REmember the setup of the FlexRay Message itself.

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Electronic Engineering

Testing of Automotive Systems (Part I)

Module 5 – FlexRay / Ethernet

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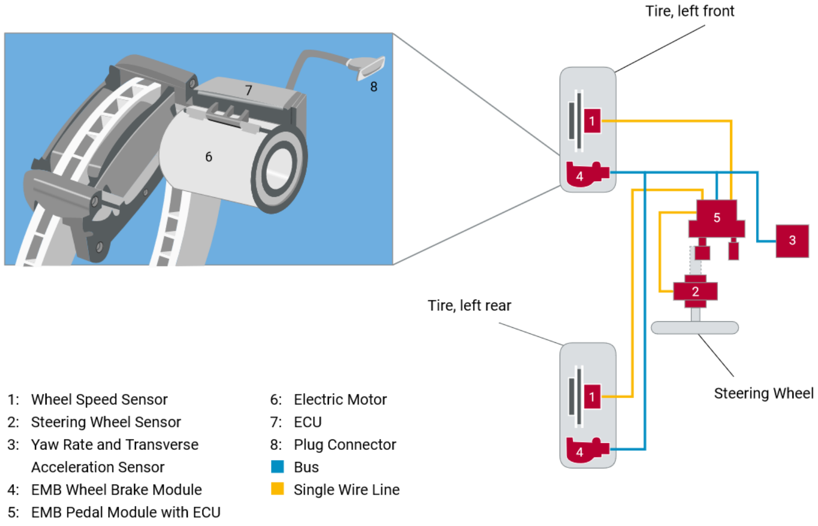
[Schedule]

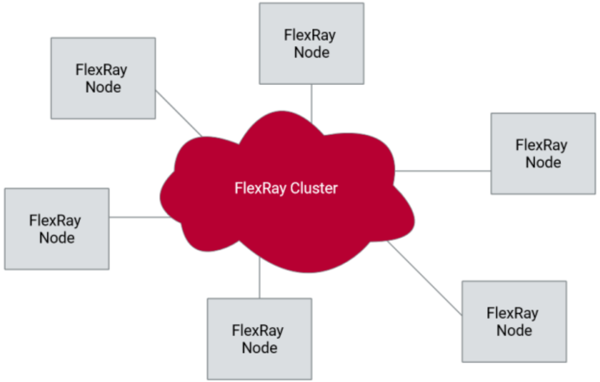
FlexRay Introduction

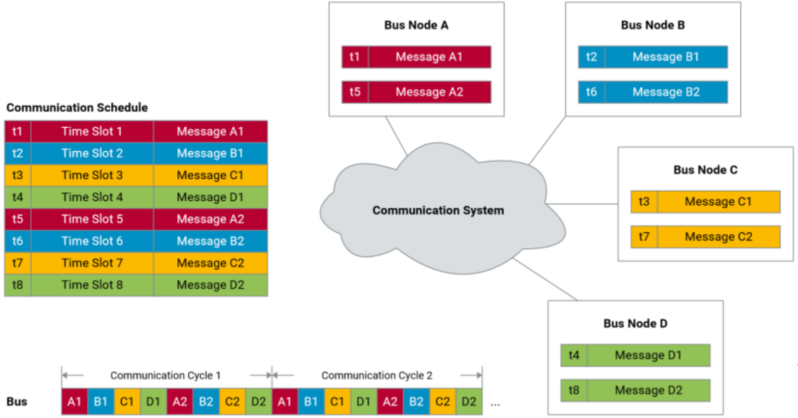
- Developed by BMW and DaimlerChrysler for safety-critical applications (e.g. steer-by-wire)
- Decribed ISO 17458
- Real-time communication systems with a time-triggered approach
- High transfer-rates up to 20Mbit/s, deterministic and fault-tolerant, while being flexible
- Time-triggered communication architecture (TDMA)



FlexRay Architecture

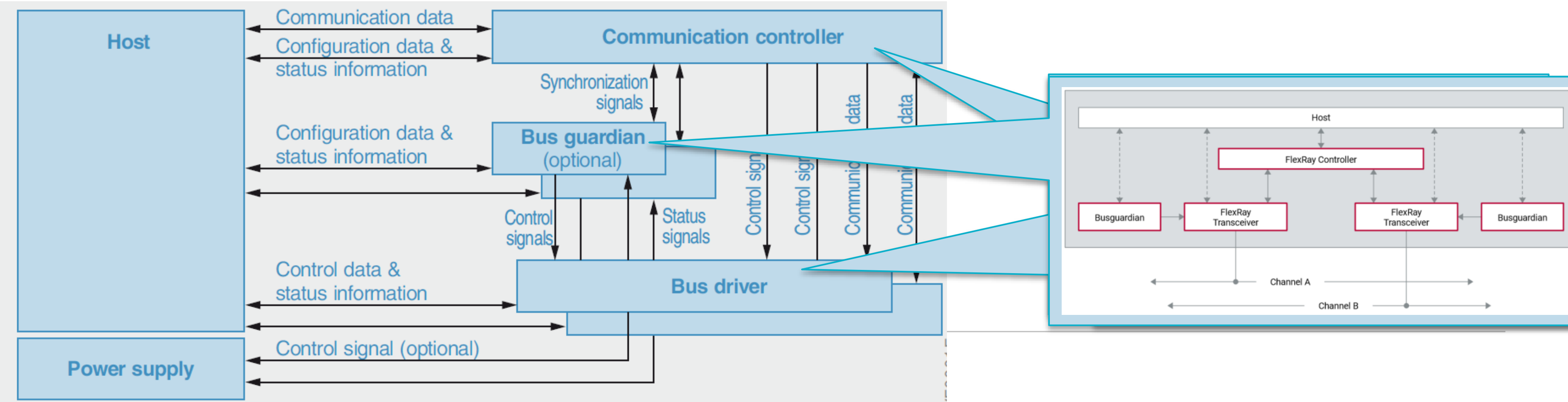
- A FlexRay communication system (Cluster) consists of nodes and transmission medium (bus)
- Two transmission channels (redundancy 10Mbit/s or increase of bandwidth 20Mbit/s individually per message)
- Several bus topologies are possible (point-to-point, bus, star, hybrid,…)
- Twisted-pair cabling design shielded or unshielded
- TDMA principle: Nodes must conform to communication schedule with specific time slot to each message per communication cycle, send times of all FlexRay messages prescribed





