Review

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Quality of Service and Associated Communication Infrastructure for Electric Vehicles

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Posted Date: 19 September 2023

doi: 10.20944/preprints202309.1204.v1

Keywords: Electric Vehicle, Grid Energy, Quality of Service, EV Communication, Energy Management, Planning and Operation.

Review

Quality of Service and Associated Communication Infrastructure for Electric Vehicles

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Abstract: Transportation electrification has been identified as a crucial shift to be made for achieving energy security and emission reduction targets. Electric Vehicles (EVs) play a significant role in achieving these targets; therefore, there is a growing trend to develop new EV technologies and associated infrastructure. Along with these developments, EVs' Quality of Service (QoS) aspects should be enhanced to increase the number of EVs on the road. Various QoS factors are defined to assess the QoS of EVs, and one of the two aims of this paper is to provide a comprehensive review of these factors. The other aim is to review recent developments of associated communication technologies which are essential for exchanging information between EVs and charging stations. This paper serves as a comprehensive review and useful reference for researchers working on QoS aspects of EVs and associated communication systems aiming to enhance the QoS.

Keywords: electric vehicle; grid energy; quality of service; EV communication; energy management; planning and operation

1. Introduction

Governments worldwide prioritise decarbonisation as a critical mission to combat climate change due to greenhouse gas emissions. Electric vehicles (EVs) significantly contribute to clean energy and integrate renewable energy resources into power networks [1-4]. As the transportation sector is the second largest producer of greenhouse gas emissions, the proliferation of EVs has gained unprecedented attention in reducing pollution and carbon emissions [5]. Figure 1 shows the concentration of carbon dioxide in the atmosphere measured in parts per million (ppm) over the years [6]. Governments and states must take appropriate measures to address environmental concerns. For instance, the Western Australian government in Australia has established an EV working group to promote a more sustainable environment and support future industries [7]. The government encourages the use of battery-operated vehicles to reduce greenhouse gas emissions.

Several studies have compared the technical performance of conventional internal combustion engine (ICE) vehicles versus EVs [8-10]. Electric Vehicles are viewed as advanced energy storage systems that use converters to transfer excess energy to the grid. Achieving optimal EV battery operations requires a well-designed energy management system (EMS) [11,12]. In [13], several energy storage systems were analysed for EVs, focusing on enhancing battery life and improving QoS in EMS. Battery swapping systems can also help improve QoS in battery management systems. To ensure the safety of EV users, charging infrastructures are implemented in various locations (indoor and outdoor) [14], with installation standards set by the International Electrotechnical Committee (IEC) [15]. In the early 2000s, EV batteries were considered interim, with unsatisfactory performance compared to ICEs, leading researchers to focus on the energy management system to enhance battery life and improve QoS [16]. As EVs continue to gain popularity, research studies are now focused on improving charging infrastructure performance to enhance QoS further [17].

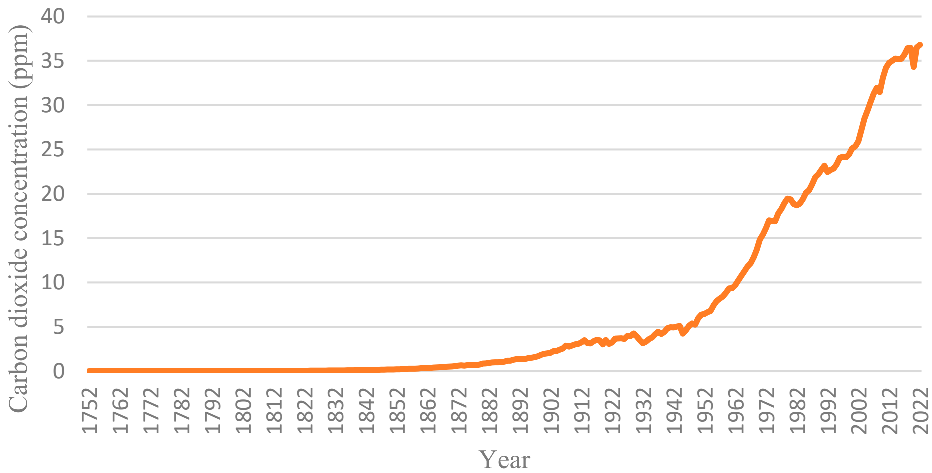

Figure 1. Carbon-dioxide Concentration in the Atmosphere.

Improving the QoS for electric vehicles requires a significant emphasis on communication. The Vehicle-to-Everything (V2X) communication network has been enhanced to support reliable, high-speed data transfer. With the advent of the fifth-generation (5G) and subsequent communication technologies, it is expected that the requirements of vehicular communications can be met, enabling higher multi-Gbps data transfer with ultra-low latency. In [18], there is a detailed analysis of the sixth-generation (6G) technology that supports wireless communication. In [19], V2X is evaluated with two communication technologies, namely dedicated short-range communication (DSRC) and long-term evolution for V2X (LTE-V2X), with a focus on ensuring reliability and security in data transmission. The 5G Automotive Association (5GAA) is a global cross-industry organisation that collaborates with automotive technology and telecommunication industries to develop future mobility and transportation services. The 5GAA currently emphasises Cellular-V2X (C-V2X) in EVs to enhance safety and transfer necessary information between EVs and charging infrastructure [20].

This review article presents a detailed examination of the QoS of EVs, along with an overview of the various communication system technologies available, recent developments, upcoming trends, and challenges. The paper is structured as follows: Section II introduces the different types of battery vehicles and their unique characteristics. Section III encompasses a comprehensive analysis of the quality-of-service aspects that are associated with EVs. The communication of EVs is discussed in Section IV. Finally, Sections V and VI present future research directions and overall conclusions.

2. Battery Electric Vehicles

In 1832, Robert Anderson created the first small-scale electric carriage, while inventors from Hungary, the Netherlands, and the United States also developed battery-powered vehicles [21]. Today, global sales of electric vehicles (EVs) have risen to about 3.2 million in 2020, showing a yearly growth of approximately 43% [22,23]. Figure 2 demonstrates the number of EVs on the road globally. EVs fall into four categories: hybrid electric vehicles (HEV), plug-in electric vehicles (PHEV), fuel cell electric vehicles (FCEV), and battery electric vehicles (BEV). The different drive technologies used in EVs are shown in Figure 3, and more details can be found in [24].

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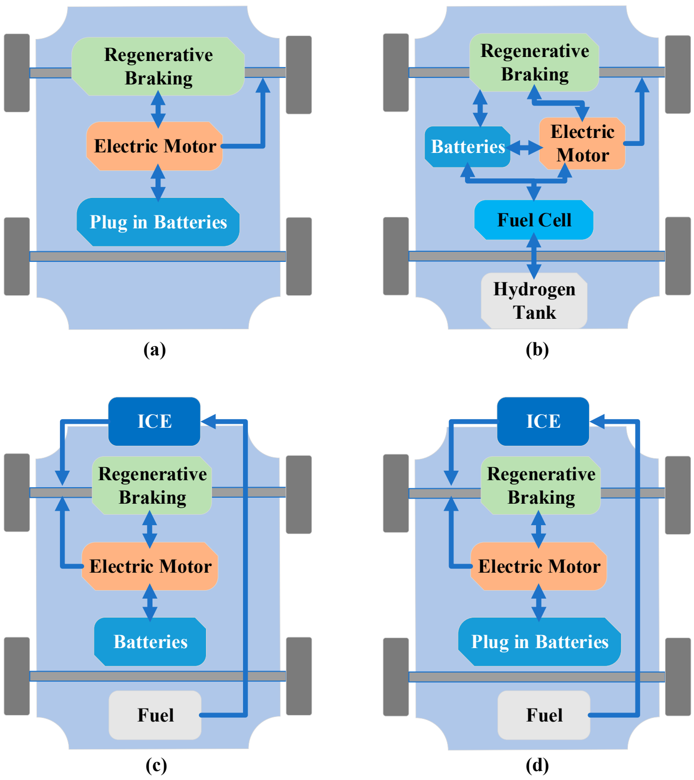

Figure 2. Drive technology in (a) BEV, (b) FCEV, (c) HEV, and (d) PHEV.

