Vehicle Networks

CAN-based Higher Layer Protocols

Univ.-Prof. Dr. Thomas Strang, Dipl.-Inform. Matthias Röckl

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

STI · INNSBRUCK

universität innsbruck

Outline

- Introduction
- General-purpose HLPs
  - ISO TP
  - TP2.0
- Special-purpose HLPs
  - Vehicle-Operational Purposes:
    - CANopen
    - SAE J1939
  - Diagnostics Purposes:
    - ISO 15765-3 (KWP2000/CAN)
    - Unified Diagnostic Services
    - On-Board Diagnostics

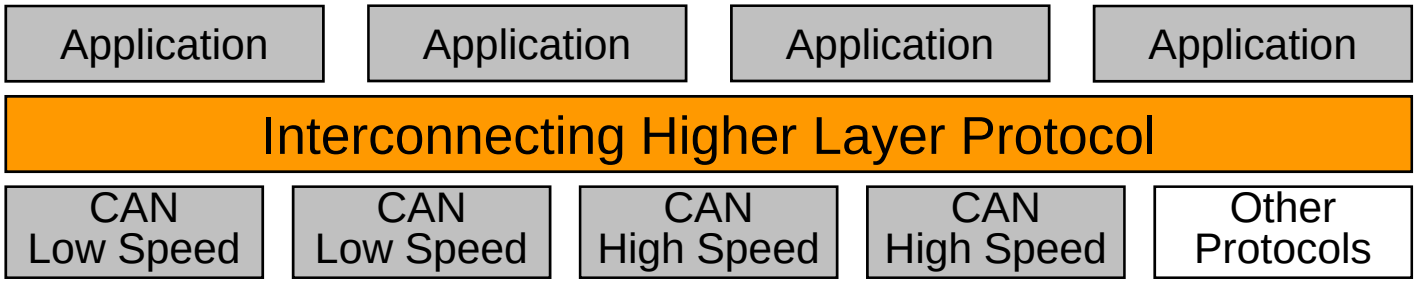
Introduction

- "Pure CAN" provides fast, prioritized, reliable, broadcast message transmission with sophisticated error detection and error handling
- Pure CAN can fulfill all requirements of small closed systems
- Pure CAN cannot satisfy the requirements that have to be fulfilled within **large, extendable, interconnected networks from different manufacturers**

  ➔ ***Higher Layer Protocols (HLP)*** required that enable the interconnection of these networks
- Inter-manufacturer connection is of major importance for all kinds of utility vehicles:
  - Trucks
  - Tractors
  - Snowcats
  - Harvesters
  - Foresters
  - Cranes
- Extension:
  - Fixed attached components: blue lights, information systems, taximeter
  - Dynamic attached components: trailers, seeders, dozer blades
  - Highly dynamic attaches components: Fleet management system

Introduction

- Functions that have to be fulfilled by HLPs:
  - Definition of common message identifiers, their meaning, format and respective data types to enable **interoperability**
  - **Flow control**
  - **Transportation** of messages > 8 bytes
  - Node **addressing** to address a specific device
  - **Networking** via gateways
  - **Network management**:
    - Startup, maintenance and shutdown behavior
    - Status reporting, diagnosis

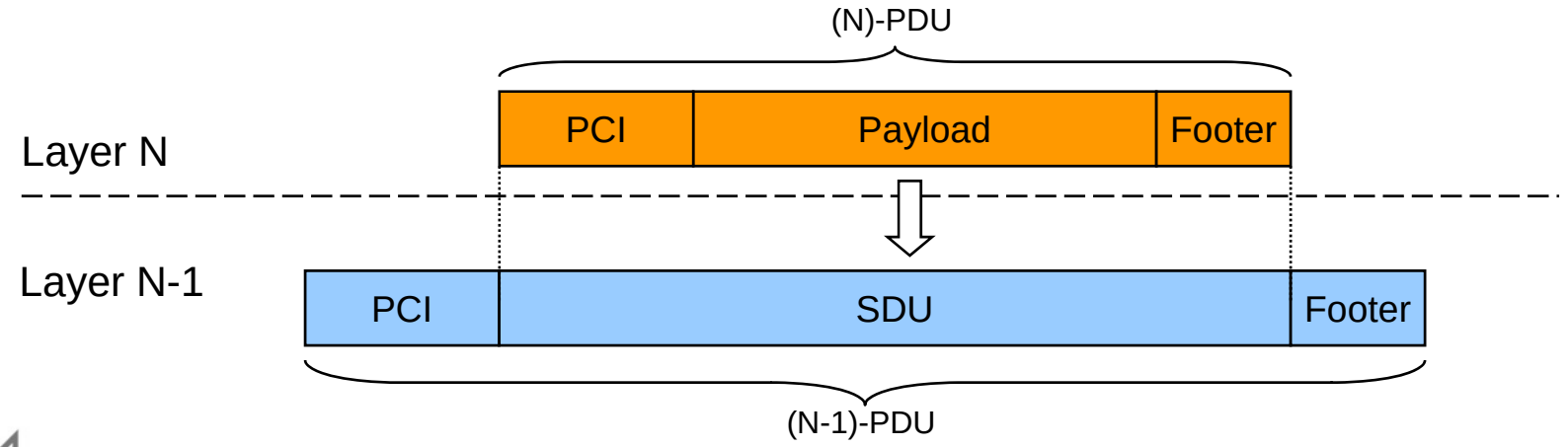


Introduction
CAN in ISO/OSI Reference Model

No. of layer	ISO/OSI ref model	CAN protocol specification
7	*Application*	Application specific
6	*Presentation*	Optional: **Higher Layer Protocols (HLP)**
5	*Session*	
4	*Transport*	
3	*Network*	
2	*Data Link*	**CAN protocol** (with free choice of medium)
1	*Physical*	

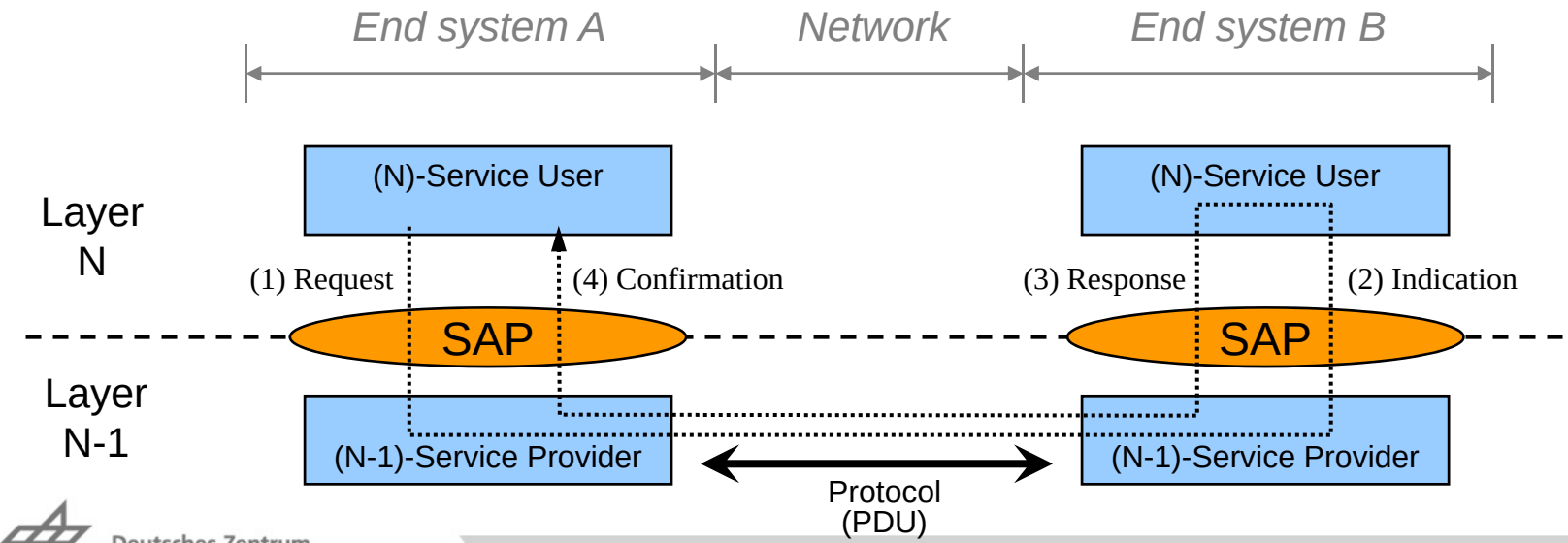
Introduction
Protocol messaging

- *Protocol Data Unit (PDU)* of layer *N* becomes *Service Data Unit (SDU)* of layer *N-1*
- (N-1)-SDU extended with *Protocol Control Information (PCI)* and Footer becomes (N-1)-PDU
- Terminology
  - Layer 1 PDU: bits
  - Layer 2 PDU: frame
  - Layer 3 PDU: packet
  - Layer 4 PDU: segment