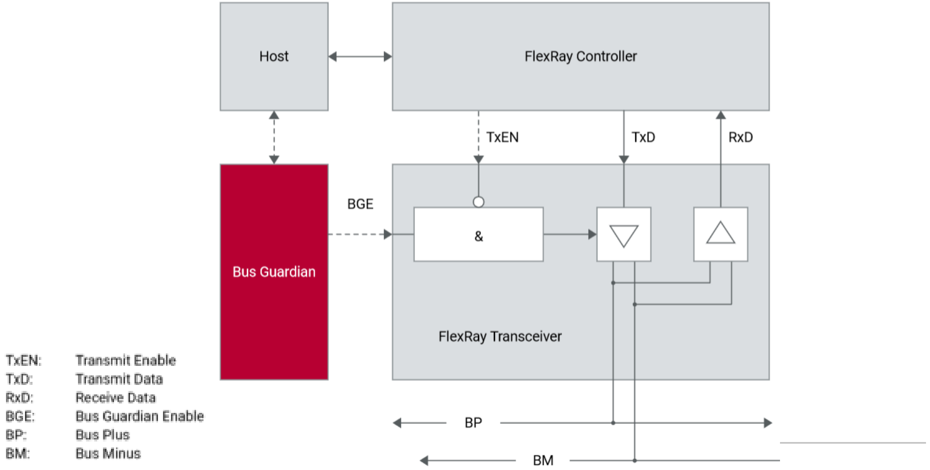
FlexRay Hardware

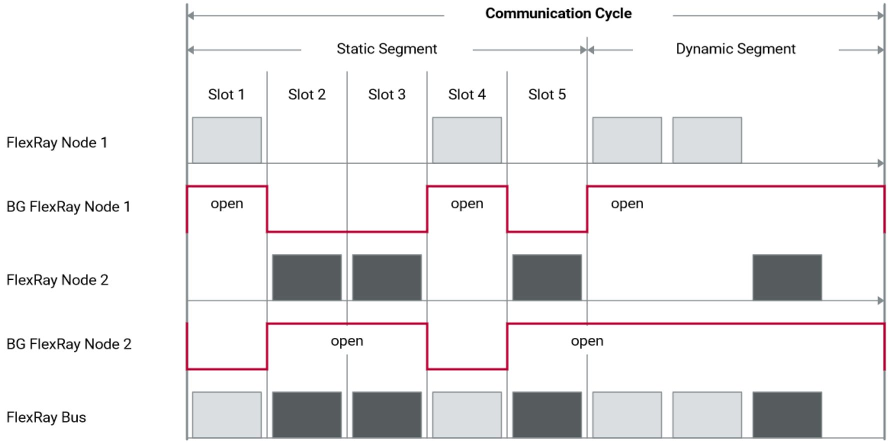
- A node comprises of
    - Host processor: gathers sensor information
    - Communication controller
        - Controller realizes FlexRay protocol , Tranceiver creates bitstream for each channel
    - Bus driver: Converts bitstream into voltage signals and vice versa (Tranceiver), power management
    - Bus guardian (optional): Checks and authorizes transmission , local inside one node or central for all nodes



Bus Guardian

- Guardians prevent unauthorized transmissions due to unsynchronized FlexRay nodes
- Each static slot is authorized by the guardian
- Authorization for dynamic segment can only be done completely
- Guardians ideally have their own time base to check communication schedule and time in the FlexRay cluster

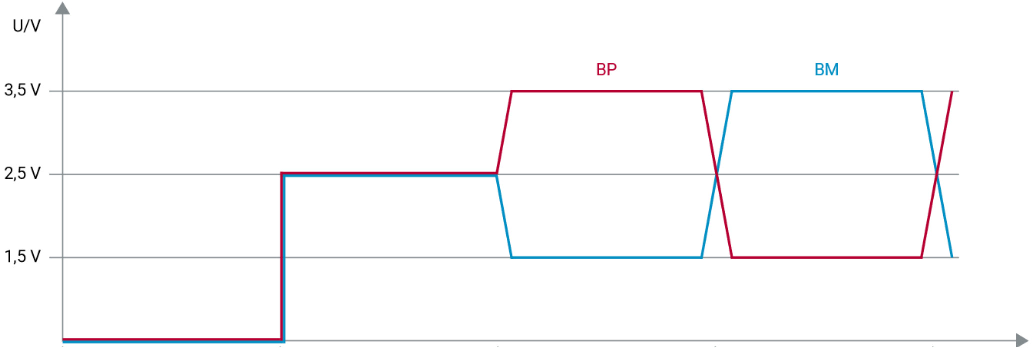




Assigned to FlexRay node 1 are slots 1 and 4 on channel A, and assigned to FlexRay node 2 are slots 2, 3 and 5 on the same channel. The two bus guardians (BG) monitor the relevant slots. In the dynamic segment, both BGs open up the path to the bus.

FlexRay Bus Level

- Non-return-to zero (NRZ) method
- Transmission of voltage differences , FlexRay bus consists of the two lines Bus Plus (BP) and Bus Minus (BM)
- Dominant: differential voltage ≠ 0V
- Recessive: differential voltage ~ 0V
- FlexRay defines four bus states
  - Idle_LP (low power) recessive → 0V +-200mV , identifies start of transmission
  - Idle state recessive → 2.5V at BP and BM
  - Data_1 dominant → logical „1“ voltage difference 2V
  - Data_0 dominant → logical „0“ voltage difference -2V



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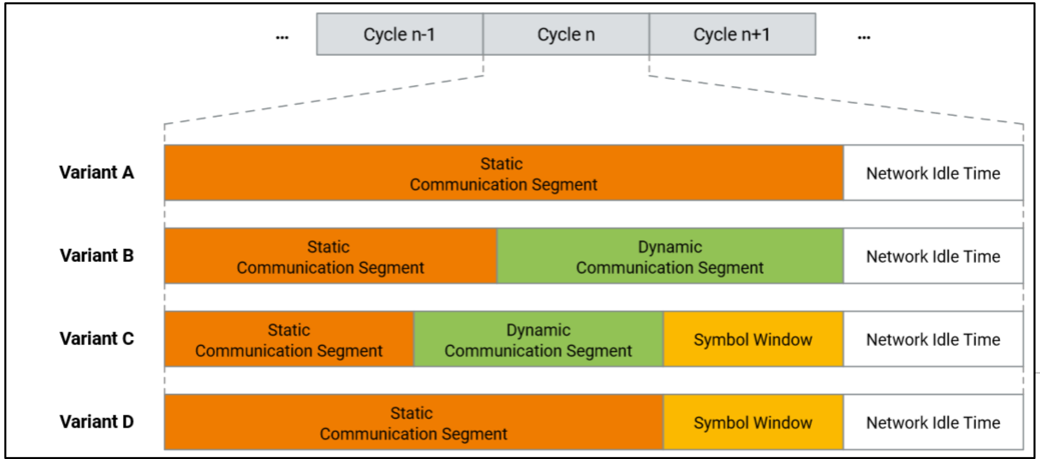
Communication Cycle

- Data communication in a FlexRay cluster is periodical and is based on a communication schedule
- Four variants of communication cycle possible
- At least two segments, **static segment** and the network idle time (NIT) segment
- NIT segment is needed to synchronize the local clocks, cycle terminates
- Optional **dynamic segment**: event-driven, asynchronous message transmission; if included it follows the static segment
- Optional Symbol window: Collision avoidance symbol, media test symbol or wake-up symbol



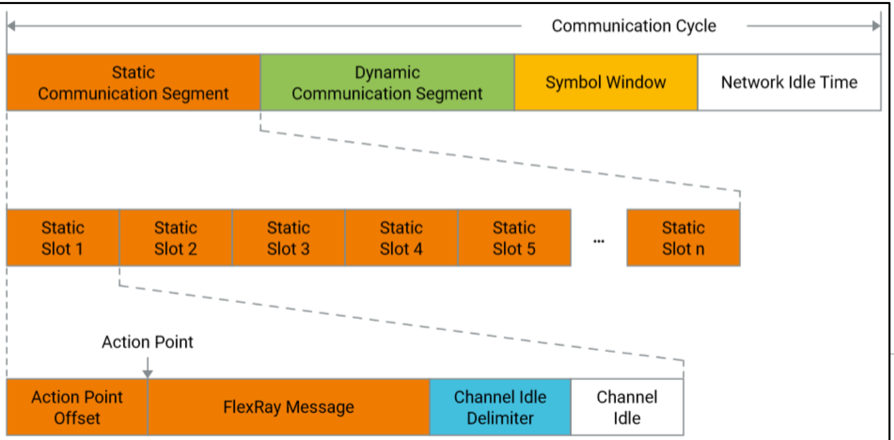
Communication Schedule

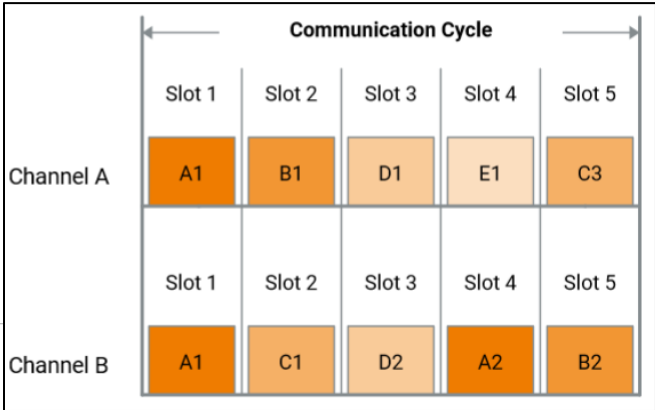
	Slot	Start	Node	Message
Static Segment	1	t_1	A	A1
	2	t_2	B	B1
	3	t_3	D	D1
	4	t_4	E	E1
	5	t_5	C	C3
Dynamic Segment				

