CAT Electronics

CAN/J1939

Basic Training Module

Presentation Content

- Background on CAN
- CAN Higher Layer Protocol – SAE J1939
  - Physical Layer
  - Data Link Layer Functions
  - Network Layer Functions
  - Message and Parameter Definitions
  - Vehicle Application Layer Functions
  - Diagnostics
  - Network Management Layer Functions
- J1939 Proprietary Communication Protocols

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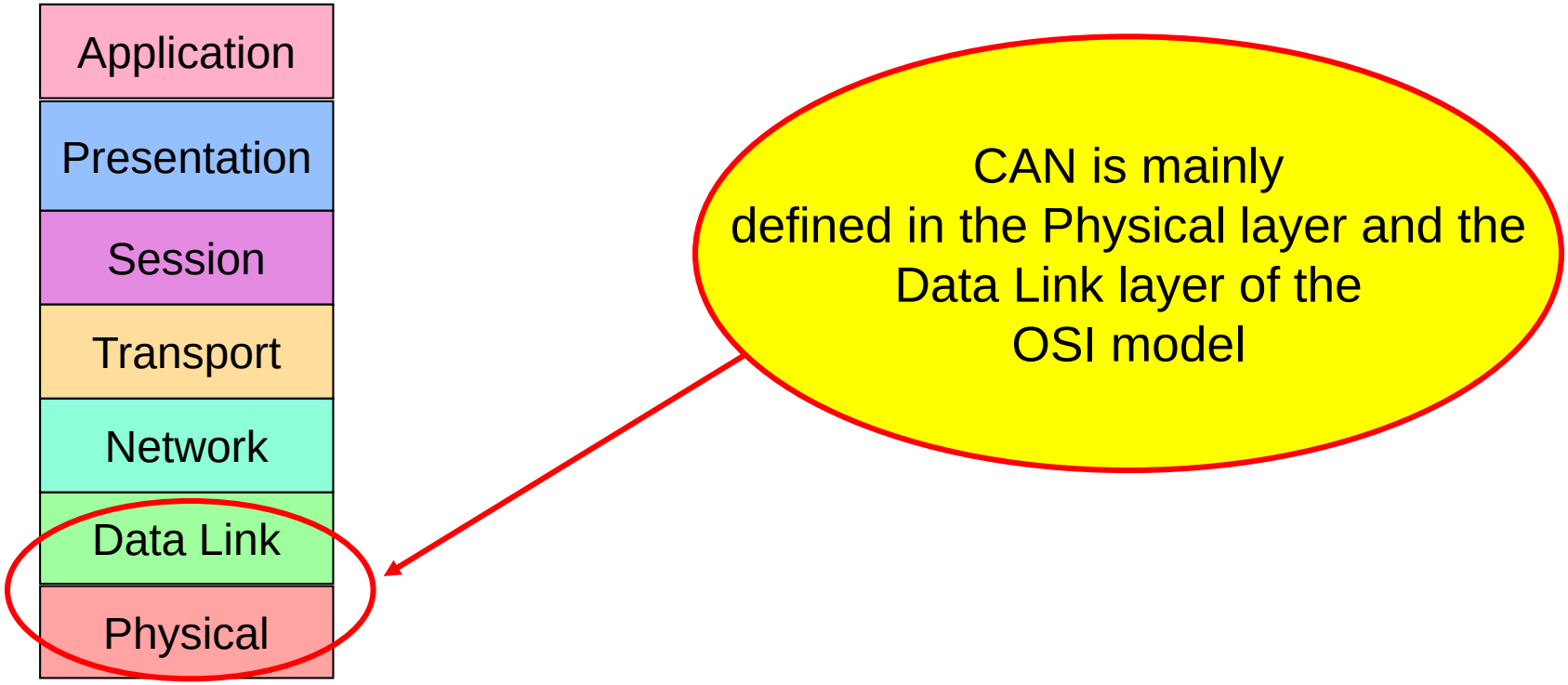
What is CAN?

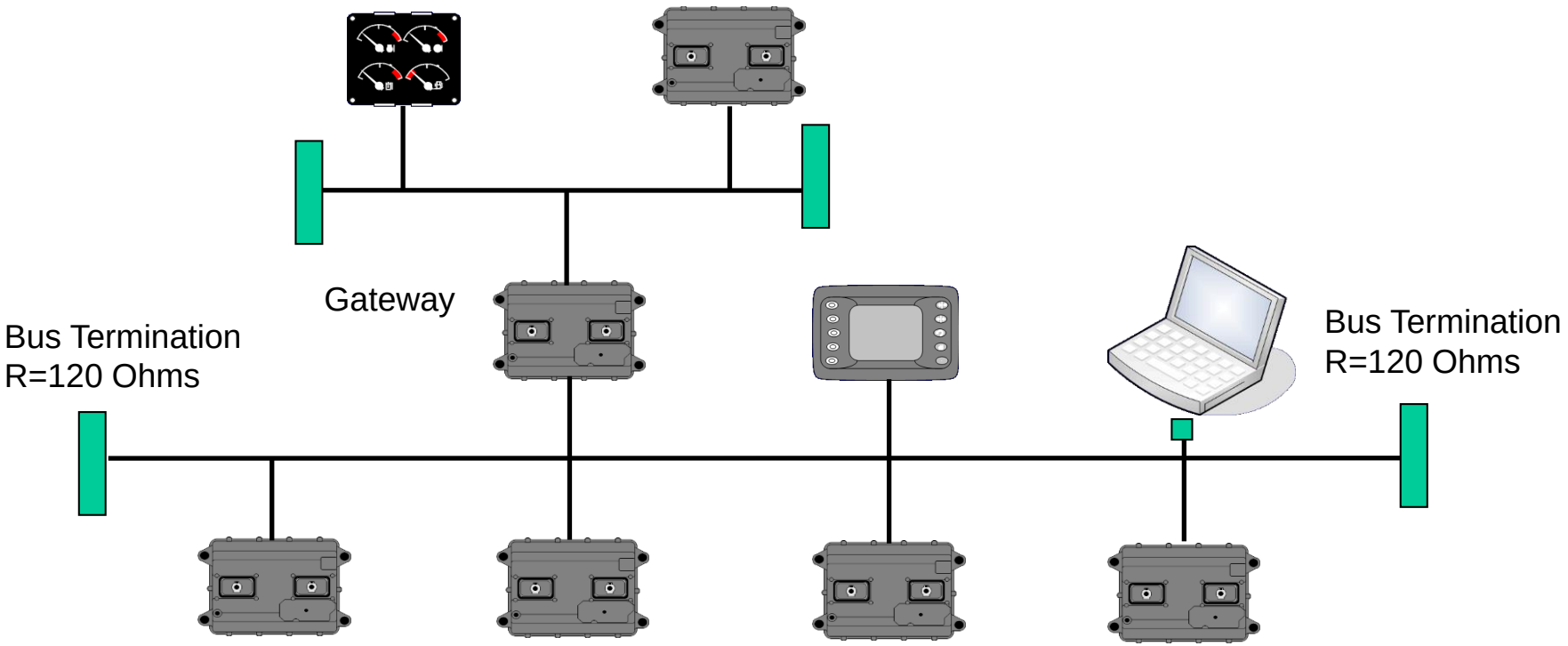
- CAN is an acronym for Controller Area Network
- ISO Standard (ISO-11898) for Serial Data Communication
- Developed in 1986 by Bosch GmbH mainly for automotive applications
- Also used in Industrial Automation and Mobile Machines
- CAN standard includes a Physical Layer and Data Link layer which defines,
  - Message types
  - Arbitration rules for bus access
  - Methods for fault detection and fault confinement

CAN and the OSI Layer Model

OSI Layers



Network Topologies



Bus Topology

CAN Physical Layer Characteristics

Hardware	• Two-wire differential signaling scheme (ISO 11898-2) • Two-wire Fault Tolerant (ISO 11898-3) • Single-wire CAN (SAE-J2411)
Baud Rate	Up to 1 Mbps serial communication
Max. Bus Length	• 100 meters (330 ft) at 500 kbit/s • 200 meters (650 ft) at 250 kbit/s • 500 meters (1600 ft) at 125 kbit/s • 6 kilometers (20000 ft) at 10 kbit/s
Bus Signaling	• Non-Return To Zero (NRZ) with bit-stuffing • Broadcast Scheme (All nodes listen to a message)
Cable	• ISO-11898 is defined for a twisted pair cable, shielded or unshielded. • Nominal cable impedance = 120 Ohms
Bus Access Type	• CSMA with Collision Avoidance and Non-Destructive Bitwise Arbitration. • In case of message collision, message with higher priority (lower ID value) gets access to the bus.

CAN Physical Layer Characteristics Contd..