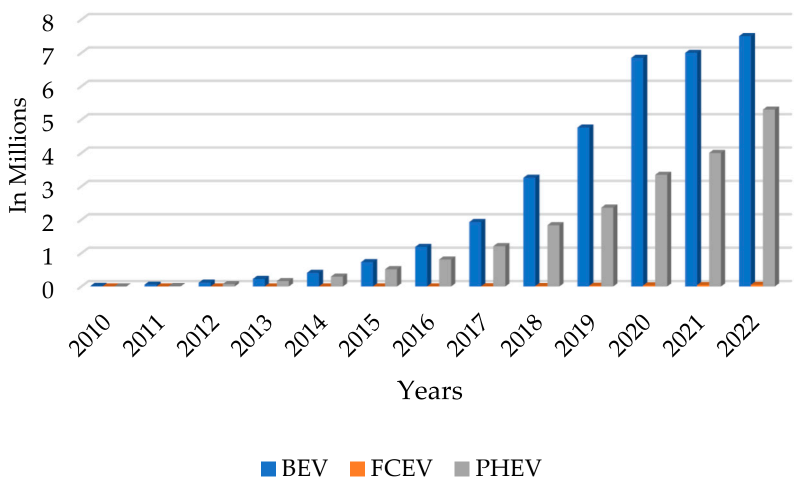

Figure 3. Number of EVs on the roads worldwide.

Electric vehicle charging can be done in two ways: unidirectional or bidirectional. Control units communicate important charging details such as the amount of charge, flow type, and charging time. Hybrid electric vehicles (HEVs) are powered by internal combustion engines (ICE) and electric propulsion mechanisms. HEVs are classified as series, parallel, and combined hybrid EVs based on their configuration [10,25-28]. Plug-in hybrid electric vehicles (PHEVs) can help reduce carbon emissions and transportation costs [29-31]. Battery electric vehicles (BEVs) use electricity as their primary power source, producing zero emissions. Researchers are exploring different ideas to develop a workable model for BEVs.

A comprehensive analysis of battery technologies used in EVs is presented in the study [32,33]. EVs can benefit from various battery technologies, including lead-acid (Pb-PbO2), nickel-cadmium

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(Ni-Cd), nickel-metal-hydride (Ni-MH), zinc-bromine (Zn-Br2), sodium chloride and nickel (NA-NiCl), sodium-sulphur (Na-S), and lithium-ion. Lithium-ion batteries are widely preferred due to their high energy density and low self-discharge capacity [34]. In-depth research on the thermal management of Li-ion batteries for EVs is discussed in [35]. EV batteries' technical and financial aspects are assessed in [36]. Charging and discharging batteries in EVs can cause battery aging, affecting their ability to interact with the grid. However, the smart grid can establish a two-way relationship between EVs and the grid. Bidirectional power flow can alleviate the pressure on energy generators and increase customer profits [37]. A study on using power generated from EVs and energy storage for smart homes is presented in [38], demonstrating that the power produced by EVs can be utilised for residential benefits. In this article [39], a new approach to communication networks and electric vehicles for smart grids and distributed generation systems is presented. The article identifies various challenges and constraints and provides recommendations to assist researchers and academics in addressing them effectively.

3. Quality of Service in Electric Vehicles

When it comes to assessing the performance of a service or technology, QoS is a crucial indicator that can be demonstrated both theoretically and practically to end-users. In the context of Electric Vehicles, QoS refers to the improvement of a particular influencing factor and the overall impact on service performance that determines a user's level of satisfaction [40]. This research paper delves into various QoS aspects, including energy demand, cost, scalability, sizing, control of charging schedule, and resource allocation. The following sections provide detailed reviews of these aspects, and Figure 4 illustrates the QoS aspects discussed in this review paper. Table 1 compiles some of the QoS parameters references used in this review paper.

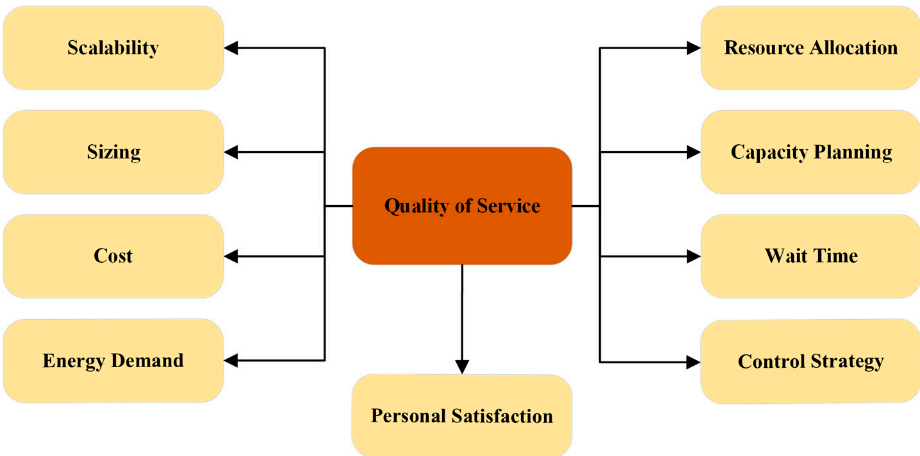

Figure 4. Quality of Service aspects.

Table 1. QoS Parameter reference mapping.

QoS Parameters	References
Cost	[41-51]
Scalability	[42,52,53]
Sizing	[43,44,54,55]
Energy Demand and optimisation	[41,42,56-64]
Resource Allocation	[41,45-49,55,62,64-69]
Capacity Planning	[50,55,66]
Personal Satisfaction	[64,70,71]
Wait Time	[48,51,67-69,72]
Control Strategy	[68,69]

3.1. Energy Demand and Optimisation

Efficient energy management is crucial in ensuring quality of service (QoS) and developing effective energy policies for specific methodologies. To achieve this, a QoS model based on network calculus was introduced in [56]. This model designs the service model of each charging station (CS) based on the energy demand, arrival rate, and departure rate of electric vehicles (EVs). The QoS requirements are met within a pre-defined time frame by considering the arrival, departure, and minimum departure curves. Thus, the model achieves superior QoS at CS under various conditions and service policies.

In [57], a game theory framework was proposed to maximize the efficiency of CS and EV. This approach employs a mathematical model to analyze solutions for diverse scenarios involving multiple parties. A mathematical formulation based on network calculus was presented to satisfy the QoS constraint at EV charging stations. The solution developed a game-based supply function equilibrium through a theoretical hybrid optimization model. The results obtained reduced peak time load and improved voltage profile for charging stations.

However, some drawbacks in energy load management are analyzed in [58] during bidirectional energy transfer between Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G). Despite these challenges, the QoS model and game theory framework represent significant strides in energy management and are critical in ensuring sustainable energy practices.

In the field of electric vehicles, there have been significant advancements in bidirectional power transfer systems. One such system, presented in [59], is a Peer-to-Peer (P2P) energy trading mechanism between energy service providers and customers. The system uses a fuzzy-based approach to match the energy trading between single consumers to multiple providers and multiple consumers to multiple providers. Additionally, [60,73] proposes an optimisation model for the charging infrastructure of EVs, which aims to minimise overall installation, maintenance, and operation costs while ensuring system reliability checks based on DC power flow to guarantee Quality of Service (QoS). QoS, in this case, is defined as the overall disposable charging time for EVs to reach their overall travel distance. Future research will focus on linearised approaches for the running EVs' power system reliability checks based on AC power. The bidirectional power transfer between EV and grid [74] is depicted in Figure 5.

