Where CAN XL fits: Here are eleven strengths in mixed-network architectures

As embedded networks evolve to support higher data rates, tighter timing requirements, and increasingly complex safety demands, engineers are looking for communication technologies that deliver more than raw bandwidth. CAN XL is a compelling answer. Far from being just the next step in the CAN family, it introduces a set of architectural and practical advantages that directly address real-world design challenges, from cabling cost and robustness to deterministic latency and functional safety.

This whitepaper explores 11 engineering-driven reasons why CAN XL is gaining traction across automotive and industrial applications. Each point listed below is examined in detail to help you understand not only what CAN XL offers, but why it matters when designing modern, scalable, and secure embedded systems.

1. CAN XL transfers unfragmented Ethernet frames.

2. CAN XL transceivers are highly integrated.
   A typical footprint is 9 mm^2 (-T1S ≈ 82 mm^2).

3. CAN XL transceivers are intrinsically robust.
   No additional area is required for protection (-T1S ≈ 22 mm^2).

4. CAN XL transceivers are cost effective.
   Approx. $0.33 per transceiver (-T1S ≈ $2.70).

5. CAN XL supports low-cost cable layouts.

6. CAN XL supports flexible drop line lengths.

7. CAN XL provides inherent real-time control.
   All messages can have predefined, deterministic latency (-T1S latency depends on system design).

8. CAN XL supports adding or removing modules without impacting real-time behaviour.
   There is consistent latency between 2 and 200 installed CAN nodes (with T1S, adding nodes or changing frame length affects latency).

9. CAN XL provides inherent consistency and time-synchronized data distribution.
   Broadcast communication ensures identical data arrives at all nodes at the same instant.

10. CAN XL enables fast and secure functional safety.
    Small, understandable, and verifiable functional safety logic.

11. CAN XL provides inherent detection of alien attacks.
    Illegal or non-compliant CAN frames are easy to detect.

1. CAN XL transfers unfragmented Ethernet frames

CAN XL supports 2048 Byte data payloads, enabling an unfragmented Ethernet frame to be placed in the CAN XL package. This facilitates the use of standard networking software functionality. including TCP/IP and UDP.

Classic CAN was designed for fast, predictable, and secure real-time control. This is achieved by using short messages that ensure high priority messages can get fast access with low latency and predictable bandwidth.

This is perfect during the real-time control but inefficient for service tasks such as ECU reprogramming or diagnostics. It is necessary to make a transport protocol to cut the long TCP/IP packet placed in the Ethernet package into 8-byte CAN packages, and at the receiver assemble the fragment back into a TCP/IP package. This is a relatively long process, and if it fails, it is necessary to have a method to recover from the fault. Even with CAN FD, protocol overhead can approach 50%, meaning half the available bandwidth is consumed by framing rather than payload. In addition, classic CAN arbitration is limited by signal propagation delay, making bit rates above 1 Mbit/s increasingly complex and costly to implement.

Like 10BASE-T1S and CAN XL, 10BASE2 (802.3a), the first Ethernet, was based on a multidrop cable with collisions. The very same package is used today at 1.6 Tbit/s. This means that if a CAN XL frame is sent with P2P through a switch without any collision, this string of bits could also be sent at 1.6 Tbit/s.

2. CAN XL transceivers are an integrated solution

CAN XL transceivers are a robust technology that can be connected directly to CAN-bus wires without any external components.

The 10BASE-T1S transceivers are designed with complex 1.8 V logic, that typically require a Bus Interface Network to protect the device. They also require a 25 MHz clock with +/- 100 ppm accuracy to run the internal logic. This adds cost and PCB area and increases the design and validation effort.

Parameter	CAN-FD/XL	CAN-CC	T1S-Driver (1)	T1S+EMC (2)
Device area mm2	9	9	16	16
Oscillator mm2			8	8
Bus Interface Network			36	36
EMC choke				9
EMC varistors				12
Total area mm2	9	9	60	81
Cost 10 nodes	$7.3	$3.3	$27.5	$33

(1) Requires at least three capacitors, three resistors and an oscillator.
(2) Includes (1) plus 2 varistors and a common-mode choke.

