energies

Review

Quality of Service and Associated Communication Infrastructure for Electric Vehicles †

Rajeshkumar Ramraj [1], Ehsan Pashajavid [2], Sanath Alahakoon [1] and Shantha Jayasinghe [3,*]

1 School of Engineering and Technology, Central Queensland University, Bryan Jordan Drive, Gladstone, QLD 4680, Australia; r.ramraj@cqu.edu.au (R.R.); s.alahakoon@cqu.edu.au (S.A.)
2 School of Electrical Engineering Computing and Mathematical Sciences, Curtin University, Bentley, WA 6102, Australia; ehsan.pashajavid@curtin.edu.au
3 Maritime and Logistics Management, University of Tasmania, Hobart, TAS 7005, Australia
* Correspondence: shantha.jayasinghe@utas.edu.au

† This paper is an extended version of our paper published in 2021 31st Australasian Universities Power Engineering Conference (AUPEC), Perth, WA, Australia, 26–30 September 2021; pp. 1–6.

Abstract: Transportation electrification is pivotal for achieving energy security and emission reduction goals. Electric vehicles (EVs) are at the forefront of this transition, driving the development of new EV technologies and infrastructure. As this trend gains momentum, it becomes essential to enhance the quality of service (QoS) of EVs to encourage their widespread adoption. This paper has been structured with two primary aims to effectively address the above timely technological needs. Firstly, it comprehensively reviews the various QoS factors that influence EVs' performance and the user experience. Delving into these factors provides valuable insights into how the QoS can be improved, thereby fostering the increased use of EVs on our roads. In addition to the QoS, this paper also explores recent advancements in communication technologies vital for facilitating in-formation exchanges between EVs and charging stations. Efficient communication systems are crucial for optimizing EV operations and enhancing user experiences. This paper presents expert-level technical details in an easily understandable manner, making it a valuable resource for researchers dedicated to improving the QoS of EV communication systems, who are tirelessly working towards a cleaner, more efficient future in transportation. It consolidates the current knowledge in the field and presents the latest discoveries and developments, offering practical insights for enhancing the QoS in electric transportation. A QoS parameter reference map, a detailed classification of QoS parameters, and a classification of EV communication technology references are some of the key contributions of this review paper. In doing so, this paper contributes to the broader objectives of promoting transportation electrification, enhancing energy security, and reducing emissions.

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

Citation: Ramraj, R.; Pashajavid, E.; Alahakoon, S.; Jayasinghe, S. Quality of Service and Associated Communication Infrastructure for Electric Vehicles. *Energies* **2023**, *16*, 7170. https://doi.org/10.3390/en16207170

Academic Editor: Piedad Garrido Picazo

Received: 14 September 2023
Revised: 9 October 2023
Accepted: 13 October 2023
Published: 20 October 2023

1. Introduction

Governments worldwide are prioritizing decarbonization 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.

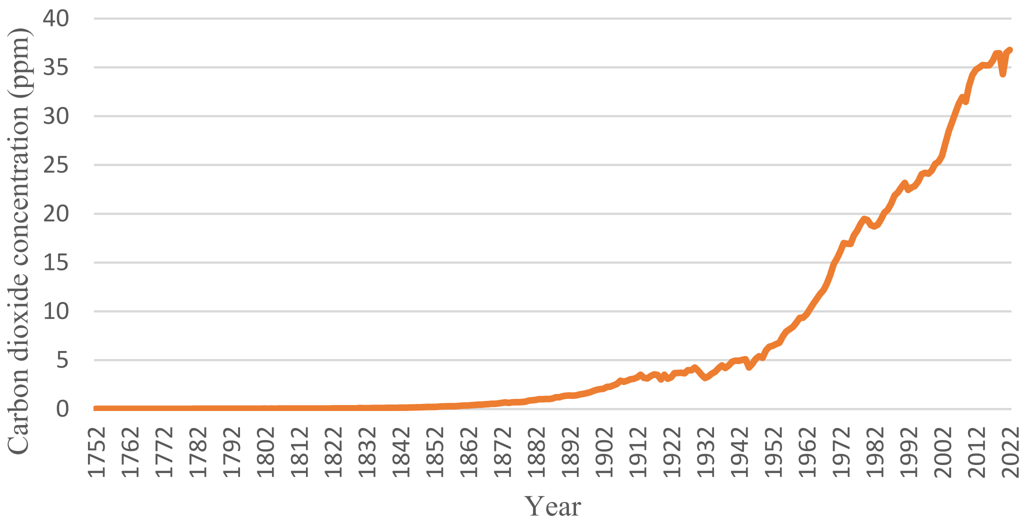

Figure 1. Carbon dioxide concentration in the atmosphere.

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 analyzed for EVs, focusing on enhancing the battery life and improving the QoS in EMS. Battery swapping systems can also help improve the QoS in battery management systems. To ensure the safety of EV users, charging structures 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 mediocre, with unsatisfactory performance compared to ICEs, leading researchers to focus on the energy management systems for enhanced battery life and improved QoS [16]. As EVs continue to gain popularity, research studies are now focused on improving the charging infrastructure performance to enhance the QoS further [17].

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 transfers. With the advent of fifth-generation (5G) and subsequent communication technologies, it is expected that the requirements of vehicular communications can be met, enabling higher multi-Gbps data transfers with ultra-low latency rates. 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 the reliability and security during data transmission. The 5G Automotive Association (5GAA) is a global cross-industry organization that collaborates with automotive technology and telecommunication industries to develop future mobility and transportation services. The 5GAA currently emphasizes the use of cellular V2X (C-V2X) technology in EVs to enhance the safety and transfer necessary information between EVs and the 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. This review article aims to amalgamate and comprehensively analyze the current research and advancements concerning the quality of service (QoS) with electric vehicles (EVs) and their communication protocols. We strive to share insights into the most recent progress, challenges, and recommended approaches within the domain of QoS for EVs and communication protocols. Furthermore, we aim to critically evaluate the impacts of different QoS enhancements and communication protocols within the EV context. Additionally, we seek to pinpoint research gaps and areas that warrant additional investigation, aiming to foster meaningful advancements in the field. The review paper is structured as follows. Section 2 introduces the different types of battery vehicles and their unique characteristics. Section 3 encompasses a comprehensive analysis of the quality-of-service aspects that are associated with EVs. The communication of EVs is discussed in Section 4. Finally, Sections 5 and 6 present future research directions and the 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, the global sales of electric vehicles (EVs) have risen to about 3.2 million as of 2022, showing a yearly growth rate of approximately 43% [22,23]. Figure 2 demonstrates the number of EVs on the road globally. EVs fall into four categories: hybrid electric vehicles (HEVs), plug-in electric vehicles (PHEVs), fuel cell electric vehicles (FCEVs), and battery electric vehicles (BEVs). The different drive technologies used in EVs are shown in Figure 3, and more details can be found in [24].

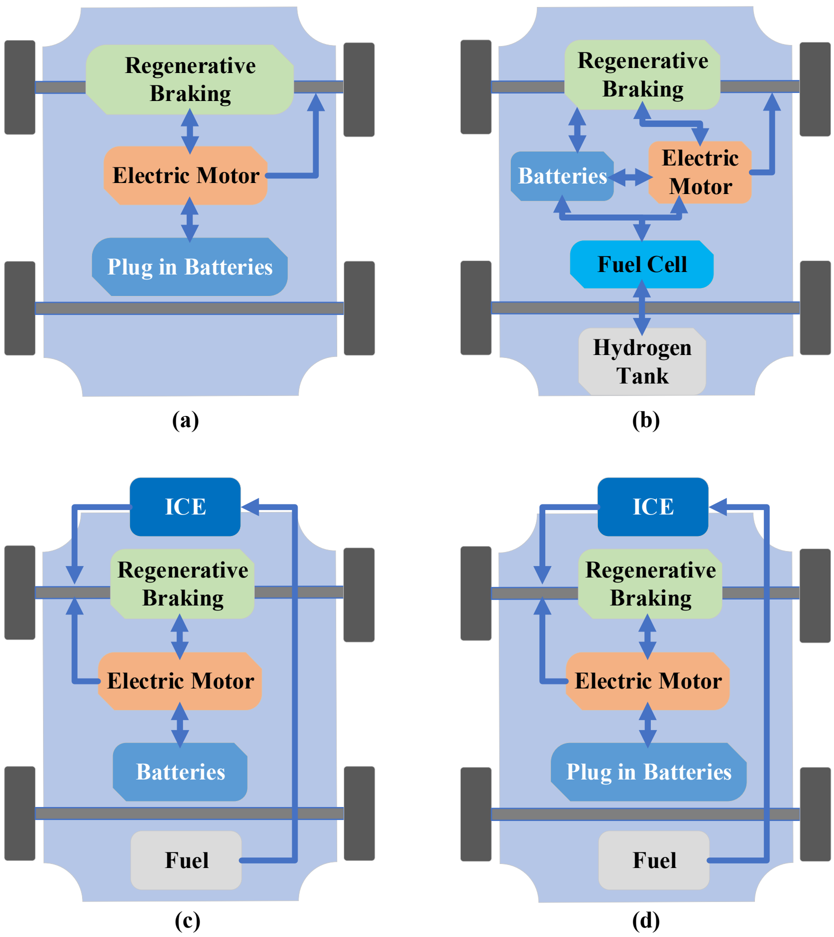

Figure 2. Drive technologies in (**a**) BEVs, (**b**) FCEVs, (**c**) HEVs, and (**d**) PHEVs.

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]. A novel approach has been developed in [32] to determine the most suitable quantity of states for plug-in hybrid electric vehicles (PHEVs), with a focus on achieving both swiftness and accuracy in reliability calculations. This approach's ability to assess smart grid reliability has been verified through simulations, utilizing an analytical PHEV model. The results of these experiments indicate that optimizing the number of discretized states for PHEV traits can significantly expedite the process of computing smart grid reliability. 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.

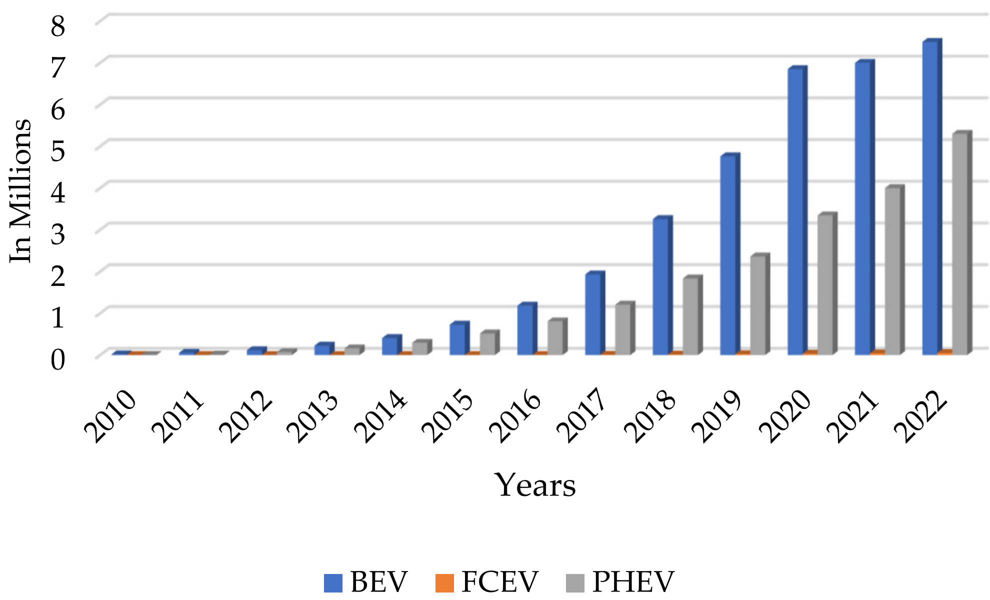

Figure 3. Number of EVs on the roads worldwide.