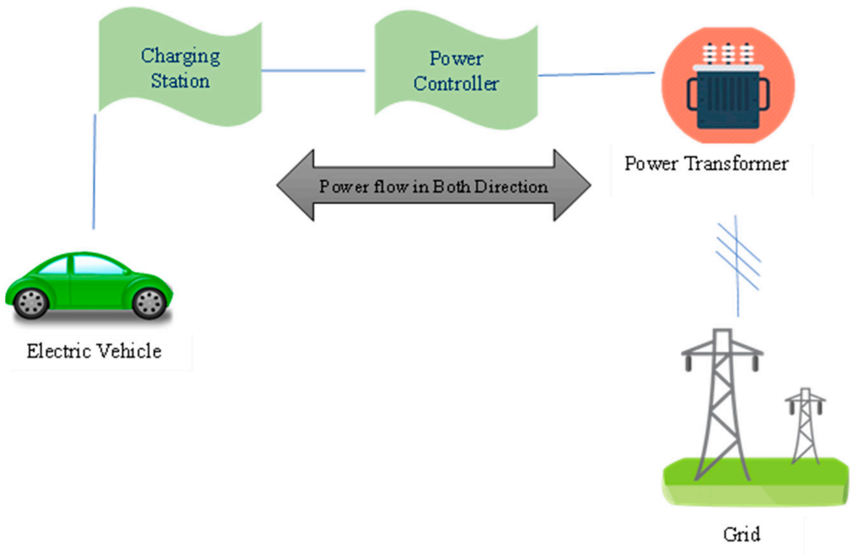

Figure 5. Bidirectional Power Transfer between EV and the Grid.

In [61], an admission control scheme that prioritizes EV users with higher power ratings and who are willing to pay more is implemented. A high demand for charging from different PHEVs can collectively put the grid in a critical condition, which prompted the proposal of a new methodology that limits charging requests simultaneously in a distributed system while providing service

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differentiation among users. A future recommendation is to suggest a QoS-aware admission control in a realistic pattern and to investigate different classes of PEVs with other CS.

A QoS model was implemented in [56], which employed an integrated traffic model to enhance energy demand at different locations and times while measuring the performance of CSes under various conditions. The main challenge is to reduce the impact on the electric network system during high charging requests. To analyze the performance of communication networks during data flow, queuing theory was utilized to examine service time, waiting time, queue length, and network calculus. Network calculus is a widely used mathematical model mainly in communication networks and other human-made systems, which provides a theoretical framework for evaluating QoS performance. Furthermore, a network calculus-based QoS constrain model was adopted in [41] to achieve maximum utilization. The proposed methodology helped flatten the total peak-to-average load profile, converged to the Nash equilibrium, and showed potential for real-time operation. Future studies were suggested by extending static-game to dynamic-game by increasing the number of EVs.

3.2. Scalability

Ensuring that Quality of Service (QoS) is maintained while accommodating an increasing number of electric vehicles or a more complex world is what scalability is all about. In [52], a distributed software-defined networking (SDN) / OpenFlow approach was implemented to enhance scalability, reduce controller workload, improve response time, manage QoS, and boost energy efficiency among controllers in the smart grid. The SDN/OpenFlow model can be theoretically implemented to demonstrate the likelihood of queue length for an individual charging station and validated through simulation, as far as our knowledge goes.

In [53], over 80,000 real-time charging data from different parts of the world are collected, and the charging characteristics are analysed to manage load balancing and shift loads from peak to off-peak hours using smart charging technology. The findings identify the optimal charging pattern with the most negligible impact on customers. Specific charging locations are suggested for the better potential for load reduction with low implications for EV users. This leads to improved scalability of the charging network, and the Quality of Charging service is defined as the "percentage of energy that the customers have changed in the measured real-life cases." Future research is recommended to develop the cost function that connects the quality of charging service to the customer experience.

In [42], a new methodology is proposed to solve the problems of scalability, cost, demand response, and charging time by sharing the locations of EVs using the IEEE 802.11p standard used to add Wireless Access in Vehicular Environments (WAVE) in vehicular communications. The EVs integrate with the grid network to transfer the required information based on this information. The proposed solution uses real-time integration. The proposed solution assumes that the EVs travel at a specified speed and communicate with Access Points (APs) using the IEEE 802.11p protocol within their transmission range. Based on this information, the APs suggest the nearest Charging Station (CS) and allocate the time required for the EVs to charge. The EVs can only charge the required power to reach their home destination within the allotted time. Finally, when the EVs arrive at their home destination, they can charge the battery 100%. This reduces the queue time in public CS and improves the QoS in cost, wait time, and resource allocation.

3.3. Sizing

To enhance the infrastructure for electric vehicle charging stations, it is crucial to address the issue of sizing. Sizing is one of the key QoS concerns that needs to be further explored and resolved to reduce network load distribution. Recent research has been focused on identifying the best locations and sizes for public charging stations. The primary concern around charging stations is minimizing the investment and running costs. An intelligent charging technology can be employed to control the charging profiles of electric vehicles, achieving a lower operational cost or a peak-to-average power consumption ratio for the charging stations. In [54,75], the author proposes an optimization framework to reduce operating costs for charging stations by achieving a certain level of QoS for the electric vehicles, thus addressing the sizing issue. The author in [76], has developed a

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divided rectangle method for better vehicle fuel efficiency and drivability. Our optimization algorithm solved a multi-input, multi-output problem using a state-space model.

In order to ensure high quality of service in terms of cost reduction and allocation of resources, a two-stage stochastic sizing method was introduced in [43] for the selection of charging stations (CS) in the parking area to schedule a charging time for the incoming electric vehicles (EVs). The author has considered several factors to achieve this level of QoS, such as locating a busy CS with a probability not exceeding 0.1, the probability of waiting for more than a specified time and ensuring that the probability of the charging time of EV exceeding its parking time is not above 0.05.

Charging service providers worldwide are working towards implementing photovoltaic-integrated fast-charging stations to use renewable energy resources better. A Markov Chain model is proposed in [44] to explore the stochastic process of PV panel utilisation. The optimisation issues with sizing are formulated to determine the optimal number of PV panels in CS, which would minimise operation costs while ensuring QoS requirements. An optimal sizing scheme is finally implemented for PV-integrated fast charging along highways to minimise operation costs and maintain QoS. The author also provides a case study to validate the feasibility of the proposed optimisation model. A future research direction is recommended where the interaction between multiple CS is expected to be evaluated more precisely.

3.4. Resource Allocation

The study in [77], delves into the energy consumption of EVs in the grid and examines recent instances of EV charging controls and optimization methods utilized for energy management of large-scale EVs charging on the grid. Managing energy in this aspect can be challenging. It involves achieving load shifting, peak shaving, and minimizing high electricity consumption expenses while maintaining a robust grid operation. This research includes BEVs, which have more massive battery banks requiring longer charging periods and higher energy consumption capacity, and PHEVs, which have smaller battery capacities, in its definition of EVs charging on the grid.

In order to achieve optimal QoS, resource allocation plays a crucial role, as highlighted in [45]. The author utilized Pareto optimality to determine the best possible outcome while avoiding any loss. To further enhance QoS, demand management strategies such as stationary and mobile demand management were also explored to reduce costs. Additionally, the author recommended future research to focus on improving planning and operation simulation models to consider the EV charging demand at an individual level rather than an aggregate level.

Maintaining a balanced load in a CS network is crucial for ensuring high quality of service. However, sudden, or additional load requests can lead to critical issues with the power grid. A study referenced as [62] proposed a decentralised control mechanism based on game theory to address this problem. The technology aims to achieve three primary goals: offer attractive incentives to users to opt for low-demand charging stations, maximise revenue by serving more customers with the same grid resources, and provide charging services to users with a certain level of QoS. This innovative framework has shown a significant improvement in guaranteed QoS and is expected to impact the overall performance of the network positively.

When providing quality service, it is essential to consider range anxiety for electric vehicles. That's why a new concept called wireless charging highways (WCH) has been introduced in [55,78] to allow EVs to recharge while driving long distances. A joint capacity model has been developed to ensure adequate planning for power and communication resources. Additionally, a Markov chain-based model has been designed to capture the dynamics of the WCH. With this model, we can estimate the outage probability and related profit and determine the QoS accordingly.

