The Role of Ethernet in Modern Vehicles: Advancing Connectivity and High-Bandwidth Networking

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ABSTRACT

The rapid evolution of the automotive industry has been driven by the increasing complexity of modern vehicles, which now rely heavily on electronic systems for critical and safety functionalities required by legislation. These systems, ranging from basic control units to Advanced Driver Assistance Systems (ADAS), demand reliable, efficient, and high-bandwidth communication networks to operate seamlessly. In this context, in-vehicle networking protocols have become the backbone of modern automotive electronics. This paper analyzes Ethernet's role in automotive communication networks, focusing on its concept, applications, advantages, disadvantages, and how it compares with common protocols such as CAN and LIN. The shift toward data-intensive infotainment systems, Over-The-Air (OTA) updates, and ADAS drives Ethernet adoption, although challenges persist in cost, wiring harness complexity, electromagnetic compatibility, cybersecurity, and integrating current protocol with newer Ethernet frameworks. Ultimately, a hybrid approach that uses conventional protocols for latency-sensitive tasks and Ethernet for data-intensive operations emerges as a balanced solution, guiding automotive technology toward higher levels of automation, connectivity, and customer-focused functionality.

INTRODUCTION

In the past, vehicles were primarily mechanical systems designed to transport drivers, passengers, and cargo reliably from point A to point B. Over recent decades, however, the automotive industry has experienced significant transformations driven by stricter regulatory requirements and evolving consumer demands focused on emission reduction, enhanced road safety, and improved comfort and connectivity. To meet these new demands, electrical and electronic (E/E) systems have been extensively integrated into vehicle architectures enabling new embedded functionalities within vehicles, transitioning from simple mechanical systems into sophisticated, electronically controlled platforms.

The increasing demand for connectivity, performance, and safety has led to a substantial rise in the number of Electronic Control Units (ECUs) used in vehicles [1], with premium vehicles currently containing up to 70 ECUs [2]. These ECUs are interconnected via In-Vehicle Networks (IVN), which enable the exchange of data required for the proper functioning of these E/E systems. IVNs need to be standardized across the vehicle, guaranteeing data integrity and interoperability among diverse vehicle subsystems [3], providing seamless communication by physically routing signals through wiring harnesses interconnecting sensors, actuators, and ECUs, and by logically managing these signals according to standardized protocols, such as the Controller Area Network (CAN), that define how data is structured, transmitted, and interpreted across ECUs [3, 4, 5].

Introduced in the mid-1980s, the Controller Area Network (CAN) protocol has become the predominant automotive communication standard due to its low cost, and robust performance in critical vehicle applications such as engine management, braking systems, and powertrain control [5]. Nevertheless, the rising demand for high-bandwidth data exchange, driven by innovations like infotainment systems, Advanced Driver Assistance Systems (ADAS), and Over-The-Air (OTA) software updates, has increasingly exposed the bandwidth limitations of traditional protocols. For instance, CAN is limited to 1 Mbps, and even enhanced versions such as CAN Flexible Data-rate (CAN FD) at 5 Mbps [5] and CAN XL at 20 Mbps [5] can become bottlenecks when supporting advanced vehicle features that demand higher data rates. As an illustration, an ADAS configuration involving four HD-resolution cameras operating at 30 frames per second with H.264 encoding requires a bandwidth of at least 12 Mbps [1], which can easily surpass more than 20 Mbps by employing higher resolution, more cameras and sensors, and uncompressed raw data.

Alternative protocols such as the Media Oriented Systems Transport (MOST), capable of handling data rates up to 150 Mbps [6] have emerged to address these needs. However, MOST is primarily specialized for multimedia applications and lacks the scalability and flexibility required for broader vehicle network integration. Similarly, FlexRay [7], offering up to 10 Mbps, still falls short in meeting the higher data-rate requirements of modern automotive applications.

Addressing these bandwidth limitations, the Ethernet protocol—traditionally associated with Information Technology (IT) and industrial applications—was introduced into automotive environments as a high-performance and versatile alternative for IVNs [8, 9]. According to Hank et al. [8], the automotive industry's integration of Ethernet can be classified into three distinct generations: (I) in the early 2010s, Ethernet was primarily utilized for diagnostics and ECU flashing; (II) in 2013, Ethernet-connected cameras first appeared in vehicles; and (III) beginning in 2015, initial implementations explored Ethernet as the primary communication backbone interconnecting all vehicle ECUs. Automotive Ethernet adoption has rapidly accelerated due to its ability to overcome bandwidth constraints inherent in conventional automotive protocols, reaching up to 1000 Mbps [10]. Another advantage of Ethernet is its widespread use beyond the automotive sector, which provides access to a broad knowledge base, enhancing the ecosystem for testing, maintenance, and development [2].

