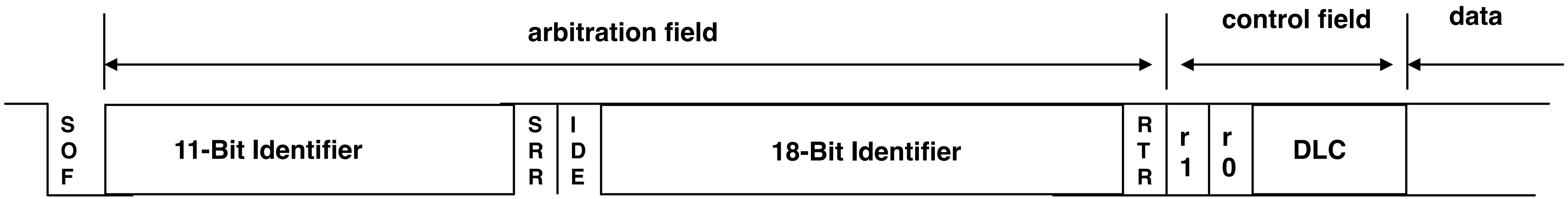


# Compatibility between standard and extended frames

## Standard Format SF (compatible to CAN Spezifikation 1.2)

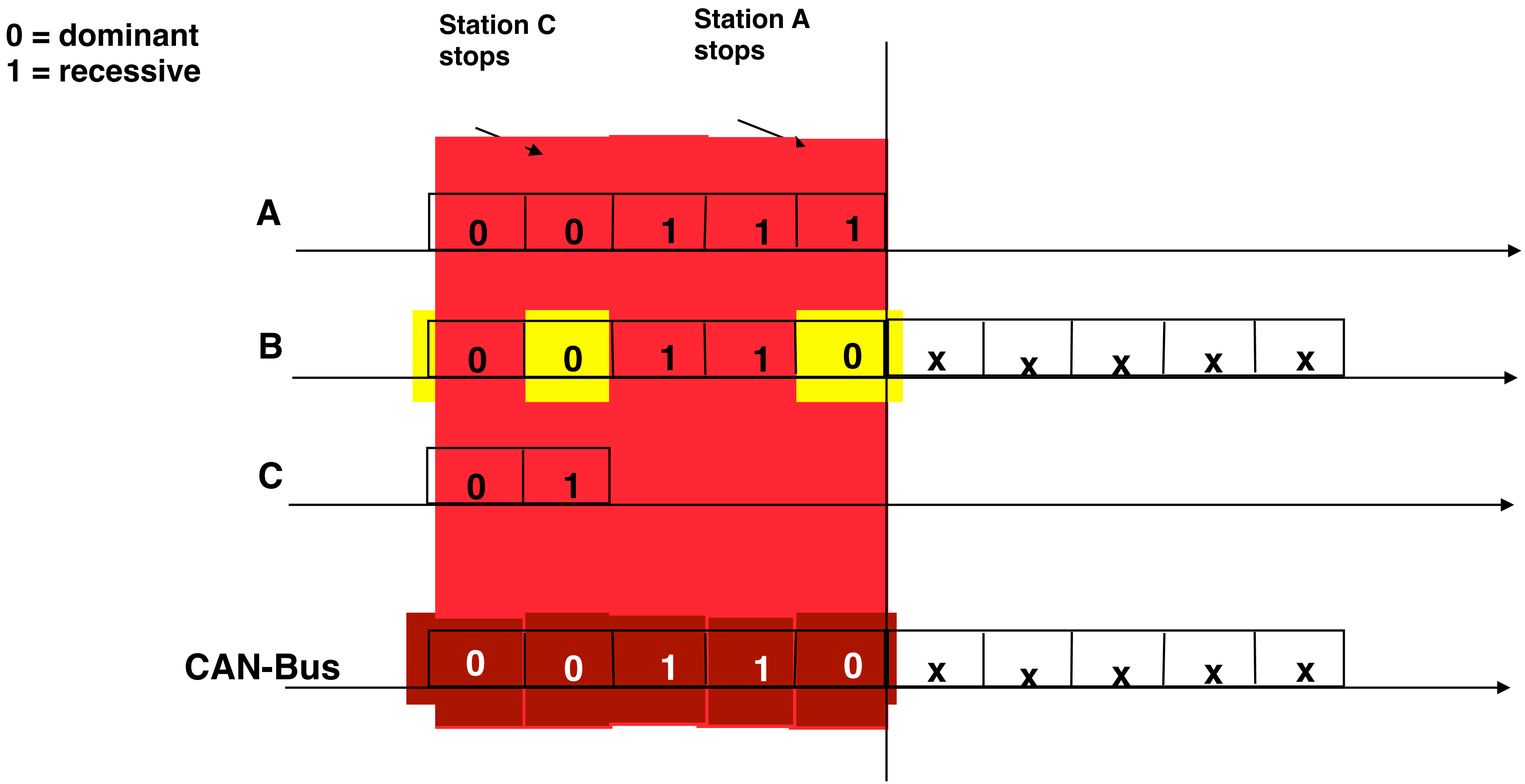



## Extended Format EF (CAN Spezifikation 2.0)



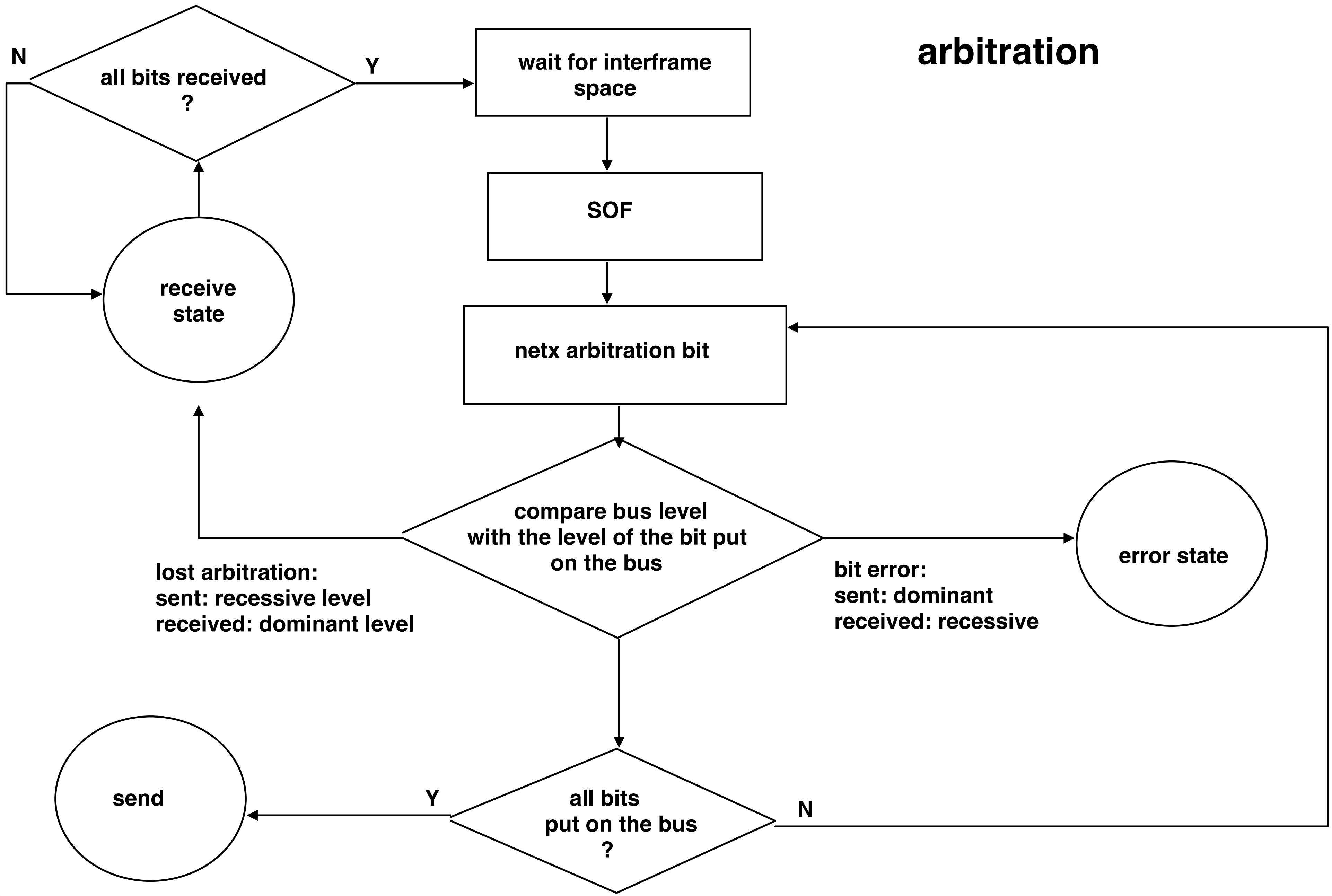

| | |
|---|---|
| **RTR:** | **Remote Transmission Request. In Data Frame: RTR = dominant. In Remote Frame: RTR = recessive.** |
| **IDE:** | **Identifier Extension. In the SF this is part of the control field, has a dominant value but is not interpreted. In the EF it is part of the addressing field,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