Recently, battery swapping technology has become more popular as the market for battery electric vehicles (BEVs) grows. In a study cited as [46,47], a closed-loop supply chain-based system for battery swapping and charging was implemented using a game theory framework. This system uses Battery Swap Stations (BSS), which allow EVs to exchange their drained battery for a fully charged one. Network calculus is used to queue these models by adapting information such as the arrival, departure, and minimal departure curves from the EVs. The proposed game theory model incorporates the Stackelberg Equilibrium (SE) concept with a differential equation-based hybrid algorithm. Simulation results have demonstrated the efficacy of this methodology, ensuring Quality of Service (QoS) for both the Charging Stations and Battery Swapping Stations.

Efficient power allocation and resource management are crucial in a fast-charging network. In a research study [65], an energy storage device in CS networks to regulate the energy supply from the grid and minimize queue time. The control scheme also directs EVs to the next available CS, ensuring a seamless charging experience. The study examined various conditions, including CS with similar charging capabilities, power allocation optimization with limited customers enabled with routing, and optimal allocation of power from the grid and EVs to CS. The simulation results demonstrated that customers receive guaranteed QoS, ensuring that the nearest CS does not block them to their current location. The researchers have also suggested future directions, including using wireless network technology such as LET-A, 5G, and WiMAX.

3.5. Cost

The popularity of electric and plug-in electric vehicles (EVs and PEVs) has highlighted the importance of considering the cost of charging at charging stations (CS) for quality of service (QoS). In a recent study [48], a new model was proposed to optimize the location of EV charging stations to minimize implementation costs while enhancing charging reliability and anticipated service quality. This model incorporated set theory and real-time location data to track EV trajectories and simulate results. Another study [47] implemented a novel battery-swapping system to improve charging efficiency and minimize costs while ensuring high QoS. This technology also considered the trade-off between charging costs and QoS requirements of a CS. The queuing theory network model employed open and closed queues so EVs could request battery swapping with depleted or fully charged batteries. The Markov decision process verified the numerical results of this model and confirmed the guaranteed QoS. These studies highlight the importance of considering cost and QoS for EV charging stations and offer promising solutions for optimizing these factors.

A strategy for decreasing the expensive operational expenses of charging stations is presented in [63]. This strategy involves using multi-port DC fast-charging stations and comparing various power policies that maintain a price of less than 0.1$/kWh without compromising the guaranteed QoS. [49] proposes a dynamic pricing system for PEV charging services that utilizes deep reinforcement learning (RL). The scheme includes a differential dynamic pricing approach for charging service providers and PEV users. Generally, every charging station has a unique QoS level that matches user expectations. The RL-based differential pricing system can dynamically adjust pricing for multi-service charging infrastructure, ensuring QoS is maintained.

3.6. Personal Satisfaction

Satisfaction with the service provided is a crucial aspect of Quality of Service. To gauge this, researchers have utilized various methods to gather feedback from the general public between 18 and 34. The SERVQUAL framework, a comprehensive research tool, has measured consumer expectations alongside desired service quality. By following the Behavioral Intention approach, policymakers can receive valuable feedback and modify public transport policy. In addressing electric mobility issues during peak hours, a stochastic game was introduced in [64] to study the complex interactions between charging stations and power grids. This helped to define the QoS index, which reflects how the charging process affects customers' charging parameters. The Nash equilibrium was reached through the development of an online algorithm, and its performance was evaluated in collaboration with real-time data from the California Independent System Operator (CAISO). The results showed a 20% reduction in electricity costs and improved QoS concerning charging and waiting time.

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3.7. Capacity Planning

The capacity planning of a CS is crucial to ensure that the QoS is guaranteed. A new framework proposed in [66] aims to enhance the QoS in capacity planning for networked electric vehicle charging infrastructure. The approach aims to provide satisfactory charging services for EV users while minimizing the investment cost for service providers. In addition, the framework ensures that the load demand of a CS complies with the reliable operation of the power grid. The QoS is measured in terms of EV user satisfaction. Increasing the CS facility can be a way to achieve this, but it may also increase the load on the distribution power grid. Therefore, the proposed solution aims to identify the research gap in maximizing QoS user satisfaction within the set budget.

In grid reliability and charging capacity, [50] presents two frameworks that can greatly assist. The first focuses on a more extensive network and offers a price-based control strategy. Users can benefit from incentives at an optimal rate that maximizes social welfare benefits based on energy demand requests. The second framework focuses on smaller networks, where customer demands can be better studied through profiling. To this end, a capacity provisioning mechanism for EV charging stations is proposed. Even with limited charging infrastructure, these frameworks are designed to provide all the necessary information and guaranteed services to meet the desired quality of service.

3.8. Wait Time

Effective service delivery requires prioritising time-saving and productivity-enhancing measures. To ensure QoS, the waiting time of EV users in queues before charging should be measured and optimised. By leveraging queueing theory, the system can be modelled, and control strategies can be implemented to improve the serviceability of a CS. One such strategy involves encouraging EV users to limit their energy demands, enabling a CS to serve more customers and reduce queue length. This proposed model holds promise for further research and development [51].

A model for a heterogeneous urban public charging network (UPCN) with limited public charging stations (PCS) is presented in [67]. The study analyses the waiting time for a charging station using queueing theory, a classic traffic model. The model estimates the travel time, waiting time and charging time for electric vehicles (EVs) and suggests feasible routes to reach a charging station. To optimise the average waiting time, the study uses a genetic algorithm (GA) to add charging stations to the Sioux Falls network randomly. Future studies could analyse the quality of service (QoS) by analysing the dynamic origin-destination matrix and studying EV behaviour patterns.

A method for fast charging of electric vehicles (EVs) using direct current (DC) has been developed [72]. This method aims to reduce wait time and improve the overall user experience. The success of this method is closely tied to the design and management of the charging stations, which should consider factors such as EV waiting time, charging duration, and power rating of the charging stations. The quality of service (QoS) is measured based on these factors, and charging stations with low waiting times and high-power ratings are more likely to attract EVs. The simulation results were verified using queuing theory and data analytics. To further improve the charging station ecosystem, future research should address the needs of a diverse range of EVs and integrate customer behavior into the station design.

3.9. Control Strategy

In a bid to alleviate stress on the power grid and ensure quality of service (QoS) for electric vehicles (EVs), a framework for control resource provisioning was proposed in [68]. The study considered two scenarios: (i) the charging station (CS) was located in a metropolitan area with high demand for charging requests, and (ii) charging requests were acquired in rural areas through profiling studies. By prioritizing reliability, cost, and resource allocation, the framework enabled every EV that approached the CS to receive QoS guarantees, resulting in significant gains. In future, the researchers suggest implementing an additional storage system to reduce strain on the CS and a different resource policy that prioritizes EVs based on their demand requests. In [69], a battery exchange management system was proposed to reduce power grid overload during high demand. A centralized scheme for optimal charging was implemented to achieve a peak-to-average ratio in an intelligent grid environment. Game theory was used to develop a mathematical formulation and simulation for the battery exchange methodology, while a demand-side management system was introduced to enhance QoS. The results showed that EVs spent only a few minutes exchanging batteries at the battery exchange unit, improving queue lengths. The study suggests that similar technology could be used with big data in future research.

3.10. Section Summary

This section comprehensively analyses the various Quality of Service (QoS) aspects, including scalability, resource allocation, sizing, cost, energy demand, control strategy, capacity planning, personal satisfaction, and wait time. The authors consider these QoS factors particularly noteworthy compared to other QoS aspects. For further reference, Table 2 presents a comprehensive summary of the QoS parameters and critical elements from the reference article utilized in this paper.

Table 2. QoS Parameters Reference in Detail.