Static segment

- FTDMA method (Flexible Time Division Multiple Access)
- Fixed number of transmission windows „static slots“ with fixed equal length
- 2-1023 static slots possible, exactly one message per static slot
- Message sent simultaneously on one channel (bandwidth increase) or two channels (redundancy increase) according communication schedule
- In each slot the exclusive frame with corresponding ID is sent periodically
- Action point offset and channel idle to synchronize to synchronize advancing and delayed receiver clocks

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



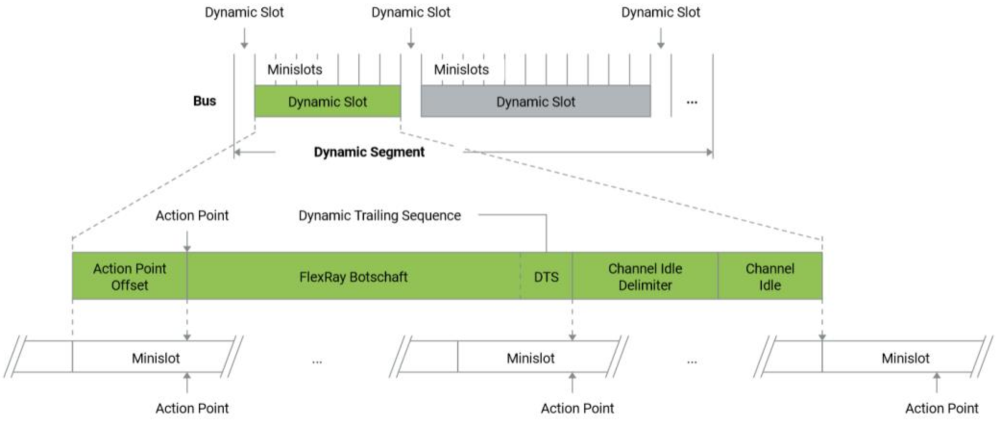


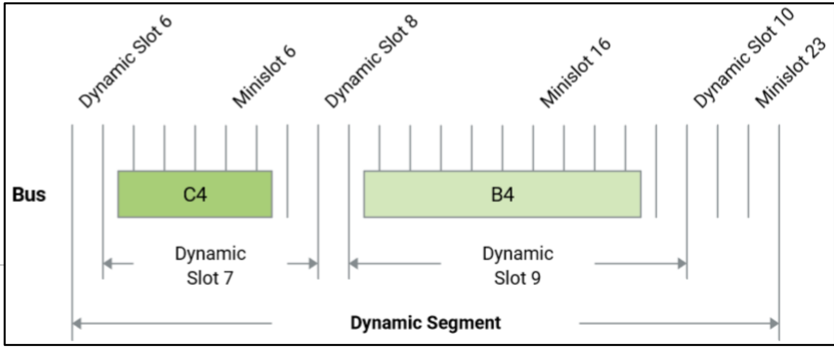
Dynamic Segment

- FTDMA (Flexible time division multiple access)
- Dynamic segments also based on schedule, always same length
- Dynamic segment consist of dynamic slots (minimum size 1 minislot)
- Dynamic slot layout similar to static slot, messages have different payload sizes
- Dynamic segment begins with all nodes incrementing their local counters
- If there is a send request, send dynamic message matching the counter
- If there is no send request, increment counter again (length 1 minislot)
- Procedure is repeated until the dynamic segment is no longer long to transmit a dynamic message

Communication Schedule (Dynamic Segment)

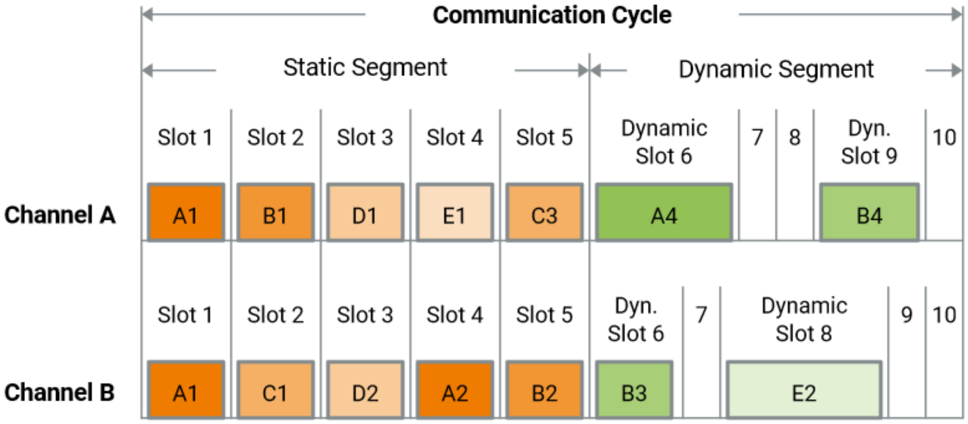
Slot	Node	Message	Event
6	A	A4	
7	C	C4	
8	D	D3	
9	B	B4	
10	E	E3	





Exercise: FlexRay Communication cycle example

	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	



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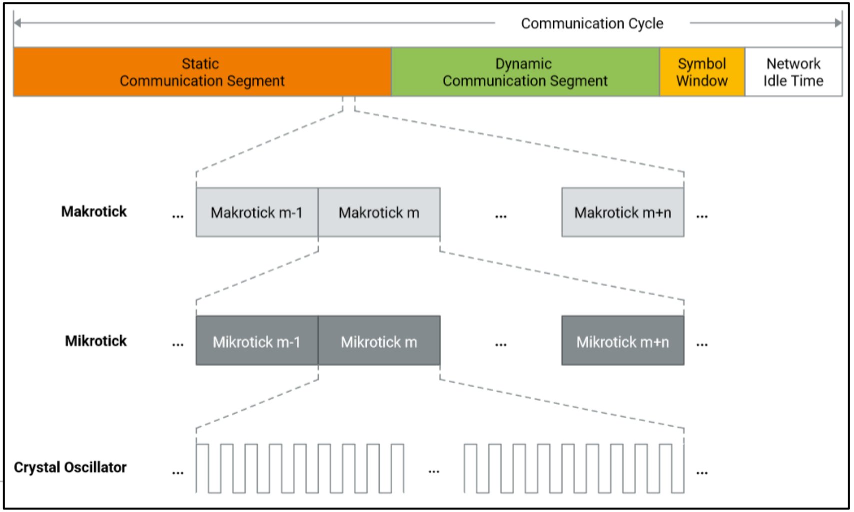
FlexRay Clock Control

