CAN in Space workshop

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The next generation of CAN technology:

Chances and challenges of CAN FD

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Presentation outline

- Introduction into CAN FD
- CAN FD physical layer
- CAN FD testing options
- New CANopen FD services
- Open issues and outlook

Takeaway: Understanding the chances and challenges of CAN FD.

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CAN standardization

SAE conference 1986 → Bosch CAN 2.0 A/B 1991 → ISO 11898 CAN 1993 → re-organized ISO 11898-1/2 2003 → ISO 11898-1 with CAN FD 2015

- **1993:** ISO 11898 — CAN protocol and high-speed transceiver
- **2003:** ISO 11898-1 — CAN data link layer
- **2003:** ISO 11898-2 — High-speed physical layer
- **2004:** ISO 16845 — CAN conformance test plan
- **2004:** ISO 11898-4 — Time-triggered CAN (TTCAN)
- **2007:** ISO 11898-5 — High-speed low-power physical layer
- **2013:** ISO 11898-6 — High-speed selective wake-up physical layer
- **2014:** ISO 16845-2 — ISO 11898-6 conformance test plan
- **2015:** ISO 11898-1 — Classical CAN and CAN FD data link layer
- **2016:** ISO 11898-2 — Improved high-speed physical layer
- **2016:** ISO 16845-1 — ISO 11898-1:2015 conformance test plan
- **2017: ISO 16845-2 — ISO 11898-2:2016 conformance test plan**

Takeaway: CAN FD is already standardized in ISO.

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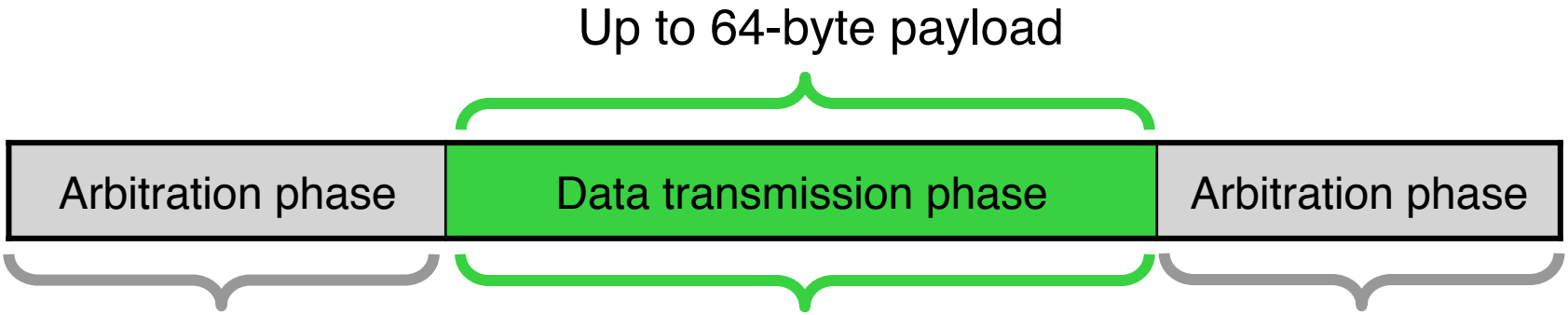
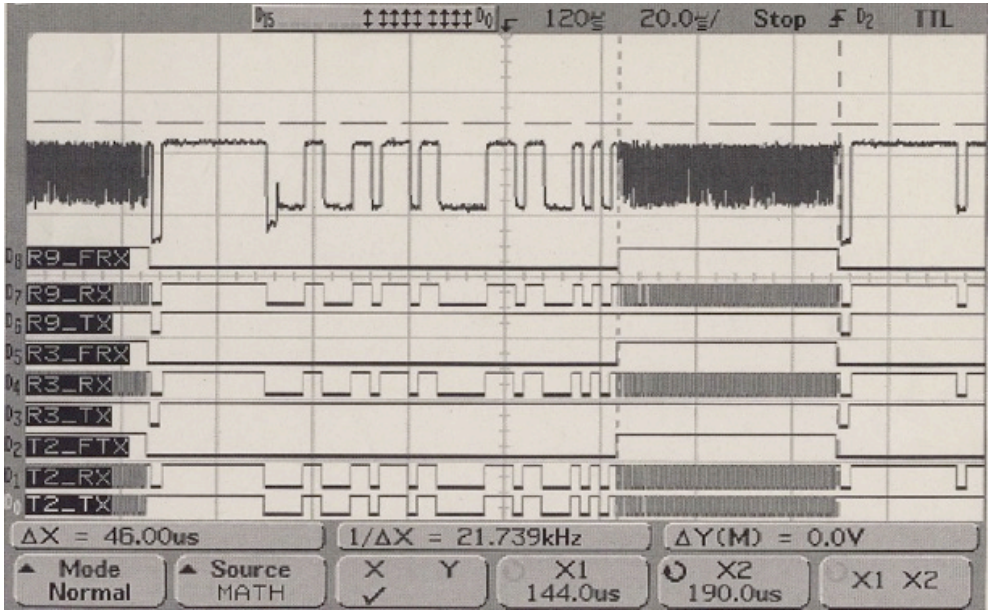
CAN FD protocol





Source: Bosch

* Currently the ISO 11898-2:2016 standard specifies the parameters for CAN transceivers supporting bit-rates up to 2 Mbit/s and up to 5 Mbit/s.

Takeaway: CAN FD is faster and provides more payload.

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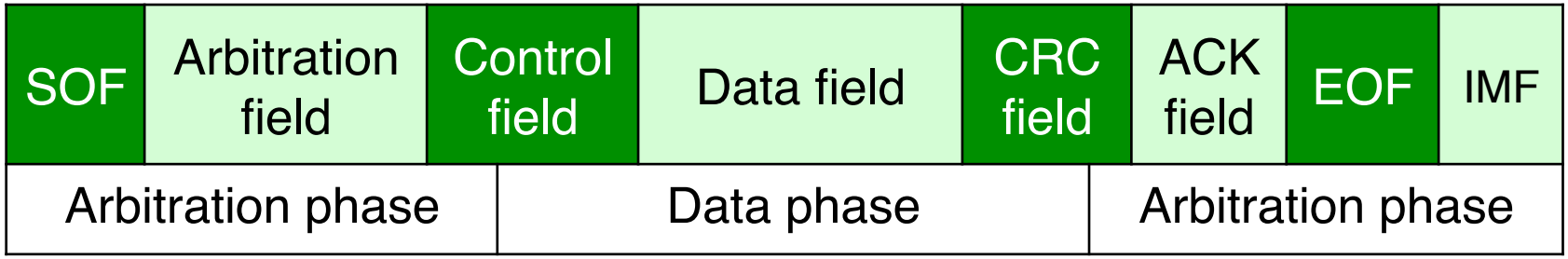
CAN FD data frame formats



KEY
SOF = start-of-frame
CRC = cyclic redundancy check
ACK = acknowledgement
EOF = end-of-frame
IMF = intermission field

The CAN FD protocol supports 11-bit and 29-bit identifiers:

- FBFF (FD base frame format)
- FEFF (FD extended frame format)
- CBFF (CAN base frame format)
- CEFF (CAN extended frame format)

Takeaway: FD frames cause error flags in Classical CAN only nodes.

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CAN FD data frame fields

SOF	Arbitration field	Control field	Data field (payload)	CRC field	ACK field	EOF	IMF
1 bit	12 *or* 32* bit	8 *or* 9* bit	0 *to* 64* byte	28 *or* 33 bit**	2 bit	7 bit	3 bit

MSB LSB

* Stuff-bits are not considered
** With fixed stuff-bits

LEGEND
- SOF = start-of-frame
- CRC = cyclic redundancy check
- ACK = acknowledgement
- EOF = end-of-frame
- IMF = intermission field

NOTE *The CAN FD protocol controller shall support also the Classical CAN protocol. Both protocols are internationally standardized in ISO 11898-1:2015. There are also non-ISO CAN FD controllers on the market, which are not compliant to the mentioned ISO standard, they don't implement the additional safe-guard features.*

Takeaway: The CRC field contains also the stuff-bit counter.

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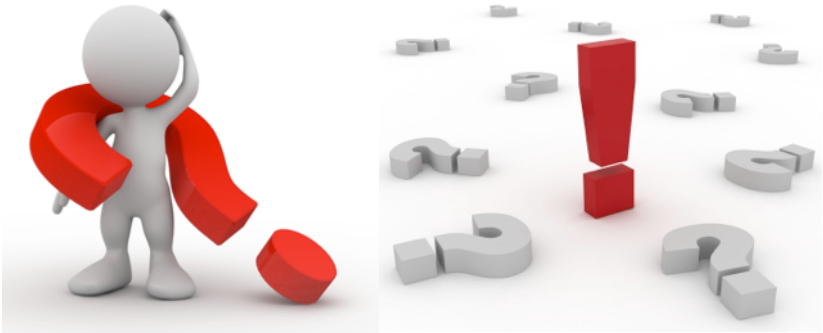
Remote frames



- The CAN FD protocol does not support remote frames, due to the not synchronized transmission in the data phase.
- However, Classical remote frames may request CAN FD data frames, but the rule of the remote frame's DLC (shall be equal to the DLC of the requested data frame) applies, too.
- The direct or indirect response to remote frames is implementation-specific.

Takeaway: Don't use CAN remote frames at all.

