Grenze International Journal of Engineering and Technology, June Issue

A Cloud-based Architecture for EV Charge Station Finder with Efficient Scheduling

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***Abstract*— In the dynamic landscape of electric vehicles (EVs), the demand for efficient and user-friendly charging station finder applications has become increasingly urgent. This paper introduces a holistic solution aimed at consolidating all charging stations across various companies into a single, user-friendly platform. The envisioned application not only assists EV users in locating suitable charging stations at optimal times but also facilitates effective planning of their charging schedules. Additionally, it seeks to address the challenge of limited charging slot availability, ultimately enhancing the overall charging experience for EV users.**

The proposed study includes features to help users strategically schedule their charging sessions during off-peak hours, mitigating the risk of traffic congestion. The paper underscores the necessity of a cloud-based architecture to ensure enhanced scalability and flexibility, adapting to the growing demand for EVs and the subsequent increase in charging station numbers.

In essence, this paper concludes by stressing the importance of a user-friendly and comprehensive EV charging station finder application. It emphasizes critical features such as slot booking and an intuitive interface while highlighting the significance of a cloud-based architecture for improved scalability and flexibility [23].

The envisioned EV charging station finder application represents a substantial advancement in promoting the adoption of EVs. It provides a convenient and efficient solution for users to discover and utilize charging stations, aligning with the broader objective of fostering sustainable transportation. Given the anticipated significant growth in the global market for EV charging stations, this proposal suggests a potentially lucrative venture for the future.

***Index Terms*— Electric Vehicle, Charging Station, slot booking, routing algorithms, ranking algorithms.**

I. INTRODUCTION

The ascent of electric vehicles (EVs) represents an achievement in the ongoing evolution of automobile technology. Projections indicate substantial growth for the global EV market, with a compound annual growth rate (CAGR) of 44.4% expected from 2019 to 2026, reaching an estimated value of $626.9 billion by 2026 [1]. This growth can be associated with various factors, encompassing heightened awareness of global warming and climate change, the decreasing cost of EV batteries, and the expansion of charging infrastructure.
In India, more and more people are jumping on the electric vehicle (EV) bandwagon, as numerous manufacturers

Grenze ID: 01.GIJET.10.2.551_1

roll out their models into the market [2]. Even with the increasing number of EV charging stations, there's still a gap that needs filling. There is a need for an application that can bring all these charging spots together under one user-friendly platform. Currently, there are numerous EV charge station finder applications available on the app market. However, these applications often do not show charging stations from all companies, leading to a lack of transparency and convenience for users [3]. Moreover, the existing applications often lack features that can help EV users plan their charging schedule effectively, such as a slot booking feature [4].

One of the issues faced by EV users is the lack of availability of charging slots at the desired time. A slot booking feature in the EV charge station finder application can help to mitigate this issue by allowing users to book slots in advance. This feature can be a game-changer in managing the limited availability of charging slots and ensuring a smoother charging experience for EV users [23]. Furthermore, a slot booking feature can help EV users avoid traffic jams, as they can plan their charging schedule during off-peak hours [4].

Several EV charge station finder applications are available in the Indian market [5]. However, they do not offer a slot booking feature. There are few applications that allow users to find fast charging stations and even offer the option to earn money by turning their store into an EV charging station [3].

Mumbai, being the financial capital of India, has a high density of EV users. With around 350+ EV charging stations, Mumbai has a significant number of charging stations [2]. However, due to the lack of an integrated platform, it is difficult at times for EV users to find a suitable charging station at the right time. Moreover, the high population density in Mumbai can lead to congestion at the charging stations, especially during peak hours [16].

The main aim of this research paper is to introduce an application for finding EV charge stations in the vicinity and find the best route to reach there. This application will provide a panoramic solution to the challenges faced by EV users, particularly in the city of Mumbai.

The first section of the paper is dedicated to the review of related work that has been done in the field of EV charging station applications. Numerous applications have already been developed to address the challenges faced by EV users, particularly in urban areas like Mumbai [5].

The second section of the paper discusses the different routing algorithms and navigation APIs available and compares them. Routing algorithms are crucial for determining the best route for an EV user to reach a charging station. Famous routing algorithms, such as the A* algorithm and Dijkstra's algorithm, have seen widespread use in EV routing [7]. Some of these algorithms often fall short when it comes to understanding the unique requirements of EV users, like the availability of charging slots. There was a thorough comparison conducted of all these algorithms to pinpoint the one that best addresses the system-specific needs.

The third section of the paper discusses how to find these charging stations. This will involve the use of various APIs that provide information about the location and availability of charging stations. Existing APIs like the Open Charge Map API and the ChargeHub API have been used in the field of EV charging station finding [8]. However, these APIs often could not provide real-time information about the availability of charging slots.

The fourth section of the paper elaborates on ranking algorithms to rank between charging stations. Ranking algorithms are crucial for determining the best charging station for an EV user. Existing ranking algorithms like the VIekriterijumsko KOmpromisno Rangiranje (VIKOR) Algorithm [9] and the Analytic Hierarchy Process (AHP) algorithm have been used in the field of EV charging station ranking [10]. The proposed application will use the best algorithm needed.

