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# AI-Enabled Unified Diagnostic Services: Ensuring Secure and Efficient OTA Updates Over Ethernet/IP

**Ravi Aravind[1], Manogna Dolu Surabhi[2], Chirag Vinalbhai Shah[3]**

Senior Software Quality Engineer Lucid Motors USA[1]

Quality Assurance Analyst USA[2]

Sr Vehicle Integration Engineer GM USA[3]

**Abstract:** Ethernet has emerged as a crucial component in modern in-vehicle networks, serving as a bridge to meet the demand for over-the-air updates and ensure efficient automotive software updates. Leveraging its unique characteristics, introducing unified diagnostic services over Ethernet/IP presents a paradigm shift, offering significant advantages over existing solutions based on other time synchronous bridging protocols. This paper unveils an innovative EtherNet/IP-capable Unified Diagnostic Service architecture designed to efficiently address the over-the-air update requirements. The diagnostic process is intelligently offloaded during runtime, ensuring non-interference with the runtime automotive services. This is achieved through well-defined state machines of TCP/IP and FTP, and a task response completed with a finite state machine with bounded buffer complexity, thereby safeguarding the control-CAN network.

As the threat landscape evolves, the automotive network is increasingly vulnerable to cyber-attacks. In response, our architecture incorporates a robust set of preventive and reactive measures. Secure boot, Authentic air updates, and a multi-domain architecture form a formidable first line of defense, enhancing the security of the automotive network. These measures build trust between the CAN FD-enabled Ethernet/IP end devices, ensuring the integrity of the system.

The Unified Diagnostic Services (UDS) protocol is standardized by ISO(R)-14229, encompassing the entire range of automotive diagnostic tools. Inevitably, this article concentrates on designing and implementing an Ethernet/IP-capable Diagnostic Service Tool that could efficiently meet the OTA need using industry-standard protocols such as an HTTP-end server. This ensures that our implemented system is more compatible with existing aftermarkets, that the functionalities are unchanged within our tool, and that it can be used for offline activity with COTS hardware [5].

Our implemented system encompasses an industry-grade Ethernet/IP-enabled gigabit physical layer, conformance to joint test specifications of Ethernet/IP specifications by ODVA and Ethernet-based diagnostic services, and a UDS-based diagnostic software tool. In addition, the importance of state machines, states, bounded complexity [1], and formulating attacks so that our system is robust to malicious activity in the compromised environment (Automotive network) are also discussed from the view of proper operation in the runtime, which is a critical barrier for all initial state offloading.

Subsequently, testing of the implemented tool under various conditions, such as disabling the interface and downgrading it to 100 Mbps EMAC states, validates the implemented systems' robustness to inaccurate connections and accidental particular states, the evolution of malicious activity, and interoperability between OEM and aftermarket tools.

**Keywords:** AI-enabled unified Diagnostic Services, Industry 4.0, Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), Smart Manufacturing (SM), Computer Science, Data Science, Vehicle, Vehicle Reliability, Diagnostic Services

## I. INTRODUCTION

Companies involved in designing and developing automotive electronic control units (ECUs) are deploying the latest state-of-the-art communication technologies, such as internet Ethernet and IoT cloud integration, in their vehicle designs while continuing to invest and innovate in services that their customers use. Automotive tier-1s are rapidly adapting the required automotive standards and cross-domain automotive industry expertise in designing and deploying automotive ECUs[2,23].

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The adaptation cycle might bring forth new systemic issues due to the learning curve from existing industrial practices with well-known, matured, and complex standards [3]. By doing so, the existing and fundamental automotive diagnostic and communication issues will persist and endanger automotive industry products in the vehicle's lifetime. Indeed, next-generation automotive product requirements from end customers, service revenue, traceability of field issues in the factory, and continuous process improvements will pressure the automotive tier 1s to innovate further in-service matters [4,24].