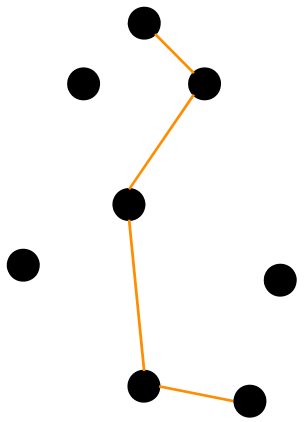
Introduction
Protocol service primitives

- *Service Access Points (SAP)* provide services to upper and lower layers
- SAP to layer (N-1)
  - Request
  - Confirmation
- SAP to layer (N)
  - Response
  - Indication



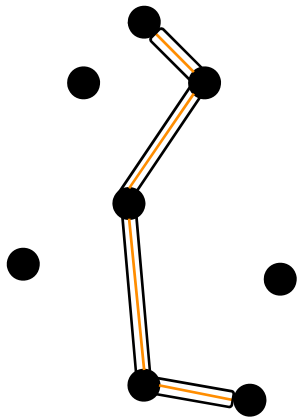
Introduction
Network Layer

- Transmission of packets over multiple intermediate hops
- Protocols: IPv4, IPv6, ICMP, IGMP
- Main functions:
  - Global addressing
  - Routing, e.g.:
    - Flooding
    - Link State Routing
    - Distance Vector Routing
    - Hierarchical Routing
  - Fragmentation
  - Quality of Service



Introduction
Transport Layer

- Data exchange over a logical connection between end-to-end systems
- Protocols: TCP, UDP, DCCP, SCTP
- Main functions:
  - Reliability management:
    - Reliable communication (e.g. TCP by acknowledgements)
    - Unreliable communication (e.g. UDP)
  - Segmentation with (un)ordered delivery
  - Flow control: Overload at receivers
  - Congestion control: Overload of the network
  - Connection management:
    - Connection-oriented (e.g. TCP)
    - Connectionless (e.g. UDP)
  - Error Control
  - Multiplexing of concurrent services



General-purpose HLPs

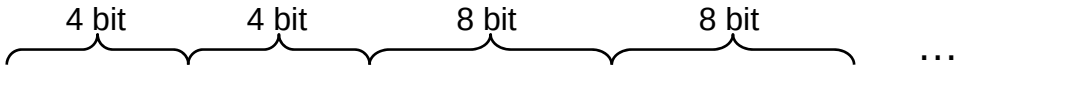
ISO-TP

ISO-TP
Overview

- ISO-TP = ISO Transport Protocol
- Designed to run existing diagnostics protocols (ISO 14230) on CAN
- Unreliable connection-oriented transport protocol enabling:
  - Segmentation (transmission of up to 4095 bytes)
  - Flow Control
  - Broadcast and unicast addressing
- Uses CAN on Data Link layer
- Standardized under ISO 15765-2
- E.g. used with diagnostics protocols KWP2000 and UDS

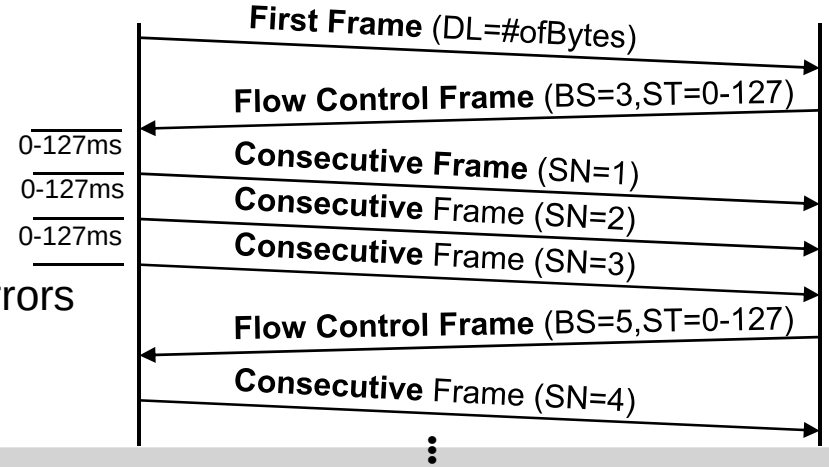
ISO-TP
Frames

- Frame Types:



  - Single Frame:
    Standard frame for unsegmented data
  - First Frame:
    Initial frame in a sequence of frames
  - Consecutive Frame:
    Subsequent frame in the sequence (SN modulo 2^4)
  - Flow Control Frame:
    Response of the receiver specifying min. timing and max. buffer size (=block size) for consecutive frames

- In case of error (timeout or wrong sequence number) application layer is informed but not sender of the message
  → no inherent reliability,
  application layer has to handle errors



ISO-TP
Addressing

- Flow control requires unicast communication
- Addresses have to be predefined and statically assigned
- Addressing schemes:
  - Normal Addressing:
    Source and destination address are encoded in CAN identifier
  - Extended Addressing (for gateways):
    Additional Transport-PCI Byte (= first byte of CAN payload) with gateway address
    → CAN payload reduced to 0..6 bytes

General-purpose HLPs

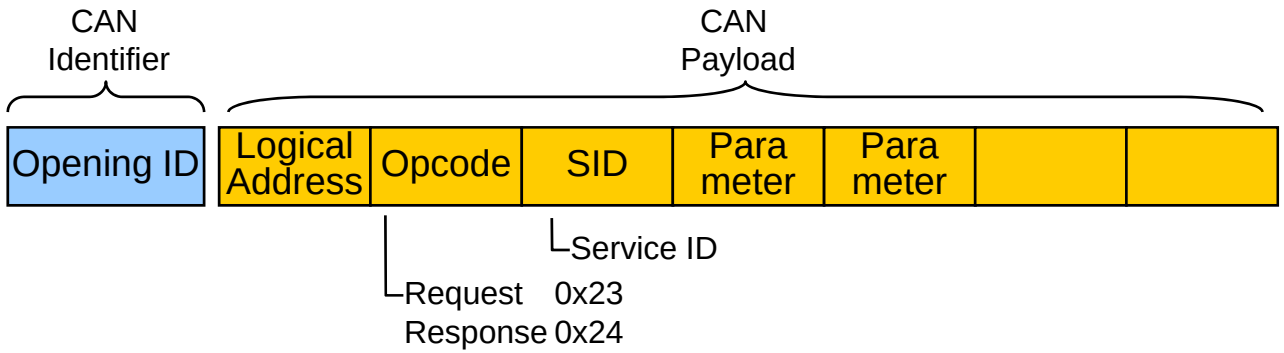
TP2.0

TP2.0
Overview

- Designed to allow existing diagnostics protocols on CAN2.0A
- Mainly used by Volkswagen Group
- Connection-oriented transport protocol enabling:
  - Segmentation of arbitrary size
  - Flow control with handshake
  - Dynamic assignment of CAN identifier per channel (vs. static assignment of CAN identifiers in ISO-TP)
  - Automatic recovery after timeout
  - Addressing:
    - Unicast
    - Multicast, e.g. all ECUs on the powertrain
    - Broadcast