# Arbitration on a CAN-Bus

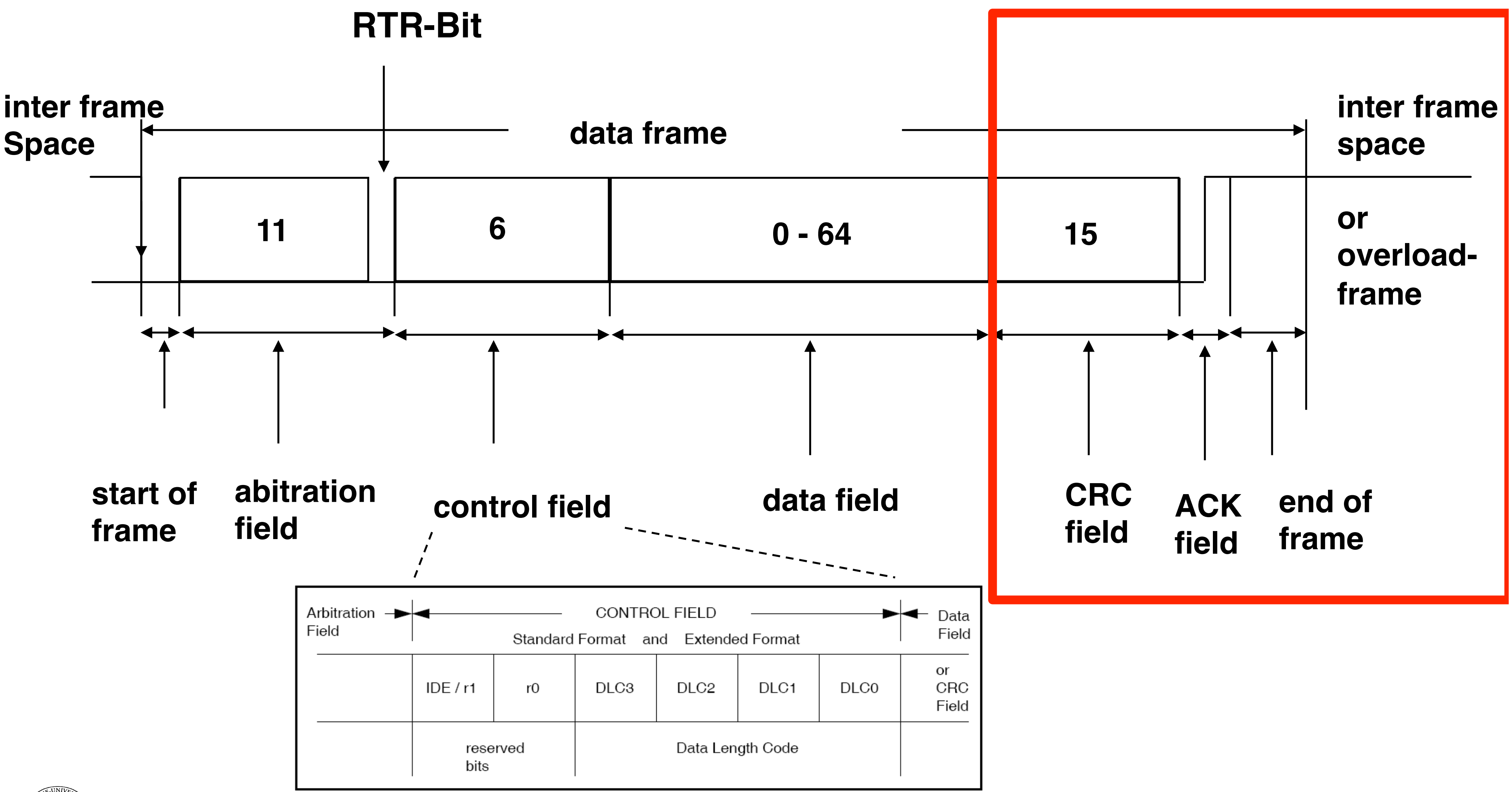



**CAN enforces a global priority-based message scheduling**

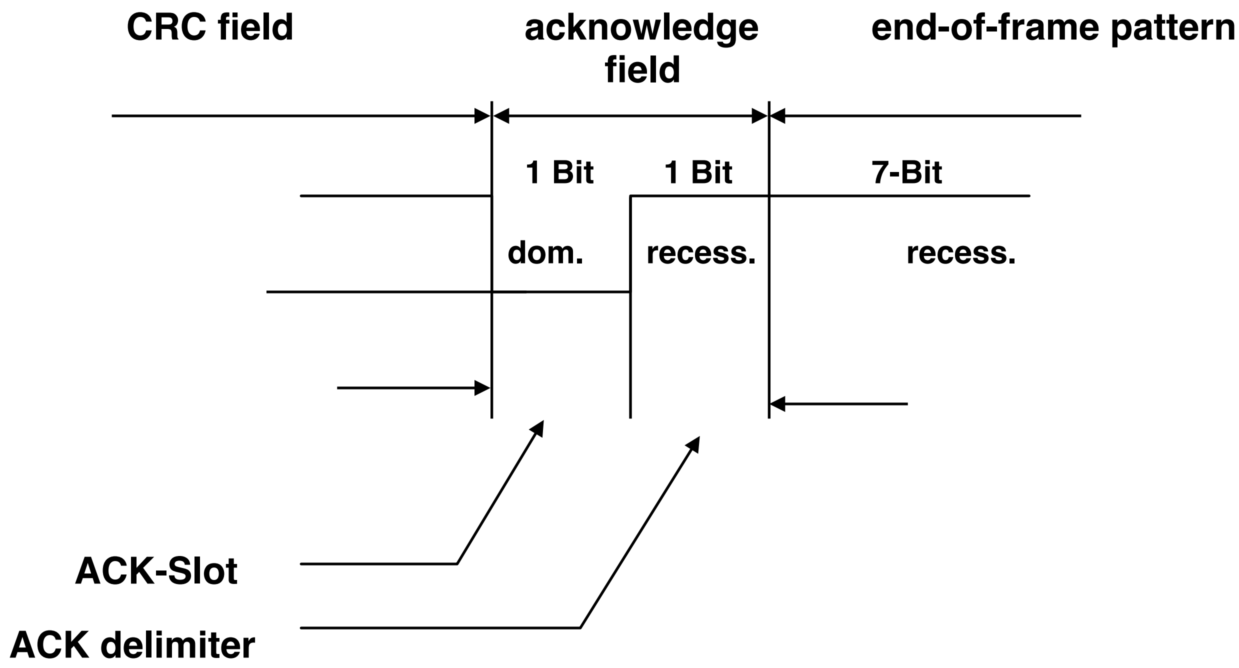
# arbitration



# CAN Standard Data Frame



# Anonymous acknowledgement of a CAN message

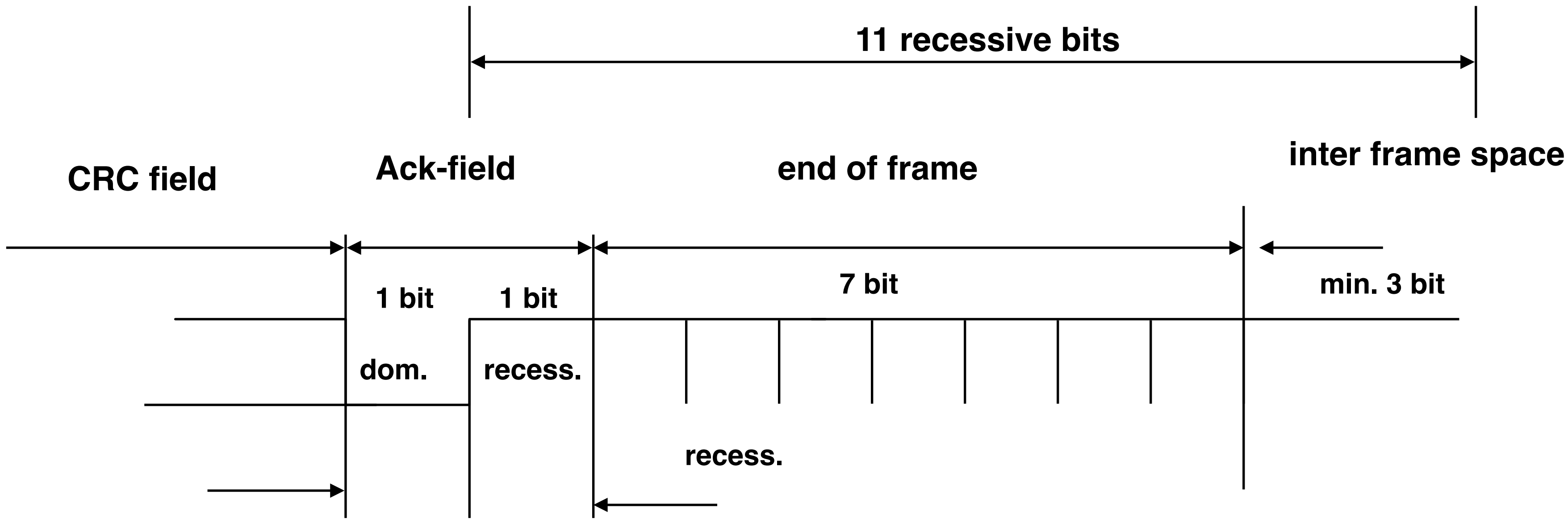



**positive anonymous acknowledgement (Broadcast !)**

**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.**

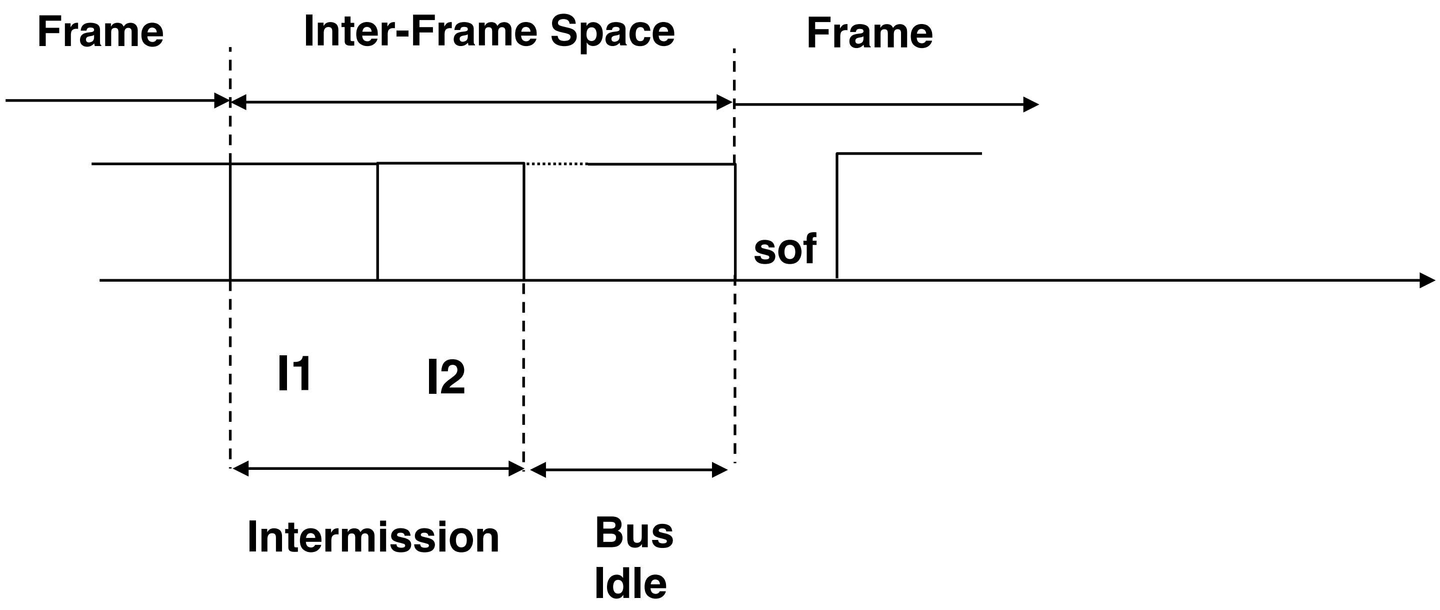
# Termination sequence of a frame




**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

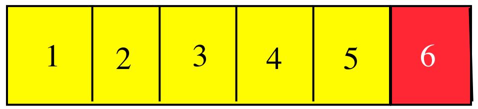