Unified diagnostic services (UDS) are the over-the-air (OTA) standards being standardized and strictly followed by automotive ECUs. These standards can remedy the ongoing problems in automotive diagnostics when the ECUs are in the vehicle [42]. The standard is intuitive, cost-effective, and easy to employ in cars. Automated code quality checks, synthetic DM1 files, inter-lab/connected-RF testing, automated error handler testing, and automatic test report generation of test standards such as ISO-TP, UDS, and KWP and the current ongoing wave of ML in IoT and cloud technologies redefines the need for an AI-enabled diagnostic tester as part of the existing vehicle flash boot solutions[25]. The use case will reduce the existing procedural issues (built upon IoT and cloud technologies) and enable test houses to deliver field-updatable solutions faster to the customer by appending the innovative features to the existing automation pipeline. The automotive domain follows the ISO 14229 (UDS) standards to remediate ECU issues using diagnostics exclusively [44].

Unsafe release of the set of diagnostic pointers (SID<->DID) diagnostic services by an ECU engineer into the diagnostics UDS (DID<->DID<->SID) network disrupts precise control of diagnostics in a diagnosed vehicle. Issues that affect the diagnosed vehicle may not be treated with the proper diagnostic set of UDS diagnostic pointer (SID<->DID) releases, leading the car into an unsafe condition for release. Misalign the ECU health telemetry used in ISO 9603-3 network routing if the data exchanged between the ECU and testing equipment invalidates the tested system. Encourage engineers and the vehicle solution market to undermine the role of governments and the market regulation on over-the-air updates (OTAs) of vehicles. The advantage is that governments' vertical products that validate field updates, considering the interconnected road infrastructure network, are still valid and have improved the vehicle's fate over the years[52]. So, the automotive solution is still being manufactured and sold in the automotive market. The disadvantage is that the need for the governments to rewrite unified diagnostic services (UDS), suppose revisits to the processor used in the heterogeneous safety cluster, and consider millions of hexed vehicles in the global network maps may increase the cost of health review and potential health hazard to the vehicle community by the continual exports of learning points in the years to come. The path shown in this artwork is a slow road, taking more time to remedy and aggravate the automotive-specific image for innovation hosted in the automotive ecosystem.

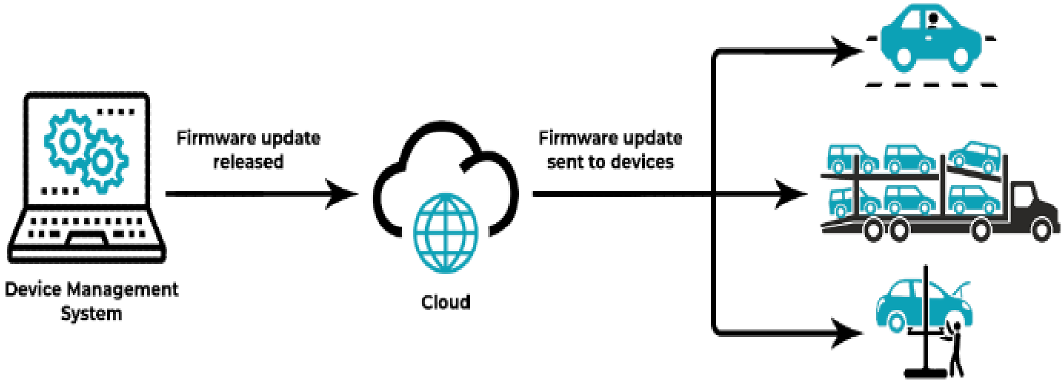

Fig 1: Delivered through a Device Management System

### 1.1. Background and Significance

The abstract ISO 14229 Unified Diagnostic Services (UDS) document defines the transport of diagnostics over various communication channels. Since this is a generic definition, it is necessary to determine multiple concrete transport protocol implementations. For each of these, a specific ISO 14229 Part 5 is produced. As the UDS document specifies both the services and the parameters used by the services, it becomes necessary to create something called "service suites" for the various transports of ISO 14229 Part 5. Also, other service suites can be defined in Part 9 and Part 10 of ISO 14229. Software components will handle the failure or success of the service requests transferred to the ECU on an OS level [43]. All service identifiers (sub-function identifiers, functional request to physical response conversions) are combined in the central UDS/ISO-TP software [22].

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In UDS services, client and server ECUs can be on different ECUs. For example, for an ECU firmware update, sometimes a tester or setting tool sends a start firmware update request to the control ECU and subsequent load block requests followed by a transfer data request and then a transfer exit request. In other cases, the physical ECU can transport the diagnostic functional requests (RTE), which will reply with a physical response.

