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A Survey of Automotive Communication Protocols and System-Level Design Considerations

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Abstract
Automotives has seen the growth in the usage of the Electronic Control Unit (ECU) over the decades spanning from Engine Control Unit to regulate the Fuel Injection to the recent applications of using Automotive Driver Assistance System (ADAS) Control Unit that provides the safety features such as Emergency Braking, Blind Spot monitoring etc. With the increased number of ECU's there's been development of features that have interdependency among ECU and thereby raising the need to adopt network protocols. Original Equipment Manufacturer (OEM) develop their Network Architectures that would be using protocols such as Controller Area Network (CAN), Local Interconnect Network (LIN), FlexRay, Media Oriented Systems Transport (MOST), and Automotive Ethernet. In this review paper a historical perspective of network protocol development is provided, along with an analysis of current trends and potential future advancements. Additionally, the applications of CAN, LIN, FlexRay, MOST, and Ethernet in automotive controllers are discussed along with reasoning for their specific usage with each protocol trade-offs, principle factors that would be influencing the choice of design and structured checklist that would be a guide for automotive network architecture decisions

Keywords**: ADAS, CAN, LIN, MOST, OEM, ECU**

I. INTRODUCTION

Network protocol has been the cornerstone of the technological advancements of various industries such as Information Technology, Computing and most importantly telecommunications. Prior to the adoption to the automotive industry, network protocol evolved to address the growing need for efficient, reliable, and scalable communication between devices.

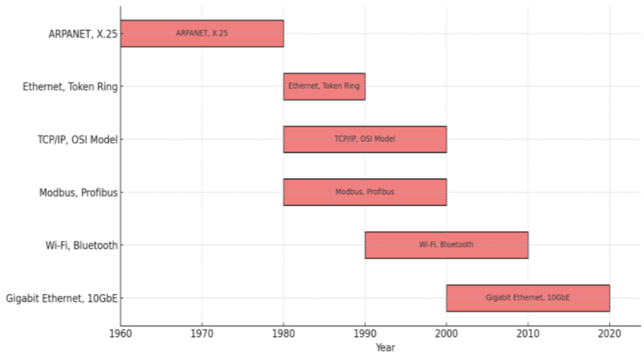

Figure 1: Evolution of General Networking Protocol

The automotive industry is undergoing a shift toward software-defined automobiles, ADAS, and autonomous driving. This shift requires reliable, deterministic, and secure communication among a growing number of ECUs. Modern automobiles contain more than 100 ECUs, connected by kilometers of wiring harness which significantly impacts cost and performance.

To satisfy different requirements—ranging from low-cost body electronics to high-speed data transfer for ADAS OEM's employ a number of different communication protocols. Each of these make a different tradeoff between speed, ruggedness, and cost which is resulting in a layered, domain-specific architecture.

This paper provides a survey of automotive network protocols and discusses the parameters that are paramount to in-vehicle communication systems' design.

II. OVERVIEW OF AUTOMOTIVE COMMUNICATION PROTOCOLS

A. Local Interconnect Network (LIN):
LIN is a low-cost UART (Universal Asynchronous Receiver Transmitter) based single wire bus that has a maximum baud rate of 20 kbps. It was developed with a master-slave architecture that enables fault tolerance with fault detection and deterministic timing. LIN is primarily used for body electronics such as window lifts, mirrors, and switches on the vehicle cluster.

B. Controller Area Network (CAN and CAN FD):
CAN is a multi-master differential bus standard based on messages defined in ISO 11898. Classical CAN defines unshielded bus communication with baud rates of upto 1 Mbps with an 8-byte payload size and CAN FD defines communication with data using a payload size of up to 64 bytes and baud rates of upto 8 Mbps. CAN and CAN FD define message formats that allow for arbitration, fault tolerance, and robustness for various communication levels and protocols, therefore CAN and CAN FD based networks are commonly used to adopt powertrain, chassis, and safety-critical use cases and are widely utilized in automotive communications today.

