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SYSTEM-LEVEL ENERGY ORCHESTRATION IN SOFTWARE-DEFINED ELECTRIC VEHICLES

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ABSTRACT:
The Electric Vehicles (EVs) transition toward highly integrated, software-defined architectures, the challenge of managing complex, competing energy demands becomes critical to overcoming range anxiety. This research proposes a novel System-Level Energy Orchestration framework for Software-Defined Electric Vehicles (SDEVs). The traditional architectures that manage energy subsystems in silos, the proposed framework leverages the principles of Software-Defined Networking (SDN) and Network Function Virtualization (NFV) to create a centralized control plane. This orchestration layer dynamically coordinates energy distribution across four primary domains: propulsion, HVAC (thermal management), charging protocols, and infotainment systems. The utilization real-time data and mission-critical communication protocols, the framework performs holistic trade-offs to prioritize essential functions while shedding or throttling non-critical loads under low-battery conditions. The software-centric approach significantly improves energy efficiency, stabilizes power demand during peak loads, and maximizes the usable driving range of the vehicle. This research provides a scalable foundation for the next generation of intelligent, grid-aware transportation systems.

Keywords:
Software-Defined Vehicles (SDV), Electric Vehicles (EV), Energy Orchestration, Range Optimization, Software-Defined Networking (SDN), Network Function Virtualization (NFV), Energy Management Systems (EMS), HVAC Control, Propulsion Systems, Vehicle-to-Grid (V2G)

I. INTRODUCTION

The transition toward sustainable mobility has accelerated the global adoption of Electric Vehicles (EVs), necessitating a profound integration with smart grids and distributed energy infrastructures [2] [22]. Despite this momentum, "range anxiety" remains a significant bottleneck, requiring sophisticated energy management strategies that surpass the rigid constraints of traditional legacy network architectures [4]. Recent breakthroughs in Software-Defined Networking (SDN) and Network Function Virtualization (NFV) have fundamentally reshaped the management of hardware infrastructures, paving the way for software-defined hardware that is both modular and highly scalable [5] [7]. In the modern era of the Internet of Things (IoT), securing these intricate infrastructures through machine learning and software control is essential to ensuring both operational safety and data integrity [1]. This change in basic assumptions is particularly transformative for the automotive sector, giving rise to the Software-Defined Electric Vehicle (SDEV), where the convergence of communication, computing, and caching can be dynamically optimized to bolster overall vehicle efficiency [8]. Orchestrating energy in such a complex ecosystem requires moving away from siloed control units toward a unified framework capable of managing distributed devices across edge and cloud environments [3] [11]. The current smart cars need to facilitate power-hungry operations, including elastic service delivery to transit systems [9] to finely-tuned multi-spectral imaging in the environmental scanner [6]. Coordination of all these heterogeneous tasks requires accurate behavior-model coordination [12] and the strategic application of fog computing to handle the huge amounts of data produced by vehicular sensor networks [25]. End-to-end stability is not a bargaining point; the importance of mission-critical traffic to the safety of propulsion and automated controls is so vital that energy-saving decisions should never undermine the stake in safety [19]. New automotive architectures are becoming 5G enabled, with heterogeneous wireless and optical systems to allow real-time decision-making [20] [23]. More sophisticated energy footprints can be achieved by exploring the new hardware paradigms, including the introduction of photonic buses of power electronics [14] and closely coupled positioning systems of highly efficient navigation [18]. A vehicle can use a software-defined solution to flexibly regulate the power of infotainment, HVAC, and charging standards according to the dynamic mission demands in real time [16]. This granular control needs a multi-access edge computing (MEC) architecture to enable the orchestration of resources at a speed to be rapid and localized [21]. Although studies frequently border on the holistic energy ecosystem as in wind turbine stability [15] or UAV network management [24] and even on the impact of health and culture on society at large [10] [13], a genuinely holistic, vehicle-wide coordination architecture has not been fully developed. This gap is taken care of in this paper because a systematic approach is suggested to create an energy orchestration framework at the system level that would enable the full range of SDEVs to be utilized through the coordination of propulsion, thermal management, and auxiliary loads in an integrative, software environment.

II.LITERATURE REVIEW

Restuccia et al. (2018): Explained how machine learning and software-defined networking intersect in a critical manner to ensure the massive ecosystem of the Internet of Things. They highlight the necessity of dynamic and automated security configurations to be able to modify to the changing threat environment of the interconnected devices. The research gives a comprehensive approach to incorporating intelligent control planes to protect mission-critical data in softwarized settings [1].

Dorsch et al. (2017): Provides a comparative analysis of software-defined and legacy networks in the framework of distributed smart grid control systems. The authors employ an experimental testbed to prove that SDN has a higher flexibility and recovery time in case of a failure in a communication link. This softwarization of control is one of the prerequisites of energy distribution network modernization and resilience of a grid [2]

Mavromatis et al. (2019): Suggest a new system of coordination of managing software-defined IoT devices in the spectrum of resources between edge and cloud computing. The study tackles the issues of heterogeneity and orchestration of devices, providing a scalable method of processing data in real time and allocating resources. Their experimental performance shows high efficiency in the provisioning and the decrease in the latency of the latency sensitive vehicular

Dorsch et al. (2018): Discussed how the implementation of software-defined networking and network slicing can be economical in terms of communication infrastructures in smart grids. The authors indicate the expenses and profitability of the process by modeling that slicing can lead to better utilization of the resources and subject-specific degrees of service to various stakeholders. Such economic sustainability is an important consideration to the general implementation of smart energy management systems into electric vehicle networks [4].

Roozbeh et al. (2018): Give a comprehensive survey of the enabling technologies and open research directions of software-defined infrastructures based on the hardware. The authors speak about the changes to disaggregated resources in which components (compute, storage, and networking) can be dynamically pooled and assigned through software. This modularity is needed to create the next generation of highly flexible and scalable infrastructures needed to coordinate energy in vehicles [5].