Reference	Key Terms	QoS Parameter
[56-61]	• Integrated power system based on IEEE-30 bus • Supply function equilibrium (SFE) model-based game theory • G2V and V2G energy transfer • The QoS-aware admission control scheme for PHEV to manage power demand • QoS-based system for P2P energy trading among EV energy providers and consumers • An optimisation model for improved CS infrastructure and to reduce cost	Energy Demand and Optimisation
[42,52,53]	• SDN / OpenFlow model to enhance scalability • Develop an optimisation methodology using real-time data • QoS scheme for Charging EVs (QCEV) is proposed.	Scalability, cost
[48,51,67,72]	• Reduce waiting time and serve more customers • Heterogeneous UPCN model for public CS to reduce wait time and improve QoS • Daily vehicle data is used to model analysis of fast charging CS for EVs, reduced wait time, and improved QoS • An optimisation model is developed that satisfy charging reliability and expected QoS.	Wait time, Cost, Resource Allocation
[41,45-47,49,63,65]	• Battery swapping using closed-loop supply chain charging system • Dynamic pricing for PEV charging services is proposed using deep reinforcement learning (RL) • Pareto optimality standard is implemented to achieve cost and service quality	Resource Allocation, Cost

	• Optimising charging and discharging for maximum utilisation and achieving better QoS • Multi-port DC fast charging station • Stackelberg Equilibrium (SE) concept is proposed in game theory with a differential equation-based hybrid algorithm to achieve better QoS.	
[43,44,54]	• A two-stage stochastic sizing method was proposed for a guaranteed QoS • PV sizing optimisation solution is proposed for minimising guaranteed • Smart charging capabilities	Cost, Sizing
[50,55,66]	• Joint capacity model for V2I enabled wireless charging highways • A new QoS aware framework is proposed for EVCI that links between CI and power distribution networks • Two different frameworks proposed controlling EV customer pricing and regulating request rates to improve QoS	Resource allocation, capacity Planning, Cost
[70,71]	• SERVQUAL framework model for better service quality in HEBs • Survey-based analysis for better service quality in public transport	Personal Satisfaction
[68,69]	• Control resource provisioning framework to improve wait time and QoS • Battery exchange stations are introduced for a smooth load transfer	Control Strategy, Wait Time
[62,64]	• A new dynamic user Behaviour model using a stochastic game approach is developed using data CAISO • Load balancing in a network charging stations	Resource Allocation, Energy Management

Electric vehicles (EVs) are set to benefit from communication capabilities that will enable vehicles to exchange information among themselves, with the infrastructure as well as other devices. The communication systems will be able to support vehicle-to-vehicle (V2V), vehicle-to-everything (V2X), and vehicle-to-infrastructure (V2I) interactions. This integration of QoS and EV communication will provide specific intelligence to the vehicles, creating numerous opportunities to revolutionise future transportation systems. The communication systems will typically include information about EV charging stations and energy management system control aggregates. This will allow for the efficient collection of necessary data from both the charging station and the EV, facilitating better integration and resulting in a higher quality of service (QoS) system.

4. EV Communication Infrastructure

The field of Intelligent Transportation System (ITS) is a fascinating area of research that explores the potential benefits of incorporating electrical vehicle communication to enhance vehicular performance and ensure a high level of quality of service. A comprehensive overview of various ITS applications can be found in [79]. Typically, EV charging is accomplished by physically connecting the EV to a charging outlet. However, innovative wireless power transfer methodologies for EVs have been introduced in [80,81], while a dynamic wireless power transfer technology for power transfer in moving EVs is presented in [82]. A cloud-based framework has been developed to efficiently manage EV charging during peak hours and ensure grid stability [83]. In the realm of EV charging advancements, the Internet of Electric Vehicles (IoEV) is a new technology that highlights EVs' intelligence and their equipped communication tools. In [84], several vehicular communication network technologies related to IoEV are presented, along with current challenges and solutions within the field [85]. EVaaS, or Electric Vehicle as a Service, employs cutting-edge vehicle-to-grid (V2G) technology to enable compatible EVs within the distribution network to share energy with the grid or customers. This innovative approach, detailed in [86], offers a seamless integration of EVs into the energy grid, while optimizing their utilization for the benefit of both the grid and consumers. EV communication is crucial for exchanging information such as State of Charge (SoC), EV location, charging requirements, power rating, and available charge in the EV [87]. A simplified EV communication model featuring mobile nodes, roadside stations, and charging stations is depicted in Figure 6.

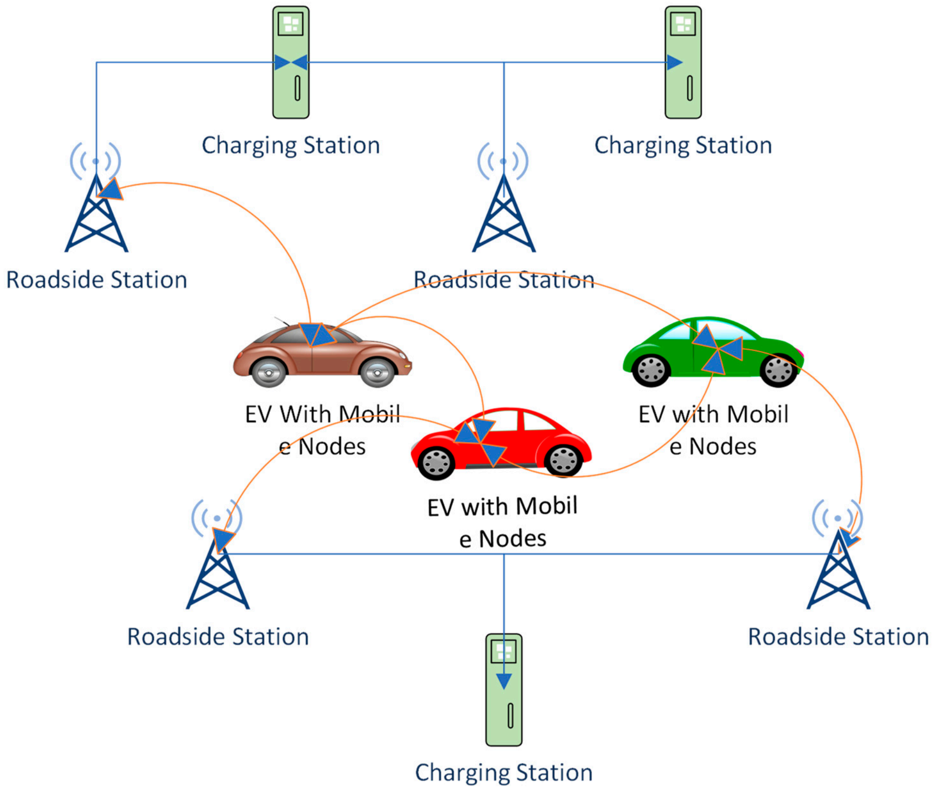

Figure 6. EV communication with mobile nodes and roadside stations.

4.1. Electric Vehicle Communication Technology

Numerous studies have been conducted to validate and demonstrate the exchange of information between electric vehicles (EVs) and charging station (CS) infrastructure. This exchange of information aims to improve driver safety and convenience by facilitating essential communication between vehicles [87]. Before selecting an appropriate communication technology, it is crucial to comprehend the characteristics of different topologies and the specific communication requirements of the target application. A comprehensive analysis of charging topologies and communication standards utilized in EVs to CS is thoroughly discussed in [88], and accompanying wired communication standards are documented in Table 3.

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Table 3. Different types of standards used in EV Communication [88].