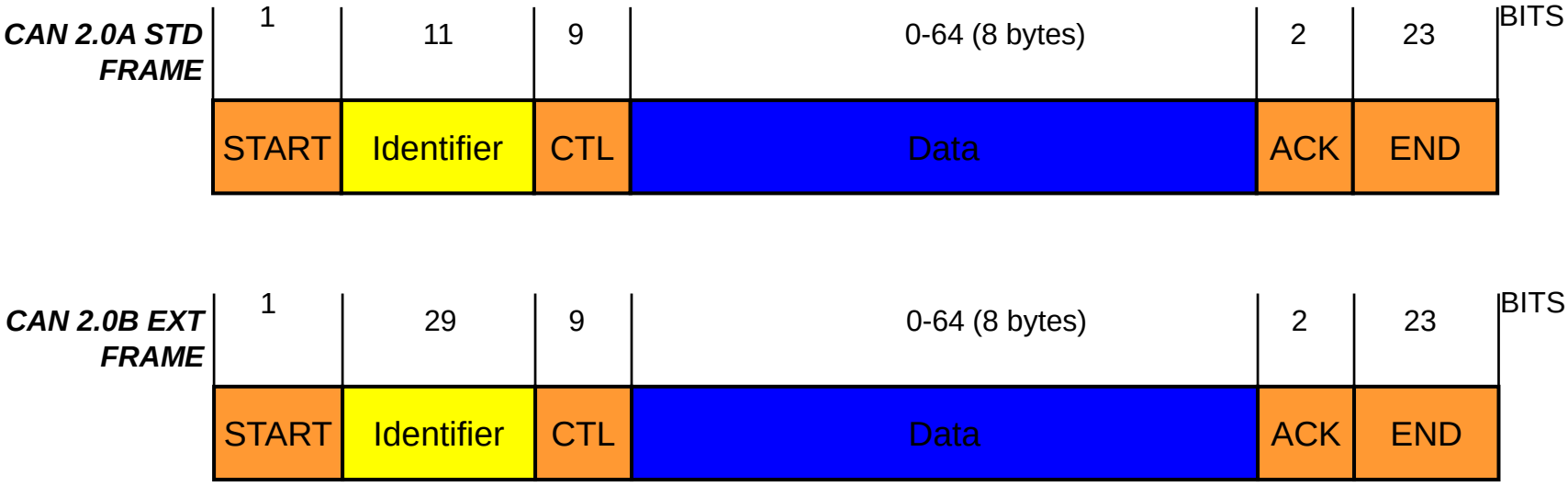
Bus Idle State	When all TX's are idle or sending logic '1'
Logic '0' (Dominant State)	+Data line is 0.2V more negative than -Data Line
Logic '1' (Recessive State)	+Data line is 0.2V more positive than -Data Line
Error Detection/Confinement	Present
Bus Termination	120 Ohms each end of backbone

CAN Data Link Layer Features

- Prioritization of messages
- Automatic retransmission of corrupted messages as soon as the bus is idle again
- Distinction between temporary errors and permanent failures of nodes and,
- Autonomous switching off of defect nodes

CAN Message Frame

- Two CAN Frame Formats,
  - CAN 2.0A Standard CAN data frame has a 11-bit Identifier Field
  - CAN 2.0B Extended CAN data frame has a 29-bit Identifier Field
- Identifiers identify the contents of the message, not its destination



CAN and CAN Higher Layer Protocols (HLPs)

- CAN describes a data link technology
- CAN Compliance doesn't mean a device is compatible with a specific CAN data link
- CAN Protocols (e.g. J1939, DeviceNet, CANopen, etc.) are CAN-based solutions
- Different CAN Protocols generally cannot be used together

CAN Higher Layer Protocols

These terms are not interchangeable!

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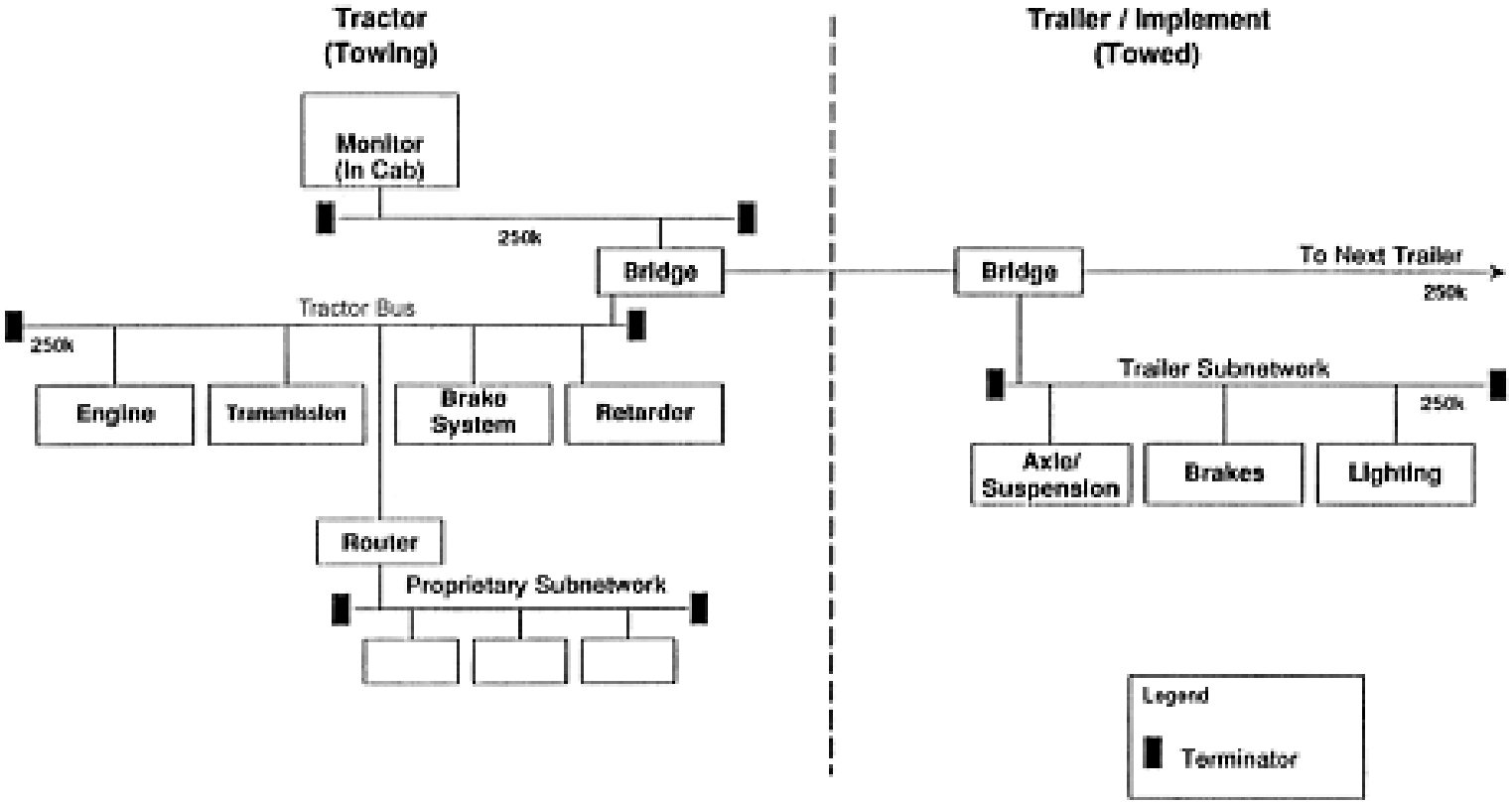
SAE J1939: Introduction

- CAN provides a framework over which higher layer protocols can be developed
- SAE-J1939 is a set of standards developed for heavy-duty (trucks and buses, mobile hydraulics, etc.)
- Uses the 29-Bit Identifiers (CAN 2.0B Extended Frame)
- Higher-layer protocol built on CAN
- Defines 250 kbit/s and 500 kbit/s networks

SAE J1939: Main Standards Overview

Document Number	Document Topic
J1939	Introduction to SAE J1939
J1939DA	J1939 Message and Parameter Definitions (Spreadsheet)
J1939-11	250 kHz Physical Layer (Shielded, Twisted Pair)
J1939-13	Diagnostic Connector
J1939-14	500 kHz Physical Layer
J1939-15	250 kHz Physical Layer (Unshielded, Twisted Pair)
J1939-21	Data Link Layer
J1939-71	Data Encoding & Data Placement Nomenclature
J1939-73	Diagnostics Messages
J1939-81	Network Management (Address Claim)

Typical SAE J1939 Vehicle Network for Truck



Source: SAE J1939 Network Layer Specification

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SAE J1939-11: Physical Layer Characteristics

Baud Rate	250 kbits/s
Cable	Shielded twisted pair wire
Bus Length	Max 40 meter bus length
Nodes	Max 30 nodes (ECUs)
Bus Termination	120 Ohms each end of backbone

SAE J1939-11: Physical Layer Characteristics

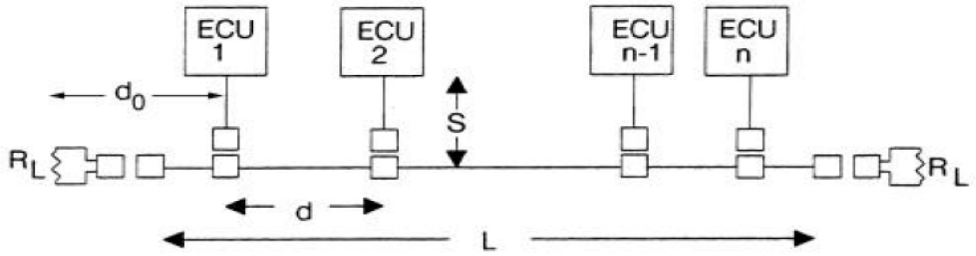

FIGURE 7—WIRING NETWORK TOPOLOGY

TABLE 8—NETWORK TOPOLOGY PARAMETERS

Parameter	Symbol	Min	Nom	Max	Unit	Conditions
Bus Length	L	0		40	m	not including cable stubs
Cable Stub Length(1)	S	0		1	m	Note 1
Node Distance	d	0.1		40	m	
Minimum Distance from R_L	d_0	0			m	R_L shall not be located within an ECU

1. The cable stub length for the diagnostic connector is 0.66 m maximum for the vehicle and 0.33 m maximum for the off-board diagnostic tool.

5.2.3 TERMINATING RESISTOR—Each end of the main 'backbone' of the linear bus must be terminated with an appropriate resistance to provide correct termination of the CAN_H and CAN_L conductors. This termination resistance should be connected between the CAN_H and CAN_L conductors. The termination resistance should meet the characteristics specified in Table 9.