A comprehensive analysis of battery technologies used in EVs is presented in this study [33,34]. EVs can benefit from various battery technologies, including lead–acid (Pb-PbO2), nickel–cadmium (Ni-Cd), nickel–metal–hydride (Ni-MH), zinc–bromine (Zn-Br2), sodium chloride–nickel (NA-NiCl), sodium–sulfur (Na-S), and lithium ion batteries. Lithium ion batteries are widely preferred due to their high energy density and low self-discharge capacity rates [35]. A recent study [36] incorporated a meticulously designed software application into the control module to faithfully replicate real-world driving scenarios. The study's results indicate that changes in the surrounding temperature impact an electric vehicle's driving range, following an inverse potential function relative to its operational temperature. The in-depth research on the thermal management of Li-ion batteries for EVs is discussed in [37]. EV batteries' technical and financial aspects are assessed in [38]. 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 [39]. A study on using power generated from EVs and energy storage for smart homes is presented in [40], demonstrating that the power produced by EVs can be utilized for residential benefits. In this article [41], a new approach to communication networks and electric vehicles for smart grids and distributed generation systems is presented. This article identifies various challenges and constraints and provides recommendations to assist researchers and academics in addressing them effectively.

3. Methodology

In this review article, we employed a systematic literature review methodology to address the question: "How can we achieve better quality of service (QoS) in electric vehicles (EVs) and their communication infrastructure?" Through evidence-based systematic literature review practices, we unearthed additional research inquiries, involving a comprehensive examination of the content, methodologies, and strategies. We also established clear inclusion and exclusion criteria for the review. In related studies [42,43], the author conducted extensive systematic literature reviews exploring the interplay between individuals and environmental factors before subsequently evaluating the findings. Our research mirrors this systematic review process to assess evidence-based outcomes, which will guide the selection of an appropriate mathematical model. Ultimately, we will consolidate the gathered information to facilitate the processes of modeling and integration.

Over the last two decades, there has been a significant upsurge in research articles focusing on electric vehicle (EV) investigations. The volume of research in this domain has substantially expanded. These investigations embrace a quantitative systematic literature review methodology, encompassing studies grounded in numerical data. In the context of this review article, we will undertake a meta-analysis, a quantitative examination that scrutinizes findings from previous research studies to gain deeper insights into our research question. Employing both a systematic literature review and a meta-analysis allows us to produce a robust level of research evidence, as exemplified by the outcomes presented in [44].

In the initial phase of this research, we conducted a literature review using general search terms. The search spanned well-known engineering databases, including the Institute of Electrical and Electronics Engineers (IEEE) digital library, ScienceDirect, the Wiley Online Library, Springer Link, Springer Open, and the Multidisciplinary Digital Publishing Institute (MDPI). We accumulated research articles from diverse sources, including library databases, Google Scholar, and a personal database comprising all research articles. Following strict inclusion and exclusion criteria, we executed a systematic literature review and conducted a meta-analysis. Additionally, in some instances, research articles were accessed from ResearchGate, a social networking platform for researchers. While some research articles were freely accessible, others were obtained through requests. To identify the most appropriate mathematical model and discern research gaps, we categorized research articles based on the mathematical models and simulations employed in the mathematical applications.

The literature review encompassed articles (1) employing mathematical models and (2) utilizing mathematical simulations, along with a comparison of the theoretical outcomes to the simulation results. Conversely, articles meeting the following criteria were excluded: (1) those involving human data in simulations; (2) those devoid of any simulation or mathematical model.

In the course of conducting research, it is imperative to identify key terms to search for pertinent articles. Subsequently, these articles should undergo a quality assessment. This initial screening process entails evaluating whether the article has a clearly defined objective, employs suitable methodologies, pertains to the subject matter, and delineates potential avenues for future research. To maintain a systematic and evidence-based research approach, we adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. This framework is widely recognized in esteemed journals and peer-reviewed publications, thereby enhancing the likelihood of acceptance. Figure 4 illustrates the application of the PRISMA framework in this research.

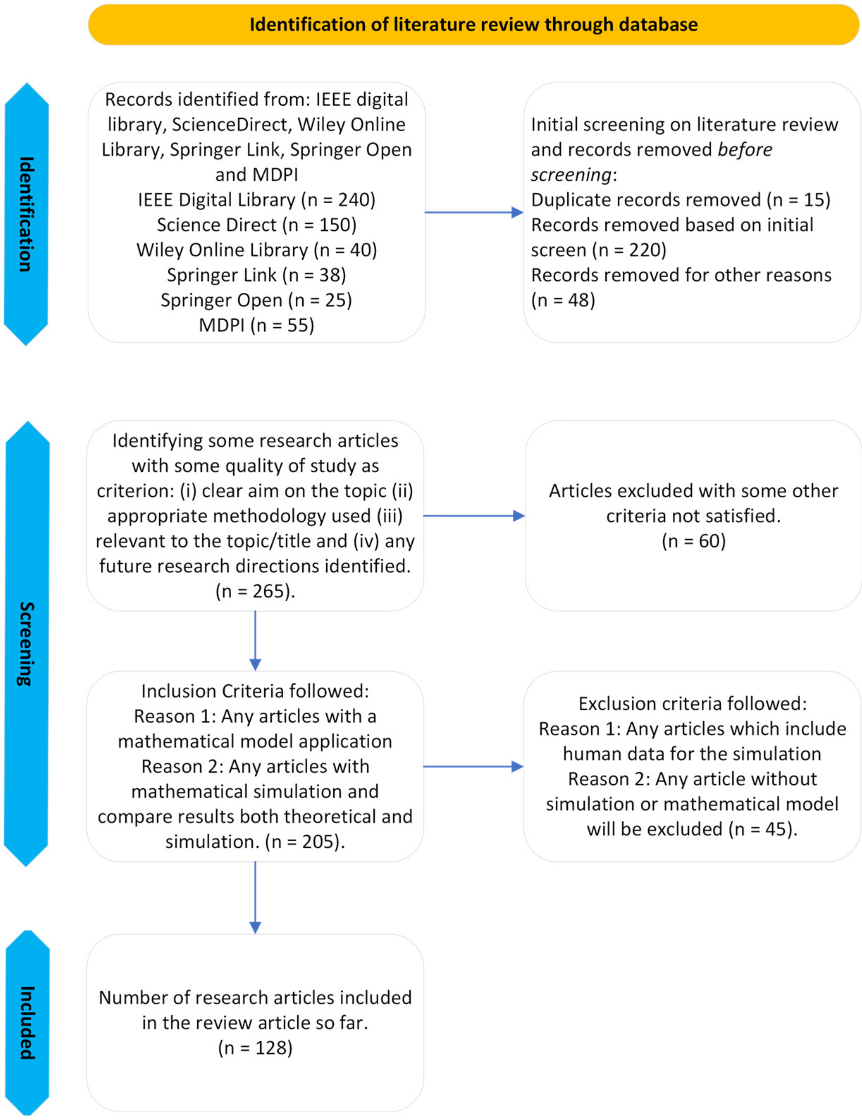

Figure 4. The PRISMA selection process for the literature review.

In the final phase, all literature review articles were compiled within the EndNote referencing tool. We conducted a meticulous cross-verification of titles, authors, and publication years to eliminate any duplicate research articles. To adopt a streamlined referencing style and retain only relevant records, we initiated a screening process involving the removal of abstracts and keywords from the literature review articles stored in the EndNote library.

4. 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 the service performance that determines a user's level of satisfaction [45]. This review article delves into various QoS aspects, including the energy demands, costs, scalability, sizing, control of the charging schedule, and resource allocation. The following sections provide detailed reviews of these aspects, and Figure 5 illustrates the QoS aspects discussed in this review paper. Table 1 compiles some of the QoS parameter references used in this review paper.

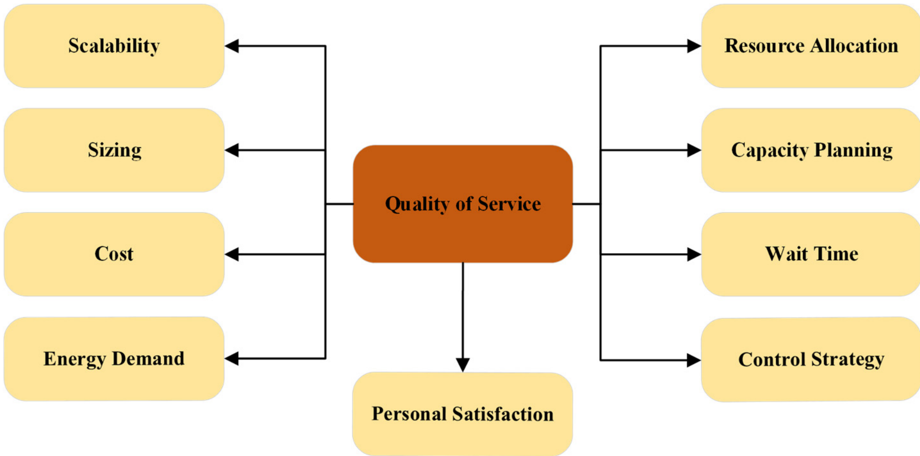

Figure 5. Quality of service aspects.

Table 1. QoS parameter reference mapping process.

QoS Parameters	References
Cost	[46–56]
Scalability	[47,57,58]
Sizing	[48,49,59,60]
Energy Demands and Optimization	[46,47,61–69]
Resource Allocation	[46,50–54,60,67,69–74]
Capacity Planning	[55,60,71]
Personal Satisfaction	[69,75,76]
Wait Time	[53,56,72–74,77]
Control Strategy	[73,74]

4.1. Energy Demands and Optimization

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 [61]. This model designs the service model for each charging station (CS) based on the energy demands, arrival rate, and departure rate of the 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 each CS under various conditions and service policies.

In [62], a game theory framework was proposed to maximize the efficiency of CSs and EVs. 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 constraints at EV charging stations. The solution involved a game-based supply function equilibrium achieved through a theoretical hybrid optimization model. The obtained results were a reduced peak time load and improved voltage profile for the charging stations.

However, some drawbacks in energy load management are analyzed in [63] during bidirectional energy transfer between grid-to-vehicle (G2V) and vehicle-to-grid (V2G) networks. 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 [64], 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 trades between single consumers to multiple providers and multiple consumers to multiple providers. Additionally, other studies [65,78] proposed an optimization model for the charging infrastructure of EVs, which aims to minimize the overall installation, maintenance, and operation costs while ensuring system reliability checks based on DC power flow to guarantee the quality of service (QoS). QoS, in this case, is defined as the overall disposable charging time for EVs to reach their overall travel distance. The future research will focus on linearized approaches to run EV power system reliability checks based on AC power. The bidirectional power transfer between an EV and the grid [79] is depicted in Figure 6.