- Each network node has its own internal clock
- System-wide global time preset is necessary for all nodes because bus access is controlled by means of time slots
- Microtick level
  - Bottom-level, not a system-wide variable
  - Derived directly from the oscillator clock of the network node
- Macrotick level
  - Range in which exactly one frame can be sent
  - Lowermost system-wide unit
  - #microticks/macrotick not the same for all macroticks
- Communication cycle level
  - Top-level
  - Contains the same, fixed number of macroticks



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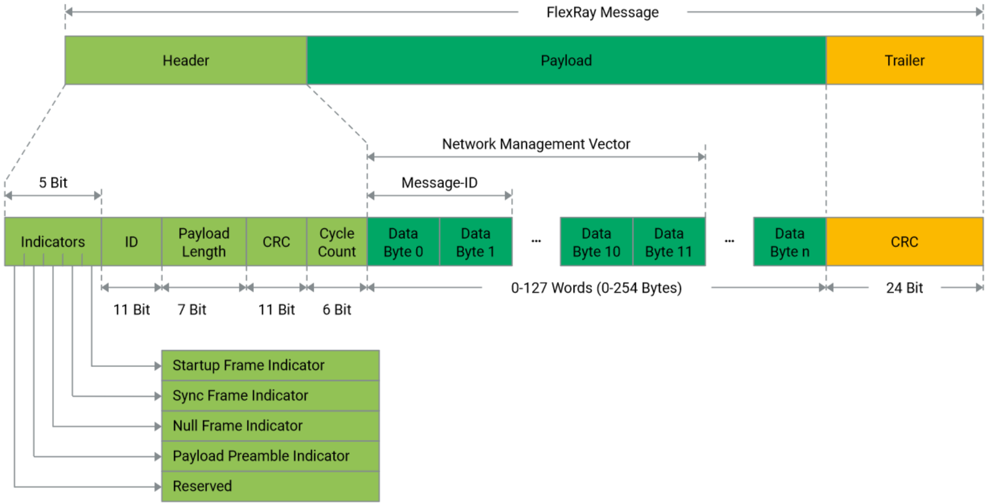
FlexRay Message – Header, payload and trailer

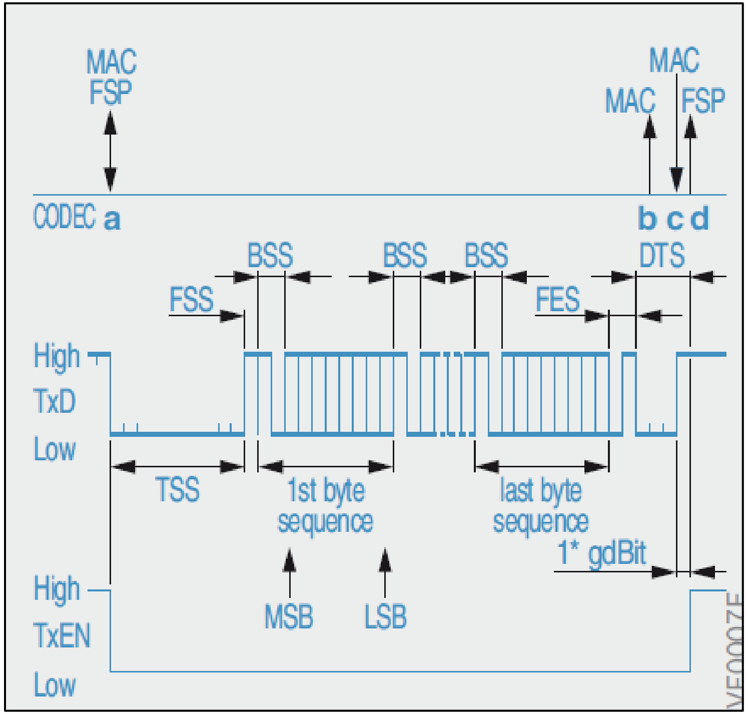


- Header (40bit), payload (254 Bytes) and trailer (24bit)
- 11-bit identifier (ID) assigned to one slot
- 7-bit payload length shows size of payload (static vs dynamic segment payload)
- Identifier protection by CRC method
- Cycle counter counts up always to 63
- Trailer: powerful 24-bit CRC calculation

- Startup frame indicator: indicates whether message in the static segment is being used as a startup frame in the context of startup
- Sync frame indicator: indicates whether messages transmitted in the static segment are being used as sync frames
- Null frame indicator: payload is regular or invalid (ID=0x00, payload all zeros)
- Payload preamble indicator: indicates whether a network management vector is being transmitted (static message) or whether a message identifier is being transmitted (dynamic message)

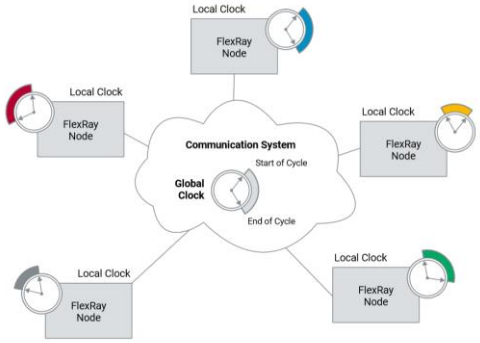
FlexRay Message Coding

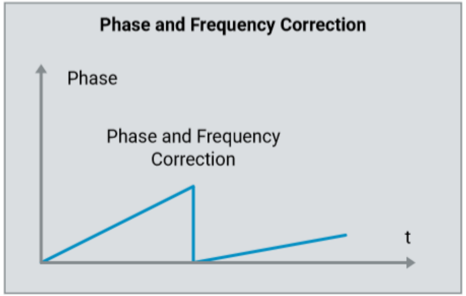
- Physical transmision of a message is coded for maximum real-time ability and redundancy
    - Transmission start sequence (TSS)
    - Frame start sequence (FSS)
    - Each message byte preceeded by Byte start sequence (BSS) for receiver synchronization
    - Extended byte sequence) = BSS + Data byte
    - 24-bit CRC = TSS+FSS+EBS
    - Frame end sequence (FES)
    - Dynamic trailing sequence (DTS) = transmission blocker for other nodes if part of dynamic segment



FlexRay Cluster Synchronization

- All FlexRay nodes share time consensus, because all activities are triggered in the time sequence
- All communication cycles and static slots always have to begin at the same point and are of equal length
- Time consensus can only be produced cooperatively based on the local time bases
- Tolerances produce different frequencies and phases at identical nominal frequencies
- Correct local clocks so that all local clocks in the FlexRay cluster run synchronous to a global clock up to a defined deviation → phase and frequency correction
- Some FlexRay nodes act as sync nodes which transmit synch messages (sync frame indicator set)
- All other nodes compare the a priori known time points with the points at which the sync messages actually arrive and compute their phase and frequency correction value using the fault tolerant midpoint (FTM) algorithm