Although automotive Ethernet is not entirely new, having been gradually introduced into passenger vehicles, there remains a scarcity of consolidated technical literature and analyses on its implementation. Despite Ethernet's growing application within advanced electronic architectures, discussions about its concept, applications, advantages, disadvantages, and how it compares with common protocols such as CAN, highlight a gap in the existing body of knowledge that this paper aims to address.

The paper is structured as follows: initially, the Ethernet protocol is introduced, outlining its key principles and operational characteristics within automotive environments. A comparative analysis then follows, examining Ethernet against widely established automotive communication protocols such as CAN, LIN, FlexRay, and MOST. Subsequently, some prominent applications of Ethernet in vehicles are presented. Finally, the paper discusses Ethernet's advantages and disadvantages, concluding with insights into potential future developments in the automotive sector.

ETHERNET CONCEPT

The IEEE 802.3 standard, first published in 1985, defines the specifications for all Ethernet applications [10]. Since its inception, it has been continuously updated and maintained by IEEE working groups. Ethernet was originally developed to enable communication between interconnected devices within a Local Area Network (LAN), transmitting data over physical cables.

Ethernet's successful history throughout the years is largely attributed to the concept of *packet switching*, a method that divides data into smaller, self-contained units known as *packets* before network transmission. Each packet includes a header containing control information, such as the source and destination addresses, along with the actual data payload. These packets can traverse different routes through the network, guided by infrastructure devices like switches and routers, ultimately reaching their designated destination. This routing flexibility enhances bandwidth efficiency and allows multiple devices to share communication resources effectively. It is important to note that Ethernet operates on a point-to-point topology, meaning each device must be connected either directly to another device or through a switch or router to function correctly.

Upon arrival at the designated receiving device, the packets are collected and reassembled based on sequence information embedded within their headers. This reconstruction process ensures that the original data is accurately structured, even if the packets arrive in a different order than they were transmitted. If a packet is lost or corrupted during its transmission, only the affected packet needs to be retransmitted, rather than the entire original message, thus improving the efficiency of error recovery.

Among the Ethernet variants specified in IEEE 802.3, automotive Ethernet includes its own standards, such as 100BASE-T1 (IEEE 802.3bw) and 1000BASE-T1 (IEEE 802.3bp) [10], specified in Table 1. The 100BASE-T1 supports data rates of 100 Mbps over a single Unshielded Twisted Pair (UTP) cable and operates in full-duplex mode, allowing simultaneous bi-directional communication. It employs Pulse Amplitude Modulation (PAM) with three voltage levels (PAM-3). Similarly, 1000BASE-T1 supports 1000 Mbps over a single UTP, uses PAM-3 encoding, and also operates in full-duplex. In both standards, the maximum cable length is limited to 15 meters to avoid excessive signal degradation and packet loss.

Table 1. Automotive Ethernet protocols and its characteristics.

Ethernet Protocol	Bandwidth	Wiring	Range	Standard
10BASE-T1S	10 Mbps	Single UTP	Up to 25m	IEEE 802.3cg
100BASE-T1	100 Mbps	Single UTP	Up to 15m	IEEE 802.3bw
1000BASE-T1	1 Gbps	Single UTP	Up to 15m	IEEE 802.3bp
2.5/5/10GBASE-T1	2.5 - 10 Gbps	Multiple UTPs	15 – 40m	IEEE 802.3ch

To bridge the gap between bandwidth of other protocols and Ethernet, the 10BASE-T1S (IEEE 802.3cg) [10] was introduced. 10BASE-T1S can achieve 10 Mbps over UTP, but unlike other Ethernet standards this one can operate without a switch. However, this introduces some limitations, when operating in this mode 10BASE-T1S becomes only half-duplex meaning that a device can transmit or receive, but not both at the same time. It uses Differential Manchester Encoding (DME), and the maximum cable length is 25m.

Ethernet with more than 1000 Mbps are also being developed under the IEEE 802.3ch [10], reaching up to 10 Gbps, however they are not mainly used like the 100BASE-T1 and 1000BASE-T1.

