Controller Area Network

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Timeline

- 1983 • Development started at Robert Bosch GmbH
- 1986 • Official release at SAE congress
- 1987 • First chips by Intel and Philips
- 1991 • Bosch publishes CAN 2.0 for standardization
- 1993 • Approved and published as ISO 11989
- 2012 • CAN FD 1.0 released by Bosch

CAN protocol basics

- Serial Bus System
- Only physical and data link layer specified
- Physical Layer
  - Effective transmission of data
  - Bit timing & Synchronization
  - High & Low Speed standards exist
- Data Link Layer
  - Medium Access Control: CSMA/**CR**
  - Logical Link Control: Interface to higher layers
- Numerous application layers rely on CAN

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Physical Layer

- Physical signalling specified in ISO 11898-1
- Medium access units (transceivers) described in two documents
  - ISO 11898-2: High-speed CAN
  - ISO 11898-3: Low-speed fault-tolerant CAN
- Connectors are not standardised by CAN specification

Network Topology

- CAN networks use shared bus topology
- Buses have to be terminated
- Topology should be as linear as possible
- Maximum bitrate and length directly dependent
- No effective way to share line for power and signalling

Transmission Medium

Several kinds of transmission media can be used:

- **Two-wire bus**: Enables differential signal transmission, ensures reliable communication. Requirement for high-speed CAN.
- **Single-wire bus**: Simpler/cheaper alternative, fall back in case of fault.
- **Optical transmission medium**: Ensures immunity to electromagnetic noise, used to interconnect different subnets.

ISO 11898-2: High-speed CAN

- Maximum bit rate 1 Mbps
- Linear bus end-terminated with 120Ω
- Stubs must be shorter than 30 cm

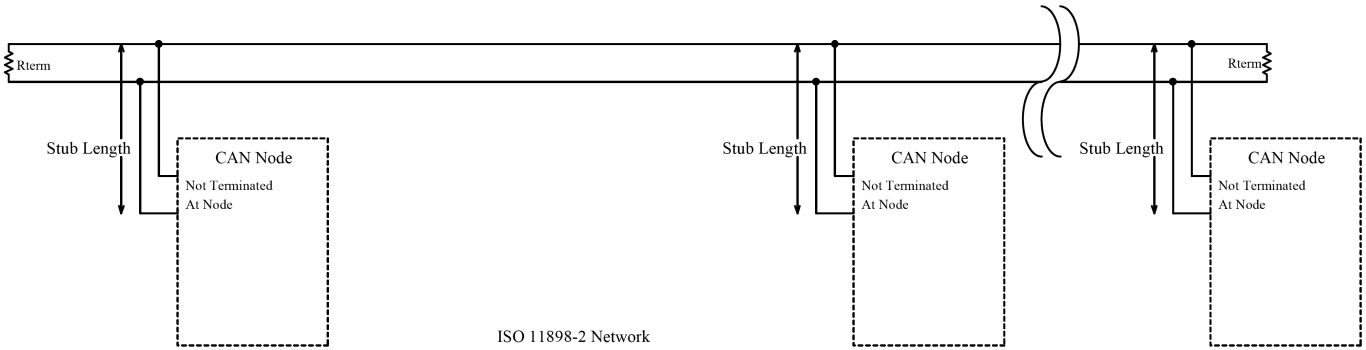

Figure: High Speed CAN Network [3]

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ISO 11898-3: Low-speed fault-tolerant CAN

- Maximum bit rate 125 kbps
- Linear or star bus terminated at node with about 100Ω
- Features energy-saving sleep mode

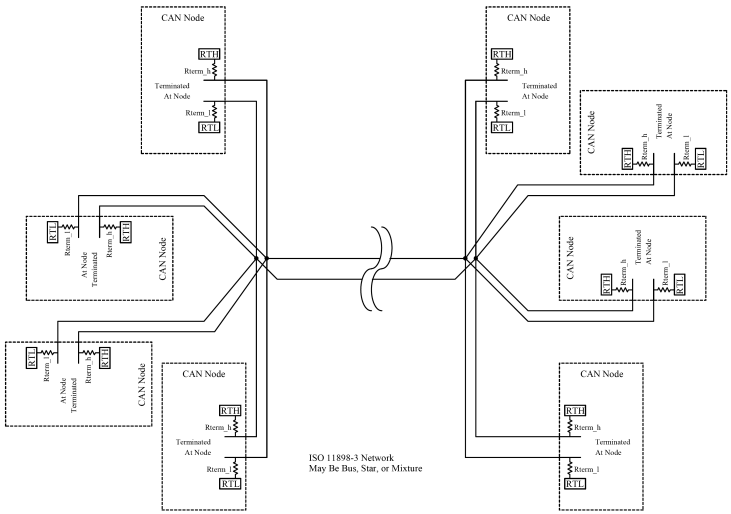

Figure: Low Speed CAN Network [4]

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Bit Encoding

- Level on bus can assume two complementary values:
  - *dominant*, usually corresponds to logical value 0
  - *recessive*, usually corresponds to logical value 1
- CAN relies on *non-return to zero* (NRZ) bit encoding