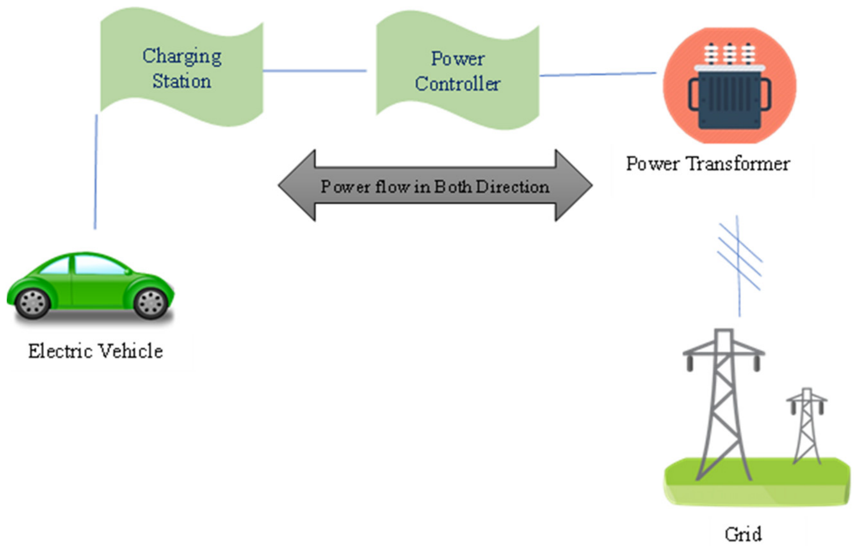

Figure 6. Bidirectional power transfer between an EV and the grid.

In [66], 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 differentiation among users. A future recommendation is to use a QoS-aware admission control approach in a realistic pattern and to investigate different classes of PEVs with other CS.

A QoS model was implemented in [61], which employed an integrated traffic model to enhance the energy demands at different locations and times while measuring the performance of CSs under various conditions. The main challenge is to reduce the impact on the electric network system during high charging request volumes. To analyze the performance of communication networks during data flow, queuing theory was utilized to examine the service time, waiting time, queue length, and network calculus. Network calculus is a widely used mathematical model that is implemented 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 [46] 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 the static game to a dynamic game approach by increasing the number of EVs.

4.2. 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 [57], a distributed software-defined networking (SDN)–OpenFlow approach was implemented to enhance the scalability, reduce the controller workload, improve the response time, manage the QoS, and boost the energy efficiency among controllers in the smart grid. The SDN–OpenFlow model can be theoretically implemented to demonstrate the queue length for an individual charging station and can be validated through simulations (to the best of our knowledge).

In [58], over 80,000 real-time charging datapoints from different parts of the world were collected, and the charging characteristics were analyzed to manage the load balancing process and shift loads from peak to off-peak hours using smart charging technology. The findings identified the optimal charging pattern with the most negligible impact on the customers. Specific charging locations were suggested for better potential for load reduction with low implications for EV users. This would lead to improved scalability of the charging network, and the quality of the charging service was 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 the charging service to the customer experience.

In [47], a new methodology was proposed to solve scalability, cost, demand response, and charging time problems by sharing the locations of EVs using the IEEE 802.11p standard used to add wireless access in vehicular environments (WAVE) to vehicular communications. The EVs integrate with the grid network to transfer the required information based on this information. The proposed solution involves 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 amount of power to reach their home destination within the allotted time. Finally, when the EVs arrive at their home destination, they can charge the battery to 100%. This reduces the queue time in public CSs and improves the QoS in terms of the cost, wait time, and resource allocation.

4.3. 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 the network load distribution. The 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. Intelligent charging technology can be employed to control the charging profiles of electric vehicles, achieving a lower operational cost or peak-to-average power consumption ratio for the charging stations. In [59,80], the author proposes an optimization framework to reduce the operating costs for charging stations by achieving a certain level of QoS for the electric vehicles, thereby addressing the sizing issue. The author in [81] developed a divided rectangle method for better vehicle fuel efficiency and drivability and the 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 reductions and the allocation of resources, a two-stage stochastic sizing method was introduced in [48] for the selection of charging stations (CSs) in a parking area to schedule a charging time for the incoming electric vehicles (EVs). The author considered several factors to achieve this level of QoS, such as locating a busy CS with a probability rate not exceeding 0.1 for the probability of waiting for more than a specified time and ensuring that the probability of the charging time of the EV exceeding its parking time was 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 was proposed in [49] to explore the stochastic process of PV panel utilization. The optimization issues with sizing were formulated to determine the optimal number of PV panels in the CS, which would minimize the operation costs while ensuring the QoS requirements. An optimal sizing scheme was finally implemented for PV-integrated fast charging along highways to minimize the operation costs and maintain the QoS. The author also provided a case study to validate the feasibility of the proposed optimization model.

A future research direction was recommended whereby the interaction between multiple CSs is expected to be evaluated more precisely.

4.4. Resource Allocation

A previous study [82] delves into the energy consumption of EVs in the grid and examines recent instances of EV charging control and optimization methods utilized for the energy management of large-scale EVs charging on the grid. Managing energy in this aspect can be challenging. It involves achieving load shifting and peak shaving and minimizing high electricity consumption expenses while maintaining a robust grid operation. This research includes BEVs, which have massive battery banks requiring longer charging periods and higher energy consumption capacity rates, 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 [50]. The author utilized Pareto optimality to determine the best possible outcome while avoiding any loss. To further enhance the 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 the planning and operation simulation models to consider the EV charging demands at an individual level rather than an aggregate level.

Maintaining a balanced load in a CS network is crucial for ensuring a high quality of service level. However, sudden or additional load requests can lead to critical issues with the power grid. A previous study [67] proposed a decentralized 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, maximize 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 showed a significant improvement in the guaranteed QoS and is expected to impact the overall performance of the network positively.

When providing quality service, it is essential to consider the range anxiety for electric vehicles. That is why a new concept called wireless charging highways (WCHs) was introduced in [60,83] to allow EVs to recharge while driving long distances. A joint capacity model was developed to ensure adequate planning for power and communication resources. Additionally, a Markov-chain-based model was designed to capture the dynamics of the WCHs. With this model, we can estimate the outage probability and related profits and determine the QoS accordingly.

Recently, battery swapping technology has become more popular as the market for battery electric vehicles (BEVs) grows. In [51,52], a closed-loop supply-chain-based system for battery swapping and charging was implemented using a game theory framework. This system uses battery swapping stations (BSSs), 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. The 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 one research study [70], an energy storage device was used in CS networks to regulate the energy supply from the grid and minimize the queue time. The control scheme also directs EVs to the next available CS, ensuring a seamless charging experience. The study examined various conditions, including CSs with similar charging capabilities, power allocation optimization with limited customers enabled with routing, and the optimal allocation of power from the grid and EVs to CSs. The simulation results demonstrated that customers receive guaranteed QoS, ensuring that the nearest CS does not block them at their current location. The researchers have also suggested future directions, including using wireless network technologies such as LET-A, 5G, and WiMAX.

4.5. Costs

The popularity of electric and plug-in electric vehicles (EVs and PEVs) has highlighted the importance of considering the costs of charging at charging stations (CS) for quality of service (QoS). In a recent study [53], a new model was proposed to optimize the locations of EV charging stations to minimize the implementation costs while enhancing the 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 [52] implemented a novel battery swapping system to improve the charging efficiency and minimize costs while ensuring high QoS. This technology also considered the trade-off between the 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 the costs 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 [68]. 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. Another study [54] 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 the pricing for multi-service charging infrastructure, ensuring the QoS is maintained.

4.6. Personal Satisfaction

Satisfaction with the service provided is a crucial aspect of the quality of service. To gauge this, researchers have utilized various methods to gather feedback from members of the general public aged 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 policies. In addressing electric mobility issues during peak hours, a stochastic game method was introduced in [69] 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 the charging and waiting time.

4.7. Capacity Planning

The capacity planning of a CS is crucial to ensure that the QoS is guaranteed. A new framework proposed in [71] aims to enhance the QoS in terms of 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, although it may also increase the load on the power grid. Therefore, the proposed solution aims to identify the research gap in maximizing QoS user satisfaction within a set budget.

In terms of grid reliability and charging capacity, ref. [55] 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 of the necessary information and guaranteed services to meet the desired quality of service.

4.8. Wait Times

Effective service delivery requires prioritizing time-saving and productivity-enhancing measures. To ensure QoS, the waiting time of EV users in queues before charging should be measured and optimized. By leveraging queueing theory, the system can be modeled 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 the queue length. This proposed model holds promise for further research and development [56].

A model for a heterogeneous urban public charging network (UPCN) with limited public charging stations (PCS) is presented in [72]. 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 optimize the average waiting time, the study uses a genetic algorithm (GA) to add charging stations to the Sioux Falls network randomly. Future studies could analyze the quality of service (QoS) by analyzing the dynamic origin–destination matrix and studying EV behavior patterns.

A method for the fast charging of electric vehicles (EVs) using a direct current (DC) network was developed in [77]. This method aims to reduce the 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 the 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.

4.9. Control Strategy

In a bid to alleviate stress on the power grid and ensure the quality of service (QoS) for electric vehicles (EVs), a framework for control resource provisioning was proposed in [73]. The study considered two scenarios: (i) the charging station (CS) was located in a metropolitan area with a high demand for charging requests; (ii) the charging requests were acquired in rural areas through profiling studies. By prioritizing reliability, costs, and resource allocation, the framework enabled every EV that approached the CS to receive QoS guarantees, resulting in significant gains. In the future, the researchers suggest implementing an additional storage system to reduce the strain on the CS and a different resource policy that prioritizes EVs based on their demand requests. In [74], a battery exchange management system was proposed to reduce power grid overload during high-demand periods. 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 the QoS. The results showed that the EVs spent only a few minutes exchanging batteries at the battery exchange unit, improving the queue lengths. The study suggests that similar technology could be used with big data in future research.

4.10. Section Summary

This section comprehensively analyzes various quality of service (QoS) aspects, including the scalability, resource allocation, sizing, costs, energy demands, control strategy, capacity planning, personal satisfaction, and wait times. 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 in detail.