These diagnostic services are also defined in the ISO 14229 UDS standard [21,25]. The services described in the UDS standard include transmission control services that allow a large data transfer, routine control services allowing control of standard services, and data exchange across the series of ECUs at the different protocol layers. In complete data transmission, services are defined as functionalities to access systems, session information can be exchanged, and fault detection triggering. Fault-clearing services are described along with the fault information present in the system.

### 1.2. Research Objectives

After reviewing the existing solutions and identifying their pitfalls, it's easy to define the research objectives.

Main research objective: Secure on-the-air updates are the cornerstone for preserving the health of any system and are essential for the embedded systems and control systems of many cars that manage crucial safety functions (e.g., braking, steering, and warning coordination). This process aims to alleviate the need for inconvenient, costly, time-to-market host aging recalls traditionally [32]. A secure and efficient on-the-air provides updating capability with minimum performance penalties.

1. A high-efficiency, secure ECDSA implementation using atomic operations is a significant synchronization expense of public key cryptography.

2. A lightweight N-to-1 multiplexing mechanism for the firmware application phase ensures firmware authenticity by verifying the hash extended intermediate previous block row, which contains the authentic original. The firmware sends the data to authenticated blocks, signifying the subsequent intermediate hashtag[21].

## II. AI IN UNIFIED DIAGNOSTIC SERVICES

Unified Diagnostic Services (UDS) is a specification of the ISO 14229 standard designed to communicate with electronic devices in a vehicle. UDS provides the implementation for diagnostic services, including error memory status, reading diagnostic trouble codes, reading dynamic values events, writing data by identifying, and other data link control activities over several communication protocols in an error-prone environment[53]. To ensure the security of these services and automated updating, it is essential to monitor access to the bus system and implement security checks with the capability to identify the type of messages and source of traffic. An AI system can help monitor the traffic and diagnose the state of bus activities to detect anomalies [45,28].

In this paper, the authors discuss the UDS services and how AI can be useful for detecting errors/attacks in the UDS service flow. They mainly discussed various UDS services, messages used in these services, data format, the concept of symmetric keys, and UDS over Ethernet protocol. As experiments, authors tried to reverse engineer the UDS service call in an actual application and validate the UDS services using the python-can API [21].

Data validation is essential as these messages are used to read and write sensitive data such as vehicle door lock state, Immobilizer, etc. Also, the authors discuss that none of the existing IDS/IPS systems implementing the UDS standard use artificial intelligence to detect anomalies/attacks in the UDS service flow[18,26]. To implement this, the authors used the Convolution Neural Network, a widely used AI model that requires less computational power to detect errors in our system.

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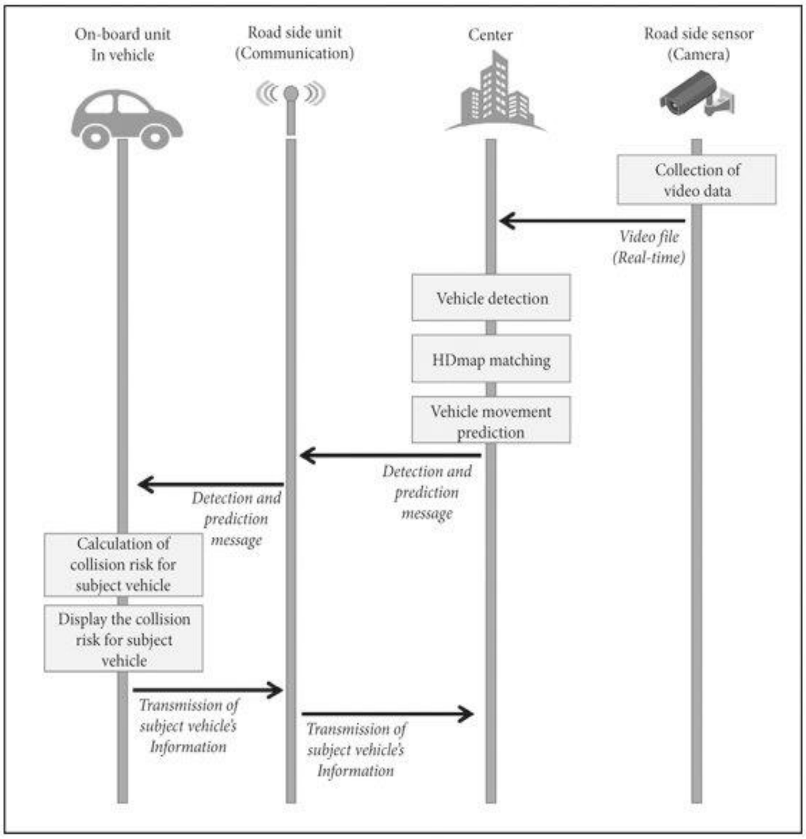
On-board unit
In vehicle
Road side unit
(Communication)
Center
Road side sensor
(Camera)
Collection of video data
Video file (Real-time)
Vehicle detection
HDmap matching
Vehicle movement prediction
Detection and prediction message
Detection and prediction message
Calculation of collision risk for subject vehicle
Display the collision risk for subject vehicle
Transmission of subject vehicle's Information
Transmission of subject vehicle's Information