As the bus wires connect directly to the CAN-driver, circuit complexity between the CAN transceiver and the CAN bus is significantly reduced.

3. CAN XL transceivers are intrinsically robust

CAN XL transceivers are a robust technology that meet most EMC requirements. There are CAN CC transceivers available for a more extreme environment, +/- 80 Volt on the CAN-bus wires. It is only in exceptional cases will you need to add external components to protect the CAN-driver.

Test type	CAN-FD/CC (5)	CAN-XL (6)	T1S-Driver (3)	T1S+filter (4)
Max voltage on bus lines	+/- 65 Volt	+/- 42 Volt	-27 – 42 Volt	+/- 65 Volt
ESD (Human Body Model)	+/- 45 kV	+/- 10 kV	+8 kV	+/- 45 kV
ESD (IEC Air-Gap Model)	+/- 30 kV	+/- 15 kV	?	+/- 30 kV
ESD (IEC Contact Model)	+/- 12 kV	+/- 8 kV	+1 kV	+/- 12 kV
Common-mode range	+/- 25V	+/- 25V	+/- 32 V	+/- 32V
Cost (10 nodes)	$7.3	$3.3	$27.5	$33

(3) Requires at least three capacitors and three resistors (≈ 36 mm2)
(4) Includes (1) plus, two varistors and a common-mode choke.
(5) MAX33011E
(6) TCAN6062

In practice, EMC filters are often added to the CAN XL driver to compensate for poor wiring-harness design, while a good cable layout will save ECU cost and increase robustness and vice versa.

4. CAN XL transceivers are cost effective

The CAN driver is an efficient power amplifier that provides good signal integrity without any complexity. All necessary complexity is integrated in the CAN XL controller. In contrast, 10BASET1S integrates significant real-time logic directly into the PHY, resulting in a transceiver comparable in complexity to a CANXL controller.

- CAN XL needs 2 pins, not 14 pins for an xMII interface.
- CAN XL uses robust logic design compatible with legacy production facilities.
- CAN XL transceiver does not need a 25 MHz +/- 100ppm oscillator.
- CAN XL controller operates with a +/- 15000 ppm oscillator tolerance.

ETH PHY	Type	Price	Interface	Pkg	mm2
LAN8671	-T1S	$2.6	xMII, 14pin	VQFN-24	16
TJA1462	-FD	$0.73	TxRx, 2 pin	HVSON-8	9
NCV7357	-CC	$0.33	TxRx, 2 pin	DFNW-8	9
Osc.		$0.1	4 pin		8
Choke		$0.8	4 pin		9

CAN transceivers are based on mature, robust technology well suited for the electrically harsh conditions found in automotive and industrial environments. While 10BASE-T1S PHYs benefit from high-density semiconductor processes, these processes are inherently more expensive. In addition, the wide xMII interface, external oscillator, power pins, and EMC components significantly increase PCB area, package size, and bill of materials cost. Although higher production volumes can reduce unit price, a larger pin count and increased system complexity will always carry a cost penalty.

5. CAN XL supports low-cost cable layouts.

With CAN XL, it is possible to match cable cost to the required performance.

CAN XL support bit rates from 50 kbit/s up to 20 Mbit/s, allowing the bit rate to be selected according to the cable layout. For example, CAN XL communication at 125 kbit/s will work reliably in a star-configuration with several meters of stub length. CAN XL can operate at up to 20 Mbit/s when the bus layout is designed to support higher bit rates.

In contrast, Ethernet -T1S or -T1L operate at fixed bit rates of 10 or 100 Mbit/s and require a cable layout that can support such high bit rates. This cost is incurred even when bandwidth utilization is very low.
Higher bit rates also demand better control of impedance variations along the bus.
Most twisted wires in a cable have continuous impedance by design.

The main sources for impedance variations are:

1. Star points, multiple drop lines close together
2. Relatively long drop lines
3. Connectors
4. EMC filters
5. Poor termination

To optimize cost, it is necessary to optimize the ECU design and bit rate according to the cable design.

How the cable affects the signal.