References	Key Terms	QoS Parameter
[61–66]	• Integrated power system based on IEEE-30 bus. • Supply function equilibrium (SFE) model-based game theory • G2V and V2G energy transfer • QoS-aware admission control scheme for PHEV to manage power demands • QoS-based system for P2P energy trading among EV energy providers and consumers • An optimization model for improved CS infrastructure and to reduce costs	Energy Demands and Optimization
[47,57,58]	• SDN–OpenFlow model to enhance scalability • Optimization methodology development using real-time data • QoS scheme for Charging EVs (QCEV) is proposed.	Scalability, Cost
[53,56,72,77]	• Reduced waiting times and more customers served • Heterogeneous UPCN model for public CSs used to reduce wait times and improve the QoS • Daily vehicle data are used to model an analysis of fast-charging CSs for EVs, reduced wait times, and improved QoS. • An optimization model is developed that satisfies the charging reliability requirements and expected QoS	Wait time, Cost, Resource Allocation
[46,50–52,54,68,70]	• 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 • Charging and discharging are optimized for maximum utilization, achieving better QoS • Multi-port DC fast-charging stations are used • Stackelberg equilibrium (SE) concept is proposed in game theory with a differential equation-based hybrid algorithm to achieve better QoS	Resource Allocation, Cost
[48,49,59]	• A two-stage stochastic sizing method is proposed for a guaranteed QoS • PV sizing optimization solution is proposed to minimize guaranteed smart charging capabilities	Cost, Sizing
[55,60,71]	• 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 are proposed controlling EV customer pricing and regulating request rates to improve the QoS	Resource Allocation, Capacity Planning, Cost
[75,76]	• SERVQUAL framework model is used for better service quality in HEBs • A survey-based analysis is conducted for better service quality in public transport	Personal Satisfaction
[73,74]	• A control resource provisioning framework is used for improved wait times and QoS • Battery exchange stations are introduced for a smooth load transfer	Control Strategy, Wait Time
[67,69]	• A new dynamic user behavior model using a stochastic game approach is developed using data from CAISO • Load balancing is implemented in 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, and with 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 communications will provide specific intelligence to the vehicles, creating numerous opportunities to revolutionize 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).

5. EV Communication Infrastructure

The field of intelligent transportation systems (ITSs) is a fascinating area of research that explores the potential benefits of incorporating electrical vehicle communication to enhance the vehicular performance and ensure a high quality of service level. A comprehensive overview of various ITS applications can be found in [84]. 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 [85,86], while a dynamic wireless power transfer technology for power transfer in moving EVs is presented in [87]. A cloud-based framework has been developed to efficiently manage EV charging during peak hours and ensure grid stability [88]. 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 [89], several vehicular communication network technologies related to the IoEV are presented, along with the current challenges and solutions within the field [90]. EVaaS, or electric vehicles 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 [91], allows the 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 the state of charge (SoC), EV location, charging requirements, power rating, and available charge in the EV [92]. A simplified EV communication model featuring mobile nodes, roadside stations, and charging stations is depicted in Figure 7.

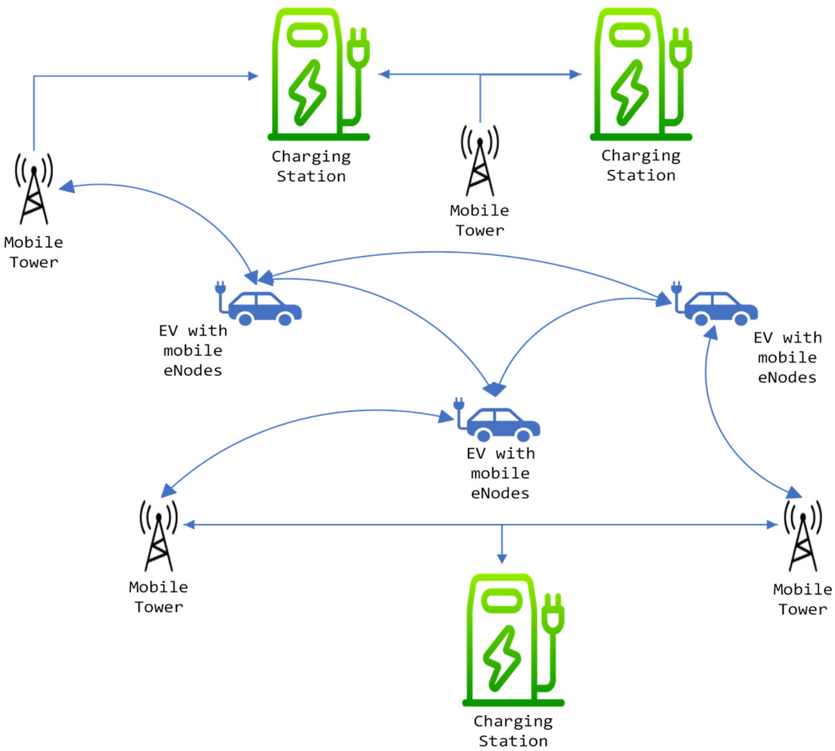

Figure 7. EV communication model.

5.1. 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 [92]. 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 for CSs is thoroughly discussed in [93], and the accompanying wired communication standards are documented in Table 3.

Table 3. Different standards used in EV communication [93].

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 for vehicular communication and ITSs. V2V, V2I, and DSRC are helping to reduce traffic congestion and fatalities on roads. In [94], a recent analysis of IoT standards for vehicular communication, DSRC, and cellular network communications, three core elements, was discussed in detail. The 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. The local network refers to communication outside the vehicle, between vehicles, and with the fixed infrastructure on the roadside. Communication networks such as DSRC/802.11p, WAVE, Wi-Fi, and 4G technologies determine QoS constraints such as the throughput, delay, and bandwidth. The IoT integrates EVs into advanced traffic management systems, focusing on critical aspects such as information, data transmission, electronic sensing, control, and computers.

This article explores the impacts 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 (V2G), vehicle-to-vehicle (V2V), vehicle-to-everything (V2X), cellular 4G or LTE, and 5G networks. Table 4 offers a comparison of wireless communication technologies and their parameters. Figure 8 illustrates the different types of EV communication examined in this article.

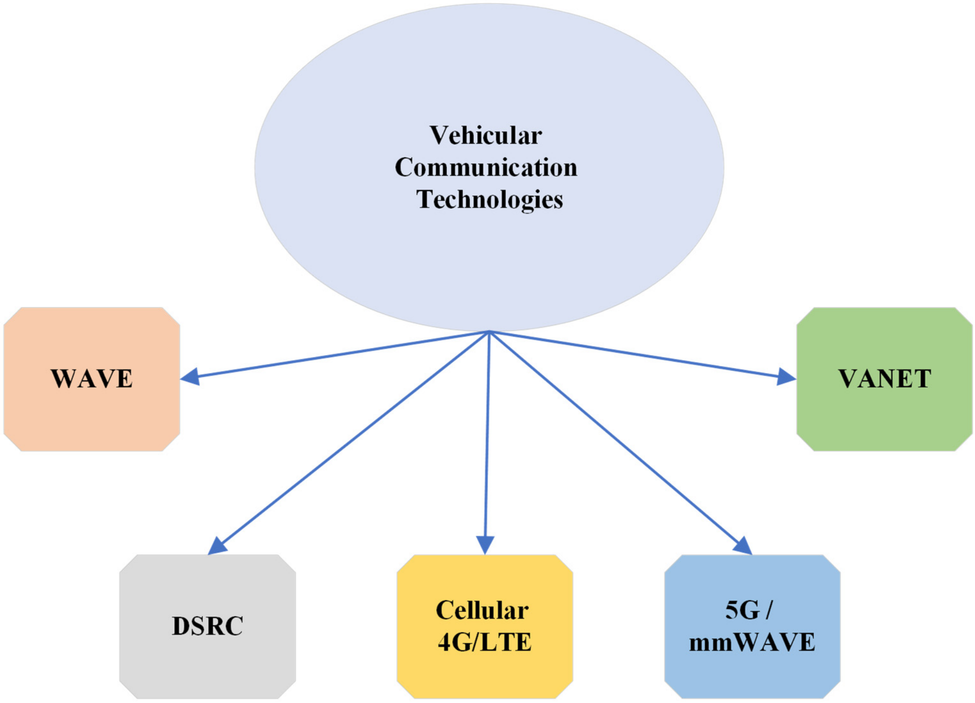

Figure 8. Vehicular communication types.

5.1.1. Dedicated Short-Range Communication (DSRC)

When it comes to vehicular communication, the essential factors to consider are the 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 the surrounding infrastructure [95]. DSRC information 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 75 MHz spectrum at 5.9 GHz 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 [96].

A previous study [97] 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 network (Het-Net) technologies. Through developing a handoff method in the application layer, traffic data collection and forward collision warning information was 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 rates, while Het-Net offered better connectivity beyond the DSRC range for a more extensive traffic network. In future research, it is suggested to implement the application layer handoff method developed in this study in Het-Net-supported vehicles. This technology can enhance the QoS in EV communication.

5.1.2. Vehicular Ad Hoc Network (VANET)

The vehicular ad hoc network (VANET) approach is a rapidly developing technology that belongs to the mobile ad hoc network (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 enhancement, blind crossing, dynamic route scheduling, real-time traffic condition monitoring, and more. Additionally, VANETs are crucial in enabling internet connectivity for electric vehicles (EVs) [98].

Intelligent V2V charging navigation for EVs using VANET-based communication was implemented in [99] 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.

5.1.3. Vehicle-to-Vehicle, Vehicle-to-Infrastructure, and Vehicle-to-Everything (V2V, V2I, and V2X) Communication

Over the past few decades, the number of cars on the road has grown exponentially. In [100], a new control framework was 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 the string stability function is considered when designing the longitudinal control method. 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 [101]. The goal of these technologies is to increase the throughput at the MAC and enable longer communication ranges by reducing the noise sensitivity [102]. To improve the overall energy efficiency and potentially enhance the QoS, a new power-splitting resource allocation approach using C-V2X technology is proposed in [103].

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 [104] delves into various communication technologies and charging services in this space. Information and communication technologies (ICTs) 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 the communication architecture for hybrid V2V and V2I networks to address critical challenges EVs face in adapting to large-scale networks [88,105,106]. Based on the recent research and an established analytical framework, it was 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 was recommended to tackle challenges such as travel costs, searching for a suitable charging station, and reducing wait times and charging duration. Additionally, future research has been proposed around software-defined networks (SDNs) [105,107,108] 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 are goals that present emerging research challenges. In [109], a new concept called the 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 analyzed and compared with four different scenarios: (i) a pull-mode communication framework; (ii) accessing real-time information from the buses; (iii) direct communication between EVs and CSs; (iv) a centralized case communication framework. Practical experiments were conducted on two public transport routes, and the results were verified [110,111]. Adopting the proposed communication framework may allow future improvements to the quality of service (QoS) in EVs, particularly in terms of the queue length and resource allocation.

The use of 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 communication (DSRC) and V2X is becoming increasingly popular, and recent advancements in LTE and 5G cellular networks have addressed challenges in supporting efficient V2X communication [112]. However, there are still challenges to overcome in areas such as the physical layer structure, synchronization, 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) networks, 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 [113,114].

5.1.4. Visible Light Communication (VLC)

A novel approach utilizing visible light communication (VLC) and unmanned aerial vehicles (UAVs) was introduced in [115] to offer flexible communication and lighting solutions. Two sub-problems were suggested to tackle the mutual dependencies of optimization variables: UVA location optimization and cell association. The findings of the numerical analysis confirmed a 53.8% increase in power efficiency. As per the study, implementing the location optimization algorithm from this approach could lead to improved quality of service (QoS) in electric vehicles (EVs).

The recent research has analyzed cyber-attacks on electronic hardware in electric vehicles (EVs), providing recommendations to protect onboard charging systems. In one worst-case scenario [116], 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 s when it has zero loading. The controller can then run the system back to its normal operating condition within 0.5 s. Several experiment trials have been conducted to prioritize the safety of EVs when implementing this new model.

A recent study [117] introduced a novel approach to wireless EV charging through the use of 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 utilizing 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 one article [118], 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 CSs according to demand requests.