TABLE 9—TERMINATING RESISTOR PARAMETERS

Parameter	Symbol	Min	Nom	Max	Unit	Conditions
Resistance	R_t	110	120	130	Ω	minimum power

SAE J1939-14: 500k Physical Layer Characteristics

Baud Rate	500 kbits/s
Cable	Shielded or unshielded twisted pair wire
Bus Length	Max 40 to 56 meter bus length (varies based upon # of ECUs)
Nodes	Max 30 nodes (ECUs)
Bus Termination	120 Ohms each end of backbone

SAE J1939-15: Physical Layer Characteristics

Baud Rate	250 kbits/s
Cable	Unshielded twisted pair wire
Bus Length	Max 40 meter bus length
Nodes	Max 30 nodes (ECUs)
Bus Termination	120 Ohms each end of backbone

SAE J1939-15: Physical Layer Characteristics

TABLE 3 - NETWORK TOPOLOGY PARAMETERS

Parameter	Symbol	Min	Max	Unit	Conditions
Bus Length	L	0	40	m	The distance between the two Load Resistors (R_L), or between any two nodes (including the diagnostic scan tool), shall not exceed 40 meters.
Node Stub Length	S	0	3	m	
Diagnostic Stub Length	S_d	0	2.66	m	
Diagnostic Tool Cable Length	S_t	0	5	m	
Stub Distance	d	0.1	40	m	The distance between stubs on the backbone.
Stub Distance from R_L	d_0	0		m	R_L may be located within an ECU, but the ECU shall be marked as a Type II J1939-15 ECU.

This table was taken from J1939-15

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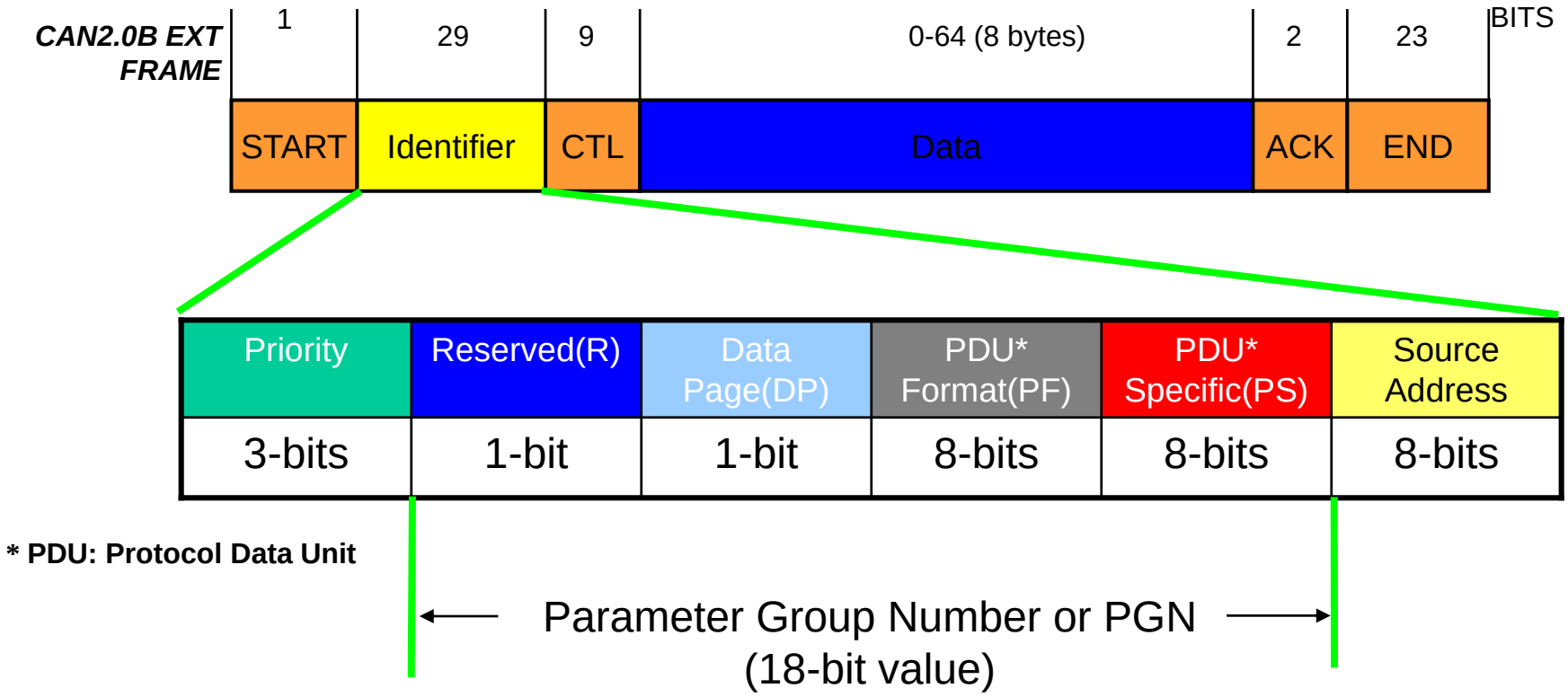
SAE J1939-21: Data Link layer Message Format

- J1939 messages are organized in to Protocol Data Units (PDU) which consists of an identifier and 8 data bytes
- Two different PDU formats present
  - PDU1: Destination Specific Messages
    - example, a request for a specific torque value from the engine instead of a specific torque value from the brake controller.
  - PDU2: Broadcast Type Messages
- J1939 uses the 29-bit identifier defined within the CAN 2.0B Extended Frame Format

SAE J1939-21: Message Frame and Identifier

- The 29-bit identifier is structured as follows,



SAE J1939-21: Message Identifier Definition (PGN)

- 29-bit identifier definition
  - Establishes 2 different message format types PDU1 and PDU2
  - ~7500 unique PDU2 message IDs and ~480 PDU1 message IDs

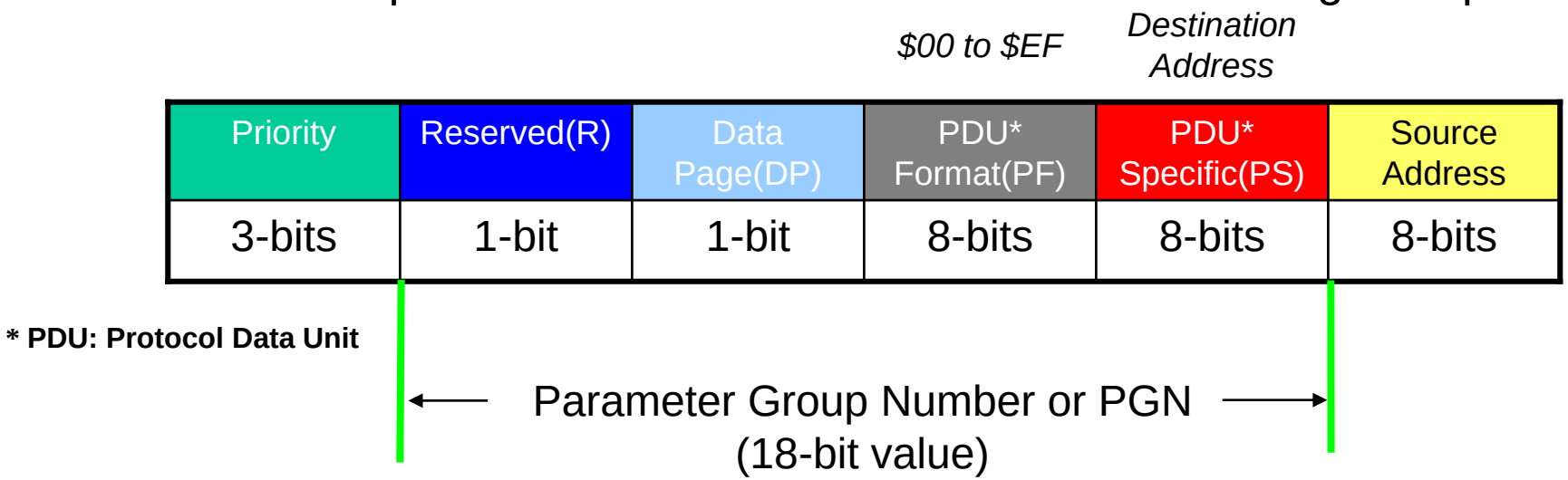
Priority	Ext. Data Page (EDP)	Data Page(DP)	PDU* Format(PF)	PDU* Specific(PS)	Source Address
3-bits	1-bit	1-bit	8-bits	8-bits	8-bits

*** PDU: Protocol Data Unit**

Priority	Defines Priority: 0-Highest, 7-Lowest
Extended Data Page	Expands number of pages, or collections, of parameter groups
Data Page	Establishes pages, or collections, of parameter groups
PDU Format (PF)	Identifies type of message, i.e. Destination Specific or Broadcast Message • PF <= 239 → destination specific message (PDU1) • PF >= 240 → broadcast message (PDU2)
PDU Specific (PS)	Destination Address or Additional Message Identifier, depends on PF • PF <= 239 → PS = Destination Address • PF >= 240 → PS = Additional Message Identifier
Source Address	Address of transmitting device

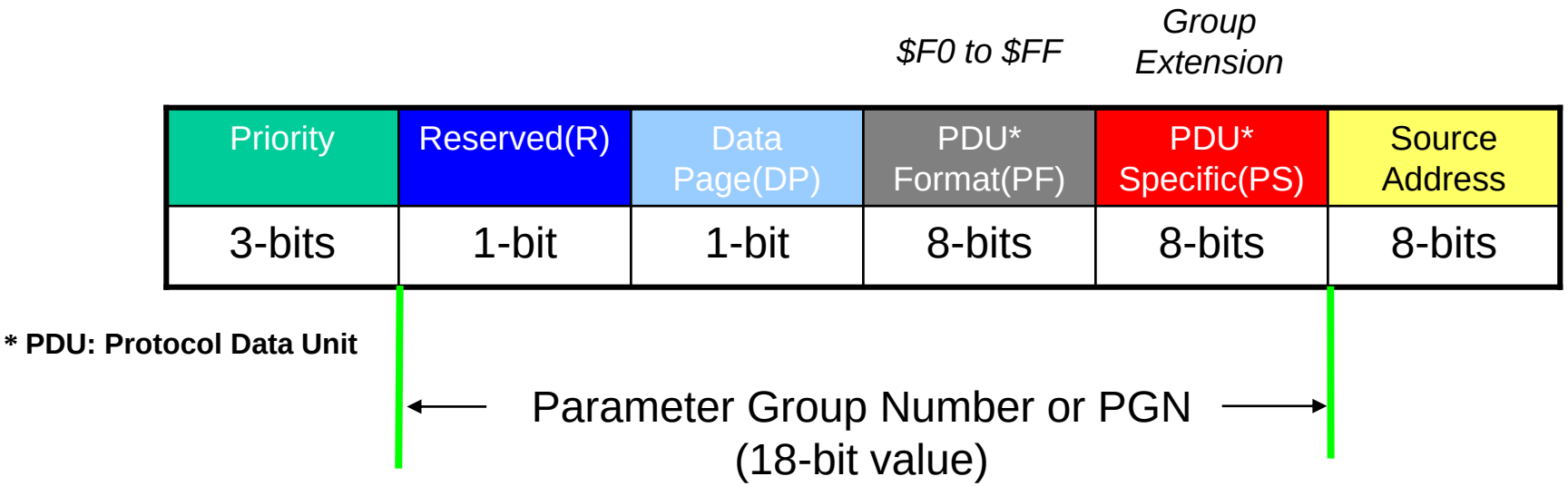
SAE J1939-21: PDU1 Format Definition

- Destination Specific messages
  - Allows sending different data to different recipients
- Uses 8 bits to uniquely identify message and its contents
- Uses 8 bits of PGN for Destination Address
  - PF: value less than or equal to 239
  - PS: value represents J1939 Address of intended message recipient