When the transmitter changes its output voltage, it also changes the current flowing into the twisted pair. The resistance of the cable is very low, so one might expect a high current.
If you have a twisted pair that is 3 m long with AWG24 wires, there is a resistance of 85 mΩ per meter. The total resistance in one wire over 3 meters is 250 mΩ. If you make a shortcut at the other end, the total resistance will be 0.5 Ω. A 1 V DC step would therefore suggest a current of 2 A.

This is only true for DC; with fast voltage transitions, the cable behaves as a transmission line with a characteristic impedance of about 100 Ω, which limits the initial current. The voltage step propagates along the cable and is reflected at impedance discontinuities, inverting at a short circuit and doubling at an open end. To avoid repeated reflections, the transmitter's output impedance is matched to the cable, causing most signal energy to be dissipated in the driver rather than the cable. As a result, a stable communication link requires point-to-point connections with matched impedances at both transmitter and receiver.

6. CAN XL supports flexible drop line lengths

Communication is all about transporting energy over a cable. To switch your light bulb on and off is straightforward, but switching a communication signal one billion times per second is challenging for both the switch and the cable. At one gigabit, each bit is 1 ns long and covers about 20 cm of cable. For a 10 meter cable, the sender will transmit 50 bits before the first bit reaches the receiver. If the communication link has impedance variations, the energy will be reflected into neighbouring bits, a phenomenon known as Inter Symbol Interference (ISI).

CAN uses arbitration, which requires a bit-length to be at least four times the signal propagation delay of the cable. With such long bits relative to the length of the communication wire, ISI becomes negligible because all energy from previous bits has dissipated before the sample point is reached. For this reason, CAN CC was inherently protected against ISI.

With CAN FD and CAN XL, higher data-phase bit rates are used after arbitration. In these cases, the bitlength will be close to the delay or even shorter than the propagation delay of the cable. As a result, the bus layout must be designed to cope with shorter bit durations.

As described earlier, signal degradation is caused by reflections due to impedance variations. If the physical length of an impedance discontinuity is less than one-tenth of the signal wavelength, its influence on signal quality is minimal.