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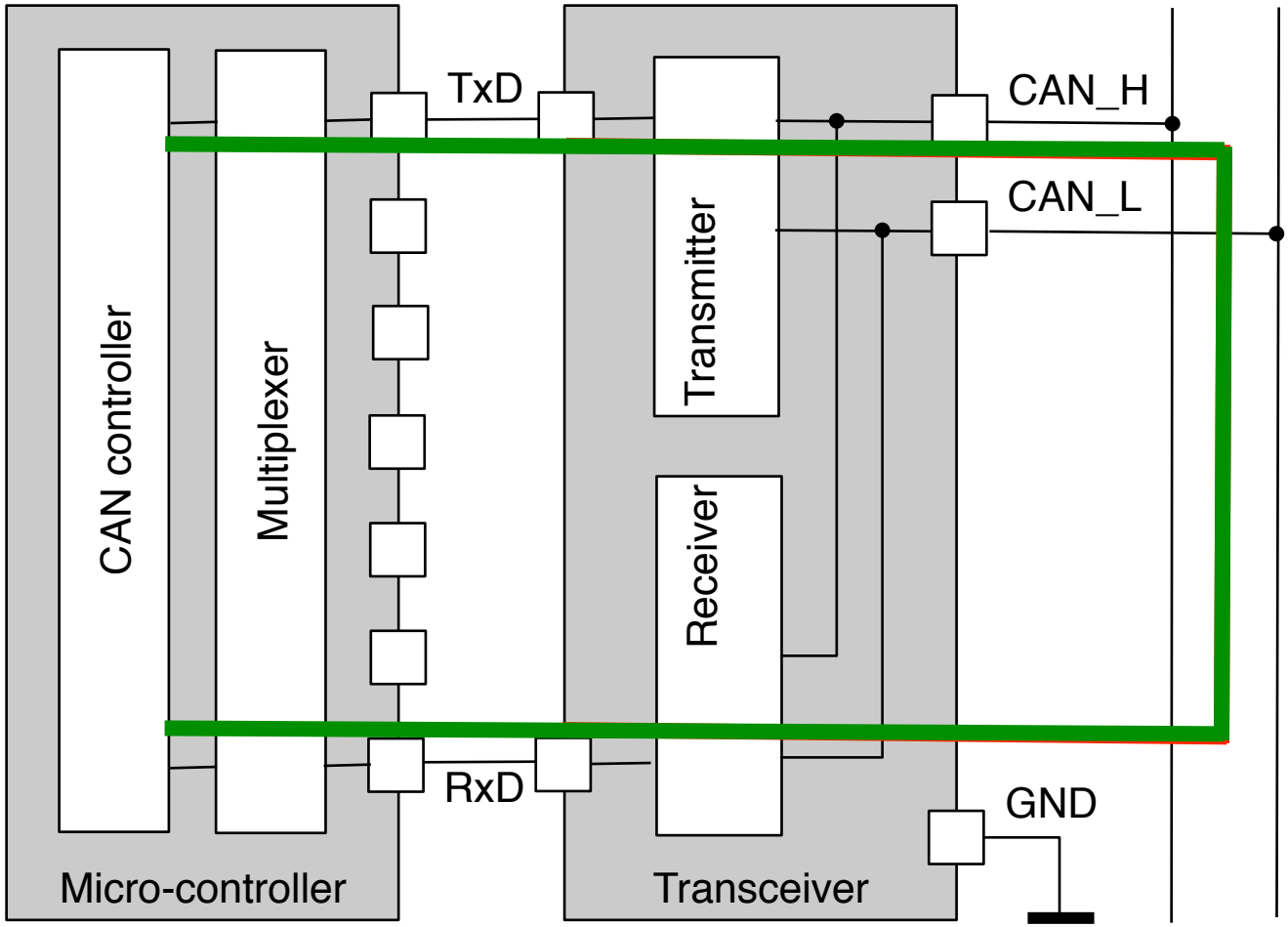
Transmitter loop-delay



Takeaway: Transmitter loop-delay is more than the transceiver loop-delay.

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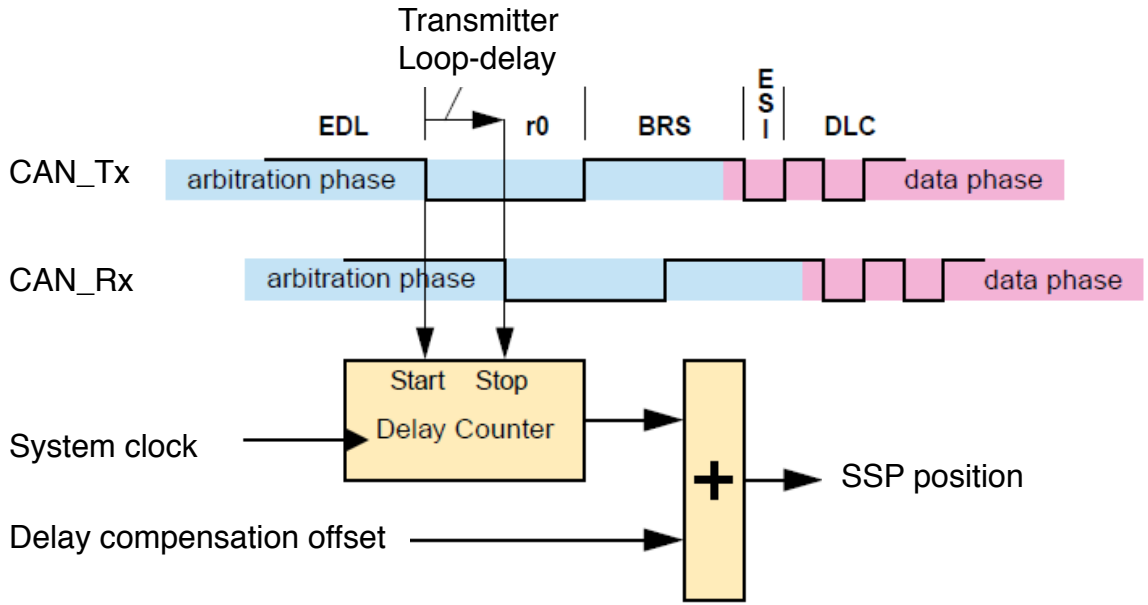
Loop-delay compensation

The transmitter loop-delay is measured for each CAN FD frame at the falling edge between FDF and res bit. The delay compensation is independent of transceiver characteristics.



Takeaway: Just enable the transmitter loop-delay compensation (TDC).

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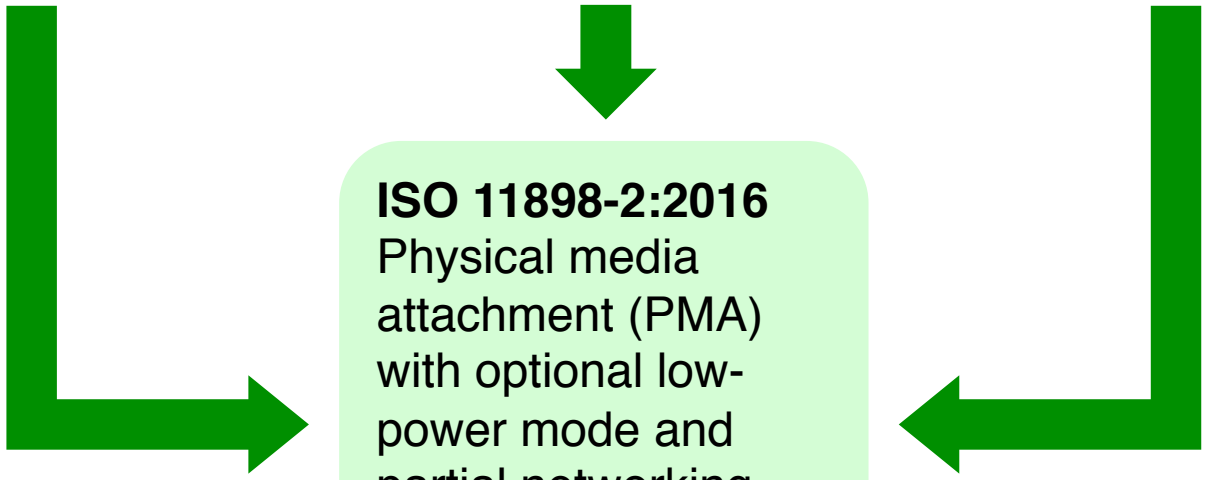
High-speed transmission

ISO 11898-2:2003
Physical media attachment (PMA)
- Up to 1 Mbit/s

ISO 11898-5:2007
Low-power mode
- Remote wake-up

ISO 11898-6:2013
Partial networking
- Selective wake-up



ISO 11898-2:2016
Physical media attachment (PMA) with optional low-power mode and partial networking
- Up to 5 Mbit/s
- Remote wake-up
- Selective wake-up

Takeaway: Now, there is only one CAN high-speed standard.