SAE J1939-21: PDU2 Format Definition

- Broadcast messages
  - Same data sent to all nodes on network
- Uses 16 bits to uniquely identify message and its contents
  - PF: value greater than or equal to 240
  - PS: additional message identifier value



SAE J1939-21: Identifier Example

- The 29-bit identifier example,
- ID 0xCF004EE can be divided into the following fields

0x0C				0xF0	0x04	0xEE
011	011	0	0	11110000	00000100	11101110
---	Priority	EDP	DP	PF	PS	SA

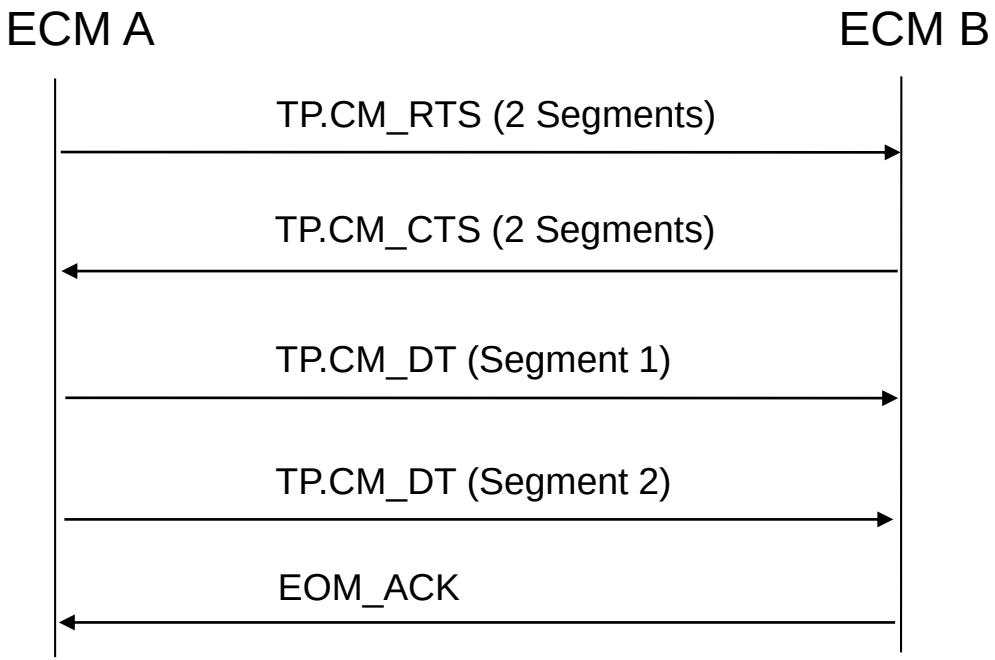
- PGN = the EDP, DP, PF and PS fields - in this case 0x0F004.
- PF = 0xF0 = 240, i.e. this is a PDU2 (broadcast) message
- PS = 0x04, i.e. the Group Extension = 4

SAE J1939-21: Transport Protocol

- Transport Protocol provides functions for transmitting PGNs with more than 8 bytes of data
- Messages > than 8 bytes are segmented into 7-byte packets with a 1-byte sequence number
- Connection Management (TP_CM) messages are used to transmit segmented messages.
  - Request to Send (RTS): Point-to-Point
  - Clear to Send (CTS): Point-to-Point
  - Data Transfer (DT): Point-to-Point
  - Broadcast Announce Message (BAM): Use global destination address

SAE J1939-21: Transport Protocol Contd..

- Total 1785 bytes of data (255 messages)
- DT message can be sent to a specific destination with handshaking or could be Broadcast without handshaking



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SAE J1939-31: Network Layer Functions

- Defines services and functions for intercommunication between different subnets of the J1939 network

- Four ECU types provide interconnection
  - Repeater (forwarding),
  - Bridge (forwarding and filtering),
  - Router (forward, filter, and address translation), and
  - Gateway (forward, filter, address translation, and message repackaging).

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SAE J1939DA: Digital Annex Spreadsheet

- Technical definitions of all J1939 PGNs
  - EDP, DP, PF, and PS values
  - PGN Data length (bytes)
  - Message transmission behavior
  - Data field content and placement
- Technical definitions of all J1939 SPNs
  - Data length (bytes)
  - Resolution (scaling and offset, unit of measurement)
  - Data range (range of the physical value, after scaling)
  - Type (status, measured value)
- J1939 NAME Function Lists
- J1939 Source Address Lists
- J1939 NAME Manufacturer Code Lists

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SAE J1939-71: Vehicle Application Layer

- Describes data encoding practices
- Describes standard 'Data Error' encoding
- Describes parameter placement practices
- Describes parameter placement nomenclature

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SAE J1939-73: Diagnostics

- Describes services and functions for accessing Diagnostic and Calibration data from devices on the network
- Diagnostic Messages (DM)
  - Reading and writing to ECU memory
  - Reporting diagnostic information when running
  - Identification of lamp status
  - Reading and clearing Diagnostic Trouble Codes (DTCs)
  - Start/Stop broadcast DMs
- DTC is a 32-bit Identifier which contains
  - Suspect Parameter Number (SPN)
  - Failure Mode Indicator (FMI)
  - Occurrence Count (OC)
  - SPN Conversion Method

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SAE J1939-81: Network Management Layer

- J1939 NAME Contents (Address Identity)
- Address Claiming Process

- J1939 NAME
  - 8-byte long number constructed from 10 different fields
  - Uniquely identifies each ECU/node on network
  - Identifies ECU function, ECU instance, Manufacturer, etc.
  - Numerical value signifies priority used during Address Claim process

SAE J1939-81: J1939 Name

- J1939 NAME is composed of 10 fields shown below
- Name identifies
  - Functionality
  - Adds unique Instance Number to that functionality

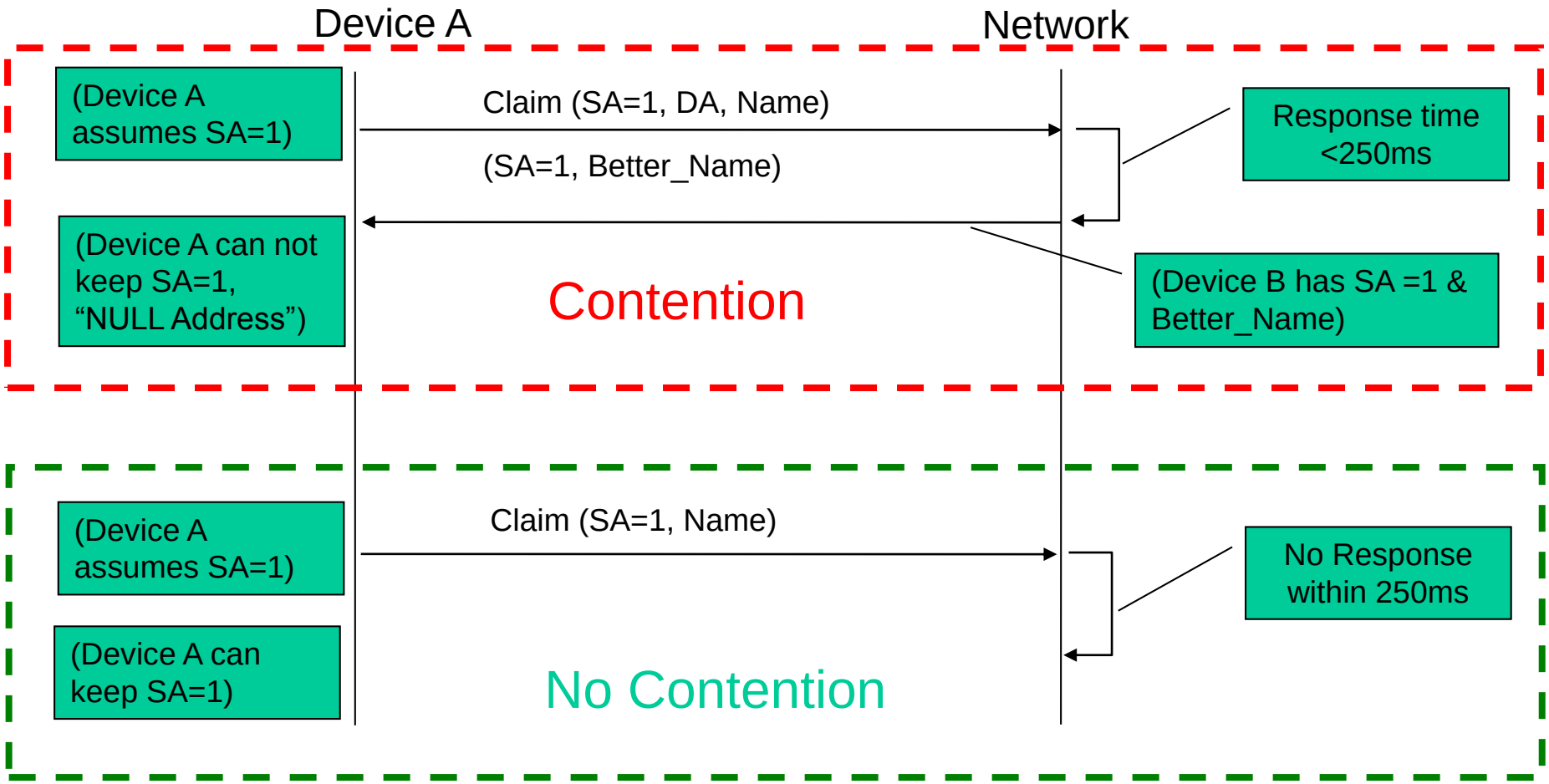
1	Arbitrary address bit
2	Industry group, length 3 bits
3	Vehicle system instance, length 4 bits
4	Vehicle system, length 7 bits
5	Reserved bit
6	Function, length 8 bits
7	Function instance, length 5 bits
8	ECU instance, length 3 bits
9	Manufacturer code, length 11 bits
10	Identity number, length 21 bits