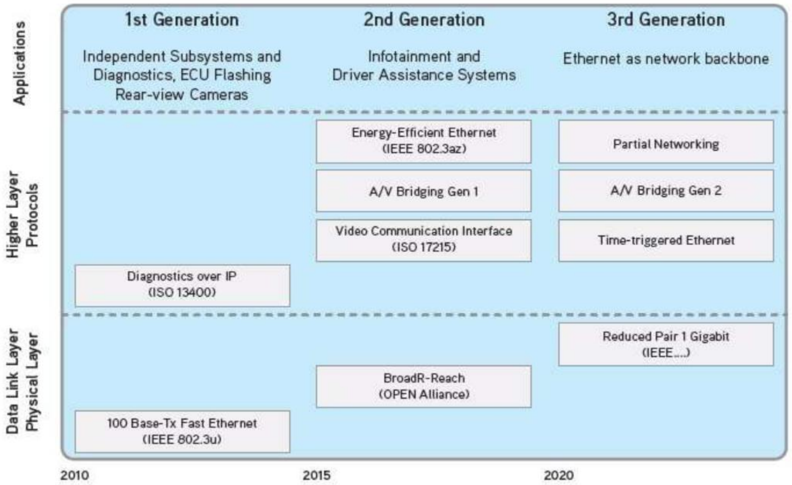


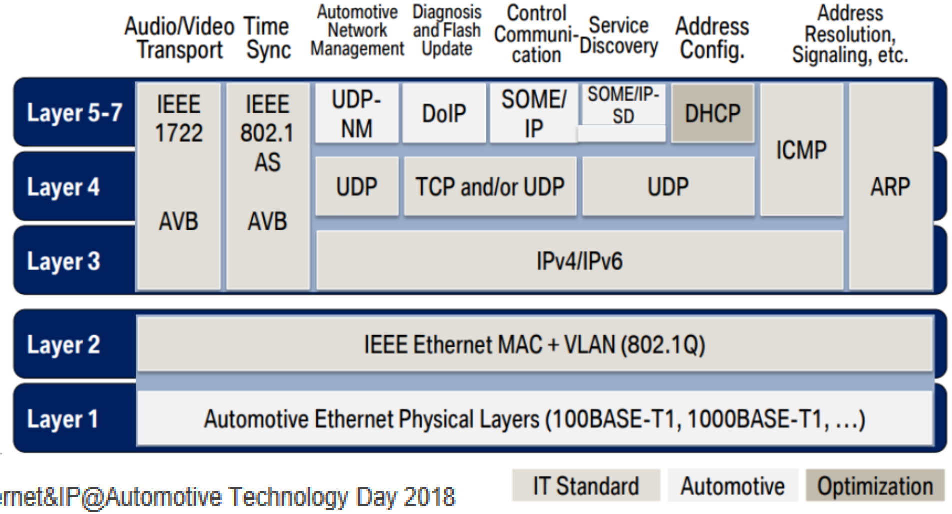


Ethernet

Overview

- The Institute of Electrical and Electronics Engineers (IEEE) has been responsible for development of Ethernet since 1980 (working group 802 → IEEE802.1, 802.2,…)
- OPEN Alliance SIG was founded in the automotive industry to promote further development of Ethernet
- Physical connection: Twisted pair cable with symmetrical differential voltages
- A major strength of Ethernet is its support of a large number of physical media





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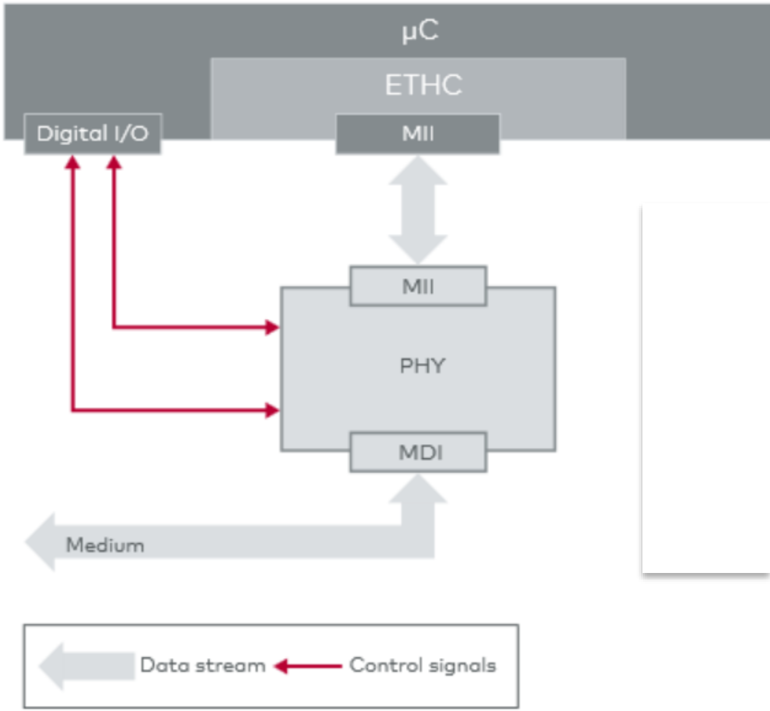
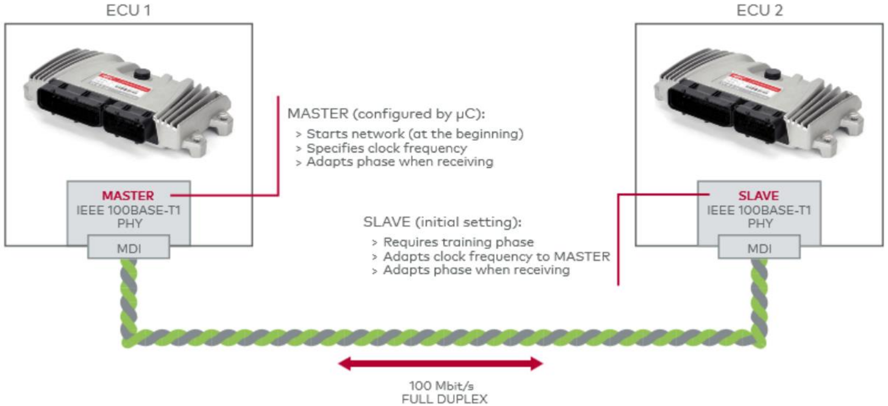
Ethernet ECU Basic Setup

- Basic setup same for different physical layers
- µC: HOST contains application SW and basis software of ECU
- ETHC (Ethernet Controller)
    - Basic functions for ethernet communication
- MII (Medium independent interface)
    - Interface of ETHC to PHY
    - IEEE 802.3 standardized interface for different transmission speeds
- PHY
    - physical layer transceiver device for sending and receiving Ethernet frames
- MDI (medium dependent interface)
    - Connection of PHY to physical medium



IEEE 100BASE-T1 / OABR

- OABR (Open Alliance BroadR-Reach) is a physical transmission technology, standardized by SIG as IEEE 100BASE-T1
- Unshielded twisted pair on which symmetrical differential voltages are applied
- Combination of 4B3B, 3B2T, and PAM3 methods are used for the encoding and decoding
- Two interconnected nodes can send and receive simultaneously at 100 Mbit/s (full duplex)
- Only point-to-point connection topology is available, more than two nodes with Layer-2 coupling element (switch)
- Both nodes must be synchronized to the symbol stream (master node specifies clock and trains slave node)