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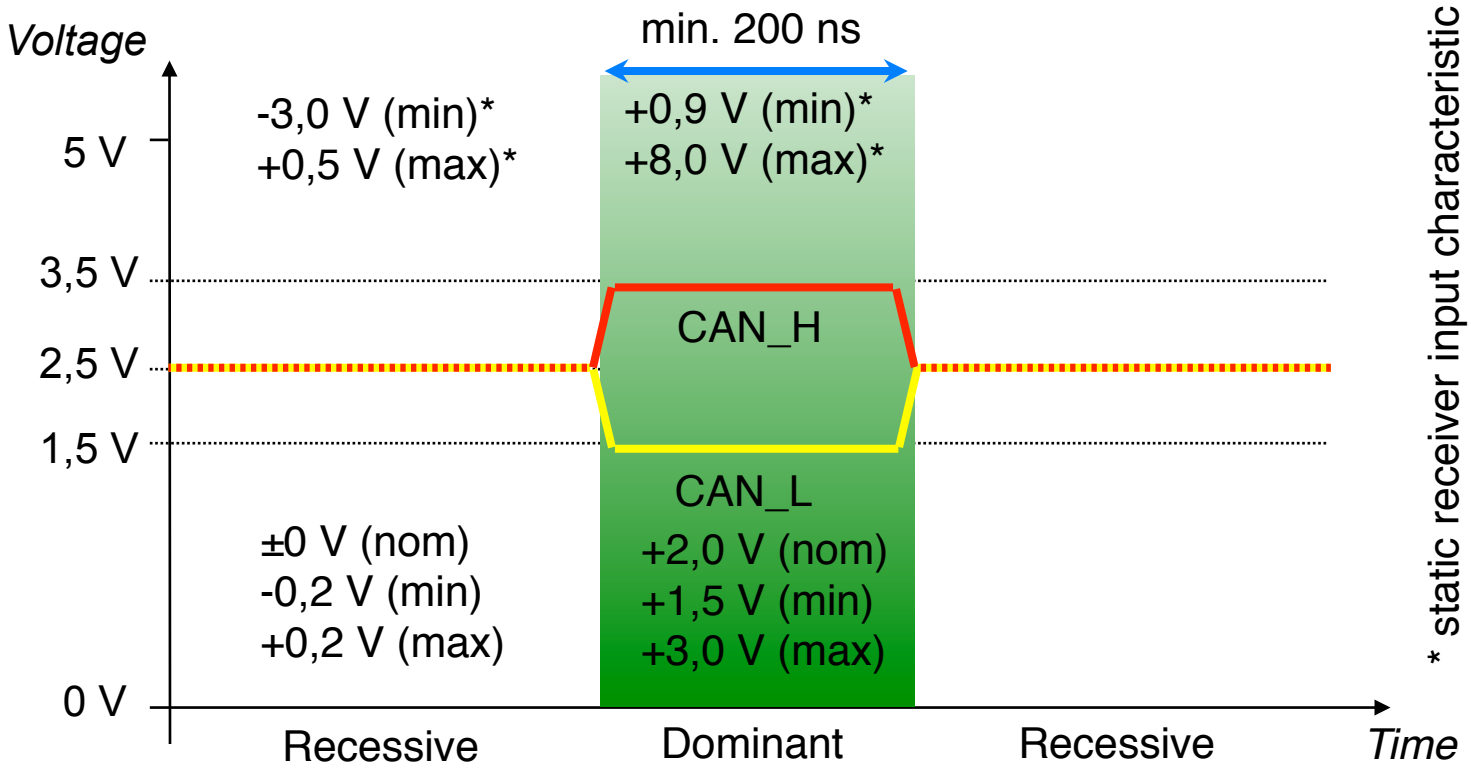
New ISO 11898-2

- High-speed transceiver are qualified for up to (500 kbit/s), 1 Mbit/s, 2 Mbit/s, or 5 Mbit/s.



Takeaway: There are no parameters specified yet for more than 5 Mbit/s.

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New ISO 11898-2 parameters

For 2 Mbit/s data-phase bitrate			
Parameter	min	max	Unit
Loop delay symmetry	400	550	ns
Transceiver Tx delay symmetry	435	530	ns
Transceiver Rx delay symmetry	-65	40	ns

For 5 Mbit/s data-phase bitrate			
Parameter	min	max	Unit
Loop delay symmetry	120	220	ns
Transceiver Tx delay symmetry	155	210	ns
Transceiver Rx delay symmetry	-45	15	ns

Takeaway: The parameters for other bit-rates need to be calculated.

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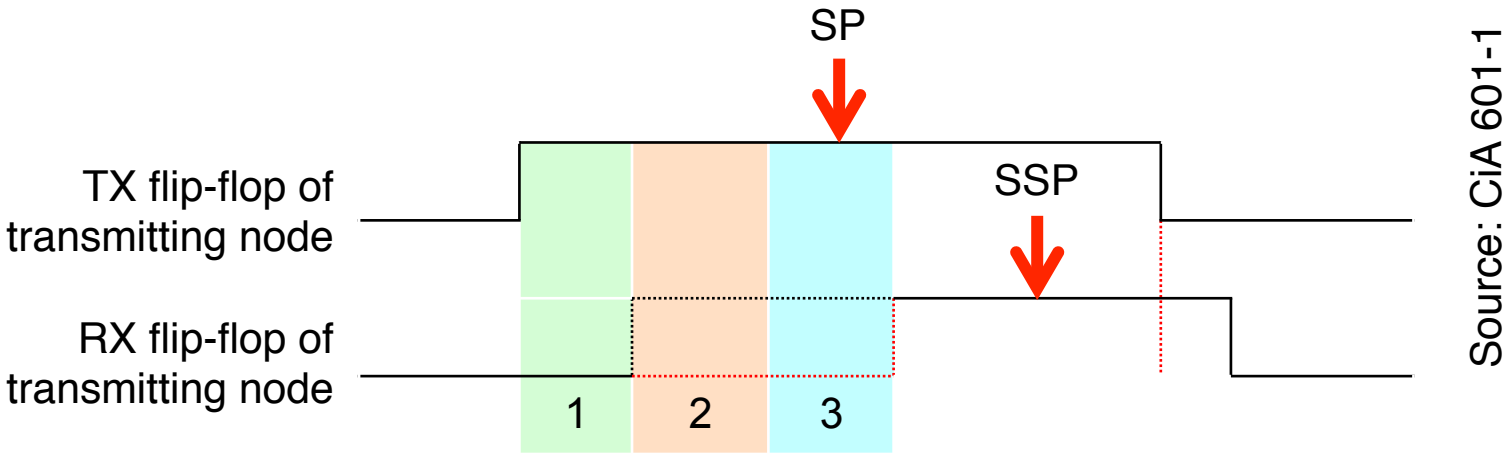
Recessive bit sampling



Source: CiA 601-1

KEY
1 (transmitting node delay including quantization error)
2 (bit asymmetry)
3 (unstable RX signal due to ringing)
SP (sample point)
SSP (secondary sample point)

NOTE System designer should select physical layer components with minimized asymmetry values and should avoid reflections caused by not matching impedance, for example.

Takeaway: The total margin is split to device and system design.

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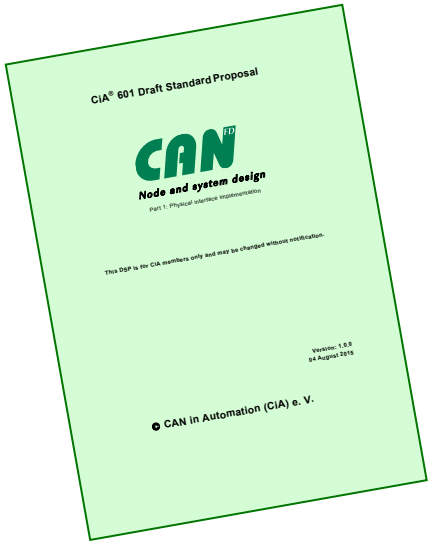
CiA 601 series



CAN FD node and system design

- CiA 601-1 (version 2.0): Physical interface implementation *
- CiA 601-2 (version 1.0): Controller interface recommendation **
- *CiA 601-3: System design recommendation ****
- CiA 601-4 (version 2.0): Ringing suppression circuitry ***
- *CiA 601-5: Reference topology examples ****

* Released as Draft Standard (DS)
** Released as Draft Standard Proposal (DSP)
*** Still under development

Takeaway: Released CiA 601 documents can be purchased.

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Bit-timing recommendation

- Set $tq_A = tq_D$ (this reduces the quantization error);
- Make tq_A as short as possible (this minimizes the quantization error);
- Choose the highest possible CAN clock frequency (e.g. 80 MHz);
- All nodes should have the very same sample-point, in both arbitration and data-phase bit (but these sample-points may be different);
- SJW_A and SJW_D should be as large as possible (this makes the network more robust);
- Enable TDC for data-phase bit-rates for 1 Mbit/s and higher.

Takeaway: These recommendations are given in CiA 601-3.

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Conformance test plans

International standards

- ISO 16845-1 (2nd edition): Classical CAN and CAN FD
- *ISO 16845-2 (2nd edition): High-speed transceiver (optionally with low-power mode and selected wake-up functionality)*

NOTE Conformance testing is like spellchecking in human communication. It increases the probability of interoperability, but doesn't guarantee it! CAN controllers and CAN transceivers tested by different test plan implementations can have different results. Complementary interoperability tests (e.g. plug-fests) are necessary to satisfy system designers.

Takeaway: Conformance does not guarantee interoperability.

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Network system testing

- *Option 1:* CAN FD plugfests
  Temporarily network at different locations in the world.
- *Option 2:* “Golden” CAN FD system testing

Takeaway: CiA organizes plugfests and will provide a “golden” system.

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CAN FD plug-fest 2015

- *March 2015 in Nuremberg:* Testing of ISO CAN FD separately from non-ISO CAN FD controllers. Additionally, long cables (up to 250 m) were tested with a 250-kbit/s arbitration phase bit-rate and a 2-Mbit/s data-phase bit-rate.
- *March 2015 in Detroit:* Testing of ISO CAN FD separately from non-ISO CAN FD controllers using GM wiring harness.

Takeaway: Device design matters.