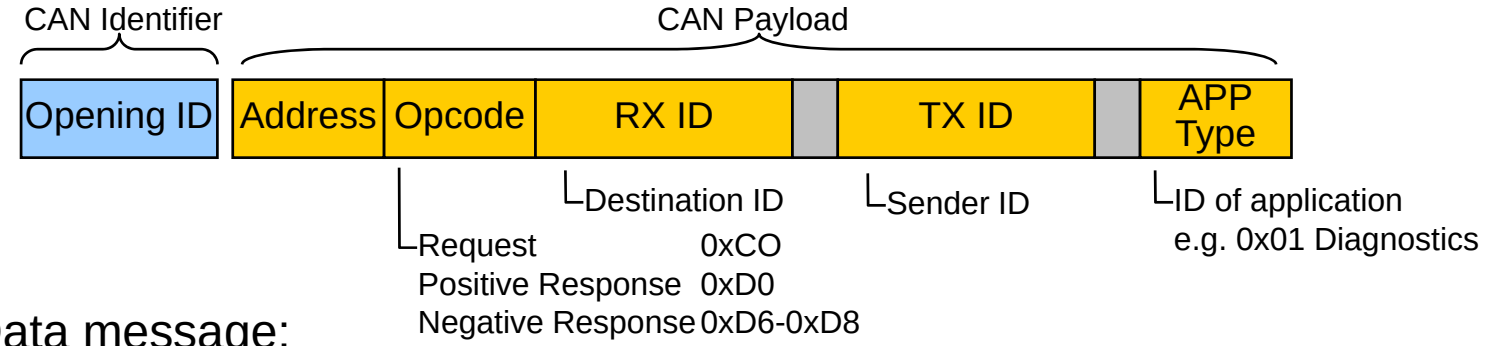
TP2.0
Broadcast communication

- Allows usage of gateways (specified by Logical Address)
- Broadcast messages with and without required response

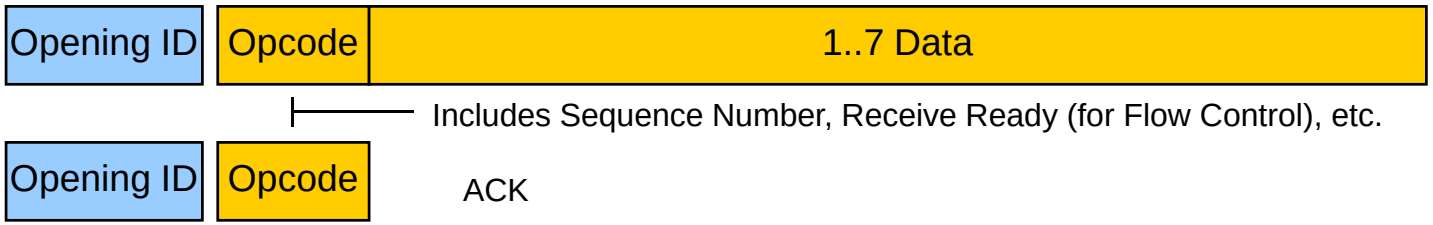


TP2.0
Connection-oriented unicast communication

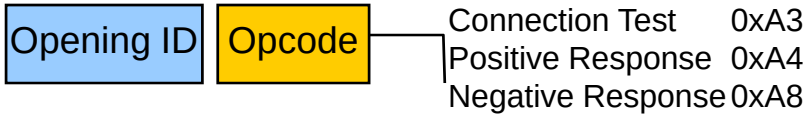
- Connection setup request/response message:



- Data message:

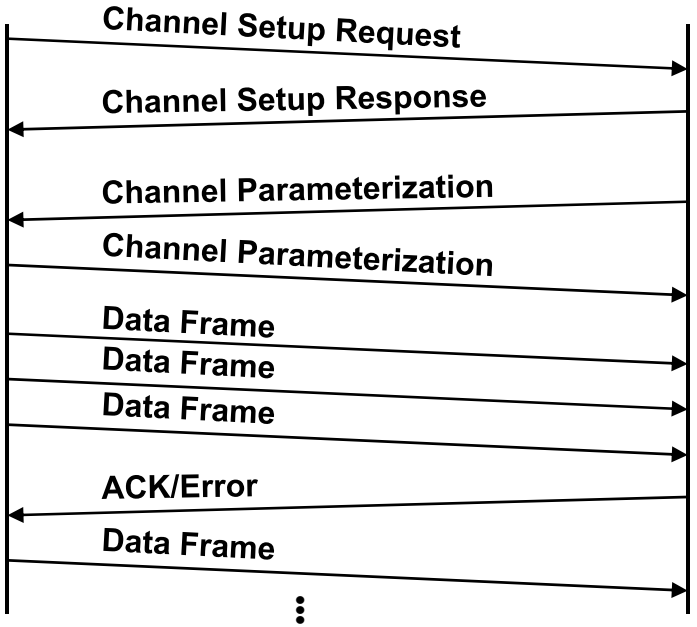


- Connection shutdown message:



TP2.0
Message sequence

1. Channel Setup
2. Data Exchange
   - Block-wise data transmission
   - Cumulative acknowledgements
3. Channel Shutdown



Special-purpose HLPs

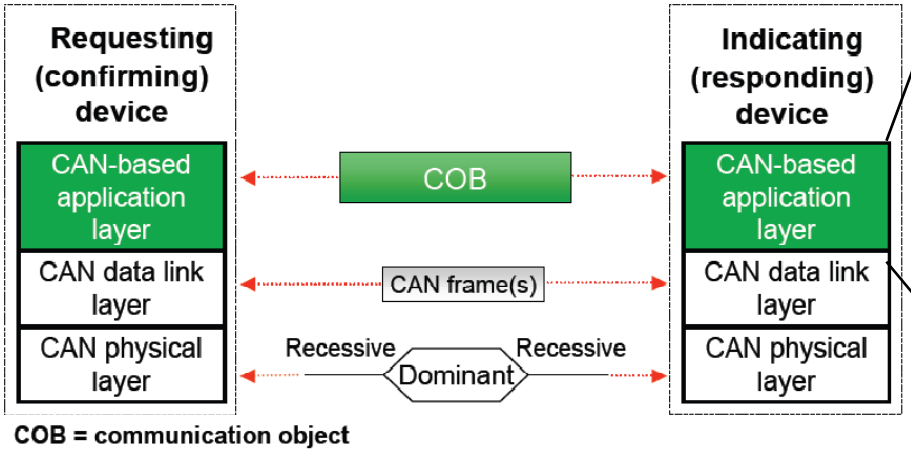
CANopen

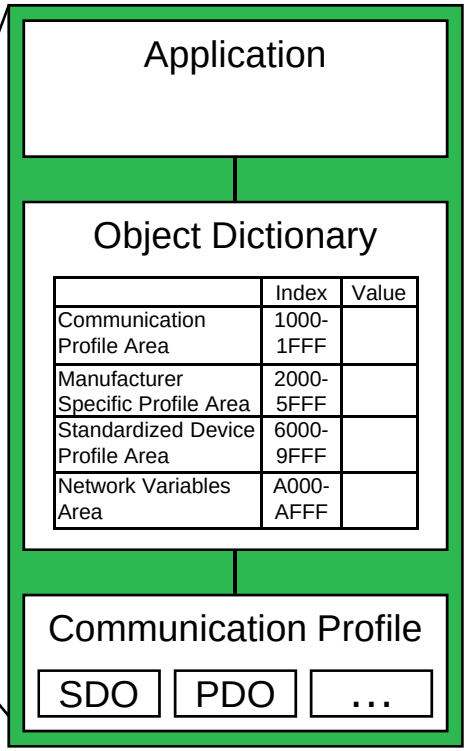
CANopen
Overview

- Developed by *CAN in Automation (CiA)* since 1995
- Originally developed for motion-oriented machine control networks, by now it is also used to network:
  - medical electronics, automotive-, industrial- and rail-vehicles, laboratory automation systems,
  - building automation systems,
  - embedded networks such as passenger information systems, gambling machines and professional coffee machines,
  - vehicle add-ons (blue lights, taximeter, etc.)
- Standardized in 2002 under EN 50325-4
- Features:
  - CAN 2.0A on Data Link layer (optional CAN 2.0B)
  - Network auto-configuration
  - Access to all device parameters
  - Device synchronization
  - Cyclic and event-driven data transfer
  - Synchronous reading or setting of inputs, outputs or parameters