**Intermission: no data- or remote Frame may be started**

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

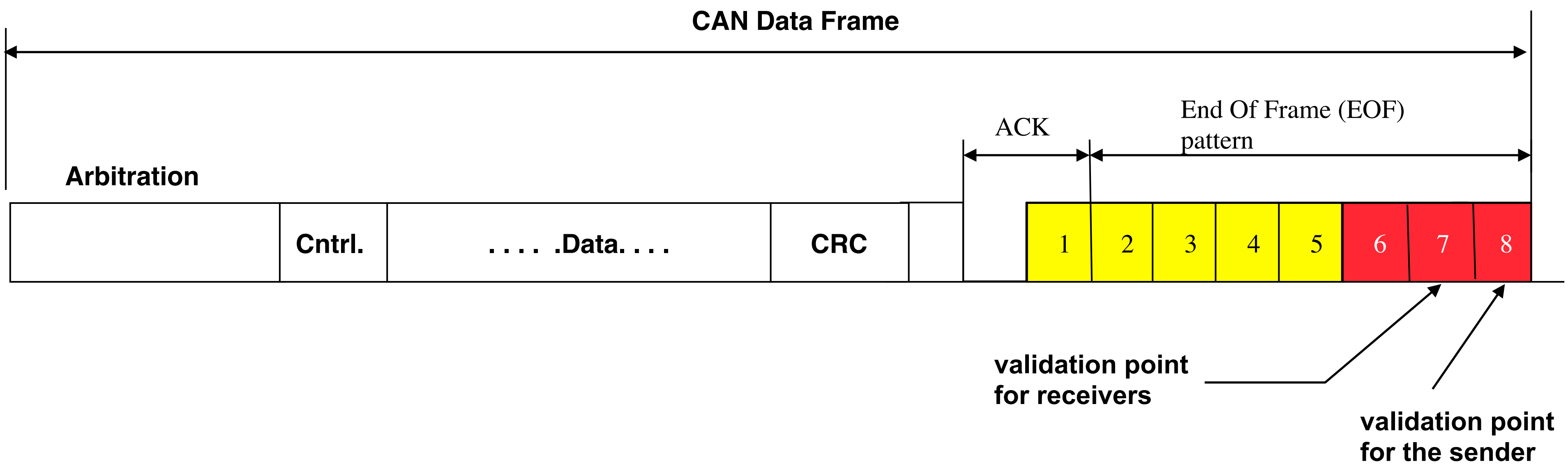
# Error Detection and Error Signalling in CAN

**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

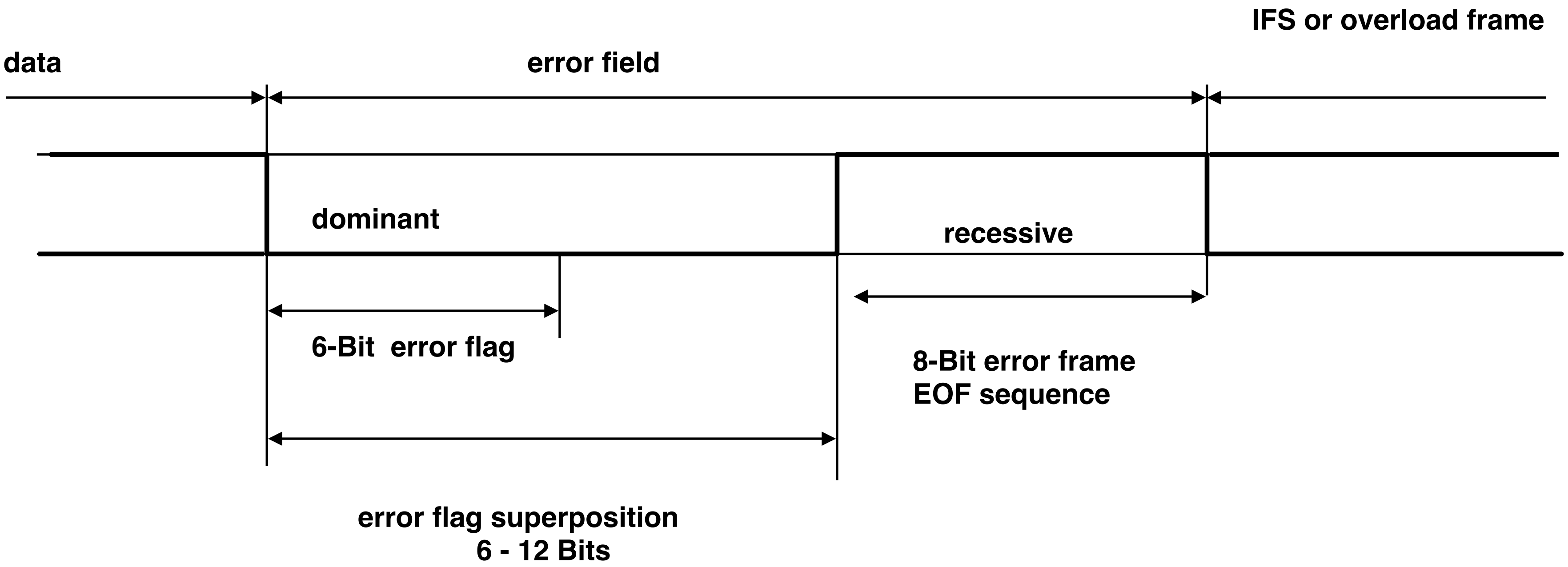
**CRC**: difference between frame sent and received is a multiple of the generator polynome.

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

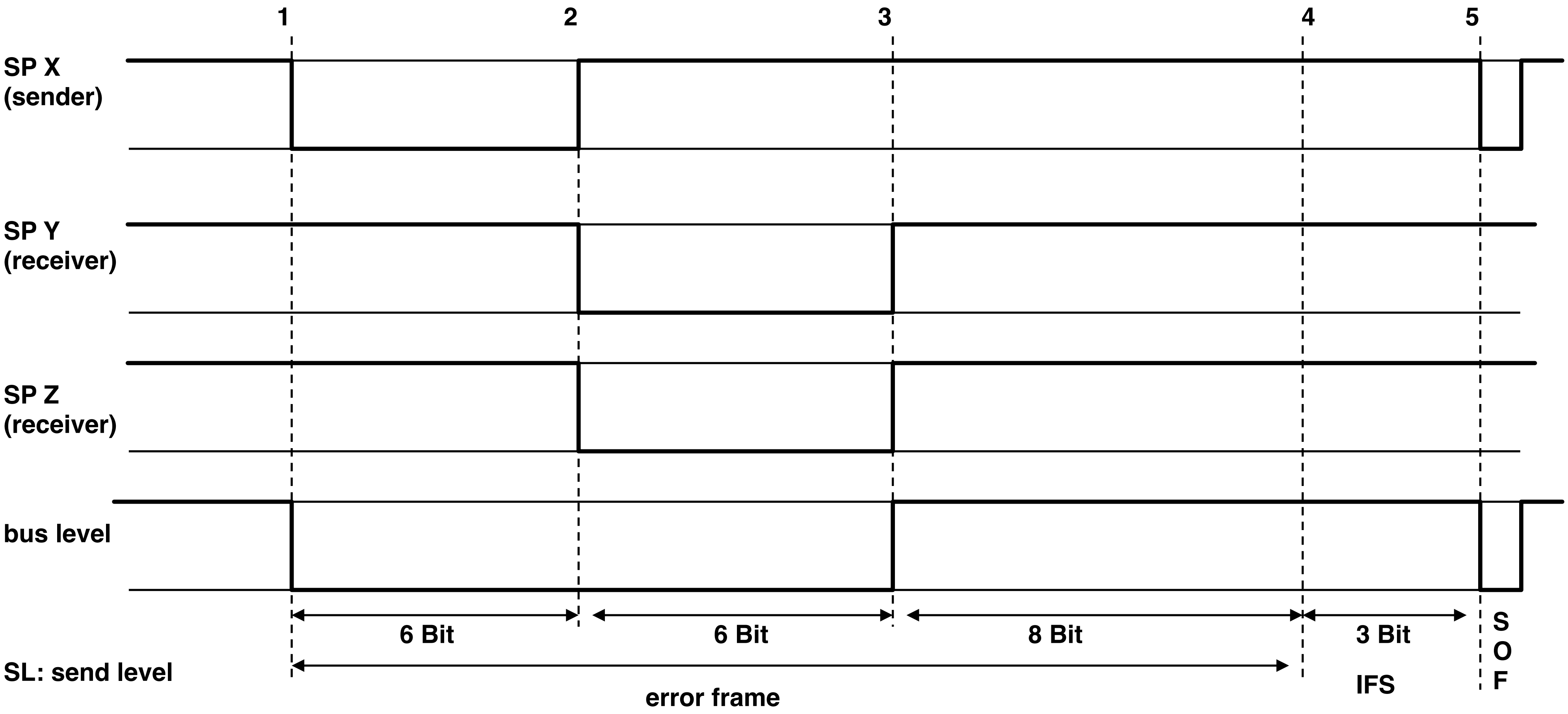
Unruh, Mathony und Kaiser:"Error Detection Analysis of Automotive Communication Protocols", SAE International Congress, Nr. 900699, Detroit, USA, 1990