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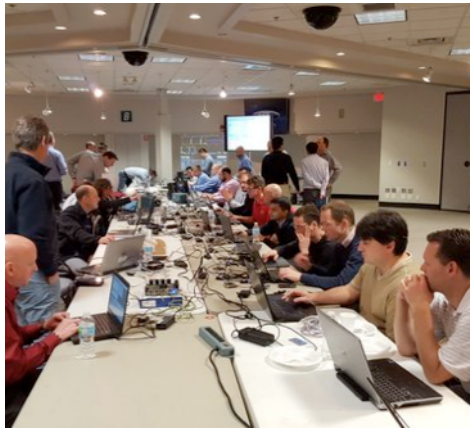
Plugfest 2016 in Detroit, MI



- Robustness and reliability tests
  (edge shifts at various positions of the data frame, bit flips of reserved bits)
- Oscillator tolerance test
  (f_{nom} + 2,5 %, f_{nom} -1,5 %)
- Glitches in res-bit
- Wiring harness tests
  (Ford and GM cabling)
- RSC testing
  (CiA 601-4 compliant ringing suppression circuitry)

Most of the tests were performed with 500 kbit/s (arbitration and 2 Mbit/s)

Takeaway: CAN FD is robust and reliable.

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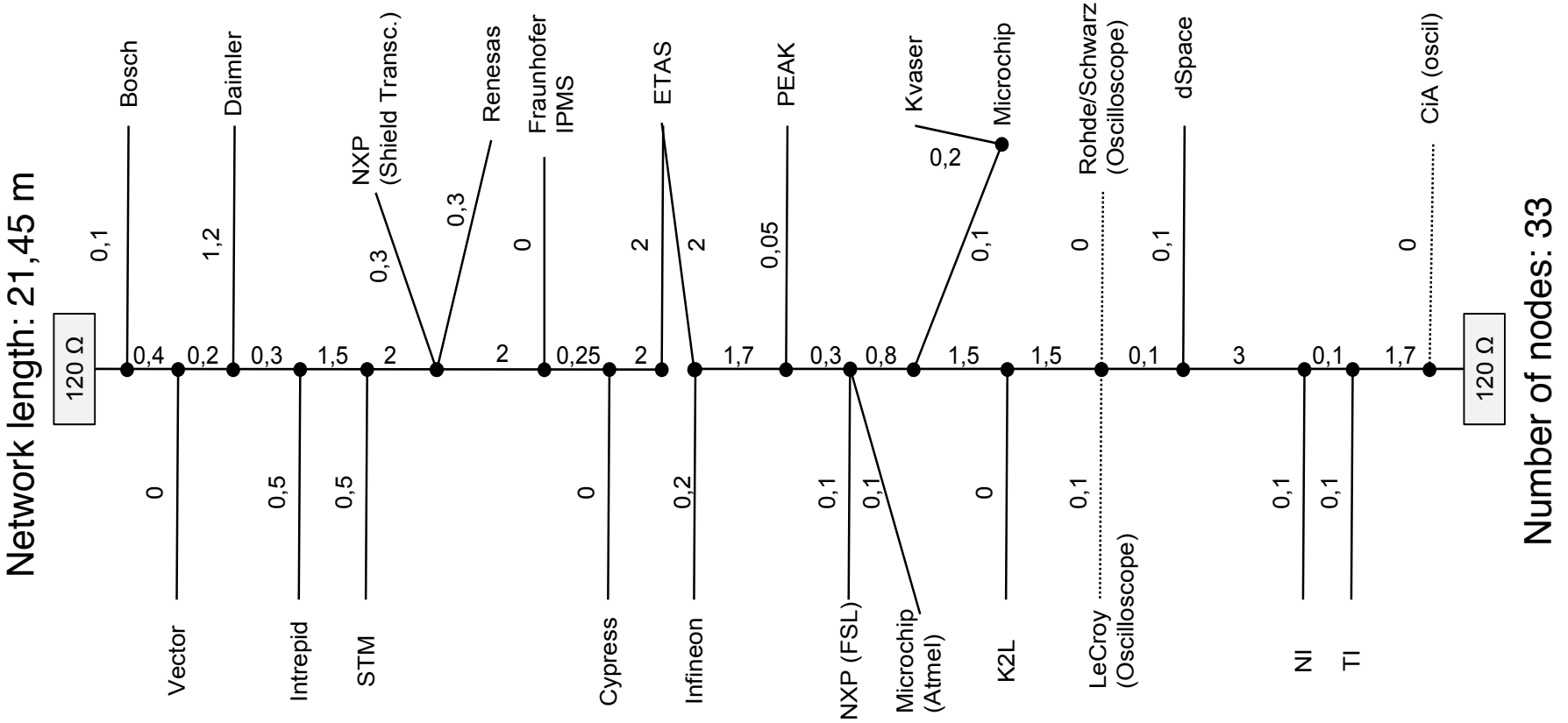
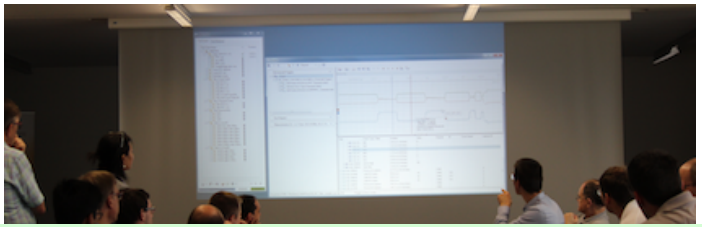
Plugfest 2016 in Nuremberg





Takeaway: Bus-line topologies with short stubs are the best choice.

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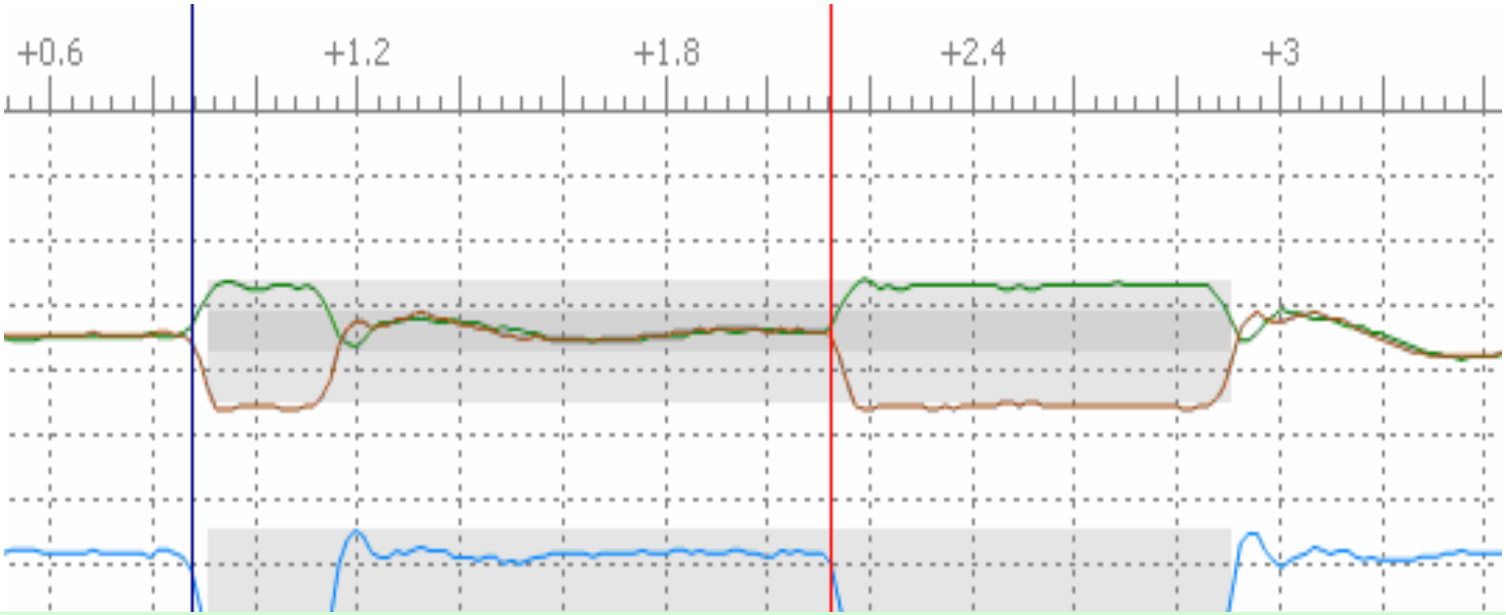
Recessive glitch in res-bit

According to ISO 11898-1 the CAN FD controller shall tolerate a recessive signal in the res-bit (see also test case 7.8.7.1 in ISO 16845-1). The figure shows an introduced recessive glitch (250 ns dominant, 1000 ns recessive, 750 ns dominant). The bit returned to dominant well before the 80 % sample point of the res-bit.



Takeaway: Plugfests showed that glitches were tolerated.