5.1.5. Wireless Access in Vehicular Environments (WAVE)

A common obstacle among the current EVs in the market is their limited mileage and charging duration. However, researchers proposed a new methodology [119] involving various machine language techniques. Additionally, the research conducted in [47] involved sharing the locations of EVs through the IEEE 802.11p standard designed for wireless access in vehicular environments (WAVE) in vehicular communications [120]. This integration allows for real-time communication and the 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 a 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 times at public charging stations and improving the quality of service in terms of the cost, waiting time, and resource allocation.

5.1.6. Long-Term Evolution (LTE) Communication

A comparison of DSRC and LET cellular networks to V2V and V2I communication is explored in [121], evaluating the simulation results and addressing the 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 the simulation results was based on the round-trip time, revealing that LET offers a higher data rate. At the same time, DSRC provides lower latency rates, making it a better fit for safety-related applications. Regarding cost-effective QoS, the LET network is the optimal choice due to its utilization of current infrastructure.

The cutting-edge real-time communication approach outlined in [122] 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 the QoS and reduce the 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 [123], the researchers proposed a distributed state estimation and stabilization algorithm that leverages IoT-enabled sensors to measure packet loss between EVs and the control center. The study employed Kalman filtering to validate the numerical results. The simulation and numerical analysis demonstrated that the proposed algorithm effectively reduces estimation errors, and the system reflection time is below 0.03 s.

5.1.7. Fifth-Generation (5G) Communication

The advent of 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) level [109]. Companies such as Qualcomm are leading in developing wireless technologies that promote traffic safety and improved 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) approaches [112]. 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, a smaller antenna is used that can be easily integrated with electric vehicles for more efficient data transfer. However, some challenges still must be overcome in supporting high-mobility vehicular networks through mmWaves [115].

5.1.8. 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 or 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 articles, please refer to Table 4.

Table 4. EV communication references in detail.

References	Key Terms	Communication Technology Focused
[84]	Next-generation vehicular communication	IEEE 802.11p, V2V, V2I
[85]	Review on wireless charging for EVs	Wireless Charging, V2G
[86,87]	Wireless power transfer	Wireless charging
[89]	Challenges in Internet of vehicles (IoVs)	DSRC, VANETS, IoV, V2X
[92,93]	Review of EV communication technologies	IoEV, V2V, V2I, DSRC, V2X
[97]	Communication in a Het-Net wireless networks	Het-Net, DSRC, V2V and V2I
[99]	Vehicle-to-vehicle charging, VANET-based communication	VANET, V2V
[100,104,109,112]	Cellular based V2x communications, EV charging using VANET, V2V communication using a control system and radar	V2V, V2I, IoT, VANET, V2X
[47]	EV charging in smart grid environments using IEEE 802.11p and WAVE	IEEE 802.11p, WAVE
[121–123]	Real-time EVS charging using GSM, DSRC, or 4G-LTE to study vehicular communication performance and minimize cyber-attacks using WSN and IoT	DSRC, IoT, 4G-LTE, GSM cellular
[124]	5G vehicular communication	5G, V2V, V2I, V2X

6. QoS Enhancements for EVs and Communication Protocols

In the domain of electric mobility, it becomes crucial to give priority to achieving a smooth user experience and the efficient use of energy resources. Thus far, our review has focused on the concept of quality of service (QoS) and its correlation with communication technologies relevant to electric vehicles (EVs), along with advancements in communication protocols. The following section will delve into the developments concerning QoS enhancements tailored specifically to EV technology and will also delve into the complexities of communication protocols.

Refinements in EV technology, such as improving electric motors, implementing regenerative braking systems, and advancing battery management approaches, hold the potential to reduce energy consumption while concurrently enhancing the QoS. Within the context of QoS enhancements, there is an opportunity to streamline the charging procedures. The use of faster and more efficient charging technologies can significantly decrease the energy required for EV recharging, ultimately promoting long-term energy efficiency.

Moreover, enhancements aimed at extending the driving range of EVs can contribute to a more energy-efficient use of these vehicles. QoS improvements often involve the optimization of communication protocols to achieve more efficient data transfer between the EV and external systems, including the charging infrastructure or cloud services. This optimization effectively reduces the energy consumed during data transmission, necessitating the use of less power when transmitting the same information.

In the realm of QoS enhancements, there is a commitment to the refining network management and resource allocation processes to ensure that the communication processes achieve the highest levels of energy efficiency. This may encompass implementing intelligent routing and load balancing approaches to mitigate energy consumption within the network infrastructure. Furthermore, QoS enhancements may prioritize critical data and communication over less vital information. The energy consumption associated with data transmission can be significantly reduced through astute data traffic management and reducing unnecessary communication.

Additionally, specific QoS improvements may involve adopting low-power communication protocols meticulously designed to reduce energy consumption in EVs and other Internet of Things (IoT) devices. These protocols are engineered to facilitate efficient communication while preserving the vehicle's battery power.

7. Current Challenges and Future Issues

In this section, we discuss the current and future challenges facing EVs and their communication infrastructure. Range anxiety is a prevalent concern among potential electric vehicle (EV) buyers, particularly on long journeys, as they fear running out of battery power before reaching their intended destination. Furthermore, the initial expense associated with acquiring an EV surpasses that of traditional vehicles, often requiring the provision of incentives and subsidies to enhance the affordability for a broader consumer base. The EV supply chain, encompassing critical components such as batteries, is vulnerable to disruptions, such as shortages of vital minerals and the influence of global economic factors. Thus, ensuring a dependable and stable supply chain is of the utmost importance.

In addition, the accessibility and availability of charging stations continue to present substantial challenges. Giving priority to establishing adequate charging points in urban, rural, and highway locations is crucial for promoting EV adoption. Enhancing the in-car experience by simplifying the user interface, including the infotainment and connectivity, is crucial to attract and retain customers. Nonetheless, the widespread adoption of EVs has the potential to strain the electrical grid. To accommodate the increased demand, upgrading the grid infrastructure and implementing strategies for managing demand are imperative tasks.

There is an urgent need to improve the charging infrastructure due to the rising number of electric vehicles on the road. The primary focus is providing ample conveniently located charging stations, especially in urban areas. As EV technology advances, it is anticipated that there may be changes in charging standards and capabilities. Maintaining the compatibility between vehicles and charging infrastructure is crucial to facilitate faster charging. The widespread adoption of EVs could potentially stress the electrical grid, particularly during peak charging times. To prevent grid overloads, it is essential to implement smart grid technology and measures for load balancing.

Although there have been recent improvements in EV driving ranges, consumers continue to seek extended ranges and faster charging times. Therefore, ongoing research and development into battery technology is of the utmost importance to meet these demands. Government authorities play a vital role in promoting EV adoption by adjusting regulations and policies, encompassing aspects such as taxation, emissions standards, and incentives for manufacturers and consumers. Additionally, as the production of EVs continues to expand, addressing the environmental impacts associated with raw material extraction, manufacturing processes, and the sources of electricity used for charging remains a significant concern.

8. Trends and Future Developments for Electric Vehicles

Concerns about range anxiety have been a significant obstacle for those interested in electric vehicles. However, manufacturers are working tirelessly for improved battery technology, resulting in longer driving ranges from a single charge. These advancements are making electric vehicles more practical for everyday use and longer trips. A campaign based on EV30@30 was launched by Clean Energy Ministerial (CEM) to boost the EV market [125]. Researchers are focused on improved battery efficiency, energy density, and charging times, which will ultimately contribute to longer ranges, faster charging, and better performance. In [126], state-of-the-art and emerging concepts in electric drive technology are studied, suggesting variations required to achieve high efficiency in electric traction drivetrains. 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 has been steadily increasing, encompassing connections such as vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-grid (V2G), and more. V2X-communication-enabled electric vehicles (EVs) share data with other cars, infrastructure, pedestrians, and the power grid, resulting in improved safety, traffic efficiency, and energy management and an overall enhanced driving experience [127,128]. Figure 9 shows the types of 5G communication technology used. The integration of wireless charging technology and communication capabilities represents a significant breakthrough, allowing proper alignment, power transfer control, and safety during wireless charging sessions. Smart charging systems with communication abilities are on the rise, empowering EVs to communicate with the power grid, optimizing energy consumption, reducing the peak demand, and supporting grid stability. Developers are also devising mobile apps and user interfaces for EV owners to monitor their charging status, locate charging stations, plan routes based on charging availability, and remotely control vehicle functions. Communication protocols and technologies are being refined for improved energy efficiency, highlighting the importance of reducing communication-related energy consumption to boost 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 reduce 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 the battery costs decrease and manufacturing scales up, electric vehicles will become even more affordable and environmentally friendly, leading to broader market adoption.

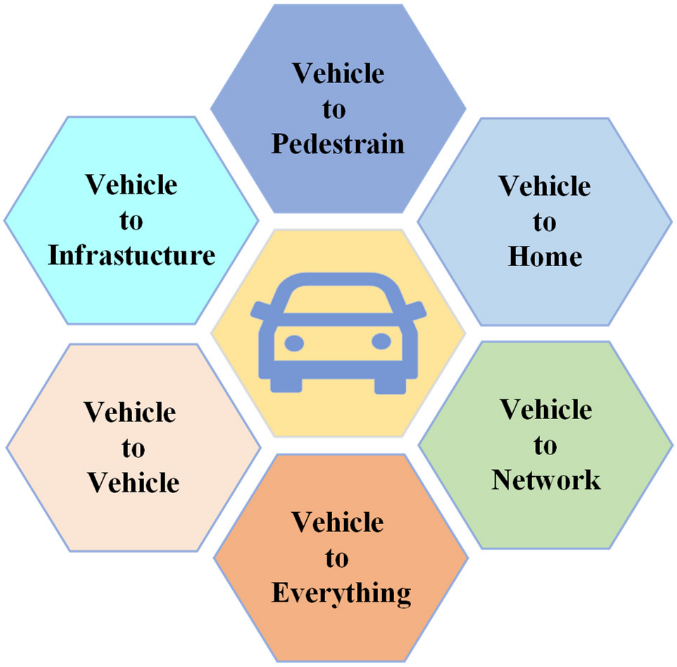

Figure 9. The 5G vehicular communication technology.

9. Conclusions

We conducted an in-depth review and gathered valuable insights into the significance of the quality of service (QoS) in electric vehicles (EVs) and their communication protocols. We aimed to consolidate the existing research studies and advancements in this rapidly evolving field. Our research indicates that quality of service (QoS) is critical for the proper functioning of electric vehicles (EVs) and their communication protocols.

The advancements in EV technologies and sophisticated communication protocols have immense potential to transform how we use and perceive electric mobility. However, the rapid growth of EVs requires a comprehensive understanding of QoS to ensure a smooth user experience and the efficient utilization of energy resources. It is crucial to optimize communication protocols for efficient data transfer between EVs and external systems, including charging infrastructure and cloud services. Despite significant progress being made in this field, the research gaps still require further investigation. These include developing energy-efficient communication protocols, integrating EVs into smart grids, and exploring novel technologies to enhance the QoS. By addressing these challenges, we can unlock the full potential of EVs and make electric mobility more accessible and affordable to everyone.

