3rd generation of the CAN data link layer

Since a couple of years, the automotive industry substitutes Classical CAN by means of CAN FD, which is internationally standardized in ISO 11898-1:2015. In parallel, the CAN community develops the next generation of the CAN data link layer protocol: CAN XL.

Priority ID	RMF	IDE	FDF	XLF	BRS	ESI	SDT	SEC	DLC	VCID	AF	LLC data
11 + 18 bit	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit	8 bit	1 bit	11 bit	8 bit	32 bit	0 to 2048 byte

Legend
RMF: remote frame
IDE: identifier extension
FDF: flexible data rate field
XLF: extra large field
BRS: bit-rate switch
ESI: error state indicator
SDT: service data unit type
SEC: DLL security indication
DLC: data length code
VCID: virtual CAN network ID
AF: acceptance field
LLC data: logical link layer data

Figure 1: LLC frame fields - support for all three CAN protocol generations (Source: CiA)

Since December 2018, the CAN in Automation (CiA) special interest group (SIG) CAN XL is specifying the CAN XL protocol features. In the meantime, the SIG CAN XL has additionally established three task forces (TF): the TF CAN XL physical layer, the TF CAN XL higher layer, and the TF CAN XL security. Relevant topics are discussed in the respective TFs (task forces). The CiA 610 document series and the CiA 611 document series will include the CAN XL relevant specifications.

The SIC CAN XL develops directly the specification of the CAN XL data link layer, which will be released as CiA 610-1 document: CAN XL specification and test plans – Part 1: Data link layer and physical signaling. After two-years intensive discussion, the CAN XL data link layer protocol specification is recently technically stable and will be released in beginning of 2021 as CiA document. As the next step, the ISO standardization will be started.

This article introduces briefly the CAN XL data link layer protocol, namely to answer the question, what is CAN XL. Have in mind that the CiA 610-1 document is still under development. Therefore, the final CiA 601-1 document could have differences compared to the content in this article – even if the probability is very low.

The CAN XL data link layer protocol has the following key features:

- Large data field with up to 2 048 byte
- Higher-layer management information
- Improved reliability by means of two CRC fields

LLC and MAC sub-layers

Similar to Ethernet, the CAN standard (ISO 11898 series) specifies two data link sub-layers:

- Logical link control (LLC): It acts as a sub-layer between the OSI network layer and the media access control (MAC) sub-layer.
- Media access control (MAC): It is responsible for moving frames from the LLC sub-layer to the PMA (physical media attachment) sub-layer and protects the transmission by means of stuff-bits, CRC fields, etc.

The LLC frame structure shall contain all content needed for all CAN frame formats and types, including the selection of a specific CAN frame format. In the interaction between LLC and MAC, the content of that parts of the LLC frame that are not used for the selected CAN frame format shall be ignored. Figure 1 shows the LLC frame format specified in CiA 610-1. The LLC frame supports all three CAN protocol generations: Classical CAN, CAN FD, and CAN XL. The fields of the LLC frame that are used by CAN XL are highlighted green.

Priority and addressing

In Classical CAN and CAN FD, the CAN-ID field (11 bit or 29 bit) is used for both arbitration and addressing purposes. In CAN XL these functions are separated. The CAN XL protocol separates the priority functions (11-bit ID) and the addressing (32-bit acceptance field).

OSI data link layer protocol data unit (PDU)

SOF	Arbitration	Control	Data (field)	CRC	ACK	EOF
1	15 bit	81 bit	1 to 2048 byte	36 bit	6 bit	7 bit

Figure 2: CAN XL MAC frame fields (Source: CiA)

Priority ID	RRS	IDE	FDF	XLF
11 bit	1 bit	1 bit	1 bit	1 bit

Figure 3: XLFF: arbitration field (Source: CiA)

- 11-bit priority ID sub-field: This field provides the uniquely assigned priority of the CAN XL data frame.
- 32-bit acceptance field: This field can contain node address or content indication information like a message ID.

Service data unit type (SDT)

The SDT is a feature that is usable for higher-layer protocols. The 8-bit SDT indicates the used next OSI layer protocol. It is an embedded (OSI) layer management information as described in ISO 7498-4:1998 and is similar to the Ethertype field in the Ethernet frame.

CiA 611-1 specifies the SDT values and the corresponding usage to unfold the power of this field. The first version of CiA 611-1, that is planned to be released in the next months, will specify SDT values for:

- Content-based addressing (i.e. use of message IDs)
- Node addressing
- Nodes tunneling of Ethernet frames
- Classical CAN and CAN FD data frames

Virtual CAN network ID (VCID)

The 8-bit VCID field allows running up to 256 logical networks on one single CAN XL physical network segment. This will allow to use many protocols in parallel, on the same physical CAN network. This field is also an embedded (OSI) layer management information as described in ISO 7498-4:1998.

Optional DLL security

The CAN XL TF security would specify the CADsec data link layer security protocol. The SEC bit in the control field indicates, if this CAN XL data frame uses the CADsec protocol. The CADsec protocol features a header with cipher control information, the CAN secure channel ID, and a freshness value. The 16-byte trailer contains the authentication tag.

MAC frame in XL format

The MAC sub-layer comprises the functions and rules related to encapsulation/de-capsulation of the transmitted/received data, error detection as well as signaling, and management of the medium access.