CANopen
Overview

- Three parts:
  - Application Layer
  - Object Dictionary
  - Communication Profile





Based on: Zeltwanger 2007, CANopen

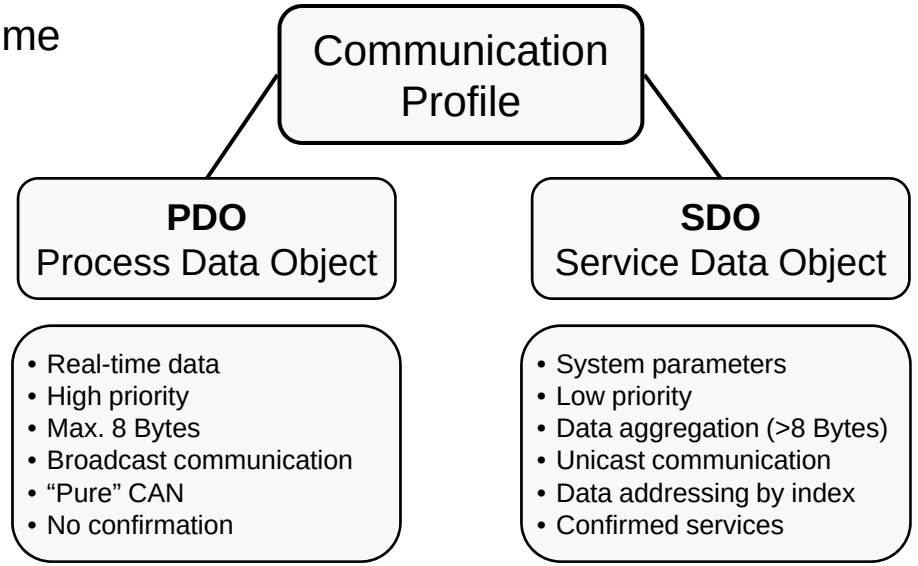
CANopen
Object Dictionary and Profiles

- Every CANopen device has a standardized device specification, the *Object Dictionary (OD)*
  - It includes general objects (ID, manufacturer, etc.) and status objects (temperature, speed, etc.)
  - Semantics of the OD-objects are defined in the *Electronic Data Sheet (EDS)*
  - Objects are addressed by 16-bit index + 8-bit subindex
    - 1000-1FFF: Communication profile area (CiA DS-301)
    - 2000-5FFF: Manufacturer-specific profile area
    - 6000-9FFF: Standardized device profile area (e.g. CiA DS-401)
    - A000-AFFF: Network variables (NWV)
- CANopen defines:
  - Communication profiles: definition of fundamental communication mechanisms
  - Device profiles: unambiguous definition of manufacturer-independent OD-parameters describing the device and its network behavior (i.e. input/output modules, drives, encoders, etc.)

  ➔ **Devices become interoperable and interchangeable between manufacturers**

CANopen
Communication Profile

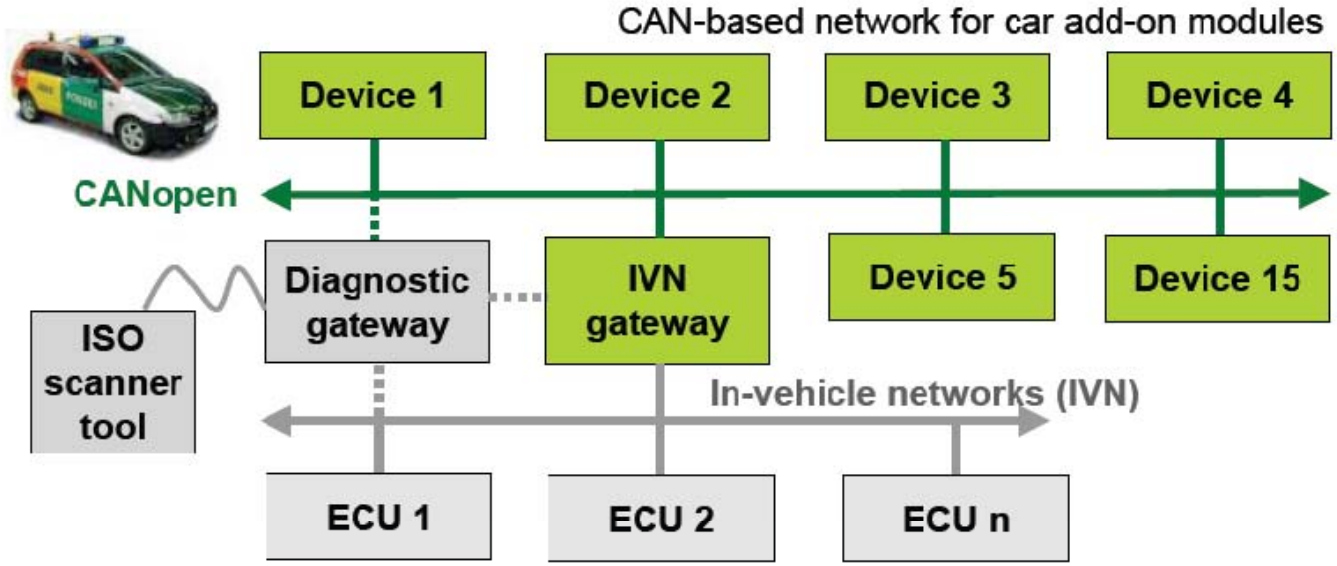
- Process Data Objects (PDO): Transport of real-time data (=operational data)
- Service Data Objects (SDO): Read and write OD entries (=system parameters)
- Special Object Messages:
  - Synchronization (SYNC)
    Cyclic time synchronization
  - Time Stamp (TIME)
    Adjustment of global network time
  - Emergency Object (EMCY)
    Indicate device internal errors
- Administrative Messages:
  - Network Management (NMT)
    Node state monitoring
  - Error Control:
    Cyclic heartbeat,
    Node/Life guarding



CANopen
Device and Application Profiles (extract)

- **CiA 301**: CANopen application layer and communication profile
- **CiA 401**: Device profile for generic I/O modules
- CiA 402: Device profile for drives and motion control (servo controller, stepper motor controller, frequency inverter)
- CiA 404: Device profile for measuring devices and closed-loop controllers
- CiA 406: Device profile for encoders (rotating and linear)
- **CiA 413**: Set of device profiles for truck gateways
- **CiA 415**: Application profile for road construction machine sensors
- CiA 418: Device profile for battery module
- CiA 419: Device profile for battery charger
- **CiA 422**: Application profile for municipal vehicles (e.g. garbage trucks)
- **CiA 423**: Application profile for power drive systems (e.g. diesel engine)
- CiA 424: Application profile for rail vehicle door control systems
- **CiA 447**: Application profile for special-purpose car add-on devices