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

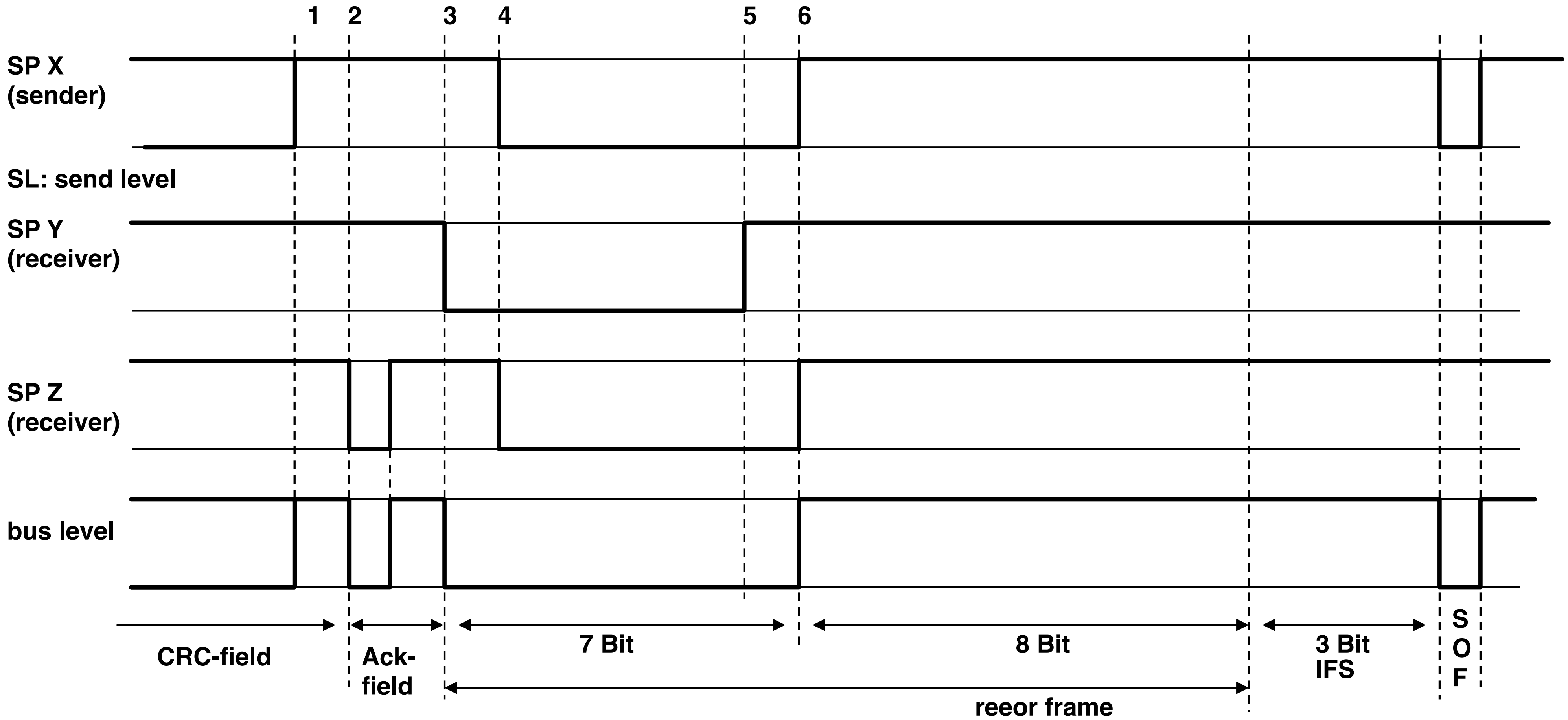


# Error frame resulting from a sender fault




**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.

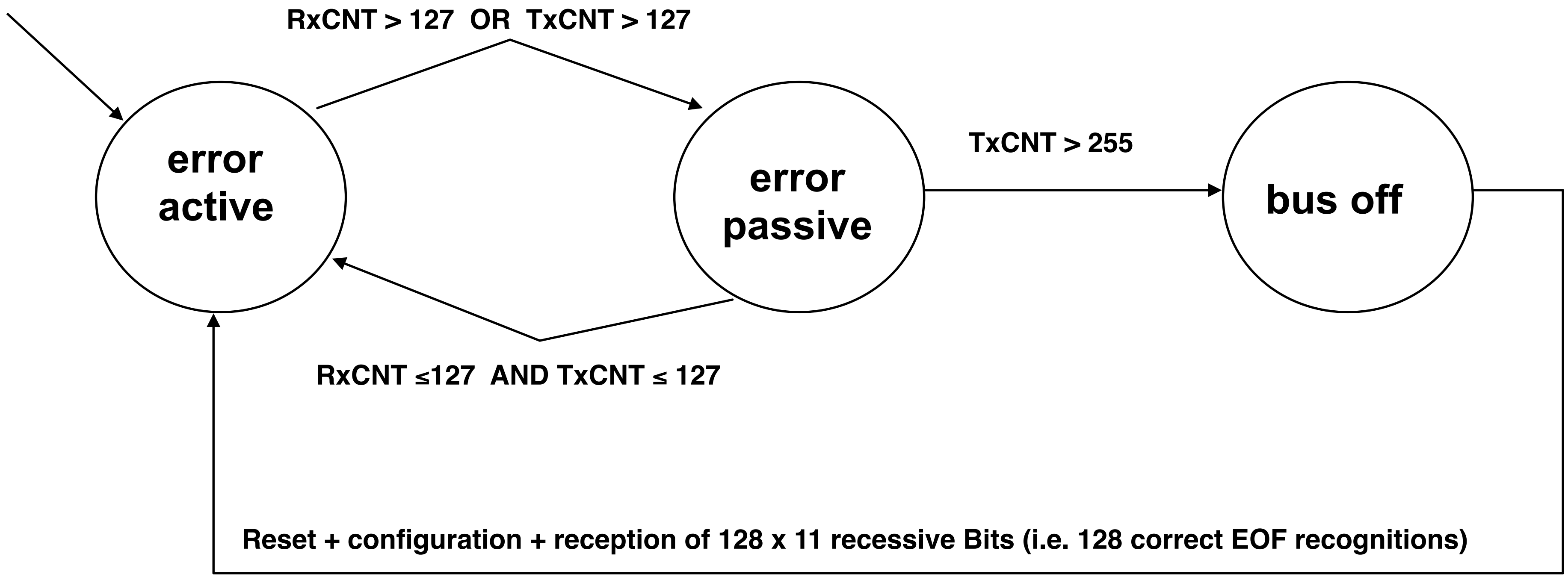
**Assumption:**
1. A faulty node detects the error first.
2. frequently being the first which detects an error --> local fault in the node

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

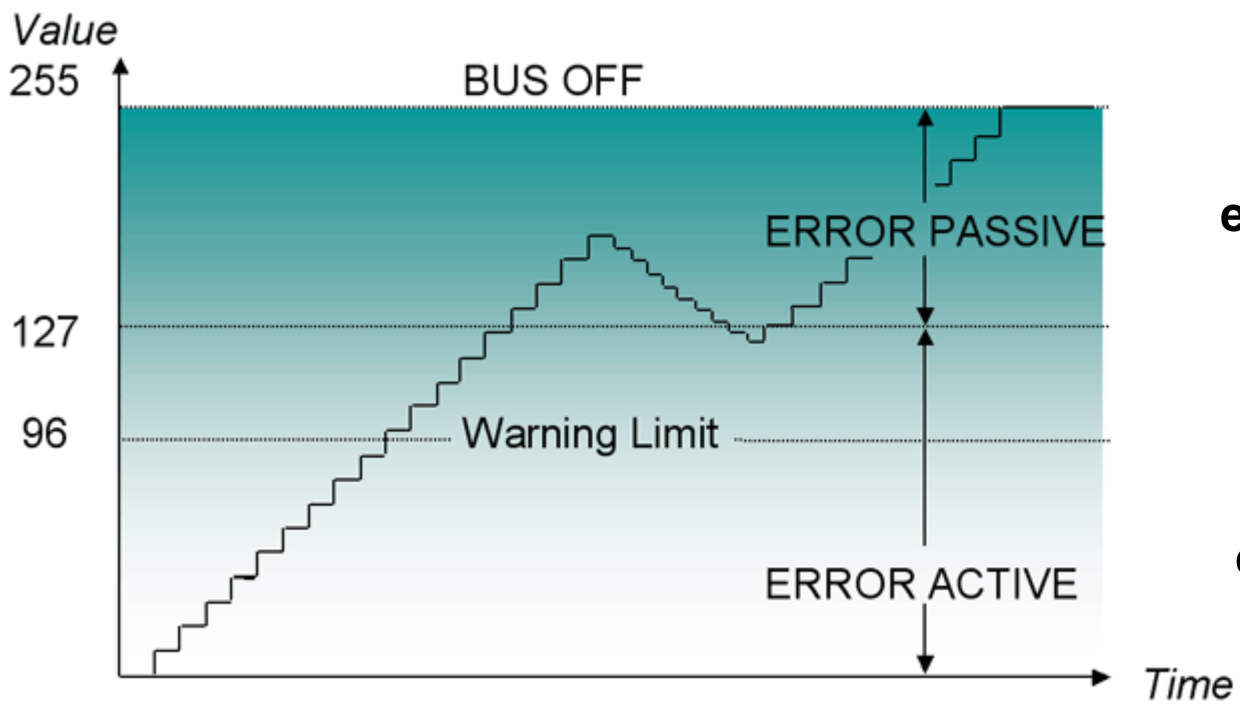
# Enforcing fault confinement and a "Fail Silent" behaviour