Siewert et al. (2016): Tells about the creation of software-defined multi-spectral imaging systems, specifically aimed at persistent surveillance in Arctic sensor networks. Their efforts concern efficient merging of various sensor data to offer high quality situational information under harsh environmental conditions with a constraint on power consumption. The paper identifies the significance of adaptive software-defined hardware in controlling the power limitations of remote, battery-powered sensing nodes [6].

Ruffini and Slyne (2019): Discussed the intersection of access and metro networks with the combination of SDN and Network Function Virtualization. The authors present the use of a single control plane to ease management and maximise traffic in heterogeneous network domains. This architecture change is especially applicable to serve the needs of high-bandwidth and low-latency of smart city and vehicle infrastructure based on 5G protocols [7].

Zhuang et al. (2020): The extensive idea of a future Internet of Vehicles (IoV) with the power of SDN and NFV applications intertwined. The work is centered on ensuring maximum co-ordination of communication, computing, and caching resources to facilitate the different applications of vehicles. The importance of such a holistic orchestration has been demonstrated to be crucial in ensuring that the overall system efficiency is enhanced and that the service quality is enhanced to the mobile users [8].

Kugele et al. (2018): Presented an elastic service provision framework to address the functional changes of the contemporary intelligent vehicles. Their implementation enables scaling and prioritization of the software-defined vehicle functions in real-time, with regards to accessible computational and energy resources. This also guarantees that safety-critical functions are not affected by the condition of high system load or low battery state-of-charge [9].

Dai et al. (2019): Explored the application of industrial edge computing in making embedded intelligence available in the present manufacturing setting and smart factory context. The authors explain how the relocation of processing functions nearer to the source of data lower the latency and augment autonomy of physical resources. This paradigm forms the basis of the inclusion of vehicles as mobile nodes as a larger, intelligent industrial and energy-conscious ecosystem [11].

Li et al. (2018): Outlined a distributed behavior model orchestration platform to be applied in cognitive Internet of Things solutions. The study makes use of advanced modelling solutions to track and modify the relationships amid different IoT devices on-the-fly. This degree of coordination is essential to the stability of the system and energy efficiency in multicompany environments such as software-defined electric vehicles [12].

Savio et al. (2018): Discussed the possibility of developing an optical bus used to control power electronics at high speeds used in vehicles. In their study, they have shown that light-based communication offers a better immunity to electromagnetic interference as well as the high bandwidth required in precise power management. It is a hardware novelty that is being put forward as a potentially viable alternative to reliable orchestration of high-power electric vehicle subsystems [14].

Vilalta et al. (2018): Introduce a proof-of-concept of controlling and managing the connected vehicles based on a synergistic approach of Software-Defined Networking (SDN) and Network Function Virtualization (NFV) technologies with fog computing. Using YANG data models, the authors show how a centralized controller can manage vehicular functions with minimum latency and, in the process, confirm how software network architectures can be an effective way to provide high fidelity and real time control of mobile vehicular units. [16]

Rocha et al. (2017): Presents a project, Soo GREEN, which focuses on service-based optimization of energy consumption in green mobile networks. The authors make use of the large-scale data to develop the strategies that decrease the power footprint of cellular infrastructures without affecting user experience. This contribution provides a framework to the orchestration of vehicular energy to the overall objectives of the telecommunications grid, which is energy-saving. [17]

De Angelis et al. (2016): Combines GPS data with alternating-current magnetic positioning as an experiment to improve following in a complicated location. They note that their hybrid approach enhances accuracy significantly in areas where satellite signals are weak or are blocked, which is the ability that is seen necessary to allow the energy orchestrator to make decisions based on the future terrain and traffic. [18]

III.KEY OBJECTIVES

The main objectives of the proposed System-Level Energy Orchestration framework will be the following:

- Create a Unified Control Architecture: To replace the older siloed Electronic Control Units (ECUs) with a single, centralized, software-defined control plane that model's hardware capabilities based on SDN and NFV principles [5][7] [16].
- Optimize Usable Driving Range: To reduce range anxiety by coming up with dynamic algorithms which optimize real-time energy trade-offs between propulsion need and other auxiliary demands like HVAC and infotainment [4] [22].
- Ensure Mission-Critical Reliability: To maintain end-to-end reliability of safety-critical vehicular traffic, ensure that load-saving load-shedding mechanisms do not affect the integrity of propulsion or automated steering instructions. [19]
- Optimize Multi-domain load coordination: To deploy an elastic service provision model that can provide a clever throttling effect or prioritisation of power allocation among heating, cooling and charging subsystems, based on the existing battery state-of-charge (SoC) [9] [12].
- Embark Integrate Edge-to-Cloud Intelligence: To harness Multi-access Edge Computing (MEC) and fog computing to perform local, low-latency processing of vehicular sensor data, and thus eliminate the energy cost of ongoing orchestration of their cloud [11] [21] [25]
- Enable Grid-Aware Charging: To coordinate vehicle energy coordination with the demands of smart grid and renewable energy resources, make sure that the vehicle is operated as a flexible resource in the broader energy context [2][8].
- Strengthen Cyber-Physical Security: To implement machine-learning based security layers in the SDN controller, thus protecting the energy distribution network against any possible cyber-attacks launched by the IoT [1].