SAE J1939-81: Address Claim

- Run time process to arbitrate for Source Address on network
  - ECUs issue Address Claim message at power up to claim Address
  - If multiple ECUs seek same Address, arbitrate using J1939 NAME to determine ECU with priority to Address
  - Other ECUs send new Address Claim message for different Address
- Used to associate Source Address with ECU Function
- Source Address Ranges
  - Fixed Addresses ($00 to $7F, $F9 to $FF)
    - Restricted for use by ECUs with specific Functions
  - Dynamic (Arbitrary) Addresses ($80 to $F8)
    - No fixed address meaning. Available for use by any ECU

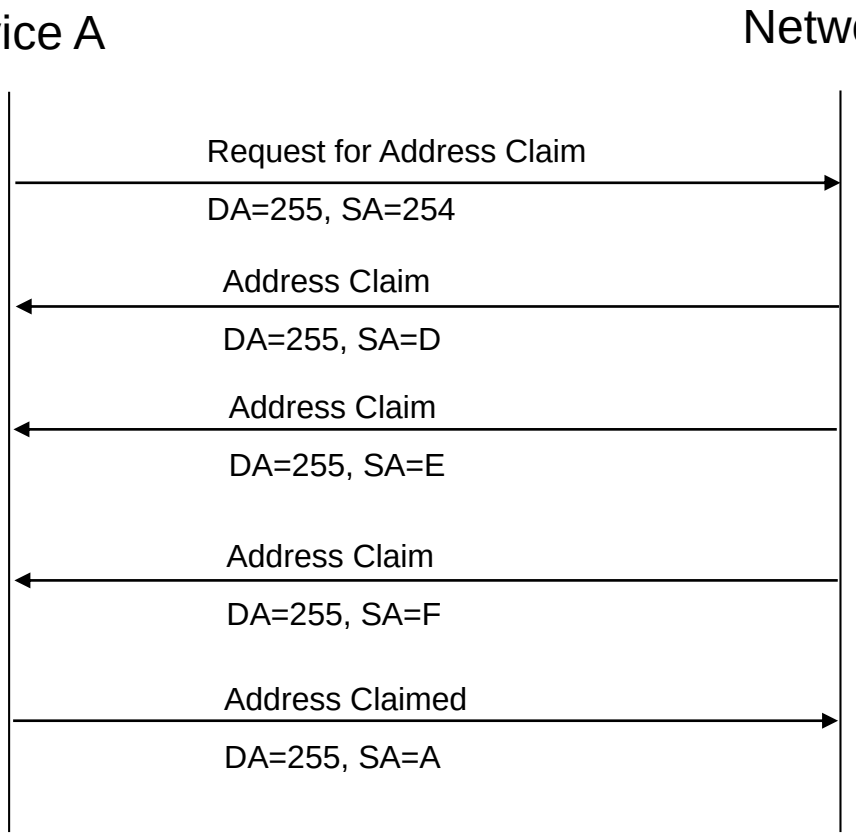
SAE J1939-81: Send Address Claim Message

- Send an Address Claim message to claim an address



SAE J1939-81: Request for Address Claim

- Send an Request for Address Claim message



- 255 is the Global Address
- 254 is the NULL Address

No Contention

SAE J1939 Memory Access Protocol (MAP)

- Communication service for special data read and write operations
- Originally established as public J1939 service for flahs programming and writing configuration parameters
- Exchange is performed using a series of one-or-more Read or Write transactions
- Communication interface for information exchange services between two devices
- Only one MA session between 2 devices at any given time

SAE J1939 Memory Access Protocol (MAP)

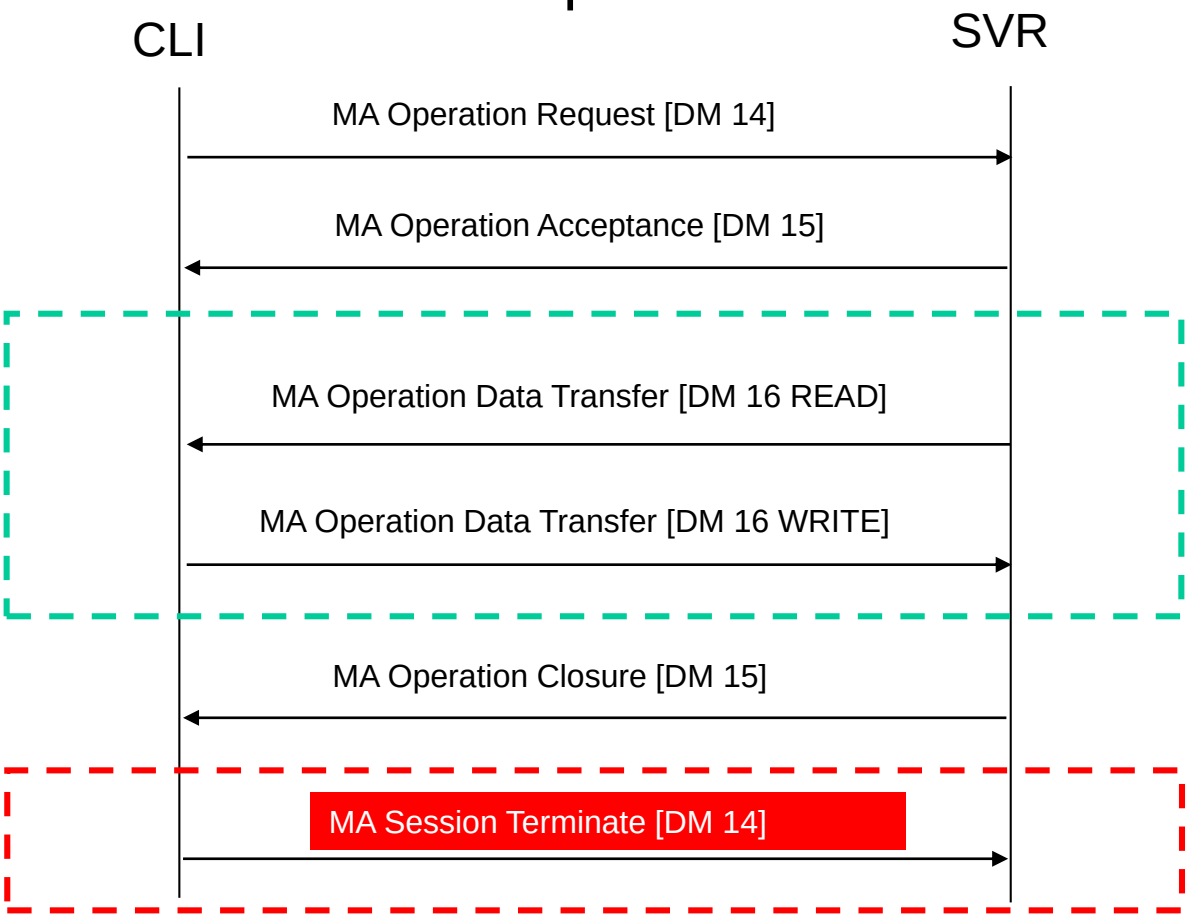
- Two addressing methods
  - Direct Memory Addressing
    - 32-bit addressing
  - Indirect Memory Addressing
    - 24-bit addressing

- Following messages are required to support MAP

Message ID	Description
$00D900 (55552)	Memory Access Request Message (DM14)
$00D800 (55296)	Memory Access Response Message (DM15)
$00D700 (55040)	Binary Data Transfer Message (DM16)

SAE J1939 Memory Access Protocol (MAP)

- General MAP Read/Write sequence flow



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SAE J1939 Proprietary Strategy

- SAE has allocated 514 PGNs for Manufacturer Specific Use
  - Interpretation of PGNs are dependent upon Manufacturer ID specified in J1939 NAME for Source and/or Destination Addresses

SAE J1939 Designation	PGN Range	Messaging Type
PropA	61184	Source & Destination Addresses
PropA1	126720	Source & Destination Addresses
PropB	65280 - 65535	Source Address Only (Broadcast)
PropB1	130816 - 131071	Source Address Only (Broadcast)

- SAE specifies that proprietary messages can account for no more than 2% of the network traffic

SAE J1939 Proprietary Strategy Contd..