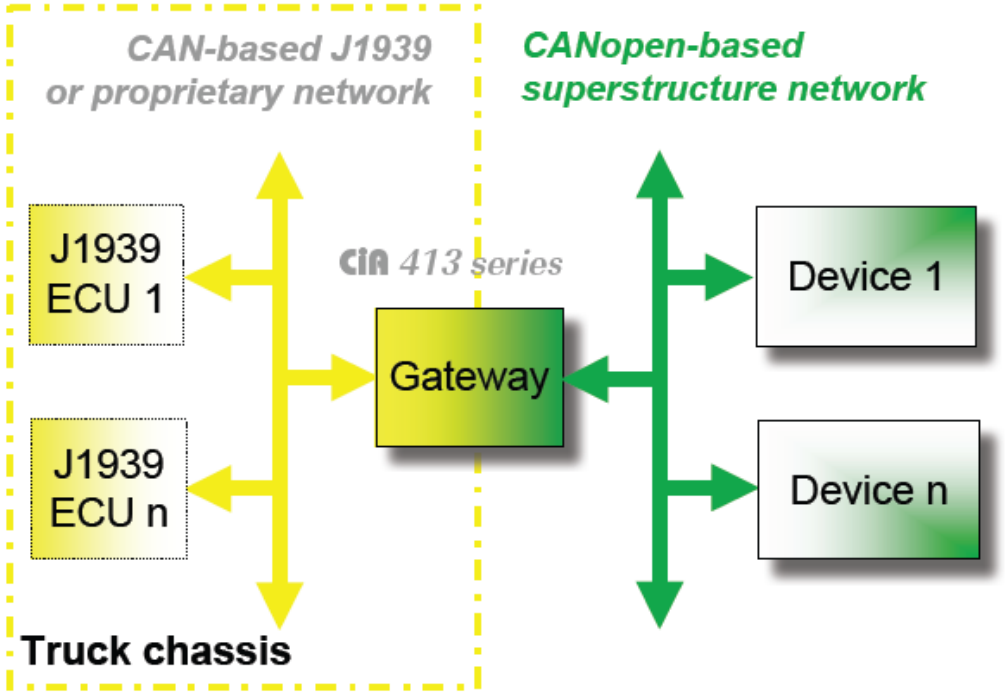
CANopen
CiA DS-447 Car add-on devices



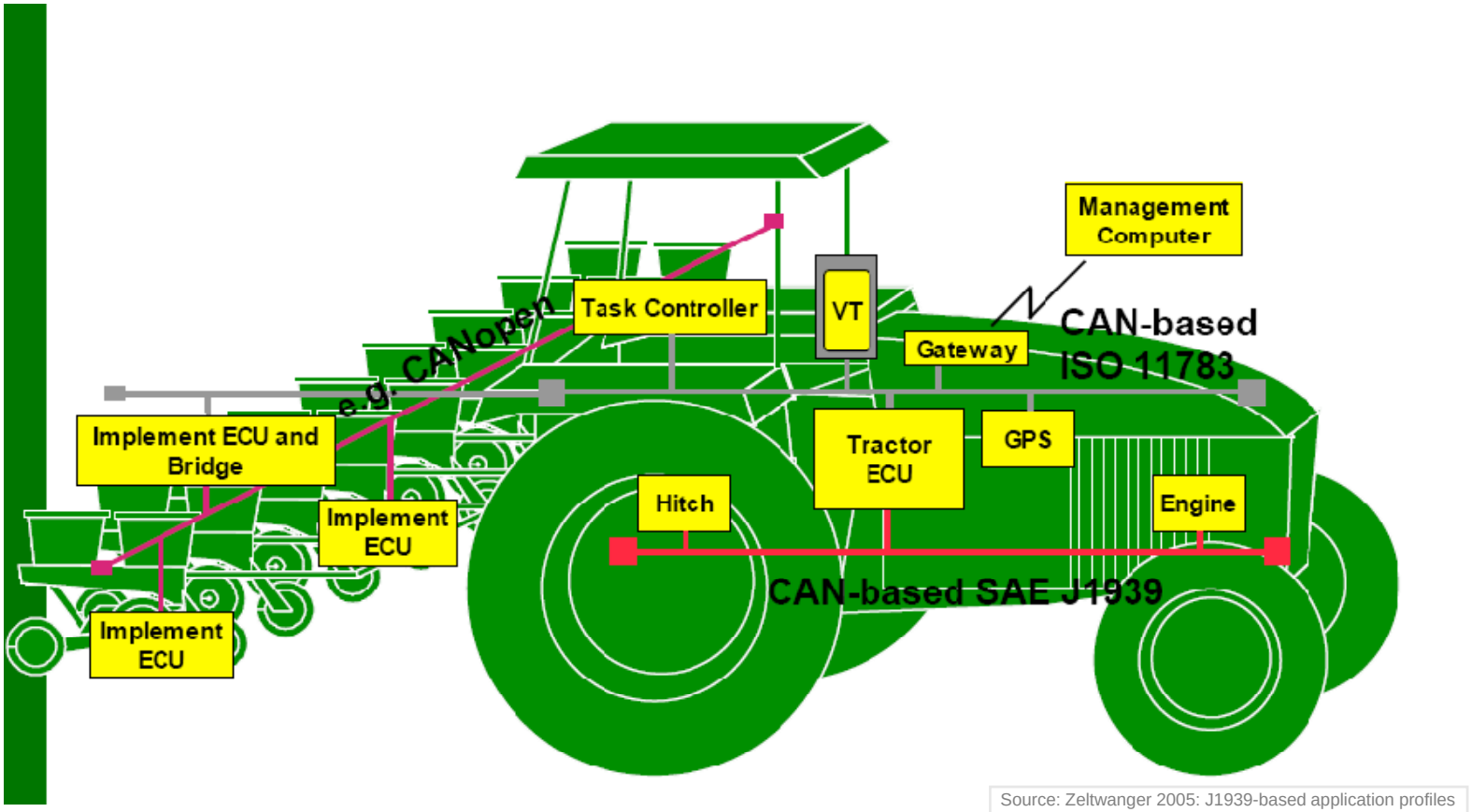
- Attachment of add-on devices, such as blue light, siren, taximeter, etc.
- Standardization finished in 2008

CANopen

CiA DS-413 Device profiles for truck gateways



CANopen



Source: Zeltwanger 2005: J1939-based application profiles

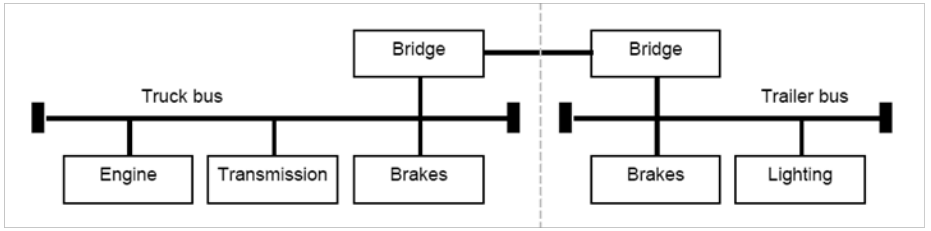
ISO 11783 (ISOBUS) for agricultural and municipal vehicles, based on J1939 and NMEA-2000

Special-purpose HLPs

SAE J1939

SAE J1939

- Specified by *Society of Automotive Engineers (SAE)* heavy trucks and bus division
- The SAE J1939 set of profiles is based on the CAN data link layer (ISO 11898-1) using the extended frame format (CAN2.0B) with 29-bit identifier
- Features
  - Unicast and broadcast communication
  - Network management
  - Transport protocol functions: data segmentation, flow control
  - Definition of parameter groups
  - Support of real-time close loop control
- Applications
  - Light to heavy trucks
  - Agriculture equipment e.g. tractors, harvester, etc.
  - Engines for public work



SAE J1939
Standards

SAE J1939-71 Truck and bus power-train network

Defines all parameters as well as assembled messages called parameter groups

SAE J1939-73 Application layer diagnostics

Defines diagnostic messages

SAE J1939-81 Network management

Defines message sequences for initialization and constraints on the use of addresses (e.g. address claiming)

SAE J1939-31 Network layer

Defines repeaters, routers, gateways and bridges

SAE J1939-21 Data link layer

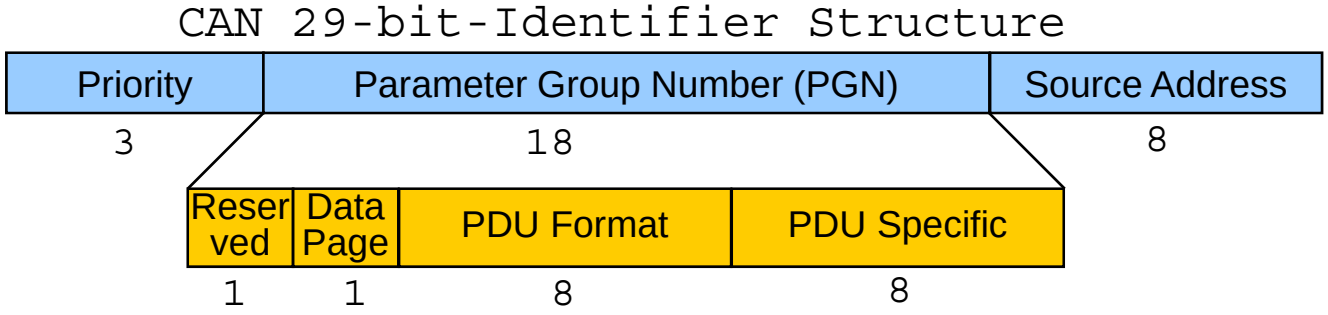
Defines commonly used messages such as Request, Acknowledgement and Transport Protocol