The main distinction between automotive Ethernet and traditional IT Ethernet lies in the automotive domain's need for determinism, security, and reliable communication across various vehicle systems. To address these requirements, Time Sensitive Networking (TSN), as defined in the IEEE 802.1 [11] standard family, extends the conventional Ethernet to support safety-critical and real-time automotive functions. TSN incorporates several key features, some of them are outlined in the next subsections.

IEEE 802.1AS – The Time Synchronization Protocol defines a precise time synchronization protocol essential for enabling coordinated operations across a distributed automotive Ethernet network. In a vehicle, dozens of ECUs must often operate on a common time base, especially for time-critical functions such as sensor fusion, brake coordination, or steer-by-wire. IEEE 802.1AS ensures that all devices share a synchronized global clock with sub-microsecond accuracy.

IEEE 802.1Qbv – The Time-Aware Traffic Scheduling standard introduces a time-aware mechanism that controls when different classes of traffic are allowed to transmit, based on a pre-configured schedule. It provides determinism over Ethernet, ensuring that critical messages are delivered at predictable intervals, without interference from lower-priority data streams.

IEEE 802.1Qbu – Frame Preemption enhances Ethernet responsiveness by allowing high-priority frames to interrupt and preempt lower-priority transmissions. This minimizes worst-case latency, especially when large, non-critical packets are already in transmission. Without this feature, a safety-critical message (e.g., an emergency stop signal) might have to wait for a full-size video frame or firmware update packet to finish, potentially introducing fatal delays. With frame preemption, the network pauses the current transmission, sends the urgent message, and then resumes the interrupted frame.

IEEE 802.1CB – The Seamless Redundancy of Data Streams provides stream replication and elimination, enhancing fault tolerance by sending multiple identical copies of critical data across disjoint network paths. The receiving node selects the first complete and error-free copy, discarding the others. This mechanism is especially valuable in fail-operational systems, such as in automated driving or steer-by-wire, where the loss of a single frame could lead to failure.

IEEE 802.1Qci – Per-Stream Policing and Filtering enables granular control over individual data streams, allowing a network switch to monitor, filter, and block misbehaving traffic. This includes mechanisms for rate limiting, error containment, and denial-of-service (DoS) mitigation. In an automotive context, this is crucial for isolating faults and preventing error propagation. For instance, if a malfunctioning camera ECU begins flooding the network with malformed packets, 802.1Qci allows an Ethernet switch to block that stream or even isolate the port entirely preventing system-wide degradation. This is especially relevant in architectures where critical and non-critical traffic coexist, and network integrity must be preserved dynamically.

In addition to the TSN mechanisms the Ethernet protocol itself incorporates several mature and standardized IT-grade cybersecurity protections. These have become increasingly important as vehicles grow more connected through telematics, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, and smartphone integration [12, 13]. Key mechanisms are stated below.

IEEE 802.1X – Provides port-based access control to ensure that only authenticated and authorized devices can join the network. By requiring credentials or certificates before permitting communication, IEEE 802.1X prevents unauthorized ECUs or compromised nodes from accessing in-vehicle systems.

MACSec – Defined in IEEE 802.1AE, Media Access Control Security ensures the confidentiality, integrity, and authenticity of Ethernet frames exchanged between trusted nodes. It encrypts data to protect in-vehicle communication against tampering and injection of falsified data.

IPSec – Internet Protocol Security protects data in transit, particularly when it crosses external networks such as the internet or wireless links. In vehicles, IPsec is commonly employed for remote diagnostics, OTA updates, and communication with cloud services. It ensures that transmitted data remains confidential and unaltered.

Firewalls – Act as gatekeepers, filtering network traffic based on predefined rules. Firewalls help contain faults, prevent cyberattacks, and reduce the risk of interference between different vehicle domains.

Intrusion detection systems (IDS) – Monitor network traffic to detect anomalies or potential malicious behavior. By identifying deviations from normal traffic patterns, such as unexpected messages or data bursts. IDS can flag possible cyberattacks or malfunctions.

COMPARISSON BETWEEN PROTOCOLS

In this section, we provide a comparison of common automotive communication protocols, highlighting their key characteristics summarized in Table 2. Each protocol serves specific purposes within an IVN, where multiple protocols operate together to meet application demands. For instance, while LIN is used for body controls such as comfort and convenience features, CAN is employed in more critical systems like powertrain control and brake applications. The choice of protocol depends on factors such as bandwidth requirements, cost constraints, real-time performance, and robustness.