C. FlexRay:
FlexRay provides deterministic fault-tolerant communications using two-channel redundancy. FlexRay operates at baud rate of 10 Mbps with both static time-triggered slots and dynamic event-triggered

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segments. FlexRay was initially designed for shift -by-wire systems and advanced driver assistance system applications; however with benefits and wide establishment of CAN FD and Ethernet, FlexRay didn't gain its utilization

D. Automotive Ethernet:
There is currently an emerging movement toward the use of Automotive Ethernet using IEEE 802.3 standards and single pair cables (100BASE-T1, 1000BASE-T1, 10GBASE-T1) for data speeds ranging from 100 Mbps to 10 Gbps along with Time-Sensitive Networking (TSN) to support deterministic communication. Automotive Ethernet is being adopted as the future asymmetric, backbone, and communications for advanced driver-assistance system (ADAS), infotainment, and over-the-air (OTA) updates for connected and autonomous systems.

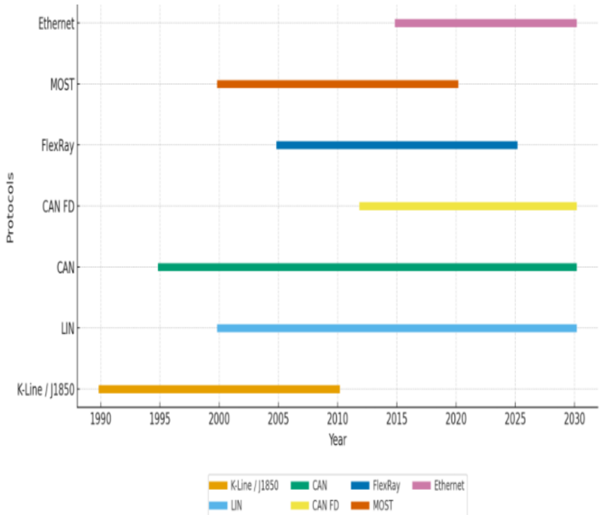

Figure 2 : Evolution of Automotive Communication Protocols

E. Media Oriented Systems Transport (MOST):
The standard, MOST, offers bandwidths of 25 to 150 Mbps on optical or electrical buses/rings. It was widely used in infotainment for streaming multimedia.

F. Legacy Protocols:
K-Line (ISO 9141), ISO 14230 (KWP2000), and SAE J1850 were the standards that controlled diagnostics and low-speed protocols before CAN was mandated. All of the standards are nearly obsolete but still have potential applications for legacy car repairs.

III. OSI MODEL CONTEXT FOR AUTOMOTIVE COMMUNICATION PROTOCOLS

The automotive protocols (LIN, CAN, FlexRay, MOST, Ethernet) can be mapped conceptually to the OSI 7-layer model, even though in practice many of them combine functions across layers

OSI Layer	Role in Automotive Networks	Protocol Examples
Physical (Layer 1)	Defines signaling, wiring, voltage, connectors	LIN (single-wire), CAN (differential pair), FlexRay (dual pair), MOST (optical/electrical), Ethernet (twisted pair)
Data Link (Layer 2)	Media Access control, error detection, framing	CAN arbitration, LIN master–slave scheduling, FlexRay static/dynamic slots, Ethernet MAC/TSN
Network (Layer 3)	Routing across domains and gateways	IP layer for Automotive Ethernet; traditional CAN/LIN rely on gateways
Transport (Layer 4)	Reliable delivery, flow control	TCP/UDP in Ethernet; not explicitly defined in CAN/LIN/FlexRay
Session (Layer 5)	Managing communication sessions	Diagnostic sessions (UDS over CAN, DoIP)
Presentation (Layer 6)	Data translation, encoding	AUTOSAR middleware abstractions, SOME/IP over Ethernet
Application (Layer 7)	Vehicle functions: diagnostics, infotainment, ADAS, control	UDS (ISO 14229), DoIP, OBD-II, audio/video streaming (MOST), sensor data (Ethernet)

Table 1: OSI Model Layers and its Application in Automotive Communication Protocols

IV. PARAMETERS TO BE ACCOUNTED FOR NETWORK ARCHITECTURE DESIGN

A. Performance: The ability of the communication system to deliver data efficiently and deterministically from one ECU to another. Performance includes throughput, timing guarantees, and consistency.

a. Data rate / Bandwidth: Amount of data transmissible per second. LIN has about 20 kbps, CAN FD up to 8 Mbps, and Ethernet up to 10 Gbps. High bandwidth is needed for applications like ADAS sensors but body modules can work on lower baud rates.

b. Latency: Maximum tolerable delay from message sending to receiving. Comfort functions tolerate milliseconds, but safety functions in cars like braking require sub-millisecond latency.

c. Determinism: Predictability of message delivery. Time-triggered buses (FlexRay, Ethernet TSN) ensure message

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delivery at predetermined intervals; event-triggered buses (CAN, LIN) rely on arbitration.

d. Jitter: Message timing deviation. Minimal jitter in control loops (e.g., throttle or steering) can destabilize the performance.

e. Payload size: Largest data sent in a single frame. CAN 8 B, CAN FD 64 B, Ethernet has loads greater than 1500 B. Large payloads reduce overhead in high-bandwidth systems.