The future research can focus on developing more sophisticated and precise mathematical models for EVs. It is essential to consider various factors such as vehicle dynamics, battery performance, and traffic conditions when building models to represent real-world scenarios accurately. Additionally, there is a need to develop communication protocols that can effectively manage the growing data load within electric vehicles. Furthermore, exploring innovative charging infrastructure designs that emphasize energy efficiency during recharging is essential. Lastly, researchers can delve into the potential of edge and fog computing solutions for local data processing, whether implemented within EVs or on nearby edge servers.

Funding: This research received no external funding.

Data Availability Statement: The information utilized for creating Figure 1 is accessible to the public through the United States Environmental Protection Agency and has been cited in reference [6]. Similarly, the data for generating Figure 3 is publicly available via the United States Department of Energy and has been cited in reference [24].

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Camacho, O.M.F.; Nørgård, P.B.; Rao, N.; Mihet-Popa, L. Electrical Vehicle Batteries Testing in a Distribution Network Using Sustainable Energy. *IEEE Trans. Smart Grid* **2014**, *5*, 1033–1042. [CrossRef]
2. Monteiro, V.; Pinto, J.G.; Afonso, J.L. Experimental Validation of a Three-Port Integrated Topology to Interface Electric Vehicles and Renewables with the Electrical Grid. *IEEE Trans. Ind. Inform.* **2018**, *14*, 2364–2374. [CrossRef]
3. Tushar, M.H.K.; Assi, C.; Maier, M.; Uddin, M.F. Smart Microgrids: Optimal Joint Scheduling for Electric Vehicles and Home Appliances. *IEEE Trans. Smart Grid* **2014**, *5*, 239–250. [CrossRef]
4. Shahjalal, M.; Shams, T.; Tasnim, M.N.; Ahmed, M.R.; Ahsan, M.; Haider, J. A Critical Review on Charging Technologies of Electric Vehicles. *Energies* **2022**, *15*, 8239. [CrossRef]
5. Sources of Greenhouse Gas Emissions. 2021. Available online: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions (accessed on 1 July 2021).
6. Climate Change Indicators: Atmospheric Concentrations of Greenhouse Gases. 2016. Available online: https://www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases (accessed on 1 June 2021).
7. WA.gov.au. Electric Vehicle Strategy. Available online: https://www.wa.gov.au/service/environment/environment-information-services/electric-vehicle-strategy (accessed on 1 August 2021).
8. Zhang, Q.; Li, C.; Wu, Y. Analysis of Research and Development Trend of the Battery Technology in Electric Vehicle with the Perspective of Patent. *Energy Procedia* **2017**, *105*, 4274–4280. [CrossRef]
9. Frieske, B.; Kloetzke, M.; Mauser, F. Trends in vehicle concept and key technology development for hybrid and battery electric vehicles. In Proceedings of the 2013 World Electric Vehicle Symposium and Exhibition (EVS27), Barcelona, Spain, 17–20 November 2013; pp. 1–12.
10. Leijon, J.; Boström, C. Charging Electric Vehicles Today and in the Future. *World Electr. Veh. J.* **2022**, *13*, 139. [CrossRef]
11. He, H.; Xiong, R.; Guo, H.; Li, S. Comparison study on the battery models used for the energy management of batteries in electric vehicles. *Energy Convers. Manag.* **2012**, *64*, 113–121. [CrossRef]
12. Yan, X.; Li, W.; Gu, J.; Xiao, X. A Simulated System of Battery-Management-System to test Electric Vehicles Charger. In Proceedings of the 2012 IEEE International Electric Vehicle Conference, Greenville, SC, USA, 4–8 March 2012.
13. Sharma, S.; Panwar, A.K.; Tripathi, M.M. Storage technologies for electric vehicles. *J. Traffic Transp. Eng. (Engl. Ed.)* **2020**, *7*, 340–361. [CrossRef]
14. Wang, L.; Pedram, M. QoS Guaranteed Online Management of Battery Swapping Station under Dynamic Energy Pricing. *IET Cyber-Phys. Syst. Theory Appl.* **2019**, *4*, 259–264. [CrossRef]
15. Jean-Francois, R.E.Y. Safety Measures for Electric Vehicle Charging. Available online: https://www.se.com/ww/en/product-range-download/62159-evlink-load-management-system/#/documents-tab (accessed on 1 July 2022).
16. Sakhdari, B.; Azad, N.L. An Optimal Energy Management System for Battery Electric Vehicles. *IFAC-PapersOnLine* **2015**, *48*, 86–92. [CrossRef]
17. Ramraj, R.; Pashajavid, E.; Alahakoon, S. Quality of Service and Energy Management of Electric Vehicles: A Review. In Proceedings of the 2021 31st Australasian Universities Power Engineering Conference (AUPEC), Perth, Australia, 26–30 September 2021; pp. 1–6.
18. Saad, W.; Bennis, M.; Chen, M. A Vision of 6G Wireless Systems: Applications, Trends, Technologies, and Open Research Problems. *IEEE Netw.* **2020**, *34*, 134–142. [CrossRef]
19. Wang, J.; Shao, Y.; Ge, Y.; Yu, R. A Survey of Vehicle to Everything (V2X) Testing. *Sensors* **2019**, *19*, 334. [CrossRef] [PubMed]
20. 5GAA. Deployment Band Configuration for C-V2X at 5.9 GHz in Europe. 5GAA Automotive Association. 2021. Available online: https://5gaa.org/wp-content/uploads/2021/06/5GAA_S-210019_Position-paper-on-European-deployment-band-configuration-for-C-V2X_final.pdf (accessed on 1 March 2022).
21. The History of Electric Car. 2014. Available online: https://www.energy.gov/articles/history-electric-car (accessed on 1 February 2022).
22. IEA. Global EV Outlook 2022. Available online: https://www.iea.org/reports/global-ev-outlook-2022 (accessed on 10 November 2022).
23. IEA. Global EV Outlook 2021. Available online: https://www.iea.org/reports/global-ev-outlook-2021 (accessed on 1 June 2021).
24. Alternative Fuels Data Center. Available online: https://afdc.energy.gov/vehicles/how-do-hybrid-electric-cars-work (accessed on 2 February 2022).
25. Kebriaei, M.; Niasar, A.H.; Asaei, B. Hybrid electric vehicles: An overview. In Proceedings of the 2015 International Conference on Connected Vehicles and Expo (ICCVE), Shenzhen, China, 19–23 October 2015; pp. 299–305.

26. Saleki, A.; Rezazade, S.; Changizian, M. Analysis and simulation of hybrid electric vehicles for sedan vehicle. In Proceedings of the 2017 Iranian Conference on Electrical Engineering (ICEE), Tehran, Iran, 2–4 May 2017; pp. 1412–1416.
27. Suhail, M.; Akhtar, I.; Kirmani, S.; Jameel, M. Development of Progressive fuzzy logic and ANFIS control for Energy management of Plug-in hybrid electric vehicle. *IEEE Access* **2021**, *9*, 62219–62231. [CrossRef]
28. Wu, G.; Zhang, X.; Dong, Z. Powertrain architectures of electrified vehicles: Review, classification and comparison. *J. Frankl. Inst.* **2015**, *352*, 425–448. [CrossRef]
29. Climent, H.; Pla, B.; Bares, P.; Pandey, V. Exploiting driving history for optimising the Energy Management in plug-in Hybrid Electric Vehicles. *Energy Convers. Manag.* **2021**, *234*, 113919. [CrossRef]
30. Fu, H.; Han, Y.; Wang, J.; Zhao, Q. A Novel Optimization of Plug-In Electric Vehicles Charging and Discharging Behaviors in Electrical Distribution Grid. *J. Electr. Comput. Eng.* **2018**, *2018*, 5091084. [CrossRef]
31. Shireen, W.; Patel, S. Plug-in Hybrid Electric vehicles in the smart grid environment. In Proceedings of the IEEE PES T&D 2010, New Orleans, LA, USA, 19–22 April 2010; pp. 1–4.
32. Hariri, A.-M.; Hejazi, M.A.; Hashemi-Dezaki, H. Investigation of impacts of plug-in hybrid electric vehicles' stochastic characteristics modeling on smart grid reliability under different charging scenarios. *J. Clean. Prod.* **2021**, *287*, 125500. [CrossRef]
33. Manzetti, S.; Mariasiu, F. Electric vehicle battery technologies: From present state to future systems. *Renew. Sustain. Energy Rev.* **2015**, *51*, 1004–1012. [CrossRef]
34. Thangavel, S.; Mohanraj, D.; Girijaprasanna, T.; Raju, S.; Dhanamjayulu, C.; Muyeen, S.M. A Comprehensive Review on Electric Vehicle: Battery Management System, Charging Station, Traction Motors. *IEEE Access* **2023**, *11*, 20994–21019. [CrossRef]
35. Kim, B.G.; Tredeau, F.P.; Salameh, Z.M. Performance evaluation of lithium polymer batteries for use in electric vehicles. In Proceedings of the 2008 IEEE Vehicle Power and Propulsion Conference, Harbin, China, 3–5 September 2008; pp. 1–5.
36. Armenta-Déu, C.; Boucheix, B. Evaluation of Lithium-Ion Battery Performance under Variable Climatic Conditions: Influence on the Driving Range of Electric Vehicles. *Future Transp.* **2023**, *3*, 535–551. [CrossRef]
37. Zhang, X.; Li, Z.; Luo, L.; Fan, Y.; Du, Z. A review on thermal management of lithium-ion batteries for electric vehicles. *Energy* **2022**, *238*, 121652. [CrossRef]
38. Sanguesa, J.A.; Torres-Sanz, V.; Garrido, P.; Martinez, F.J.; Marquez-Barja, J.M. A Review on Electric Vehicles: Technologies and Challenges. *Smart Cities* **2021**, *4*, 372–404. [CrossRef]
39. Rastogi, S.K.; Sankar, A.; Manglik, K.; Mishra, S.K.; Mohanty, S.P. Toward the Vision of All-Electric Vehicles in a Decade [Energy and Security]. *IEEE Consum. Electron. Mag.* **2019**, *8*, 103–107. [CrossRef]
40. Rehman, U.U.; Yaqoob, K.; Khan, M.A. Optimal power management framework for smart homes using electric vehicles and energy storage. *Int. J. Electr. Power Energy Syst.* **2022**, *134*, 107358. [CrossRef]
41. Hasan, M.K.; Habib, A.K.M.A.; Islam, S.; Balfaqih, M.; Alfawaz, K.M.; Singh, D. Smart Grid Communication Networks for Electric Vehicles Empowering Distributed Energy Generation: Constraints, Challenges, and Recommendations. *Energies* **2023**, *16*, 1140. [CrossRef]
42. Austmann, L.M. Drivers of the electric vehicle market: A systematic literature review of empirical studies. *Financ. Res. Lett.* **2021**, *41*, 101846. [CrossRef]
43. Tobi, H.; Kampen, J.K. Research design: The methodology for interdisciplinary research framework. *Qual. Quant.* **2018**, *52*, 1209–1225. [CrossRef] [PubMed]
44. Tawfik, G.M.; Dila, K.A.S.; Mohamed, M.Y.F.; Tam, D.N.H.; Kien, N.D.; Ahmed, A.M.; Huy, N.T. A step by step guide for conducting a systematic review and meta-analysis with simulation data. *Trop. Med. Health* **2019**, *47*, 46. [CrossRef]
45. ITU. *Communications Quality of Service: A Framework and Definitions*; ITU-T Recommendation G.1000; ITU: Geneva, Switzerland, 2001.
46. Liu, X.; Zhao, T.; Soh, C.B.; Wang, P. Quality of Service Guaranteed Flexibility Harvesting from Electric Vehicles: A Game Theoretic Approach. In Proceedings of the 2020 IEEE Power & Energy Society General Meeting (PESGM), Montreal, QC, Canada, 2–6 August 2020; pp. 1–5.
47. Al-Anbagi, I.; Mouftah, H.T. A QoS Scheme for Charging Electric Vehicles in a Smart Grid Environment. In Proceedings of the 2014 IEEE 80th Vehicular Technology Conference (VTC2014-Fall), Vancouver, BC, Canada, 14–17 September 2014; pp. 1–5.
48. Graber, G.; Calderaro, V.; Mancarella, P.; Galdi, V. Two-stage stochastic sizing and packetized energy scheduling of BEV charging stations with quality of service constraints. *Appl. Energy* **2020**, *260*, 114262. [CrossRef]
49. Chen, N.; Wang, M.; Shen, X.S. Optimal PV sizing scheme for the PV-integrated fast charging station. In Proceedings of the 2016 8th International Conference on Wireless Communications & Signal Processing (WCSP), Yangzhou, China, 13–15 October 2016; pp. 1–6.
50. Woo, S.; Bae, S.; Moura, S.J. Pareto optimality in cost and service quality for an Electric Vehicle charging facility. *Appl. Energy* **2021**, *290*, 116779. [CrossRef]
51. Zhao, T.; Zhang, J.; Wang, P. Closed-loop supply chain based battery swapping and charging system operation: A hierarchy game approach. *CSEE J. Power Energy Syst.* **2019**, *5*, 35–45. [CrossRef]
52. Sun, B.; Tan, X.; Tsang, D.H.K. Optimal Charging Operation of Battery Swapping and Charging Stations With QoS Guarantee. *IEEE Trans. Smart Grid* **2018**, *9*, 4689–4701. [CrossRef]
53. Davidov, S.; Pantoš, M. Planning of electric vehicle infrastructure based on charging reliability and quality of service. *Energy* **2017**, *118*, 1156–1167. [CrossRef]