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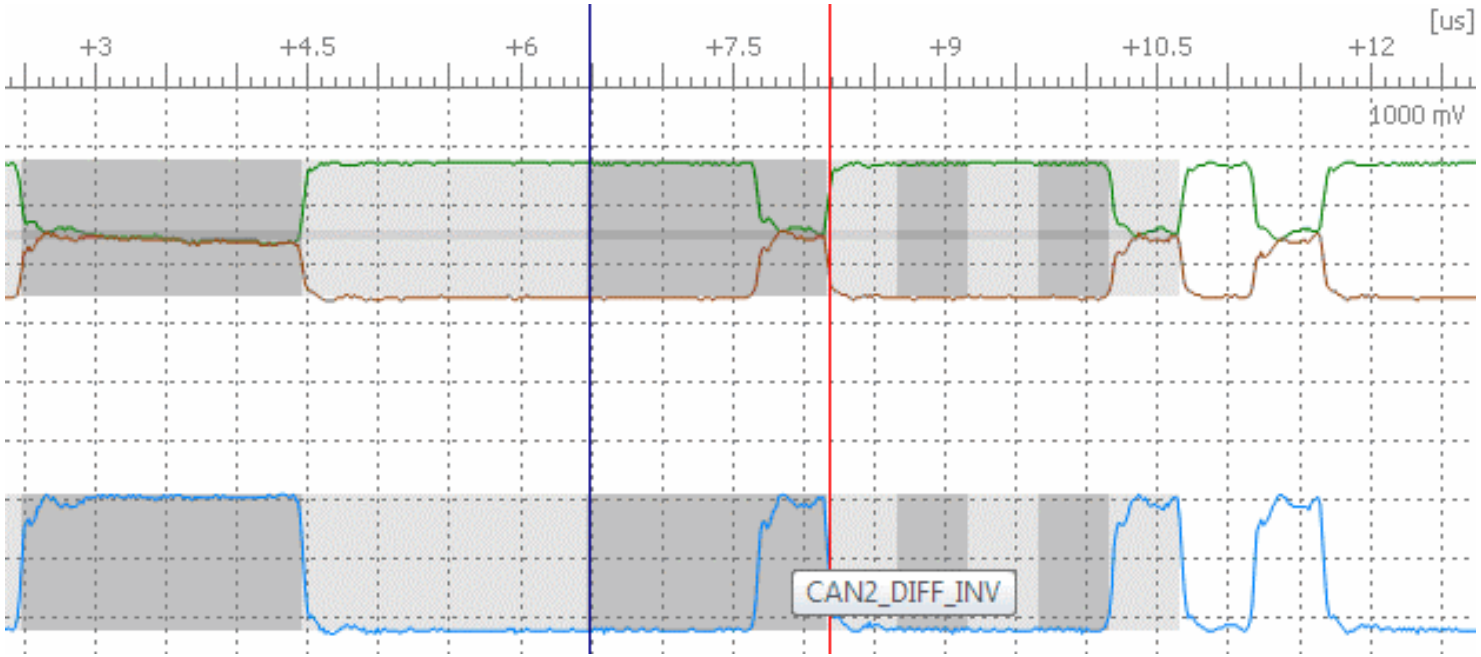
CAN FD robustness proof

Shifting the FDF-to-res and the res-to-BRS edge is a proof of the robustness of the CAN FD communication.



Test case 8.8.1.1 from ISO 16845-1 corresponds to a res-to-BRS edge shift by 150 ns, what means that the res-bit is dominant for only 1,85 μs.

Takeaway: During the plugfests, the robustness was proofed.

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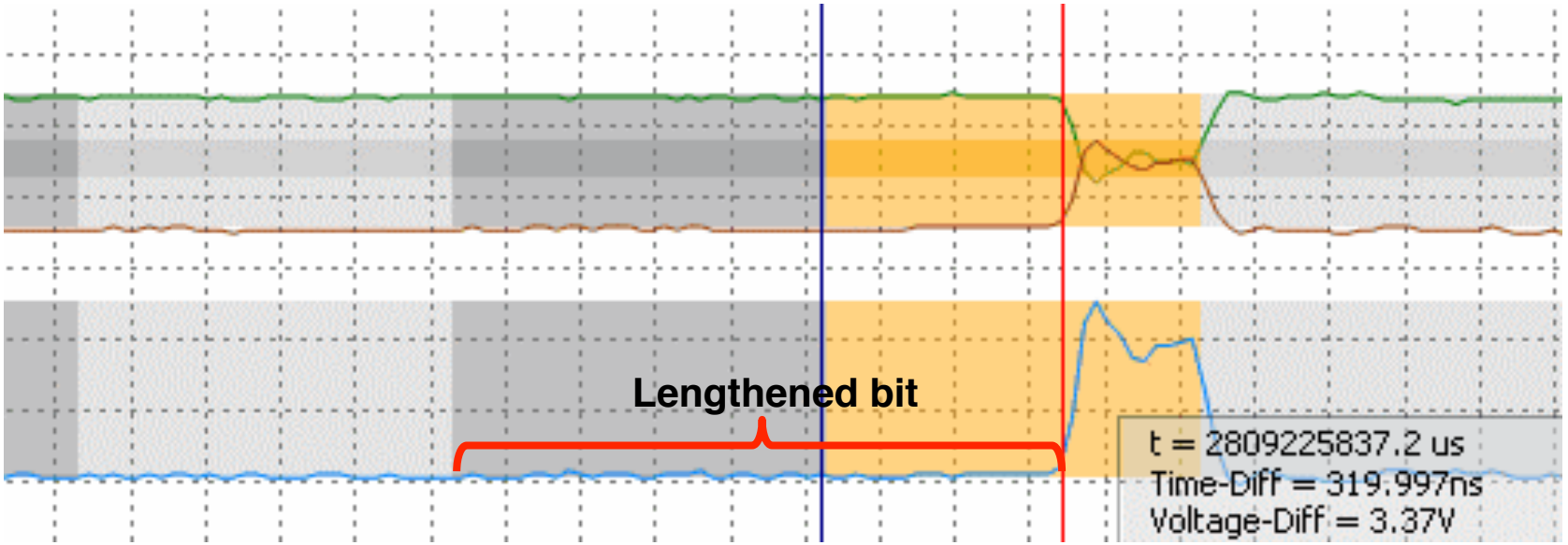
Edge-shifting



In the plugfest all dominant-to-recessives edges (lengthening the dominant bit and shortening the recessive bit) in a CAN FD frame were shifted.
RESULT: Up to a shift of 322 ns all nodes received the CAN FD data frames correctly. At the used settings, the theoretical largest tolerable shift with ideal oscillators is 375 ns. Consequently, the achieved 322 ns are a very good result, as it is very close to the theoretical limit.

Takeaway: The CAN FD communication is really very robust.

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CAN FD support

- CiA 301 version 5.0 (CANopen FD application layer)
- CiA 602 series (J1939 mapping to CAN FD)
- ISO 15765-2:2016 (ISO transport layer)
- XCP version 1.2 (ASAM universal measurement and calibration protocol)
- SAE-IT Arinc 825 CAN FD (Arinc application layer)

Takeaway: Several higher-layer protocols have adapted CAN FD.

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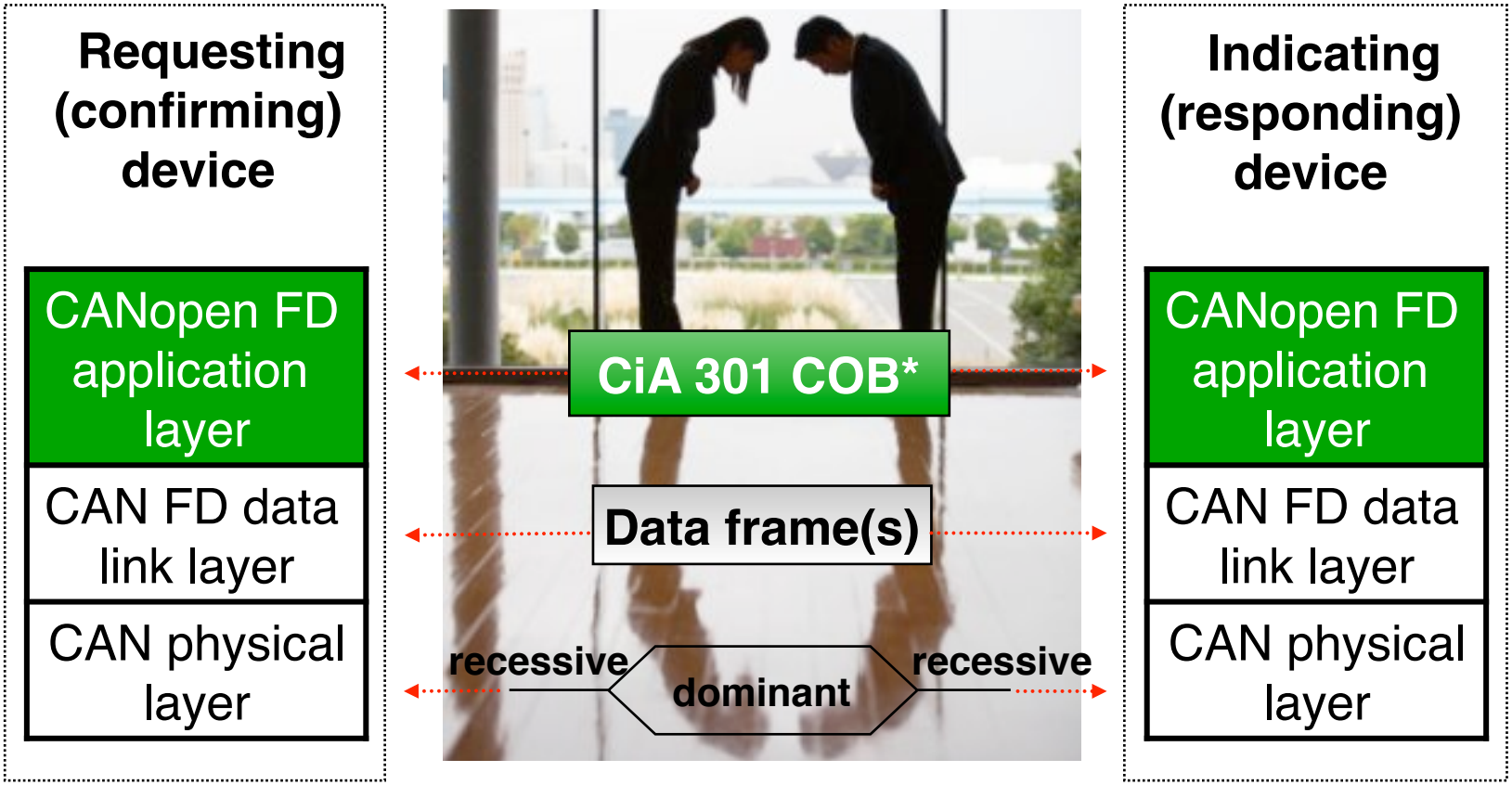
CANopen FD protocol layers



*** COB = communication object**

Takeaway: CANopen FD application layer is specified in CiA 301 (5.0).

