Communication Protocols

In Vehicle

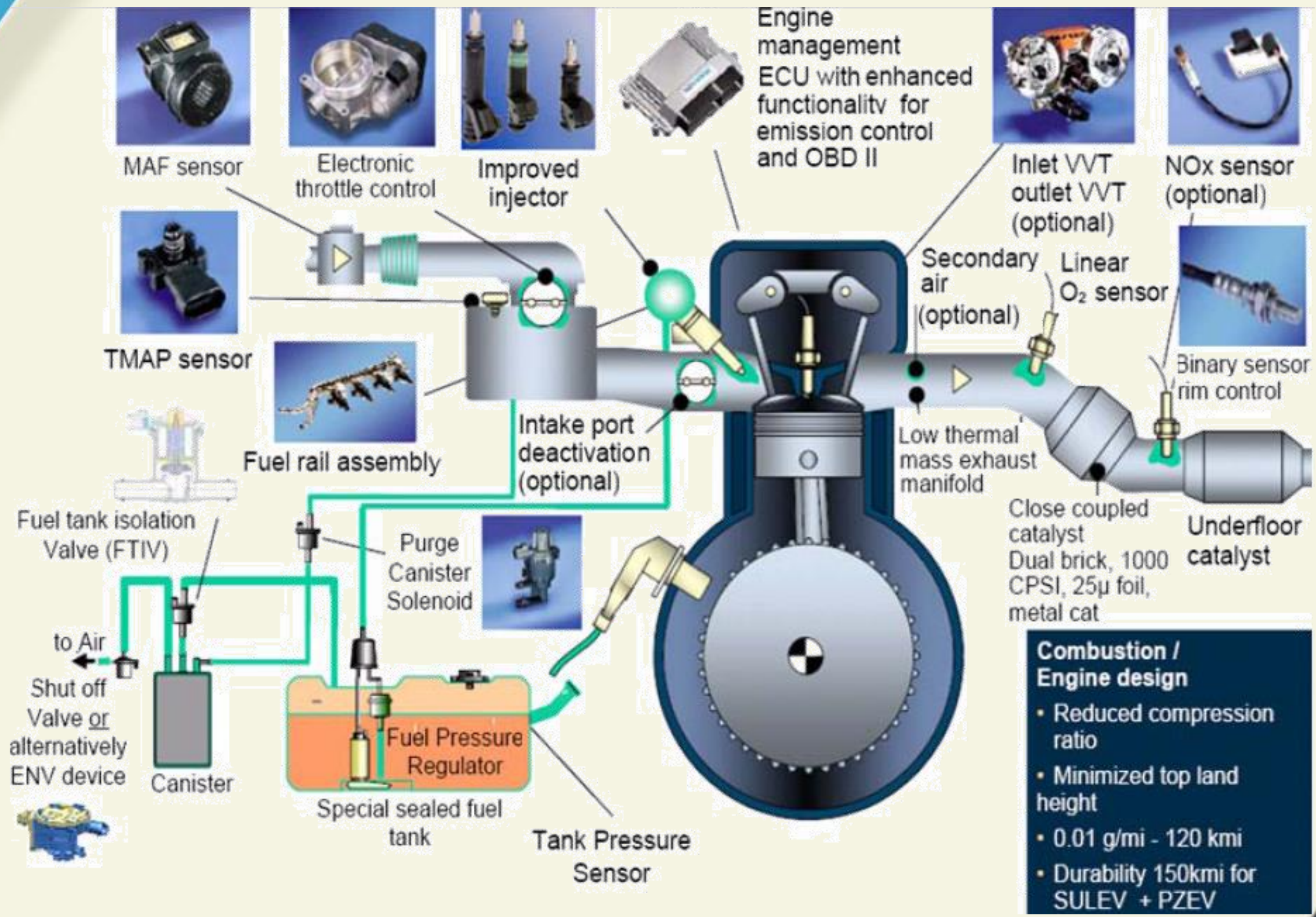
الدكتور مصطفى شبل

Applications

- Assist the driver to control the vehicle
  - ABS (Anti-lock Braking System),ESP (Electronic Stability Program),EPS (Electric Power Steering)
- Control devices
  - Lights, wipers, doors, entertainment and communication equipments
- Add Advanced Driver Assistance Systems (ADAS)
  - Park assistance, lane departure detection, night vision assistance
- Large intelligent transportation systems
  - Car-to-car and car-to-infrastructure communications.

Power train

Gasoline Engine System



The ECU Control Loop

SENSORS

- ✓ Throttle position
- ✓ Intake air temperature
- ✓ Manifold air pressure
- ✓ Mass air flow (MAF)
- ✓ Fuel pressure
- ✓ In-cylinder pressure
- ✓ Coolant temperature
- ✓ Crankshaft position
- ✓ Camshaft position
- ✓ Engine speed
- ✓ Engine knocking
- ✓ Exhaust gas oxygen

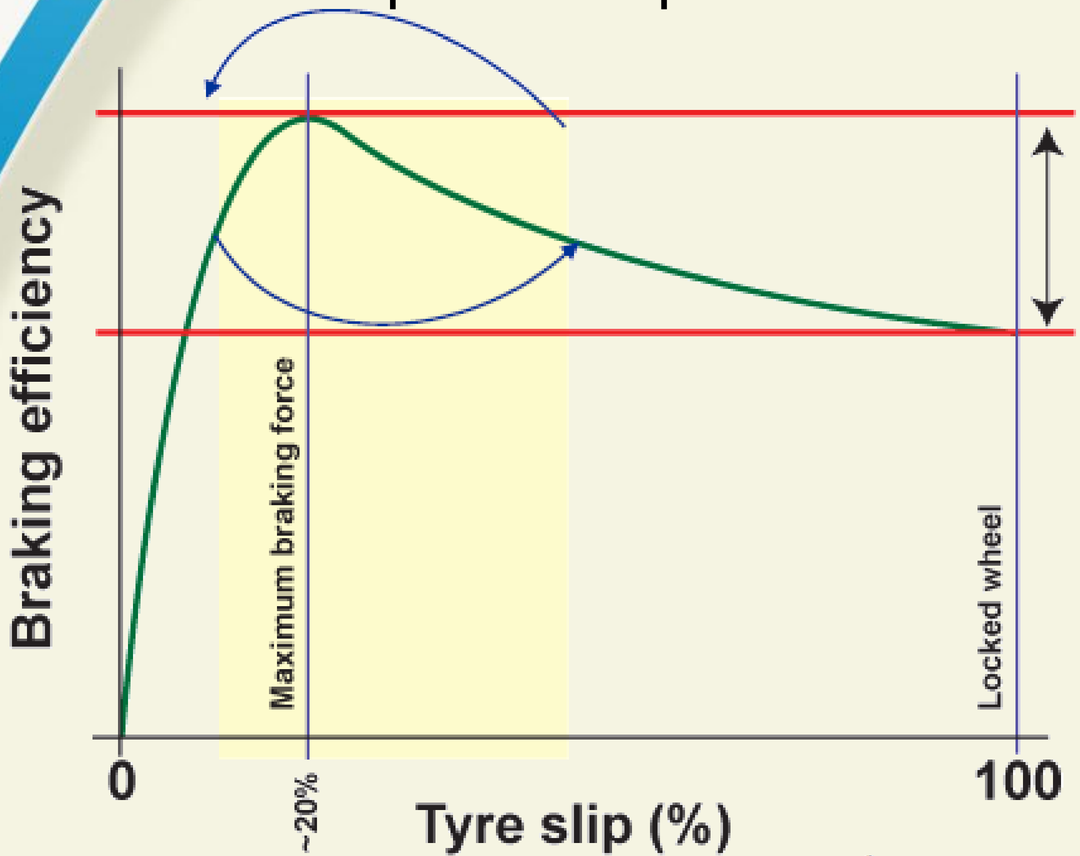
ACTUATORS

- ➢Fuel injection
- ➢Idle speed control
- ➢Ignition timing
- ➢Multispark timing
- ➢Dwell angle
- ➢Valve timing (VVT)
- ➢Camless valve actuation
- ➢Exhaust gas recirc. (EGR)
- ➢Turbo boost
- ➢Transmission control

Safety and Breaking Systems

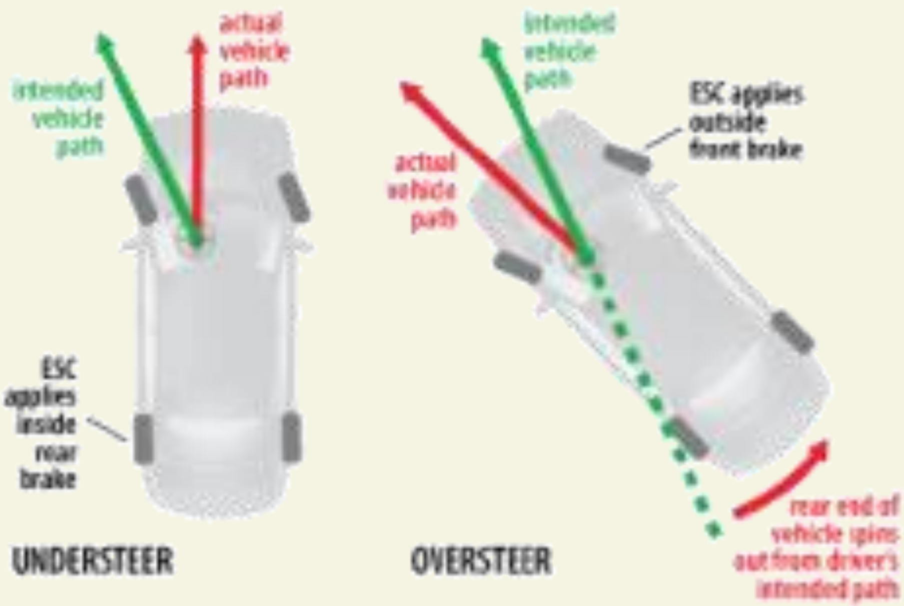
Anti-lock Braking System(ABS)

During emergency braking, ABS automatically cycles tire slip around point of maximum braking efficiency



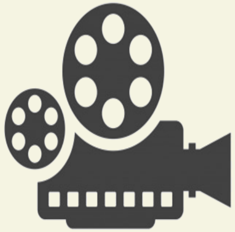
$$\left(\frac{(Vehicle\_speed)-(Wheel\_speed)}{Vehicle\_speed}\right)\times 100\%$$

Electronic Stability Program/Control (ESP/ESC)

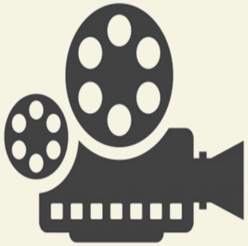


Bosch VDC / Mercedes ESP Stability Control

- Enhances stability through asymmetric braking (yaw)
- ESC may be required during ABS, DRP or TCS events
- Sensors collect information
  - ✓ Individual wheel speeds
  - ✓ Steering angle
  - ✓ Yaw rate
  - ✓ Lateral acceleration…
- ECU runs algorithms to detect and correct ESC events
- Mercedes W-140 S-Class had first complete ESC in 1995

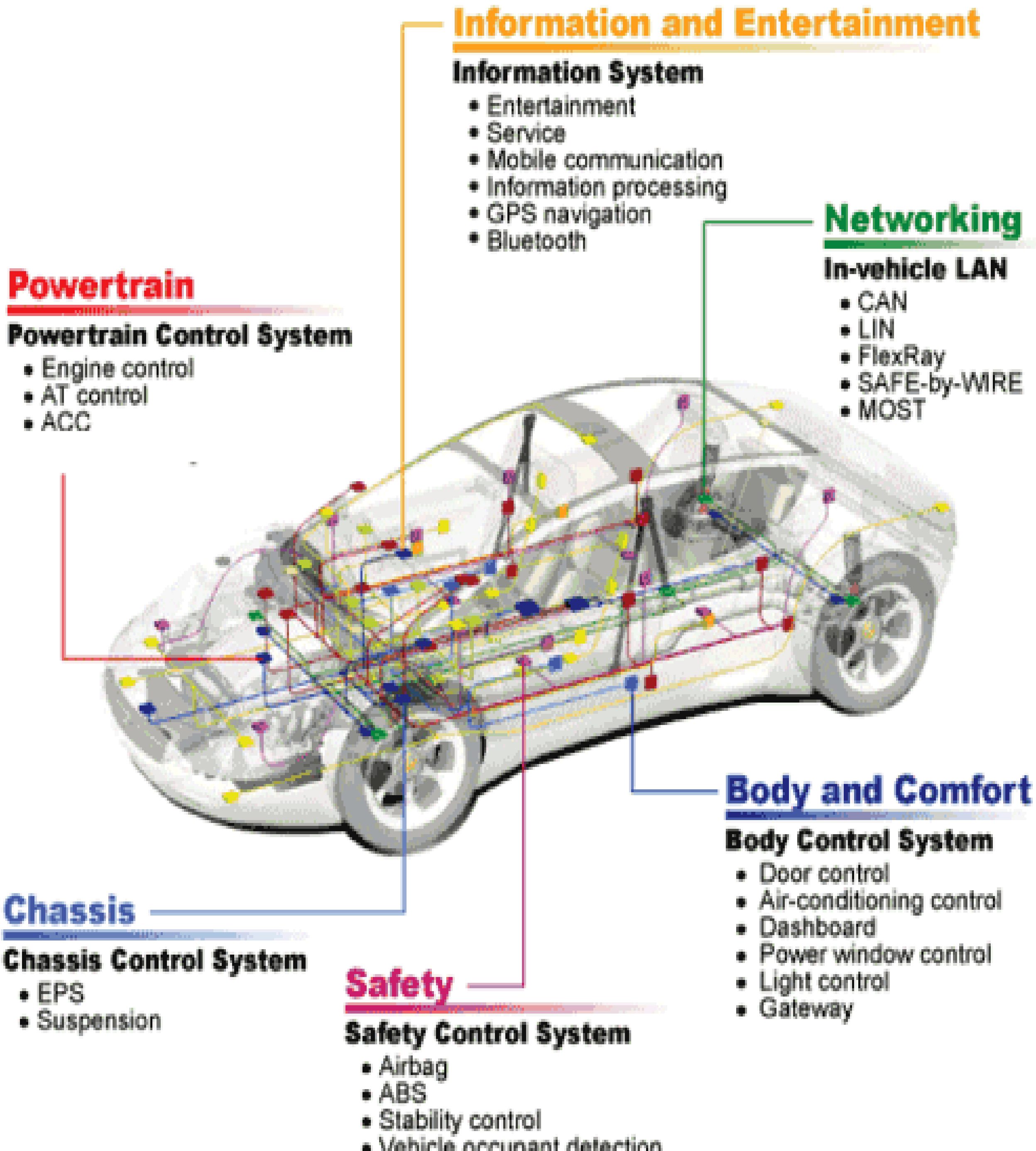


Electronic Power Steering (EPS)



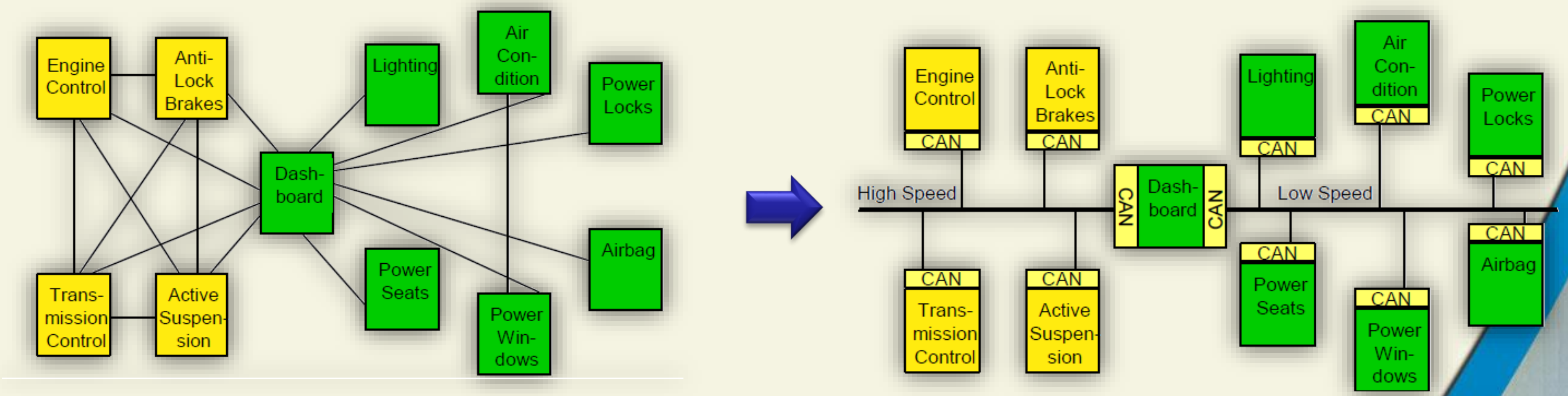
Automotive Networking

Systems


Information and Entertainment
Information System
• Entertainment
• Service
• Mobile communication
• Information processing
• GPS navigation
• Bluetooth
Networking
In-vehicle LAN
• CAN
• LIN
• FlexRay
• SAFE-by-WIRE
• MOST
Powertrain
Powertrain Control System
• Engine control
• AT control
• ACC
Body and Comfort
Body Control System
• Door control
• Air-conditioning control
• Dashboard
• Power window control
• Light control
• Gateway
Chassis
Chassis Control System
• EPS
• Suspension
Safety
Safety Control System
• Airbag
• ABS
• Stability control
• Vehicle occupant detection

The problem

- There are more than 70 ECUs (Electronic Control Unit) need to control diverse functions .
- P2P communication links=n^2
- Weight, cost, complexity and reliability increased by the wires and the connectors .



**1998 press release, the replacement of a wiring harness with LANs in the four doors of a BMW reduced the weight by 15 kilograms.

In-vehicle networking
Provides

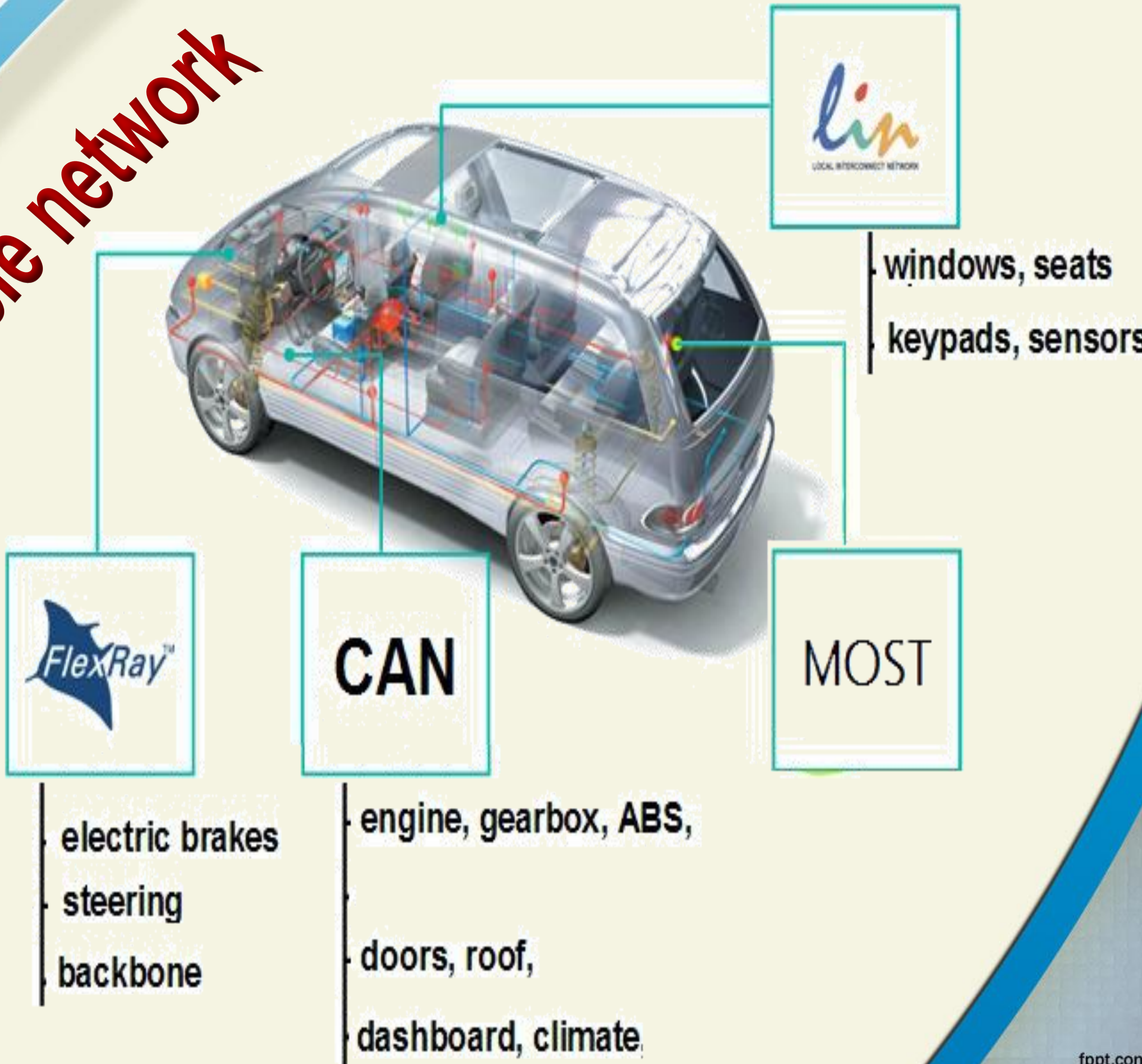
- Fewer wires required for each function, which reduces the size of the wiring harness and improves system cost, weight, reliability, serviceability and installation time .
- Additional functions can be added by making software changes, allowing greater vehicle content flexibility
- Common sensor data available on the network so it can be shared, eliminating the need for multiple sensors

In-vehicle networking
Provides

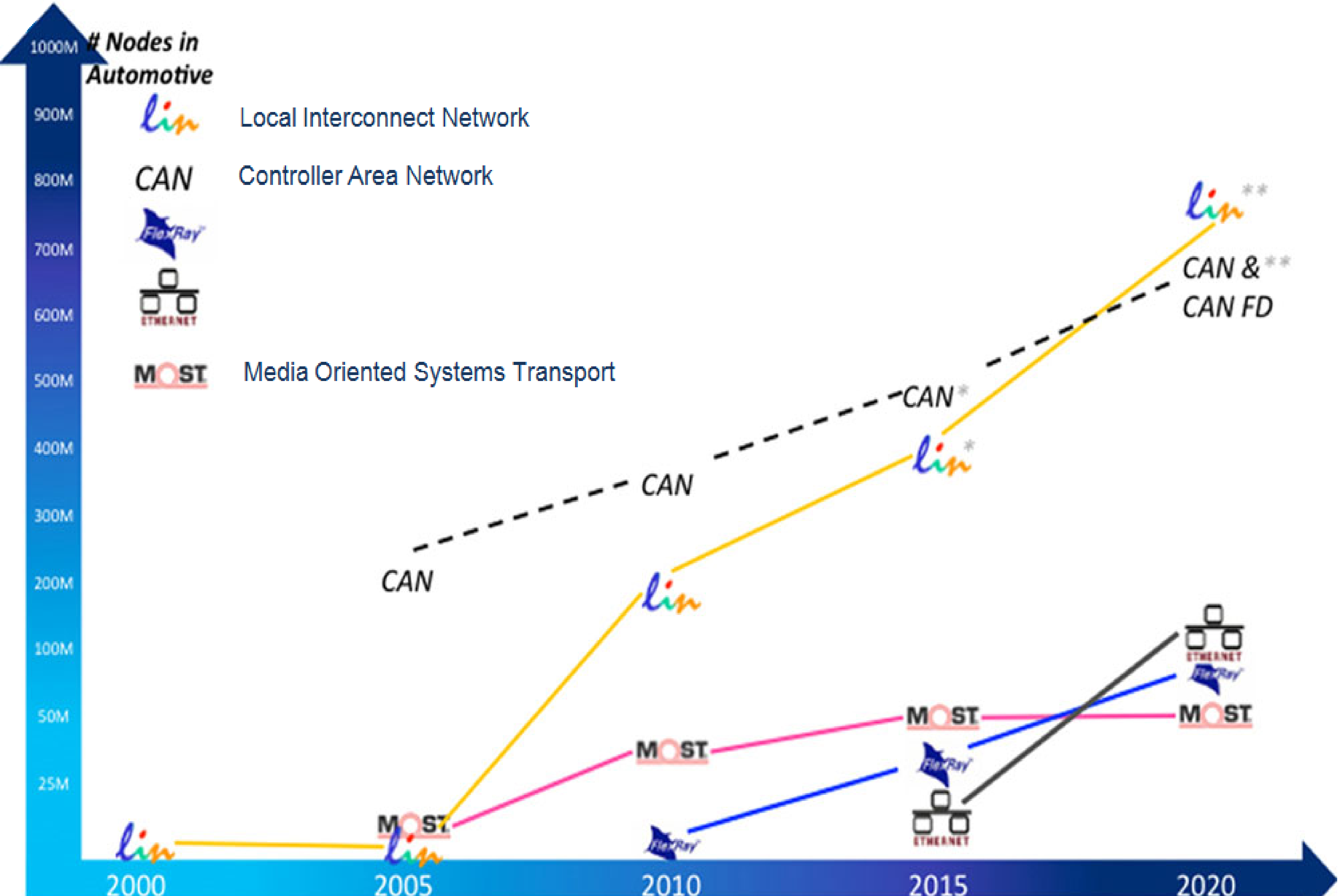
- Protection against :
  - (ESD) **Electrostatic discharge .**
  - (EMI) Electromagnetic interference .
  - Short circuits

- Failure detection and containment .
- Hardware operating mode control.

Intra-vehicle network



Growth in In- Vehicle Networks



*2014 SA Data;
** REA estimate based on Market knowledge

Sources: Strategy Analytics, Automotive High Speed Bus Networks January 2012
Strategy Analytics, Automotive Network Protocol Demand Forecast 2005-2014

Comparison

BUS	LIN	CAN	FLEXRAY	MOST
Cost/Node [$]	1.50	3.00	6.00	4.00
Used in	Subnets	Soft real-time	Hard real-time	Multimedia
Applications	Body	Chassis, Powertrain	Chassis, Powertrain	Multimedia, Telematics
Message transmission	Synchronous	Asynchronous	Synchronous & Asynchronous	Asynchronous & Synchronous
Data rate	20 kbps	1 Mbps	10 Mbps	24 Mbps
Physical layer	Single Wire	Dual-Wire	Dual-Wire (Optical-Fiber)	Optical-Fiber (Dual-Wire)
Latency jitter	Constant	Load dependent	Constant	Data stream
Extensibility	High	High	Low	High

Controller Area Network (CAN)

Eye on History

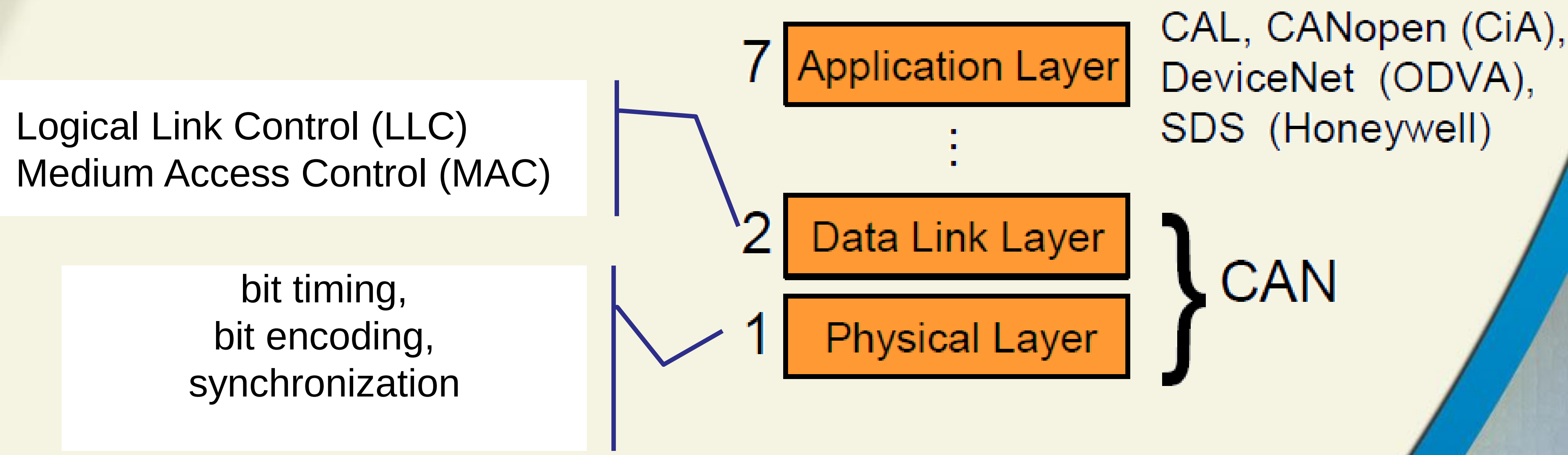
1. By Robert Bosch GmbH, Germany, in the late 1980s
2. Standardized by the International Standardization Organization (ISO) and the Society of Automotive Engineers (SAE)

Basic Concepts

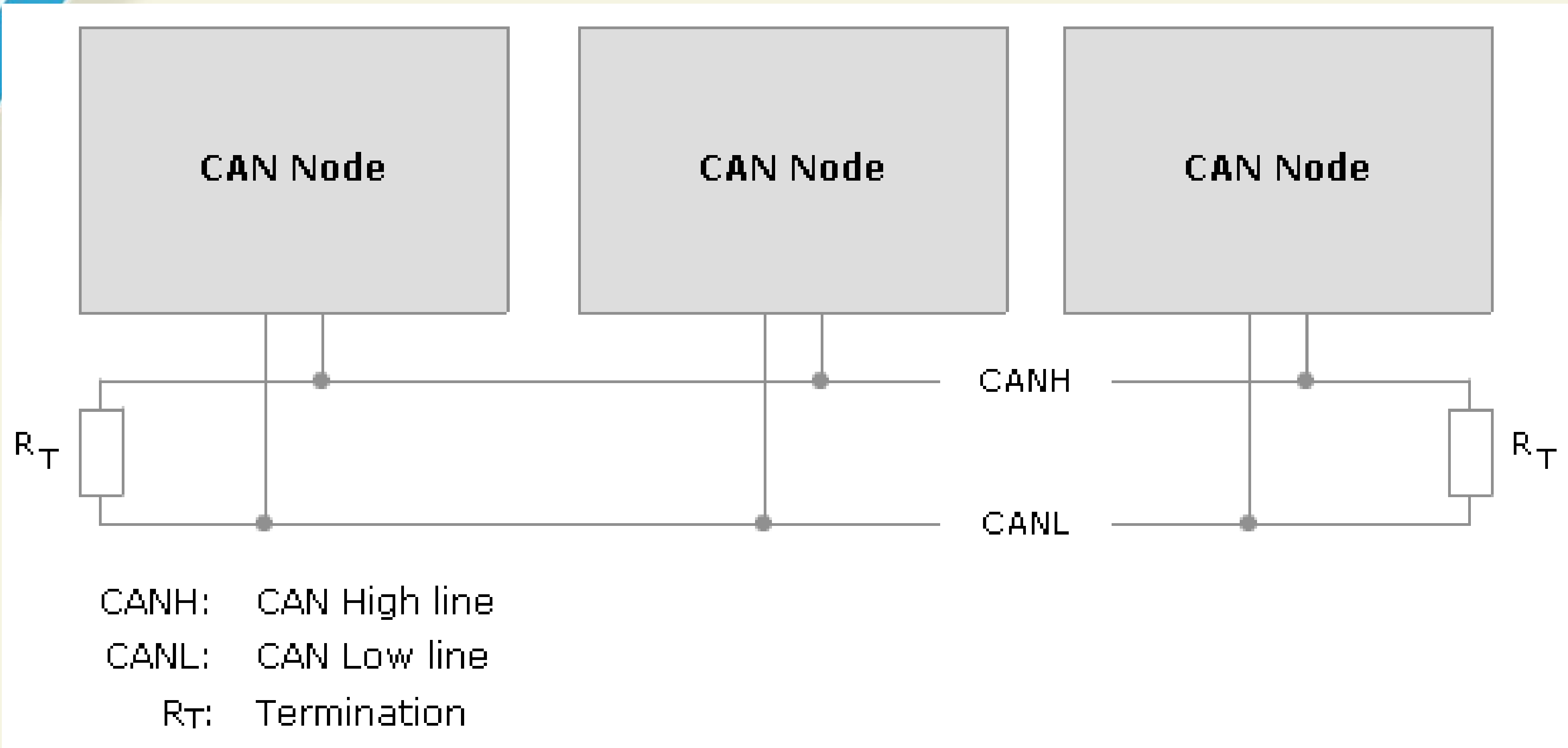
- ✓ Message priority assignment and guaranteed maximum latencies.
- ✓ Multicast communication with bit-oriented synchronization.
- ✓ System-wide data consistency.
- ✓ Bus multi-master access.
- ✓ Error detection and signaling with automatic retransmission of corrupted messages.
- ✓ Detection of permanent failures in nodes, and automatic switch-off to isolate faulty node.