Despite being introduced in 1986, CAN remains widely used by automotive manufacturers. It is cost-effective, requiring only UTP cabling, and its differential signaling enhances noise immunity against Electromagnetic Interference (EMI). CAN also offers robust error-handling mechanisms, including cyclic redundancy checks, acknowledgement bits, and automatic retransmission [5]. Although CAN is not deterministic, meaning it cannot guarantee precise message timing, it uses message prioritization to ensure that the most critical data is transmitted and read first. At 1 Mbps, CAN is often sufficient for applications with low data requirements and can deliver near real-time performance. However, as the demand for data exchange increased, its bandwidth limitations became evident. This led to the introduction of CAN FD in 2012 and CAN XL in 2024, both of which preserve protocol compatibility while offering higher bandwidth.

In contrast, LIN has not evolved beyond 20 kbps [14] due to physical limitations of its single-wire transmission and poor EMI resistance. Nevertheless, it remains widely adopted in non-critical applications due to its extremely low cost and ease of implementation.

Before CAN FD and CAN XL addressed bandwidth limitations, other protocols emerged to support data-intensive systems like ADAS and infotainment. One such protocol is MOST [6], designed to transport audio and video signals with low latency via UTP (MOST50 and MOST150) or Polymer Optical Fiber (POF) (MOST25 and MOST150). As an infotainment protocol, MOST lacks robust error-handling mechanisms, making it unsuitable for safety-critical functions. However, when using POF, the signal becomes immune to EMI, as light transmission is unaffected by electromagnetic interference.

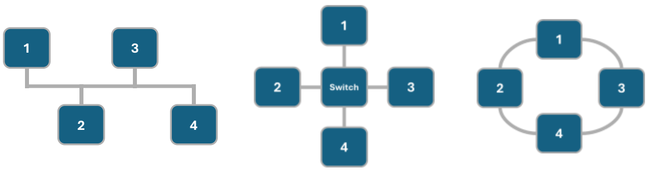
FlexRay [7] was introduced to overcome some of CAN's limitations. It supports up to 10 Mbps bandwidth and includes dual-channel communication for redundancy, enabling continued operation at reduced bandwidth if one channel fails, effectively reaching 20 Mbps. FlexRay also introduces time determinism, ensuring precise message delivery timing, which is essential for *x-by-wire* systems (e.g., drive-by-wire, brake-by-wire). However, FlexRay is more costly due to the need for advanced ECUs, clock synchronization, and dual-channel hardware. Until 2009, it also required royalty payments to the FlexRay consortium, limiting its adoption mostly to luxury vehicles from member companies [3].

More recently, Ethernet has rapidly gained ground over MOST and FlexRay, addressing the bandwidth limitations previously covered by these protocols [1, 3, 8, 9]. Automotive Ethernet standards like 10BASE-T1S, 100BASE-T1, and 1000BASE-T1 provide 10 Mbps, 100 Mbps, and 1000 Mbps over a single UTP cable, respectively. Although implementation costs remain high due to the need for switches and automotive-grade ethernet connectors, Ethernet benefits from the maturity of the IEEE 802.3 standard [10] and its extension through IEEE 802.1, which includes the TSN aspects [11]. TSN enhances Ethernet robustness with features such as time synchronization (IEEE 802.1AS), frame preemption (IEEE 802.1Qbu), and redundancy (IEEE 802.1CB), making it suitable for safety-critical and high-bandwidth automotive applications.

Scalability and network topology are also key factors when evaluating communication protocols. CAN, LIN, and some FlexRay applications use a bus topology (Figure 1a), where all nodes share a single communication line, and messages are broadcast to all devices. While simple, this configuration is vulnerable, any break in the line results in complete communication failure. It is important to note that 10BASE-T1S can operate in this kind of topology, bridging the gap between Ethernet and other low bandwidth protocols.

MOST uses a ring topology (Figure 1b), where devices are connected in a closed loop, allowing data to flow continuously. However, a single node failure can disrupt communication to downstream devices in the loop.

The star topology (Figure 1c), used in Ethernet and in some implementations of FlexRay and MOST, connects all nodes to a central switch. This configuration isolates faults and prevents one system's failure from affecting others. It also supports scalability by allowing interconnection of multiple switches. But MOST and FlexRay have limited capabilities regarding its scalability over star and other topologies, as seen in Table 1. This kind of star topology requires efficient data routing and sufficient bandwidth between switches, a task that Ethernet handles particularly well with packet switching.