B. Topology and Scalability: Topology refers to the physical and logical layout of ECUs on the network, and scalability is the ability to add new nodes or restructure the network.

a. Network topology: Bus (CAN, LIN), ring (MOST), star (Ethernet), or switched (Ethernet TSN). All of these topologies are of interest with regard to redundancy, latency, and cost.

b. Number of nodes: The networks must support both currently present ECUs and future expansion. Ethernet essentially has unlimited scalability, while LIN supports a maximum of 16 nodes.

c. Domain architecture: In older designs, an abundance of distributed ECU's are used; newer vehicles utilize domain/zonal controllers, reducing wire and cost.

d. Expansion flexibility: New ECUs may be inserted without redesign. Ethernet is better with switching; CAN/LIN are less flexible.

C. Reliability and Robustness: Reliability describes how well the network delivers valid data, robustness, describes fault and environmental noise insensitivity.

a. Error detection and correction: CRC, checksums, ACKs, and bit monitoring prevent faulty messages from propagating.

b. Fault tolerance: Networks like FlexRay (two channels) and Ethernet TSN (redundant paths) continue to function even with faults.

c. Error handling: CAN has excellent error confinement properties, isolating failed nodes to maintain system survivability.

d. Electromagnetic compatibility (EMC): Enabling noise immunity from motor or ignition system interference.

e. Environmental robustness: Networks must survive high-temperature, vibration, and aging conditions in harsh automotive environments.

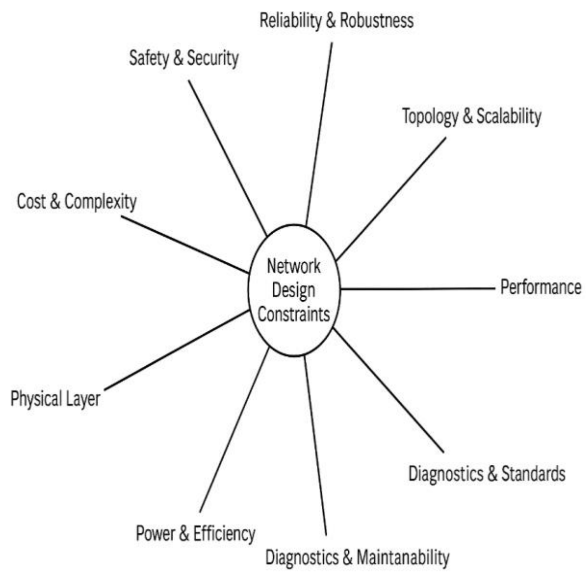

Figure 3 : Factors for the Automotive Network Design

D. Safety and Security: Safety ensures the system does not experience hazards under faults; security protects against malicious tampering.

a. Functional safety: Networks must comply with ISO 26262 and provide required ASIL levels (e.g., ASIL D for brakes).

b. Message priority: Arbitration or slotting ensures critical messages (e.g., airbags) are sent before non-critical ones.

c. Cybersecurity: Authentication, encryption, and intrusion detection are required, particularly on Ethernet, which is exposed via external interfaces.

d. Fail-safe modes: Networks must support safe fallback (limp-home) when ECUs fail.

E. Cost and Complexity: Considering both upfront and lifecycle expenses, and integration complexity and design.

a. Hardware cost: The networking shall be chosen based on trade off between cost and application, LIN transceivers are cheapest whereas Ethernet hardware is more expensive due to PHYs and switches.

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b. Software complexity: Ethernet stacks require TCP/IP, TSN scheduling, and security modules, while LIN software is limited.

c. Development tools: Availability of bus analyzers, simulators, and debuggers affects the feasibility of a project

d. Maintenance cost: Diagnostic protocols (UDS, DoIP) establish serviceability and longevity cost.

