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A Review of In-Vehicle Diagnostic Protocols: OBD-II, UDS, and Cloud-Based AI Diagnostics

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ABSTRACT—

As automotive systems grow increasingly electronic and software-defined, effective vehicle diagnostics have become essential. Traditional protocols such as On-Board Diagnostics II (OBD-II) and Unified Diagnostic Services (UDS) are widely implemented for monitoring faults in vehicle subsystems. OBD-II primarily supports standardized access to engine and emission-related data, while UDS offers more advanced capabilities including memory access, session control, and ECU reprogramming. More recently, cloud-based and AI-enhanced diagnostic methods have emerged, enabling remote monitoring, real-time fault prediction, and data analytics through virtual CAN networks and machine learning frameworks. This paper reviews OBD-II, UDS, and AI-driven diagnostics, highlighting their communication models, functionality, and potential in modern software-defined vehicles.

Keywords – OBD-II, UDS, CAN Protocol, Diagnostic Trouble Codes (DTC), Cloud Diagnostics, ECU, Virtual CAN, Predictive Maintenance

INTRODUCTION

The automotive industry is undergoing a paradigm shift from mechanical control to software-defined and network systems, with Electronic Control Units (ECUs) acting as the backbone of vehicle intelligence. As modern vehicles integrate more than 70 ECUs interconnected via communication protocols such as Controller Area Network, the complexity of identifying, interpreting, and resolving system faults has significantly increased. This has necessitated robust diagnostic frameworks capable of real-time monitoring, fault detection, and error recovery.

Traditional vehicle diagnostics are governed by two principal standards On-Board Diagnostics (OBD-II) and Unified Diagnostic Services. OBD-II, standardized under SAE J1979 and ISO 15031, provides access to a set of predefined Parameter IDs (PIDs) that report engine metrics, emissions data, and diagnostic trouble codes. While adequate for regulatory and consumer-grade diagnostics, OBD-II lacks extensibility and is limited in scope for deep vehicle-level analysis.

UDS, formalized under ISO 14229, introduces a more granular diagnostic interface. It allows for extended services like session management, ECU reprogramming, and secure access to internal memory maps, making it indispensable for OEM development and after-market service workflows. UDS operates over CAN, K-Line, or IP-based protocols, providing versatility across embedded environments complementing these traditional approaches, cloud-based and AI-driven diagnostics represent the next frontier in automotive fault management. Leveraging real-time data acquisition via virtual CAN buses, cloud storage, and machine learning models, this paradigm enables remote fault detection, predictive analytics, and dashboard visualization. Such systems are especially relevant in fleet management, over-the-air (OTA) servicing, and preventive maintenance in software-defined vehicles.

This paper provides a structured comparison of these diagnostic protocols OBD-II, UDS, and AI-based methods by analyzing their communication architecture, functional capabilities, and implementation complexity. It further explores the integration of cloud computing and artificial intelligence in automotive diagnostics, highlighting practical use cases, limitations, and future directions.

REVIEW OF DIFFERENT SYSTEMS

A) On-Board Diagnostics (OBD-II)

On-Board Diagnostics II, commonly known as OBD-II, is a standardized vehicle diagnostic system introduced to monitor and report faults in automotive powertrain and emission systems. It became mandatory in the United States in 1996 and has since been adopted globally across various automotive markets. The main purpose of OBD-II is to ensure that vehicles comply with emission regulations and to assist mechanics and users in identifying engine-related problems.

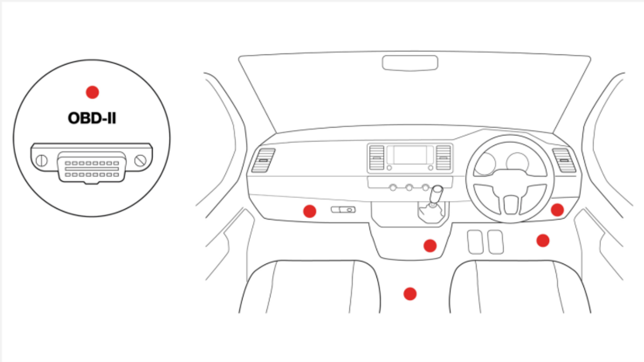

Fig. 1: OBD-II port location in car

OBD-II operates through a universal 16-pin connector, usually located under the driver's dashboard as seen in Fig. 1. This connector interfaces with the vehicle's Electronic Control Units via standard communication protocols such as the Controller Area Network, ISO 9141, or SAE J1850. These protocols allow scan tools to retrieve real-time vehicle data DTCs, which indicate specific malfunctions.