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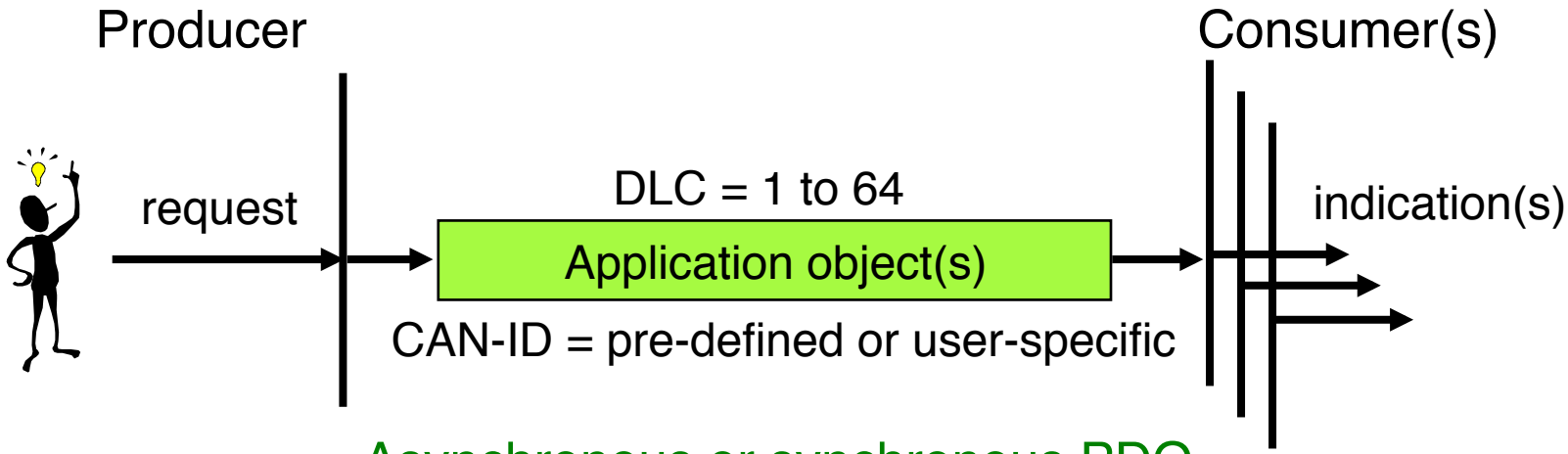
PDO with 64-byte payload



Asynchronous or synchronous PDO
triggered by CoS event, elapsing of event-timer (periodic), SYNC message (synchronous cyclically and acyclically)

NOTE PDOs shall not be requested remotely by means of Remote Transmission Requests.

Takeaway: PDOs in CANopen FD can map 64 process data.

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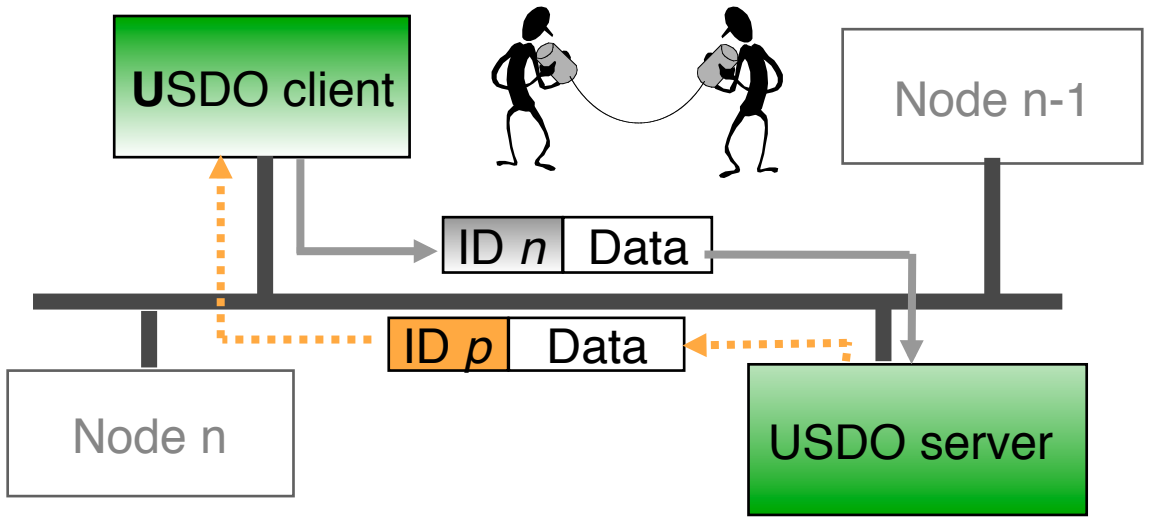
Universal SDO (preliminary)

USDO attributes:

- Confirmed data transfer in unicast, multicast, and broadcast
- Single or multiple sub-index access
- Expedited and segmented data transfer
- Inherent routing capability
- Physical (net-ID and node-ID) and logical (name) addressing



Takeaway: The Universal SDO substitutes the SDO.

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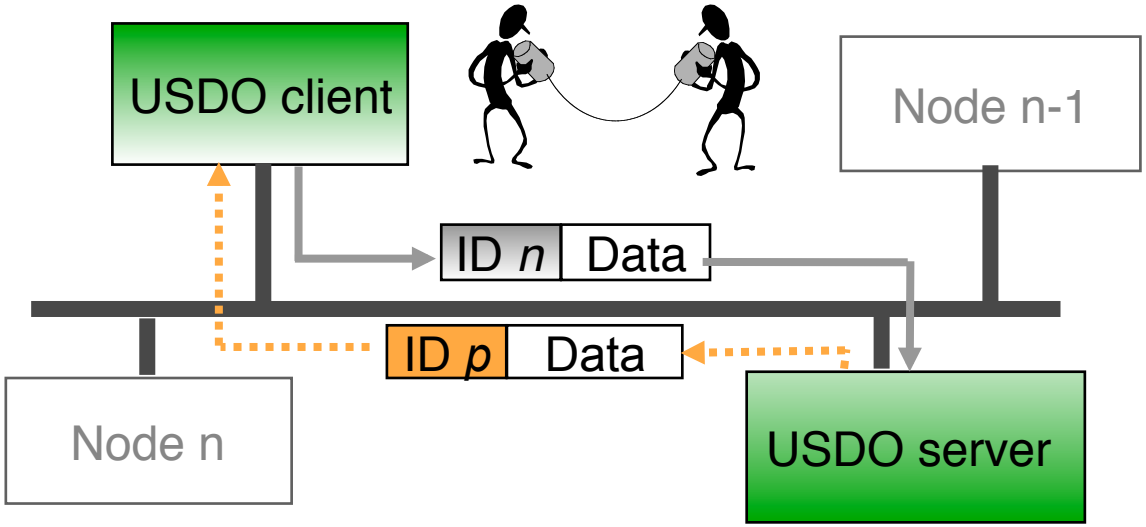
Universal SDO

USDO addressing:

- CAN-IDs identify the sender of the telegram
  - Client-to-server: 600_h + USDO client node-ID
  - Server-to-client: 580_h + USDO server node-ID
- Destination is coded in the USDO protocol



Takeaway: The CAN-IDs contains the node ID of client resp. server.

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USDO uni-/multi-/broad-cast

Client

Server

USDO download request

Destination address	Command specifier	Session ID	Index	Sub-index	Data type	Size	Application data
0	1	2	3+4	5	6	7	8 up to 63

Destination address	Description
00_h	Broadcast (to all nodes)
01_h to $7F_h$	Unicast (to node with indicated node-ID)
80_h to FF_h	Multicast (to some nodes part of indicated group)

USDO download response

Destination address	Command specifier	Session ID	Index	Sub-index
0	1	2	3+4	5

Takeaway: The USDO protocol support broadcast and multicast.