- Caterpillar Strategy for SAE J1939 Proprietary Messages
  - Applications shall only used as Approved through ID Coordinators
  - All Proprietary Messages shall be Centrally Managed
    - Basic Communication Services
      - Read/Write, PGB, BDT, Flash Programming, etc.
    - Service support Protocols
      - Component calibrations, Service Tests, etc.
    - Parameter data for control and service support
  - Limited Allocation of Application Specific Messages
    - Peer-to-Peer control communications

SAE J1939 CAT Extension ID (CAT EXT ID)

- Caterpillar Use of Proprietary A Messages
  - Part of Data Field Contains Message Identifier
  - Data Field Message Identifier called CAT EXT ID (also PPGN)
    - CAT EXT ID occupies first 1 or 2 bytes of Data Field
    - CAT EXT ID uniquely identifies message content or function
    - CAT EXT IDs only applies with PropA messages by CAT ECUs
    - Applies to PropA (PGN 61184)
    - Plan to apply same model to PropA2 (PGN 126720)

- Caterpillar Use of Proprietary B Message
  - No strategy for Data Field Message Identifier for Proprietary Broadcast (PropB) messages at this time

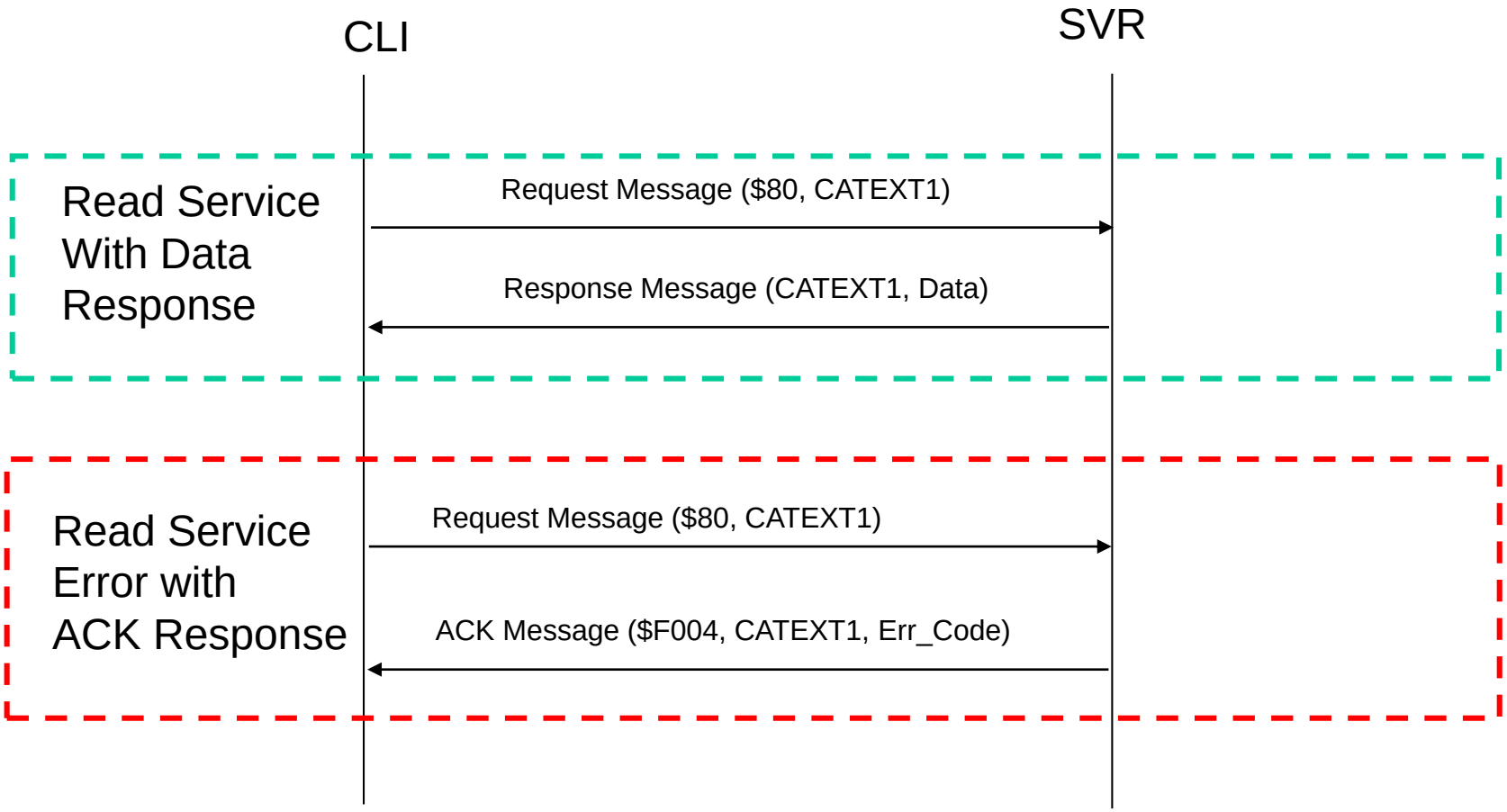
SAE J1939 Proprietary Basic Comm. Services

- Basic Communication Services
  - Read
  - Write
  - Acknowledgement
  - Data Exchange Protocols

CAT EXT ID	Description
$80	Read Request
$81	Write Request with Data Response
$82	Write Request with Acknowledge Response
$83	Write Data Response
$F004	Acknowledge Response

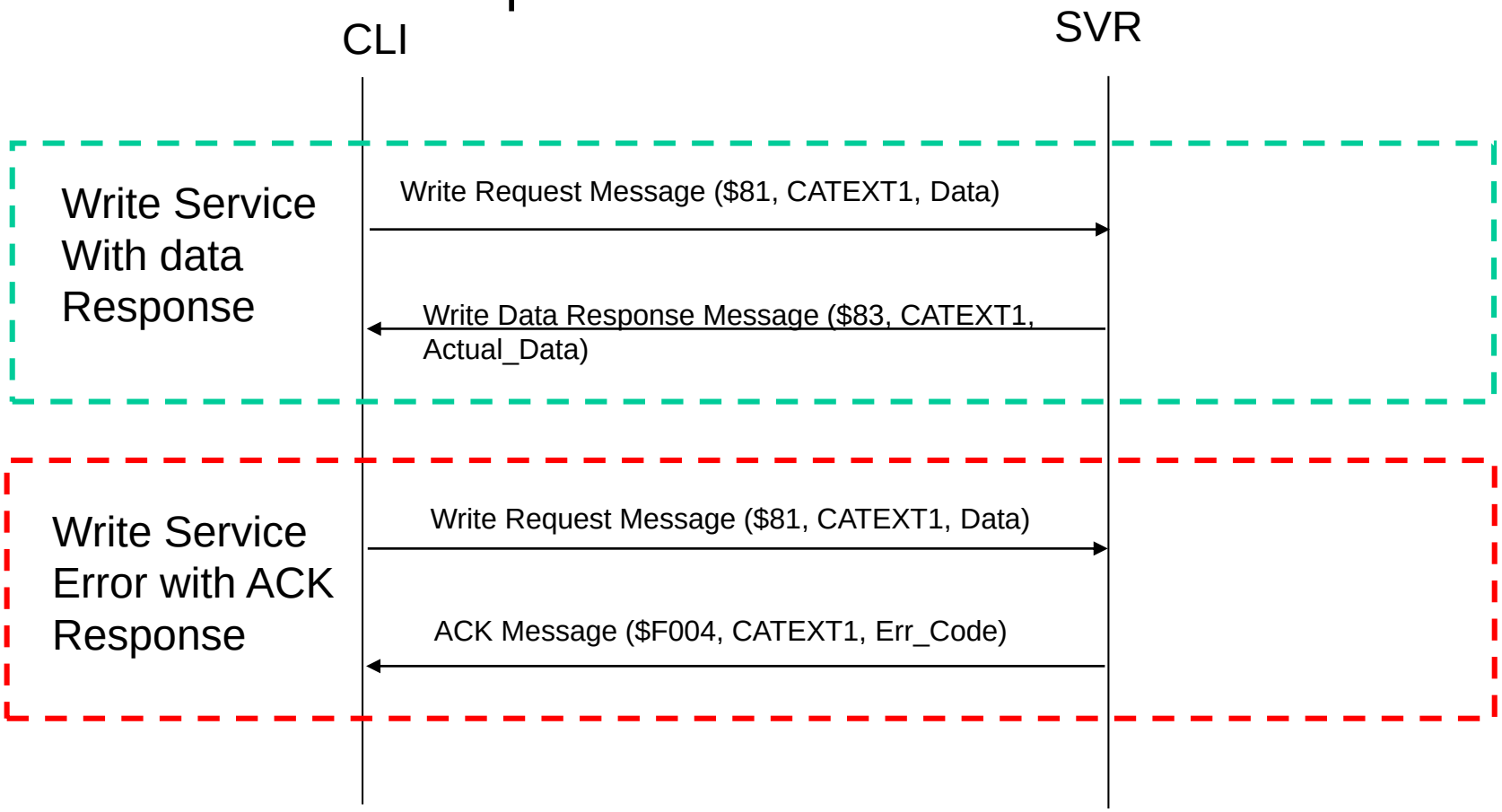
SAE J1939 Proprietary Basic Comm. Services