SAE J1939-11 Physical layer

Physical layer based on ISO 11898-2 at 250 kbit/s with up to 30 devices and a maximum of 40 m bus length (twisted shielded pair)

SAE J1939

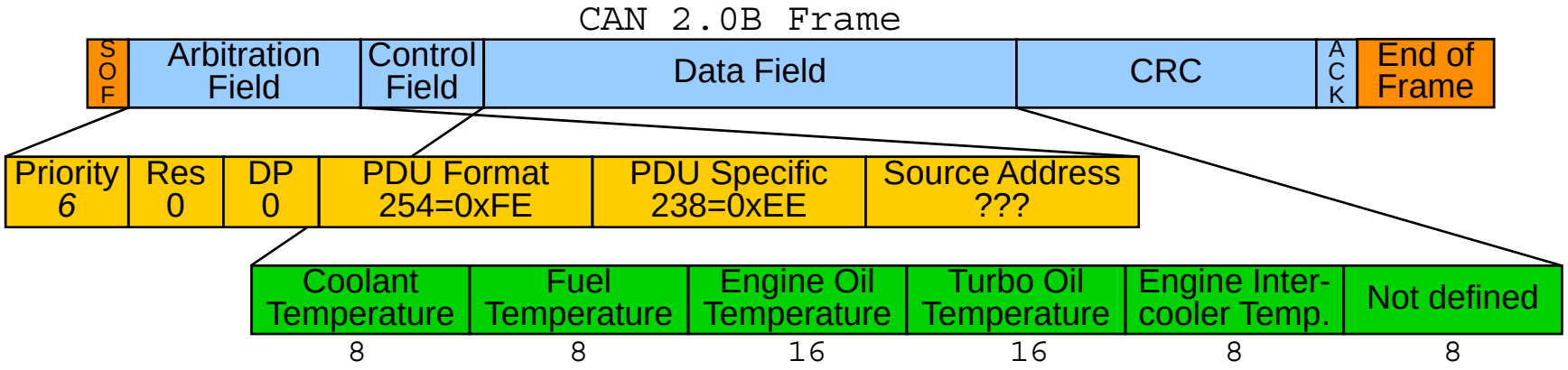
Message Format



- Priority: Priority during the arbitration phase (lower value = higher priority)
- Reserved: Reserved for future usage (always 0)
- Data Page selector: Expands parameter groups (for future usage)
- PDU Format:
  - Global PGNs for **broadcast** parameter groups
    - PDU Format >= 0xF0 = 240_{10}
    - PDU Specific: Group Extension (further PDU type specification)
  - Specific PGNs for **unicast** parameter groups
    - PDU Format <= 0xEF = 239_{10}
    - PDU Specific: Destination Address

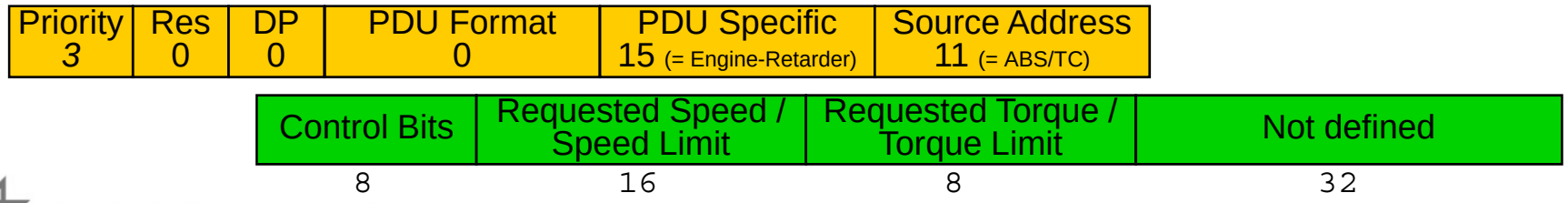
SAE J1939
Example

Engine Temperature message: Broadcast transmission with 1 Hz



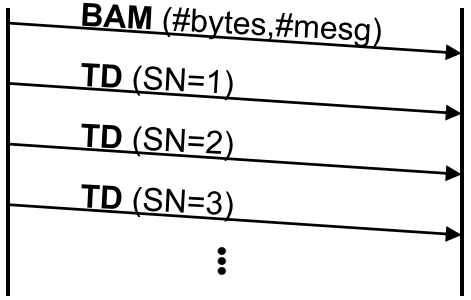
Torque/Speed Control message: Unicast transmission

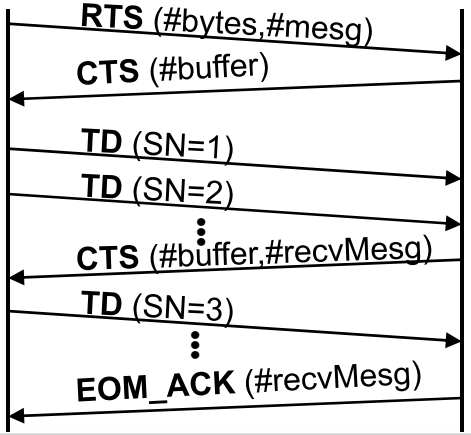
- to Engine (=00) with 100 Hz
- to Engine-Retarder(=15) with 20 Hz



SAE J1939
Transport Layer

- The Transport Protocol specifies the breaking up of large amounts of data into multiple CAN-sized frames, along with adequate communication and timing to support effective frame transmission between nodes
- Two types:
  - Broadcast Announcement Message (BAM)
    - Broadcast communication
    - Connection-less (e.g. no handshake)
    - Unreliable
    - No flow control
  - Connection Mode Data Transfer (CMDT)
    - Unicast communication
    - Connection-oriented (2-way handshake)
    - Reliability by cumulative ACKs
    - Flow control by windowing





SAE J1939
Addressing

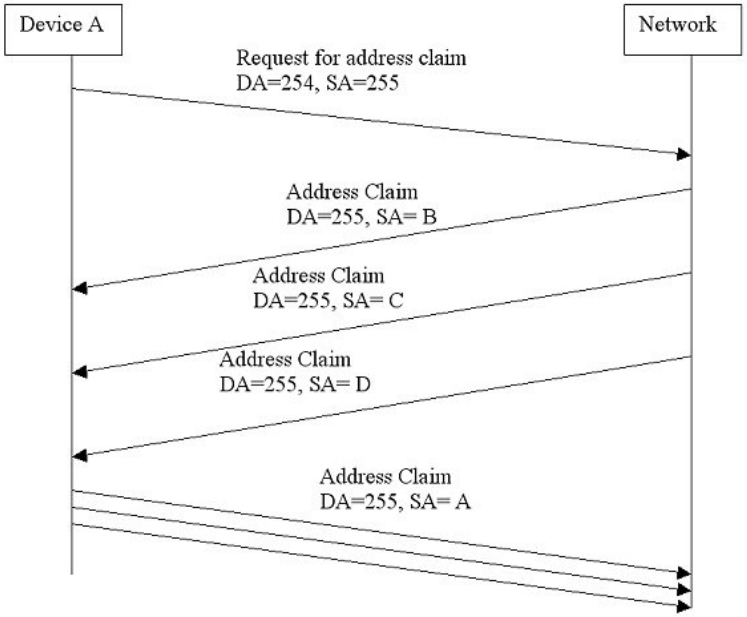
- Address:
  - Unique identity within a session
  - Every device requires a unique address (0-253)
    - 254: zero address
    - 255: broadcast address
  - Included in every message
  - Can change during re-configuration
- Name:
  - Probably unique identifier within the network
  - Provides functional identification of ECUs
  - Used to arbitrate in the case of an address selection conflict