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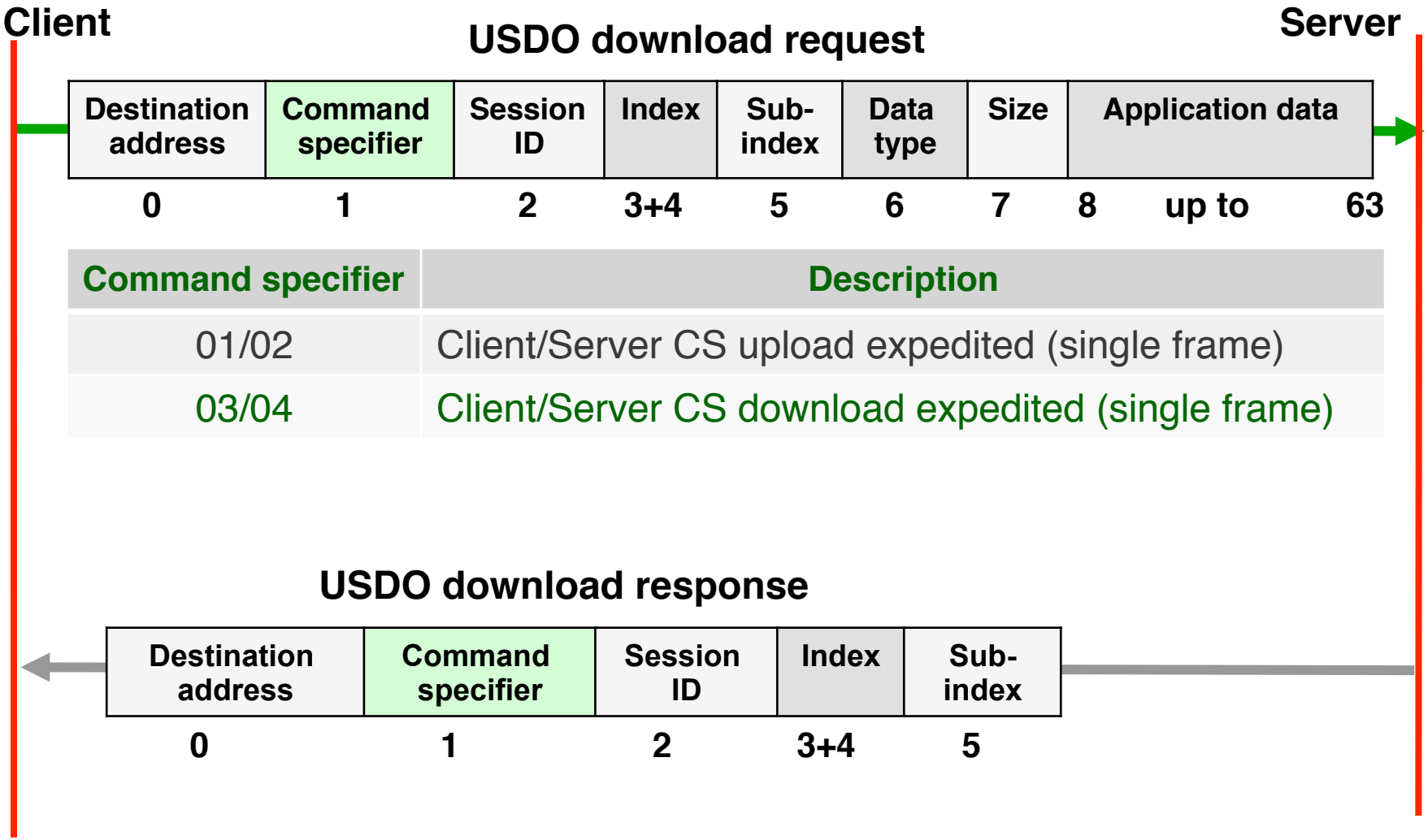
Expedited USDO download



Command specifier	Description
01/02	Client/Server CS upload expedited (single frame)
03/04	Client/Server CS download expedited (single frame)

Takeaway: An Expedited USDO contains up to 56 byte payload.

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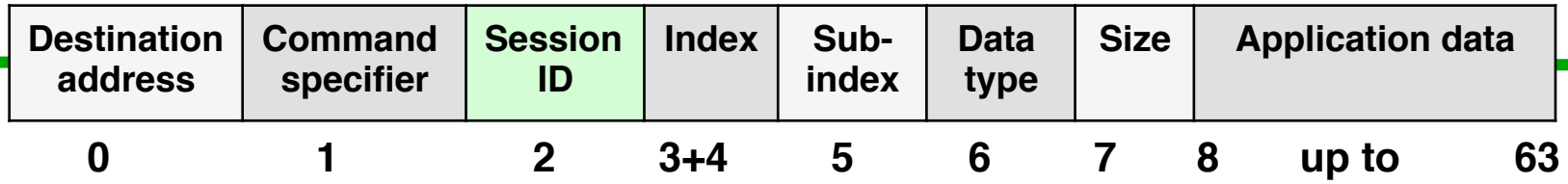
USDO Session ID

Client

Server

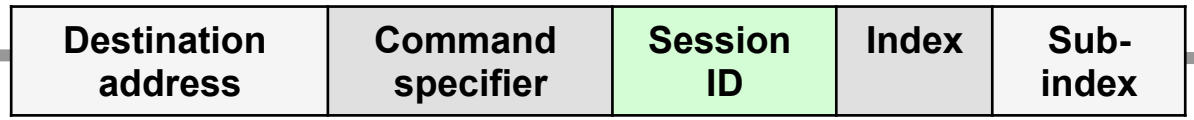
USDO download request



The Session ID:

- Identifies exactly one USDO transfer between one USDO server and one USDO client
- Is equal in all transactions of exactly one USDO transfer
- Differs for all currently running USDO transfers of one USDO clients to the very same USDO server
- Enables several parallel USDO accesses from one USDO client to the very same USDO server

USDO download response



Takeaway: The session ID enables to handle in parallel multiple USDOs.

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USDO data type information

Client

Server

USDO download request

Destination address	Command specifier	Session ID	Index	Sub-index	Data type	Size	Application data
0	1	2	3+4	5	6	7	8 up to 63

Data type	Description
01	Boolean
02	Integer8
03	Integer16
04	Integer32
...	Further simple CANopen data types according to CiA 301

USDO download response

Destination address	Command specifier	Session ID	Index	Sub-index
0	1	2	3+4	5

Takeaway: The data type of the payload is provided in the USDO header.

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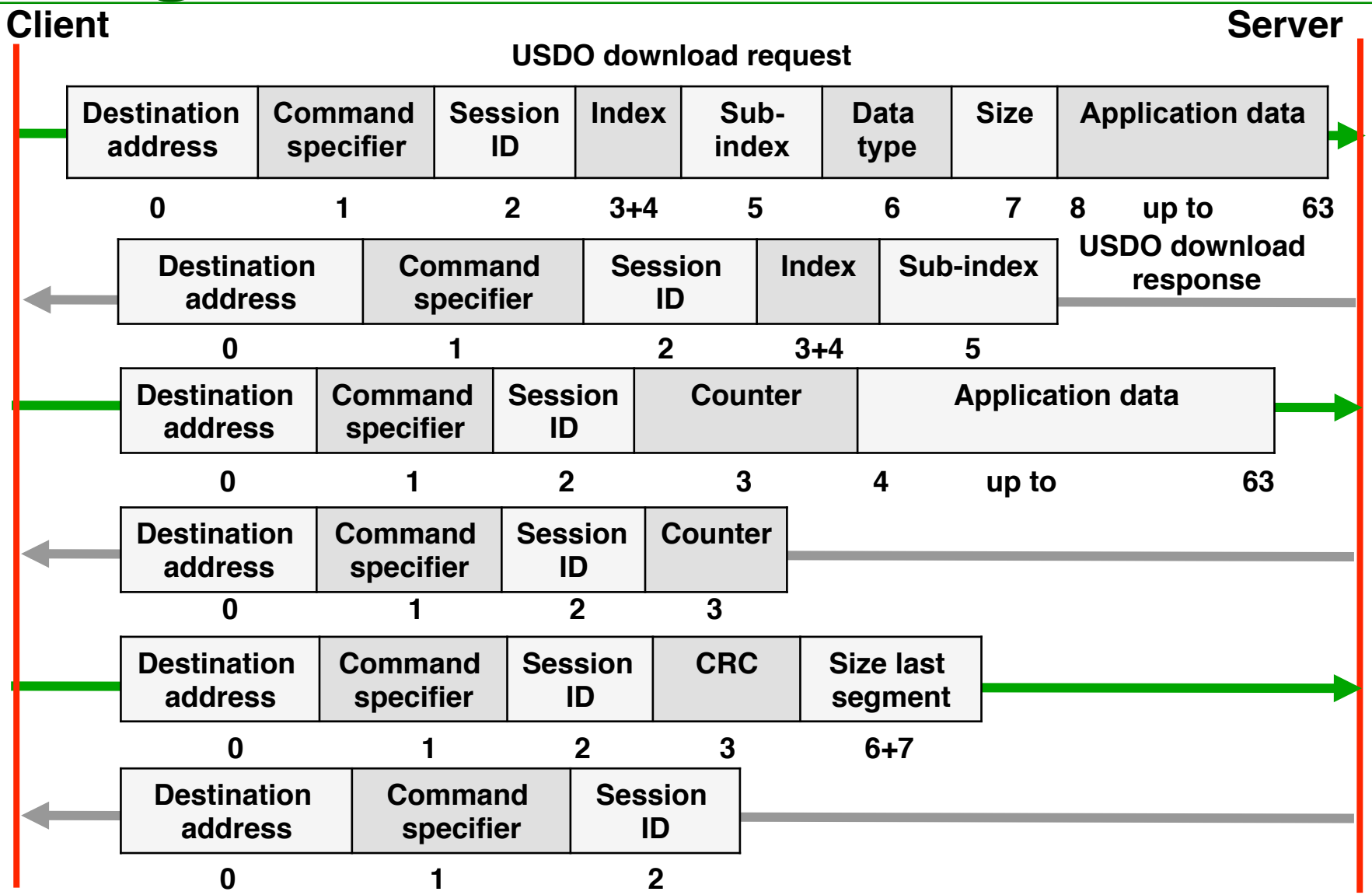
Segmented USDO download