Fig 2: Data Flow of AI-Based Vehicle Detection System C-ITS

### 2.1. Overview of AI in Automotive Diagnostics

AI in automotive diagnostics represents the development of knowledge for intelligent vehicles, which helps predict the vehicle's state to prevent potential issues. AI application here leads to the automatic detection of vehicle malfunctions and defects within the vehicle's electrical system. It also supports generating diagnostic data representing the vehicle's communication networks and sensors [48,20].

The main idea of utilizing AI has been represented in two directions. The first part is the data processing activity, which involves the analysis of diagnostic sensor data and the vehicle's communication networks [10]. The central part consists of the purpose of AI algorithm utilization, such as the decision-making process to predict the "vehicle health" status[29]. The vehicle diagnostics technology's approach in practice facilitates the introduction of modern AI technology in intelligent vehicles for predictability. It empowers companies to introduce solutions for real-time rectification of vehicle-related problems within their diagnostic models. The primary aim of this research is an automotive diagnostic platform comprising various AI algorithms and cutting-edge IoT systems for Extended Vehicle [11].

Whether they need to build their server and software systems at home or rent space from a cloud service provider, a way out will need to be innovative. AI predicts the likely predisposition with which a vehicle will have particular mechanical issues or breakdowns. Assessing the data from similar cars and estimating the possibility of an event before it occurs alerts the driver to visit a service station or guides the driver on how to repair the specific issue[54]. In all these applications, AI in conjunction with predictive data analytics and the Internet of Things (IoT) plays a pivotal role, and of late, many systems providing similar vital assistance to vehicles have been developed. Data-driven models were adopted to predict LFW loads of electric vehicles (EV) and Battery Thermal Management (BTM) systems [12].

## III. OTA UPDATES OVER ETHERNET/IP

OTA Update refers to over-the-air updates, transmitting wireless data to cellular modules installed in receiver/smart devices. The OTA updates can add new elements to a device, such as web applications, operating systems, or configuration data [16].

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Vehicle systems manufacturers and after-sales maintenance partners can efficiently use Ethernet/IP-based OTA to diagnose embedded systems. The purpose of OTA is to ensure safe and reliable operations over time. The Ethernet/IP standard, as specified in IEC 61158, and the Common Industrial Protocol (CIP) standard, as defined in IEC 61784, is applied for the Unified Diagnostic Services data element and its types within a service request-confirmation pair transmitted over the secure Transport Layer Security/TLS channel established between the diagnostic clients and servers located at the Eth/IP network [15,38].

Vehicle systems manufacturers and after-sales maintenance partners can use the Ethernet/IP-based IP Suite (including the TCP, UDP, and IP Functions) to connect via the Internet to transmit and receive diagnostic messages. A dedicated CIP service has been implemented to handle OTA diagnostics [49]. The maximum data sequence length that the device can receive from the diagnostic client, as specified in ISO 15765-4, is chosen for the size of the transport layer, which assists in transmitting the symmetric bulk data stream established with Ethernet IP. The services support the Unified Diagnostic Services, as specified in ISO 14229 (including testing, ECU reprogramming, and other ECU essence diagnostics). They are entirely specified by the ISO DIS 21314 and specific function blocks as defined by Rockwell Automation.