Standard	IEC	SAE	GB	Rest of the World
Plug	62196-1 62196-2 62196-3	J1772	20234-1 20234-2 20234-3	
Charging Topology	61439-5 61851-1 61851-21 61851-22	J2953	18487-1 29781 33594	
Communication Topology	61850 61980-2 61980-3	J2293-2 J2836 J2847	27930	ISO 15118
Safety	60364-7 60529 61140 62040	J1766 J2894-2	18384-1 18384-3 37295	ISO 6469-3 ISO 17409 NBT 33008
Security				ISO 27000

The Internet of Things (IoT) has caught the attention of EV and automobile industry manufacturers and researchers in vehicular communication and ITS. V2V, V2I, and DSRC are helping to reduce traffic congestion and fatalities on the roads. In [89], a recent analysis of IoT standards for vehicular communication, DSRC and cellular network communications, three core elements were discussed in detail: (i) Node performance refers to the EV's internal network element responsible for sending and receiving traffic data, battery information, resource requests, traffic camera positions, and other mobile applications. (ii) A local network refers to communication outside the vehicle, between vehicles and the fixed infrastructure on the roadside. Communication networks such as DSRC/802.11p, WAVE, Wi-Fi, and 4G technologies determine QoS constraints such as throughput, delay, and bandwidth. (iii) The IoT integrates EVs with advanced traffic management systems, focusing on critical aspects such as information, data transmission, electronic sensing, control, and computers.

This article explores the impact of 5G communication technology on vehicular communication and suggests potential areas for future development. Various communication standards are currently used in electric vehicles, including Dedicated Short Range Communication (DSRC), IEEE 802.11p, Wireless Access in Vehicular Communication (WAVE), Vehicular Ad-Hoc Networks (VANET), Visible Light Communication (VLC), wireless fidelity (Wi-Fi), vehicle to grid/vehicle/everything (V2V, V2I and V2X), Cellular 4G/LTE, and 5G networks. Table 4 offers a comparison of wireless communication technologies and their parameters. Figure 7 illustrates the different types of EV communication examined in this article.

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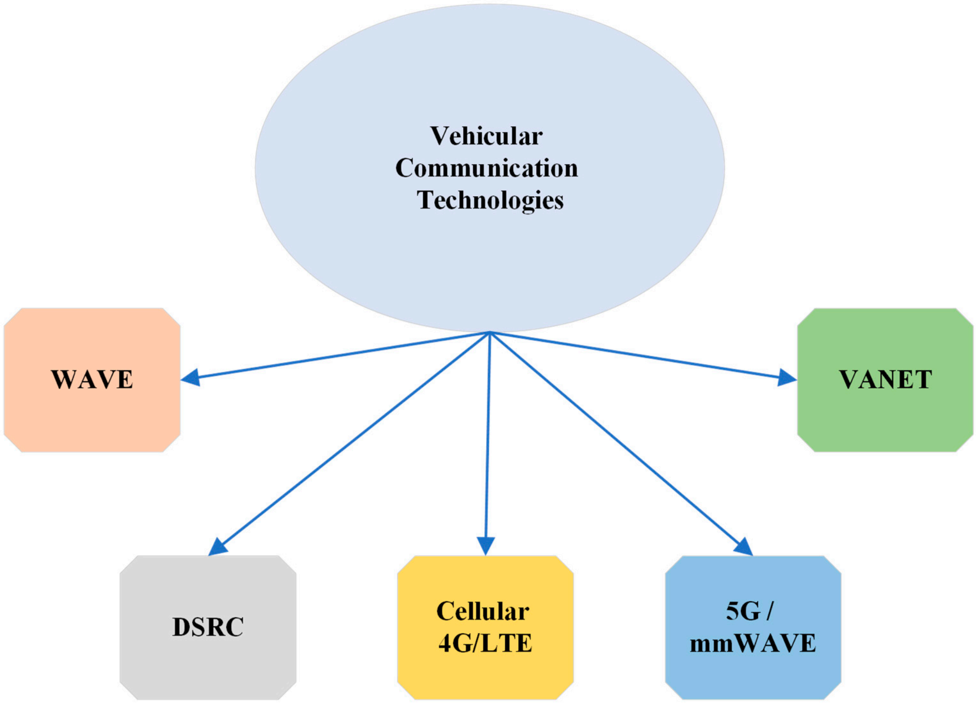

Figure 7. Vehicular Communication Types.

4.1.1. Dedicated Short Range Communication (DSRC)

When it comes to vehicular communication, essential factors to consider are latency, throughput, reliability, security, and privacy. Dedicated Short Range Communication (DSRC) and Cellular technologies are superior communication options for electric vehicles. DSRC uses physical layer protocols based on two IEEE 802.11p and IEEE 802.11bd standards, providing a secure communication channel for EVs and surrounding infrastructure [90]. Communication with DSRC can be transmitted to nearby vehicles or a roadside station (RSS), and the RSS unit can share information with nearby control stations via wired and secure data transfer. The Federal Communications Commission (FCC) has allocated a dedicated 75MHz spectrum at 5.9GHz for V2V and V2I communications with DSRC. DSRC is perfect for use in Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication due to its low latency, high security, and reliability. Additionally, DSRC is considered a preferred technology for short-range vehicular communication because of its high-priority message allocation [91].

A study [92] explored various network options for V2V and V2I communication. While DSRC was the primary option considered, other wireless technologies, such as LTE and WiMAX, were also analyzed. The pros and cons were compared with DSRC and other Heterogeneous wireless networks (Het-Net) technologies. Through developing a handoff method in the application layer, traffic data collection and forward collision warning information were obtained and transmitted to the roadside unit (RSU). The NS-3 network simulator was used to evaluate the simulation performance. DSRC was demonstrated to have better safety and lower latency, while Het-Net offered better connectivity beyond the DSRC range for a more extensive traffic network. Future research is suggested by implementing the application layer handoff method developed in this study in Het-Net supported vehicles. This technology can enhance QoS in EV communication.

4.1.2. Vehicular Ad-Hoc Network (VANET)

Vehicular Ad Hoc Network (VANET) is a rapidly developing technology that belongs to the Mobile Ad Hoc Networks (MANET) sub-class. It is predominantly used in vehicular networks to facilitate V2V and V2I communications. VANETs offer a broad spectrum of applications in vehicular communications, including collision prevention, safety, blind crossing, dynamic route scheduling,

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real-time traffic condition monitoring, and more. Additionally, VANETs are crucial in enabling internet connectivity for electric vehicles (EVs) [93].

Intelligent V2V charging navigation for EVs using VANET-based communication has been implemented in [94] to facilitate flexible and speedy energy exchange without CS support. The study focused on developing an efficient charging navigation structure that minimizes communication loads and computational issues. A semi-centralized charging navigation framework was analyzed to ensure reliable communication, and a local charging navigation scheme was proposed to identify the optimal EV route with locations. The study utilized a Q-learning-based algorithm. Further research could involve designing and implementing an adaptive computational algorithm for EVs and dynamically assigning charging navigation calculation tasks.

4.1.3. Vehicular-to-Vehicle, Vehicle-to-Infrastructure and Vehicle-to-Everything (V2V, V2I and V2X)

Over the past few decades, the number of cars on the road has grown exponentially. In [95], a new control framework has been implemented for automated vehicles, which uses onboard sensors and V2V communication technology. This framework is designed to allow for longitudinal and lateral vehicle-following and string stability function is considered when designing longitudinal control. A path estimation algorithm is used to calculate the path history, and linear time-varying model predictive control (LTV-MPC) is used for front steering. The efficacy of this methodology was demonstrated through simulations carried out with CarSim software, as well as through real-time experiments involving DSRC-supporting EVs outfitted with an inertial navigation system (INS) and GPS to transmit information. The results of these experiments, which were conducted under a specified test scenario involving low-speed driving situations on different road surfaces, showed that the adapted control framework was effective. Various communication technologies such as DSRC and Long-term Evolution for V2X (LTE-V2X) are discussed in [19], and a comparison of DSRC and Cellular-V2X (C-V2X) is carried out in [96]. The goal of these technologies is to increase throughput at MAC and enable longer communication ranges by reducing noise sensitivity [97]. To improve overall energy efficiency and potentially enhance QoS, a new power-splitting resource allocation using C-V2X technology is proposed in [98].

Around the world, there is a growing trend towards green intelligent transportation, which leverages cutting-edge IoT technology to facilitate vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. A recent study [99] delves into various communication technologies and charging services in this space. Information and communication technologies (ICT) are critical in unlocking the potential of this emerging field, as they allow for the development of advanced communications and control systems for electric vehicle (EV) communication by utilizing IP cellular systems.