Basic Concepts 2

- ✓ The CAN protocol uses the Data Link Layer and the Physical Layer in the ISO - OSI model. There are also a number of higher level protocols available for CAN.



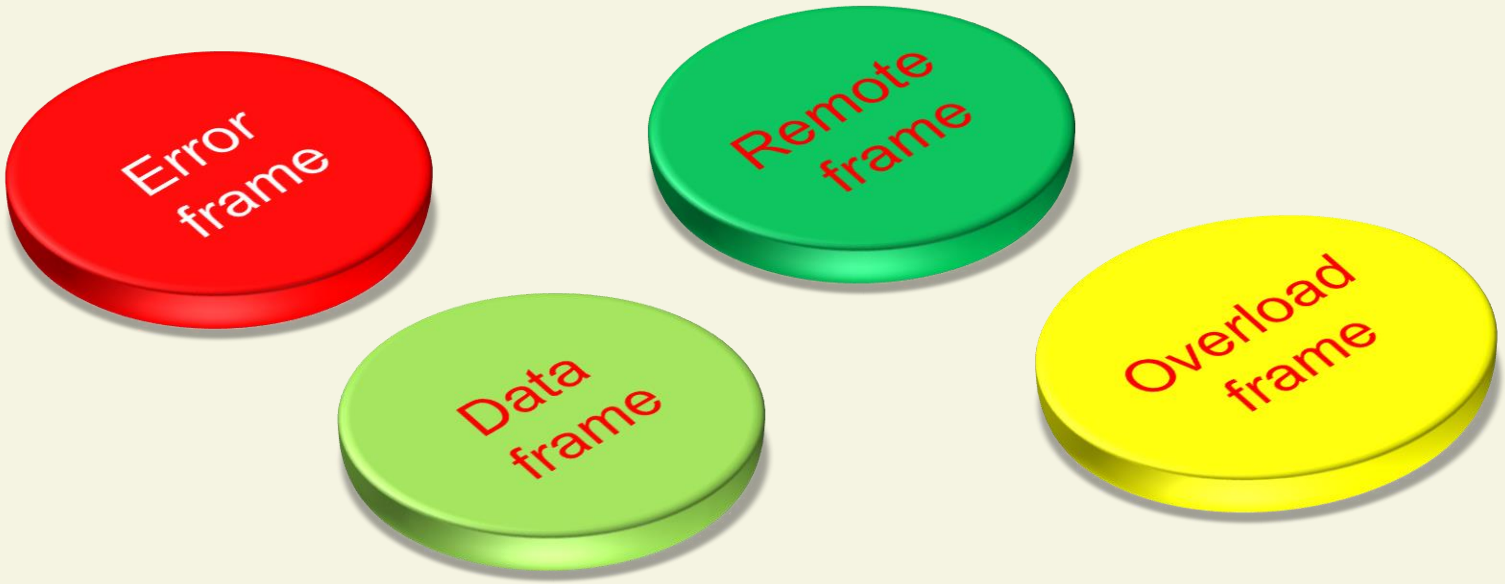
CAN Network



- **line topology** with a linear bus.
- **Unshielded Twisted Pair — UTP.**
- The maximum data rate is **1 Mbit/s**
- A maximum network extension is 40 meters

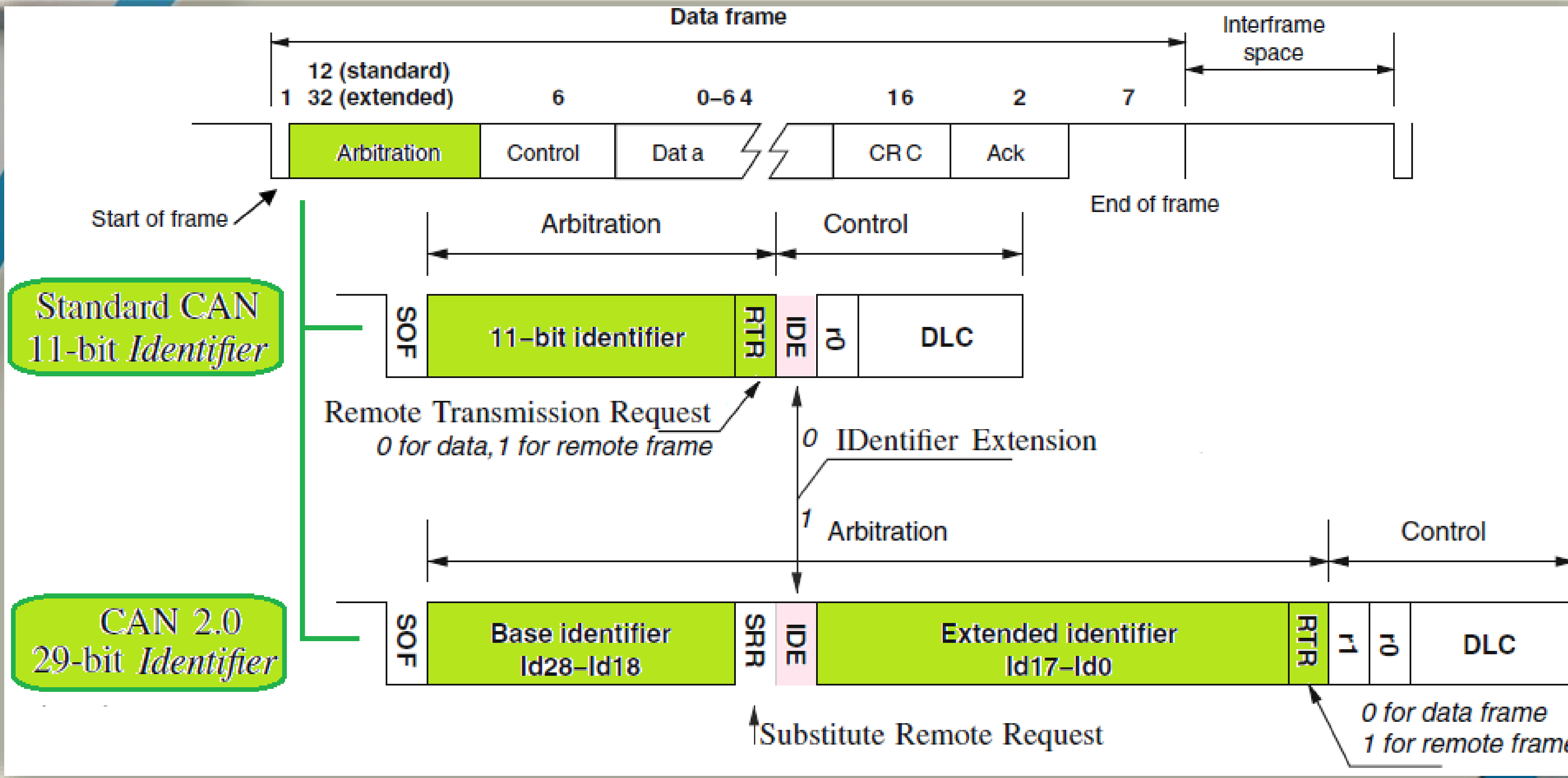
DATA LINK LAYER

Message Frame Formats



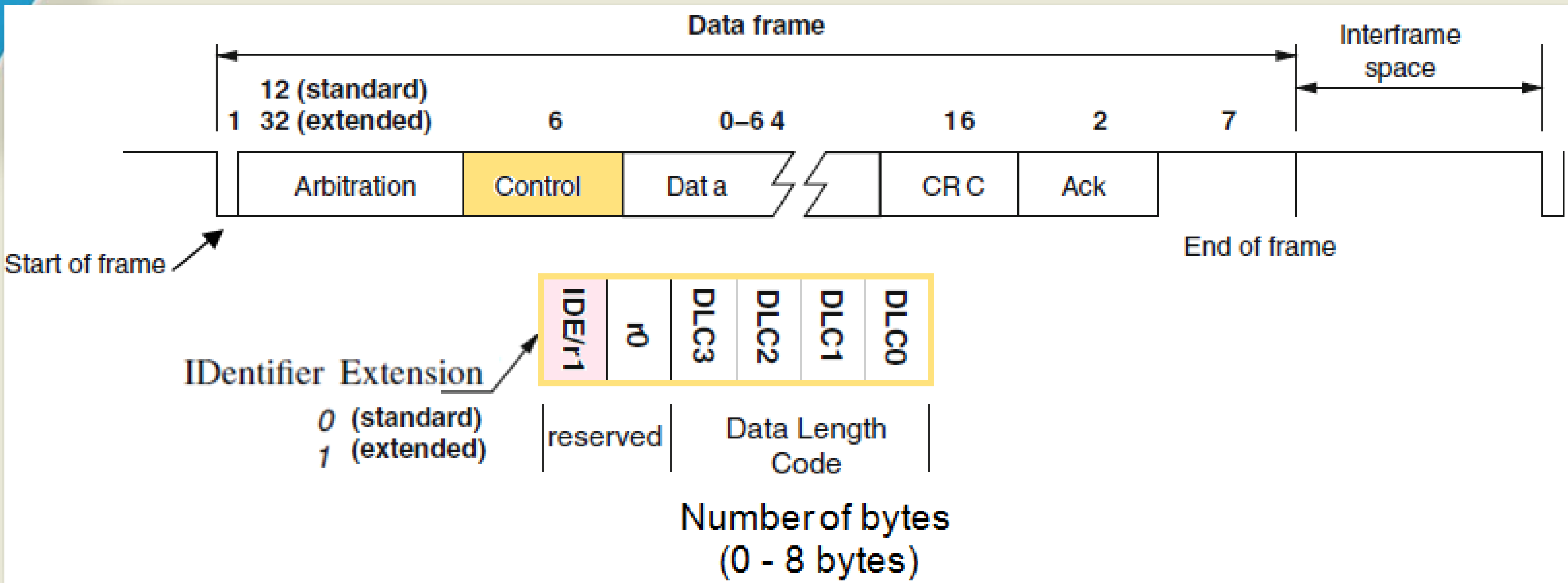
fppt.com

DATA Frame: Identifier

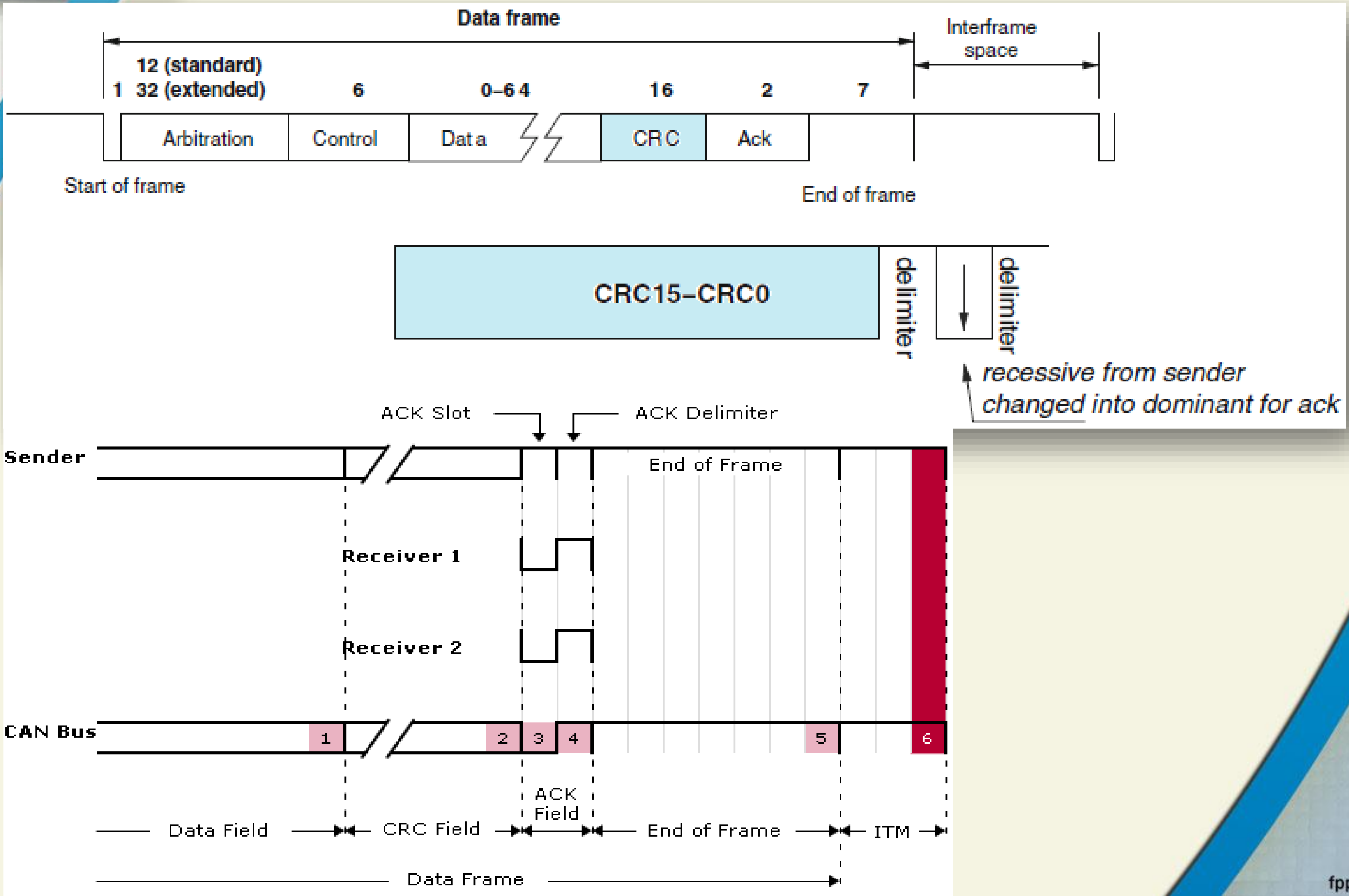


1. Maximum payload is eight bytes.

DATA Frame: Control

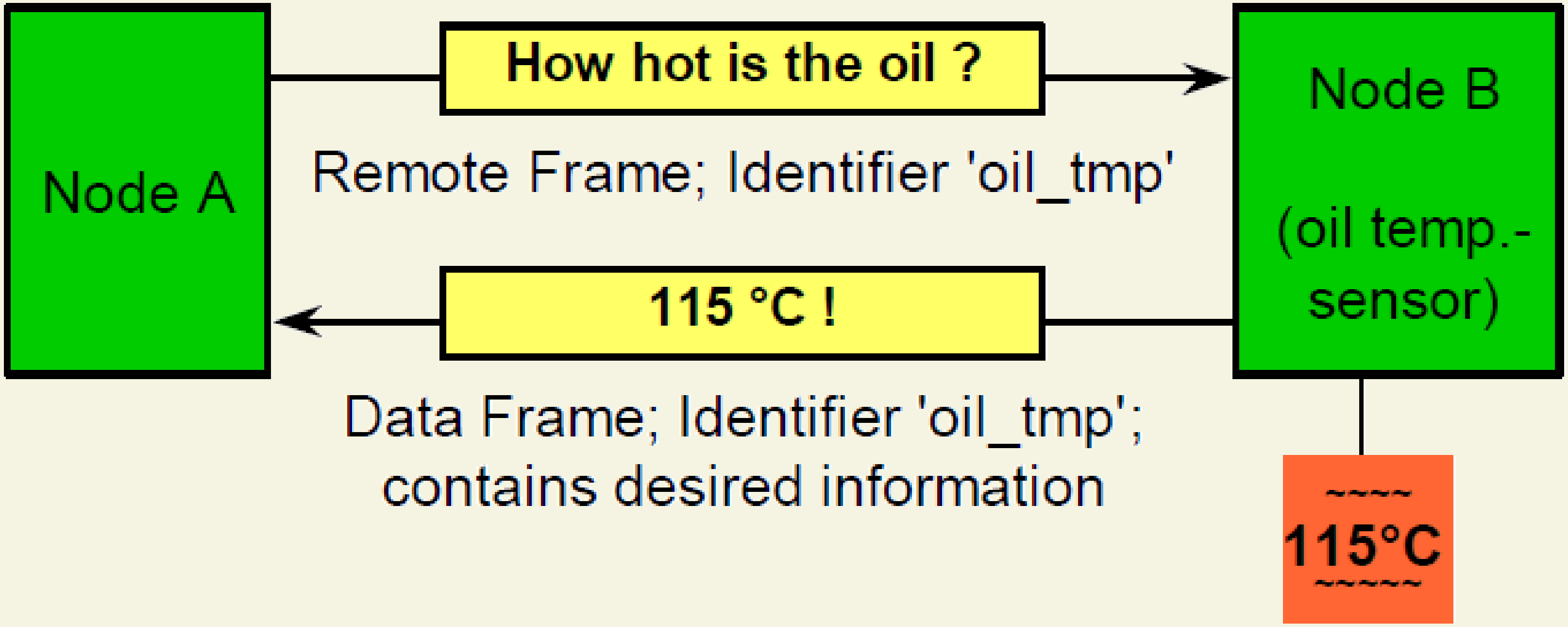


DATA Frame: CRC + Ack



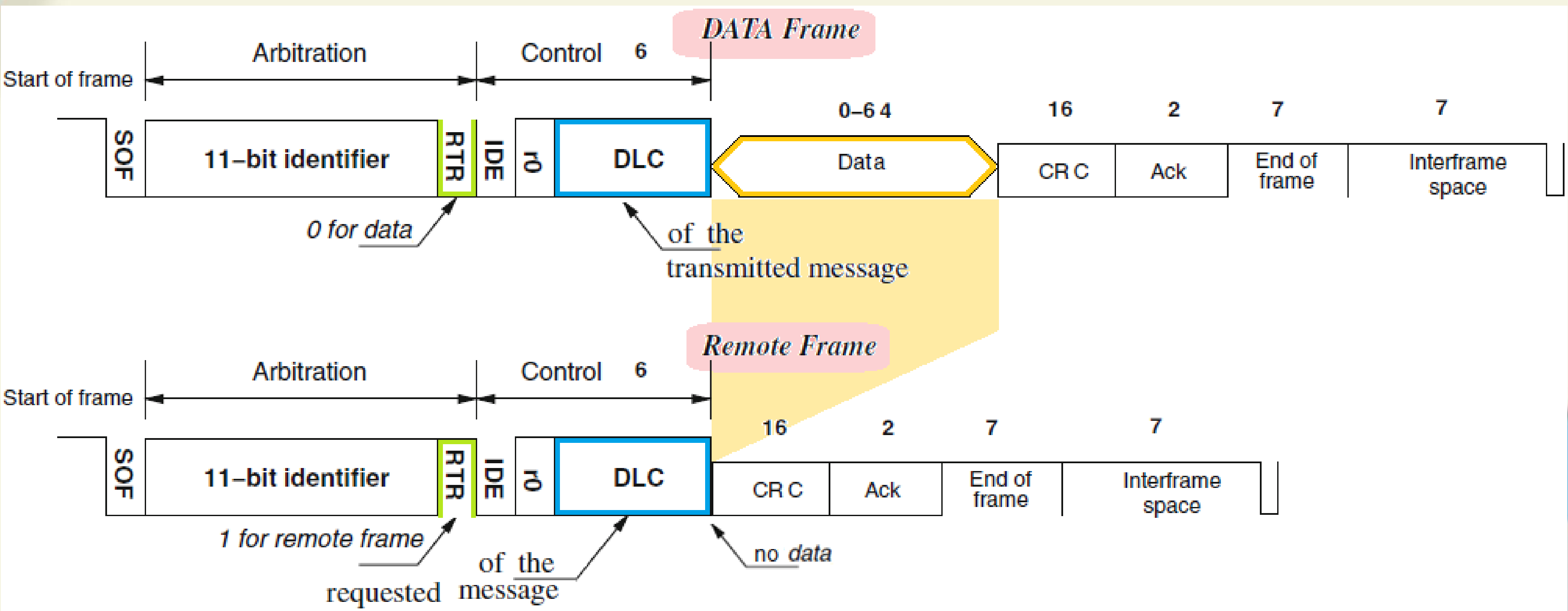
Remote Frame

To request the transmission of a message with a given Identifier from a remote node.



Remote Frame

To request the transmission of a message with a given Identifier from a remote node.

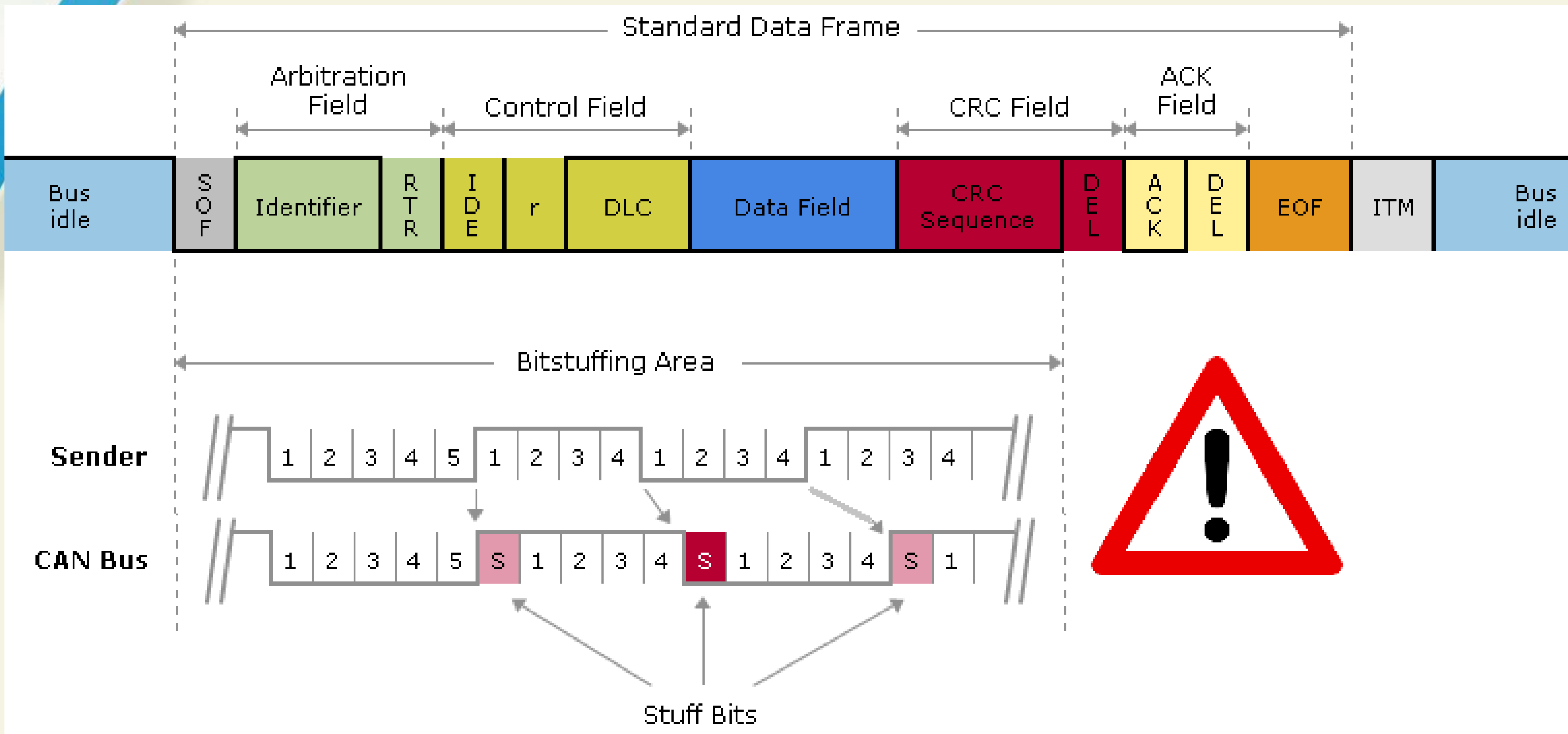


The data frame wins arbitration

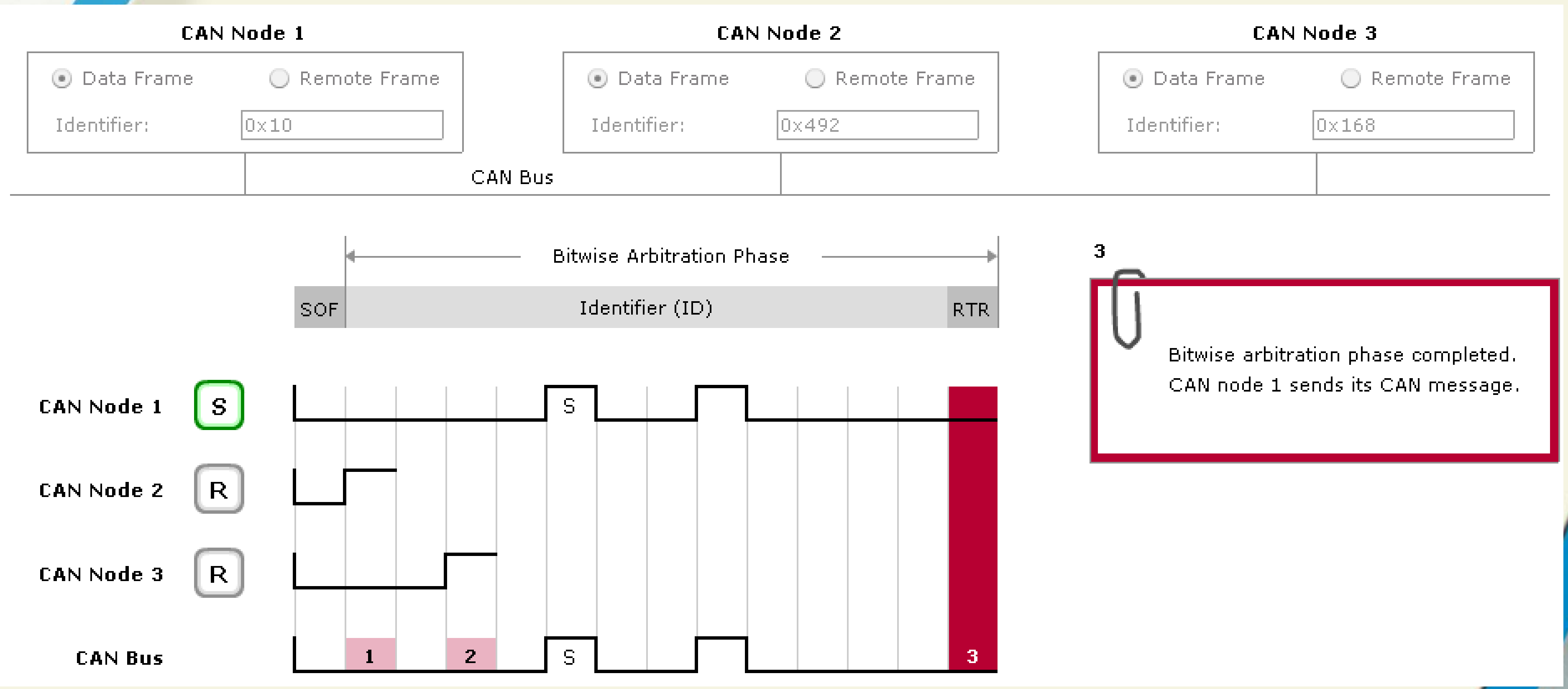
Stuffing bit

- The frame segments *Start of frame (SOF), Identifier, Control, Data and CRC are* subject to bit stuffing.
- The remaining bit fields of the data frame or remote frame (CRC delimiter, *ACK, and End Of Frame (EOF) fields) are in fixed form and not* stuffed.