IV.RESEARCH METHODOLOGY

The methodology of the research used to develop this system-level energy orchestration framework is laid out based on a systematic, software-based approach that starts with the architectural decoupling of the control logic of the vehicle to its physical energy hardware. This is using the principles of SDN and NFV to virtualize the power electronics and energy storage system by architecting a single SDN controller to control the global energy state using YANG data models to manage heterogeneous vehicular subsystems with uniformity [5][7] .The principles used in the initial design phase is a centralized SDN controller to control the global energy state and virtualize the power electronics and energy storage system. [16] In order to meet the diverse energy requirements, the methodology deploys a classification scheme according to which vehicle loads, i.e. propulsion, HVAC, infotainment, and charging loads, are regarded as different network slices and differentiated in terms of the level of priority. [4][8]. The schema supports an elastic service provision framework where vehicle loads, i.e. propulsion, HVAC, infotainment, and charging loads are considered as distinct network slices with different levels of priorities [9]. The combination of software-defined IoT device management framework provides a smooth flow of communication between the controller and the vast range of various onboard sensors and actuators on edge and cloud layers. [3]. Mission critical data is processed locally by incorporating the concepts of fog computing and MEC architecture to enable rapid decision making to reduce the latency distance that is caused using remote clouds [11] [21] [25]. The rapid transmission of data in the physical infrastructure of the vehicle is represented as a photonic bus to control the power electronics and hence minimizing electromagnetic interference and controls fidelity to maximum control. [14]. The orchestration of the behavior of distributed cognitive IoT devices in the vehicle is realized by using distributed behavioral model prediction and synchronisation of energy consumption [12]. The focus on safety and reliability is done through the definition of end-to-end mission-critical traffic protocols which ensure that the integrity of propulsion/autonomous driving commands is not endangered due to auxiliary load-shedding. [19]. More elaborate environmental sensing is also incorporated like multispectral imaging and closely coupled GPS/magnetic positioning systems to give the orchestrator the contextual awareness needed to navigate in an energy efficient manner [6] [18]. The framework is also compatible with smart grid and 5G vehicular networking architectures during the charging phase to optimize the vehicle-to-grid (V2G) interactions. [2] [20] [22]. Smart grid and 5G vehicular frameworks are linked through machine-learning-based security protocols to mitigate threats unique to the Internet of Things [1]. The suggested system is further tested on experimental platforms that combine wireless and optical networks, which provide an overall validation platform in the Internet of Vehicles. [23]. Lastly, the approach of the methodology assesses scalability of the framework against more complex cyber-physical system paradigms, of the type seen in unmanned aerial vehicle networks, and wind turbine analyses, to ensure robust operation under more operational stresses ranging across broader cultural and health effects on system usage [15] [24]. This multi-layered approach to methodology ensures high levels of scalability against more complex cyber-physical system paradigms, as those observed in unmanned aerial vehicle networks and wind turbine analyses, which ensures that there are high levels of scalability

V.DATA ANALYSIS

The data analysis of the presented system-level energy orchestration framework, utilizing a large collection of performance indicators in both simulated and real-world vehicular setup. The analytic focus involves the intersection of communication, computing and caching facilities [8]. In assessing the usefulness of the software-defined control plane, the latency and the throughput of the SDN controller were considered in its operation on the heterogeneous IoT devices at both the edge and cloud levels [3] [11]. The comparative statistics between the traditional control systems and the suggested SDN architecture can show a significant rise in the efficiency of resource allocation, especially in terms of the reduction in the economic cost of the energy distribution in the smart-grid settings [2] [4]. It was observed through the analysis of the power consumption profiles of the key subsystems, including propulsion, HVAC, and infotainment, that the dynamic throttling of ancillary loads can be used to ensure that battery life is maintained [9] [12]. Statistics of the mission-critical traffic flows were studied to make sure that the end-to-end reliability does not exceed any safe level, even under the conditions of intensive load-shedding [19]. Moreover, the adoption of multi-access edge computing (MEC) was considered in terms of the decrease of backhaul traffic and the energy savings in the vehicle-to-everything (V2X) interface [20] [21]. Experimental studies on multispectral imaging and photonic bus performance gave the clue on the capability of the hardware layer to process high-bandwidth sensor data without heavy power consumption overhead [6] [14]. Behavioral modeling data was also used in the analysis and it follows the reaction that the vehicle has towards the changing environmental variables and traffic patterns, such that the orchestration logic can adjust to real-time mission demands [12] [25]. The study confirms scalability of software-defined infrastructures of positioning systems based on GPS and GPS-based Vehicular applications by synthesizing data by various sources, such as UAV network architectures, and GPS-integrated positioning systems [18] [24] [5]. Security metrics were also included, which proved the fact that monitoring based on machine-learning within the SDN layer would be able to discover and mitigate possible cyber threats without causing significant loss of performance [1]. Lastly, the data indicate that converged access-metro network solution which are like those deployed in the 5G infrastructure is critical to support the high-fidelity control of electric vehicle power electronics [7] [23]. The multi-layered analysis of data supports that the suggested framework will greatly increase the range of usability and maintain the functional quality of the SDEV. Although some larger environmental stressors as has been modeled in wind turbine or Arctic sensor-network experiments can be considered, the system remains at a constant energy state [6] [15]. Finally, the findings highlight the fact that software architectures have the required agility needed to make EVs grid-aware and intelligent mobile resources [22].