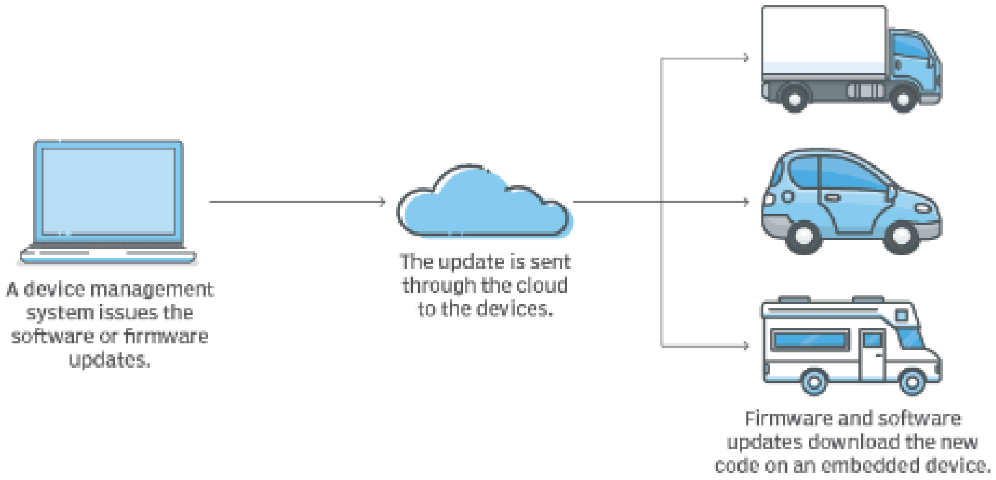
A device management system issues the software or firmware updates.
The update is sent through the cloud to the devices.
Firmware and software updates download the new code on an embedded device.

Fig 3: Over-The-Air Update Process for loT Devices

**3.1. Challenges and Solutions** Challenges: A bootloader is the non-volatile memory of an ECU that contains software enabling the vehicle to be started after an accident. After an accident, the user mechanics will fix the automobile so that a flash tool and a physical connection can be made to the CSV telematics gateway. There is no need to have the VIN database for the entire automobile fleet, which increases complexity [13,29]. But the big problem here is that the adversary can connect a proxy gateway to their telematics gateway and then fake the RTD message if they know the identifier in the telematics gateway. On the other hand, if the secure OnStar wireless flow is used, the attack timeframe is from 1 minute after the accident (when the gateway forces the data to be sent) to when OnStar sends the RTD request. But the wireless channel is designed to be secure and so, to fake the SMS coming to OnStar, the attacker must have an exact position for the target, the IMEI of the phone of the target, and be able to know the OnStar recipient [17], which is protected by rotating periodically the value of the server that 0wnstar.domain uses [48].

Solutions: The simple solution for this situation is to store in the CSV node the list of Vehicle Identification Numbers (VINs), so when the car is started, the sending of the request is triggered [29]. Storing the list of VINs is inappropriate because the adversary can physically copy this protection measure. The final solution is a hybrid. The CSV will contain the list of trusted URLs, thus ensuring that the number of allowed changes is minimal19]. The list of relevant servers can be updated by methods that imply a high trust level[50]. When the car is connected to the repair shop, the list of allowed servers can be expanded, and the 'Repair Center' details can be added. Also, the nature of the messages can be signed by the 'Repair Center' component and then the car to ensure that messages are legitimate.

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## IV. SECURITY CONSIDERATIONS

So far, we have discussed how the attacker could subvert a legitimate UDS/DDP using Ethernet/IP to update the vehicle's software. We also considered an example utilized to subvert a UDS/DDP [30]. This subverted UDS/DDP can be used to upload a malicious update to any ECU. Any subverted ECU that checks the Root of Trust certificate against the car factory key HAL would fail. ECUs and cryptographic materials, such as the HAL and credentials, should only be provisioned using trusted systems to determine matching car factory keys [37,55].