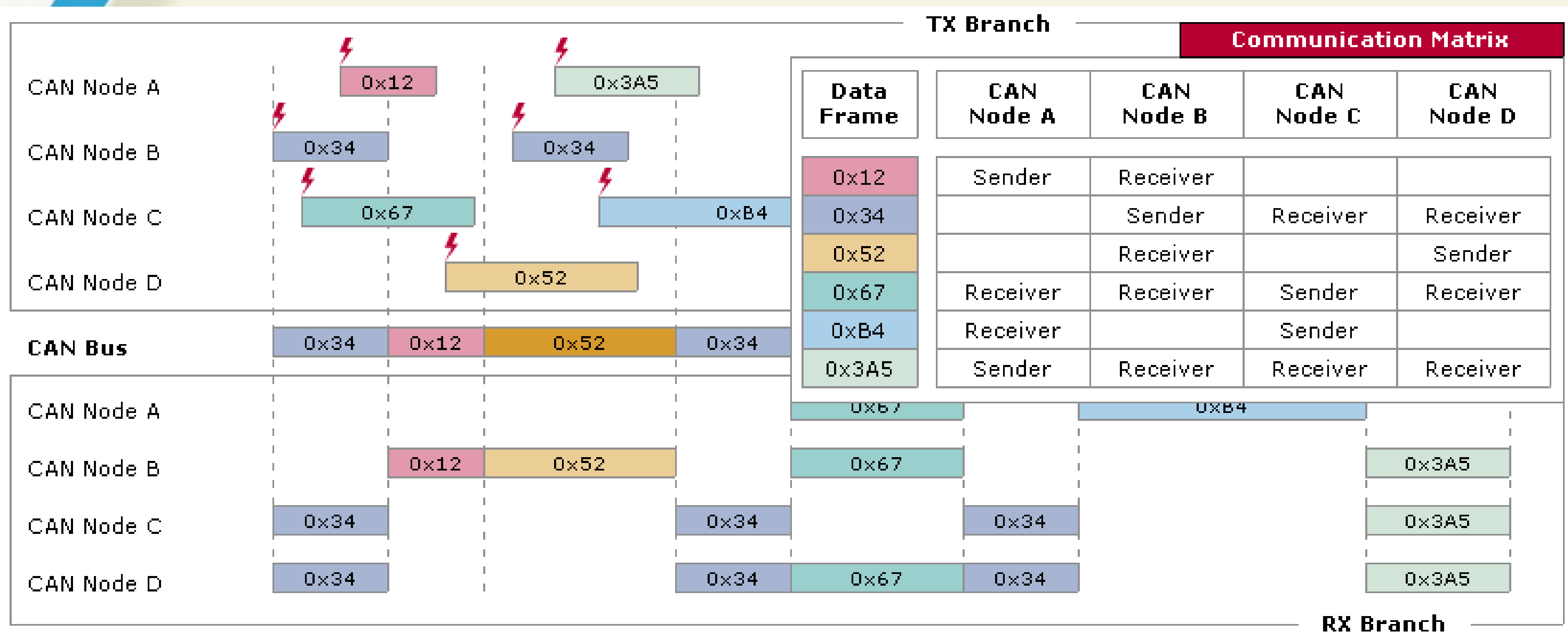
Stuffing Bit



CAN Communication



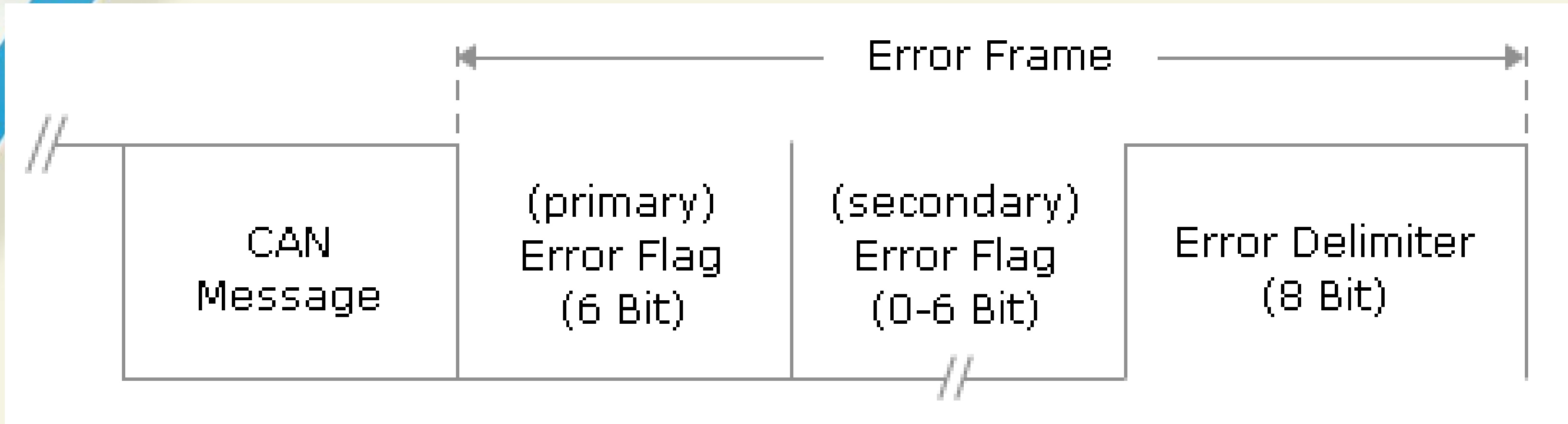
CAN Communication



Communication Matrix

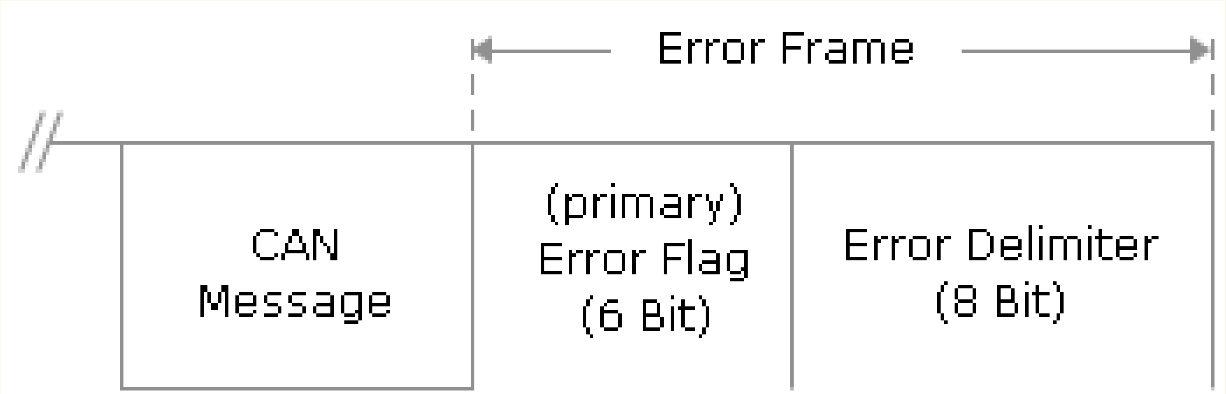
Data Frame	CAN Node A	CAN Node B	CAN Node C	CAN Node D
0x12	Sender	Receiver		
0x34		Sender	Receiver	Receiver
0x52		Receiver		Sender
0x67	Receiver	Receiver	Sender	Receiver
0xB4	Receiver		Sender	
0x3A5	Sender	Receiver	Receiver	Receiver

Active Error Frame



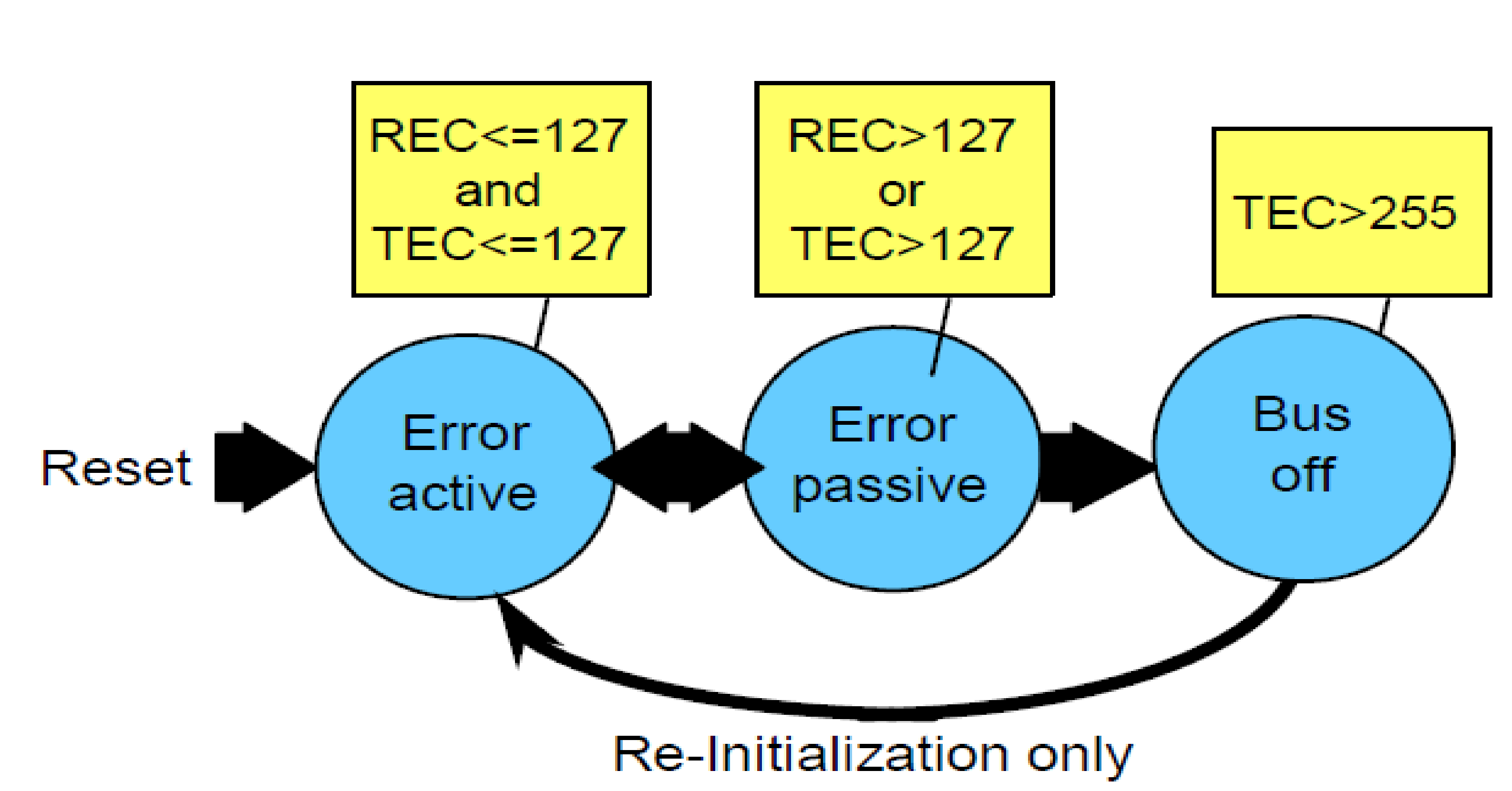
1. Six consecutive dominant bits actively violates the bit stuffing rule.
2. This intentional violation of the bit stuffing rule, force other nodes to generate an Error Frame (for **bit stuffing error)**.
3. Therefore, Error flag varies up to 12 bits.

Passive Error Frame



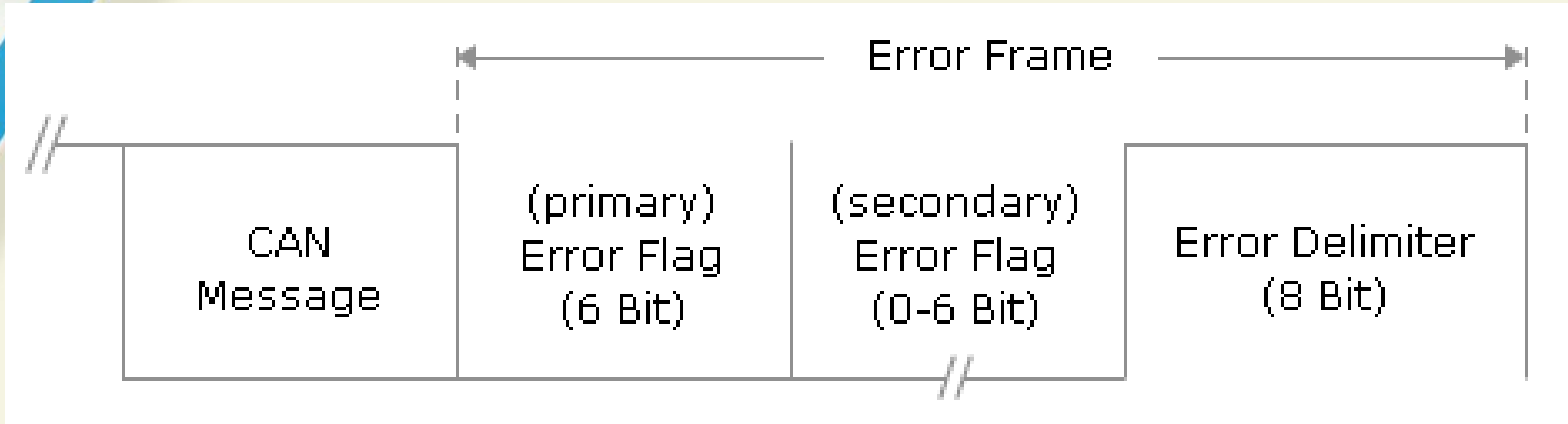
1. Six consecutive recessive bits actively violates the bit stuffing rule.
2. This intentional violation of the bit stuffing rule, force other nodes to generate an Error Frame (for **bit stuffing error)**.
3. Therefore, Error flag varies up to 12 bits.

Error Tracking



TEC: Transmit Error Counter
REC: Receive Error Counter

Overload Frame

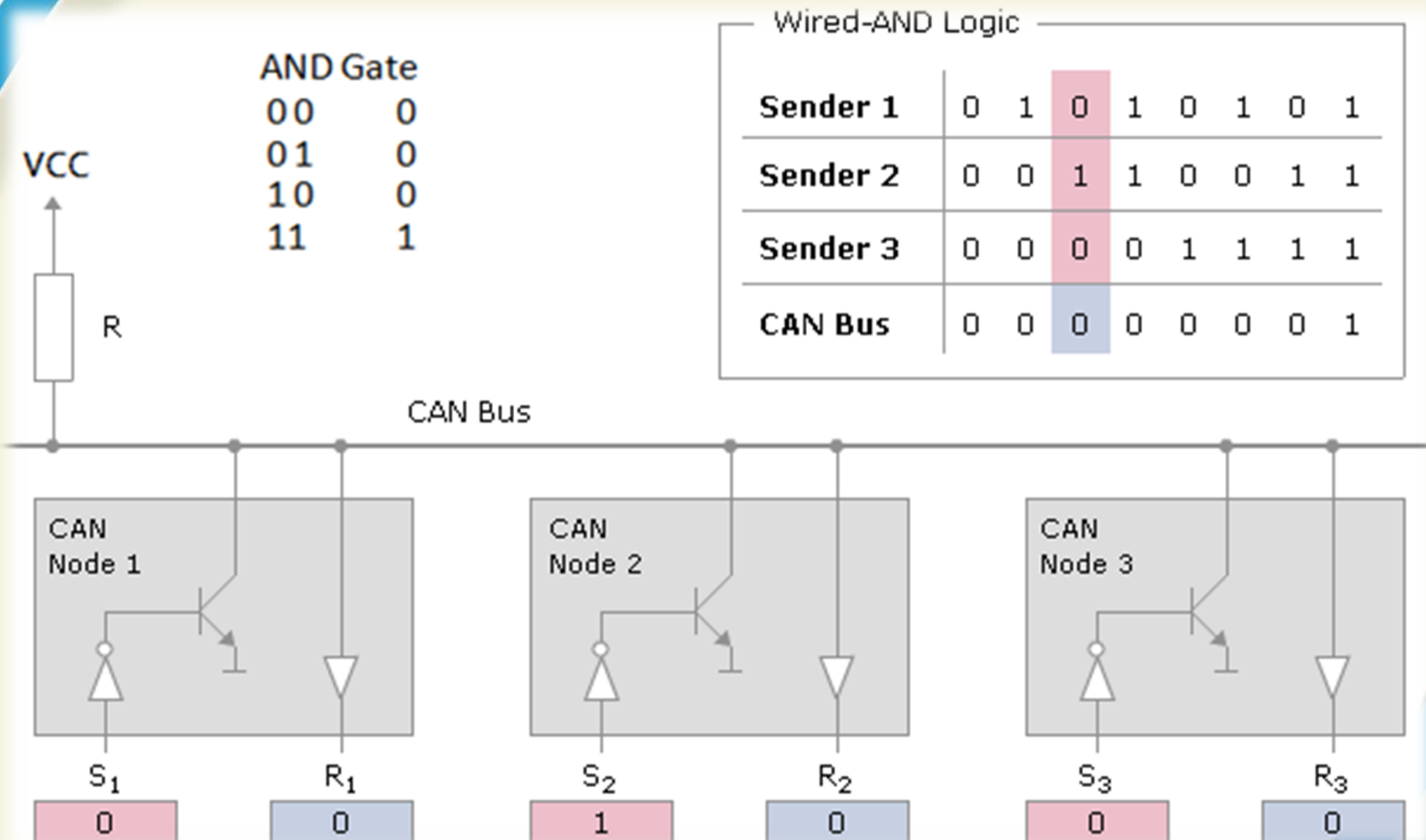


1. Used to delay next CAN message.
2. Same as an "active" error frame.
3. Generated during inter-frame space..

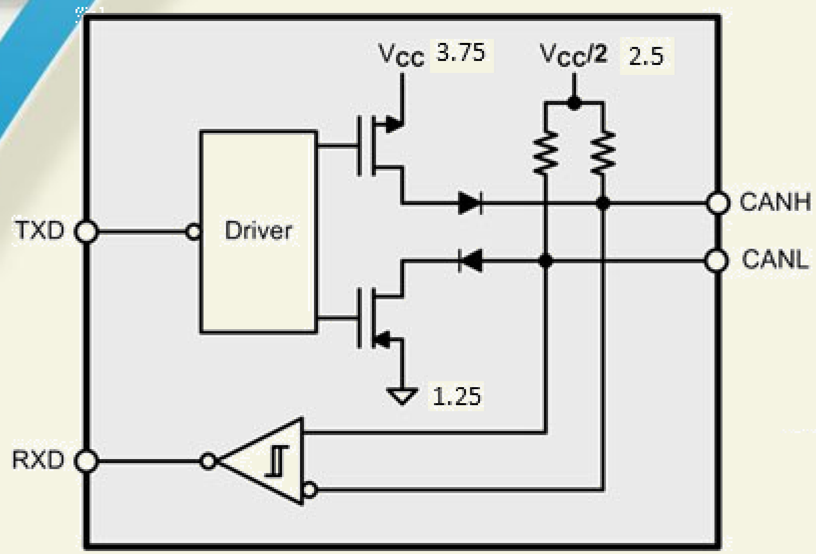
PHYSICAL LAYER

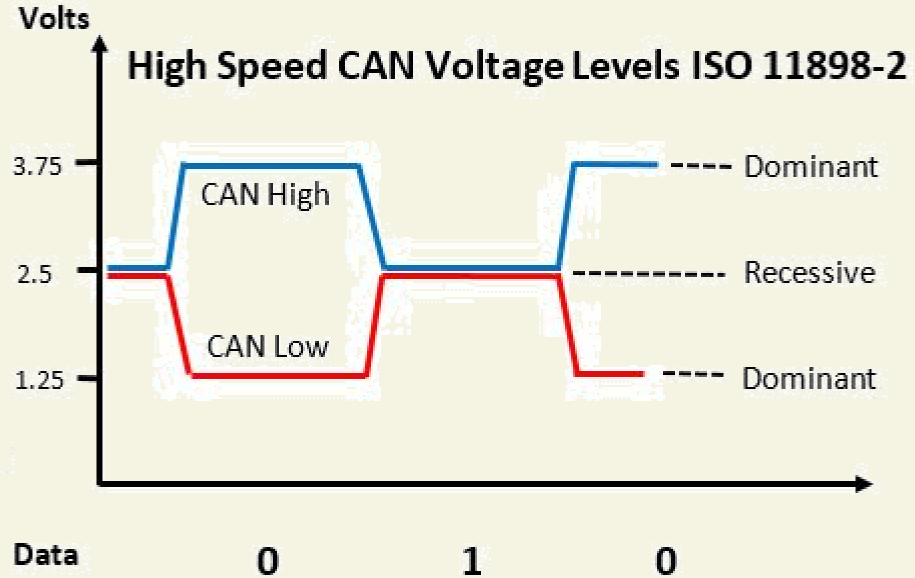
Physical Layer:

Open-Collector/Drain

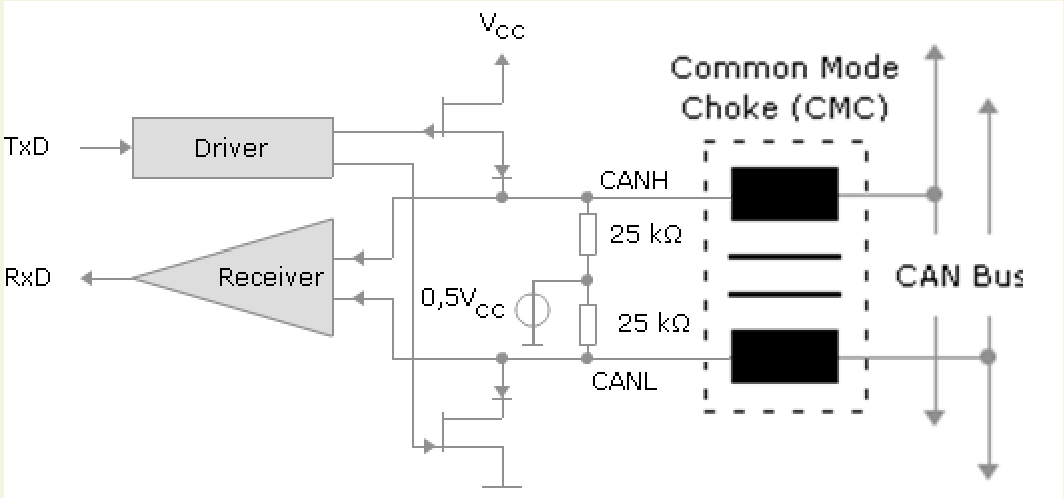


Physical Layer:
Open-Collector/Drain

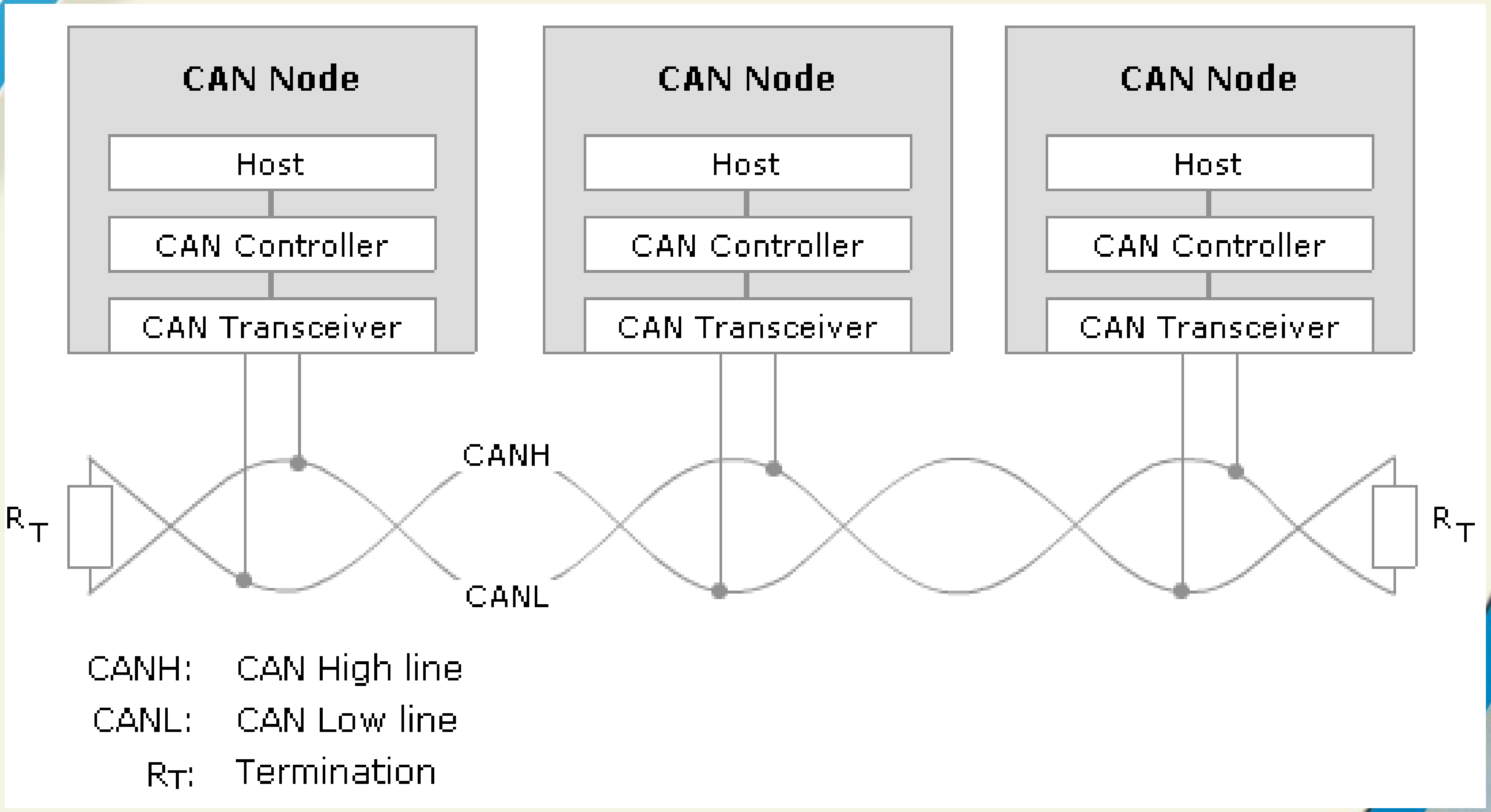




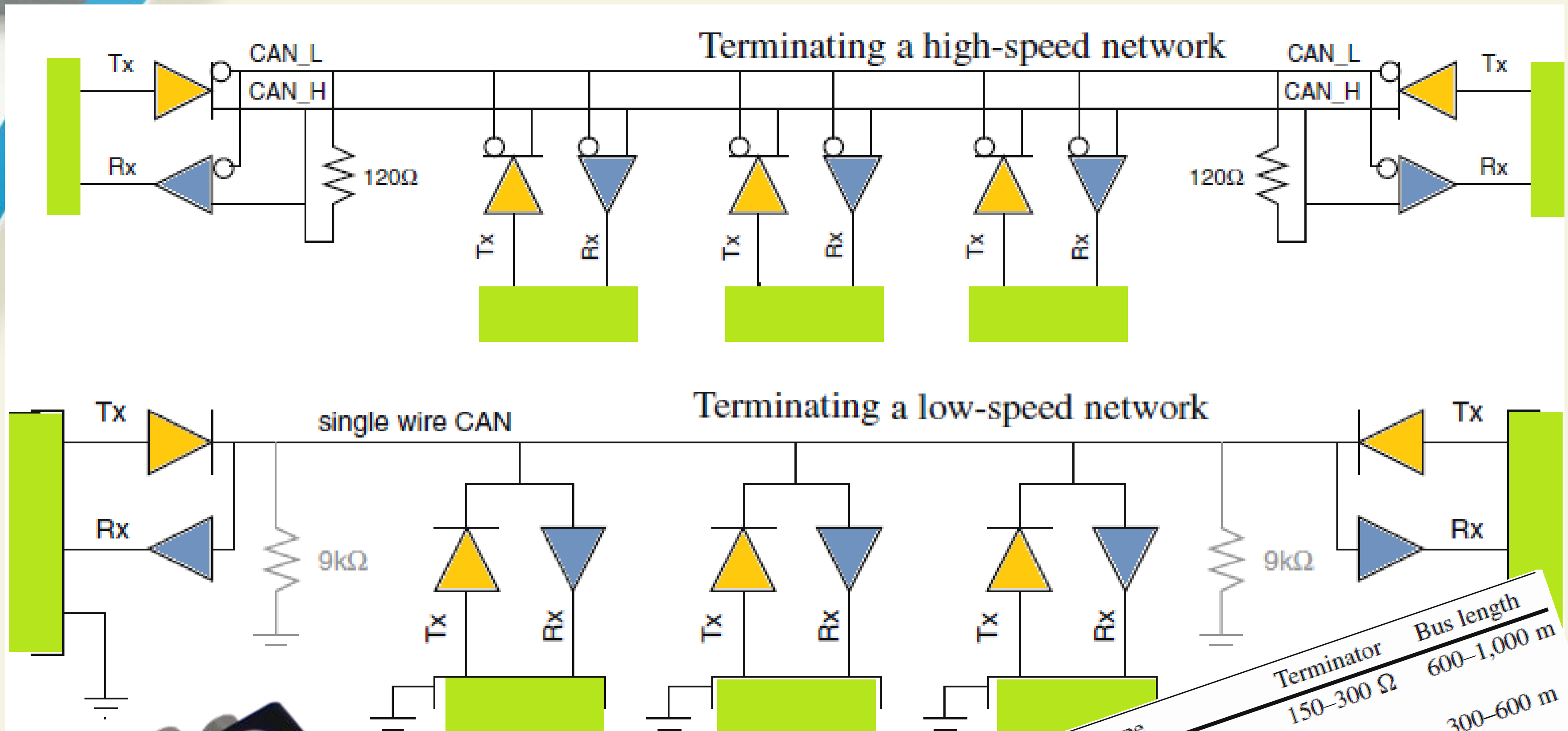
•***Bit Timing: Non Return to Zero (NRZ)*** 1= "recessive" and 0="dominant"