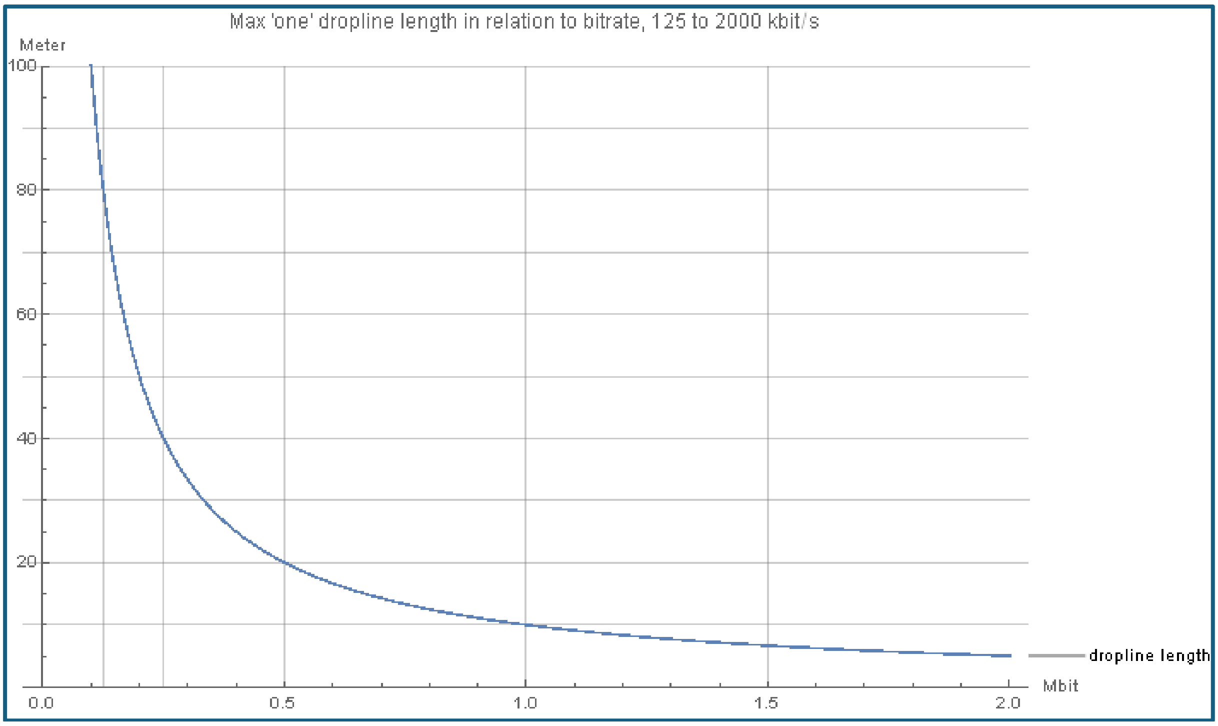


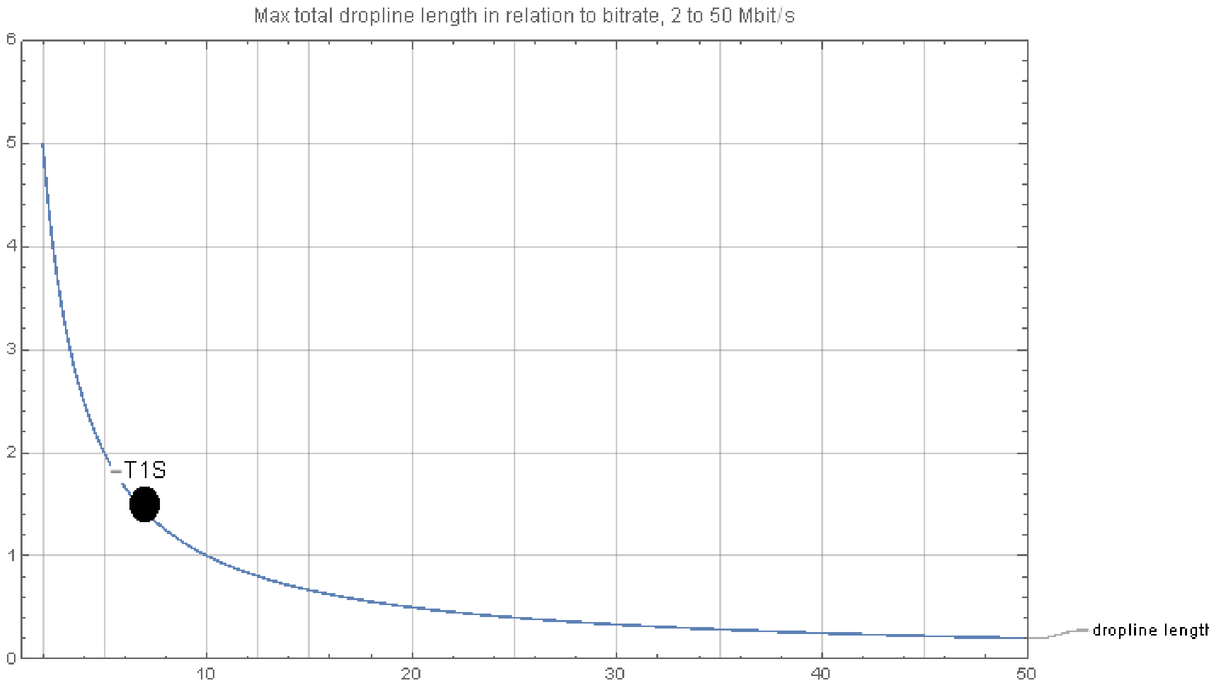
Figure 1Maximal drop-length to the bit rate.

From this figure we can read:

- At 125 kbit/s, drop lines of up to 80 m are acceptable.
- At 1000 kbit/s, it is possible to have a 10-meter drop line.
- Doubling the bit rate requires the allowable drop line length to be halved.
- The figure represents a conservative, safe total drop line length.
- The drop lines can be longer if they of equal length and evenly distributed along the main bus line.
- Shorter limits apply if drop lines are concentrated in a star configuration.