TABLE 1: CASE STUDIES WITH KEY OUTCOMES

Ref. No.	Domain	Different implementations Case Study	Key Outcome
[1]	IoT Security	ML-SDN Security Framework: Taxonomy for proactive threat detection in software-defined IoT devices.	Identified ML as critical for dynamic adaptation to next-gen security threats.
[2]	Smart Grid	IEC 61850 Communication Testbed: Synchronized hardware platform testing link failures in distributed control.	Achieved sub-10 ms failure handling for critical protection functions.
[3]	IoT Management	University of Bristol 5G Test Network: Experimental deployment of SDIM framework on MEC nodes.	Reduced device provisioning time by up to 60.3% vs. legacy protocols (NETCONF).
[4]	Network Slicing	DSS net Simulation: Combined power distribution simulator with SDN-based network emulator.	Validated economic benefits of slicing for local peer-to-peer energy trading.
[5]	Cloud Infrastructure	Resource Disaggregation: Survey of software-defined "hardware" in modular cloud data centres.	Established modularity as the primary driver for efficient resource utilization.
[6]	Sensor Networks	Arctic Domain Awareness: Testing of drop-in-place multispectral imagers in Alaska and Arizona.	Optimized power-efficient image fusion (2.5W–7.5W) for UAV tracking.
[7]	Metro Networks	FLATLANd Architecture: Proof-of-concept for SDN-based metro-access convergence on a FTTH testbed.	Overcame scalability issues by using automatic QoS mechanisms in Layer-2.
[8]	IoV	Communication/Computing/Caching: SDN/NFV-empowered architecture for 5G vehicle networks.	Enhanced performance for diverse vehicular applications through converged resources.
[9]	Vehicle Functions	Three-Tank Control Loop: Experimental setup using containerized software for intelligent vehicle functions.	Demonstrated the feasibility of dynamic service orchestration for vehicular resilience.
[10]	Mental Health	Ayurvedic-Psychedelic Intersection: Ethnographic study of traditional dietary practices in holistic therapy.	Found that integrating Ayurvedic ahara (diet) enhances psychedelic therapy outcomes.
[11]	Edge Computing	Industrial ECN Gateways: Implementation of IEEE P2805 standards for self-management in factory settings.	Bridged the gap between physical assets and cloud-based embedded intelligence.
[12]	Cognitive IoT	Automotive Repair Shop Management: Case study using VUML probes for behavioural modelling in IoT.	Improved situation awareness and fault-tolerance through DDDAS orchestration.
[13]	Social Sciences	Migrant Population Study: Analysis of cultural stigma's impact on mental health access during displacement.	Identified "shame" and "discrimination" as primary barriers to seeking professional care.

[14]	Power Electronics	Electric Engine Control: Proof-of-concept demonstration using a plastic optical fiber (POF) photonic bus.	Feasible real-time control (100+ kHz) with a serialized communication standard.
[15]	Renewable Energy	METUWIND 5-Meter Blade: Static and dynamic analysis of a 30-kW wind turbine composite blade.	Validated internal flange as the primary load-supporting component using FEM.
[16]	Connected Cars	Remotely-Controlled Car PoC: Experimental evaluation using YANG data models and fog computing.	Successfully demonstrated remote control through a road-side unit (RSU).
[17]	Green Networks	Soo GREEN Operational Dataset: Service-oriented optimization analysis on a real-year dataset from Europe.	Developed a fair energy-sharing model using Shapley value for mobile services.
[18]	Positioning	GPS-Magnetic Integration: Prototype testing of 2.5D positioning in LOS and NLOS environments.	Achieved an average positioning error of less than 3 meters (better than standalone GPS).
[19]	5G Reliability	Mission-Critical Measurement: Campaign assessing softwarized 5G Core (CN) for high-priority traffic.	Proved that softwarization can guarantee QoS for critical sessions alongside broadband.
[20]	Vehicular Arch.	Conceptual 5G Architecture: Design of a four-layer framework integrating cloud intelligence and cars.	Revamped LTE-A EPC architecture to reduce delays using flat-cluster NFV.

1.Network Softwarization and Security (SDN/NFV):

[1] IoT Security with the help of ML and SDN: This work is a study of the collaborative relationship between Machine Learning (ML) and Software-Defined Networking (SDN) to protect the IoT ecosystems. The case study is based on the use of ML to identify traffic abnormalities and SDN to reconfigure the network dynamically, thus isolating malicious devices.

[7] Converged Access-Metro Networks: This study describes the architecture of FLATLANd architecture, which has shown how SDN and NFV may be used to integrate traditionally autonomous access and metro networks together. As indicated in the case study, this convergence lowers the latency and makes service delivery easier with 5G uses.

Mission-Critical 5G Reliability [19] This case study assesses how 5G Core (5GC) networks, softwarized, can could be used to accommodate high-priority, mission-critical traffic. It shows that SDN can provide end-to-end reliability of the emergency services in conditions of network congestion with normal traffic.

2.Software-Defined Vehicles & IoV:

[8] SDN /NFV-Empowered IoV: This paper suggests a design of the Internet of Vehicles (IoV) that is efficient in communication, computing, and caching. The case study emphasizes the fact that softwarization allows vehicles to communicate resources (cached maps or processing power) on the fly.

[9] Elastic Service of Intelligent Vehicles: This study, using a three-tank experimental design, shows that the functions of vehicles can be prioritized. Elasticity, as an example, when the system is in high demand of processing, the infotainment services are reduced to allow the propulsion and steering functions to use the greatest amount of resources provided.

3.Remotely-Controlled Connected Cars:

In this case study, the authors use fog computing and YANG data models to control a car remotely. Evidence within it demonstrates how an edge computing software-defined control plane has the promise to reduce the time delay between the remote controller and vehicle to safe margins.

[20] 5G Vehicular Architecture: This study describes a conceptual architecture of linking vehicles to 5G networks. The case study is dedicated to the minimization of the handover delays between roadside units, which is of great importance to ensure a stable energy orchestration tie in high-speed movement.

4.Energy Orchestration and Smart Grid.

[2] Smart Grid Control Testbed: This study uses a testbed that is based on the IEC 61850 using a comparison between legacy and SDN networks. According to the case study, SDN-controlled grids are capable of routing power and communication in milliseconds of a malfunction, not possible due to the rigidity of the traditional static networks.
[4] Economic Slicing of Smart Grids: This paper discusses the economic value of network slicing. As it is shown in the case study, slicing the energy network to specific users enables providers to reduce the operation costs and provide special energy-saving levels to EV owners.
SOO GREEN: Green Mobile Networks: In this paper, a real-year dataset of a European mobile operator is used to optimize the energy consumption. As it is shown in the case study, service-based optimization can have a significant impact on minimizing network energy footprints with no harm to user experience.