- Read Service



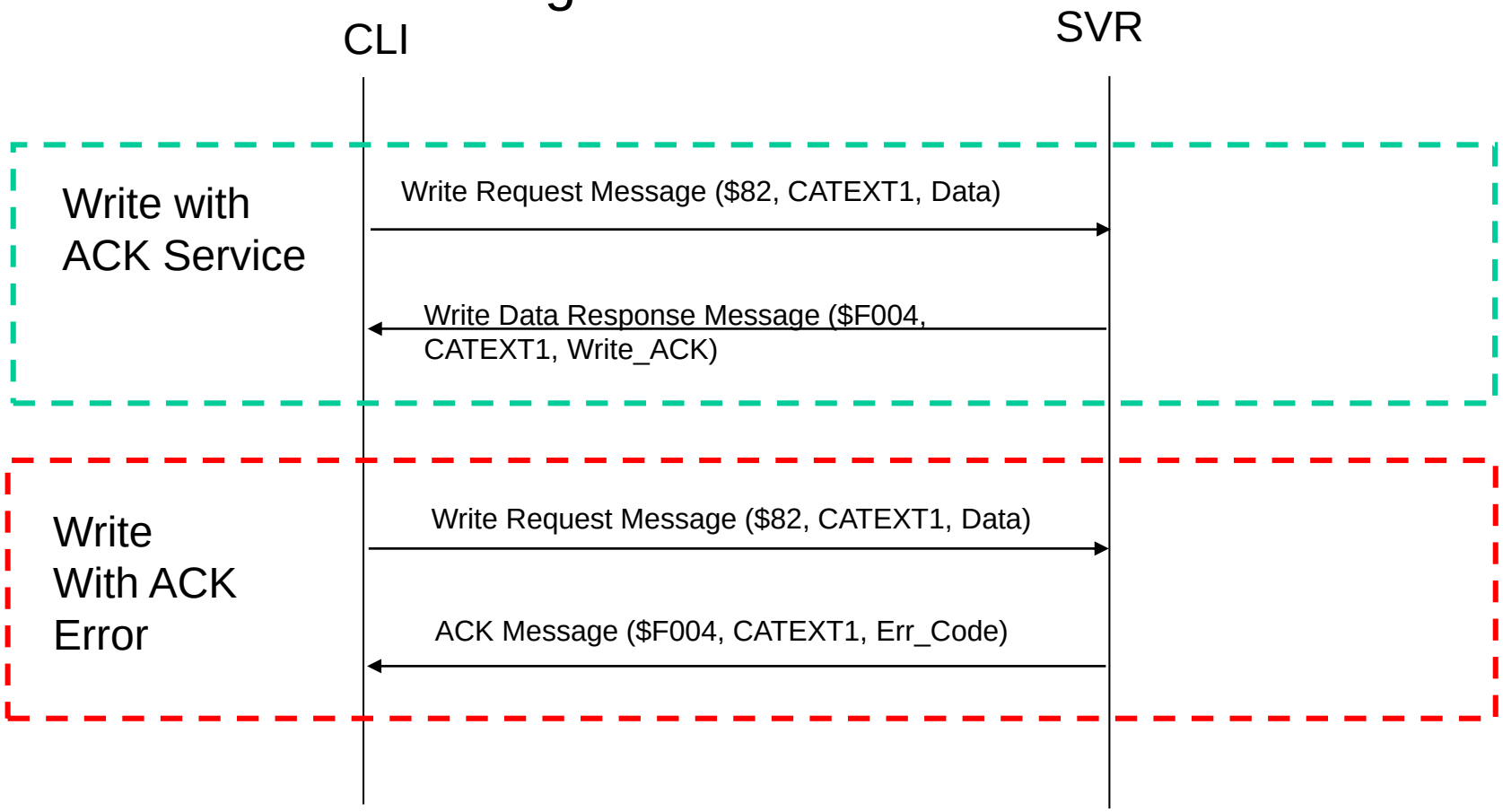
SAE J1939 Proprietary Basic Comm. Services

- Write with Data Response Service



SAE J1939 Proprietary Basic Comm. Services

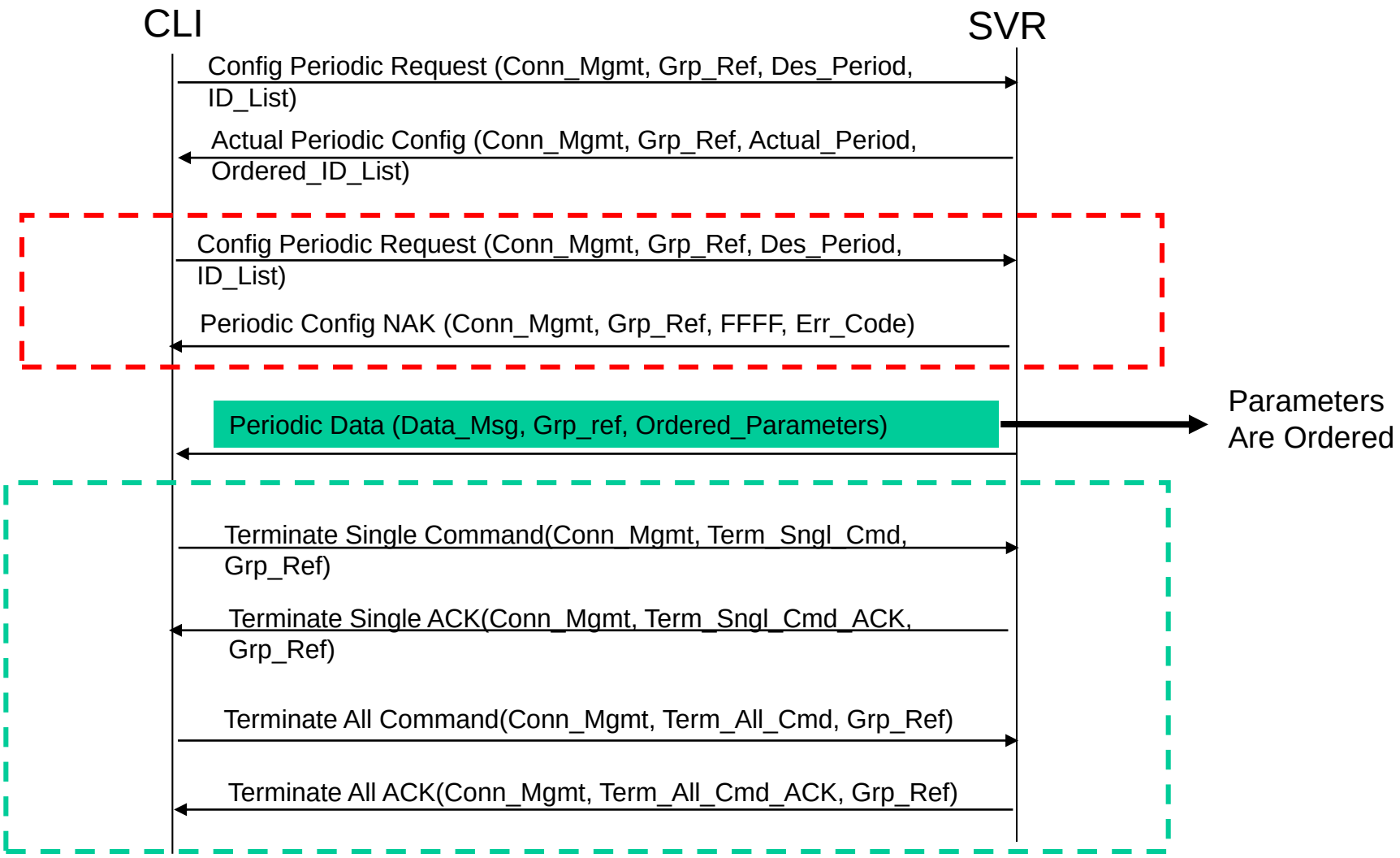
- Write with Acknowledge Service



Periodic Group Broadcast (PGB) for CDL PIDs

- Allows Periodic transfer of information between ECMs using existing CDL PIDs over J1939 network
- Supports transfer of 1-byte, 2-byte and 4-byte data PIDs
- Allows easy transition from CDL to J1939 to support periodic transfers on J1939
  - Eliminates rewriting of data handlers for public J1939 parameters and/or proprietary CAT EXT IDs
  - Applications can take advantage of extensive CDL PID library

Periodic Group Broadcast (PGB) for CDL PIDs



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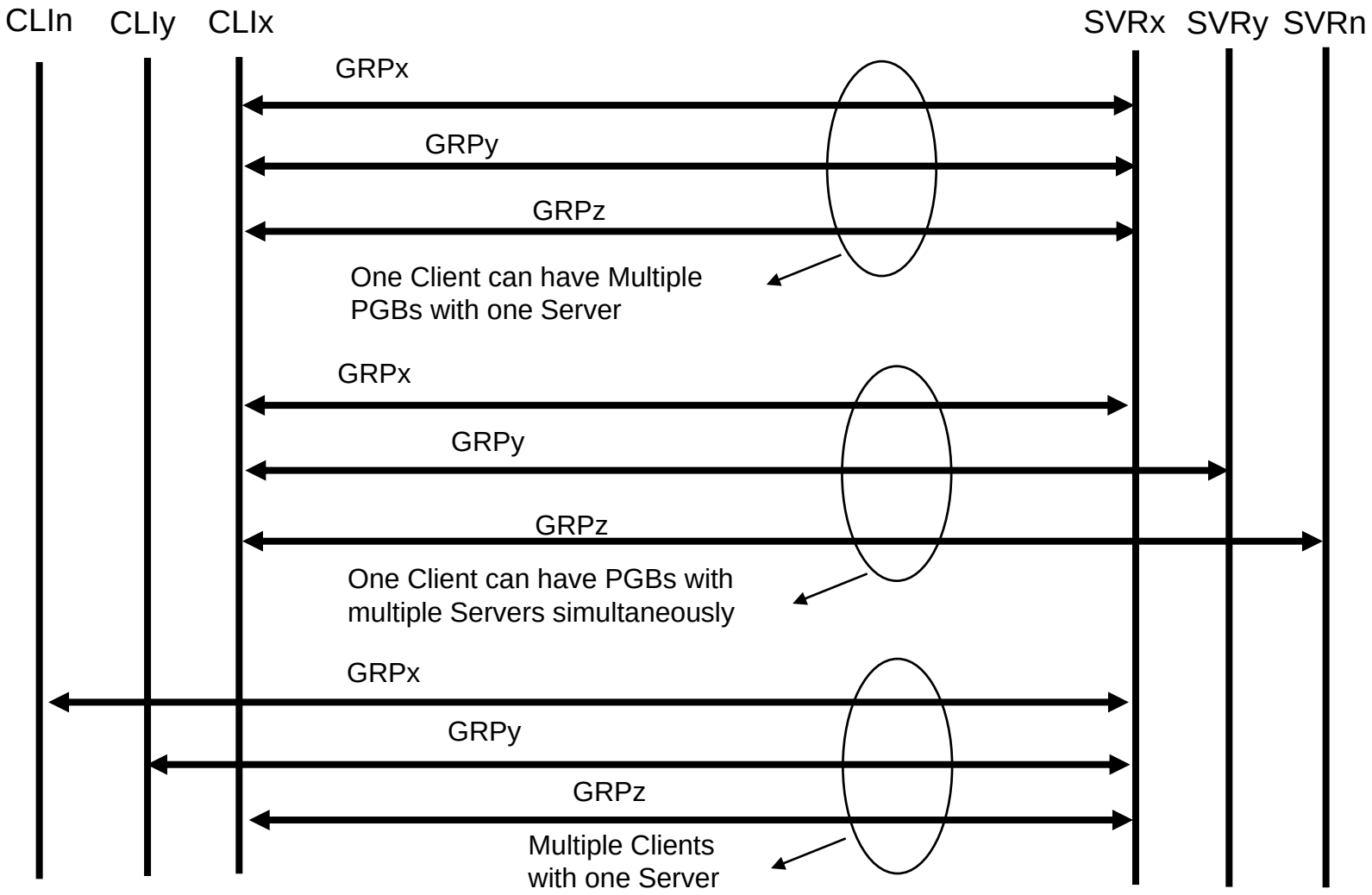