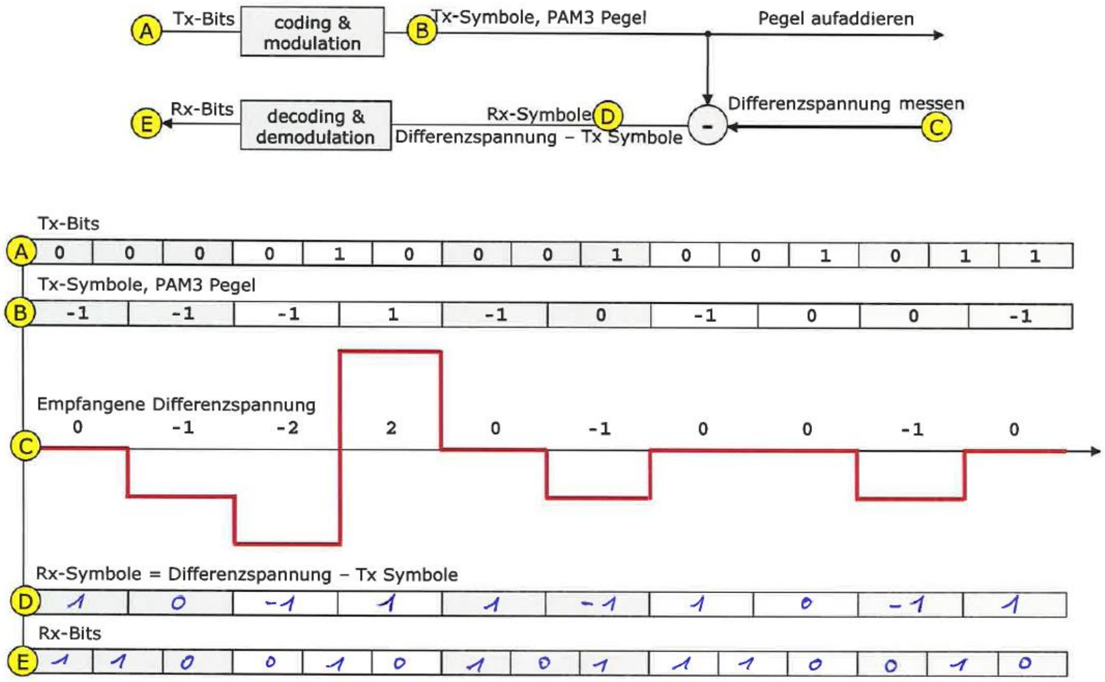


Look-up Table 3B2T

3B	TA_n	TB_n
000	-1	-1
001	-1	0
010	-1	1
011	0	-1
100	0	1
101	1	-1
110	1	0
111	1	1

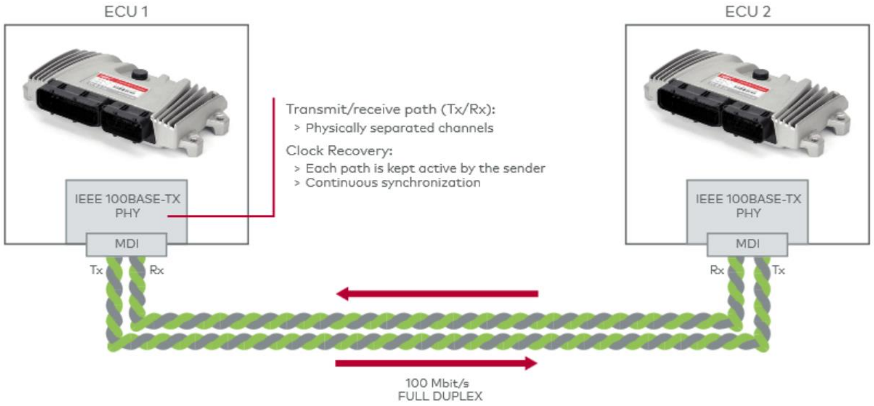
Full duplex data transmission

- Echo cancellation procedure
- Tx: a node adds its own differential voltage to the two wires
- Rx: it subtracts its own voltage from the applied total voltage
- The result of the subtraction corresponds to the voltage that was sent by the opposite node



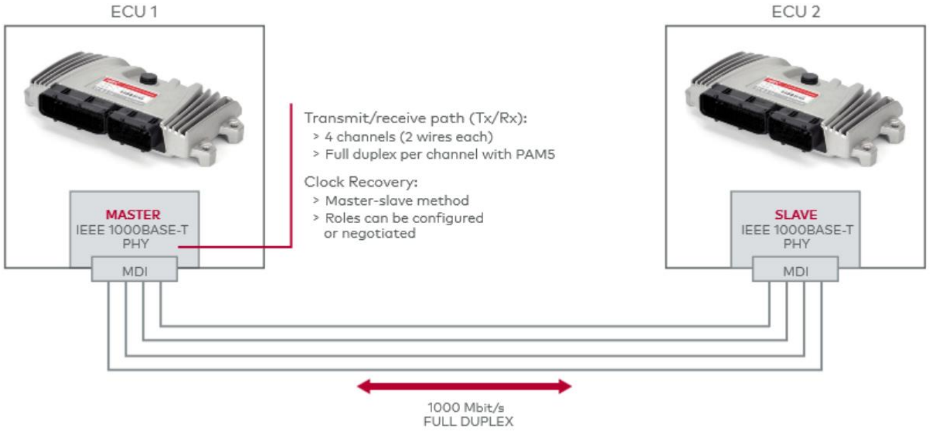
IEEE 100BASE-TX

- IEEE 100BASE-TX typically needs two separated channels, each of which has two twisted wires on which symmetrical differential voltages are applied
- Combination of NRZI (Non-return to zero inverted), 4B5B (4bit to 5bit) and MLT-3 (Multi level transmit with 3 states) methods are used for the encoding and decoding
- Information can be transmitted bidirectionally at 100 Mbit/s (dual simplex)
- Only point-to-point connection topology is available, more than two nodes with Layer-2 coupling element (switch)
- Both nodes must be synchronized to the symbol stream (each path kept active by sender)



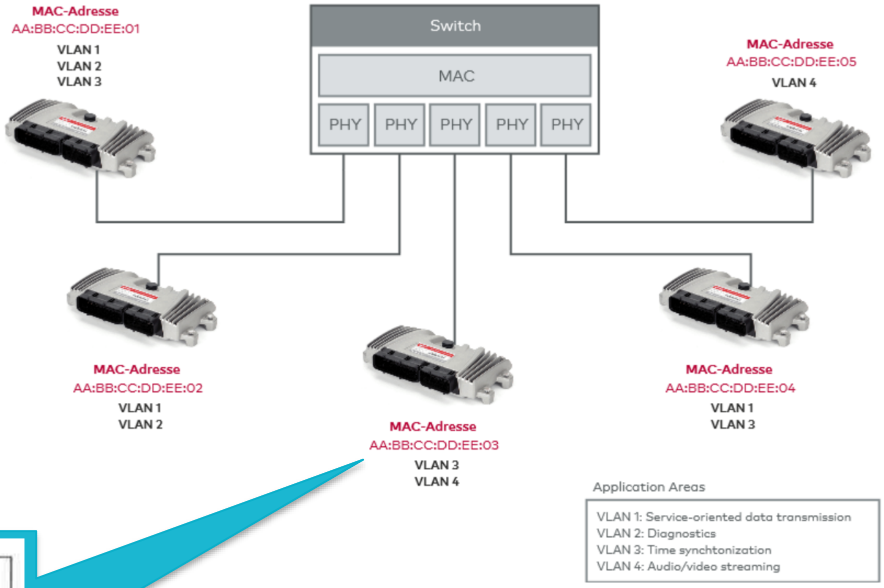
IEEE 1000BASE-T

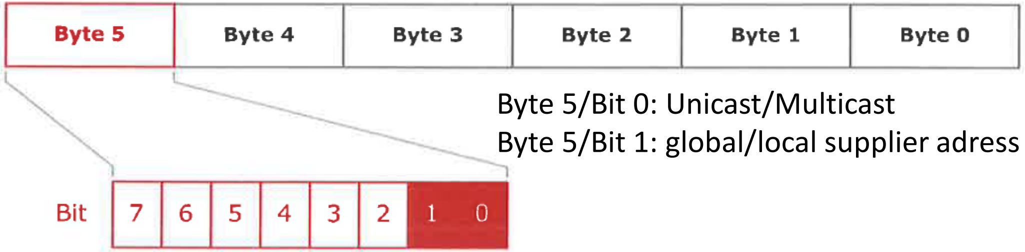
- IEEE 1000BASE-T requires four channels, each of which has two twisted wires on which symmetrical differential voltages are applied
- Combination of 8B1Q4, Trellis, Viterbi, and PAM5 methods are used for the encoding and decoding
- Two interconnected nodes can send and receive simultaneously on four channels at 1Gbit/s (full duplex)
- Only point-to-point connection topology is available, more than two nodes with Layer-2 coupling element (switch)
- Both nodes must be synchronized to the symbol stream (master/slave same as OABR but roles are negotiated)