Name

Arbitrary Address Capable	Industry Group	Vehicle System Instance	Vehicle System	Reserved	Function	Function Instance	ECU Instance	Manufacturer Code	Identity Number
1 Bit	3 Bits	4 Bits	7 Bits	1 Bit	8 Bits	5 Bits	3 Bits	11 Bits	21 Bits

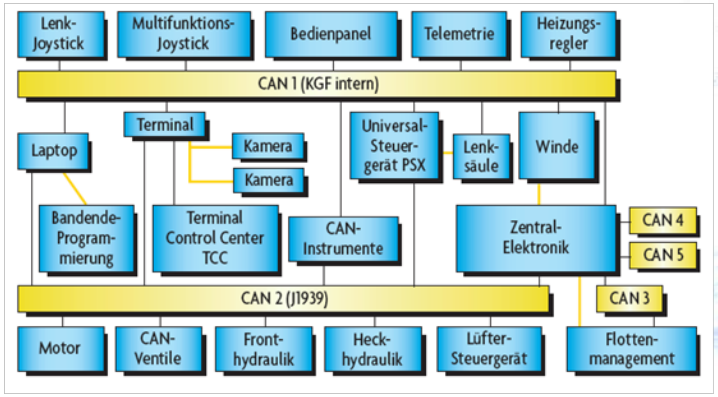
SAE J1939
Network management

- Dynamic address allocation (address claiming)
- Address conflict detection
- Address conflict resolution

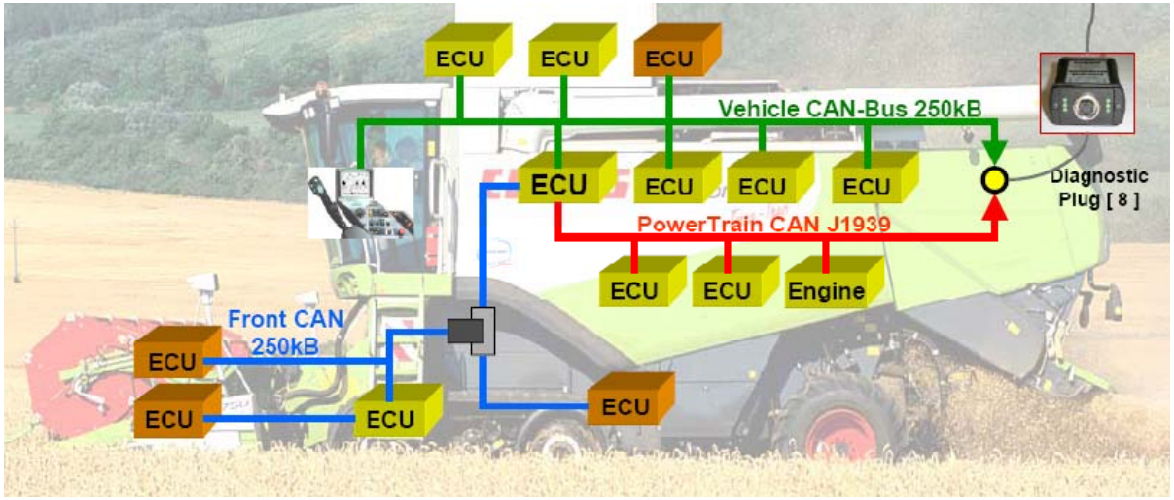


Address Claim with no complications.

SAE J1939
Application



Source: Vector 2006, CAN und J1939
Unter extremen Einsatzbedingungen

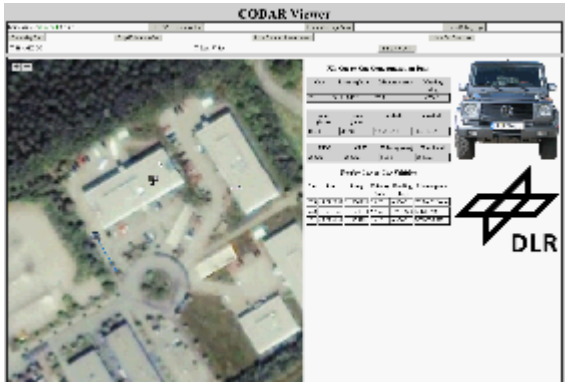


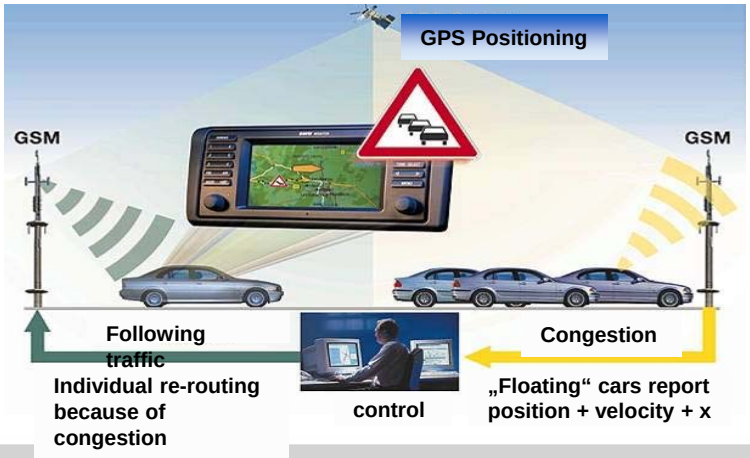
Source: CLAAS 2005, Diagnose bei CLAAS

SAE J1939

Fleet Management System (FMS)

- Supervise a whole fleet - consisting of vehicles from different manufacturers - over the Internet
- Developed by the 6 major European truck manufacturers Daimler, MAN, Scania, DAF, IVECO, Volvo/Renault
- Based on J1939
- Vehicle data shall be available for third parties but internal vehicle busses shall be untouched
- Secure and legal solution for the remote download of data e.g. from the digital tachograph