(a) Bus topology. **(b) Star topology.** **(c) Ring topology.**

Figure 1. Topology options used by automotive protocols.

ETHERNET APPLICATIONS

Ethernet has emerged as a viable solution to support features with high data exchange requirements especially when compared to communication protocols such as CAN, CAN-FD, LIN, and FlexRay. As technology developed, the amount of data transferred from one ECU to another has steadily increased, driven by the evolution of components like sensors, radars and cameras. In this scenario the communication network has become the bottleneck to applying new technologies that are data-intensive due to the bandwidth required.

Table 2. Comparison of Automotive Protocols.

Characteristic	**CAN [5]**	**LIN [14]**	**FlexRay [7]**	**MOST [6]**	**Ethernet [10]**
Bandwidth	CAN: 1 Mbps CAN FD: 5 Mbps CAN XL: 20 Mbps	20 kbps	10 Mbps single channel 20 Mbps dual channel	MOST25: 25 Mbps MOST50: 50 Mbps MOST150: 150 Mbps	100BASE-T1:100 Mbps 1000BASE-T1:1000 Mbps 10BASE-T1S: 10 Mbps
Year of introduction	1986	1999	2004	1998	2008
Standardization	ISO 11898	ISO 17987	ISO 17458	ISO 21806	IEEE 802.3
Cabling	UTP	Single wire	UTP	POF or UTP	UTP
Topology	Bus	Bus	Bus and Star (hybrid)	Ring or Star	Star and Bus with 10BASE-T1S
Used for safety and critical applications	Yes	No	Yes	No	Yes
Cost	Low	Very Low	High	High	High
Robustness (EMI immunity, error tolerance, determinism)	High	Low	Very High	Medium	High
Use cases	Powertrain (Engine, Transmission) ABS)	Body Electronics (Power Seats, Accessories, Switches)	Safety (Drive-by-wire, active suspension, adaptive cruise control)	Infotainment (audio and video)	Infotainment, ADAS, OTA, Diagnostics, Backbones
Scalability	Moderate (Typically 30 – 50 nodes)	Limited (up to 16 nodes)	Moderate (up to 64 nodes)	Moderate (up to 64 nodes)	High (scalable via switches)

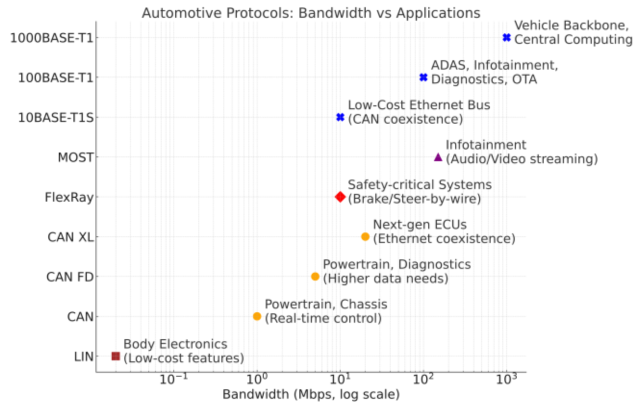


Figure 2. Common automotive protocols applications and its bandwidths.

Figure 2 illustrates common applications of each protocol and its bandwidth. Among the embedded systems that are particularly data-intensive and therefore benefit from Ethernet implementation are:

INFOTAINMENT SYSTEMS – modern vehicles have evolved from mere means of transportation into fully connected entertainment hubs. Features such as high-definition video, navigation systems, hands-free calling, and internet access require fast and stable data transmission to ensure seamless user experience [15]. It is relevant to say that system responsiveness is essential for users' perceived quality of the product. For instance, simply streaming video content from a storage device to the head unit can demand between 5–25 Mbps, which may exceed or saturate the bandwidth provided by traditional protocols (e.g., CAN, CAN-FD) becoming an issue for the user experience. In this scenario, Ethernet becomes essential to enable these functionalities efficiently.

Another relevant point in the context of infotainment systems is the growing replacement of MOST protocol by Ethernet networks. This shift is primarily driven by two key factors: (I) MOST is a proprietary technology developed by a consortium of automotive manufacturers, which limits its scalability and widespread adoption; (II) its ring topology makes the network vulnerable to single-point failures, if one node fails, the entire network goes down, representing a significant disadvantage.

ADAS – Advanced Driver Assistance Systems are designed to enhance safety, improve the driving experience, and pave the way toward vehicle automation. These systems are data-intensive and heavily rely on the fast and reliable communication between sensors, cameras, radars, and their corresponding ECU.