**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

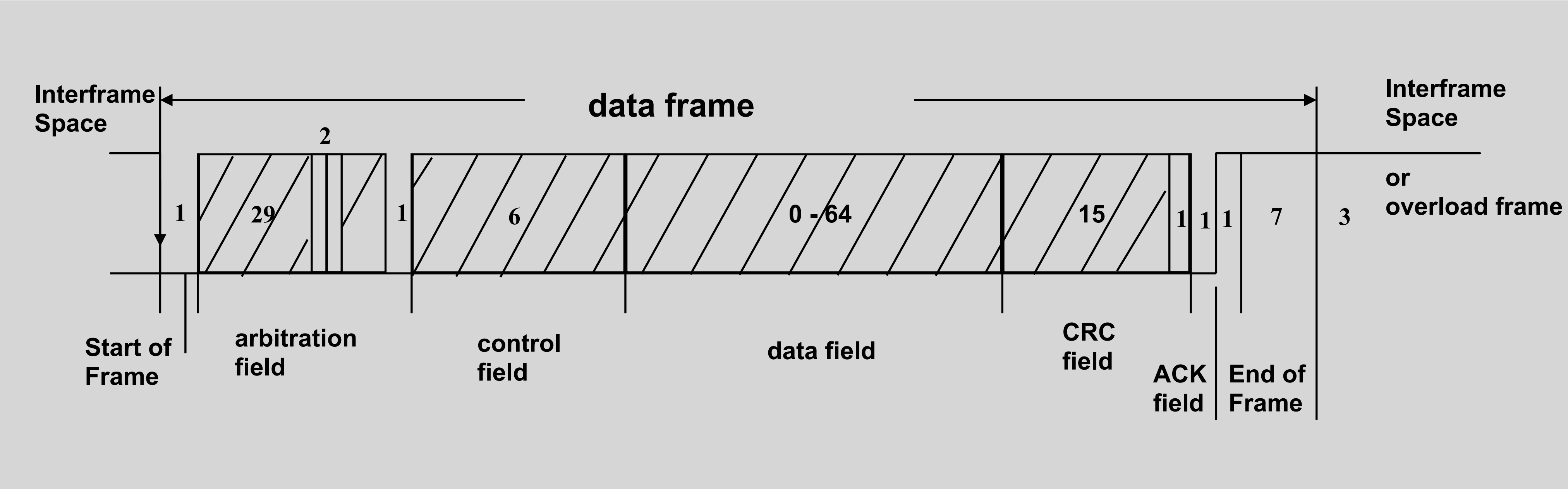



**error passive state**

**error active state**

# 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 | |

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

# 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 (system wide messaging)**
  - **identification of faulty nodes**
  - **immediate synchronization and retransmission**
- **content-based addressing with a high flexibilitx (system elasticity)**

# High level issues

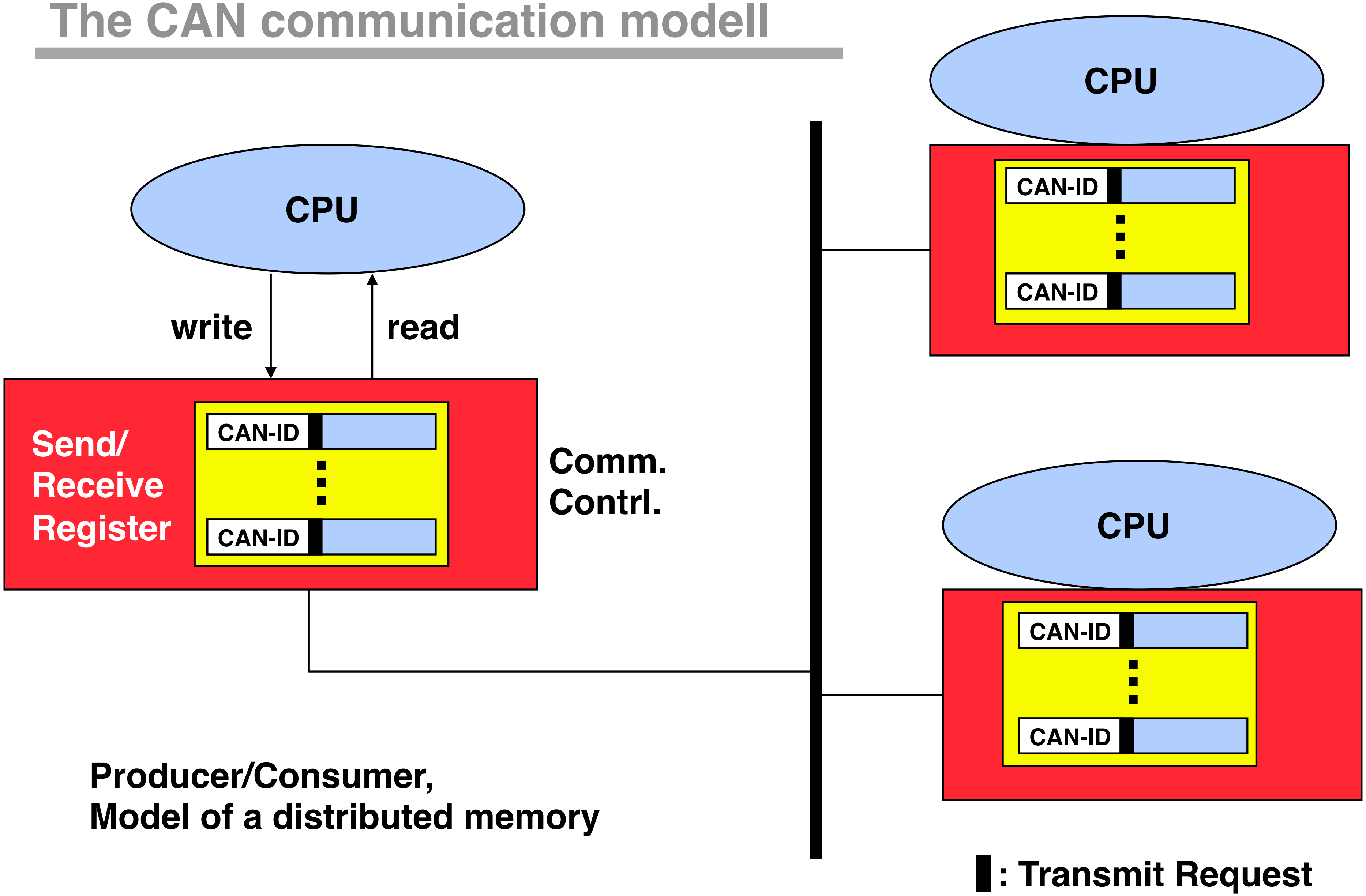
**Routing:** How does a message reach a receiver ?