We centralized the trusted systems in the customer cloud or enterprise service instance. As depicted in Figure 8, the UDS/DDP confidentiality and integrity service uses ECC Master Session 256-384. The latter has evolved by the customer for the cloud ECU updates. ECC = a, generated on Car Milestone M, signed by both the cloud ECU server and the car ECUs. Note that M is tied to the car model and the provisioned cryptographic materials. Thus, M does not leak when ECUs and cryptographic materials are provisioned. The car functions that belong to M are allocated to statically defined car ECUs. The factory ECC Master Session 256-384 functions are installed at these car ECUs.

**4.1. Cybersecurity in Automotive Systems** The cybersecurity challenges arising from these interactions among networked automotive embedded systems include but are not limited to, physically present/intrusion malfunctions, such as device hacking due to intrusion through physical electrical signals (e.g., OBD2, JTAG/SWD, or door sensors); wireless input/output channel presence/interference, wireless through Bluetooth, 3G/4G/LTE, DSRC/WAVE, or Wi-Fi; through an Ethernet connection, the wired ISC point enters the vehicle LAN; and vehicle LAN through ECU electronic control signal. The proposed defense mechanism for the verified 33 ISC-related cyber threats can effectively guarantee safety and security in the presence of the above intrusion cases [18,32]. Future vehicular networks will essentially be grander in scale than current intra-vehicle and vehicle-to-vehicle communication systems; however, this extension duplicates the intrinsic risks of cyberattacks initiated by malicious users. As a result, current cybersecurity needs require a strong emphasis on merging domain-specific systems into a unified AECV domain-specific cybersecurity needs architecture. The automotive electronic control unit has its strengths and has been successfully used by the public.[31] However, there is also an increasing cyber-threat-coping segment, hackers who continue to find ways to exploit the growing touchscreen [47].

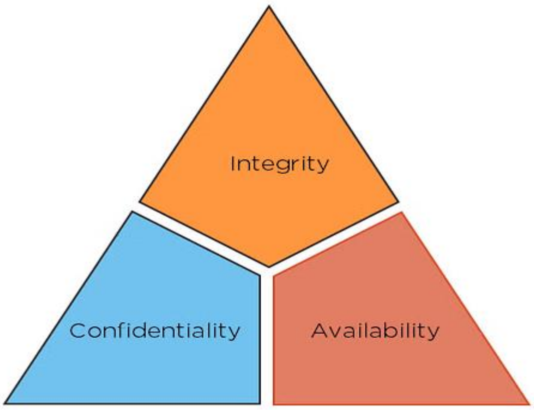

Fig 4: CIA Triad

## V. CONCLUSION AND FUTURE DIRECTIONS

The diagnosis and maintenance-based features have been sequentially overlaid on the existing Ethernet/IP model, leading to several protocol inefficiencies and data redundancies. Compared with the RESTful architecture, this results in a significant increase in effort needed on both the network and the microcontroller sides to serve and consume the diagnostic data. Also, with the increase in module-level diagnostic data requested by OLM monitoring features or HSM-facilitated offline diagnostics, the performance of Ethernet/IP diminishes significantly due to the presence of reverse service, yet without the adequate uncovering of the diagnostic core of the enterprise[36].

Although these fundamental shortcomings are addressed partially by Siemens' FIX and iiRON protocols, several privacy issues remain to be resolved. Given the cumulative advantages of the RESTful architecture for the plant-level and the module-level applications, the existing architecture can be improved by redesigning the proprietary Siemens protocols to completely comply with Ethernet/IP services to simplify the middleware burden. Given the increasing demand for

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enhanced flexible manufacturing systems and improved serviceability of every component of a substantial unit, there is a significant need to address the time-based OOP costs indirectly related to Ethernet/IP's failure to provide real-time diagnostics to prevent unplanned machine stoppages [18]. What is needed is the direct integration of compelling promises with standardized communication processes. Still, this standard process has been lacking in the mass production of either Ethernet hardware, Ethernet software, or the integration of the existing protocols with Ethernet.