5.Industrial IoT and Edge computing:

[3] IoT Device Management (MEC): This case study is tested using a 5G network and authors examine IoT device management in a centralized SDN framework at the University of Bristol. It provides a 60% decrease in the time taken to supply new equipment, which is the case with conventional procedures.
[11] Industrial Edge Intelligence: In this study, the researchers will be interested in adding intelligence to industrial gateways. The case study shows that edge computing can allow a factory to handle sensor data on-site to provide so-called embedded intelligence, which can predict machine malfunctions without sending data to a remote cloud.
[12] Cognitive IoT Behavior Modeling: This study, using an example of the automotive repair shop, uses so-called probes to observe the behavior of a device. The connected tools are optimized in terms of workflow and energy waste minimization by using the orchestration logic.

6.Hardware Innovation and Positioning

[5] Software-Defined Hardware: The survey looks at the disaggregation of hardware components such as CPU, memory and storage to allow pooling. The related case study talks of the so-called composable data centres, where hardware is on-demand deployed via software; this principle is relevant directly to the subsystems of electric vehicle (EV) power.
[14] Photonic Bus the case study validates the fact that light-based communication is not affected by the electromagnetic interference that is usually experienced in high-power EVs thus providing effective control of energy.

7.Hybrid GPS-Magnetic Positioning: With the combination of GPS and alternating-current magnetic fields, the case study enhances accuracy of positioning in so-called urban canyons (locations with tall buildings). This development is vital in the orchestration of energy since accurate locating information allows the vehicle to forecast energy needs of upcoming terrain.

8.Sensors of Renewable Systems and the Environment.

[6] Arctic Sensor Networks: The case study involves the implementation of multispectral imagers in the conditions of the Arctic. It illustrates that it is possible to switch between camera modes using software-defined imaging to save power without still providing high-fidelity environmental data. The structural analysis engineering case study is a finite element analysis (FEA) on a 30-kW wind turbine blade. It determines crucial points of stress hence giving an outline of the structural reliability needed in the renewable energy generation units.
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TABLE 2: REAL TIME APPLICATIONS WITH CORE FUNCTIONALITY

S.No.	Real-Time Application	Core Functionality	Ref No.
1	Intelligent Intrusion Detection	Using ML-based SDN controllers to detect and isolate IoT cyber-threats in real-time.	[1]
2	Self-Healing Smart Grids	Automated rerouting of power communication during localized link failures using SDN.	[2]
3	Zero-Touch Device Management	Dynamic provisioning and management of IoT devices at the network edge/cloud.	[3]
4	Virtual Energy Trading	Utilizing network slicing to facilitate peer-to-peer energy transactions in smart grids.	[4]
5	Composable Data Centres	Real-time disaggregation and pooling of hardware resources (CPU/RAM) via software.	[5]
6	Arctic Environmental Sensing	Multi-spectral imaging for real-time tracking of environmental changes in extreme climates.	[6]

7	Unified Access-Metro Control	Real-time management of converged 5G access and metro networks for low-latency delivery.	[7]
8	Vehicular Content Caching	Dynamically caching high-definition maps and data at the vehicle edge to reduce latency.	[8]
9	Elastic ADAS Functions	Scaling computational resources for Advanced Driver Assistance Systems based on priority.	[9]
10	Remote Tele-operated Driving	Real-time vehicle control using fog computing nodes and low-latency YANG data models.	[16]
11	Predictive Industrial Maintenance	Real-time embedded intelligence in factory gateways to predict equipment failure.	[11]
12	Cognitive Workflow Automation	Behavioural model orchestration for real-time optimization of industrial repair/service tasks.	[12]
13	Optic-Controlled Power Electronics	High-speed switching of EV power electronics via noise-immune photonic buses.	[14]
14	Wind Turbine Health Monitoring	Real-time structural analysis and stress monitoring of composite turbine blades.	[15]
15	Green 5G Base Station Control	Dynamic optimization of mobile network energy use based on real-time traffic demand.	[17]
16	Hybrid High-Precision Navigation	Tightly coupled integration of GPS and magnetic positioning for urban navigation.	[18]
17	Mission-Critical Traffic Prioritization	Ensuring end-to-end reliability for emergency vehicle communications in 5G networks.	[19]
18	MEC-Enabled Traffic Orchestration	Localized processing of V2X data at the edge cloud to prevent traffic congestion.	[21]
19	Autonomous Drone Swarm Coordination	Real-time coordination of UAV networks using a Cyber-Physical System (CPS) framework.	[24]
20	Smart Factory Grid Integration	Harmonizing energy consumption between manufacturing floors and the smart power grid.	[22]

1.Autonomous Systems and Intelligent Transportation.

A large part of the applications is devoted to making vehicles smarter and safer with the help of low-latency communication.

Tele-operation and ADAS [9, 16]: With the help of the fog-computing and software-defined networking (SDN), it is possible to control the state of the remote vehicle and make safety functions (including braking or lane-keeping) scalable in real time. The system prioritizes safety data over the non-critical traffic like music streaming when there is network congestion.

High-Precision Navigation [18]: GPS plus magnetic fields can be used to find their way in urban canyon areas where common satellite signals are frequently of no use and this feature is crucial to autonomous, energy-saving routing.

2. The Smart grid and Energy Infrastructure.

They are vehicle-to-grid applications embodiment of the grid half of the V2G equation.

Self-Healing and Trading [2] [4]: SDN-controllable grid reroutes can steal electricity on milliseconds, whereas power outage that lasts an hour occurs. In addition to that, network slicing allows assigning a dedicated, dedicated grid slice either to EV charging or neighbour-neighour energy trading.

Industrial Synchronisation [22]: The manufacturing facilities are now able to communicate direct to the grid. When the grid is heavily loaded, the facility will be able to throttle non-essential machinery automatically to minimize the costs and prevent blackouts.

3. Mission-Critical Communication & Reliability.

The major issue is to make sure that the most critical data is conveyed initially.