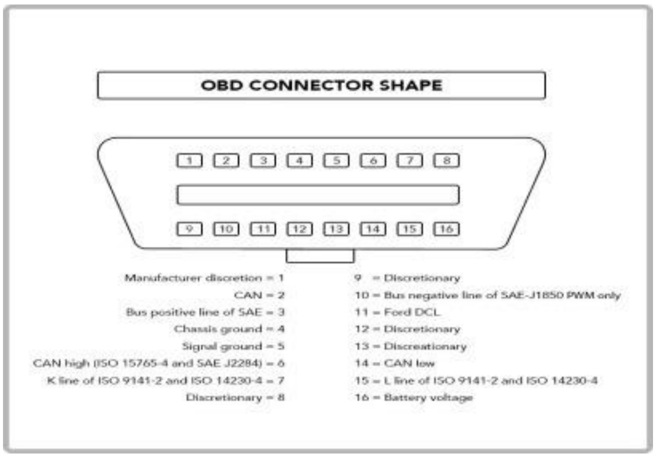

Fig. 2: OBD-II Connector pin Diagram

When a fault occurs, OBD-II generates a unique trouble code (e.g., P0171 for "system too lean"), which is stored in the ECU's memory. These codes can be accessed using a basic scan tool or mobile-based diagnostic apps connected via Bluetooth devices like the ELM327. In addition to fault codes, OBD-II provides live data from various sensors, including engine RPM, vehicle speed, throttle position, and coolant temperature.

The technical advantages of OBD-II lie in its standardization, interoperability, and real-time accessibility. By defining a universal set of Parameter IDs and Diagnostic Trouble Codes, OBD-II enables seamless communication between any compliant scan tool and the vehicle's ECUs, regardless of manufacturer.

It's real-time data acquisition is crucial for early fault detection, ensuring compliance with emission standards and aiding in root-cause analysis. Its simplicity of access via low-cost hardware and widespread adoption across vehicles makes it an essential tool in garages, inspection centres, and fleet maintenance operations.

Table 1 – OBD Characteristics

Features	**Description**
Standardization	**SAE J1979, ISO 15031**
Connector Type	**16 pin DLC**
Protocols Supported	**CAN, ISO 9141, SAE J1850**
Main Use	**Emission diagnostics, real-time engine data**
Data Access	**PIDs and DTCs**
End-User Accessibility	**High**

Advanced Services	**Limited**

B) Unified Diagnostic Services (UDS)

Unified Diagnostic Services (UDS), standardized under ISO 14229, is a comprehensive diagnostic protocol used in modern vehicles for both development and after-sales service. Unlike OBD-II, which focuses on emission-related data, UDS provides advanced diagnostic capabilities such as ECU reprogramming, session control, memory access, and security authentication. It is widely used by automotive OEMs and Tier-1 suppliers during production, testing, and maintenance phases.

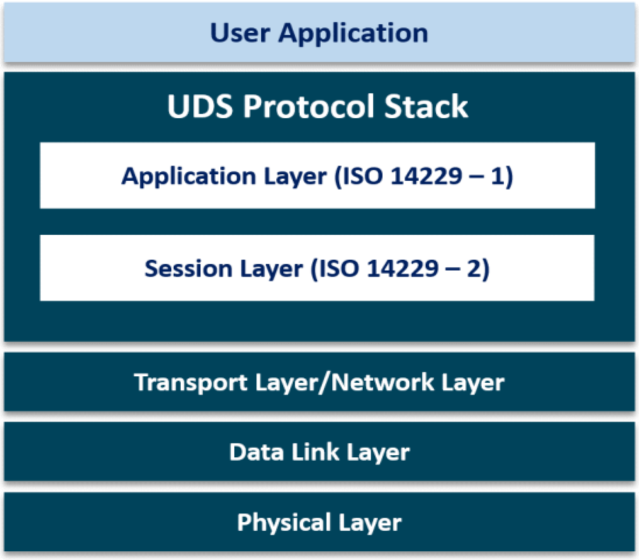

Fig. 3: UDS communication stack (ISO 14229)

UDS typically operates over CAN (ISO 15765-2), K-Line, or Ethernet/IP, making it adaptable to different in-vehicle network architectures. As shown in Fig. 3, UDS is layered on top of the transport protocol, enabling structured communication between diagnostic tools and vehicle ECUs. The service identifiers (SIDs) defined in UDS cover a wide range of functionalities such as reading DTCs (0x19), writing data by identifier (0x2E), security access (0x27), and routine control (0x31).

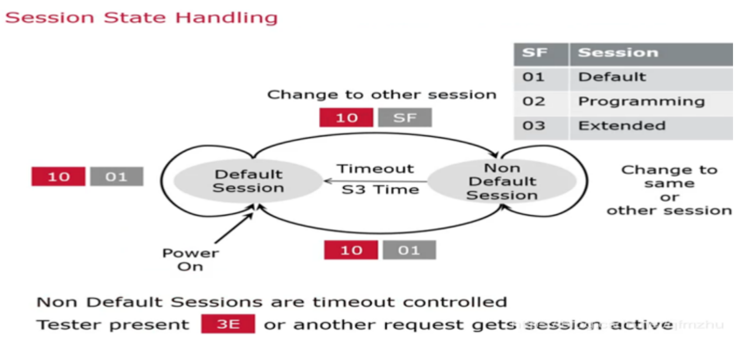

Fig. 4: UDS session states

UDS communication is session-based, meaning operations are grouped under specific diagnostic sessions. For example, a "default session" allows limited access, while an "extended session" or "programming session" grants deeper interaction like ECU flashing or configuration. The session control process ensures safety and stability during high-risk operations like firmware updates, as depicted in Fig. 4.