Ethernet Layer 2 – Adressing

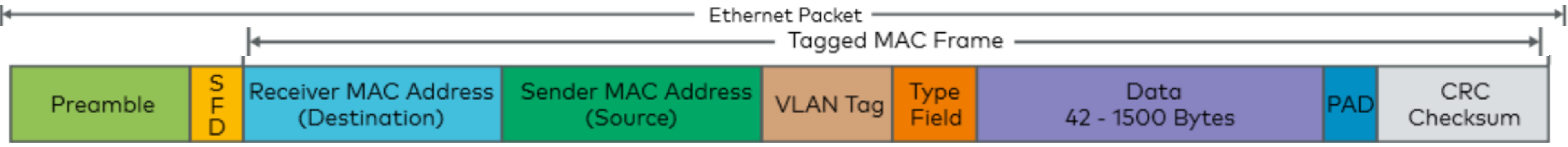
- Each node has MAC (Medium Access Control) address that is used for unique identification in the local network (LAN)
- The nodes are uniquely/multiple addressed using unicast/multicast addresses
- OEM specifies these addresses, or suppliers may select from their own address range
- Virtual LAN (VLAN) address virtual networks that are present within an overall network and allow a delimitation of communication





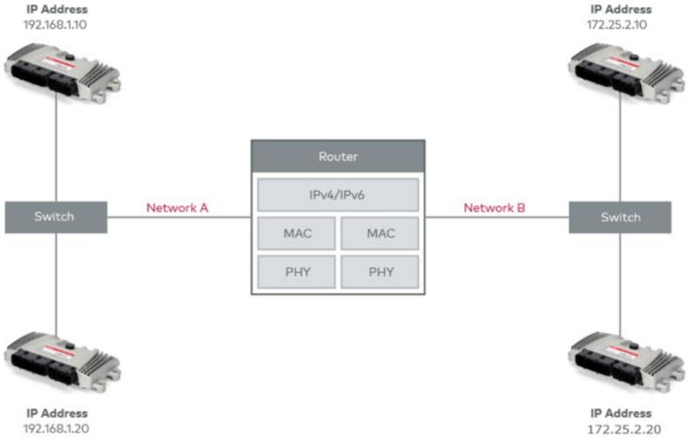
Ethernet Layer 2 – Frame

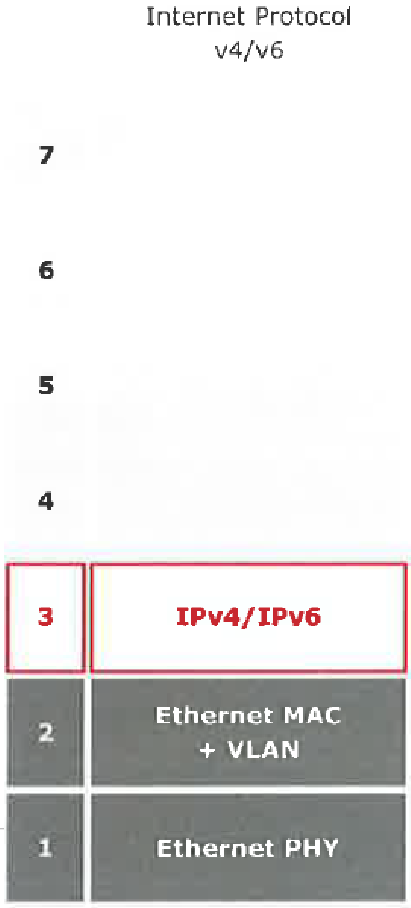
- The automotive industry typically uses the Ethernet II frame (w/o VLAN extension)
- frame generally begins with (unicast/multicast/broadcast) receiver address, followed by one sender address
- VLAN Tag basically consist of priority and identifier (VLAN-ID)
- Type field indicates VLAN extension and higher layers (e.g. IPv4)
- Payload data up to 1500 bytes
- Ethernet frame ends with a checksum that assures the integrity of entire message
- Ethernet controller inserts a preamble and a Start Frame Delimiter (SFD) at the beginning
- The combination of preamble, Start Frame Delimiter, and Ethernet II frame is referred to as the Ethernet packet



Internet Protocol (IP)

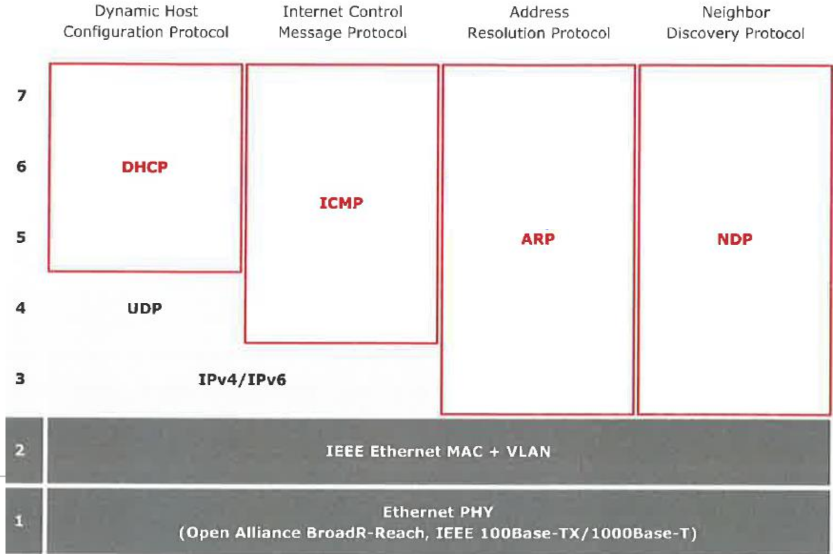
- Internet Protocol (IP) enables communication beyond the boundaries of a local network (LAN), abstraction layer 3
- The standardized communication is realized with the help of the IP packet
- In order to interconnect various networks, a router is used as a coupling element
- The standardized communication is realized with the help of the IP packet
- Defined header with a destination and a source address
- This enables any node to be addressed worldwide
- Two versions
  - IPv4 - four-byte addresses
  - IPv6 – sixteen-byte addresses





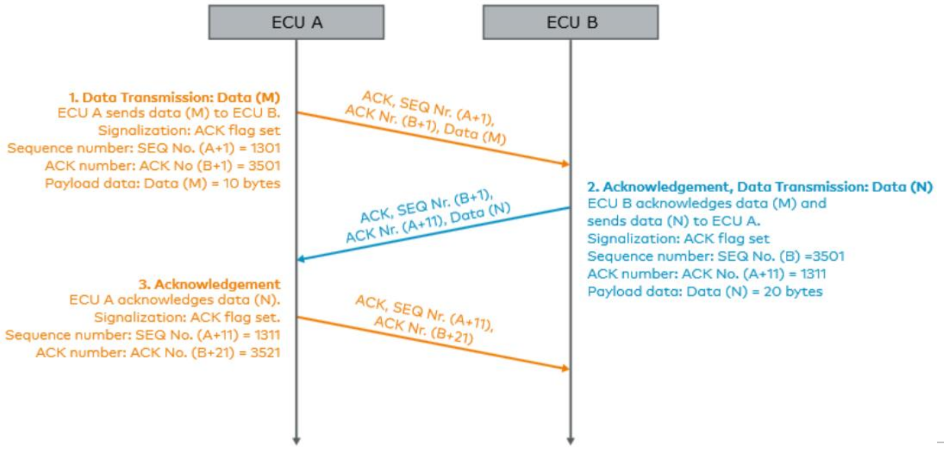
Additional protocols (IP)