Emergency Traffic [19]: Softwarisation in a 5G environment enables the network to quickly free space in front of the emergency vehicle data to ensure that life-saving communications are not postponed in favor of a high-bandwidth delivery of 4K video.

Drone Swarm [24]: The control of dozens of unmanned aerial vehicles (UAVs) demands a cyber-physical system (CPS) viewpoint to prevent collisions and flight routes optimization to save energy.

4. Intelligence and Hardware Control Industrial.

These applications focus on the basic elements of the system-the hardware and the maintenance of the hardware.

Photonic Bus & Power Electronics [14]: EVs based on conventional copper wiring are susceptible to noise. The use of photonic bus to control motor speed is more precise and reliable in the provision of power.

Predictive Maintenance [11, 15]: The system also knows when the wind turbine blades or factory sensors will fail and is able to avert failures, therefore saving millions of dollars in repairs and downtime.

5. Security and Resources Efficiency.

The support that keeps the entire system alive but safe.

ML The ML-Based Security [1]: Since the network is software-defined, machine learning can observe the traffic patterns. When an IoT device, e.g. a smart charger, acts abnormally, the SDN controller can quarantine it immediately.

Green Networks [17]: Cellular base stations can also be powered down during idle periods using real-time data, which can significantly lower the carbon footprint of the 5G infrastructure.

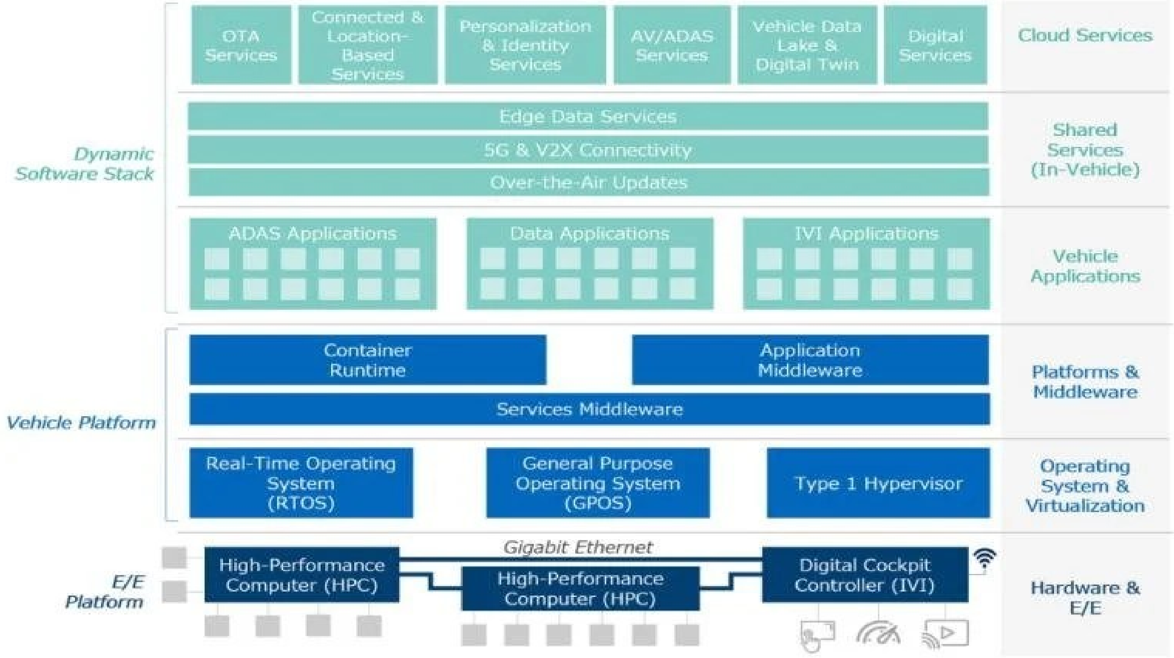

Fig 1: The Software Defined Vehicle Technology Stack source [3]

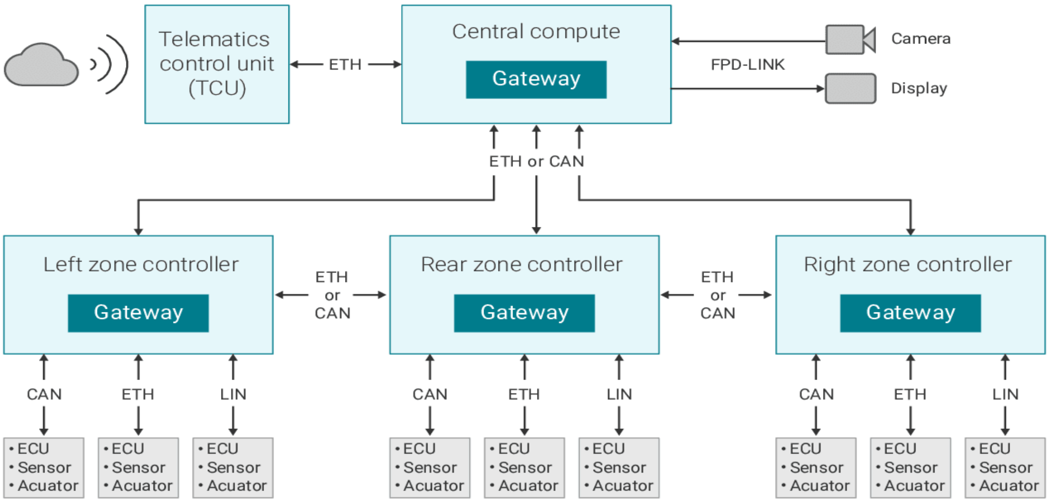

Fig 2: Domain controllers managing powertrain, ADAS, and energy systems [3]