Features such as lane departure warning, traffic sign recognition, and collision avoidance require the analysis of data captured by cameras, sensors and radars, which must be collected, transmitted, and processed in real time, leading to a high volume of data exchange that can exceed 1 Gbps [1]. An Ethernet network is essential for ADAS implementation as it provides the necessary bandwidth to meet these demands, overcoming the limitations of traditional networks like CAN and FlexRay, which have become bottlenecks for such applications.

OVER-THE-AIR SYSTEM – The implementation of OTA system, referring to the remote update of vehicle software, parameters, and firmware, is becoming increasingly common and critical in the automotive industry. Ethernet plays a key role in enabling these updates to be carried out efficiently, securely, and at scale.

Vehicle software can be remotely updated via network connections typically through the internet, 4G/5G, or Wi-Fi, eliminating the need for physical visits to service bodyshops. These updates aim to fix software bugs, update navigation data, refresh embedded systems or introduce new functionalities.

OTA processes often involve the transfer of large data packages, particularly when multiple ECUs are updated simultaneously. Once the data reaches the vehicle, it must be distributed internally to the relevant ECUs. At this point, Ethernet becomes crucial, as it allows faster and more efficient data distribution, significantly reducing update times.

Another critical aspect is cybersecurity. Since OTA updates involve modifying core software, secure communication protocols are essential to prevent unauthorized access and to maintain system integrity. Ethernet supports robust security measures, thereby enhancing cybersecurity for OTA operations.

DIAGNOSTICS – The higher bandwidth enabled by Ethernet is also beneficial for On-Board Diagnostics (OBD). The number of embedded systems in modern vehicles has increased rapidly due to ongoing advancements in electronic features [2].

OBD serves multiple purposes, such as component diagnostics, emission monitoring, and vehicle maintenance services, including downloading and updating various embedded software components. The time required to reprogram an ECU (commonly referred to as flashing) has become a significant cost factor in both vehicle manufacturing and repair processes. For this reason, fast diagnostics and short update cycles are strongly recommended to increase operational efficiency and reduce costs.

As a practical example, BMW has been using Ethernet to flash software ECUs since 2008 [16]. To illustrate the importance of fast flashing, BMW reported that back in 2004 uploading 1 GB via CAN would have taken around 16 hours, whereas making the same upload via Ethernet in the 5th Generation BMW Series 7 took less than 1 hour [13]. Thus, adopting Ethernet for diagnostic-related activities offers significant productivity gains and cost-saving potential.

BACKBONE – A backbone refers to the primary data highway within a vehicle, responsible for transporting high-bandwidth, latency-sensitive communication between the various electronic zones and a high performance centralized computing unit. As vehicles become more complex and feature-rich, the traditional domain-based architecture, where systems are grouped by functions or domains (Figure 3), is giving way to the more flexible zonal architecture [1]. In zonal architecture, ECUs are organized based on physical location (Figure 4), and each zone aggregates local signals and communicates them to the vehicle's central computing, and between zones, through a high-speed Ethernet backbone.

This shift brings about two core challenges: the need for deterministic, real-time communication and the ability to handle large volumes of data coming from all zones. Automotive Ethernet, especially the 1000BASE-T1, directly addresses both requirements. Also, Ethernet backbones enable modular development and scaling. New zones or components can be added to the network without rearchitecting the entire wiring harness.

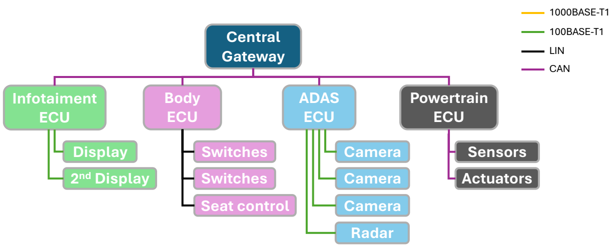


Figure 3. Example of domain E/E architecture.

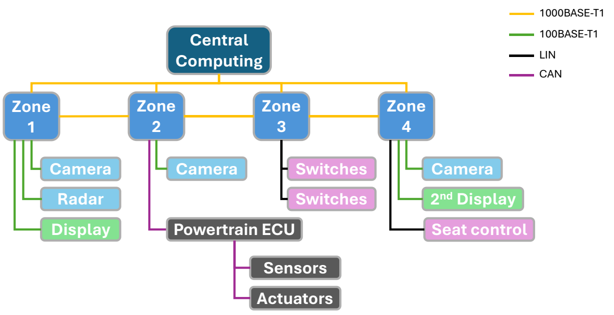


Figure 4. Example of zonal E/E architecture.