A comprehensive investigation was conducted on communication architecture for hybrid V2V and V2I networks to address critical challenges EVs face in adapting to large-scale networks [83,100,101]. Based on recent research and an established analytical framework, it is suggested to develop an optimal data forwarding and routing protocol to ensure a guaranteed QoS in EV communication. To mitigate range anxiety issues in the widespread adoption of EVs, an intelligent charging management system is recommended to tackle challenges such as travel costs, searching for a suitable charging station, and reducing wait times and charging duration. Additionally, future research proposes software-defined networks (SDNs) [100,102,103] as a potential solution for network and resource management issues.

Developing an efficient charging management system for electric vehicles (EVs), overcoming key challenges surrounding intelligent decision-making in selecting a charging station (CS), and developing a communication channel for exchanging information presents an emerging research challenge. In [104], a new concept called mobility as a service (MaaS) communication framework was proposed through transportation buses based on vehicle-to-vehicle (V2V) communication for broadcasting CS information to EVs while they are on the move. This methodology also offers remote reservations for EVs on available CSs based on predicted information received from the EVs. A pull mode communication framework is proposed to maintain concurrent end-to-end connectivity between the buses and the EVs. The developed communication framework was analysed and compared with four different scenarios: (i) pull mode communication framework, (ii) accessing real-time information from the buses, (iii) direct communications between EVs and CS, and (iv) centralised case communication framework. Practical experiments were conducted on two public transport routes, and the results were verified [105,106]. Adopting the proposed communication framework may address the future improvement of Quality of Service (QoS) in EVs, particularly in enhancing queue length and resource allocation.

Vehicle-to-everything (V2X) technology is gaining in popularity as a means to improve traffic safety, efficiency, and passenger communication. The combination of Dedicated Short-Range Communications (DSRC) and V2X is becoming increasingly popular, and recent advancements in LTE and 5G cellular networks have addressed challenges in supporting efficient V2X communication [107]. However, there are still challenges to overcome in areas such as physical layer structure, synchronisation, multimedia broadcast multicast service (MBMS) resource allocation, and security. This research article explores challenges in 5G based vehicular communication, including the use of heterogeneous and small cell networks, millimeter wave communication, massive multiple-input multiple-output (MIMO), Vehicular cloud and fog computing, SDNs, mobile edge computing, network slicing, and dynamic spectrum sharing. The article offers solutions to these challenges and suggests future research directions for vehicular communication[108,109].

4.1.4. Visible Light Communication (VLC)

A novel approach utilising visible light communication (VLC) and unmanned aerial vehicles (UAVs) has been introduced in [110] to offer flexible communication and lighting solutions. Two sub-problems have been suggested to tackle the mutual dependencies of optimisation variables: UVA location optimisation and cell association. The findings of the numerical analysis confirm a 53.8% increase in power efficiency. As per the study, implementing the location optimisation algorithm from this approach could lead to improved Quality of Service (QoS) in Electric Vehicles (EVs).

Recent research has analysed cyber-attacks on power electronic hardware in electric vehicles (EVs), providing recommendations to protect onboard charging systems. In one worst-case scenario [111], the attack impacted controller data, created fake communication channels between electronic control units (ECUs), and interfered with battery management system functionalities. An algorithm has been proposed to prevent attacks by isolating the system by zeroing the output voltage and load current. The algorithm has been implemented, and the system can regain its initial state within 0.25 seconds when it is in zero loads. The controller can then run the system back to its normal operating condition within 0.5 seconds. Several experiment trials have been conducted to prioritise the safety of EVs when implementing this new model.

A recent study [112] introduced a novel approach to wireless EV charging through simultaneous wireless power and data transmission (SWPDT). The study employed 5 MHz and 6.25 MHz data carriers for a bidirectional, full-duplex communication system utilising frequency-division multiplexing. The implemented model achieved up to 64 kbps full-duplex data transmission while transferring 3.3 kW of power. These results demonstrate the potential of using SWPDT for high-speed communication during kilowatt-level wireless EV charging.

It has been discovered through recent research studies that the integration of wireless technology in vehicular communication is fulfilling data transmission needs and advancing towards intelligent transportation and Electrification. In an article published in [113], the wireless vehicle-integration perspective highlights essential functions in vehicular communications and networking (VCN) applications. A cooperative charging protocol grounded on the V2V matching algorithm has been developed to offer a versatile energy management system. This protocol can gather real-time information from moving vehicles and supply data on the nearby CS according to demand requests.

4.1.5. Wireless Access in Vehicular Environments (WAVE)

A common obstacle among current EVs in the market is their limited mileage and charging duration. However, researchers proposed a new methodology [114] involving various machine

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language techniques. Also, research conducted in [42] sharing the locations of EVs through the IEEE 802.11p standard designed for wireless access in vehicular environments (WAVE) in vehicular communications [115]. This integration allows for real-time communication and transfer of information between the EVs and the grid network, leading to the resolution of cost, demand response, and charging time issues. The proposed solution requires EVs to maintain a specified speed and communicate with access points (APs) using the IEEE 802.11p protocol within their transmission range. Based on the gathered information, the APs suggest the nearest charging station and allocate charging time to the EVs. The EVs can only charge the necessary power to reach their home destination within the deadline. Upon arriving at their home destination, the EVs can charge their battery to 100%, reducing the waiting time in public charging stations and improving the quality of service in terms of cost, waiting time, and resource allocation.

4.1.6. Long Term Evolution (LTE) Communication

The comparison of DSRC and LET cellular networks to V2V and V2I is explored in the paper [116], which evaluates simulation results and addresses dynamic charging requirements. During the experiment, an EV travelled at speeds ranging from 30 to 120 km/h while encountering DSRC units on the roadside communicating with LET networks. The analysis of simulation results is based on round-trip time, revealing that LET offers a higher data rate. At the same time, DSRC provides lower latency, making it a better fit for safety-related applications. As for cost-effective QoS, the LET network is the optimal choice due to its utilization of current infrastructure.

A cutting-edge real-time communication approach, outlined in [117], facilitates seamless communication between PHEVs and fast-charging CSs. This method allows for the exchange of crucial information such as the SOC of PHEV batteries, location, available resources, and nearest charging location, resulting in prompt service. The proposed methodology employs current cellular technology, global system for mobile (GSM) technology, and global positioning through a dedicated website where all pertinent information is consolidated. Further research could explore leveraging DRSC or 5G technology to enhance QoS and reduce Queue length.

As previously discussed, the Internet of Things (IoT) has emerged as a promising platform for managing smart Electric Vehicles (EVs). In a recent study [118], researchers proposed a distributed state estimation and stabilization algorithm that leverages IoT-enabled sensors to measure packet loss between EVs and the control centre. The study employed Kalman filtering to validate numerical results. Simulation and numerical analysis demonstrated that the proposed algorithm effectively reduces estimation errors, and system reflection time is below 0.03 seconds.

4.1.7. Fifth-Generation (5G) Communication

The 5G technology represents an exciting advancement in vehicular communication that seeks to improve current radio access technologies. One of the key features of 5G communication is its proximity service, which provides valuable information to discoverable devices within range. This service presents some unique research challenges, such as dynamically allocating resources and ensuring a high quality of service (QoS) [104]. Companies like Qualcomm are leading in developing wireless technologies that promote traffic safety and improve QoS. To achieve this goal, they are exploring a range of technologies, including Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Everything (V2X), Vehicle-to-Pedestrian (V2P), Vehicle-to-Home (V2H), and Vehicle-to-Network (V2N) [107]. The 5G MM WAVE technology is particularly promising for direct V2V communication, thanks to its ability to support non-line-of-sight communication and its resistance to weather interference. Additionally, it has a smaller antenna that can be easily integrated with electric vehicles for more efficient data transfer. However, some challenges still exist to overcome in supporting high-mobility vehicular networks through mmWaves [110].