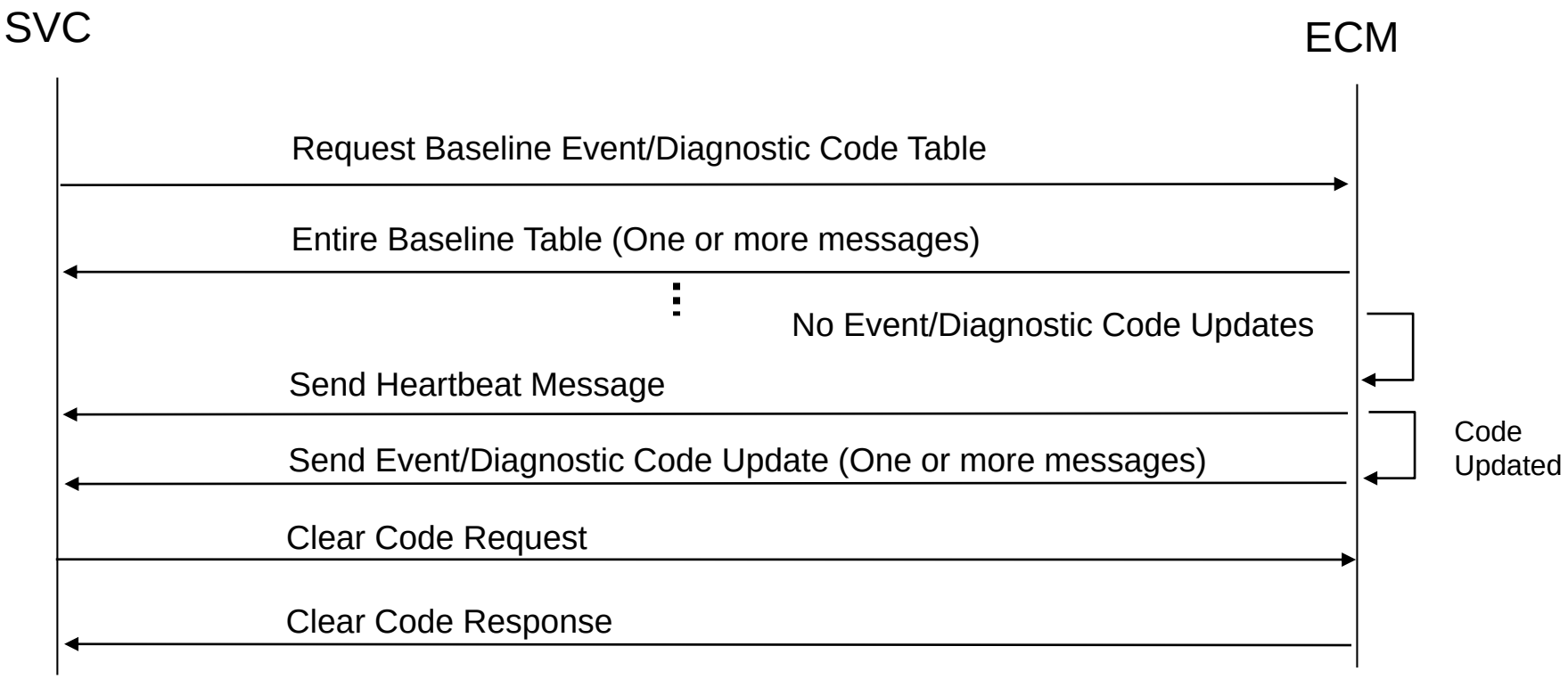
J1939 Override Protocol

- Allows Service, Diagnostic tool to temporarily override certain ECM IO. E.g. Actuators, Sensors etc.
- Used during servicing, troubleshooting and installation testing of an application

J1939 Events & Diagnostic Data Transfer (EDDT) Protocol

- Allows a mechanism to transfer CDL format Event and Diagnostic Data over J1939
- Exchange the CAT Data Link format CID-WCI-FMI and/or EID-WCI information on J1939
- Baseline Event and Diagnostic code table is communicated during initialization
- Event based data exchange (Event/Diagnostic code data is communicated only when status changes)
- Reduces bus load and CPU load

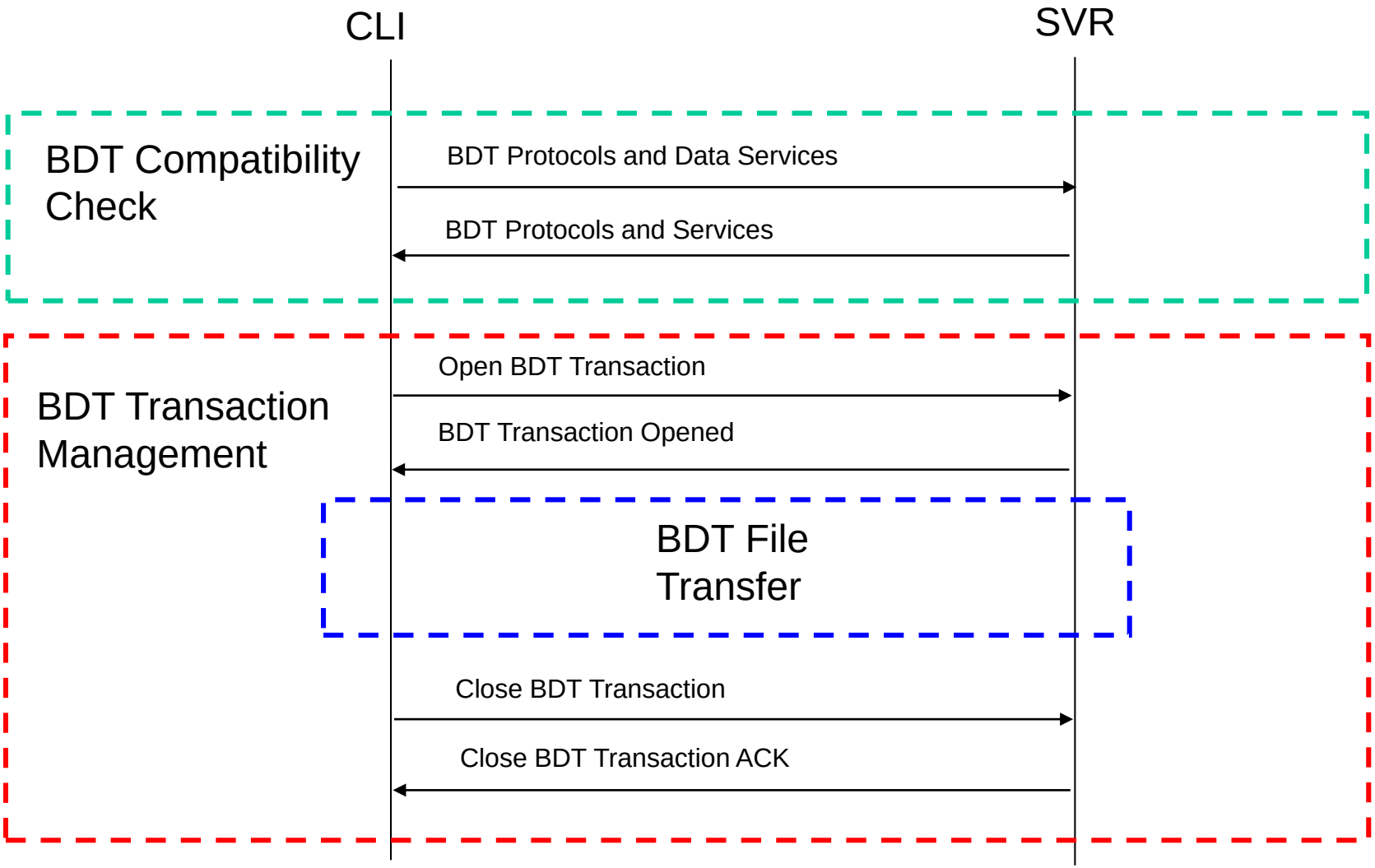
J1939 EDDT Generic Protocol Exchange



J1939 Block Data Transfer (BDT) Protocol

- BDT is used to exchange large amounts of data over J1939 data link
- Utilizes J1939 Transport Protocol services
- The BDT file formats are pre-defined by System Standards
- Types of data exchanged include for e.g. Histogram list or Histogram data between an ECM and service tool
- Max size of approximately 16MB can be transferred

J1939 BDT Generic Protocol Exchange



J1939 Calibration Protocol

- Provides common protocol structure for all component calibrations over J1939
- Used to program/modify operating set-points, boundaries, limits for a component within a system
- Service Tools and On-Board Monitoring Systems provide the user interface for the calibration
- Execution of calibration completely handled by the ECM

J1939 Programmable Monitoring System

- Protocol for configuring event and diagnostic trip criteria over the J1939 Data Link
- Examples,
  - Trip threshold
  - Delay time between the reaching the trip threshold and raising the event/diagnostic,
  - Severity of the abnormal condition, etc
- ECM can communicate some of these trip conditions to another device on the link
- Allows configuration of trip criteria on a device

CAN/J1939 Basic Training Module

- End of Presentation