MEGAWATT CHARGER – Developed to meet the evolving demands of heavy-duty electric vehicles, the Megawatt Charging System (MCS) is adopting 10BASE-T1S as its standard communication layer [17,18]. This standard supports power line communication, enabling data transmission over the same electrical cables used for power distribution, a method already established in transmission lines and energy distribution centers. Using Ethernet not only introduces robust cybersecurity mechanisms but also facilitates faster integration with the electrical grid, allowing for advanced applications such as bidirectional charging and automated billing. Additionally, 10BASE-T1S enables real-time coordination between the vehicle and charger, supporting functions such as charging negotiation, safety checks, power delivery regulation, and system diagnostics.

DISCUSSION

The analysis presented in this paper highlights a paradigm shift in the automotive networking. Traditional protocols such as CAN, LIN, FlexRay, and MOST, though foundational to earlier E/E architectures, are increasingly insufficient to support the demands of modern, data-intensive applications. Emerging functionalities such as ADAS, infotainment streaming, multiple systems diagnostics, OTA updates, and zonal architectures are pushing these protocols beyond their intended performance capabilities.

Automotive Ethernet, particularly through its 100BASE-T1 and 1000BASE-T1 standards, has demonstrated the ability to bridge the bandwidth gap of previous automotive protocols without compromising latency or safety. Higher bandwidth enables scalability, allowing more components to be integrated into the architecture without necessitating a network redesign due to bandwidth limitations.

In conjunction with the TSN standards and cybersecurity measures, Ethernet offers several mechanisms that enhance safety and reliability during data transmission. This family of standards is continuously updated and revised, ensuring that Ethernet remains compliant with the most stringent requirements of automotive industry. The continuous evolution of Ethernet and TSN driven by their widespread use not only in the automotive sector but also in IT, industrial applications, and telecommunication, highlights Ethernet's maturity, interoperability, and ability to keep pace with advances in technology and cybersecurity demands. This contrasts with protocols developed for automotive applications, which often evolve more slowly, for instance, CAN FD was introduced 26 years after the original CAN protocol.

The integration of Ethernet into modern E/E architectures also paves the way for V2V, V2I, and broader vehicle-to-everything (V2X) applications. Leveraging a well-established protocol widely used in several environments, ranging from smartphones to power grids, Ethernet's standardized nature across multiple domains facilitates interoperability with external systems. Consequently, vehicles increasingly function as connected devices capable of interfacing with any system utilizing the Ethernet protocol, thereby simplifying the development and deployment of V2X and automation technologies.

Furthermore, Ethernet serves as a key enabler of zonal architecture and the transition toward software-defined vehicles. Its scalability, high bandwidth, and ability to manage heterogeneous traffic types, ranging from sensor data and actuator commands to infotainment and OTA updates, allow for the consolidation of multiple signals into a unified backbone. This shift toward zonal architecture presents a promising approach to reducing wiring harness complexity and cost, as it simplifies system interconnection by allowing sensors, actuators, and ECUs to connect to zonal gateways, which are then unified through an Ethernet backbone, rather than requiring direct connections between them, thus using less wires to route the data across the vehicle. Additionally, it allows modularity and scalability, enabling manufacturers to develop a single architecture capable of easily integrating customer-focused functionalities.

However, 1000 Mbps or even 100 Mbps may be excessive for certain applications, leading to the development of 10BASE-T1S. This standard allows Ethernet to cover a broader range of bandwidth requirements while maintaining consistent transmission methods, eliminating the need for protocol translation and enabling a fully connected, homogeneous Ethernet-based IVN. At the same time, CAN XL is also designed to address the bandwidth range targeted by 10BASE-T1S. Building on CAN's mature and widely adopted protocol, CAN XL ensures compatibility with sensors and systems that continue to rely on CAN, allowing them to operate within modern architectures.

As previously discussed, Ethernet enables zonal architecture, and 10BASE-T1S plays a critical role in connecting low-bandwidth components, especially given its support for bus topology. Nonetheless, the adoption of Ethernet in some components remains limited, primarily due to the high development costs associated with replacing systems that have relied on CAN for over three decades. Consequently, certain components are expected to continue using CAN, with CAN XL or other CAN variants remaining the preferred protocol in these scenarios. Additionally, CAN XL is being developed to have Ethernet frames compatibility, further bridging the gap between both CAN and Ethernet.