F. Physical Layer Considerations: Performance, cost, and longevity are determined by the signaling characteristics and physical medium of the network.

a. Medium: LIN employs single-wire, CAN/Ethernet twisted pairs, and MOST is able to employ fiber optics

b. Length and cable weight: Wiring harness weight influences fuel efficiency; Ethernet makes harness complexity easy.

c. Voltage levels: Automotive networks require support for varying 5 V/12 V/24 V power supplies.

d. Termination and impedance: Termination (e.g., 120 Ω for CAN) prevents reflections in high-speed signals.

e. Connector durability: Connectors must be robust in the face of vibration, dust, and water, and meet IP standards.

G. Power: Communication should minimize power usage, especially when idling, and allow for wake-up in efficient ways.

a. Bus idle consumption: Communication Transceiver devices shall be designed to consume minimal power, for example LIN Transceivers spend most of their time in sleep mode to conserve battery.

b. Wake-up mechanisms: Nodes should allow wake-up based on user input or network activity.

H. Diagnostics and Maintainability: Protocols must be capable of managing tools and mechanisms for fault detection, maintenance, and upgrades.

a. Protocol support: UDS (ISO 14229) supports CAN, LIN, and Ethernet; DoIP is Ethernet native.

b. Service tool compatibility: Global access via OBD-II connector since 2008 (CAN mandatory).

c. Error reporting: ECUs buffer Diagnostic Trouble Codes (DTCs) for isolation and repair.

I. Regulatory and Standardization: Networks must comply with world and regional regulatory regulations and industry standards.

a. Conformance: Protocol specifications are established by ISO, SAE, IEEE, and AUTOSAR standards.

b. Local standards: EU/US demand OBD-II with CAN since 2008; China demands diagnostics extensions.

c. Future-proofing: Protocols need to accommodate for Ethernet backbones, OTA updates, and zonal architectures

V. COMPARATIVE ANALYSIS

Protocol	Speed	Topology	Strengths	Applications
LIN	≤20 kbps	Master–slave	Low-cost, simple	Windows, seats, HVAC
CAN / CAN FD	1–8 Mbps	Multi-master	Robust, widely supported	Powertrain, chassis
FlexRay	10 Mbps	Dual-channel	Deterministic, redundant	X-by-wire, ADAS
Ethernet	100 Mbps–10 Gbps	Switched	High bandwidth, scalable	ADAS, autonomy, OTA
MOST	25–150 Mbps	Ring/Bus	Multimedia streaming	Infotainment

Table 2: Comparative Features of Automotive Communication Protocols

VI. TRENDS AND FUTURE OUTLOOK

Currently automotive networks are transitioning towards Ethernet and CAN FD as the new backbones. Adopting zonal architectures allows combinational wire harness simplifications while offering the opportunity for software-defined vehicles. Coupled with this connectivity, the requirements for security will increase, while the functional safety standards of ISO 26262 remain important. Ethernet with TSN will eventually become the primary solution to legacy networks for the deterministic high-speed communication necessary for safe autonomy.

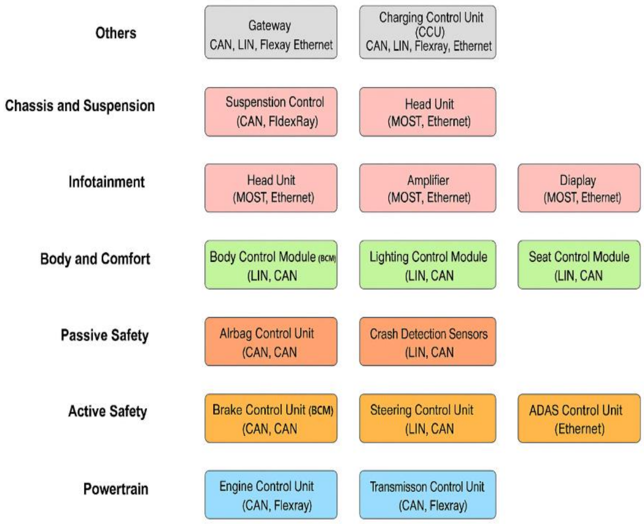

Figure 4 : Application of Various Automotive Communication Protocols

VII. CONCLUSION

The paper presented a summary of automotive networking protocols and discussed the considerations impacting communication design. While LIN and CAN are likely to remain prevalent for cost-conscious and control applications, Ethernet is emerging as the main architecture of the future. The checklist provided in this paper offers a pragmatic systematic framework for protocol selection and network design in modern vehicles.

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