**CAN: Broadcast, message subjects**

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

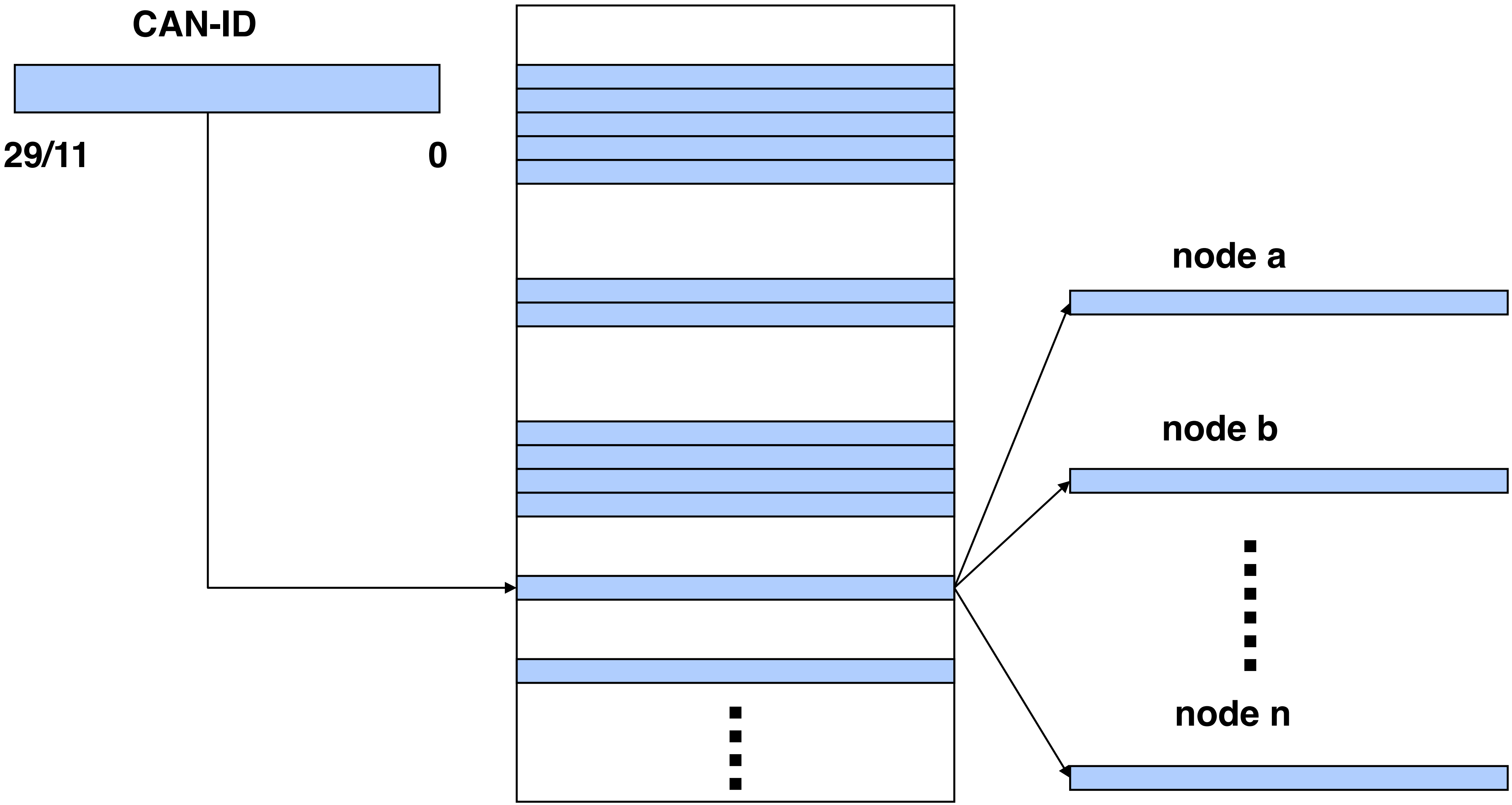
**CAN: message filters**

# The CAN communication modell

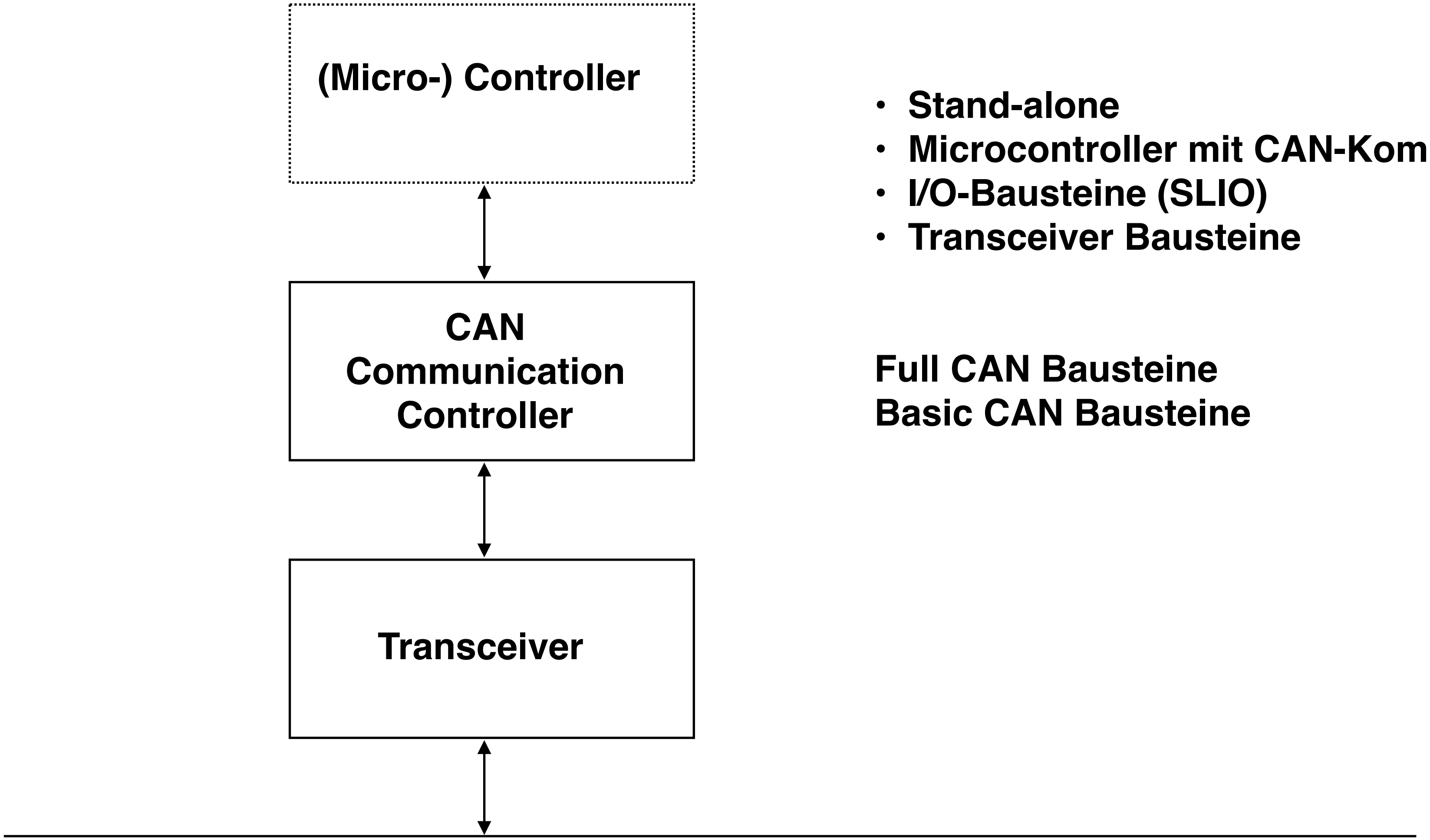



**Producer/Consumer,**
**Model of a distributed memory**

# The CAN communication modell



# CAN Bausteine



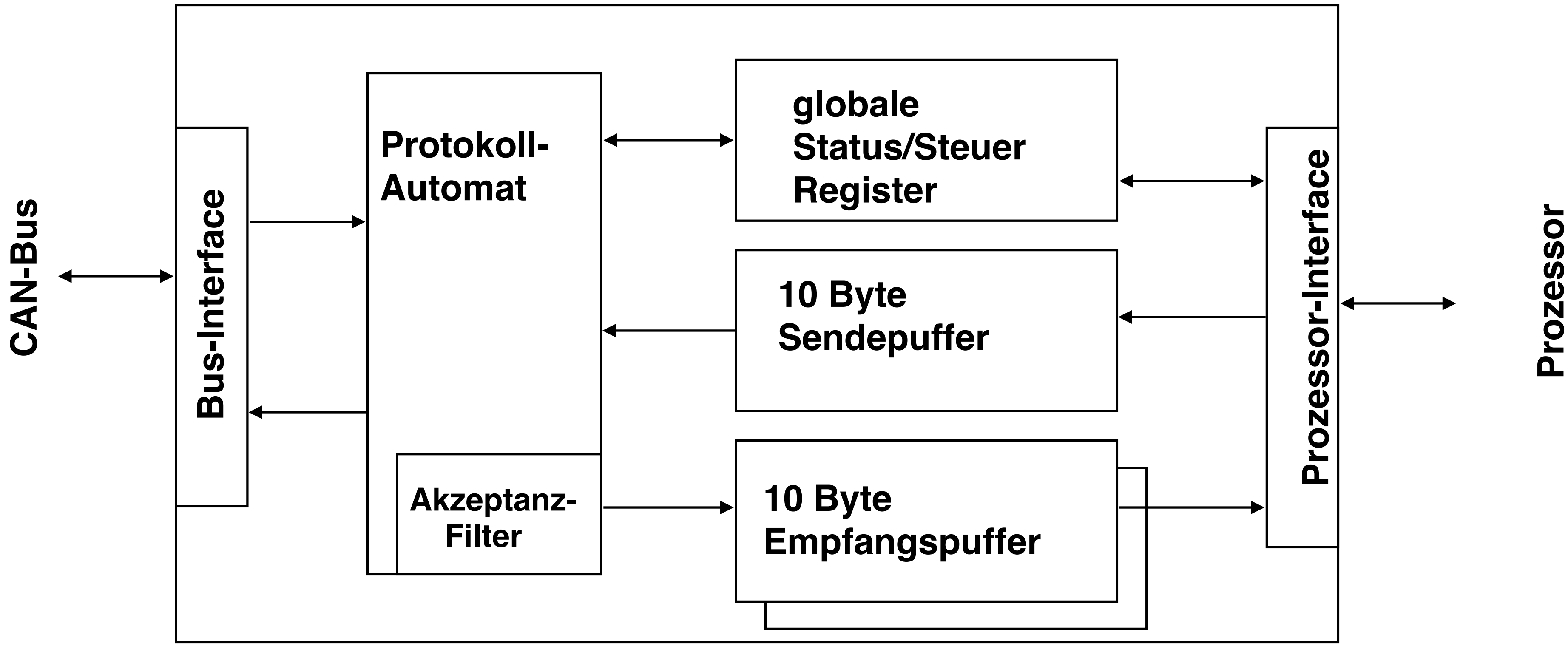

- Stand-alone
- Microcontroller mit CAN-Komponente
- I/O-Bausteine (SLIO)
- Transceiver Bausteine

**Full CAN Bausteine**
**Basic CAN Bausteine**

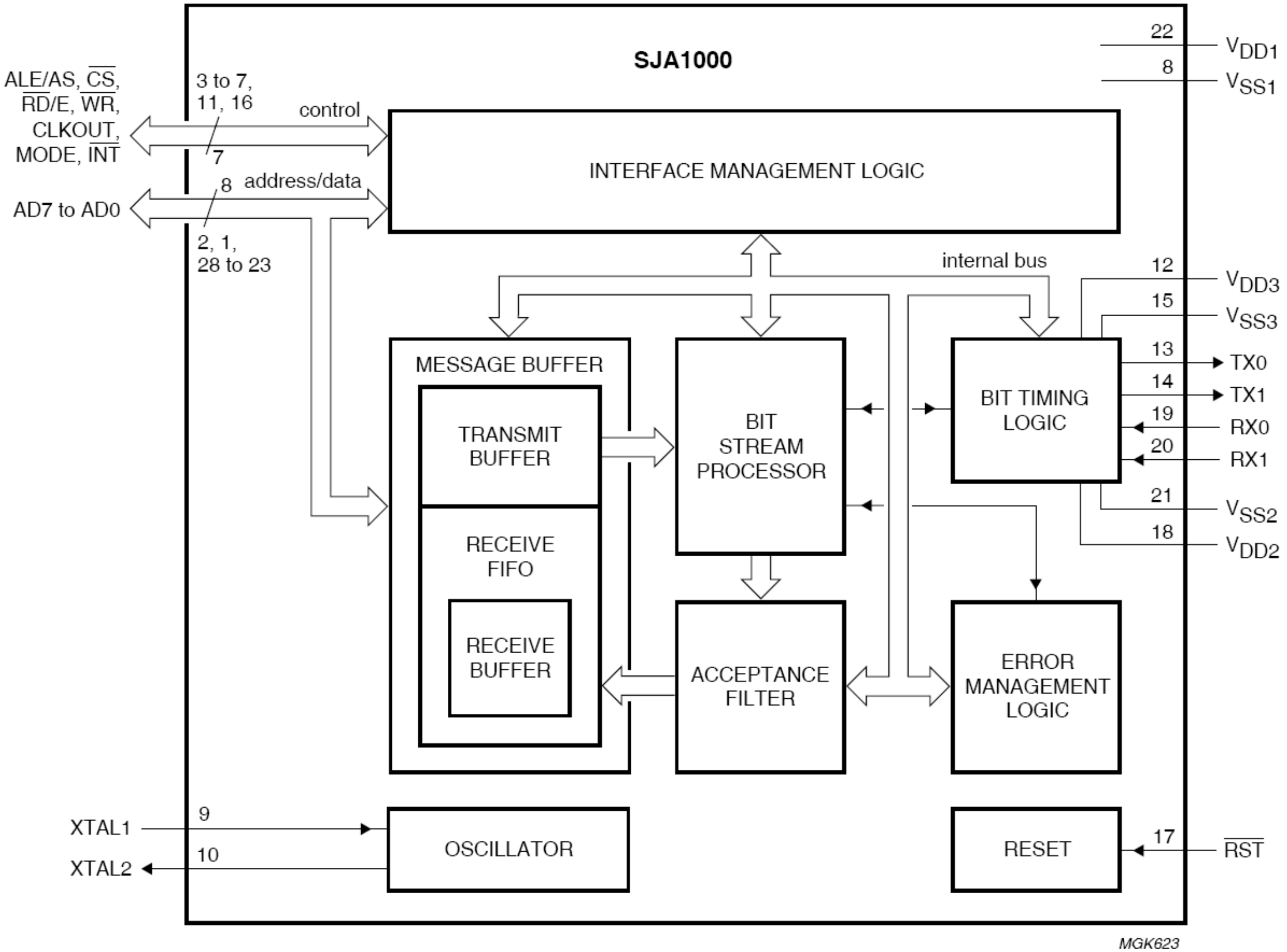
## Aufgaben des CAN Controllers

- Busarbitrierung
- Serialisierung der zu sendenden Telegramme
- Assemblierung der empfangenen Telegramme
- Berechnung bzw. Überprüfung der Checksumme
- Filterung von Nachrichten
- 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)