Physical Layer: CAN Bus

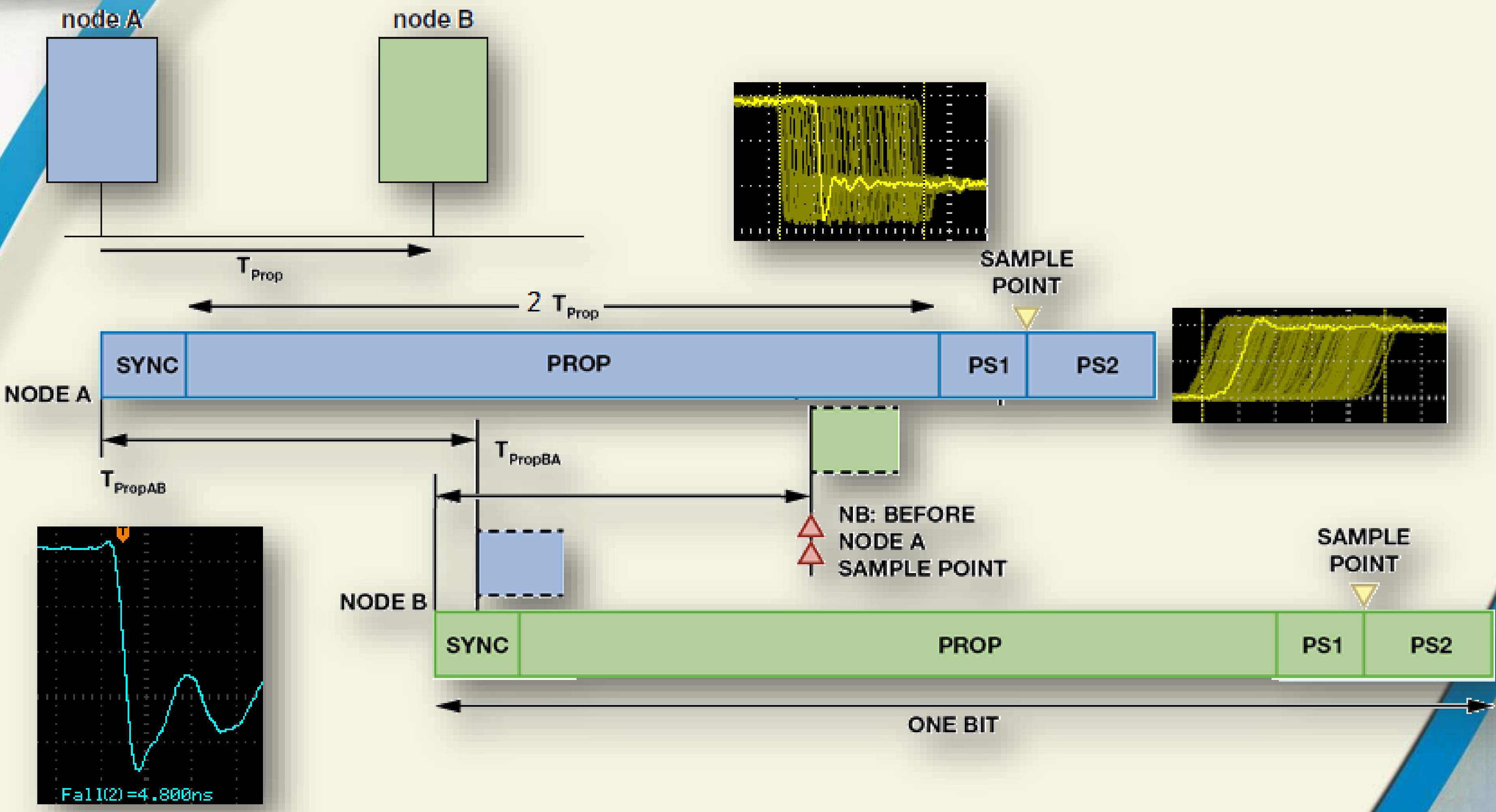


Bus Construction: Termination



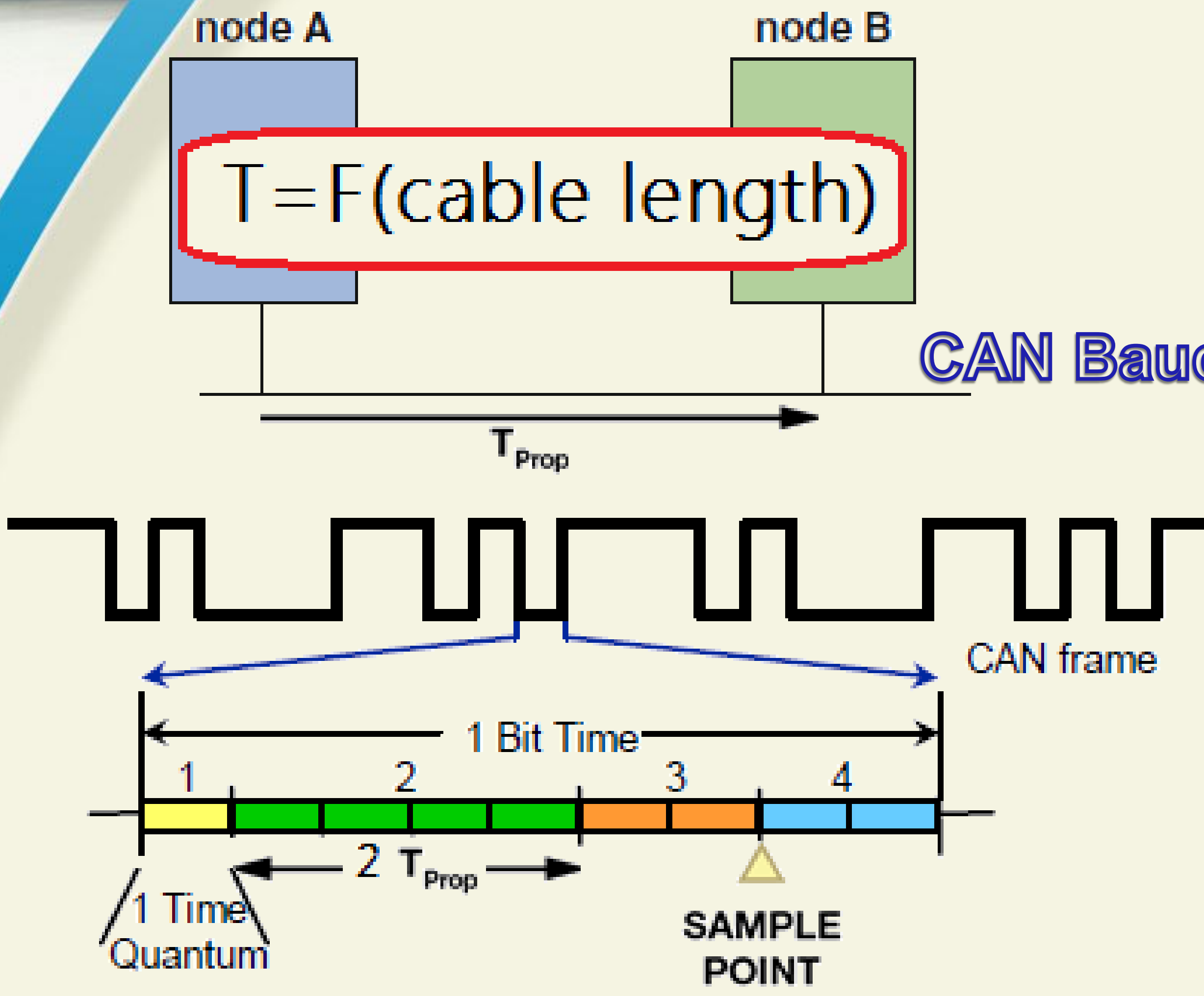
Bus speed	Cable type	Terminator	Bus length
50 kb/s at 1,000 m	0.75–0.8 mm² (AWG18)	150–300 Ω	600–1,000 m
100 kb/s at 500 m	0.5–0.6 mm² (AWG20)	150–300 Ω	300–600 m
500 kb/s at 100 m	0.34–0.6 mm² (AWG22, AWG20)	127 Ω	40–300 m
1,000 kb/s at 40 m	0.25–0.34 mm² (AWG23, AWG22)	124 Ω	0–40 m

Bit Construction



CAN Baud Rate (= 1 / Bit Time)

Bit Construction: Time Quantum

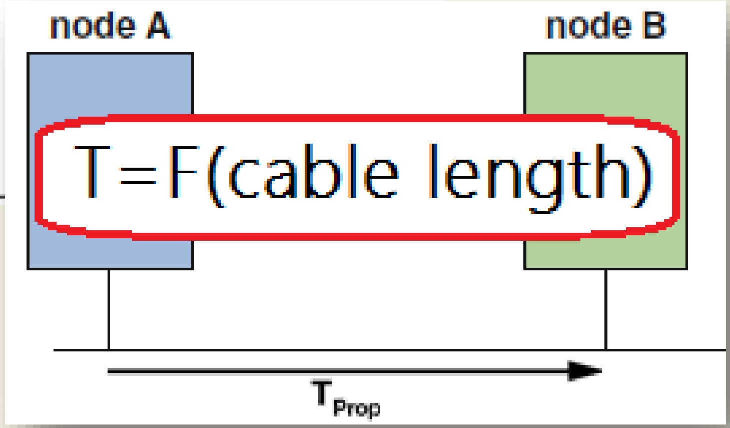


CAN Baud Rate (= 1 / Bit Time)

**There is a minimum of 8 and a maximum of 25 Time Quanta per bit.

Bit Construction: Cable length

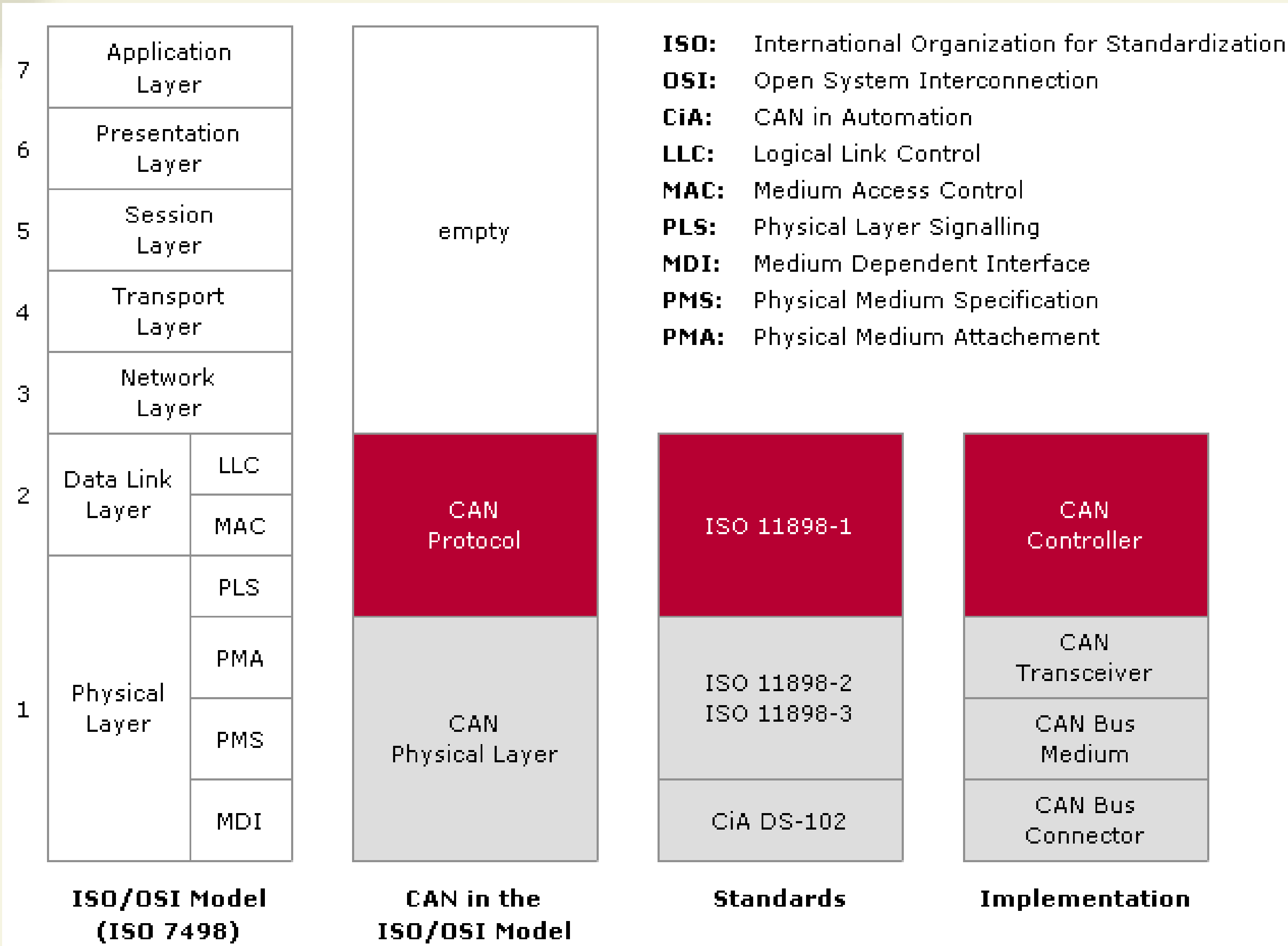
Bit rate	Bit time (μs)	Bus length (m)	Cable type
1 Mb/s	1	30	1,000 kb/s at 40 m 0.25–0.34 mm^2 (AWG23, AWG22)
800 kb/s	1.25	50	
500 kb/s	2	100	500 kb/s at 100 m 0.34–0.6 mm^2 (AWG22, AWG20)
250 kb/s	4	250	
125 kb/s	8	500	
62.5 kb/s	16	1,000	
20 kb/s	50	2,500	
10 kb/s	100	5,000	



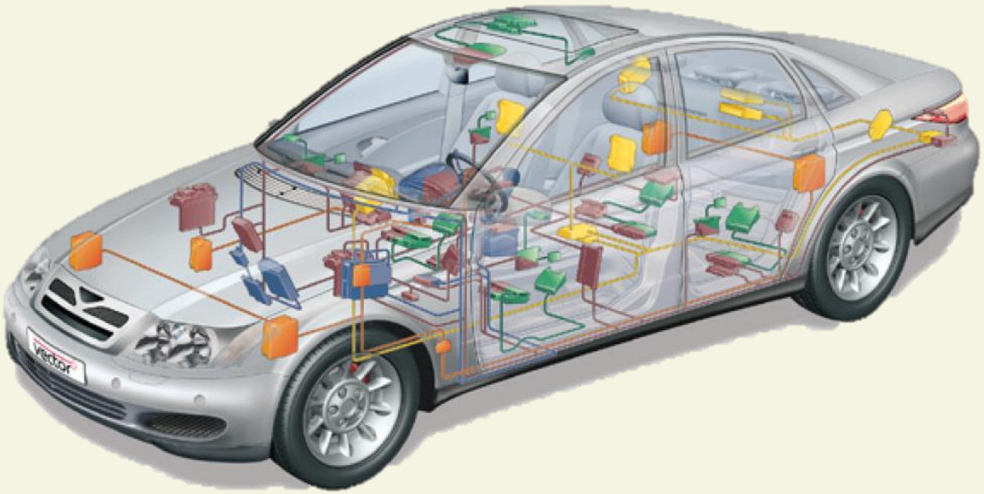
Standards

ISO 11898-2	ISO 11898-3	SAE J2411
Bus length of 40 m	Short network length	Short bus length
	Open bus line possible	Open bus line possible
	Bus topology is not limited to be linear	Branching is possible
	Voltage symmetric on both wires.	
Up to 1 Mbit/s	Up to 125 kbit/s and	Up to 33.3 kbit/s
Two-wire differential bus	Two-wire differential bus	Single-wire
		32 nodes per network walkup/sleep capability

CAN Standerds



Local Interconnect Network



LOCAL INTERCONNECT NETWORK

Eye on History

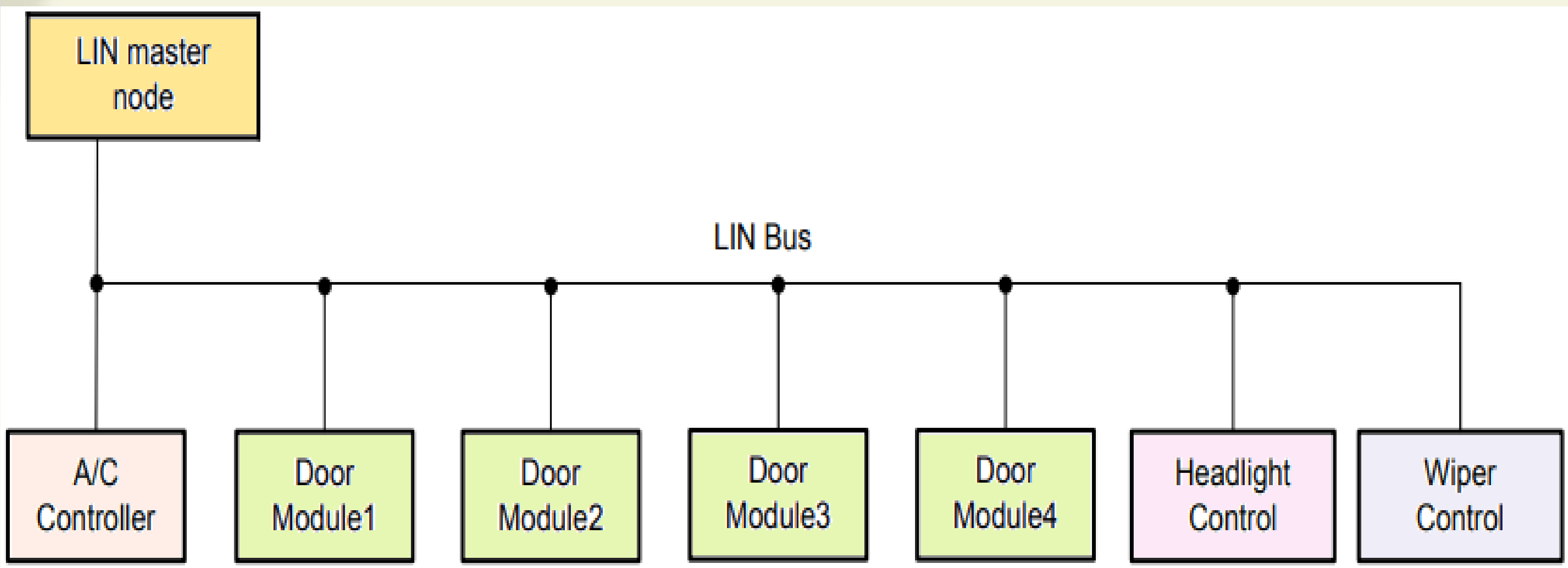
1. By Motorola company (now Freescale), in the late 1999
2. Consortium : Audi AG, BMW AG, Daimler Chrysler AG, Volkswagen AG, Volvo Cars Corporation AB, Motorola and Volcano Communications Technologies.
3. The final specification, ‘LIN rev. 2.0’ was issued in September 2003.

Basic Concepts

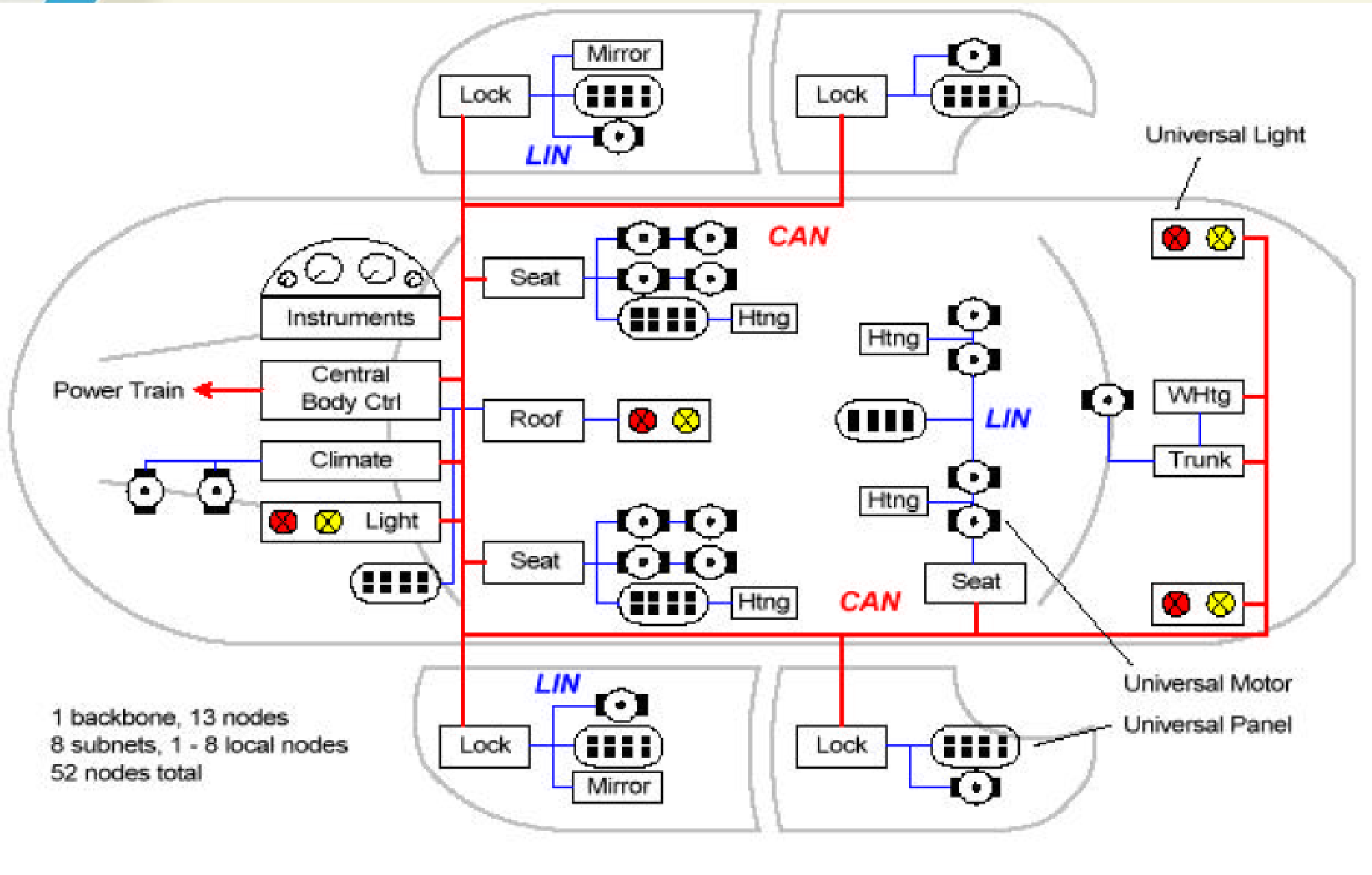
- ✓Multicast reception solution with synchronization .
- ✓CRC and error detection.
- ✓ LIN provides cost-efficient communication in applications where the bandwidth is not required.
- ✓Single master multiple slaves (Full deterministic).
- ✓No problems of conflict and arbitration
- ✓The primary and original purpose of LIN (1999) is therefore to provide a ‘sub-bus’ for CAN(1980).
- ✓64 message addresses (identifiers).

lin Network architecture

- A lin bus length is limited to 40 meters and up to 16 ECUs could be connected

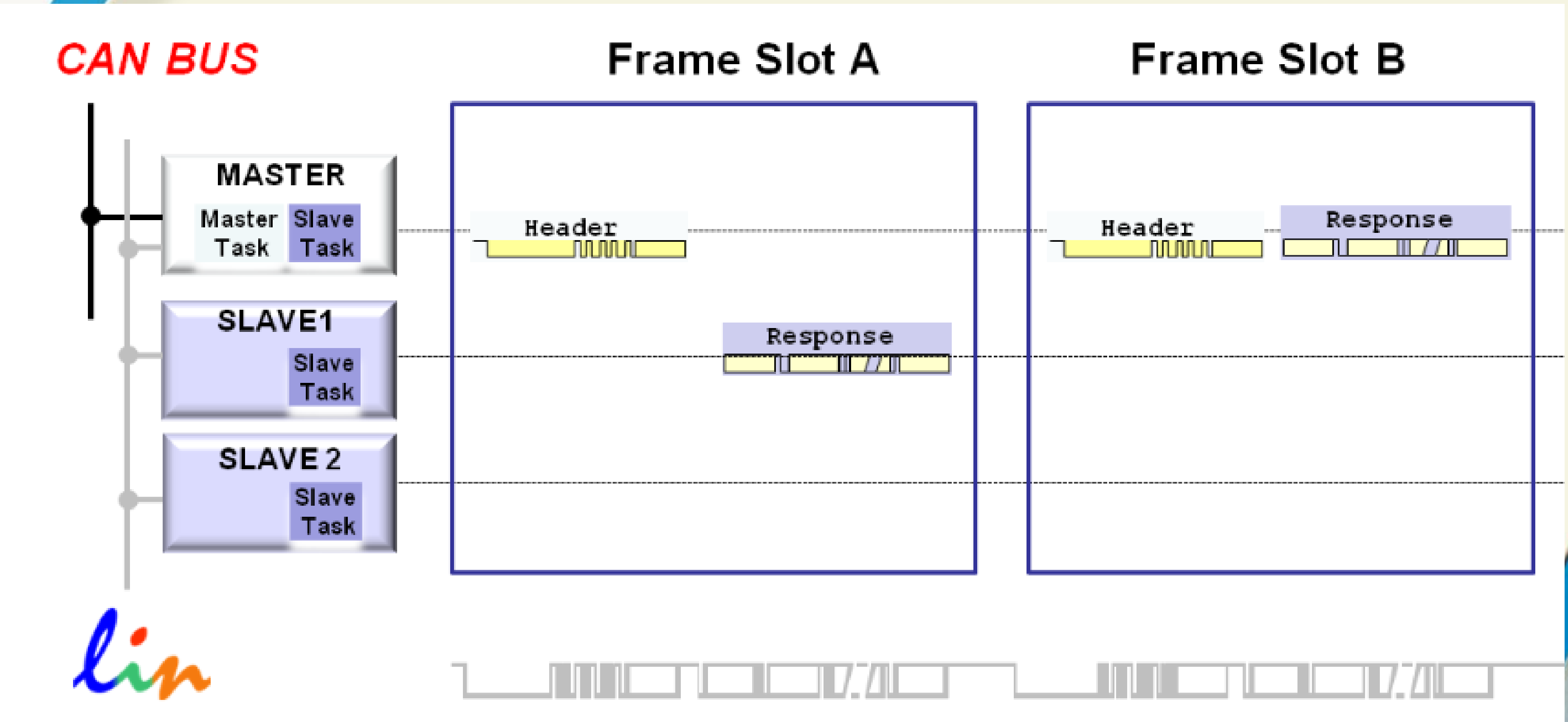


Hybrid LIN/CAN Network architecture

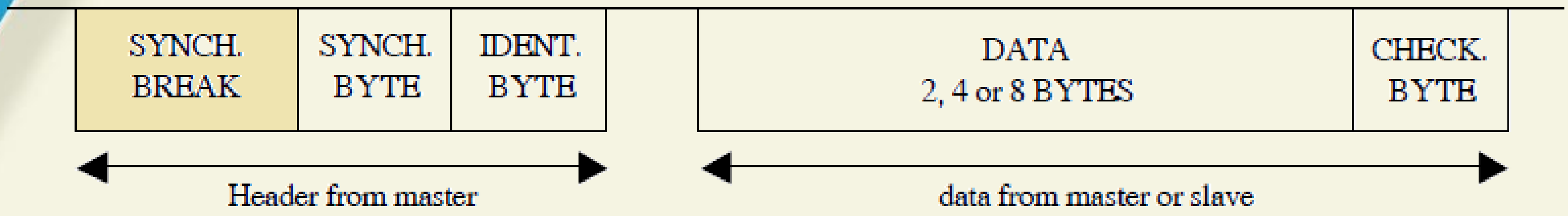


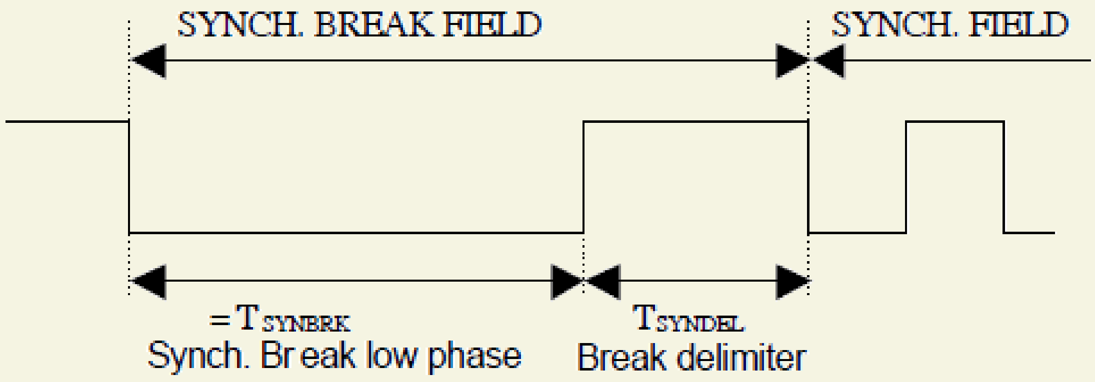
LIN Scenario

Point-to-Point **Multicast**



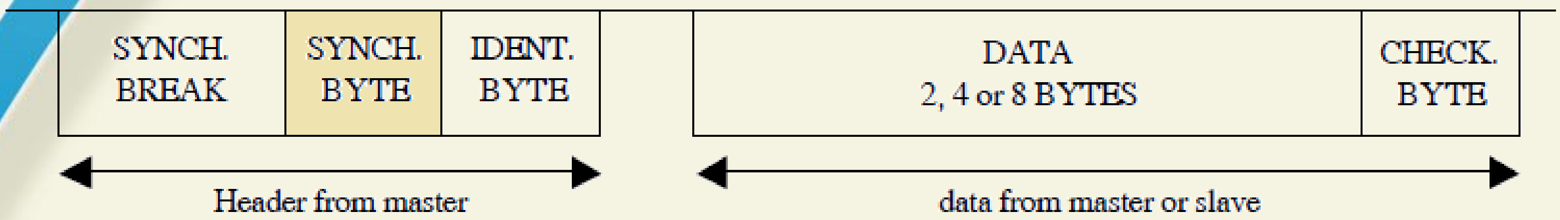
Structure of a message

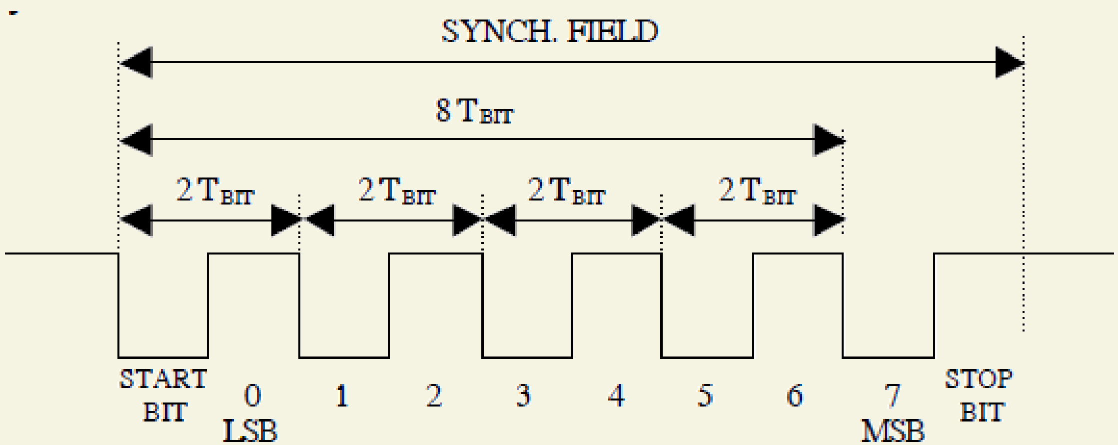


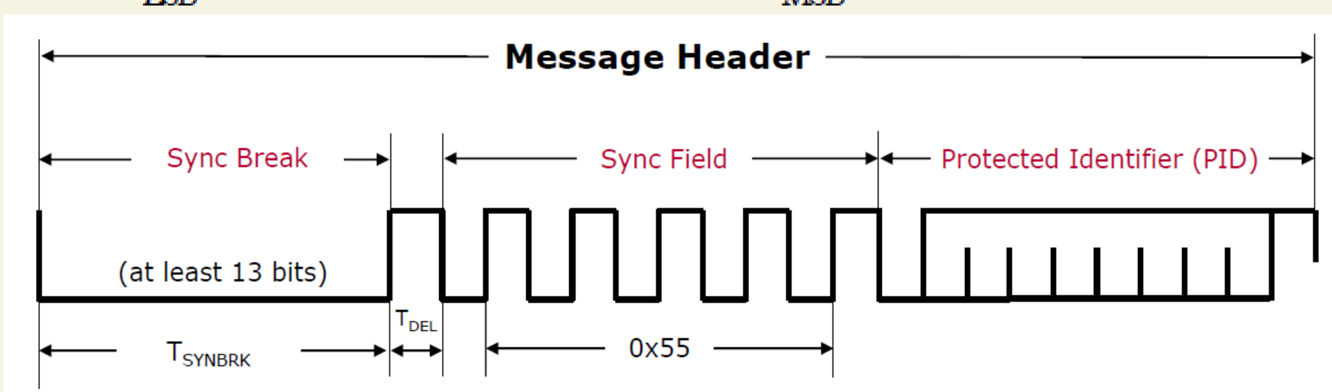


Structure of a message:

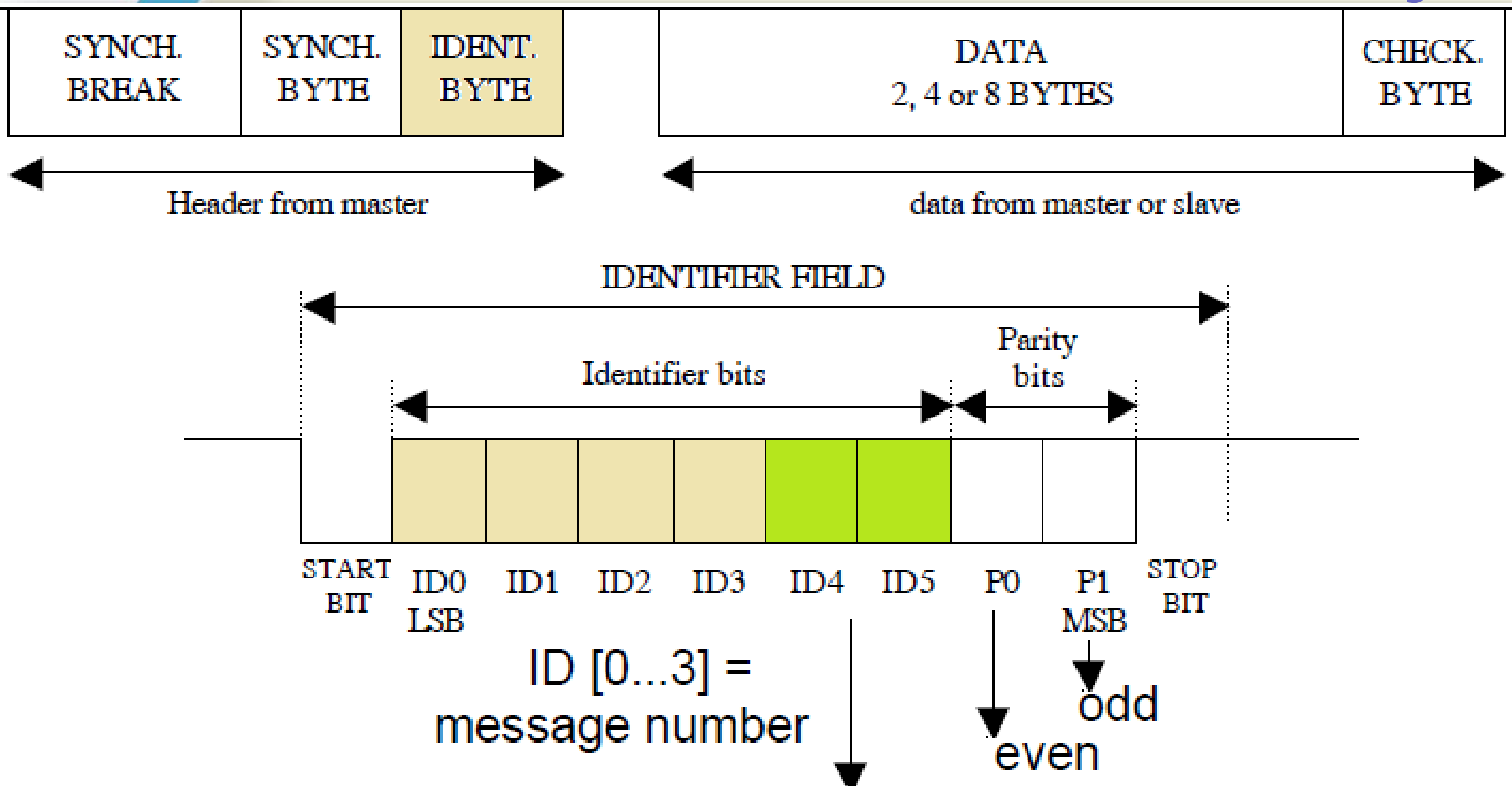
Synchronization byte







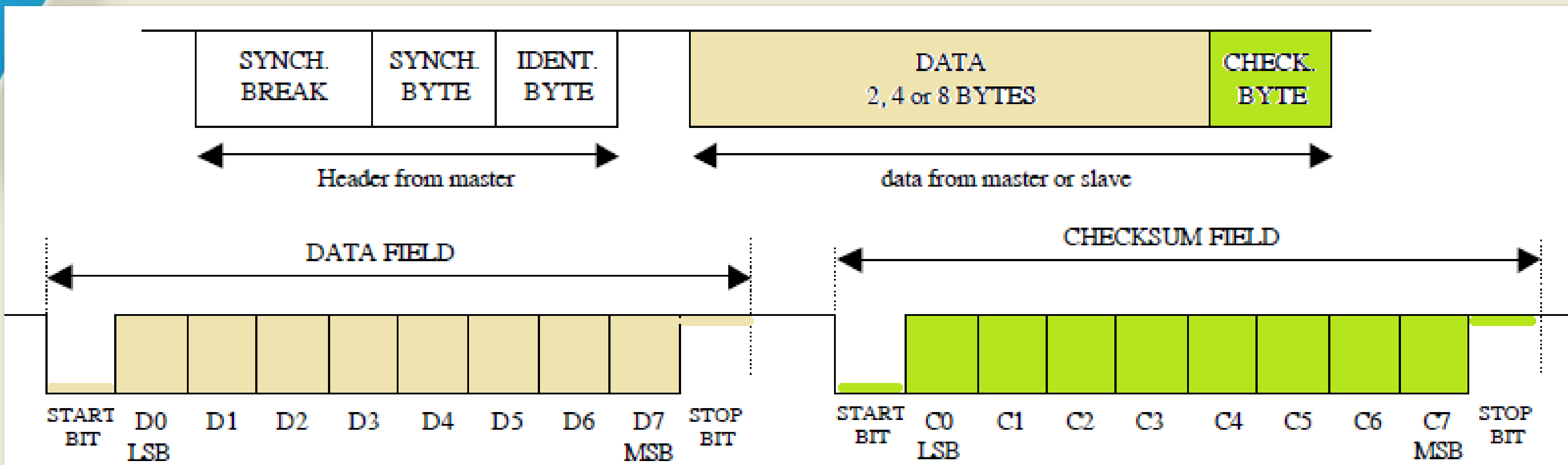
Structure of a message: Identifier byte



ID4	ID5	data length
0	0	2 bytes
0	1	2 bytes
1	0	4 bytes
1	1	8 bytes

Structure of a message:

Data /Checksum byte

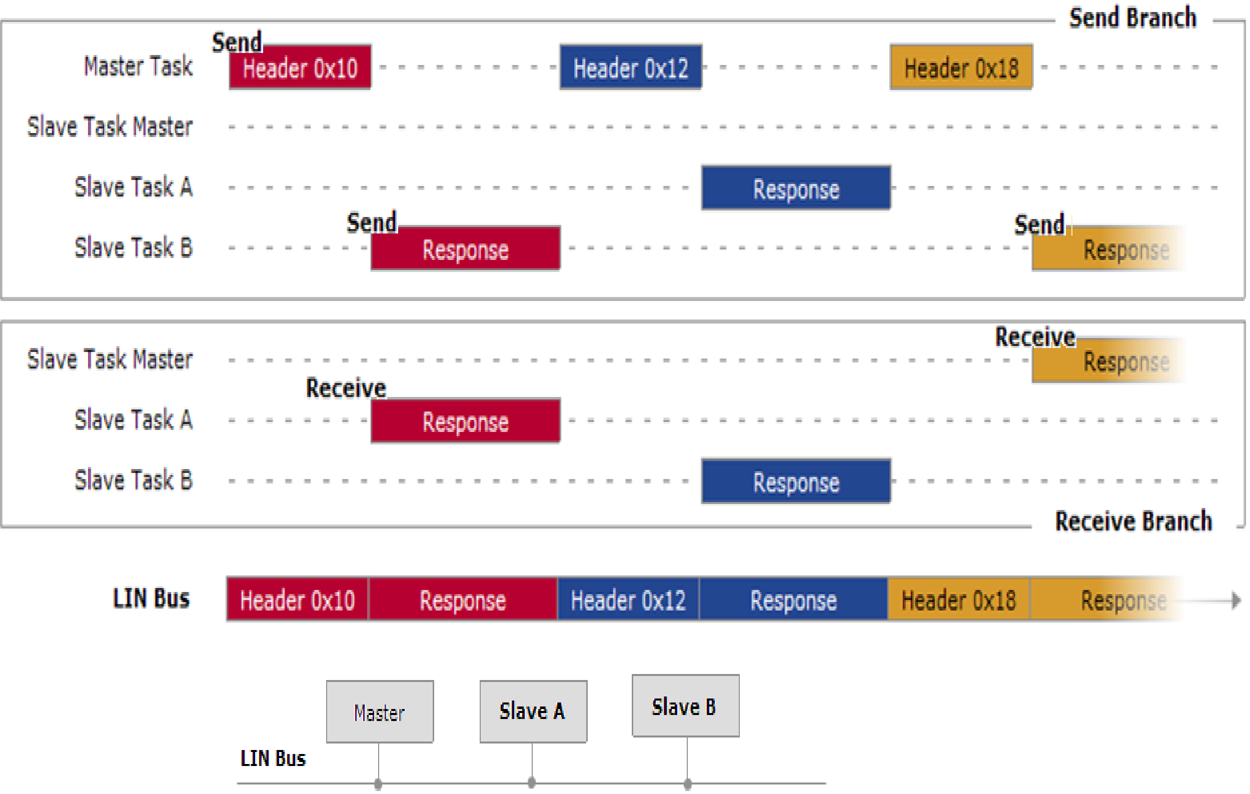


Message types

- Unconditional Frames (ID 0-59)
  - One Message Response is assigned to the Message Header
  - Message Header is always sent in the reserved frame slot
- Diagnostic Frames (ID 60-61)
  - Master Request Frame (ID=60, ID=0x3C)
  - Slave Response Frame (ID=61, ID=0x3D)
- Other Frames (ID 62-63)
  - User-defined (ID=62, ID=0x3E)
  - Future extensions (ID=63, ID=0x3F)

Scenario

Unconditional Frames



Communication Matrix

LIN Schedule		Frame \ Slave Task	Slave Task Master	Slave Task A	Slave Task B
T_1	Frame Slot 1	Unconditional Frame ID = 0x10		Receiver	Sender
T_2	Frame Slot 2	Unconditional Frame ID = 0x12		Sender	Receiver
T_3	Frame Slot 3	Unconditional Frame ID = 0x18	Receiver		Sender
T_4	Frame Slot 4	Unconditional Frame ID = 0x1C	Receiver	Sender	Receiver
T_5	Frame Slot 5	Unconditional Frame ID = 0x20	Receiver		Sender
T_6	Frame Slot 6	Unconditional Frame ID = 0x24	Sender	Receiver	

Communication Cycle

- Headers always by Master according to communication Matrix.
- Senders could be any slaves or master itself (Only one).
- Receivers could be any slaves or master itself.

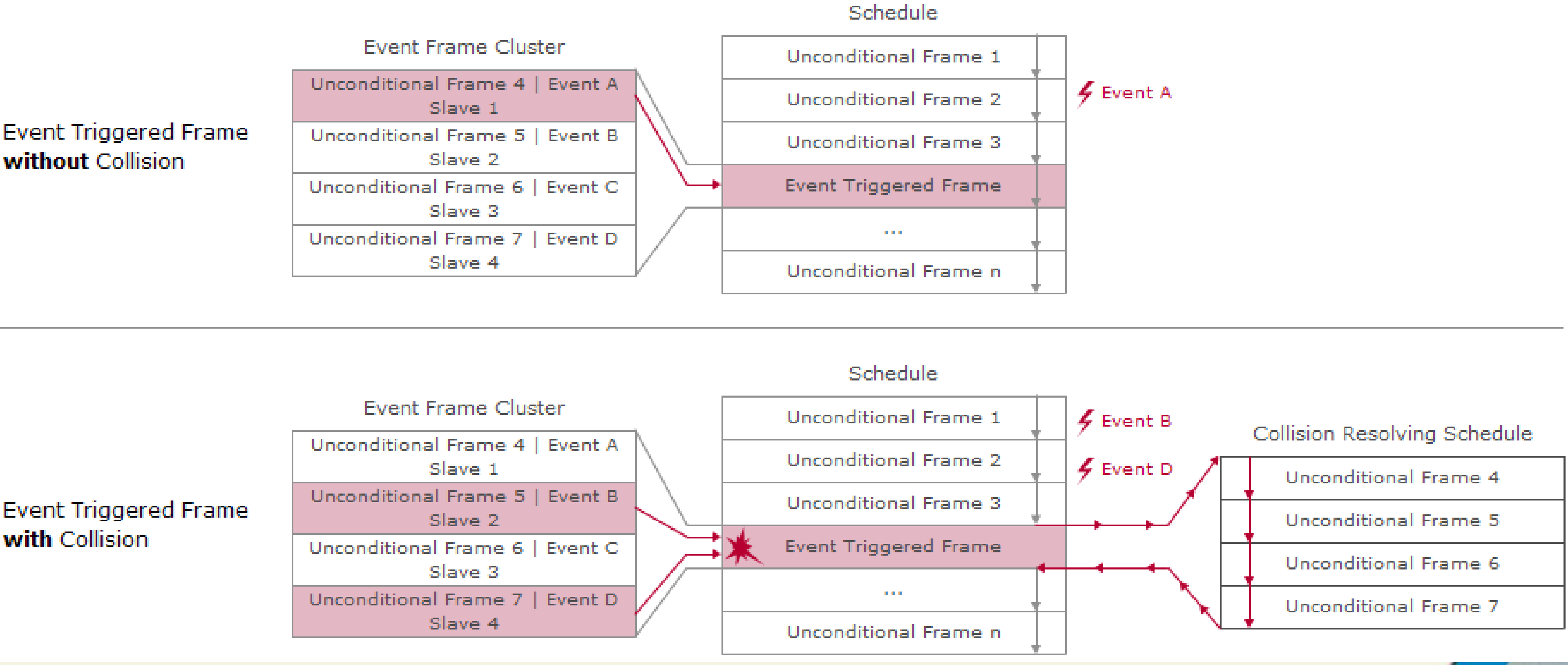
lin Scenario

Event Triggered Frames

1. Master asks slaves if a certain event has occurred.
2. Identifiers 0x00 to 0x3b (0-59) Like unconditional; The difference is that multiple slaves may send a response to a header from the master.
3. The first data byte contains an **additional PID**. This makes it possible to determine which node has sent its response on the bus.
4. Collisions are possible - If more than one slave has detected the specified event, all respond simultaneously resulting in a collision
5. When detected, MASTER reverts to unconditional frames

Scenario

Event Triggered Frames

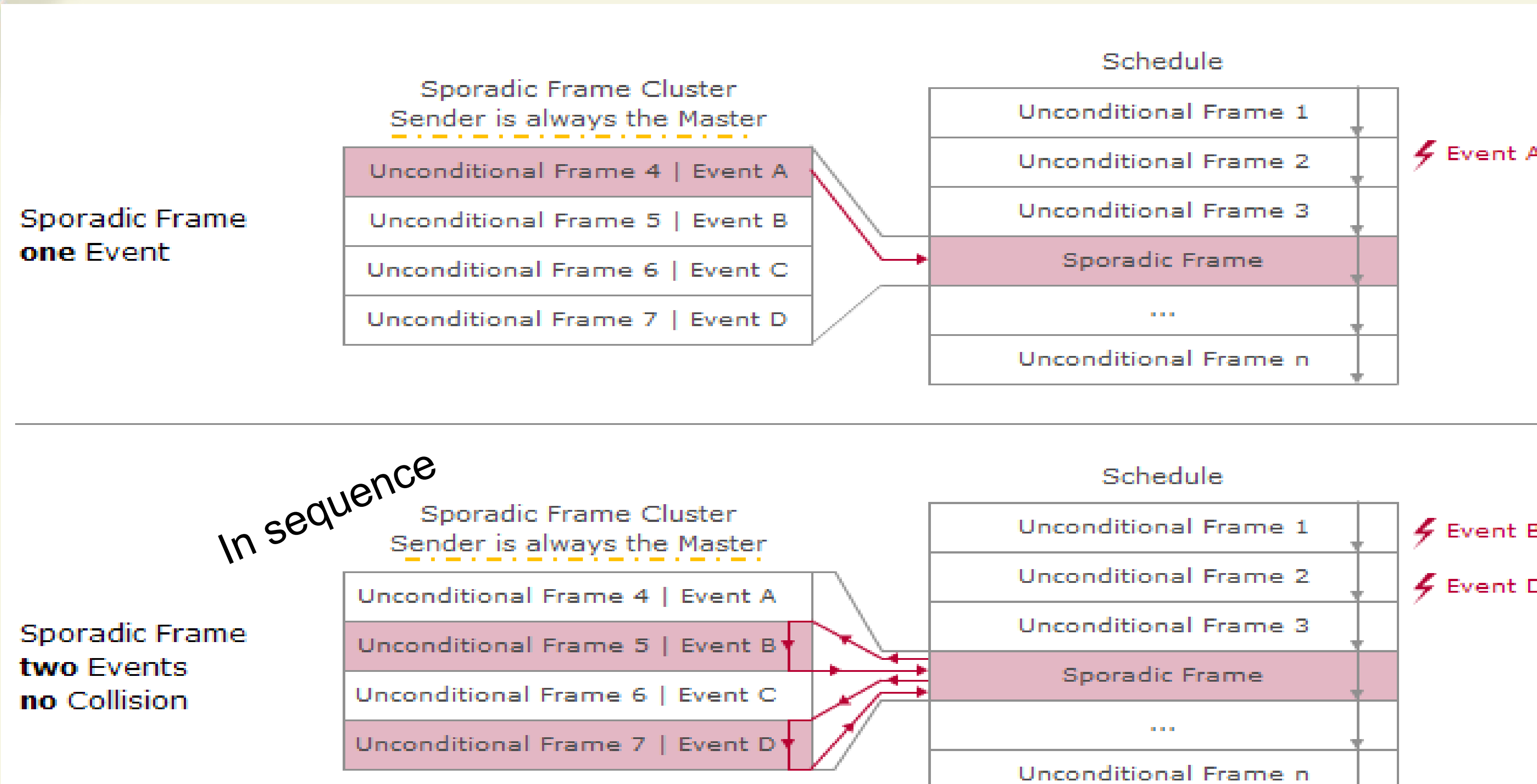


Collision Detection

- Since each node will send another PID at 1st data byte.
- The lin bus will show a new PID not in lin cluster

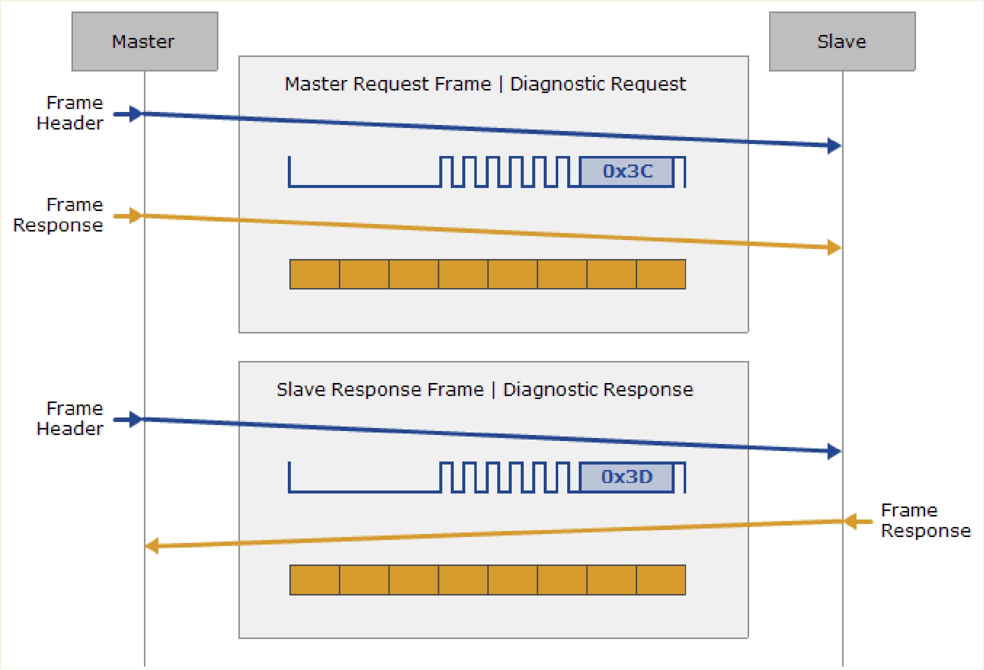
Sporadic Frame

- Means: not happening or appearing in a pattern; not continuous or regular:



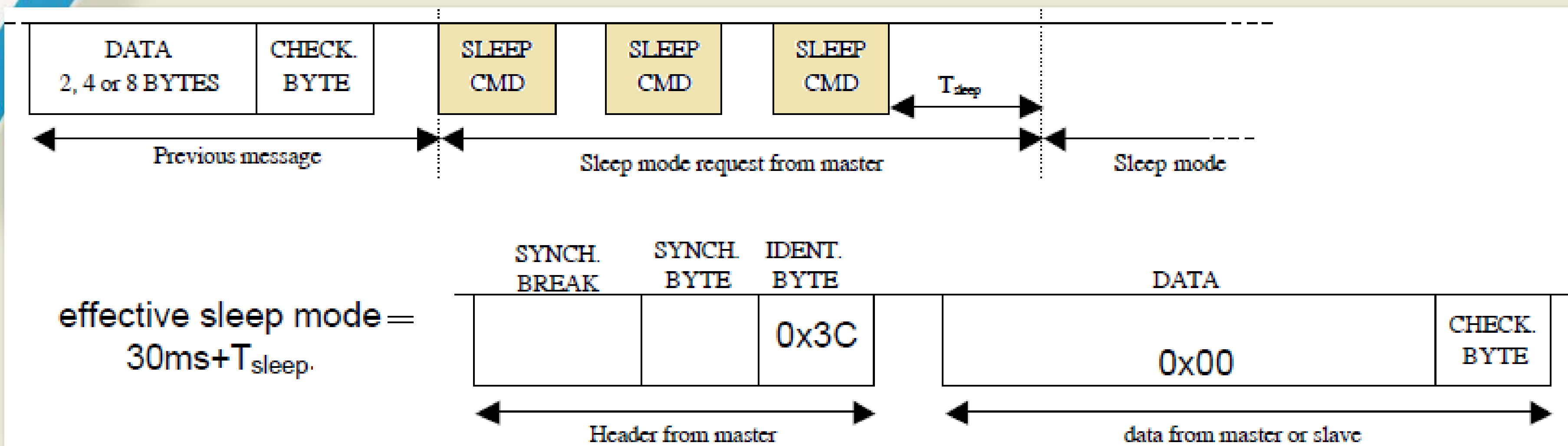
Diagnostic Frames

- Master Request Frame (ID=0x3C)
  - Message Header and Message Response are sent by the LIN Master
  - Used for: Diagnostic Request and Configuration Services
- Slave Response Frame (ID=0x3D)
  - Message Header is sent by the LIN Master
  - Message Response is sent by the relevant LIN Slave
  - Used for: Diagnostic Response and Configuration Services



Structure of a message:
Sleep Mode

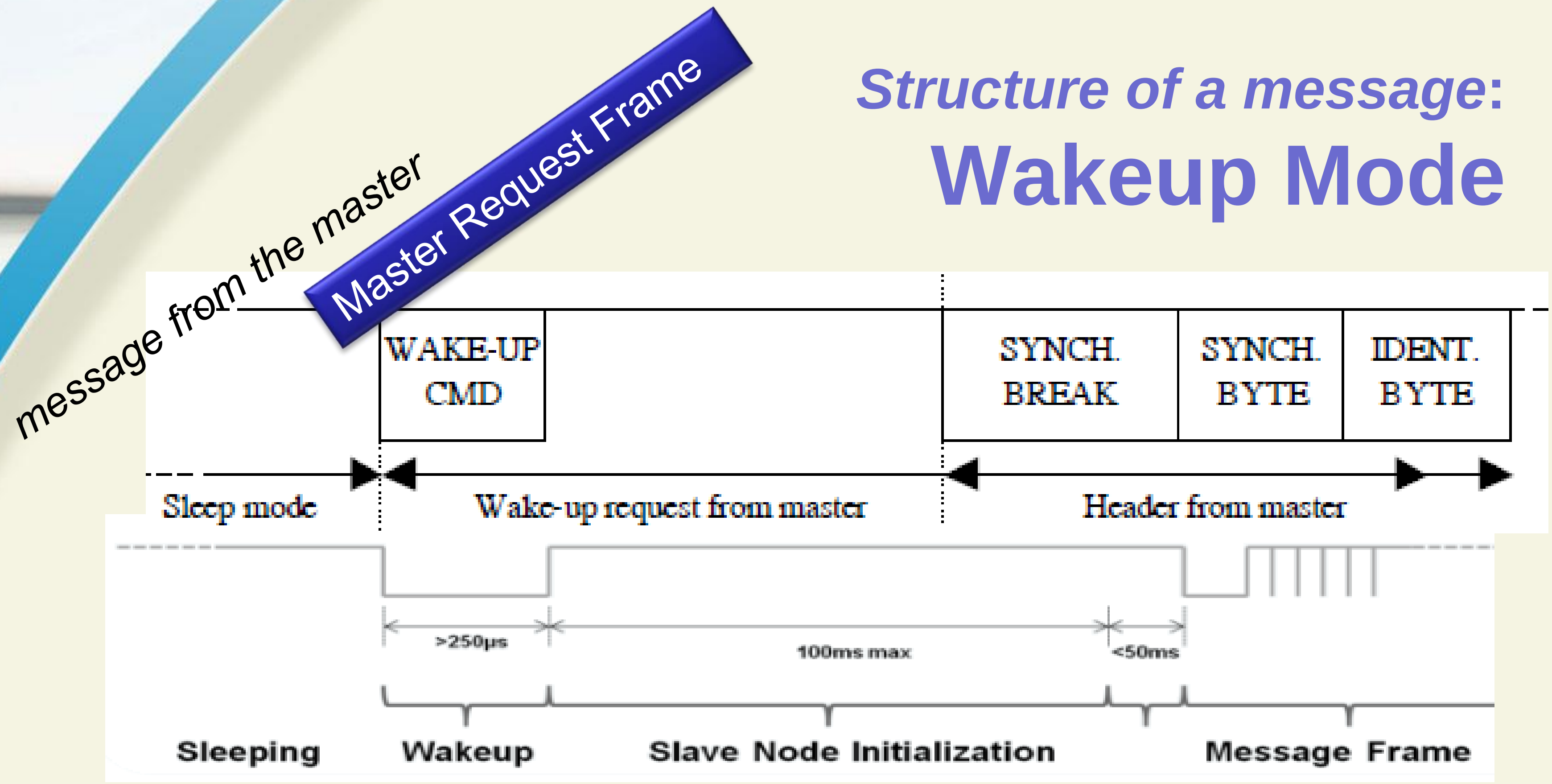
Master Request Frame



Bus inactivity:

When the bus remains in the recessive level during a specified time, the ECUs have to enter in sleep mode.