4.1.8. Section Summary

This section thoroughly examines the various communication technologies employed in electric vehicles, including DSRC, VANET, V2V/V2I/V2X, visible light communication, WAVE, 4G/LTE, and 5G networks. Our research suggests that these communication technologies have a more significant influence than other technologies in this context. For a comprehensive overview of the key terms in the reference article, please refer to Table 5 in this research paper.

Table 1. EV Communication references in detail.

References	Key Terms	Communication Technology Focused
[79]	Next-Gen vehicular communication	IEEE 802.11p, V2V, V2I
[80]	Review on wireless charging for EVs	Wireless Charging, V2G
[81,82]	Wireless power transfer	Wireless charging
[84]	Challenges in Internet of Vehicles (IoV)	DSRC, VANETS, IoV, V2X
[87,88]	Review of EV communication technologies	IoEV, V2V, V2I, DSRC, V2X
[92]	Communication in a Het-Net wireless networks	Het-Net, DSRC, V2V and V2I
[94]	Vehicle-to-vehicle charging, VANET based communication	VANET, V2V
[95,99,104,107]	Cellular based V2x communications, EV Charging using VANET, V2V communication using control system and radar.	V2V, V2I, IoT, VANET, V2X
[42]	EV charging in Smart grid Environment using IEEE 802.11p and WAVE	IEEE 802.11p, WAVE
[116-118]	Real-time EVS charging using GSM, DSRC vs $G-LTE to study vehicular communication performance, minimise cyber-attacks using WSN and IoT	DSRC, IoT, 4G-LTE, GSM cellular
[119]	5G Vehicular Communication	5G, V2V, V2I, V2X

5. Trends and Future Developments of Electric Vehicles

Concerns about range anxiety have been a significant obstacle for those interested in electric vehicles. However, manufacturers are working tirelessly to improve battery technology, resulting in longer driving ranges on a single charge. These advancements are making electric vehicles more practical for everyday use and longer trips. A campaign on EV30@30 was launched by Clean Energy Ministerial (CEM) to boost the EV market [120]. Researchers are focused on improving battery efficiency, energy density, and charging times, which will ultimately contribute to longer ranges, faster charging, and better performance. In [121], state of the art and emerging concepts in electric drive technology are studied, suggesting variations required to achieve high efficiency in electric traction drive. The widespread adoption of electric vehicles depends on the expansion of charging infrastructure, and government, business, and independent providers are investing in building a network of charging stations, including fast-charging stations, to facilitate the recharging of electric vehicles. Automakers are introducing a wider variety of electric vehicle models, catering to different consumer preferences and needs. Not only are electric vehicles environmentally friendly alternatives, but some manufacturers are also creating high-performance electric vehicles that can rival traditional internal combustion engine sports cars in terms of acceleration and handling.

The trend of Vehicle-to-Everything (V2X) communication was steadily increasing, encompassing connections like Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Grid (V2G), and more. V2X communication enabled electric vehicles (EVs) to share data with other cars, infrastructure, pedestrians, and the power grid, resulting in improved safety, traffic efficiency, energy management, and an overall enhanced driving experience [122,123] and Figure 8 shows the types of 5G communication technology used. The integration of wireless charging technology and communication capabilities was a significant breakthrough, allowing proper alignment, power transfer control, and safety during wireless charging sessions. Smart charging systems with communication abilities were on the rise, empowering EVs to communicate with the power grid, optimizing energy consumption, reducing peak demand, and supporting grid stability. Developers were also devising mobile apps and user interfaces for EV owners to monitor charging status, locate charging stations, plan routes based on charging availability, and remotely control vehicle functions. Communication protocols and technologies were being refined for energy efficiency, recognizing the importance of reducing communication-related energy consumption for boosting the driving range of EVs.

Electric vehicles are also becoming platforms for integrating autonomous driving technologies, with many exploring self-driving capabilities and driver-assistance features. Manufacturers are also looking at making the entire production process of electric vehicles more sustainable, using eco-friendly materials and adopting environmentally responsible manufacturing practices. Governments worldwide are offering incentives to promote electric vehicle adoption, such as tax credits, rebates, and reduced registration fees, playing a significant role in encouraging consumers to consider electric vehicles. Automakers are forming collaborations and partnerships with tech companies and other industries to leverage expertise and resources for electric vehicle development, including collaborations on battery technology, software development, and more. As the first wave of electric vehicles reaches the used car market, there is increasing interest in second-hand electric vehicles, providing more opportunities for consumers to enter the electric vehicle market at a lower cost.

Exciting advancements in battery technology are underway, offering improved energy density, longer life spans, quicker charging times, and lower costs. With the development of ultra-fast charging stations and bidirectional charging technology, electric vehicles are becoming more practical and competitive with traditional cars. They also offer designers more flexibility in vehicle design and contribute to developing autonomous driving technologies. The electrification of commercial vehicles will significantly impact reducing emissions in the transportation sector. Governments and companies are working together to accelerate the transition to EVs through stricter emissions regulations, incentives, and partnerships between automakers and tech companies or energy providers. As battery costs decrease and manufacturing scales up, electric vehicles will become even more affordable and environmentally friendly, leading to broader market adoption.

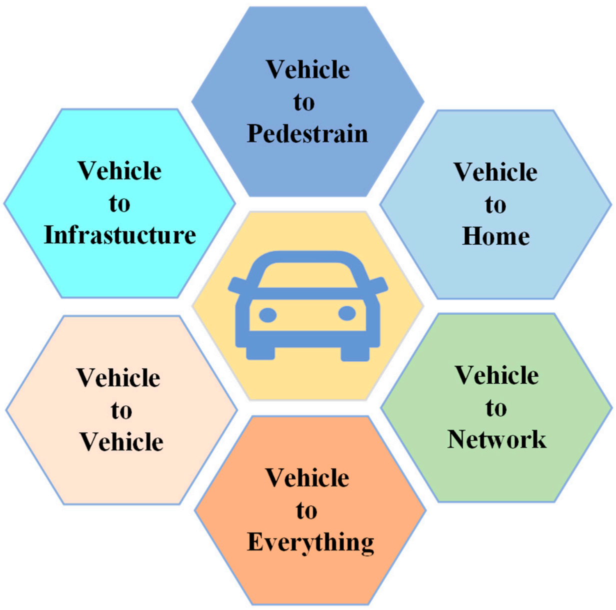

Figure 8. 5G Vehiculars Communication Technology.

6. Summary and Future Research Directions

It is clear that the transition to more sustainable transportation is happening too slowly despite the need to reduce greenhouse gas emissions. Many researchers are working towards developing batteries with higher energy density to extend the range of electric vehicles without increasing their size and weight. Efforts are also being made to improve fast-charging capabilities while ensuring the longevity of batteries through innovative chemistries, materials, and thermal management. Additionally, researchers are focusing on developing ultra-fast charging technologies that can deliver high energy levels rapidly without compromising battery life. Another approach is to focus on lightweight materials and vehicle design optimization to reduce energy consumption and extend the range of electric vehicles.

Furthermore, developing advanced algorithms and systems to predict battery health, optimize charging behaviour, and prolong battery life is crucial. Research is underway to improve the reliability of charging stations through predictive maintenance based on usage patterns and monitoring of station health. There is also an exploration of the potential for electric vehicles to interact with the electrical grid, allowing them to store and supply energy based on grid demands. Methods are being studied to integrate electric vehicle charging seamlessly with renewable energy sources to enhance sustainability.

Additionally, research could focus on developing efficient and secure communication protocols that allow electric vehicles to interact with the power grid and home energy systems for bidirectional energy exchange and management. Communication protocols that enable dynamic power transfer control and energy management for wireless charging systems are also being explored, ensuring optimal charging efficiency and avoiding interference with other wireless devices. Finally, methods to efficiently manage communication networks supporting many electric vehicles, including addressing network congestion, scalability, and quality of service, are being developed, with algorithms that distribute communication loads among various network elements to prevent bottlenecks and ensure smooth communication even during peak demand periods.

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