In terms of capabilities, UDS surpasses OBD-II by supporting detailed subsystem diagnostics, calibration routines, and secure operations. It is indispensable during ECU development and validation, where engineers require low-level access to memory, software versions, and functional states. However, due to its complexity and OEM-specific customization, UDS is primarily used by automotive engineers and not typical end-users or mechanics.

The key strengths of UDS lie in its flexibility, modularity, and depth of access. It enables diagnostic tools to communicate across different ECUs in a secure and coordinated way, allowing seamless development, debugging, and software reprogramming in embedded automotive systems. As vehicle electronics continue to grow in complexity, UDS plays a central role in enabling robust and secure diagnostics across the vehicle lifecycle.

Table 2 – UDS Characteristics

Features	**Description**
Standardization	**ISO 14229(UDS)**
Transport Layer	**CAN, K-Line, Ethernet**
Session Management	**Default, Extended, Programming sessions**
Complexity	**High**
Security	**Yes**

C) Cloud-Based AI Diagnostics

Cloud-based AI diagnostics represent a modern, data-driven approach to automotive fault detection and health monitoring. Unlike traditional protocols that rely on in-vehicle analysis, this method utilizes real-time data collection from the vehicle's CAN bus, transmits it to cloud platforms, and applies machine learning models to predict faults, identify anomalies, and support preventive maintenance strategies.

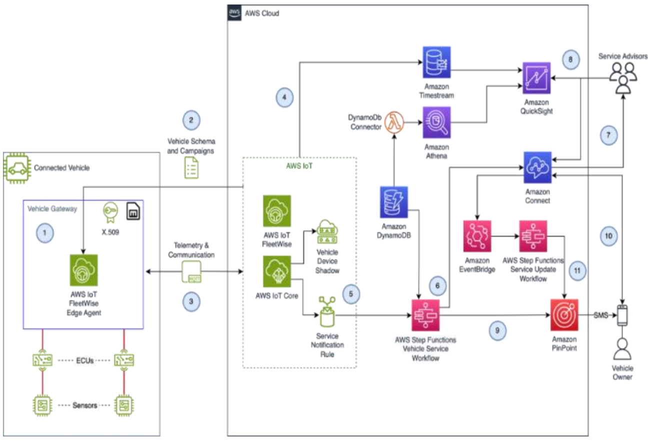

Fig. 5: Cloud-Based Vehicle Diagnostics Architecture

As illustrated in Fig. 5, the vehicle data is first captured via an on-board telematics unit or virtual CAN interface, then transmitted over the internet to a cloud platform like Firebase or AWS. There, AI algorithms often built with tools like TensorFlow or PyTorch analyze the incoming stream to detect patterns that might indicate emerging faults. The results can be visualized through dashboards or used to send alerts to users and technicians.

These systems are particularly useful in:

- Predictive Maintenance: Estimating failures before they occur to avoid breakdowns.
- Remote Fault Alerts: Notifying vehicle owners or fleet operators instantly via apps or dashboards
- AI-Based Fault Mapping: Enhancing DTCs by linking raw CAN data with higher-level fault categories.

The main benefits of cloud diagnostics include:

- Scalability: Can handle thousands of vehicles and large datasets.
- Intelligence: Learns from past data to improve over time.
- Flexibility: Works across locations, especially useful for fleets and connected cars.

However, these systems rely on strong data security and internet access, and raise data privacy concerns. Still, they are a key part of the future of diagnostics in software-defined vehicles and autonomous cars, where remote, AI-powered insights are essential for maintaining safety and uptime.

Table 3 – AI Diagnostics Characteristics

Features	**Description**
Data Source	**CAN bus, telematics unit, virtual CAN**
Processing Location	**Cloud (AWS)**
Real Time Capability	**Yes**
Complexity	**High**

CONCLUSION

This review presents a comparative study of OBD-II, UDS, and Cloud-Based AI Diagnostics, each representing a different generation and scope of in-vehicle fault detection and analysis.

- OBD-II is ideal for basic diagnostics and emissions checks, especially in older or non-connected vehicles. It is widely accessible and suited for real-time sensor monitoring and basic fault detection using affordable tools or mobile apps.
- UDS is designed for OEMs and advanced technicians, offering deep diagnostics, firmware updates, and secure ECU access. Best used in development, production testing, and authorized servicing, though it requires specialized tools and knowledge.
- Cloud-Based AI Diagnostics enable remote monitoring, predictive maintenance, and data-rich analysis. Ideal for connected fleets, EVs, and autonomous vehicles, where AI insights and scalability are critical for proactive fault management.

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In summary, each protocol has distinct advantages based on system requirements, user roles, and vehicle connectivity. For basic, local diagnostics, OBD-II is sufficient. For in-depth engineering or secured reprogramming, UDS is essential. For remote, intelligent, and scalable diagnostics, cloud-based AI solutions offer the greatest potential. Together, these protocols form a complementary ecosystem that supports diagnostics across the vehicle lifecycle from development and validation to deployment and long-term service.

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