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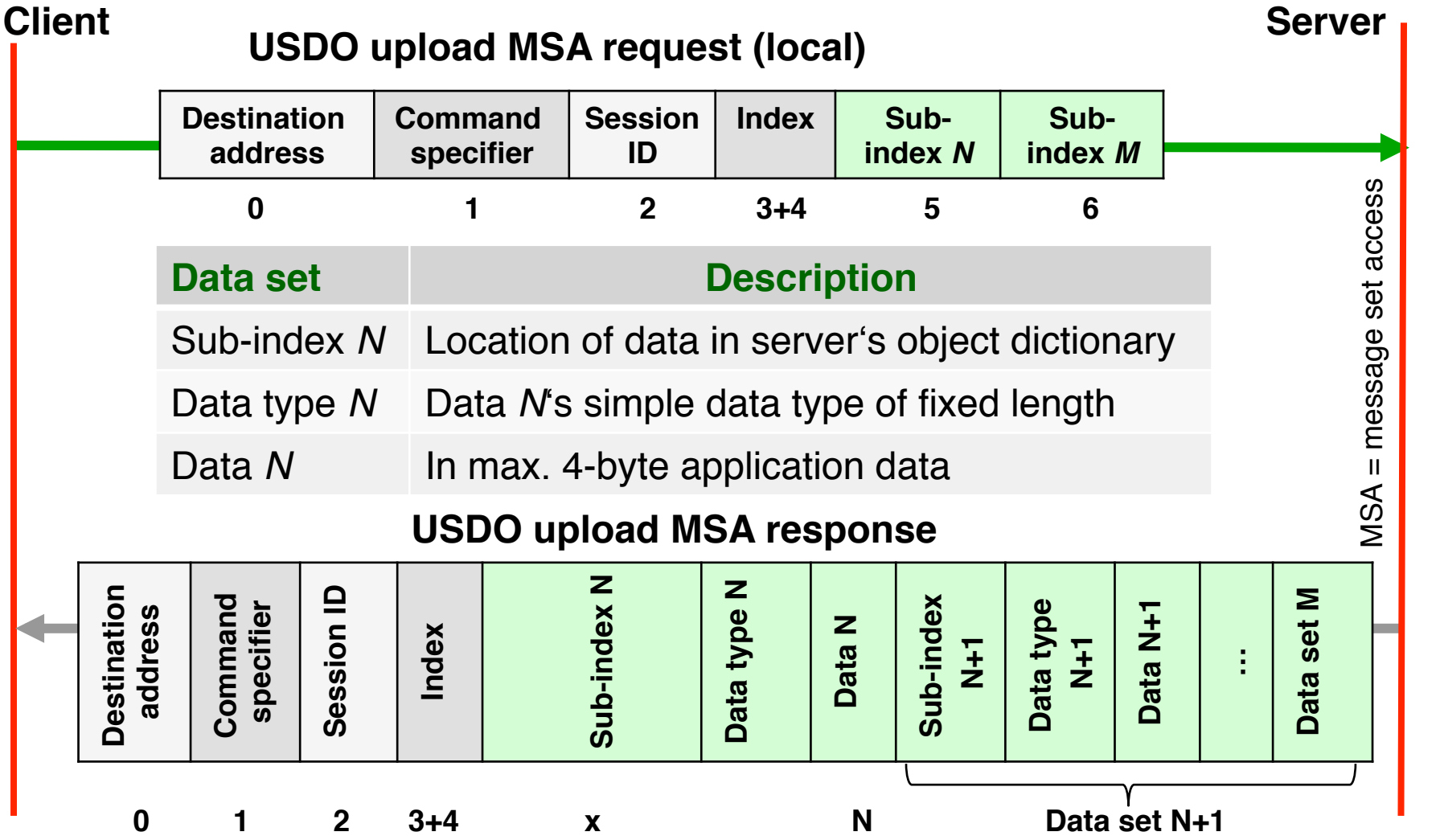
MSA USDO upload



Data set	Description
Sub-index *N*	Location of data in server's object dictionary
Data type *N*	Data *N*'s simple data type of fixed length
Data *N*	In max. 4-byte application data

Takeaway: Multiple indexes can be addressed.

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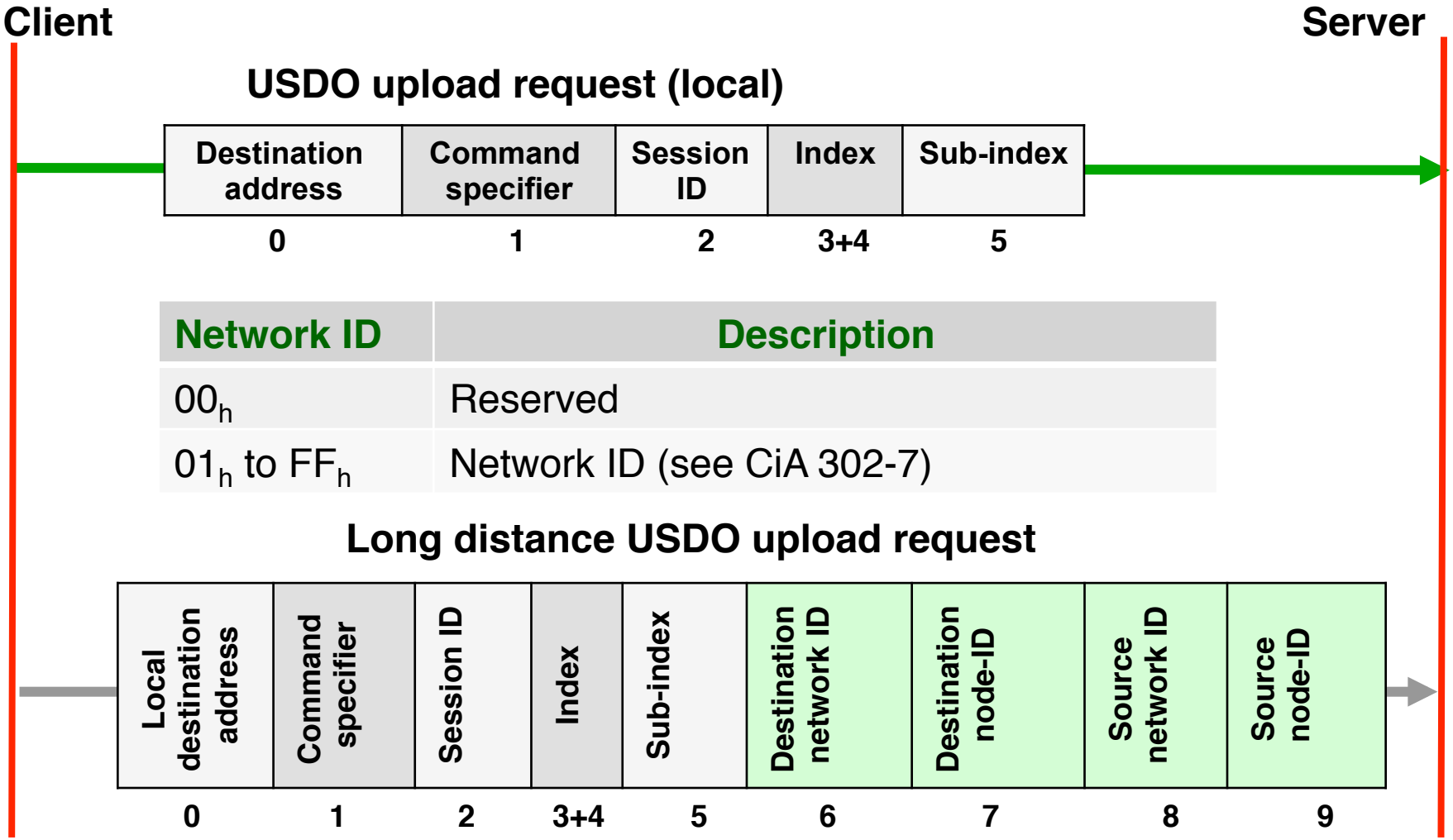
Long distance USDO upload



Network ID	Description
00_h	Reserved
01_h to FF_h	Network ID (see CiA 302-7)

Takeaway: USDO supports remote access to CANopen FD segments.

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Open issues and outlook

- CAN FD controllers for industrial applications are partly available, CAN FD capable transceiver are available.
- CAN FD physical layer recommendations need to be validated by means of practical experiences.
- CANopen FD is still under development, basic functionality is already specified.
- CANopen FD conformance test plan is under development; the related conformance test tool needs to be implemented.
- CANopen device and application profiles need to be adapted.
- Functional safety and cyber security protocols for CANopen FD need to be specified.
- CAN FD will be implemented in most of the market-leading passenger cars.
- The success story of CAN technology continues!

Takeaway: CAN FD is available, but there are still things to do.

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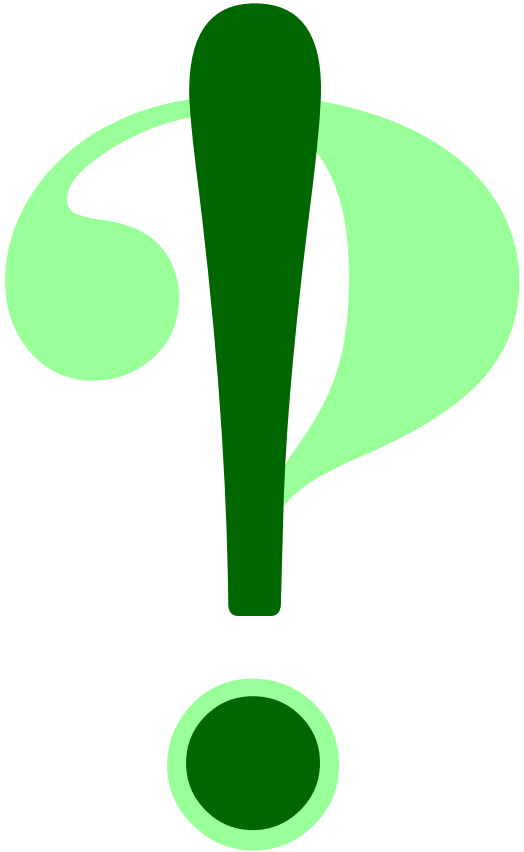
Questions and answers



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