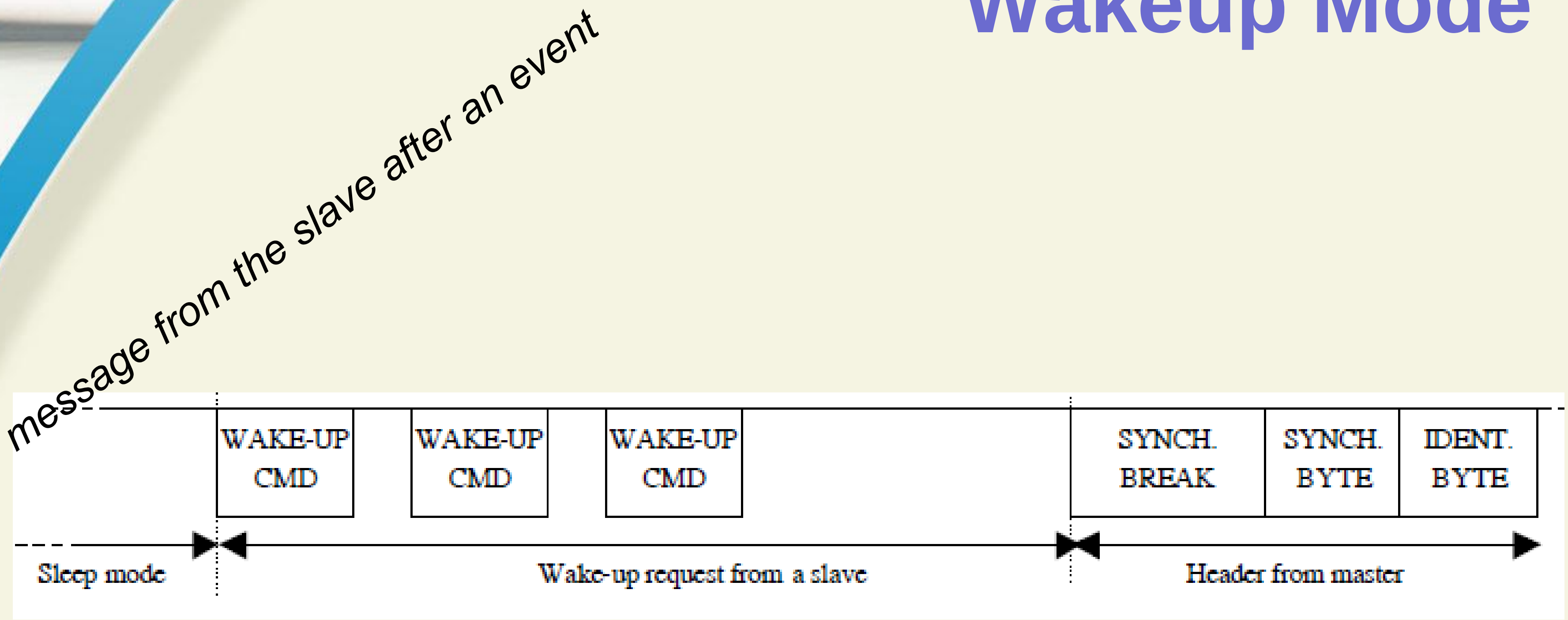
Structure of a message: Wakeup Mode



1. Any node can request a wakeup
2. Node forces dominant from 250 µs – 5 ms
3. All nodes should then wakeup within 100 ms from end of wakeup signal
4. Master node must transmit within 150 ms

Structure of a message:

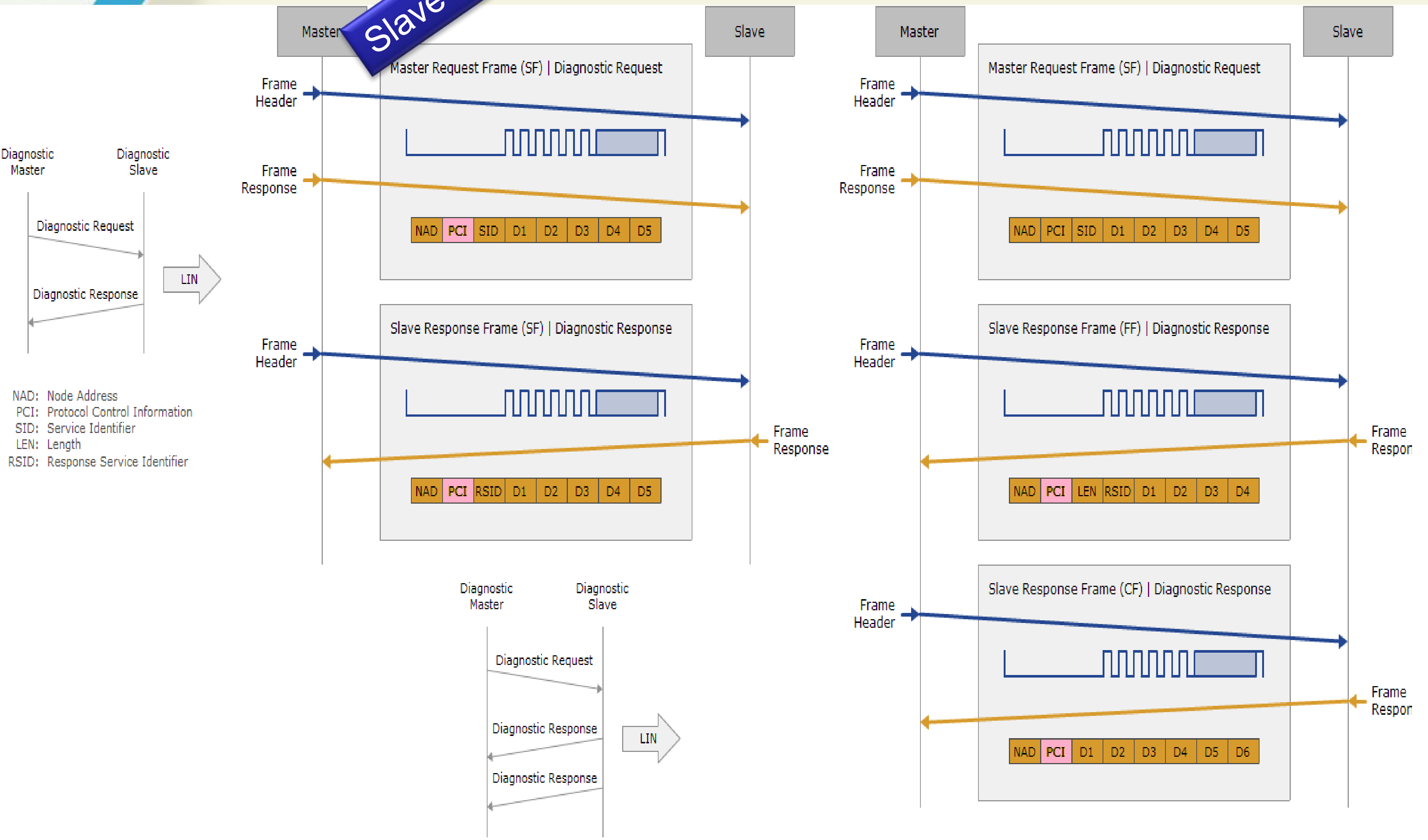
Wakeup Mode



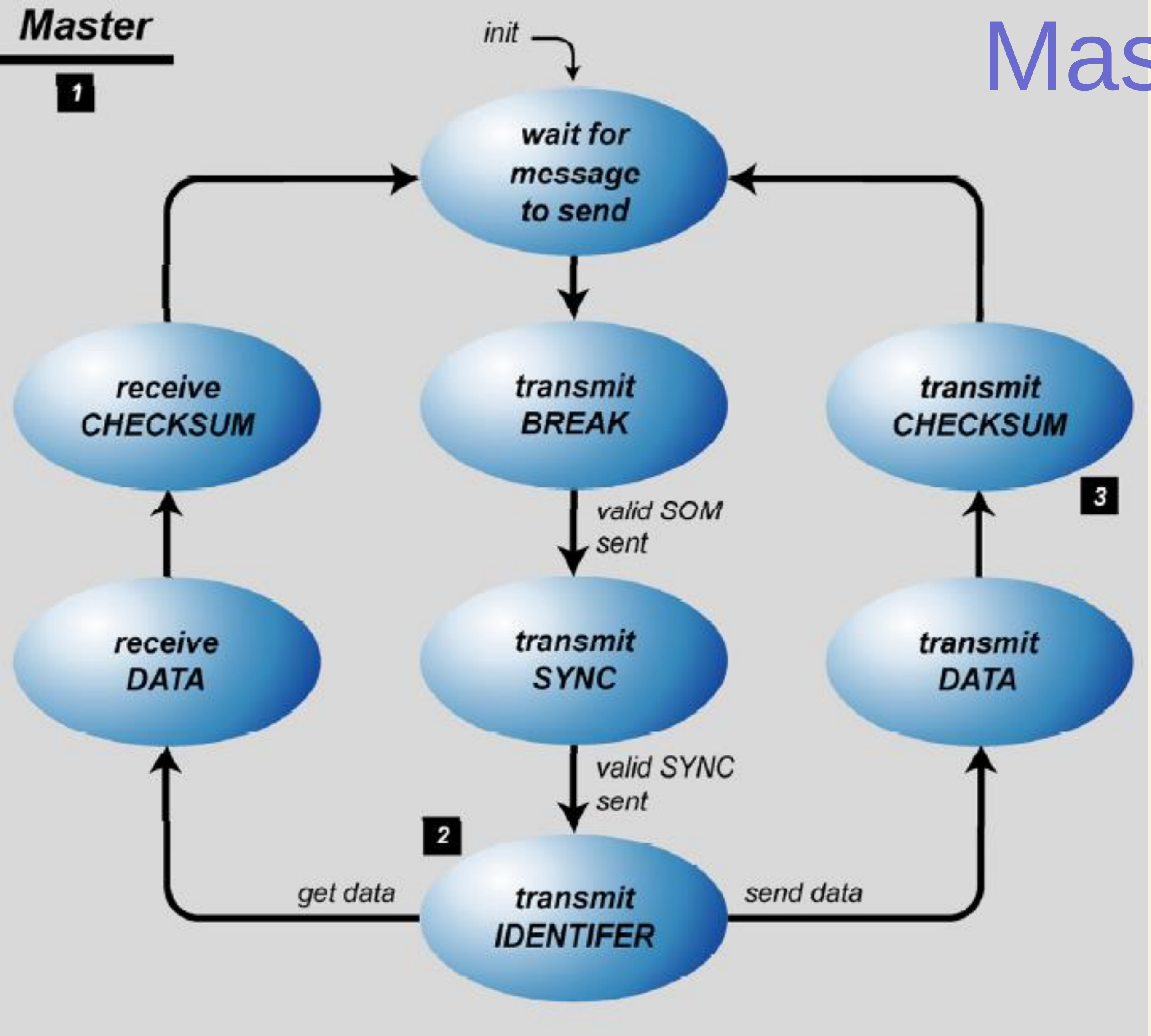
1. Any node can request a wakeup
2. Node forces dominant from 250 µs – 5 ms
3. All nodes should then wakeup within 100 ms from end of wakeup signal
4. Master node must transmit within 150 ms

Slave Response

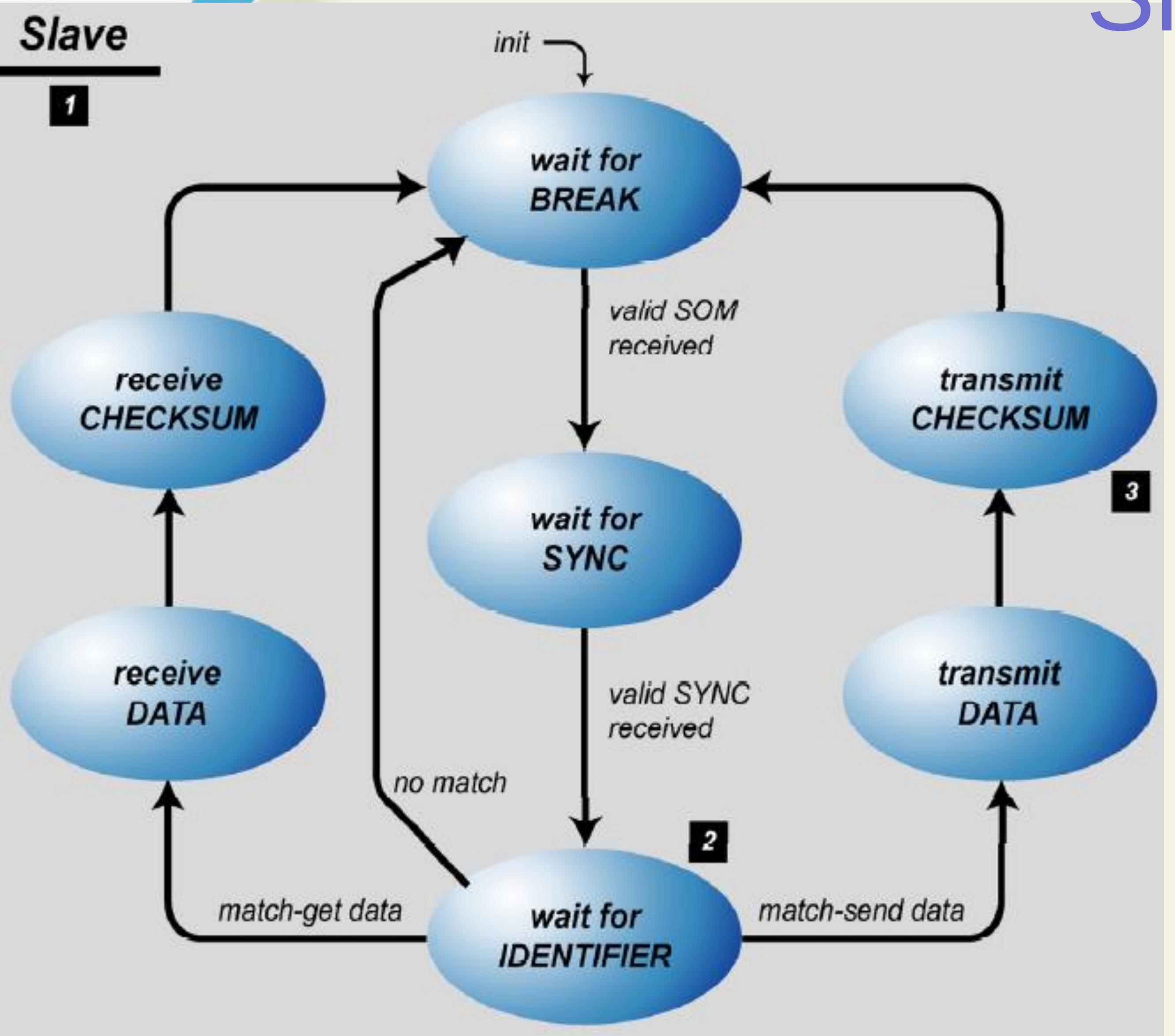
Slave Response Frame



Master FSM

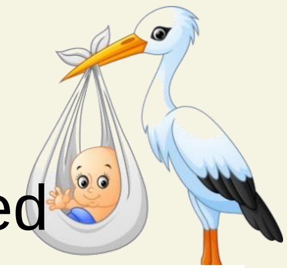

Master
1
init
wait for message to send
receive CHECKSUM
transmit BREAK
transmit CHECKSUM
3
valid SOM sent
receive DATA
transmit SYNC
transmit DATA
valid SYNC sent
2
get data
transmit IDENTIFER
send data

Slave FSM


Slave
1
init
wait for BREAK
valid SOM received
receive CHECKSUM
transmit CHECKSUM
3
wait for SYNC
receive DATA
transmit DATA
valid SYNC received
no match
2
match-get data
wait for IDENTIFIER
match-send data

FlexRay™

FlexRay™ Consortium



- In 2000, a consortium agreement was signed

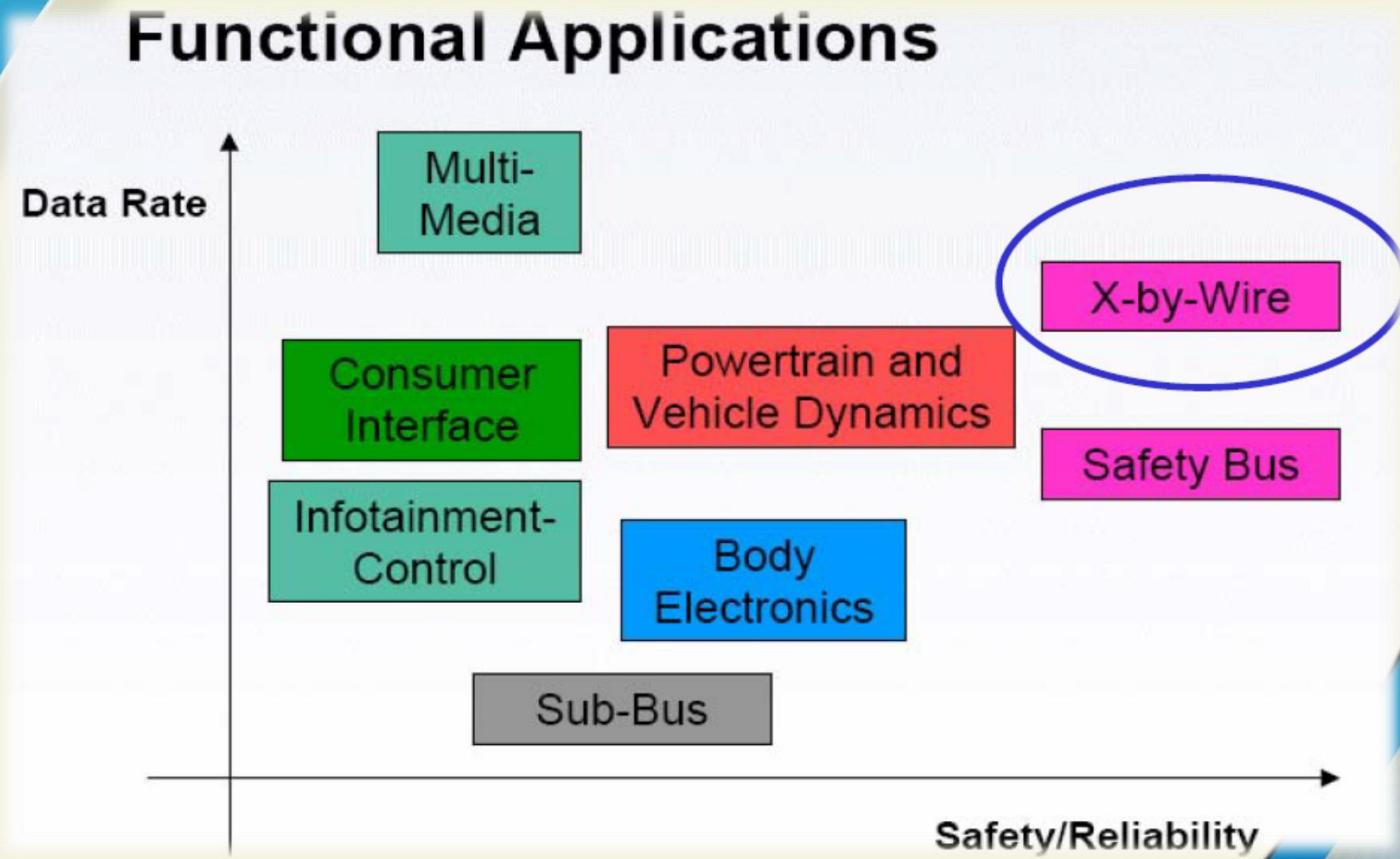

I can't do it

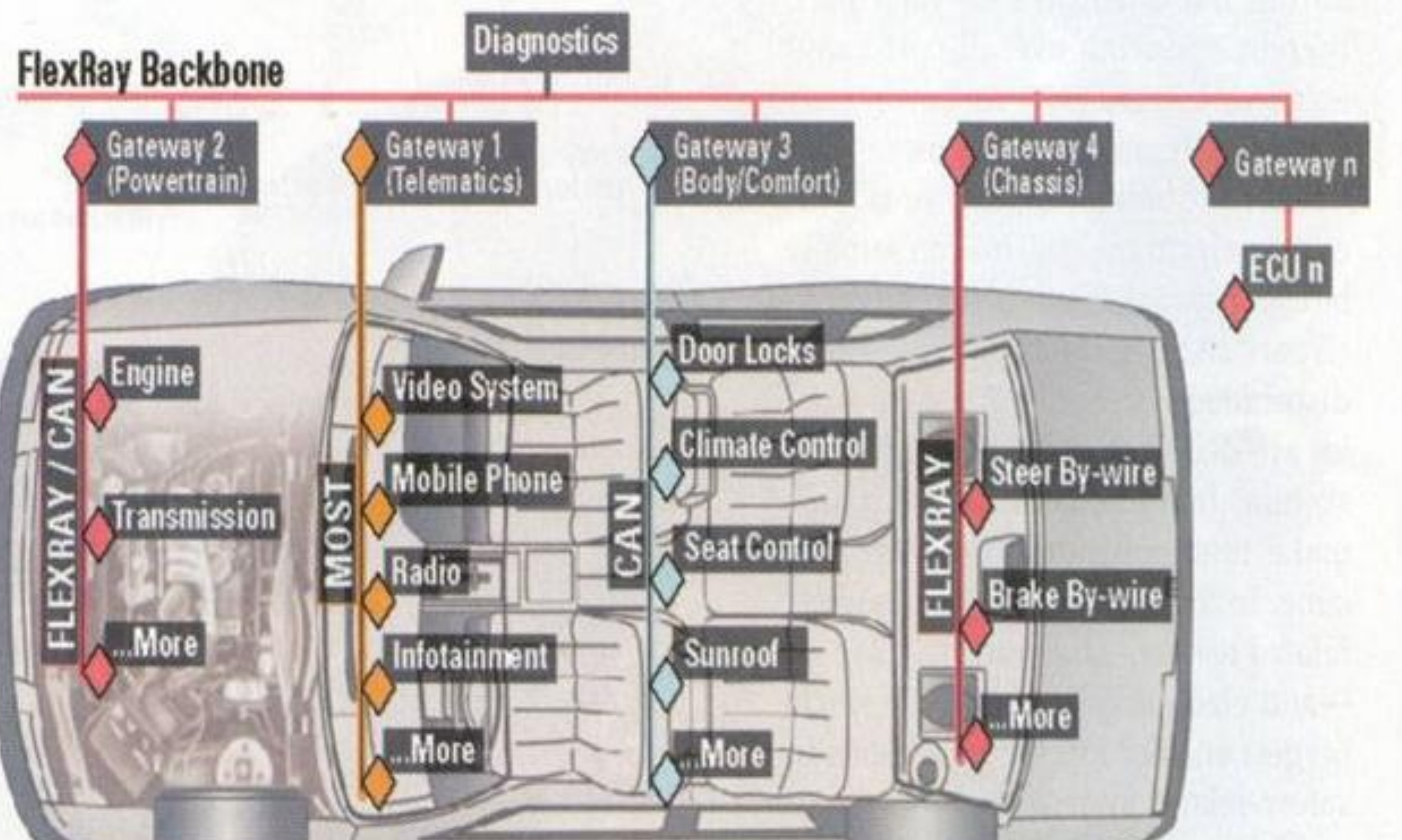
Motivation


Extrinsic Motivation
Motivated to perform an activity to earn a reward or avoid punishment
Intrinsic Motivation
Motivated to perform an activity for its own sake and personal rewards
verywell

- **Safety-critical driver assistance functions.**
- **Deterministic and fault tolerant data communication** independent of bus load.
- Event-driven communication systems (CAN) do **not** exhibit **composability**.
- Data rates up to 10 Mbit/s per channel.

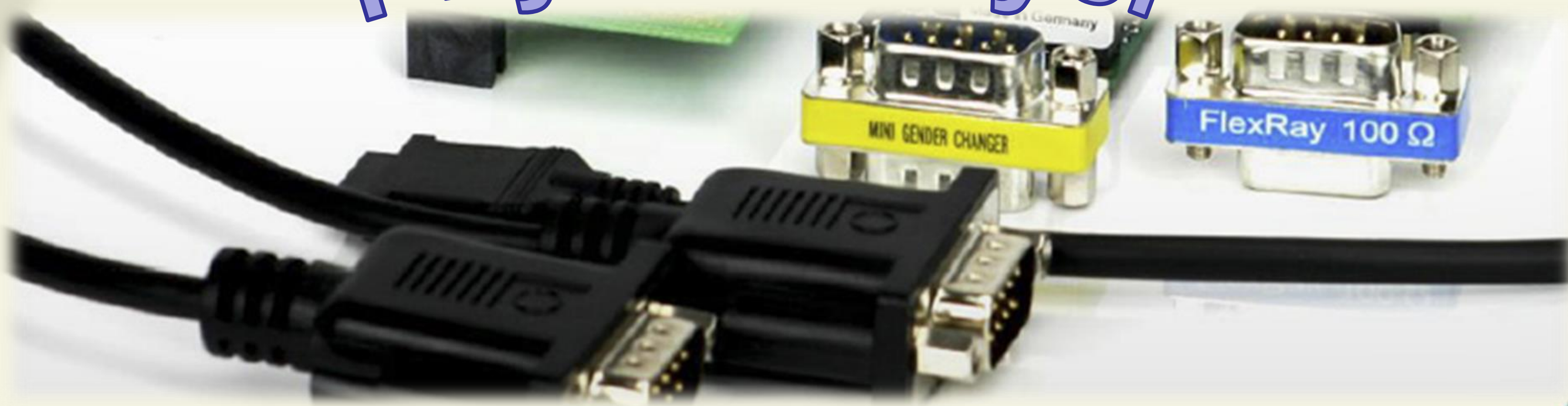
Automotive Network Demands





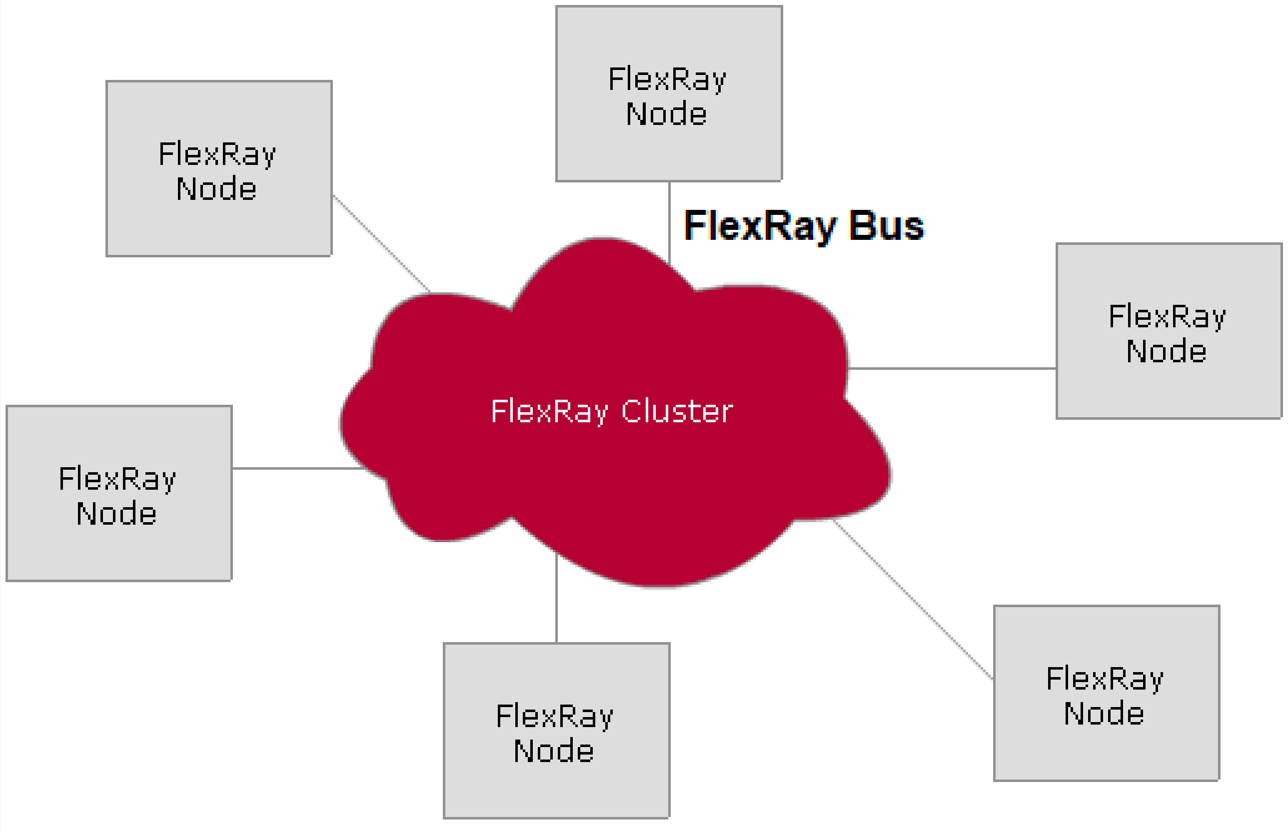
FlexRay Backbone
Diagnostics
Gateway 2 (Powertrain)
Gateway 1 (Telematics)
Gateway 3 (Body/Comfort)
Gateway 4 (Chassis)
Gateway n
ECU n
FLEXRAY / CAN
Engine
Transmission
...More
MOST
Video System
Mobile Phone
Radio
Infotainment
...More
CAN
Door Locks
Climate Control
Seat Control
Sunroof
...More
FLEXRAY
Steer By-wire
Brake By-wire
...More

Physical layer

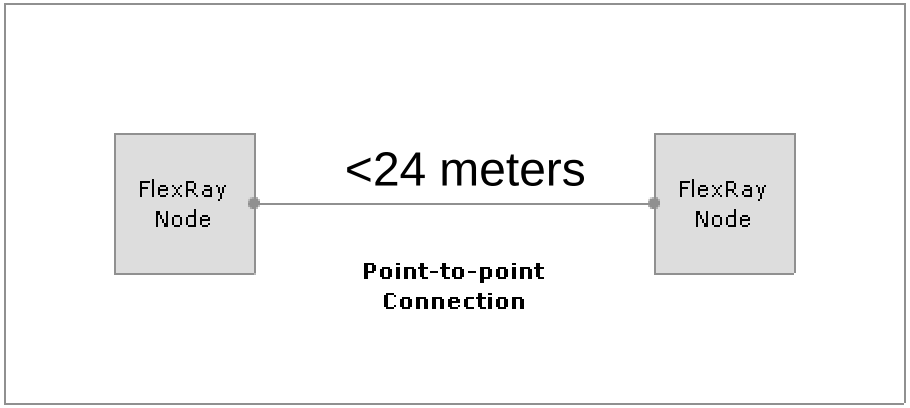


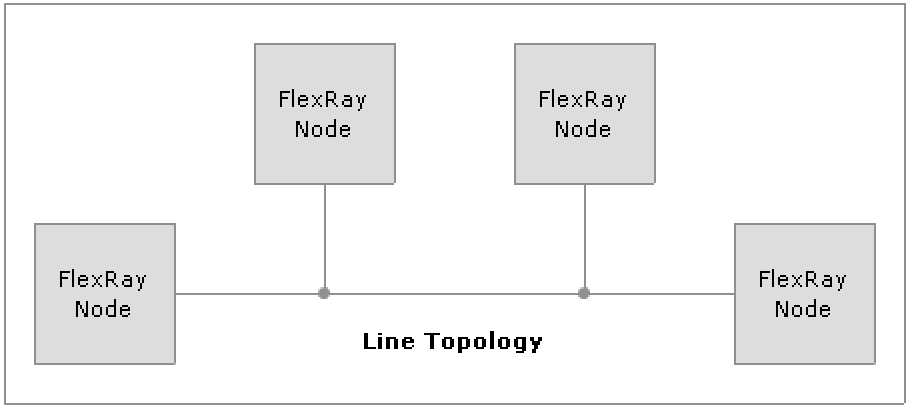
FlexRay Cluster

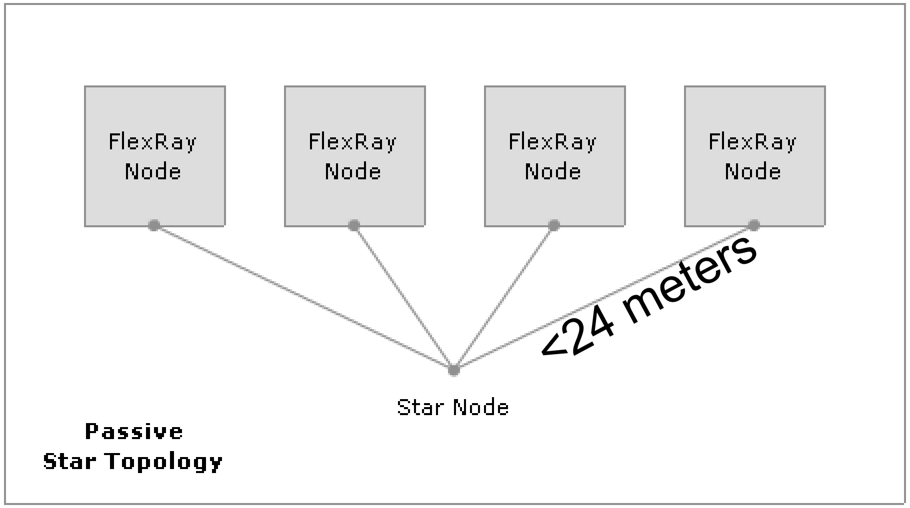
- FlexRay Node.
- FlexRay Bus.