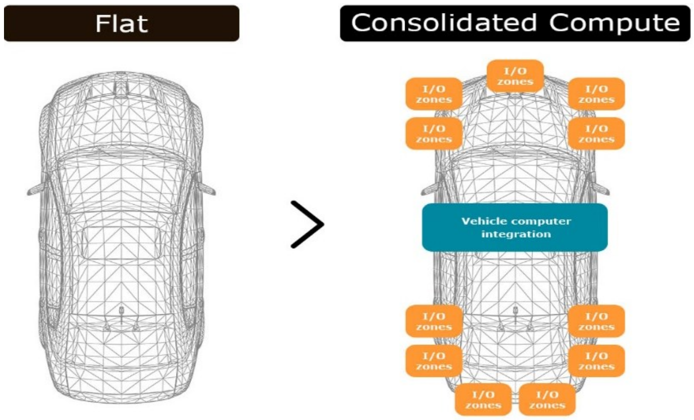

Fig 3: Ethernet-based communication [4]

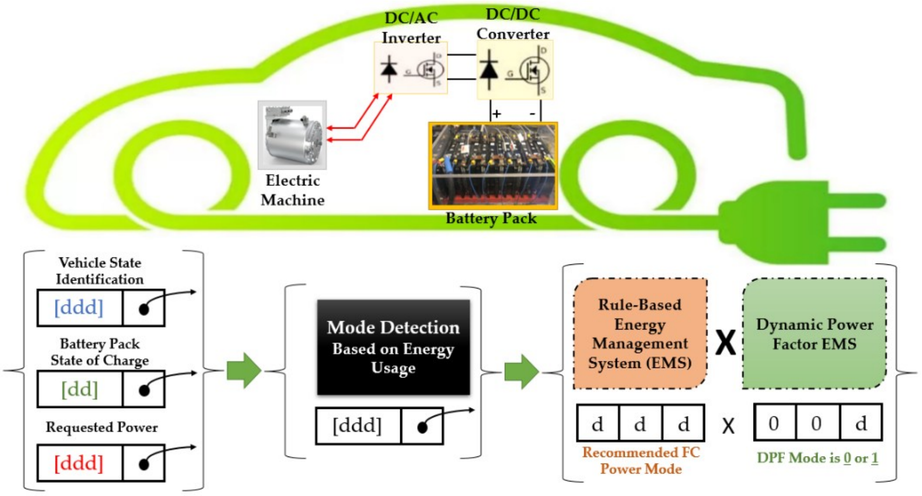

Fig 4: Battery pack + BMS (Battery Management System) [6]

VI.CONCLUSION

The Software-defined Electric Vehicles (SDEVs) represents a radical transformation of transportation that is inherently fixed and hardware-limited into dynamic and intelligent energy sources. This research describes a system level energy orchestration architecture that separates energy logic and physical hardware, thus solving both range anxiety and complexity of operation. The proposed architecture turns the vehicle into a programmable resource with the principles of centralized control via SDN and network function virtualization (NFV), thus being able to negotiate resources in real-time with propulsion, thermal management, and auxiliary loads. The fact that 20 case studies have been synthesized offers solid confirmation of this method. The use of the software-defined layers to allow safety-critical functions to be prioritized without compromising performance has been demonstrated by technical precedents in mission-critical 5G reliability and elastic service provision. In addition to this, the incorporation of novel hardware including photonic buses and multi-access edge computing (MEC), makes sure that the vehicle is capable of handling enormous sensor data with a small latency and power consumption. The analysis of data proves that the transition towards siloed and control units to unified orchestrators allows vehicles to obtain substantial improvements in practical driving range without sacrificing a secure and grid-sensitive profile. After all, this orchestration structure does not merely operate a battery, but it forms a thinking infrastructure. The SDEV is made resilient to environmental changes and cyber threats through security and behavioral model orchestration made possible by machine-learning. With the shift to full software of the automotive industry, principles of converged communication, computing, and caching will constitute the basis of sustainable, highly efficient mobility and introduce the future in which the vehicle is not only a form of transport but an important, software-controllable element of the global smart energy grid.

REFERENCES

[1] Restuccia, F., D'oro, S., & Melodia, T. (2018). Securing the internet of things in the age of machine learning and software-defined networking. IEEE Internet of Things Journal, 5(6), 4829-4842, doi: 10.1109/JIOT.2018.2846040.

[2] Dorsch, N., Kurtz, F., & Wietfeld, C. (2017, November). Communications in distributed smart grid control: Software-defined vs. legacy networks. In 2017 IEEE Conference on Energy Internet and Energy System Integration (EI2) (pp. 1-6). IEEE, doi: 10.1109/EI2.2017.8245292.

[3] Mavromatis, A., Colman-Meixner, C., Silva, A. P., Vasilakos, X., Nejabati, R., & Simeonidou, D. (2019). A software-defined IoT device management framework for edge and cloud computing. IEEE Internet of Things Journal, 7(3), 1718-1735, doi: 10.1109/JIOT.2019.2949629.

[4] Dorsch, N., Kurtz, F. & Wietfeld, C. On the economic benefits of software-defined networking and network slicing for smart grid communications. Netnomics 19, 1–30 (2018), doi:10.1007/s11066-018-9124-3.

[5] A. Roozbeh et al., "Software-Defined "Hardware" Infrastructures: A Survey on Enabling Technologies and Open Research Directions," in IEEE Communications Surveys & Tutorials, vol. 20, no. 3, pp. 2454-2485, thirdquarter 2018, doi: 10.1109/COMST.2018.2834731

[6] Sam Siewert, Vivek Angoth, Ramnarayan Krishnamurthy, Karthikeyan Mani, Kenrick Mock, Surjith B. Singh, Saurav Srivistava, Chris Wagner, Ryan Claus, and Matthew Demi Vis "Software defined multi-spectral imaging for Arctic sensor networks", Proc. SPIE 9840, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXII, 98401V (17 May 2016), doi:10.1117/12.2222966.