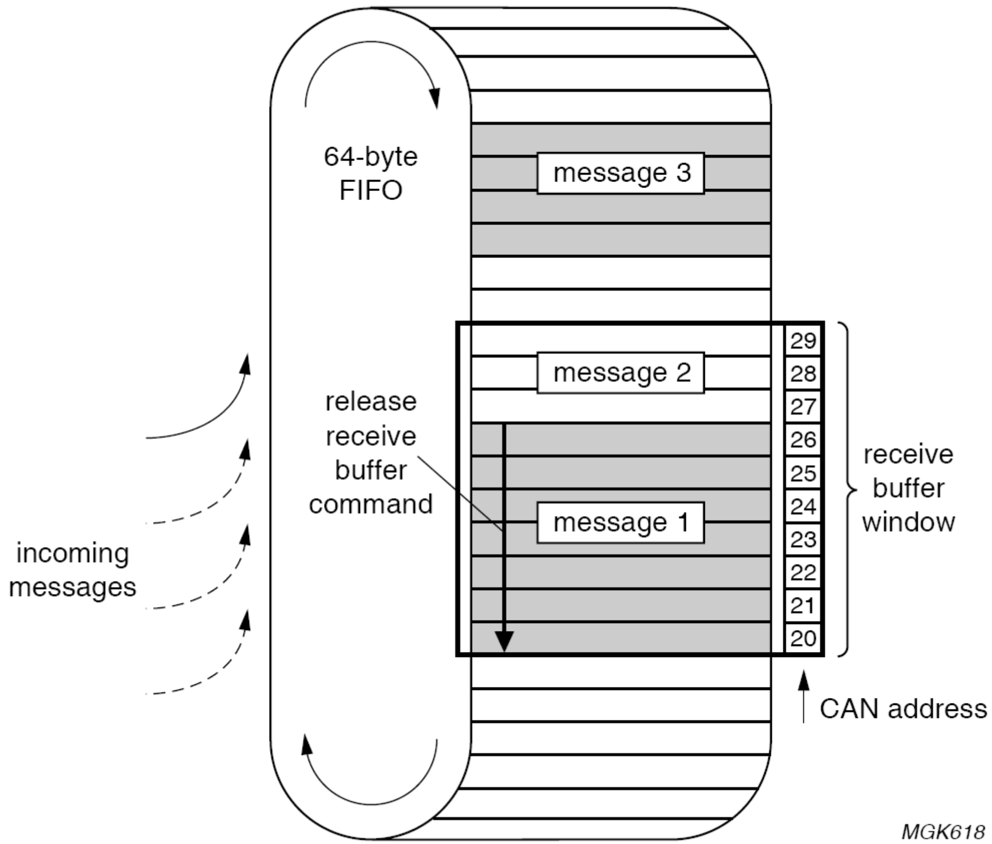


# SJA1000 Transmit Buffer Layout

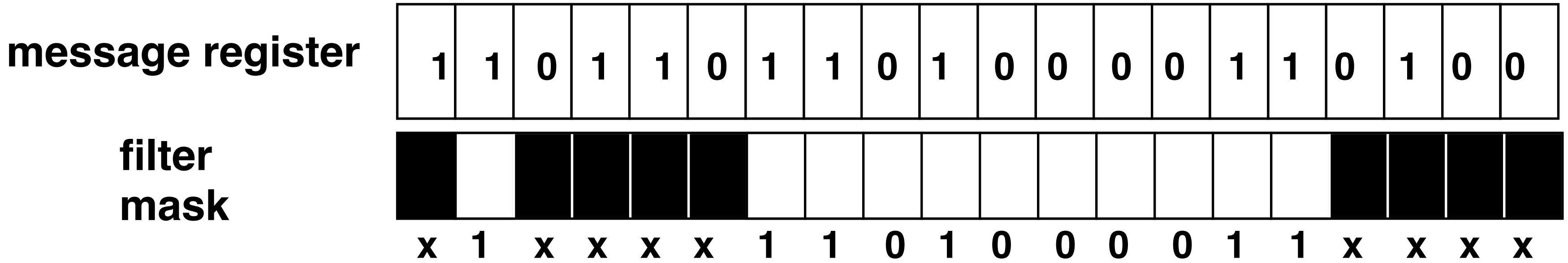
| CAN ADDRESS | FIELD | NAME | BITS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 10 | descriptor | identifier byte 1 | ID.10 | ID.9 | ID.8 | ID.7 | ID.6 | ID.5 | ID.4 | ID.3 |
| 11 | | identifier byte 2 | ID.2 | ID.1 | ID.0 | RTR | DLC.3 | DLC.2 | DLC.1 | DLC.0 |
| 12 | data | TX data 1 | transmit data byte 1 | | | | | | | |
| 13 | | TX data 2 | transmit data byte 2 | | | | | | | |
| 14 | | TX data 3 | transmit data byte 3 | | | | | | | |
| 15 | | TX data 4 | transmit data byte 4 | | | | | | | |
| 16 | | TX data 5 | transmit data byte 5 | | | | | | | |
| 17 | | TX data 6 | transmit data byte 6 | | | | | | | |
| 18 | | TX data 7 | transmit data byte 7 | | | | | | | |
| 19 | | TX data 8 | transmit data byte 8 | | | | | | | |

For extended CAN the Address range is extended accordingly to 4 Bytes of ID Descriptor.