Following these guidelines will ensure you remain on the safe side and you will have a very nice eye-diagram. It is possible to violate these limits, but each violation will make the eye smaller and increases the risk of bit errors.

With the introduction of CAN FD and CAN XL with a bit rate above 1 Mbit/s, drop line design has suddenly become a critical concern.



At 20 Mbit, the drop line should be less than 0.5 m. With 10 nodes, that would be a 5 cm drop line each. It can be longer if the nodes are evenly spread, or by analyzing and testing the effect of the cable layout. The -T1S communication is due to the 8b/10b coding, which is actually 12.5 Mbit/s, but the analog signal is optimized for this specific frequency. This makes it possible to have longer drop lines compared to CAN XL at 12.5 Mbit/s. It could be possible to make a CAN-driver optimized to one single bit rate, but that will prevent such device from being used at any other bit rate.

7. CAN XL provides inherent real-time control.

ARBITRATION is a simple, built-in and efficient mechanism to secure predictable real-time behaviour!

- The highest priority package has guaranteed latency.
  - By limiting repetition interval on each priority level, all
  - priorities can have guaranteed latency.
- Work the same from 2 to 200 nodes.
- New nodes with lower priority can be added or removed without modification of existing nodes.

Achieving the same predictability with Ethernet requires TSN (Time Sensitive Network), which is a logic that ensures that Ethernet frames are sent in a controlled order without collision, guaranteeing delivery within a certain latency.

However, TSN ethernet switches with six ports are complex and costly. One TSN switch is equivalent to more than 20 CAN XL controllers and typically relies on a micro-controller with 500 kB code. This cost is acceptable for the central computer, with or without AI, to help a driver control the car. For distributed IO-modules, a less sophisticated solution is PLCA ((Multi-drop) Physical Layer Collision Avoidance).

As indicated, 10BASE-T1S is similar to CAN: multiple nodes share a single communication medium. This has clear advantages for synchronized broadcasting communication, as every receiver has the exact same information at the same time. The challenge is that there must be a set of rules to ensure that package transfer is not delayed by collision.

When using a common media, there are two approaches:

1. Orthogonal channels (frequency, code, or physical separation).
    a. Easy to use, but expensive
2. Common channel with base band signaling, and time-division between different users. The division of time can be done in several ways.
    a. Fixed timeslots for different users
    b. Token passing

(Both a and b demand some kind of organizer that controls all members of the media.)

Another approach is to use CSMA (Carrier Sense Multiple Access, of which there are two variants:
CSMA/CA (Collision Avoidance) – Used in classic Ethernet, nodes wait a random time after collisions. This works well at low utilization but becomes unpredictable at high load due to increasing collision rates. This is the fallback solution if the PLCA scheduling breaks down.
CSMA/CR (Collision Resolution) – Used in CAN, arbitration occurs bit by bit. Nodes with lower priority drop out, allowing the highest priority message to continue without data loss. The only requirement is careful CAN ID assignment, which is comparable in complexity to assigning IP addresses.

Ethernet switching and real-time constraints

Modern Ethernet (>10 Mbit/s) typically uses point-to-point full duplex links, eliminating collisions on the physical link. However, this effectively moves collisions to the switch.

When Ethernet frames arrive simultaneously and must exit through the same port, a resource conflict occurs, whereby one frame must be sent before the other frame. In a standard office switch, this is solved with a simple FIFO, where the first frame that arrived gets through first. In a real-time system, it is necessary to control the latency for all critical information. This makes it necessary to add some rules that prevent low priority information from delaying important information. This is solved by placing a TSN logic and configuring this logic so that high priority Ethernet frame reaches the destination member with lowest possible latency.

If you fail to assign CAN-IDs to get a working real-time control system, you will find that configuring TSN is not simpler.

PLCA: Deterministic Ethernet without TSN complexity

TSN is relatively expensive and needs complex configuration tools. To remove TSN complexity and cost, real-time logic can be included in the 10BASE-T1S transceiver. Node-ID "0" acts as the coordinator and sends a beacon. After this beacon, each node has an opportunity to send

Ethernet frames, as determined by the Node ID order. If a node has nothing to send, it passes its opportunity to the next node.
To make the system work, it is necessary to set up the PLCA in every installed node. Optimal performance is achieved when all nodes from Node ID 0 to *N* are present, forming a continuous round robin sequence. Missing nodes are tolerated, but a full sequence is preferred.