There is just one single CAN XL MAC frame format, called CAN XL frame format XLFF. The frame has a variable length and can hold 1 byte to 2 048 byte in the data field, while the data length can change in one-byte steps.

resXL	ADS (ADH, DH1, DH2, DL1)	SDT	SEC	DLC	SBC	PCRC	VCID	AF
1 bit	4 bit	8 bit	1 bit	11 bit	3 bit	13 bit	8 bit	32 bit

Legend
ADS: arbitration-to-data phase switch;
PCRC: preface CRC (cyclic redundancy check);
SBC: stuff-bit counter

Figure 4: XLFF: control field (Source: CiA)

On transmission, an LLC frame is converted into a MAC frame. On reception, a MAC frame is converted into an LLC frame. MAC frames in XL format are composed of seven different bit fields as shown in figure 2. In figure 2, 3, 4, and 5 the fields marked in green are automatically added by the MAC sub-layer, and the grey fields are provided by the LLC frame.

ADS field in control field and DAS field in ACK field

For higher bit-rates (10 Mbit/s and above) the new CAN SIC XL transceivers specified in CiA 610-3 are suitable. The CAN SIC XL transceivers have three modes to achieve the “fast bits” in the data phase but also allow arbitration in the same frame. The modes are named SIC mode, Fast TX mode, and Fast RX mode. In the SIC mode, the transceiver drives dominant and recessive bits, as known from Classical CAN. In the Fast TX mode, the transceiver drives level-1 and level-0 signals with differential voltage levels of -1 V and +1 V. In Fast RX mode the transceiver does not drive the network. Additionally, CAN SIC XL transceivers support the medium-independent CAN interface (MICI), that is required to signal the mode switching.

The first bit in the ADS field is the ADH bit. It is sent as logical 1. During this bit, the CAN SIC XL transceiver is switched from SIC mode in Fast TX or Fast RX mode. The MICI interface sends PWM symbols of arbitrary value to perform the proper transceiver mode switch. All CAN XL nodes ignore the sampled value of the ADH bit. The first bit in the DAS field is DAH bit. It is sent as logical 1. This is the bit, where the transceiver mode in the CAN XL SIC transceiver is switched back to SIC mode.

The CAN XL data frame includes two CRC (cyclic redundancy check) fields: the 13-bit Preamble CRC (PCRC) and the 32-bit frame CRC (FCRC). The CRCs are cascaded, which means FCRC protects the whole frame, including the PCRC. Both CRCs are able to detect any five randomly distributed bit-errors. This corresponds to a Hamming distance of 6. The university of Stuttgart proposed the CRC polynomials for PCRC and FCRC, and they published their argumentation in iCC (international CAN conference) 2020 proceedings. At the moment, the University of Kassel is evaluating the error detection capabilities of the CAN XL MAC layer, what also means that the CRC polynomials are double-checked. The research report by the Kassel University is expected by end of 2020.

CAN XL and transceivers

CAN XL is highly scalable regarding bit-rates and the medium access unit (MAU) physical sub-layer (normally implemented in transceiver chips or system base chips). CAN XL controllers can be used with CAN high-speed and CAN SIC (signal improvement capability, specified in CiA 601-4 version 2.0.0) transceivers using the AUI (attachment unit interface) as specified in ISO 11898-2:2016. Additionally, CAN XL controllers can be used with CAN SIC XL transceivers to support bit-rates of 10 Mbit/s and beyond. To signal the mode switch from the CAN controller to the transceiver, CAN XL controllers and transceivers implement the MICI (medium-independent CAN interface). The MICI is based on a TX-based single-path PWM (pulse width modulation) symbols. This preserves the two-pin interface (RxD, TxD) also for CAN SIC XL transceivers. The specification for MICI is still under development.

Higher-layer protocols

The standardization of higher-layer protocols is essential to enable interoperability of devices with CAN XL connectivity. The CAN XL TF higher layer works for example on the following topics: specification of SDU types, Multi-PDU concept (similar to the concept known from Autosar) that allows to aggregate several different PDUs and to send this as a Multi-PDU inside a single CAN XL MAC frame. Previously, the TF higher layer defined, that CAN XL controllers would use 64-bit time stamps, which cannot wrap around during life time. TF higher layer also requested the introduction of the SDT field and the VCID field in the LLC and XL MAC frame.

Summary

In summary, CAN XL runs in the data phase bit-rates of up to 10 Mbit/s, it provides a data field of 1 byte to 2 048 byte, and it features some embedded layer management information for higher-layer protocols. Important is its backwards compatibility with CAN FD. It is highly scalable regarding the applications but also regarding the sup-

CRC field

Frame CRC	FCP
32 bit	4 bit

ACK field

DAS (DAH, AH1, AL1, AH2)	ACK	Dlm
4 bit	1 bit	1 bit

EOF field

End-of-frame
7 bit

Figure 5: XLFF: CRC field, ACK field, and EOF field (Source: CiA)

ported bit-rate, as CAN XL can be used with many different transceivers.

CiA planned to introduce CAN XL on the 17th international CAN Conference that ought to take place in Baden-Baden Germany on March 17 and March 18, 2020. Because of the Covid-19 pandemic the CAN conference could not take place. The CiA technical group SIC CAN XL and its TFs are working intensively on CAN XL in 2020, and expect the release of the first document of the CiA 610 series, CiA 610-1, at the beginning of 2021. After that, the international standardization at ISO will be started. CiA will also organize plugfests (interoperability tests) to test interoperability of CAN XL protocol controllers, but also of the CAN SIC XL transceivers in network environments, as soon as prototypes or engineering samples are available. ◀

References

[1] CiA 610-1, CAN XL specification and test plan – Part 1: Data link layer and physical coding (in preparation)

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[3] F. Hartwich, "Introducing CAN XL into CAN Networks" in Proceedings of the 17th international CAN Conference, Baden Baden, Germany, 2020.

Author

Yao Yao
CAN in Automation
yao@can-cia.org
www.can-cia.org