Passive Topology





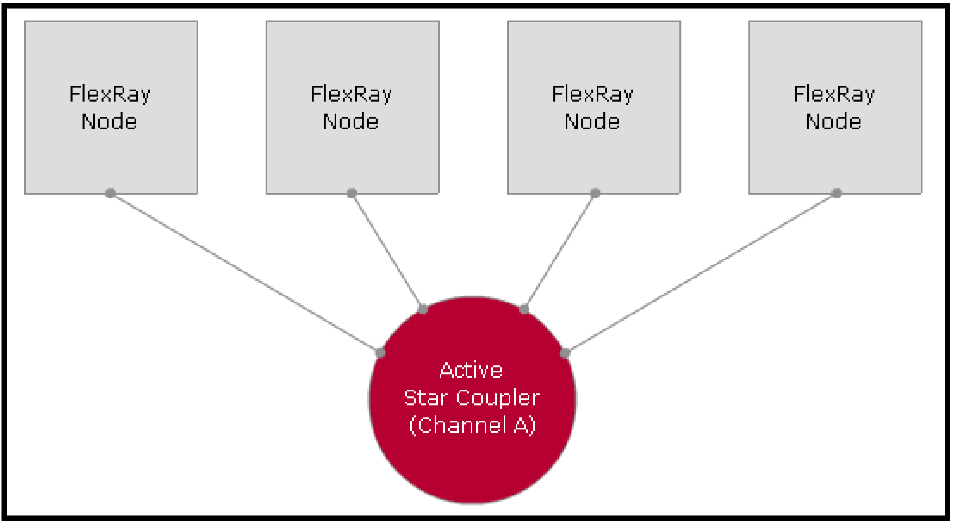


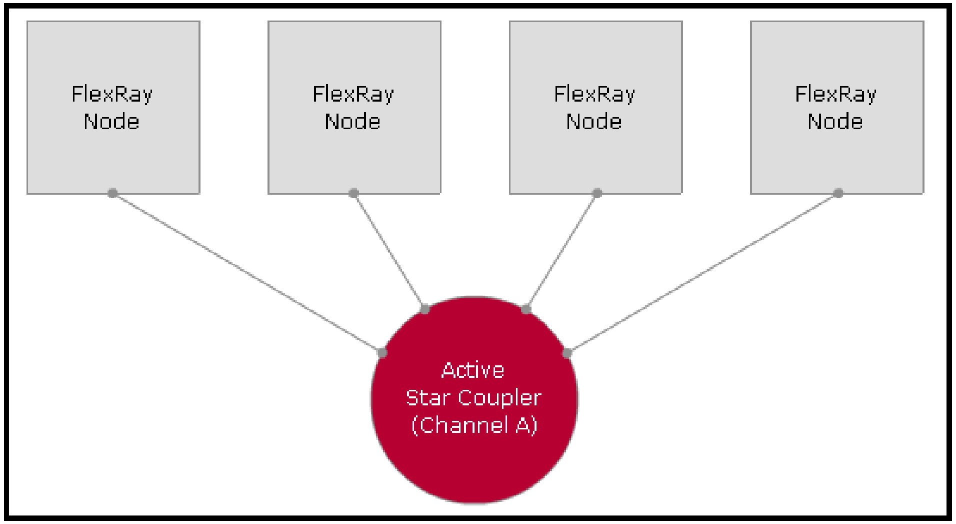
<u>Electrical Physical Layer Specification (EPL Specification)</u>

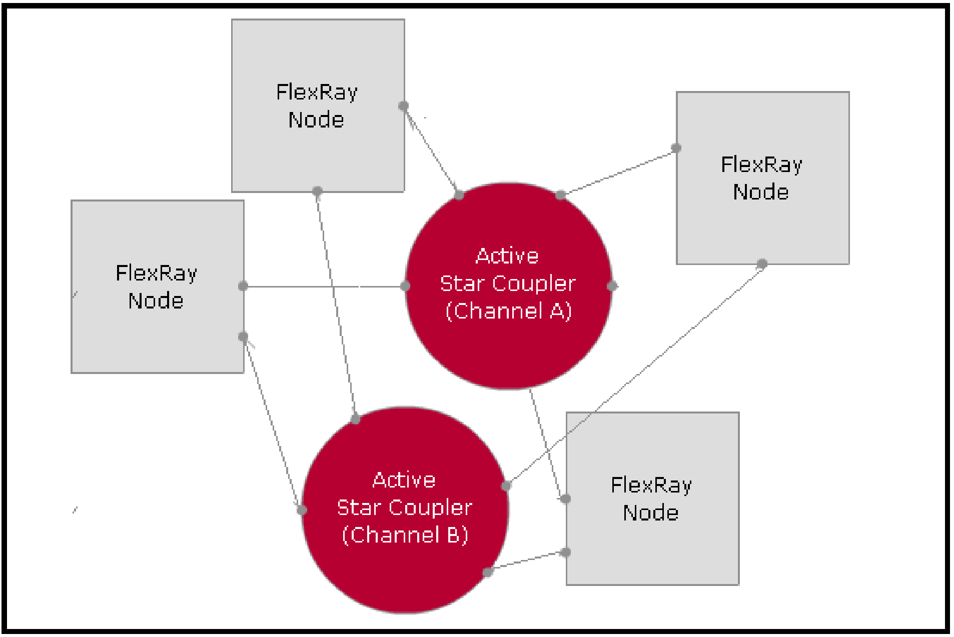
- No more than 22 FlexRay Node.
- <24 meter between any nods.

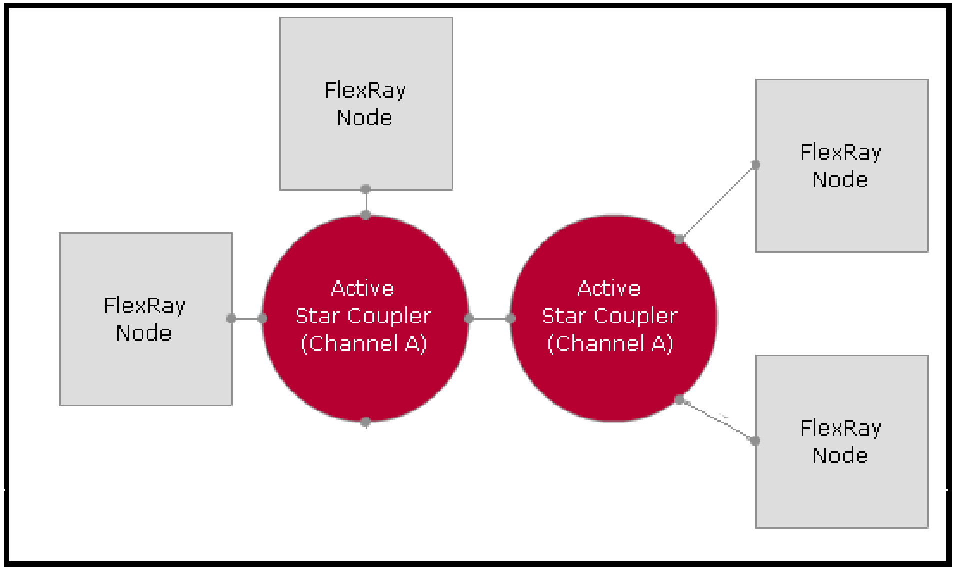
**Electrical Physical Layer Specification (EPL Specification)

Active Topology









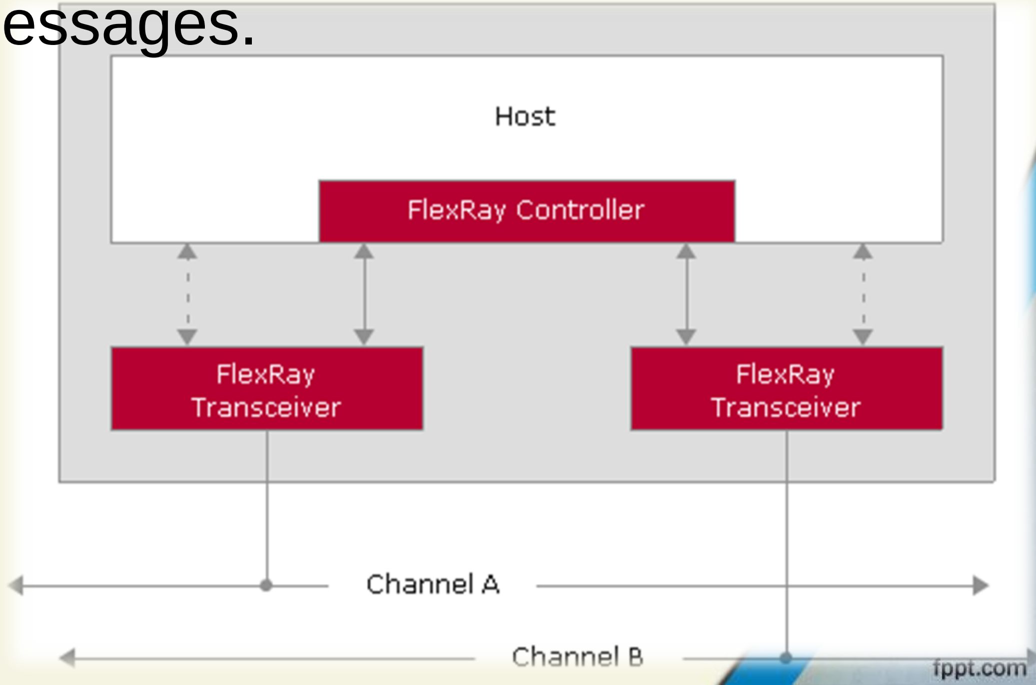
Active Topology

- Avoids propagation of errors by disconnecting faulty communication branches.
- Active star coupler and any FlexRay node may not exceed **24 meters.**
- **Connecting two active star couplers in series** extends wire length to a maximum of 72 meters.

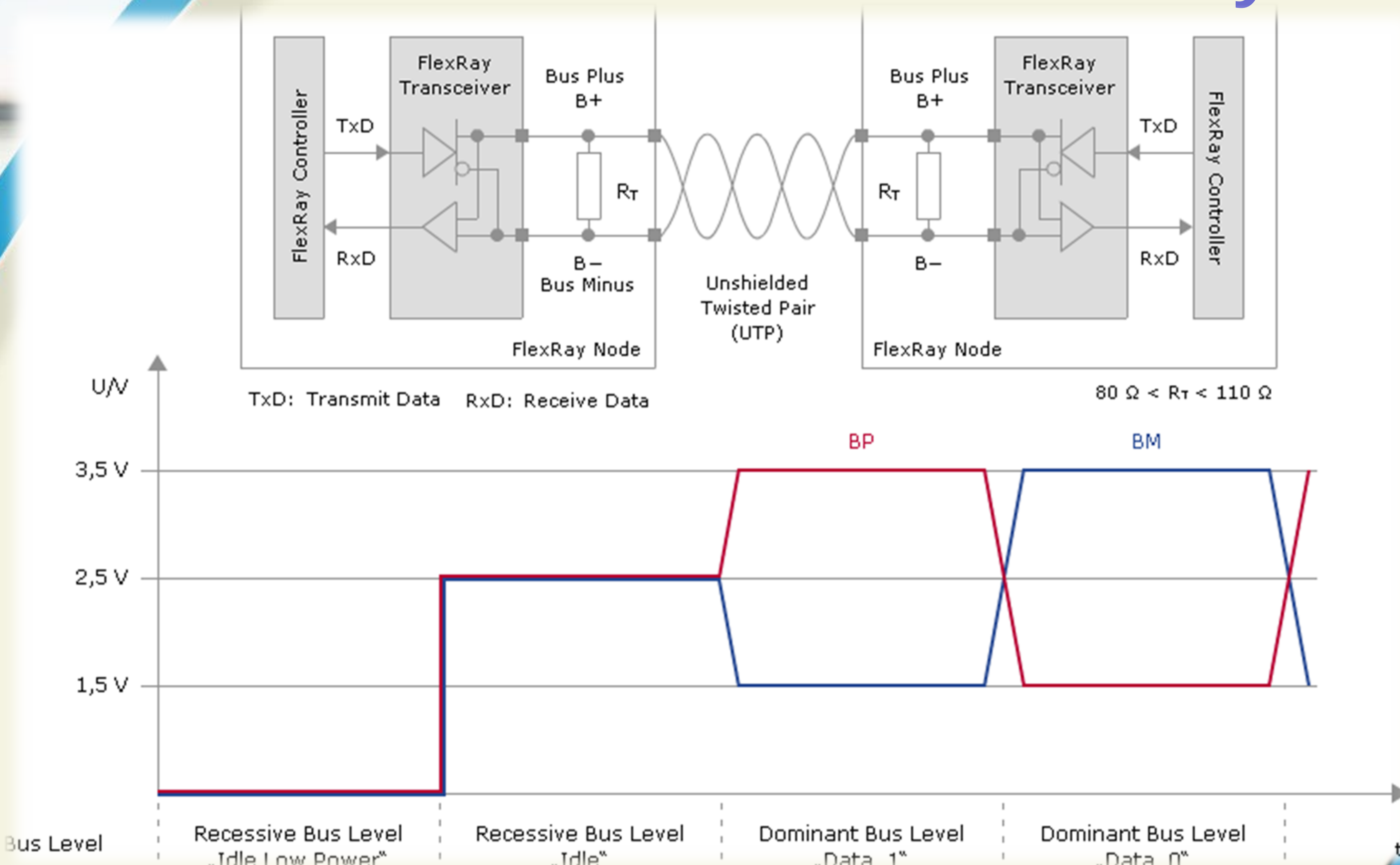
Node

The primary tasks of the FlexRay controller:

1. Framing,
2. Bus access,
3. Error detection and handling,
4. Synchronization,
5. FlexRay bus to sleep and waking it up
6. Coding/decoding messages.

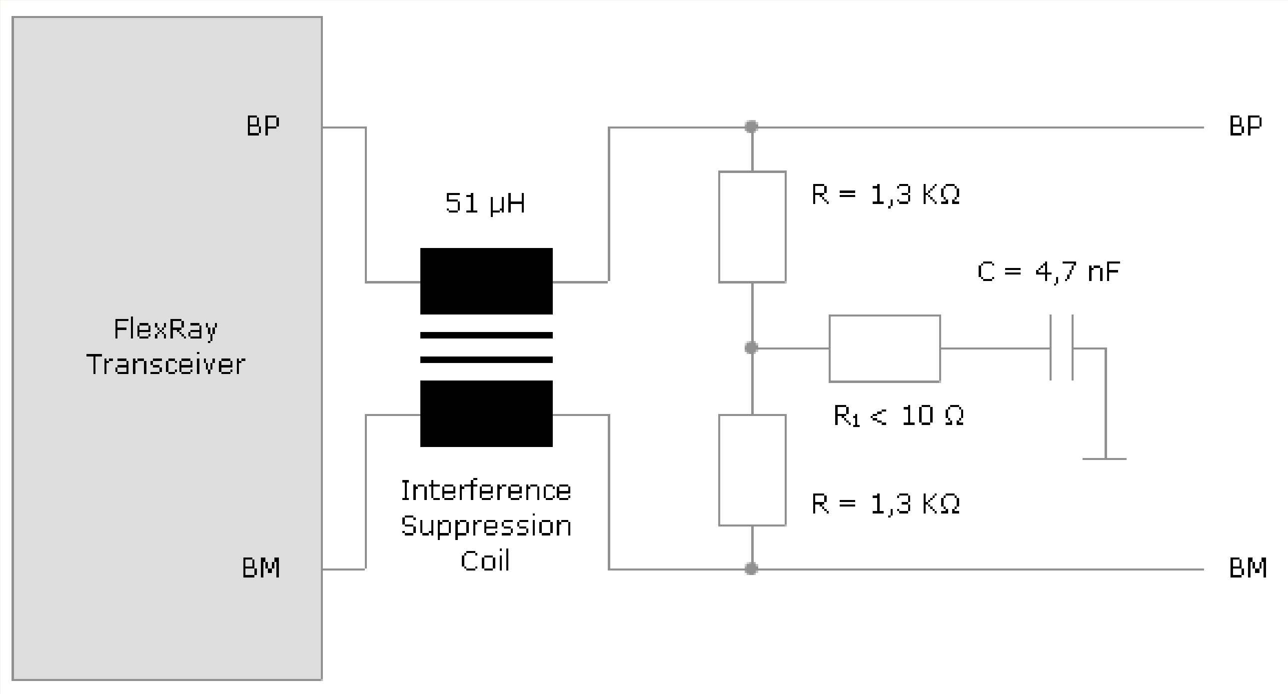


FlexRay Bus



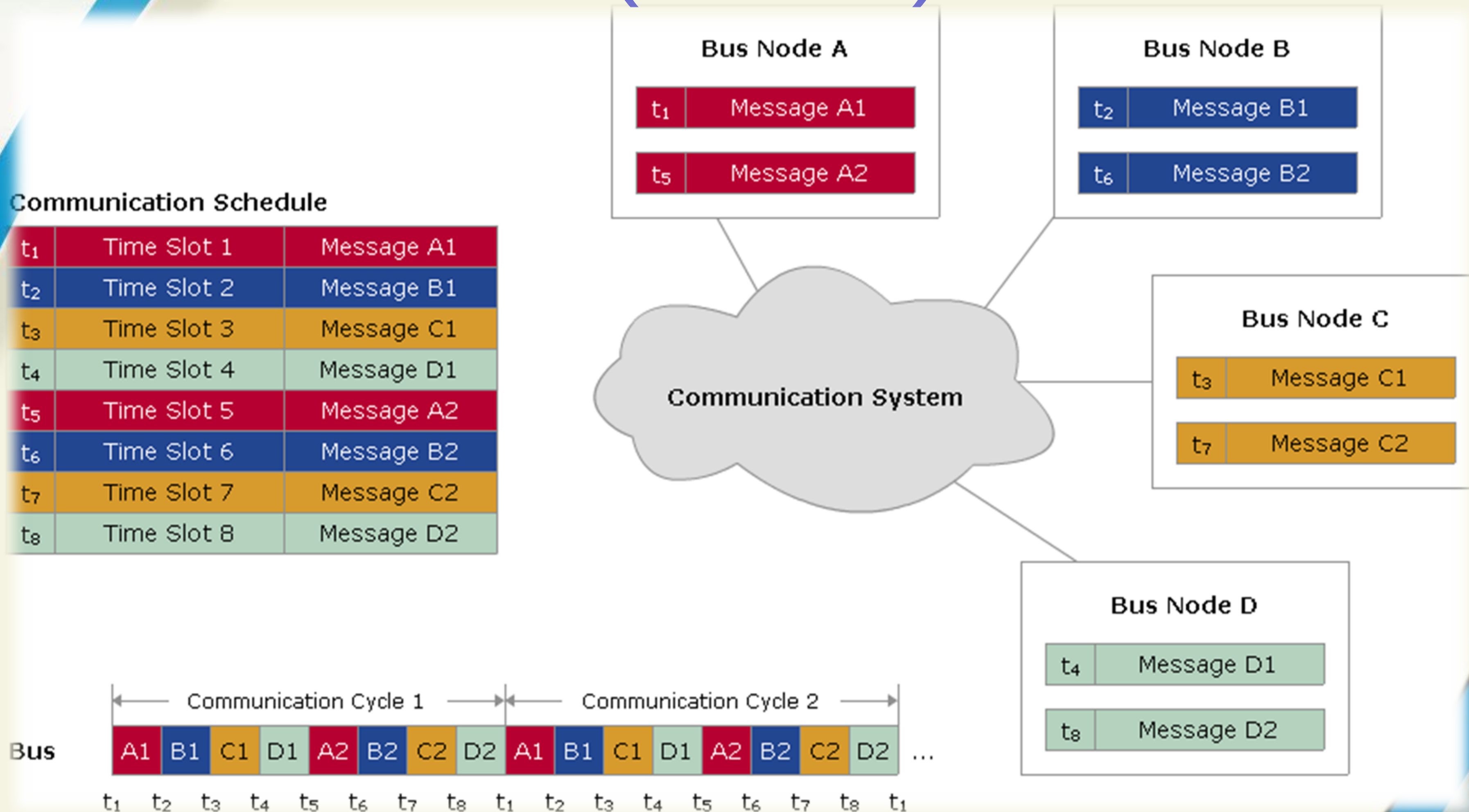
- **Differential** voltages.(External Noise)
- **Termination** of the ends of the communication channel prevents reflection. **Split bus termination** act like LPF.
- **Twisted** pair (Crosstalk).

LC Suppression Circuits

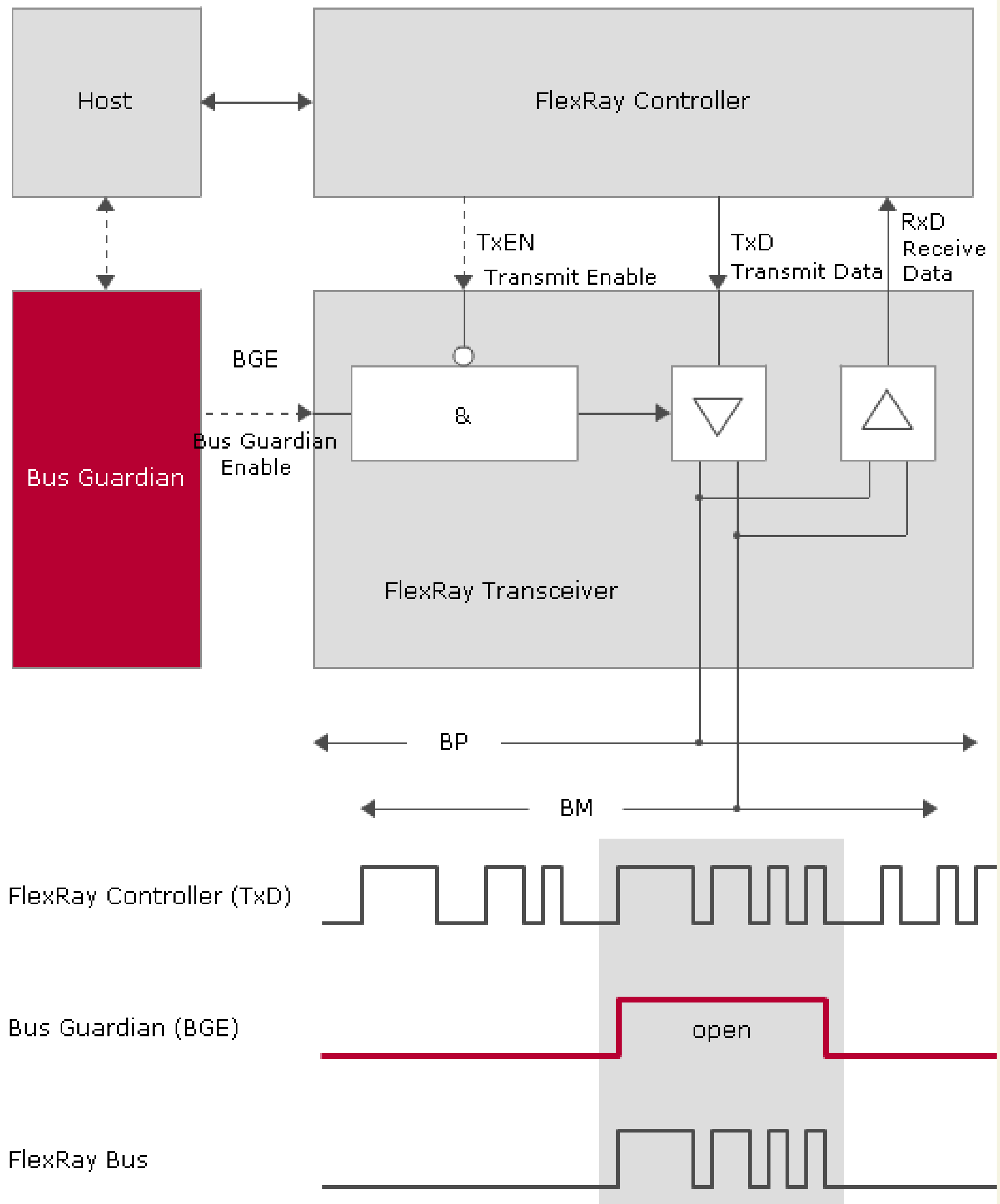


Suppresses any interference currents that might be generated by asymmetrical circuits.

Time Division Multiple Access (TDMA)



Time-triggered Communication Architecture



Bus Guardian (BG)

- Bus guardian must know the communication **schedule** and the **time** in the FlexRay cluster.
- Generates **its time** base independent of the FlexRay controller.
- Complex and Controller **duplicate**.

Principle of Bus Access

TDMA method (Time Division Multiple Access)

- Based on a **communication schedule**,
- Organized into a **periodically** number of time of equal length, each assigned to a FlexRay node.
- **FlexRay communication cycle** guarantee bus **deterministic.**

FTDMA method (Flexible Time Division Multiple Access)

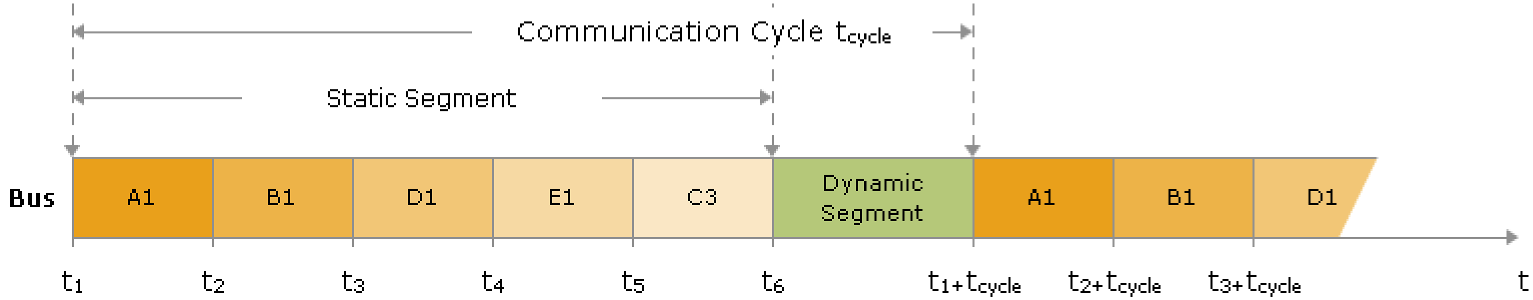
- **Asynchronous processes** (dynamic segment).
- Based on event schedule.