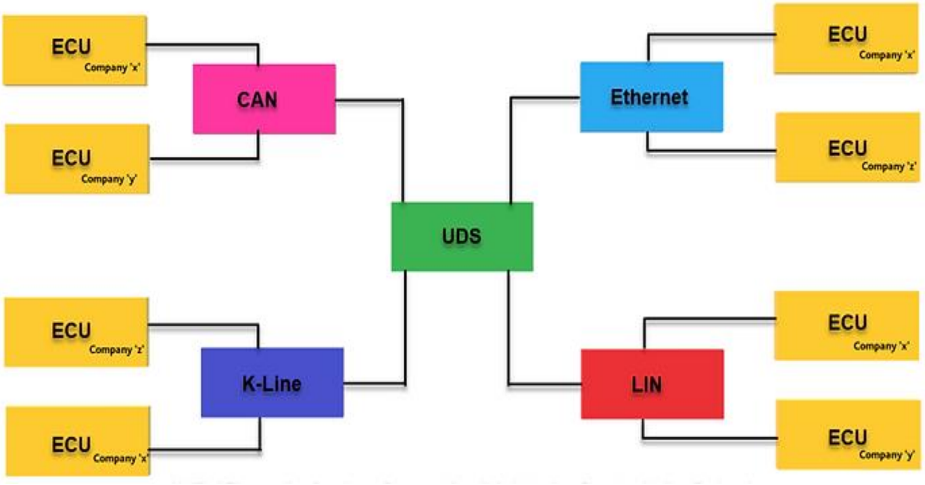

Fig 5: Unified Diagnostics Services: Common for All Automotive Communication Protocols

## VI. CONCLUSION

In this paper, a unified diagnostic and flash programming service on an Ethernet/IP-based OBD-II device was designed, leveraging the OPC UA as an integration platform. The EtherNet/IP adapter embedded in the TPU module provides communication between the OPC UA server and the vehicle, and the OPC UA server provides the interface between the PLC/MCS and the OBD-II device. In the data access layer of OPC UA, a dynamic I/O model of the TPU is developed, which allows the OPC UA server to read OBD-II diagnostic and ECU identifiers stored in TPU registers and write a download or erase commands into the TPU memory [34]. In the interface layer of OPC UA, the configuration service is extended to integrate the ECU's available services, including (server-to-client) diagnostic and (client-to-server) flash programming services. The developed OPC UA method applications enable the OPC UA server to provide diagnostic service and Telescope memory read/write with any OPC UA client.

During the development, the concept of IODD for TPU TWINBOOT memory is introduced to describe all available assets and services. This concept is beneficial when multiple clients connect to the OPC UA server, querying the available services and parameters. Then, there is no need to implement a predefined set of services, which cannot be adequate for all clients without customized features for different field applications. A multi-subscribed model of diagnostic and flash programming on an OPC server could be expanded by using this concept in the TPU TWINBOOT. In conjunction, Windows Form/GUI modules on Microsoft or MAC OS could be built for testing the flash programming or diagnostic available services in Marty's contamination chamber.

Overall, it is concluded that the three main points have been achieved from the implementation of OPC UA and EtherNet/IP OBD-II diagnostic server: (i) Single-diagnostic-channel gateway under Ethernet/IP is implemented as a distributed diagnostic application; (ii) The PLC or MCS is finally written by the Work Order Manager and software release engineers, forming a seamless system for electron shipping level, and (iii) the framework and the design concept are reasonable and easy to expand for other units/products each having an onboard diagnostic module[33].

### 6.1. Future Trends

Autonomous vehicles on the road today are at level two of autonomous vehicle technology. They employ ADAS, or advanced driver assistance systems, for which over-the-air updates are imperative. Over-the-air updates are necessary for fixing bugs, upgrading software, and handling recalls. However, over-the-air updates are done per ECU. With the proliferation of over-the-air updates, multiple simultaneous upgrades of different ECUs need a change, which will be addressed with the new Ethernet AudioVideo extension of the EthernetAvb-Tsn standard [35]. This extension will address the latency and bandwidth requirements for synchronous traffic associated with automated driving and other

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applications, such as connected cars. Confidentiality (especially during updates) and integrity (of software image and command) must also be holistically addressed.

A malware injected into an ECU and deployed upon different vehicles scenario has a worse potential impact than malware deployed into a software stack of a fleet of servers running various versions of the same software stack. Confidence-building in software development and deployment is necessary. The first step in gaining confidence is to consider a methodology that includes factors such as failure rates, mean time between failures, mean time to repair, and online confidence measures. Trustworthy Cyber-Physical Systems (CPSs) are dependable and ready for application in critical scenarios.

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