- Dynamic host configuration protocol (DHCP) - automatically assign IP addresses to one or more nodes
- Internet control message protocol (ICMP) – exchange of diagnostics and error messages
- Adress resolution protocol (ARP) - used to determine the correlation between IP and MAC addresses (iPv4)
- Neighbor discovery protocol (NDP) - replaces the ARP protocol when using IPv6

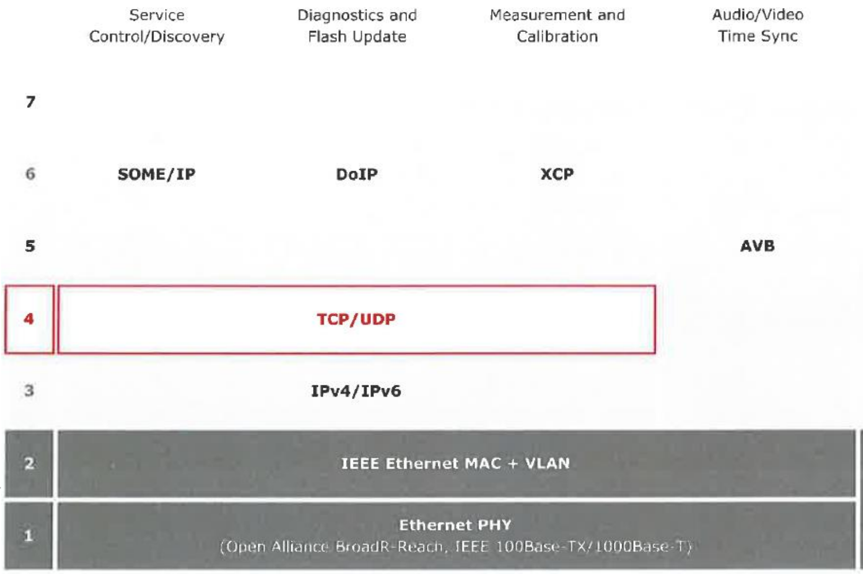


Transport protocol: TCP/UDP

- User datagram protocol (UDP) - connectionless transmission
- Transmission control protocol (TCP) - connection-oriented transmission
- To reach destination node, data are transmitted via Internet Protocol (IP) on the underlying layer (Layer 3)
- Ports that allow addressing of functions and applications are used to connect to the higher layers, source port and destination port needed

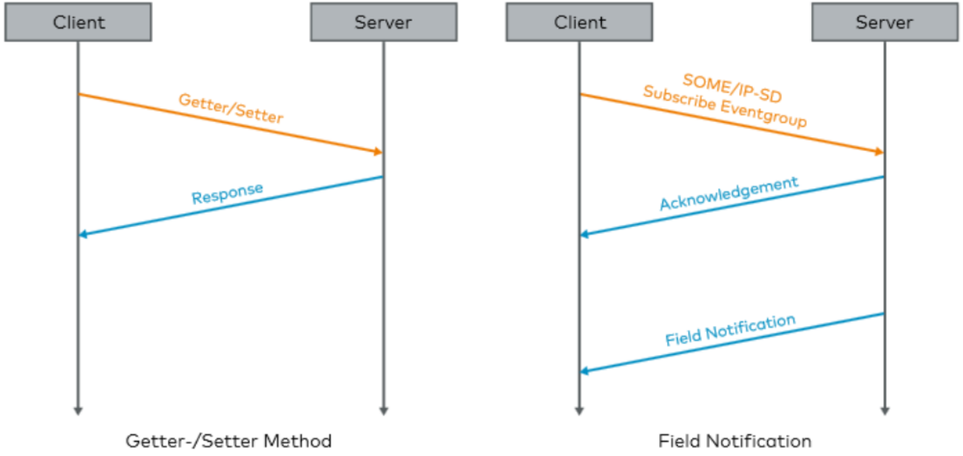


Data transmission example TCP



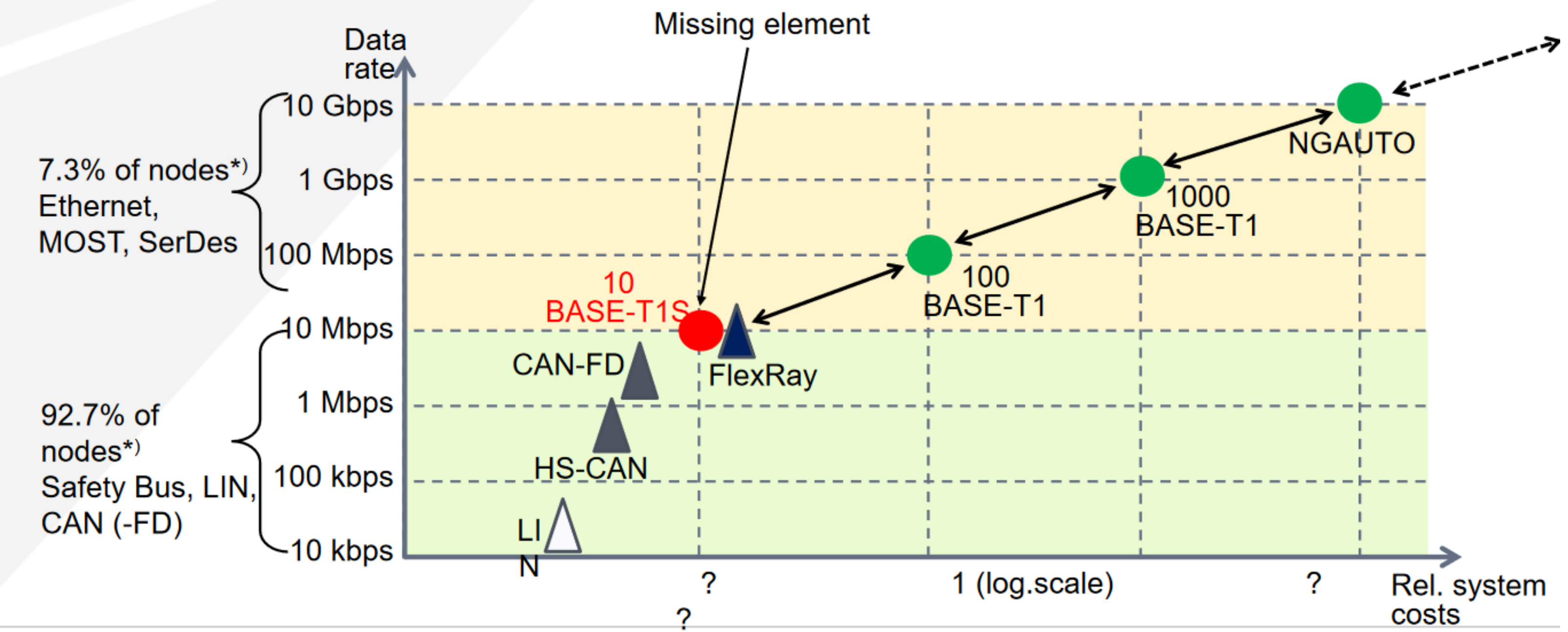
SOME / IP

- New philosophy for automotive data transmission: While signal-oriented data transmission is used on classic bus systems (CAN, LIN, FlexRay), SOME/IP (Scalable service-Oriented MiddlewarE over IP) allows the introduction of service-oriented transmission of information
- Transmission upon demand: sender only sends data when at least one receiver in the network needs this data
- Needs UDP/TCP-packets , decription – files *.arxml
- Methods: Request/response, fire&forget, event, field



Why not use Ethernet for everything?

Cost goes up.



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References and quotations

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