54. Abdalrahman, A.; Zhuang, W. Dynamic Pricing for Differentiated PEV Charging Services Using Deep Reinforcement Learning. *IEEE Trans. Intell. Transp. Syst.* **2020**, *23*, 1415–1427. [CrossRef]
55. Bayram, I.S.; Tajer, A.; Abdallah, M.; Qaraqe, K. Capacity Planning Frameworks for Electric Vehicle Charging Stations with Multiclass Customers. *IEEE Trans. Smart Grid* **2015**, *6*, 1934–1943. [CrossRef]
56. Zenginis, I.; Vardakas, J.S.; Zorba, N.; Verikoukis, C.V. Analysis and quality of service evaluation of a fast charging station for electric vehicles. *Energy* **2016**, *112*, 669–678. [CrossRef]
57. Qureshi, K.N.; Hussain, R.; Jeon, G. A Distributed Software Defined Networking Model to Improve the Scalability and Quality of Services for Flexible Green Energy Internet for Smart Grid Systems. *Comput. Electr. Eng.* **2020**, *84*, 106634. [CrossRef]
58. Rauma, K.; Funke, A.; Simolin, T.; Järventausta, P.; Rehtanz, C. Electric Vehicles as a Flexibility Provider: Optimal Charging Schedules to Improve the Quality of Charging Service. *Electricity* **2021**, *2*, 225–243. [CrossRef]
59. Khaksari, A.; Tsaousoglou, G.; Makris, P.; Steriotis, K.; Efthymiopoulos, N.; Varvarigos, E. Sizing of electric vehicle charging stations with smart charging capabilities and quality of service requirements. *Sustain. Cities Soc.* **2021**, *70*, 102872. [CrossRef]
60. Sikeridis, D.; Devetsikiotis, M. Joint Capacity Modeling for Electric Vehicles in V2I-enabled Wireless Charging Highways. In Proceedings of the 2020 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm), Tempe, AZ, USA, 11–13 November 2020; pp. 1–6.
61. Liu, X.; Zhao, T.; Wang, P.; Soh, C.B. Quality of Service Oriented Impact Analysis on Power Systems Considering EV Dynamics. In Proceedings of the 2018 IEEE Power & Energy Society General Meeting (PESGM), Portland, OR, USA, 5–10 August 2018; pp. 1–5.
62. Li, Y.; Ni, Z.; Zhao, T.; Zhong, T.; Liu, Y.; Wu, L.; Zhao, Y. Supply Function Game Based Energy Management Between Electric Vehicle Charging Stations and Electricity Distribution System Considering Quality of Service. *IEEE Trans. Ind. Appl.* **2020**, *56*, 5932–5943. [CrossRef]
63. Harighi, T.; Bayindir, R.; Hossain, E. Overview of quality of service evaluation of a charging station for electric vehicle. In Proceedings of the 2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), San Diego, CA, USA, 5–8 November 2017; pp. 1180–1185.
64. Al-Obaidi, A.A.; Farag, H.E.Z. Decentralized Quality of Service Based System for Energy Trading Among Electric Vehicles. *IEEE Trans. Intell. Transp. Syst.* **2021**, *23*, 6586–6595. [CrossRef]
65. Davidov, S.; Pantoš, M. Optimization model for charging infrastructure planning with electric power system reliability check. *Energy* **2019**, *166*, 886–894. [CrossRef]
66. Erol-Kantarci, M.; Sarker, J.H.; Mouftah, H.T. Quality of service in Plug-in Electric Vehicle charging infrastructure. In Proceedings of the 2012 IEEE International Electric Vehicle Conference, Greenville, SC, USA, 4–8 March 2012.
67. Bayram, I.S.; Michailidis, G.; Devetsikiotis, M. Unsplittable Load Balancing in a Network of Charging Stations Under QoS Guarantees. *IEEE Trans. Smart Grid* **2015**, *6*, 1292–1302. [CrossRef]
68. Buckreus, R.; Kisacikoglu, M.; Yavuz, M.; Balasubramanian, B.; Aksu, R. Analyzing Quality of Service and Operation Costs of a Multi-port DC Fast Charging Station. In Proceedings of the 2021 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), Washington, DC, USA, 16–18 February 2021; pp. 1–5.
69. Chung, H.; Maharjan, S.; Zhang, Y.; Eliassen, F. Intelligent Charging Management of Electric Vehicles Considering Dynamic User Behavior and Renewable Energy: A Stochastic Game Approach. *IEEE Trans. Intell. Transp. Syst.* **2020**, *22*, 7760–7771. [CrossRef]
70. Bayram, I.S.; Michailidis, G.; Devetsikiotis, M.; Granelli, F. Electric Power Allocation in a Network of Fast Charging Stations. *IEEE J. Sel. Areas Commun.* **2013**, *31*, 1235–1246. [CrossRef]
71. Abdalrahman, A.; Zhuang, W. QoS-Aware Capacity Planning of Networked PEV Charging Infrastructure. *IEEE Open J. Veh. Technol.* **2020**, *1*, 116–129. [CrossRef]
72. Fu, J.; Lin, L.; Gao, X. Comprehensive QoS Analysis of Urban Public Charging Network in Topology and Capacity With Its Application in Optimization. *IEEE Access* **2020**, *8*, 53636–53648. [CrossRef]
73. Bayram, I.S.; Abdallah, M.; Qaraqe, K. Providing QoS guarantees to multiple classes of EVs under deterministic grid power. In Proceedings of the 2014 IEEE International Energy Conference (ENERGYCON), Cavtat, Croatia, 13–16 May 2014; pp. 1403–1408.
74. Ye, F.; Qian, Y.; Hu, R.Q. *Intelligent Charging for Electric Vehicles—Scheduling in Battery Exchanges Stations*; John Wiley & Sons Ltd.: Chichester, UK, 2018; pp. 147–170.
75. de Oña, J.; Estévez, E.; de Oña, R. Public transport users versus private vehicle users: Differences about quality of service, satisfaction and attitudes toward public transport in Madrid (Spain). *Travel Behav. Soc.* **2021**, *23*, 76–85. [CrossRef]
76. Munim, Z.H.; Noor, T. Young people's perceived service quality and environmental performance of hybrid electric bus service. *Travel Behav. Soc.* **2020**, *20*, 133–143. [CrossRef]
77. Ucer, E.; Koyuncu, I.; Kisacikoglu, M.C.; Yavuz, M.; Meintz, A.; Rames, C. Modeling and Analysis of a Fast Charging Station and Evaluation of Service Quality for Electric Vehicles. *IEEE Trans. Transp. Electrif.* **2019**, *5*, 215–225. [CrossRef]
78. Tarafdar-Hagh, M.; Taghizad-Tavana, K.; Ghanbari-Ghalehjoughi, M.; Nojavan, S.; Jafari, P.; Shotorbani, A.M. Optimizing Electric Vehicle Operations for a Smart Environment: A Comprehensive Review. *Energies* **2023**, *16*, 4302. [CrossRef]
79. Rücker, F.; Schoeneberger, I.; Wilmschen, T.; Chahbaz, A.; Dechent, P.; Hildenbrand, F.; Barbers, E.; Kuipers, M.; Figgener, J.; Sauer, D.U. A Comprehensive Electric Vehicle Model for Vehicle-to-Grid Strategy Development. *Energies* **2022**, *15*, 4186. [CrossRef]
80. Krishnamurthy, N.K.; Sabhahit, J.N.; Jadoun, V.K.; Gaonkar, D.N.; Shrivastava, A.; Rao, V.S.; Kudva, G. Optimal Placement and Sizing of Electric Vehicle Charging Infrastructure in a Grid-Tied DC Microgrid Using Modified TLBO Method. *Energies* **2023**, *16*, 1781. [CrossRef]