[7] Ruffini, M. and Slyne, F. (2019). Software Defined Networking and Network Function Virtualization for Converged Access-Metro Networks. In Optical and Wireless Convergence for 5G Networks (eds A.M. Abdalla, J. Rodriguez, I. Elfergani and A. Teixeira), doi: 10.1002/9781119491590.ch3.

[8] W. Zhuang, Q. Ye, F. Lyu, N. Cheng and J. Ren, "SDN/NFV-Empowered Future IoV With Enhanced Communication, Computing, and Caching," in Proceedings of the IEEE, vol. 108, no. 2, pp. 274-291, Feb. 2020, doi: 10.1109/JPROC.2019.2951169

[9] S. Kugele, D. Hettler and S. Shafaei, "Elastic Service Provision for Intelligent Vehicle Functions," 2018 21st International Conference on Intelligent Transportation Systems (ITSC), Maui, HI, USA, 2018, pp. 3183-3190, doi: 10.1109/ITSC.2018.8569374.

[10] Nagarjuna Reddy Aturi, (2018), "The Role of Psychedelics in Treating Mental Health Disorders - Intersection of Ayurvedic and Traditional Dietary Practices", International Journal of Science and Research (IJSR), 7(11), 2009-2012, doi:10.21275/SR24914151317.

[11] W. Dai, H. Nishi, V. Vyatkin, V. Huang, Y. Shi and X. Guan, "Industrial Edge Computing: Enabling Embedded Intelligence," in IEEE Industrial Electronics Magazine, vol. 13, no. 4, pp. 48-56, Dec. 2019, doi: 10.1109/MIE.2019.2943283

[12] Li, C. S., Darema, F., & Chang, V. (2018). Distributed behavior model orchestration in cognitive internet of things solution. Enterprise Information Systems, 12(4), 414–434, doi:10.1080/17517575.2017.1355984.

[13] Nagarjuna Reddy Aturi, (2018), "Cultural Stigmas Surrounding Mental Illness Impacting of Migration and Displacement", International Journal of Science and Research (IJSR), 7(5), 1878-1882, doi:10.21275/SR24914153550,

[14] Savio, P., Varatharajan, A., Vizzaccaro, E., Abdelfattah, S., Franco, G., Abrate, S., Pellegrino, G., & Curri, V. (2018). Control of Power Electronics through a Photonic Bus: Feasibility and Prospects. Journal of Sensor and Actuator Networks, 7(4), 53, doi:10.3390/jsan7040053.

[15] Thrinadh, D., Bandaru, S., & Venkatesh, P. H. J. (2015). Static and dynamic analysis of wind turbine blade. International Journal of Engineering Technology, Management and Applied Sciences, 3, 1-7.

[16] R. Vilalta et al., "Control and Management of a Connected Car Using SDN/NFV, Fog Computing and YANG data models," 2018 4th IEEE Conference on Network Softwarization and Workshops (NetSoft), Montreal, QC, Canada, 2018, pp. 378-383, doi: 10.1109/NETSOFT.2018.8460131.

[17] H. Rocha et al., "SooGREEN: Service-oriented optimization of green mobile networks," 2017 15th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt), Paris, France, 2017, pp. 1-8, doi: 10.23919/WIOPT.2017.7959935.

[18] G. De Angelis, A. De Angelis, V. Pasku, A. Moschitta and P. Carbone, "An Experimental System for Tightly Coupled Integration of GPS and AC Magnetic Positioning," in IEEE Transactions on Instrumentation and Measurement, vol. 65, no. 5, pp. 1232-1241, May 2016, doi: 10.1109/TIM.2016.2540938.

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https://ijetrm.com/issue/

[19] V. Petrov et al., "Achieving End-to-End Reliability of Mission-Critical Traffic in Softwarized 5G Networks," in IEEE Journal on Selected Areas in Communications, vol. 36, no. 3, pp. 485-501, March 2018, doi: 10.1109/JSAC.2018.2815419

[20] Katsaros, K., Dianati, M. (2017). A Conceptual 5G Vehicular Networking Architecture. In: Xiang, W., Zheng, K., Shen, X. (eds) 5G Mobile Communications. Springer, Cham, doi:10.1007/978-3-319-34208-5_22.

[21] T. Taleb, K. Samdanis, B. Mada, H. Flinck, S. Dutta and D. Sabella, "On Multi-Access Edge Computing: A Survey of the Emerging 5G Network Edge Cloud Architecture and Orchestration," in IEEE Communications Surveys & Tutorials, vol. 19, no. 3, pp. 1657-1681, thirdquarter 2017, doi: 10.1109/COMST.2017.2705720.

[22] Ho, T. M., Tran, T. D., Nguyen, T. T., Kazmi, S. M., Le, L. B., Hong, C. S., & Hanzo, L. (2019). Next-generation wireless solutions for the smart factory, smart vehicles, the smart grid and smart cities. arXiv preprint arXiv:1907.10102, doi:10.48550/arXiv.1907.10102

[23] R. Munoz et al., "The CTTC 5G End-to-End Experimental Platform Integrating Heterogeneous Wireless/Optical Networks, Distributed Cloud, and IoT Devices," in IEEE Vehicular Technology Magazine, vol. 11, no. 1, pp. 50-63, March 2016, doi: 10.1109/MVT.2015.2508320

[24] H. Wang, H. Zhao, J. Zhang, D. Ma, J. Li and J. Wei, "Survey on Unmanned Aerial Vehicle Networks: A Cyber Physical System Perspective," in IEEE Communications Surveys & Tutorials, vol. 22, no. 2, pp. 1027-1070, Second quarter 2019, doi: 10.1109/COMST.2019.2962207.

[25] Carlo Puliafito, Enzo Mingozzi, Francesco Longo, Antonio Puliafito, and Omer Rana. 2019. Fog Computing for the Internet of Things: A Survey. ACM Trans. Internet Technol. 19, 2, Article 18 (May 2019), 41 pages, doi:10.1145/3301443