Principle of Bus Access

Communication Schedule

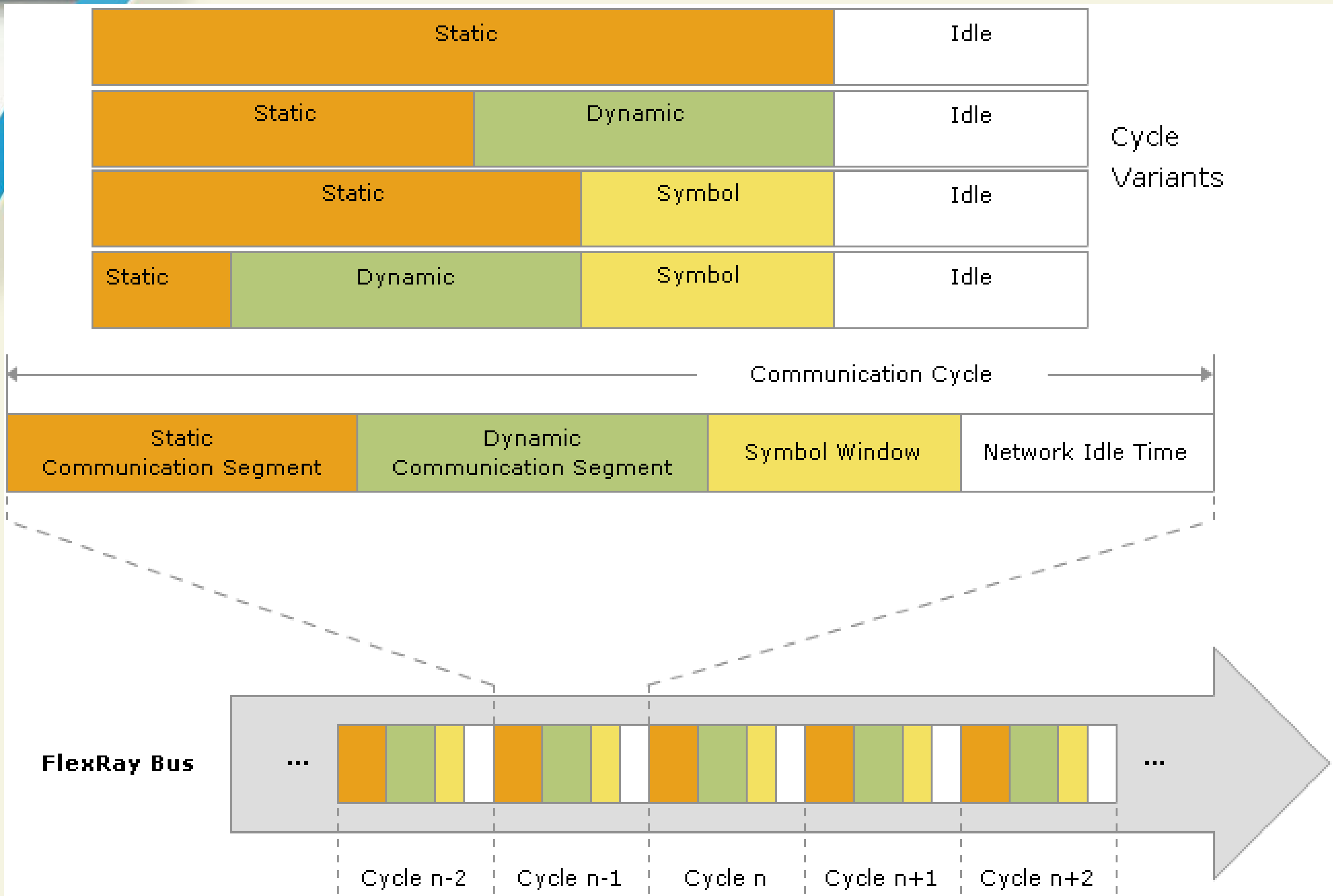
	Slot	Start	Node	Message
Static Segment	1	t_1	A	A1
	2	t_2	B	B1
	3	t_3	D	D1
	4	t_4	E	E1
	5	t_5	C	C3
Dynamic Segment				

TDMA method
(Time Division Multiple Access)



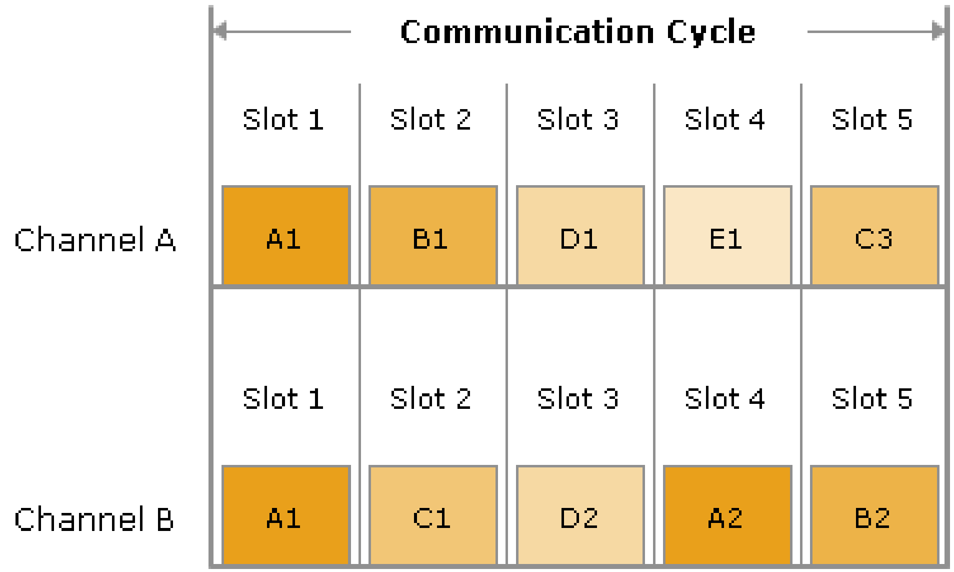
FTDMA
(Flexible Time Division Multiple Access)

Communication Cycle



Static Segment

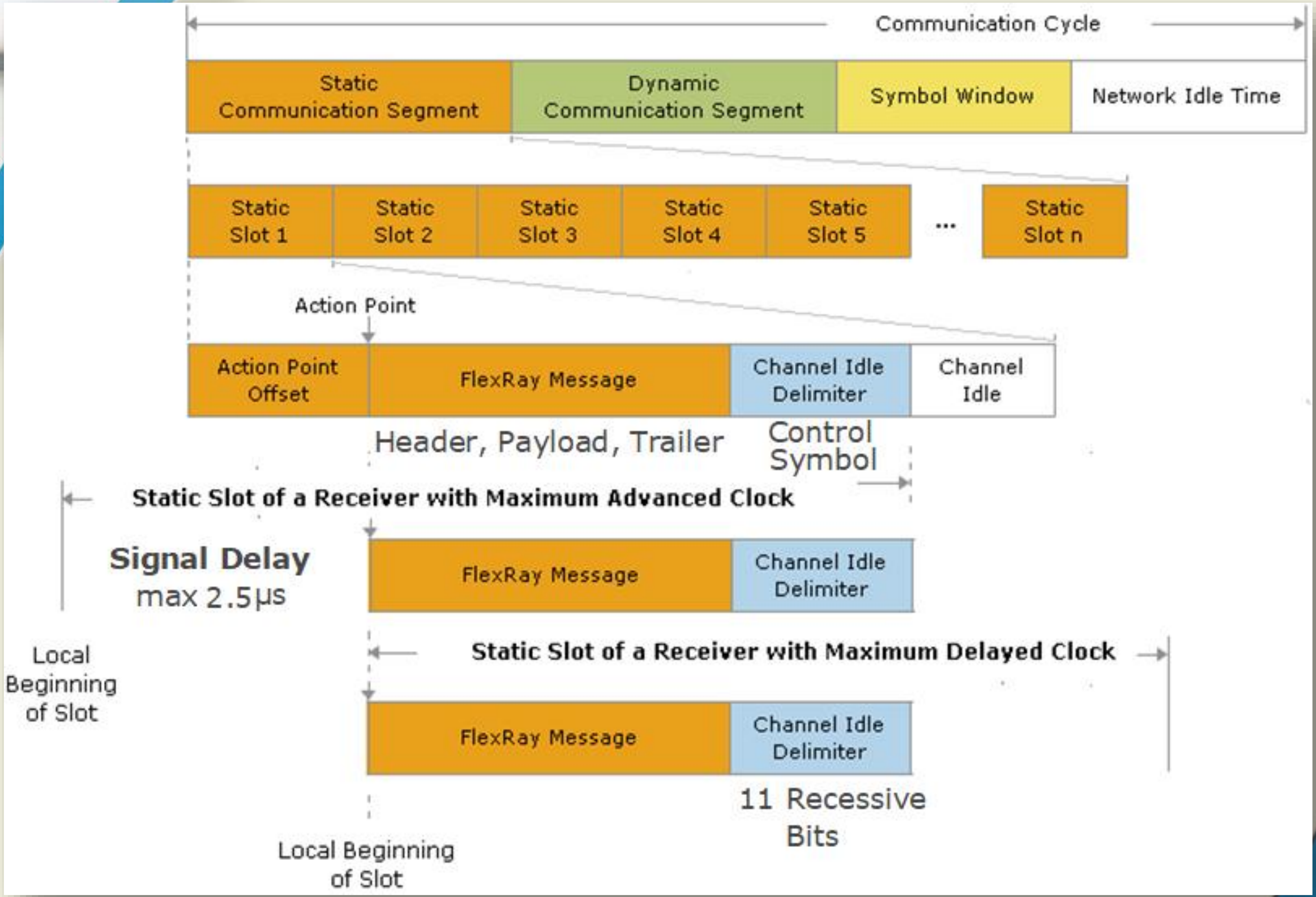
Slot	Node	Message	Channel
1	Node A	A1	A
		A1	B
2	Node B	B1	A
	Node C	C1	B
3	Node D	D1	A
		D2	B
4	Node E	E1	A
	Node A	A2	B
5	Node C	C3	A
	Node B	B2	B



TDMA method (Time Division Multiple Access)

- Based on a **communication schedule**,
- Organized into a **periodically** number of time of equal length, each assigned to a FlexRay node.
- **FlexRay communication cycle** guarantee bus **deterministic.**
- The redundant communication channel might be used to increase the **data rate** (Slot 3).
- The redundant communication channel might be used to increase **fault tolerance** (Slot 1).
- Maximum of 1023 static slots may be defined.

Static Slot



Action point offset size increase poorer local clocks or signal delays

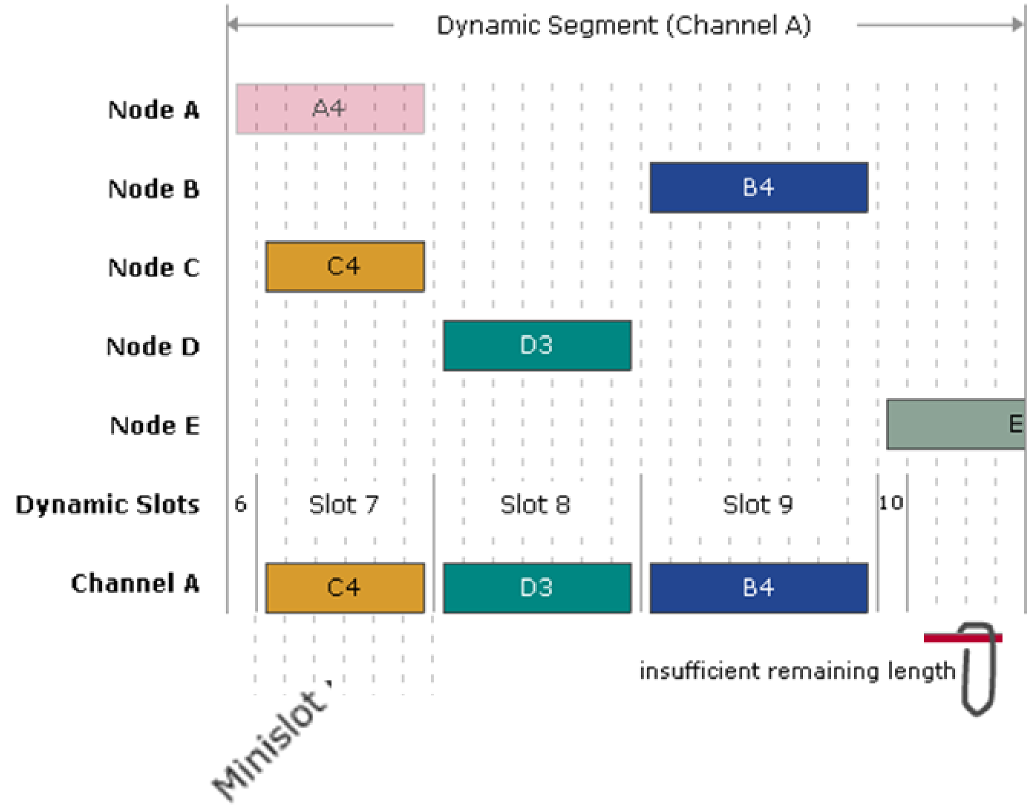
Symbol Window

- The collision avoidance symbol is used to indicate the start of the first communication cycle to a FlexRay node.
- The media test symbol is used for testing of a bus guardian.
- the Wake-up symbol for waking up the FlexRay cluster.

Dynamic Segment

Communication Schedule for Dynamic Segment

	Slot	Node	Message	Channel	Event
Dynamic Segment	6	Node A	A4	A	
		Node B	B3	B	
	7	Node C	C4	A	
		Node D	D3	B	
	8	Node D	D3	A	
		Node E	E2	B	
	9	Node B	B4	A	
		Node A	A5	B	
	10	Node E	E3	A	
		Node C	C5	B	



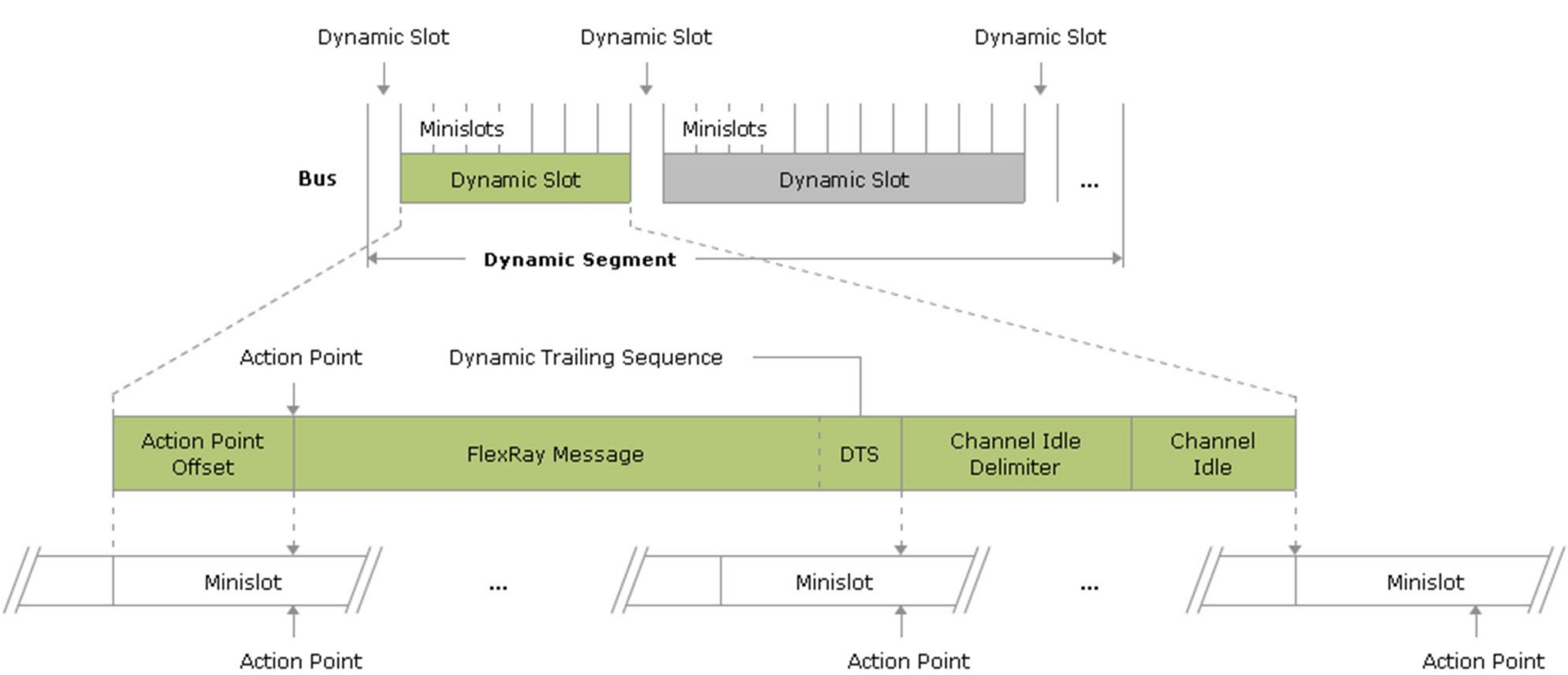
FTDMA method (Flexible Time Division Multiple Access)

- **Asynchronous processes** (dynamic segment).
- Based on event driven.
- Dynamic time segment always exhibits the same length(deterministic).

System designer who must ensure that

- Dynamic messages with lower priority can be transmitted – at least if no other needs with higher priority exist.
- It will be possible to transmit the longest dynamic message.

Dynamic Slot

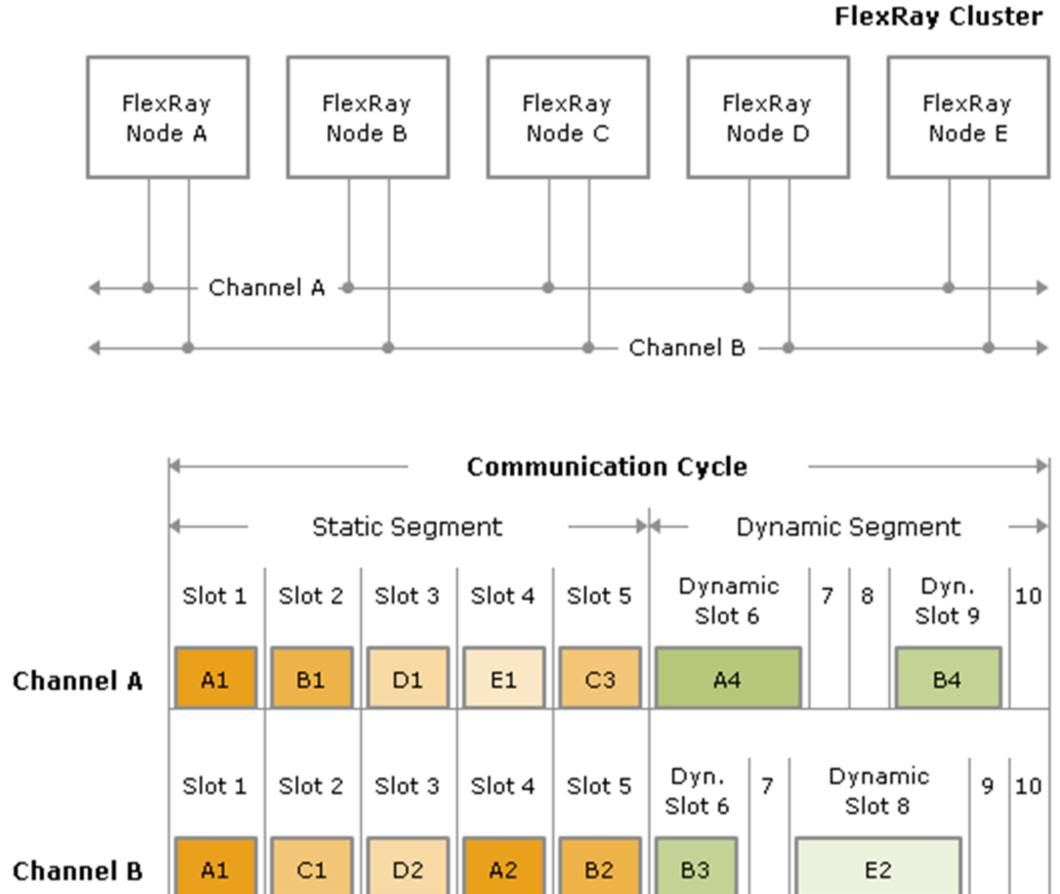


Different payload sizes

Hybrid Bus Access Methods

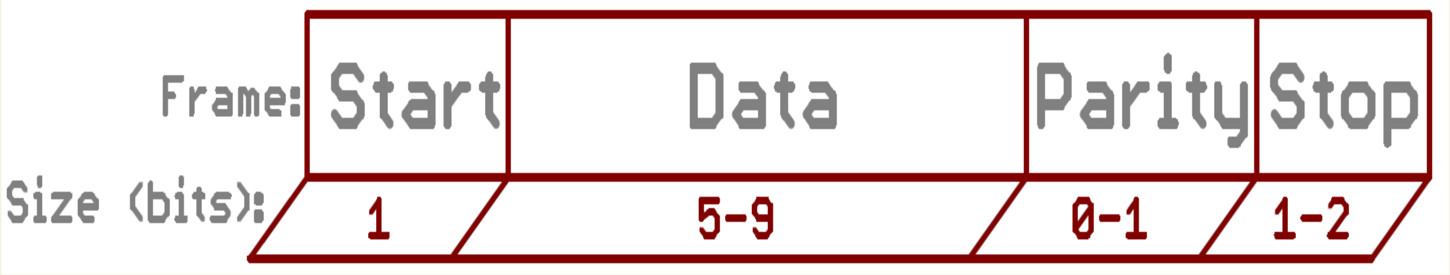
Communication Schedule

	Slot	Node	Frame	Channel	Event
Static Segment	1	Node A	A1	A	
			A1	B	
	2	Node B	B1	A	
		Node C	C1	B	
	3	Node D	D1	A	
			D2	B	
	4	Node E	E1	A	
		Node A	A2	B	
	5	Node C	C3	A	
		Node B	B2	B	
Dynamic Segment	6	Node A	A4	A	
		Node B	B3	B	
	7	Node C	C4	A	
		Node D	D3	B	
	8	Node D	D3	A	
		Node E	E2	B	
	9	Node B	B4	A	
		Node A	A5	B	
	10	Node E	E3	A	
		Node C	C5	B	

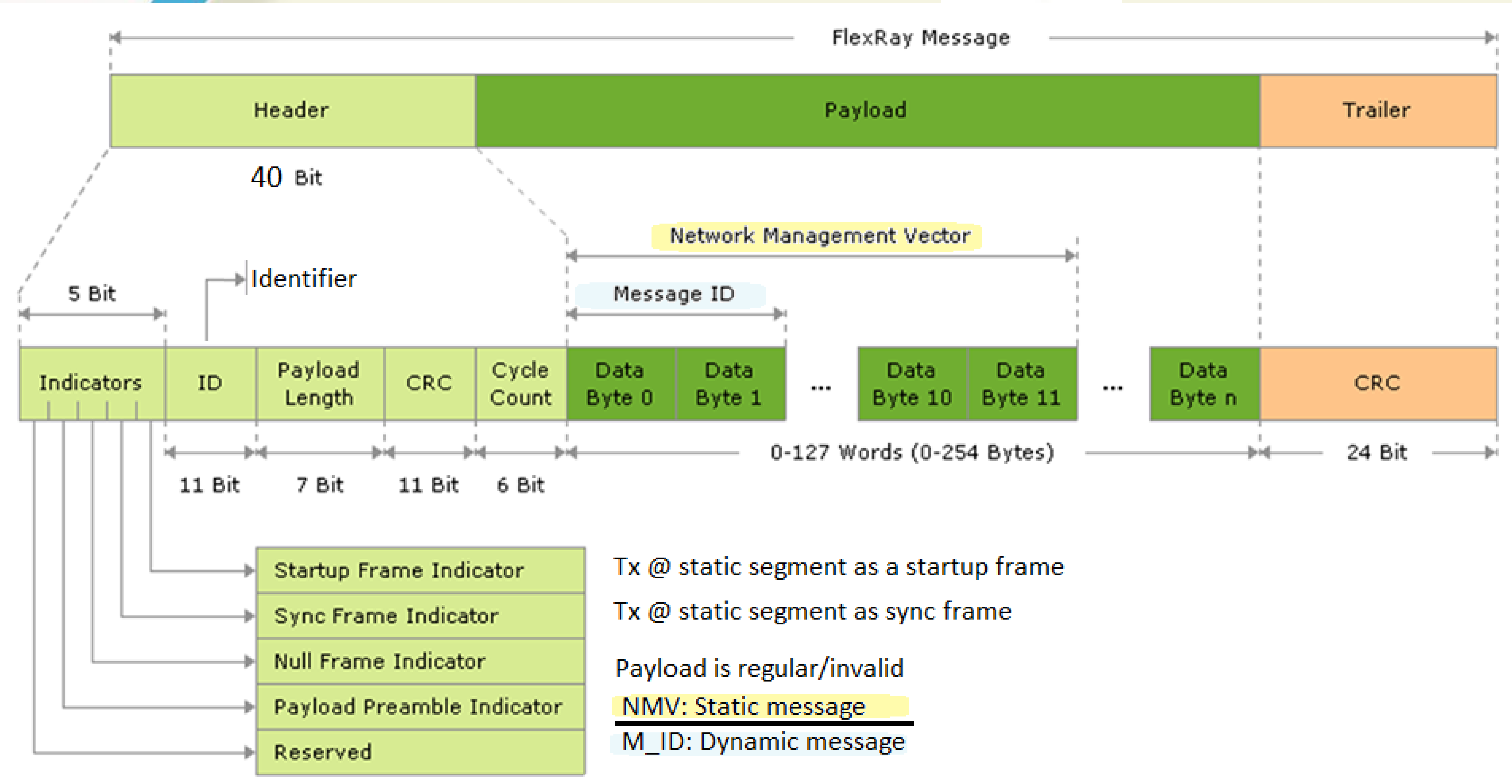


- 5 Nodes
- Second Cycle Variant
- The communication channel is designed to be **redundant.**

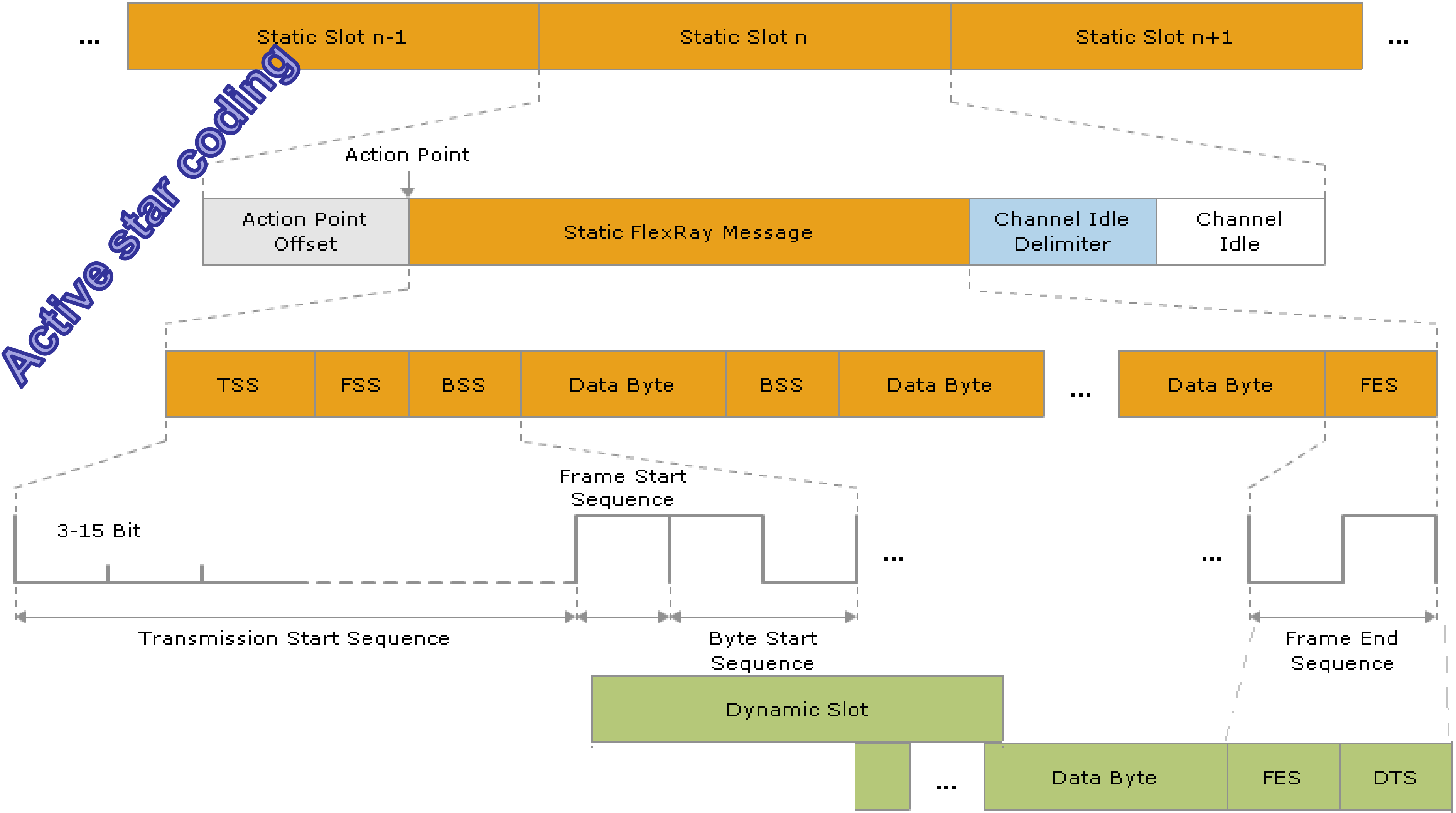
Data Link Layer

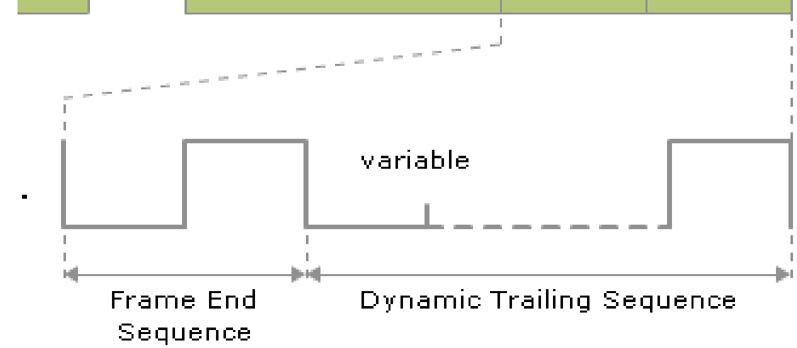


Frame



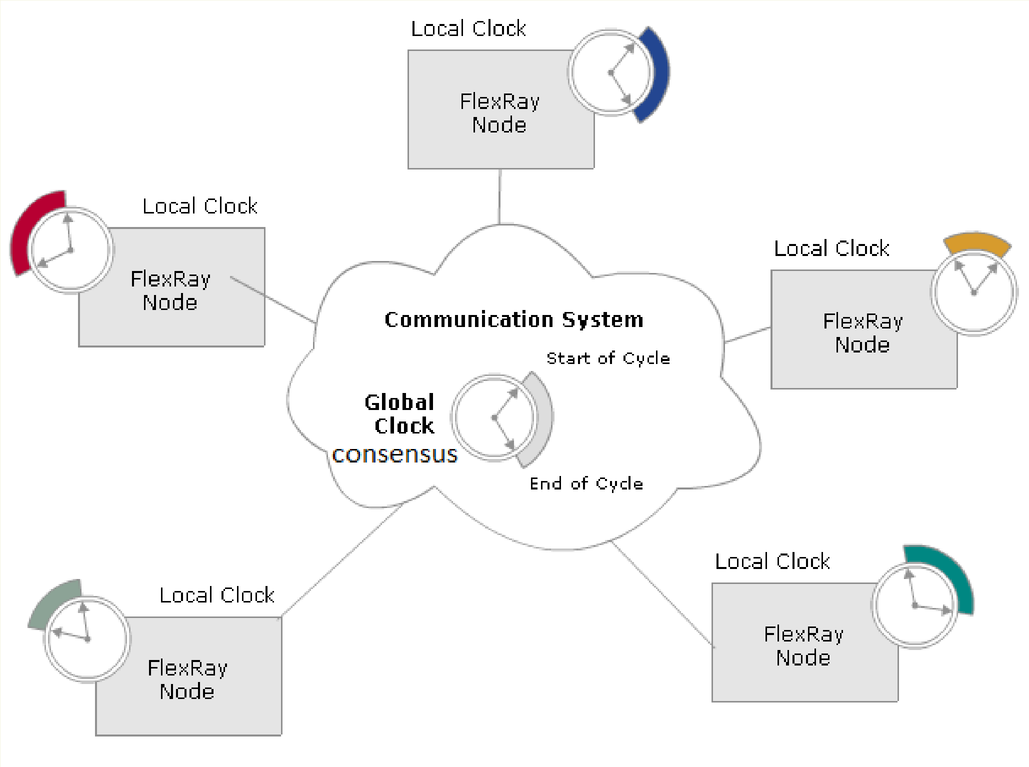
- The payload length has same value for all messages transmitted in the static segment.





The reason for this is that an active star coupler requires a certain amount of time to reach its operating state (**star truncation**)

Synchronization Methods



Global time consensus Challenges:

- Tolerances of the passive components in the crystal oscillator circuits
- Aging: ten years, tolerances of about 250 ppm

Solutions:

1. Use PLL with frequency dividers to adjust.
2. Send Synchronization frame from sync nodes