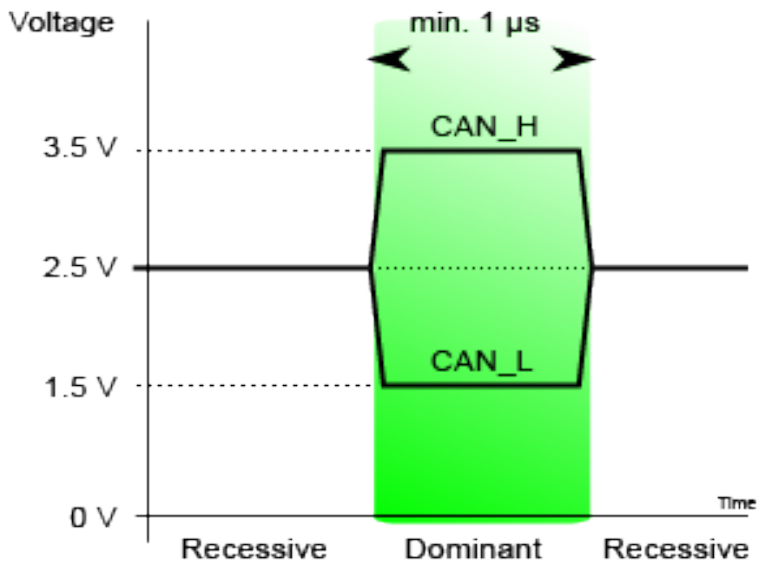

Figure: Levels on the CAN bus [5]

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Synchronization

- Timing information extracted from bit stream
- Edges of the signal are used for synchronization
- Bit stuffing to ensure sufficient number of edges

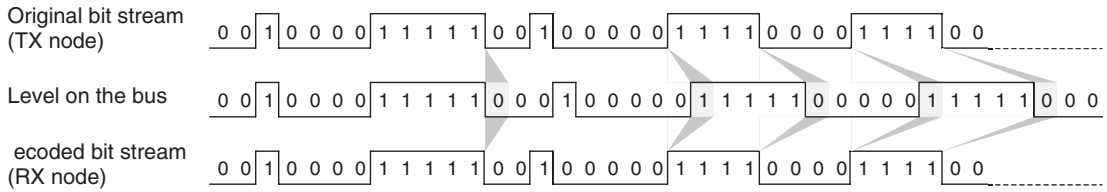

Figure: Bit stuffing technique [1]

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Frame Format

- Specifications define standard and extended frame format
  - Standard: 11 bit identifier
  - Extended: 29 bit identifier
- Standard frame format mostly used
- Identifier describes meaning of message
- Protocol foresees four kinds of frames: *data, remote, error* and *overload*

Data Frames

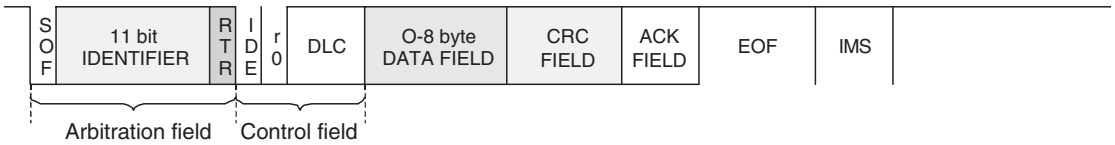

Figure: Format of standard data frames [1]

- Dominant *start of frame* (SOF) bit
- Arbitration field: identifier and *remote transmission request* bit
- *Data length code* (DLC): Length of data field encoded in 4 bits
- *Cyclic redundancy check* (CRC) encoded in 15 bits
- ACK slot: Recessive at transmitter, dominant at receiver
- *End of frame* (EOF) slot: Seven recessive bits

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Remote Frames

- Generally, source sends out data autonomously
- Protocol allows to poll for data
- Remote format similar to data format
- RTR field is recessive, data frames have higher priority
- Remote frames carry no data

Error Frames

- Notify nodes that an error has occured
- Consist of two fields:
  - Error flag: Six dominant/recessive bits.
    $\rightarrow$ Violates bit stuffing rules, error condition is detected
  - Error delimiter: 8 recessive bits.
- Active flag: dominant, transmitted by node in state *error active*
- Passive flag: recessive, transmitted by node in state *error passive*

Fault Confinement

- Supervises correct operation of MAC sublayer
- Disconnect defective node from bus
- Uses two counters: *transmission* and *receive error count*
  - On error detect, counter is increased by a given amount
  - On success, counter is decreased by one
  - Increase amount of detecting node is higher than relying nodes
- When counter exceeds 127, node switches from error active to error passive
- When counter exceeds 255, node switches to bus off

Overload Frames

- Used to slow down operations on the bus by adding delays
- Format similar to the error frames
- Hardly ever used because today's CAN controllers are very fast

Access Technique

- CAN relies on CSMA for access control:
  - When no data is exchanged, level on the bus is recessive
  - Before transmission, nodes observe the state of the network
  - When network is idle, transmission starts immediately
- Collisions are improbable but not impossible
- CAN introduces collision resolution scheme: **Bus arbitration**

CSMA/CR: Bus Arbitration

Bus arbitration essentially identifies the most urgent frame.