Required PLCA configuration (per node)

Following configurations must be done in each 10BASE-T1S transceiver to have a working PLCA

1. Set the unique PLCA Local ID, ID=0 will send beacon.
2. Set the PLCA Node Count, maximum number of nodes.
3. Set the PLCA Transmit opportunity timer register. All units must have the same value.
4. Set the PLCA maximum Burst; this sets the maximum number of frames to be sent.
5. Set the PLCA Burst timer, limiting the time for the Burst.

There are several other registers to control the device, status information, handling events, and to get diagnostic information. If node-ID=0 is lost, the beacon will be lost, and the communication will fall back to classic CSMA/CA

8. CAN XL supports adding or removing modules without real-time interference

Once the real-time system has been tested and all latency requirements have been met, new CAN-package can be added if the priority level (CAN-ID) is lower than any CAN-package with strict latency constraints. It is possible to design the system for future high-priority CAN messages, but this requires those messages to be simulated during all tests to ensure that high-priority traffic continues to function correctly under the additional high priority CAN bus load.

9. CAN XL provides inherent consistency and time-synchronized data distribution

Every CAN-package is broadcasted to all nodes connected to the common CAN bus. A correct CAN-package will ensure that all installed nodes receive the same information at the same instance in time, thus providing natural time alignment across nodes. Ethernet demands time stamping and acknowledgement to achieve this. This time stamping induces a cost in terms of latency and overhead (additional data in the package) and to achieve acknowledgment, it requires a second frame in return which also takes bandwidth and time to return this information to the data producer.

CAN provides a simple solution for free that is good for most control systems. The same function can be achieved with 10BASE-T1S by using broadcast, ensuring that all connected units receive the same Ethernet packet at the same time. If a switch exists between the sender and receivers, synchronization becomes more complex as it is necessary to configure TSN to ensure that sending to all receivers starts in the same instance in time. A simpler solution would be to synchronize the data utilization to a certain time event when you know that all receivers have received the information. This requires that the system has a global common time, which is useful in many other cases, for example, to compensate for latency in the control algorithms.

10.CAN XL enables fast and secure functional safety

CAN was designed to deliver real-time performance and high reliability with minimal logic. The effort required to analyse and verify communication logic grows at least linearly with protocol complexity. As shown in the table below, only very simple interfaces such as SPI, I^2C, UART, and LIN require less logic than CAN.
For UART and LIN, this reduced hardware complexity comes at the cost of real-time software involvement: protocol timing, arbitration, and error handling must be managed in software.

Type of IP	LUTs	BRAM	RAM	Comment
UART	600	1	100	
LIN	700	1	100	
CAN CC	1 800	1	100	
CAN FD	2 300	1	300	
CAN XL	3 500	8	8 000	
CAN CC safe	7 000	1	100	
CAN FD safe	8 300	1.5	500	
CAN XL safe	12 000	13	12 000	
PLCA	1 200		100	+ Ethernet MAC
Ethernet MAC	6 000	9	9 000	
CANsec	9 000			Designed for CAN
MACsec	18 000			Can be used also for CAN
TSN 1 simple	2 000	12	12 000	
TSN switch	40 000	355	355 000	+MCU

11. CAN XL provides inherent detection of alien attacks

1. Every CAN message has a priority level (CAN-ID) that is owned by a single node in the system.
2. All CAN messages are sent by broadcast on the CAN-bus.
3. The owner of a CAN-ID will detect if this CAN-ID is misused by an alien node or alien software in some other legal node. This detection can be reported and used to prevent the effect of this misuse of communication.
4. In real-time systems, CAN messages are sent at a certain time interval.
    - A receiver can easily detect if the time interval is too short or too long.
    - This is always a functional problem, even if this a caused by some internal problem. An attack on signals is a signal quality problem, independent of the source (internal or from an alien).
5. All advertised automotive hacks worked because the system ignores this inherent protection in the CAN protocol as described above.