Even though Ethernet incorporates several robust mechanisms for data transmission, such as TSN, electromagnetic compatibility remains a challenge when transmitting data over electrical cables, and Ethernet is no exception. Proper cable shielding, cable routing, and switches positioning are still essential, particularly when transmitting safety-critical data from systems like ADAS.

From a cost perspective, the implementation of Ethernet networks in the automotive environment presents an increase in cost price compared to traditional communication networks such as CAN, LIN, among others. Although the adoption of Ethernet introduces factors that can potentially reduce costs—mainly due to economies of scale in hardware and software driven by its widespread use outside the automotive sector—under current conditions, the cost-increasing factors still outweigh the savings. The main contributors to this cost increase are the wiring harness and the switch used in Ethernet networks.

Regarding the wiring harness, even though Ethernet requires fewer wires and connectors, its overall cost tends to be higher. This is primarily due to manufacturing complexities and the limited availability of specialized suppliers. The reduced wire cross-section of Ethernet cables necessitates more precise and fully automated crimping processes. While this automation ensures high dimensional accuracy, it also requires significant tooling investment, as it relies on specialized, application-specific equipment designed for automotive Ethernet. Additionally, the limited number of suppliers producing these cables contributes further to the increased costs.

The switch, the second factor contributing to increased costs, is necessary to connect more than two Ethernet nodes, since the protocol is inherently point-to-point. It is also required to integrate the Ethernet network with traditional communication systems such as CAN and LIN. This component represents a significant cost increase, as it involves robust hardware, high processing capacity, and embedded software designed to route Ethernet protocol messages within the vehicle.

Most Ethernet cables implemented in vehicles are of the UTP type. These are commonly integrated within the main wiring harness, benefiting from added protection through supplemental insulation. However, this integration also introduces challenges in terms of reparability. Repairability represents a notable limitation, especially in commercial vehicles. The small Ethernet conductor size hinders the execution of reliable splices, complicating rapid or provisional repairs. Moreover, terminating these cables with crimped connectors is particularly demanding, as automotive Ethernet systems require precise tooling and application-specific connectors to preserve signal integrity and long-term performance.

Within the automotive sector, the implementation of Ethernet initially took place in passenger vehicles and has more recently expanded to commercial vehicles. In the context of commercial vehicles, the application conditions differ significantly from those in passenger vehicles, primarily because portions of the wiring harness are exposed to external elements such as water, dust, and sunlight. This exposure raises concerns regarding the durability of Ethernet harnesses.

CONCLUSION

In this paper, we presented a review of automotive Ethernet, its key applications, and discussed its advantages and disadvantages compared to other protocols. Rather than representing a radical disruption, Ethernet marks a natural evolution and strategic complement to existing networks. Its growing adoption is driven by the increasing demand for high-bandwidth communication to support advanced features such as ADAS, infotainment, and OTA updates. In addition to bandwidth, Ethernet offers improved cybersecurity, scalability, interoperability, and the ability to unify heterogeneous traffic within a single backbone.

Despite these strengths, challenges remain particularly in terms of cost, implementation complexity, and reparability. In the short term, a hybrid architecture remains the most practical solution using Ethernet for data intensive operations while other protocols manage lower bandwidth communications. Nevertheless, the emergence of zonal architectures, software-defined vehicles, and V2X applications suggests a future in which fully homogeneous Ethernet-based networks are not only feasible but also architecturally advantageous in terms of modularity, maintainability, and scalability. In this context, traditional protocols like CAN are unlikely to disappear but will instead be strategically deployed in scenarios where their cost-efficiency and bandwidth limitations are acceptable.

In next-generation E/E architecture, both 10BASE-T1S and CAN XL are expected to play important roles in medium-bandwidth applications. While 10BASE-T1S enables a full Ethernet network at higher price, CAN XL maintains CAN well-know reliability with higher data rates. The choice between the two remains under discussion, as each offers distinct advantages depending on the specific use case.

Ultimately, the growing demand for connectivity and high-bandwidth applications positions Ethernet as a central enabler of next-generation vehicle E/E architectures. However, the cost of integration along with concerns about reparability and durability, particularly in commercial vehicles where price sensitivity is high and operating conditions differ from those of passenger vehicles, continue to pose challenges for Ethernet widespread adoption, thus use LIN if you can, CAN if you must, and Ethernet when you need to.

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