# SJA1000 (Philips)



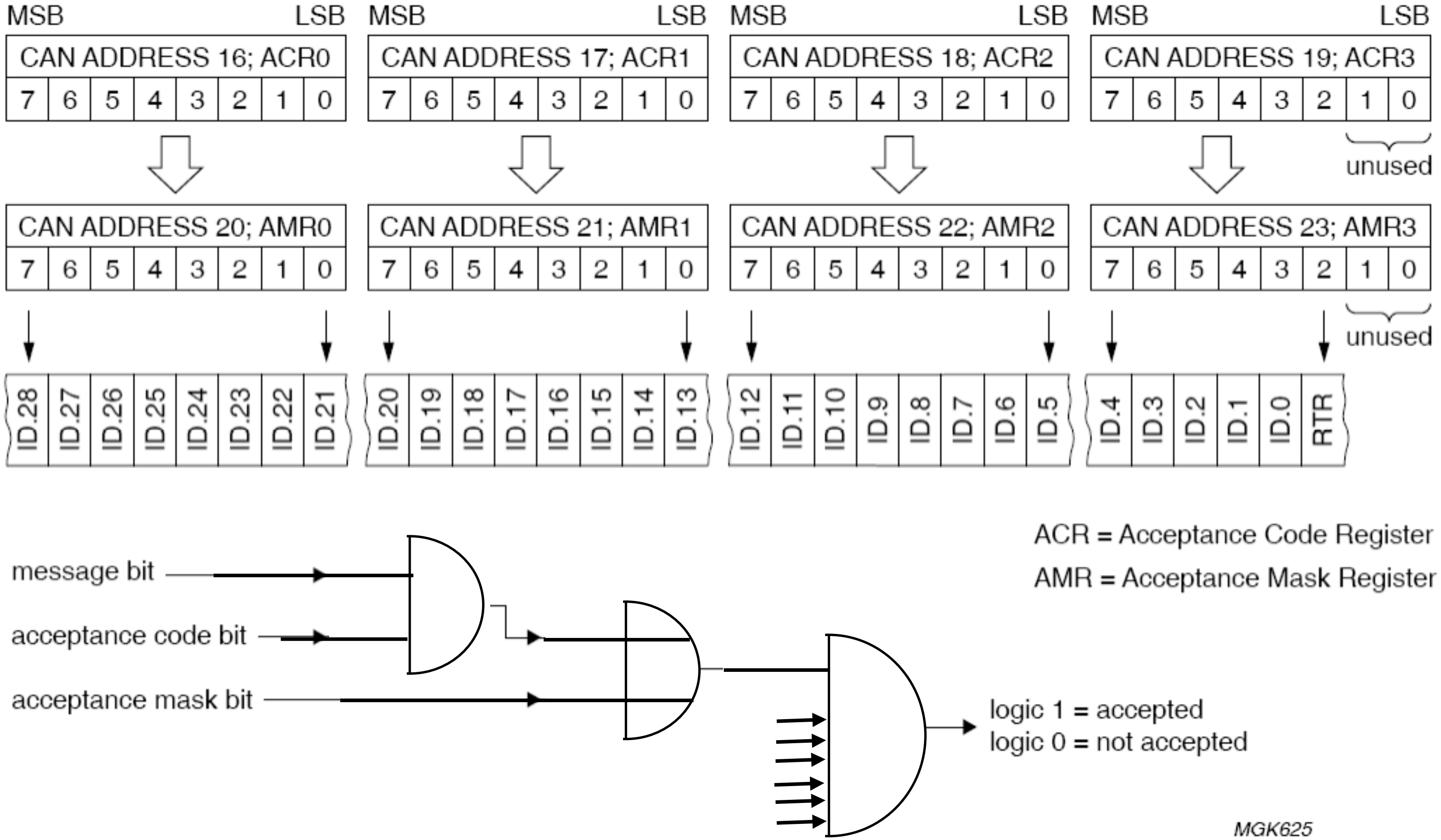
# message filtering




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

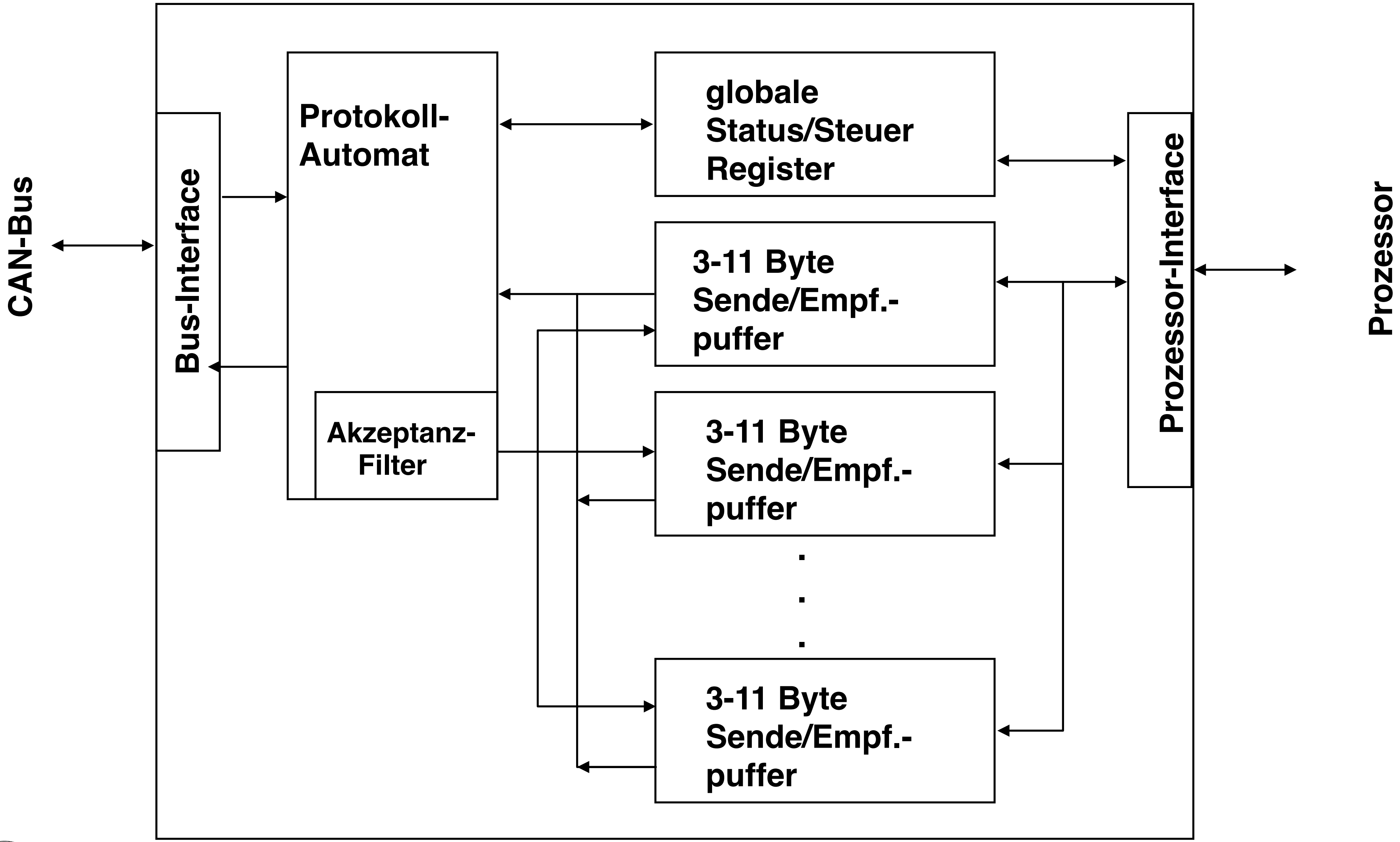
# SJA1000 (Philips)

**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

- Consistent order of messages

- Temporal guarantees for message transmissions

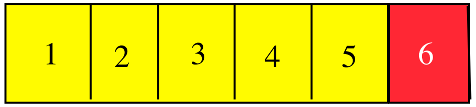
➡ TTCAN
FTTCAN

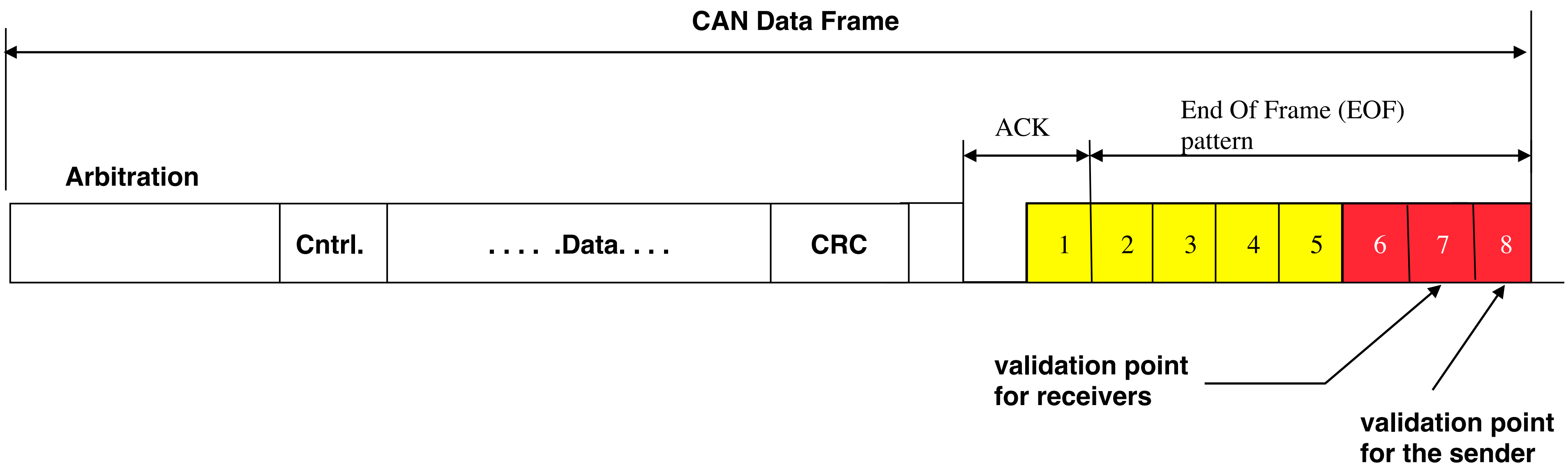
# Error Detection and Error Signalling in CAN
# The Case for Inconsistencies

**Bit-Stuffing enforces the following rule:**

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

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



# Consequences from the validition protocol

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

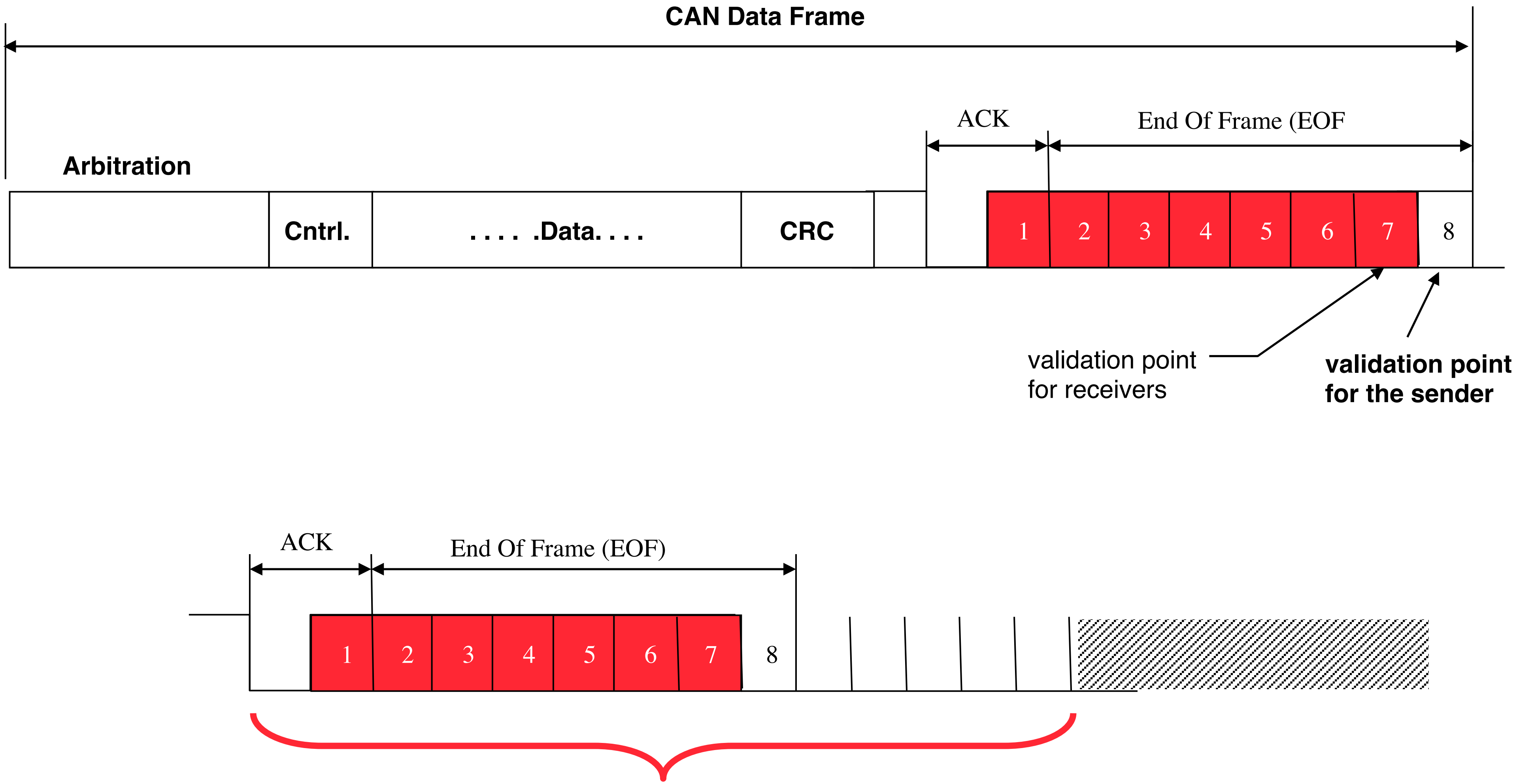
J. Kaiser, Mohammad Ali Livani: “Achieving Fault-Tolerant Ordered Broadcasts in CAN” *Proc. of the 3rd European Dependable Computing Conference, (EDCC-3), Prague, Sept. 1999*

→ **inconsistent message duplicates**

→ **inconsistent omission faults**

→ **(potentially) unbounded latencies**

# The Case for SHARE: Inconsistent Omissions




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

# The Architecture of SHARE