81. Srivastava, S.; Maurya, S.K.; Chauhan, R.K. Fuel-Efficiency Improvement by Component-Size Optimization in Hybrid Electric Vehicles. *World Electr. Veh. J.* **2023**, *14*, 24. [CrossRef]
82. Kene, R.O.; Olwal, T.O. Energy Management and Optimization of Large-Scale Electric Vehicle Charging on the Grid. *World Electr. Veh. J.* **2023**, *14*, 95. [CrossRef]
83. Song, K.; Lan, Y.; Zhang, X.; Jiang, J.; Sun, C.; Yang, G.; Yang, F.; Lan, H. A Review on Interoperability of Wireless Charging Systems for Electric Vehicles. *Energies* **2023**, *16*, 1653. [CrossRef]
84. Paul, A.; Chilamkurti, N.; Daniel, A.; Rho, S. Future trends and challenges in ITS. In *Intelligent Vehicular Networks and Communications*; Elsevier: Amsterdam, The Netherlands, 2017; pp. 185–210.
85. Ahmad, A.; Alam, M.S.; Chabaan, R. A Comprehensive Review of Wireless Charging Technologies for Electric Vehicles. *IEEE Trans. Transp. Electrif.* **2018**, *4*, 38–63. [CrossRef]
86. Patil, D.; McDonough, M.K.; Miller, J.M.; Fahimi, B.; Balsara, P.T. Wireless Power Transfer for Vehicular Applications: Overview and Challenges. *IEEE Trans. Transp. Electrif.* **2018**, *4*, 3–37. [CrossRef]
87. Jeong, S.; Jang, Y.J.; Kum, D. Economic Analysis of the Dynamic Charging Electric Vehicle. *IEEE Trans. Power Electron.* **2015**, *30*, 6368–6377. [CrossRef]
88. Rimal, B.P.; Kong, C.; Poudel, B.; Wang, Y.; Shahi, P. Smart Electric Vehicle Charging in the Era of Internet of Vehicles, Emerging Trends, and Open Issues. *Energies* **2022**, *15*, 1908. [CrossRef]
89. Shen, X.; Fantacci, R.; Chen, S. Internet of Vehicles. *Proc. IEEE* **2020**, *108*, 242–245. [CrossRef]
90. Apata, O.; Bokoro, P.N.; Sharma, G. The Risks and Challenges of Electric Vehicle Integration into Smart Cities. *Energies* **2023**, *16*, 5274. [CrossRef]
91. Umoren, I.A.; Shakir, M.Z. Electric Vehicle as a Service (EVaaS): Applications, Challenges and Enablers. *Energies* **2022**, *15*, 7207. [CrossRef]
92. ElGhanam, E.; Hassan, M.; Osman, A.; Ahmed, I. Review of Communication Technologies for Electric Vehicle Charging Management and Coordination. *World Electr. Veh. J.* **2021**, *12*, 92. [CrossRef]
93. Un-Noor, F.; Padmanaban, S.; Mihet-Popa, L.; Mollah, M.N.; Hossain, E. A Comprehensive Study of Key Electric Vehicle (EV) Components, Technologies, Challenges, Impacts, and Future Direction of Development. *Energies* **2017**, *10*, 1217. [CrossRef]
94. Yang, Y.; Hua, K. Emerging Technologies for 5G-Enabled Vehicular Networks. *IEEE Access* **2019**, *7*, 181117–181141. [CrossRef]
95. Kenney, J.B. Dedicated Short-Range Communications (DSRC) Standards in the United States. *Proc. IEEE* **2011**, *99*, 1162–1182. [CrossRef]
96. FCC. Dedicated Short Range Communications (DSRC) Service. Available online: https://www.fcc.gov/wireless/bureau-divisions/mobility-division/dedicated-short-range-communications-dsrc-service (accessed on 1 August 2021).
97. Dey, K.C.; Rayamajhi, A.; Chowdhury, M.; Bhavsar, P.; Martin, J. Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication in a heterogeneous wireless network—Performance evaluation. *Transp. Res. Part C Emerg. Technol.* **2016**, *68*, 168–184. [CrossRef]
98. Badis, H.; Rachedi, A. Modeling tools to evaluate the performance of wireless multi-hop networks. In *Modeling and Simulation of Computer Networks and Systems*; Obaidat, M.S., Nicopolitidis, P., Zarai, F., Eds.; Morgan Kaufmann: Boston, MA, USA, 2015; pp. 653–682.
99. Li, G.; Sun, Q.; Boukhatem, L.; Wu, J.; Yang, J. Intelligent Vehicle-to-Vehicle Charging Navigation for Mobile Electric Vehicles via VANET-Based Communication. *IEEE Access* **2019**, *7*, 170888–170906. [CrossRef]
100. Wei, S.; Zou, Y.; Zhang, X.; Zhang, T.; Li, X. An Integrated Longitudinal and Lateral Vehicle Following Control System With Radar and Vehicle-to-Vehicle Communication. *IEEE Trans. Veh. Technol.* **2019**, *68*, 1116–1127. [CrossRef]
101. Ansari, K. Joint use of DSRC and C-V2X for V2X communications in the 5.9 GHz ITS band. *IET Intell. Transp. Syst.* **2021**, *15*, 213–224. [CrossRef]
102. Zeadally, S.; Javed, M.A.; Hamida, E.B. Vehicular Communications for ITS: Standardization and Challenges. *IEEE Commun. Stand. Mag.* **2020**, *4*, 11–17. [CrossRef]
103. Jameel, F.; Khan, W.U.; Kumar, N.; Jantti, R. Efficient Power-Splitting and Resource Allocation for Cellular V2X Communications. *IEEE Trans. Intell. Transp. Syst.* **2021**, *22*, 3547–3556. [CrossRef]
104. Cai, L.; Pan, J.; Zhao, L.; Shen, X. Networked Electric Vehicles for Green Intelligent Transportation. *IEEE Commun. Stand. Mag.* **2017**, *1*, 77–83. [CrossRef]
105. Alouache, L.; Nguyen, N.; Aliouat, M.; Chelouah, R. Toward a hybrid SDN Architecture for V2V Communication in IoV Environment. In Proceedings of the 2018 Fifth International Conference on Software Defined Systems (SDS), Barcelona, Spain, 23–26 April 2018; pp. 93–99. [CrossRef]
106. Klaina, H.; Guembe, I.P.; Lopez-Iturri, P.; Astrain, J.J.; Azpilicueta, L.; Aghzout, O.; Alejos, A.V.; Falcone, F. Aggregator to Electric Vehicle LoRaWAN Based Communication Analysis in Vehicle-to-Grid Systems in Smart Cities. *IEEE Access* **2020**, *8*, 124688–124701. [CrossRef]
107. Nkenyereye, L.; Nkenyereye, L.; Islam, S.M.R.; Choi, Y.-H.; Bilal, M.; Jang, J.-W. Software-Defined Network-Based Vehicular Networks: A Position Paper on Their Modeling and Implementation. *Sensors* **2019**, *19*, 3788. [CrossRef]
108. Chen, N.; Wang, M.; Zhang, N.; Shen, X.S.; Zhao, D. SDN-Based Framework for the PEV Integrated Smart Grid. *IEEE Netw.* **2017**, *31*, 14–21. [CrossRef]

109. Cao, Y.; Wang, N. Toward Efficient Electric-Vehicle Charging Using VANET-Based Information Dissemination. *IEEE Trans. Veh. Technol.* **2017**, *66*, 2886–2901. [CrossRef]
110. Ahmad, A.; Khalid, M.; Ullah, Z.; Ahmad, N.; Aljaidi, M.; Malik, F.A.; Manzoor, U. Electric Vehicle Charging Modes, Technologies and Applications of Smart Charging. *Energies* **2022**, *15*, 9471. [CrossRef]
111. Tang, Q.; Li, D.; Zhang, Y.; Chen, X. Dynamic Path-Planning and Charging Optimization for Autonomous Electric Vehicles in Transportation Networks. *Appl. Sci.* **2023**, *13*, 5476. [CrossRef]
112. Gyawali, S.; Xu, S.; Qian, Y.; Hu, R.Q. Challenges and Solutions for Cellular Based V2X Communications. *IEEE Commun. Surv. Tutor.* **2021**, *23*, 222–255. [CrossRef]
113. Salahdine, F.; Han, T.; Zhang, N. Security in 5G and beyond recent advances and future challenges. *Secur. Priv.* **2023**, *6*, e271. [CrossRef]
114. Pons, M.; Valenzuela, E.; Rodríguez, B.; Nolazco-Flores, J.A.; Del-Valle-Soto, C. Utilization of 5G Technologies in IoT Applications: Current Limitations by Interference and Network Optimization Difficulties & Mdash: A Review. *Sensors* **2023**, *23*, 3876.
115. Yang, Y.; Chen, M.; Guo, C.; Feng, C.; Saad, W. Power Efficient Visible Light Communication With Unmanned Aerial Vehicles. *IEEE Commun. Lett.* **2019**, *23*, 1272–1275. [CrossRef]
116. Chandwani, A.; Dey, S.; Mallik, A. Cybersecurity of Onboard Charging Systems for Electric Vehicles—Review, Challenges and Countermeasures. *IEEE Access* **2020**, *8*, 226982–226998. [CrossRef]
117. Qian, Z.; Yan, R.; Wu, J.; He, X. Full-Duplex High-Speed Simultaneous Communication Technology for Wireless EV Charging. *IEEE Trans. Power Electron.* **2019**, *34*, 9369–9373. [CrossRef]
118. Cheng, X. *5G-Enabled Vehicular Communications and Networking*, 1st ed.; Springer International Publishing: Berlin/Heidelberg, Germany, 2019; Imprint.
119. Mazhar, T.; Asif, R.N.; Malik, M.A.; Nadeem, M.A.; Haq, I.; Iqbal, M.; Kamran, M.; Ashraf, S. Electric Vehicle Charging System in the Smart Grid Using Different Machine Learning Methods. *Sustainability* **2023**, *15*, 2603. [CrossRef]
120. Jiang, R.; Zhu, Y. Wireless Access in Vehicular Environment. In *Encyclopedia of Wireless Networks*; Shen, X., Lin, X., Zhang, K., Eds.; Springer International Publishing: Cham, Switzerland, 2019; pp. 1–5.
121. Xu, Z.; Li, X.; Zhao, X.; Zhang, M.H.; Wang, Z. DSRC versus 4G-LTE for Connected Vehicle Applications: A Study on Field Experiments of Vehicular Communication Performance. *J. Adv. Transp.* **2017**, *2017*, 2750452. [CrossRef]
122. George, V.; Dixit, P.; Gaurav, K.; Swaroop, A.; Jaiswal, P. A Novel Web-Based Real Time Communication System for PHEV Fast Charging Stations. In Proceedings of the 2018 3rd International Conference on Circuits, Control, Communication and Computing (I4C), Bangalore, India, 3–5 October 2018; pp. 1–4.
123. Rana, M.M. Attack Resilient Wireless Sensor Networks for Smart Electric Vehicles. *IEEE Sens. Lett.* **2017**, *1*, 1–4. [CrossRef]
124. Shah, S.A.A.; Ahmed, E.; Imran, M.; Zeadally, S. 5G for Vehicular Communications. *IEEE Commun. Mag.* **2018**, *56*, 111–117. [CrossRef]
125. EV30@30 Campaign. Clean Energy Ministerial. Available online: https://www.cleanenergyministerial.org/campaign-clean-energy-ministerial/ev3030-campaign (accessed on 1 October 2021).
126. Husain, I.; Ozpineci, B.; Islam, M.S.; Gurpinar, E.; Su, G.J.; Yu, W.; Chowdhury, S.; Xue, L.; Rahman, D.; Sahu, R. Electric Drive Technology Trends, Challenges, and Opportunities for Future Electric Vehicles. *Proc. IEEE* **2021**, *109*, 1039–1059. [CrossRef]
127. Kei Sakaguchi, R.F.; Yu, T.; Fukuda, E.; Mahler, K.; Heath, R.; Fujii, T.; Takahashi, K.; Khoryaev, A.; Nagata, S.; Shimizu, T. Towards mmWave V2X in 5G and Beyond to Support Automated Driving. *Soc. Inf. Netw.* **2020**, *E104-B*, 587–603. [CrossRef]
128. Flament, M. Cellular Vehicle-to-Everything (C-V2X). 5GAA. Available online: https://www.gsma.com/iot/wp-content/uploads/2020/07/02_5GAA_Maxime-Flament.pdf (accessed on 1 October 2021).