- Level on bus is dominant if one node is sending dominant bit
- Nodes can reliably check level on bus
- On transmission, each node compares level on bus against written value
- If node transmits recessive bit but reads dominant, it backs off

CSMA/CR: Bus Arbitration

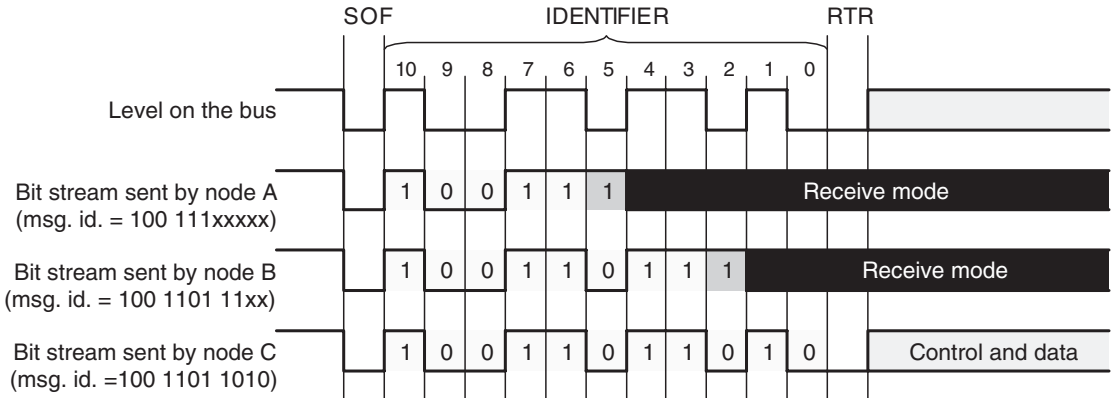

Figure: Arbitration phase in CAN

- Nodes transmit message identifier starting with MSB
- Lowest identifier corresponds to highest priority
- Message with highest priority wins contention

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Error Management

- Fundamental requirement for CAN is robustness
- Specifications foresee five mechanisms for error detection:
  - 15 bit wide CRC: Discover up to five erroneous bits
  - Frame check: CRC, ACK, EOF delimiters have to be recessive
  - Acknowledgement check: Transmitter checks for set ACK bit
  - Bit monitoring: Transmitter checks level on bus against written value
  - Bit stuffing: Each node verifies if bit stuffing rules have been violated
- Residual probability for undetected corrupt message is $4.7 \cdot 10^{-11}$ times the frame error rate or less

Logical Link Layer

- Sublayer of Data Link Layer
- Provides communication services to higher layers
- Exports only two types of frames:
  - **L_DATA**: Broadcast value over the network
  - **L_REMOTE**: Ask for value over the network
- Error and overload frames invisible to higher layers
- Provides *frame acceptance filtering* function

Frame Acceptance Filtering (FAF)

- Producer transmits information on the bus
- Frame is read by every node in a receive buffer
- FAF determines if information is relevant to the node

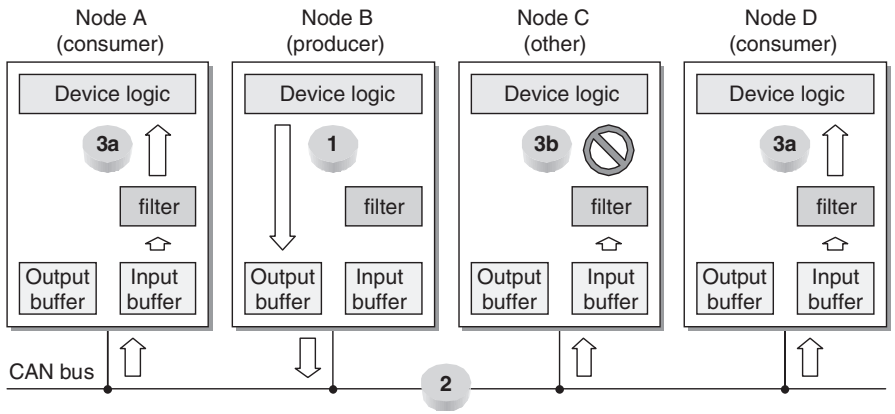

Figure: Producer/consumer model

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Higher Layer Implementations

- CAN specifications do not include application layer tasks
  - Flow Control
  - Device Addressing
  - Fragmentation/Defragmentation
- Several higher layer protocols rely on CAN
- Industrial automation: CANopen, DeviceNet
- Passenger cars: Each manufacturer has its own standard

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Advantages & Disadvantages of CAN

CAN implements a distributed priority-based multi-master communication system.

- Advantages:
  - Much more simple and robust than token based access schemes
  - More flexible than TDMA approaches
  - No message will be delayed by lower priority exchanges
- Drawbacks:
  - Relatively low maximum throughput
  - Bus length limited by bandwidth, arbitration, timing
  - Offers no security or authentication schemes

Thanks for your attention!

Questions? Ideas? Suggestions?

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