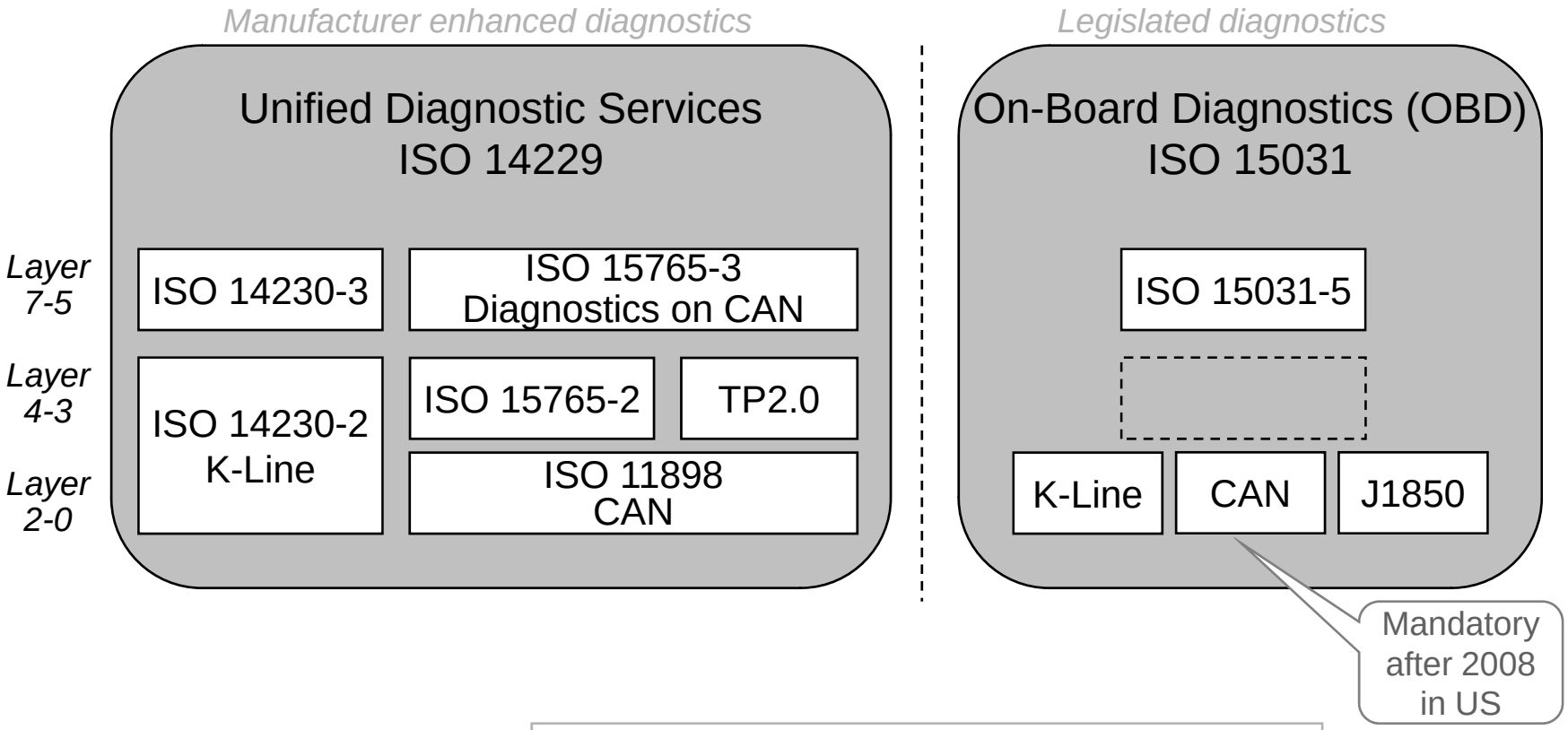


Special-purpose HLPs

Diagnostics

Diagnostics

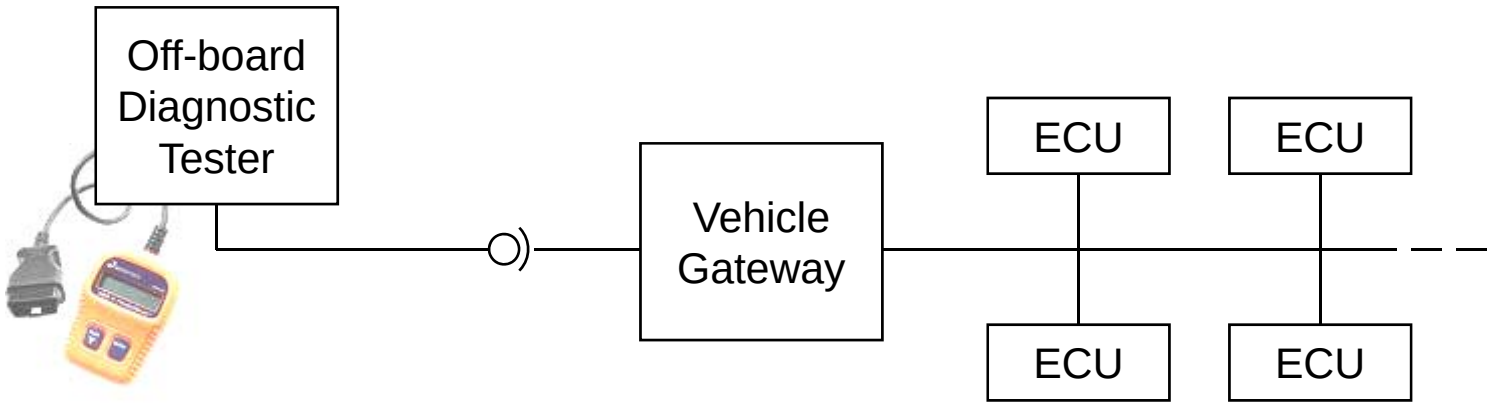
Interchange of digital information between an on-board ECU and a off-board diagnostic tester to facilitate inspection, test, diagnostics and configuration



Based on: Zimmermann, Schmidgall 2007: Bussysteme in der Fahrzeugtechnik

Diagnostics
ISO 15765-3 Diagnostics on CAN

- *Diagnostics on CAN* standardized in ISO 15765-3 in 2004
- Enables interoperability between off-board diagnostic tester and on-board ECU
- ISO 15765-3 is based on the *Keyword Protocol 2000 (KWP2000)* protocol
- Client-Server with simple request-response communication



Diagnostics
ISO 15765-3 Diagnostics on CAN

- Client-Server communication:
  - Client (=diagnostic tester) initiates request and waits for confirmation
  - Server (=ECU) receives indication and sends response
- Services
  - Diagnostic Management: Control of diagnostic sessions
  - Network Layer Protocol Control
  - Data Transmission: Read from and write to ECUs
  - Stored Data Transmission: Read *Diagnostic Trouble Codes (DTC)*
  - Input/Output Control: Control of ECU I/O
  - Remote Activation of Routines: ECU program startup
  - Upload/Download: ECU Flashing

Diagnostics
ISO 15765-3 Diagnostics on CAN

- Message formats:

Service Request

Service ID SID	Request Parameters

Positive Response

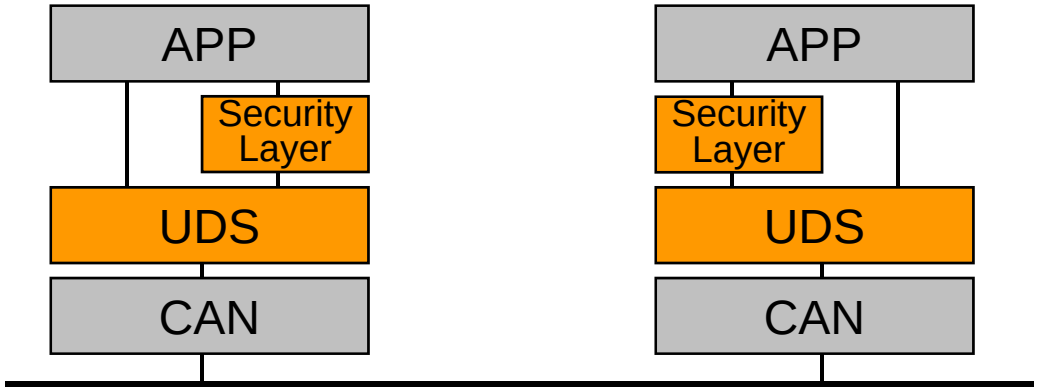
SID | 0x40	Response Parameters

Negative Response

Error ID	SID	Error Code

Diagnostics
Unified Diagnostic Services

- *Unified Diagnostics Services (UDS)* standardized by ISO 14229
- Advancement of *Diagnostics on CAN* for general usage
- Whereas ISO 15765-3 relies on CAN, UDS is independent of lower layer protocols
- Technically UDS is almost identical to *Diagnostics on CAN*, advancements are mainly the restructuring of SIDs and unification
- UDS also defines, as one of the first protocols, a security layer in order to encrypt data



Diagnostics
On-Board Diagnostics

- Self-diagnostic and reporting capability of modern vehicles
- Guarantees standardized access to vehicle information for:
  - fault diagnostics by repair shop and
  - emission inspection by technical inspection agencies (“TÜV”)
- Mandatory in Europe for:
  - gasoline vehicles manufactured since 2001
  - diesel vehicles manufactured since 2003

- OBD provides diagnostic data on:
  - Emission-related components (e.g. lambda sensor, catalytic converter)
  - Engine
  - Vehicle electronics

Diagnostics
On-Board Diagnostics

Service Request

Service ID SID	Parameter ID PID	0..6 Byte Request Parameters

- Service Identifiers (SID):
  - Fault memory
    - *0x03* Request emission-related diagnostic trouble codes
    - *0x02* Request powertrain freeze frame data
    - *0x04* Clear emission-related diagnostic information
  - Test of emission-related components
    - *0x05* Request oxygen sensor monitoring test results
    - *0x06* Request control of on-board system, test or component
  - Read ECUs
    - *0x01* Request current powertrain diagnostic data
    - *0x09* Request vehicle information
- Parameter Identifier (PID):
  - *0x04* Calculated Load Value
  - *0x05* Engine Coolant Temp
  - *0x0A* Fuel Pressure (gage)
  - *0x0C* Engine RPM
  - *0x0D* Vehicle Speed
  - *0x11* Absolute Throttle Position

Questions

- Why are Higher Layer Protocols (HLP) required?
- What are the main functions of HLP in automotive environments?
- Why almost all HLPs introduce unicast communication?