The fifth part of the paper focuses on the user flow design of the proposed system. User flow is crucial for understanding the behavior of EV users and improving the user experience of the application. Existing user mapping techniques like User Personas Mapping and User Experience Mapping have been used in the field of EV user mapping [4]. Hence, the study suggests developing an application characterized by a high level of user-friendliness and simplicity.

In the last part of the paper, the proposed system architecture is described. Existing system architectures like the Cloud-Based Architecture and the Mobile-Based Architecture have been used in the field of EV applications [11].

II. Related Work

The transition to electric mobility has accelerated in recent years, leading to a surge in Electric Vehicle (EV) adoption [1]. As a result, the demand for efficient and user-friendly EV application finders has also grown. These apps play a crucial role in helping EV owners and enthusiasts locate charging stations, plan routes, and manage their electric vehicles [4]. This literature review examines the landscape of EV application finders, focusing on their features, user experiences, and the influence of artificial intelligence in enhancing their functionality.

A. User Experiences and Satisfaction

User experiences and satisfaction play a pivotal role in the success of EV application finders. To assess this aspect, researchers have conducted user surveys and analyses.

- A study by Alan Jenn and Jake Highleyman in 2022 surveyed EV owners in California who used PlugShare. Their findings revealed a high level of user satisfaction due to the app's user-friendly interface and ease of use. User reviews and ratings were noted as valuable in helping others make informed decisions [12].
- ChargePoint's user satisfaction was evaluated in a similar survey. The results showed that users appreciated the app's reliability, advanced features, and compatibility with various EV models. ChargePoint's focus on business solutions, such as providing charging options for employees or customers, also received positive feedback [12].
- EVgo's fast-charging network was the subject of a study by Alan Jenn and Jake Highleyman. Users in major U.S. cities expressed satisfaction with the app's accessibility and the speed of charging. The membership plans offered by EVgo were perceived as cost-effective, especially for those who frequently relied on fast chargers [12].

III. MOTIVATION

While the current EV application finders offer a wide range of features, they also have limitations. For instance, the real-time availability of charging stations can be inconsistent, and the accuracy of the information provided can vary. Moreover, the user interface of some apps can be complex and difficult to navigate, leading to a less optimal user experience.

The proposed system aims to address these limitations by incorporating AI technologies to improve the accuracy of charging station availability and route planning. The system will also feature a user-friendly interface that makes it easy for users to find and book charging stations. Furthermore, the system will include a community-driven approach, where users can leave reviews and ratings for charging stations, contributing to a more reliable and trustworthy platform.

IV. PROBLEM FORMULATION

This section contains a comparative study of the routing and ranking algorithms for navigation and ranking in the application.

A. EV Station Ranking

The decision-making process in an Electric Vehicle (EV) charging station finder application can be compared to the task of selecting the most suitable charging station based on specific EV-related features. Users assess and prioritize criteria essential to their charging needs. Here's an illustration that draws parallels between an EV charging station search and the process of planning a road trip:

Users searching for an EV charging station can be likened to road trippers looking for the ideal place to stay overnight. Just as road trippers consider factors like location, amenities, and pricing when selecting accommodations, EV users evaluate charging station features such as charging speed, station availability, and pricing. [6]

Advanced algorithms such as AHP (Analytic Hierarchy Process) and VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) enhance the accuracy and effectiveness of this process, particularly when addressing trade-offs between criteria. These algorithms can be compared to a road trip planner's ability to balance different factors, such as the distance of the journey versus the cost of fuel. [10]

When ranking EV charging stations in their application, one may consider employing a multi-criteria decision-making (MCDM) method. These approaches are adept at ranking alternatives according to various criteria, akin to how a road trip planner might assess and rank different routes based on multiple factors such as distance, scenic views, and road conditions. Several MCDM methods are available for consideration when ranking charging stations: [9]

Analytic Hierarchy Process (AHP): This is a widely-used MCDM method that can be used to determine the relative importance of different criteria and then rank alternatives based on these criteria. In this case, criteria could include factors like charging speed, cost, availability, environmental impact, and user ratings. AHP can help you assign weights to these criteria and rank charging stations accordingly. [10]

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS): This method can be used to rank charging stations by calculating their proximity to the ideal solution. This would need to define what constitutes the ideal charging station based on criteria like cost, speed, and availability. TOPSIS will then rank the stations based on their similarity to this ideal. [15]

VIKOR (Multi-Criteria Optimization and Compromise Solution): VIKOR is a method that aims to find a compromise solution that balances the best performance on multiple criteria. It can be useful when you want to consider trade-offs between factors like cost and speed. VIKOR provides a compromise ranking for the charging stations. [9]

Elimination and Choice Expressing Reality (ELECTRE): ELECTRE is a family of methods that can help you rank charging stations by comparing their performance against predefined criteria. You can set up thresholds for each criterion and use ELECTRE to determine which stations meet these criteria the best. [15]

Weighted Sum Method (WSM): While not a traditional MCDM method, the Weighted Sum Method is a simple way to rank charging stations by assigning weights to each criterion and then calculating a weighted sum for each station. This method is straightforward and can work well if you have a clear understanding of the relative importance of each criterion. [15]

By effectively addressing trade-offs between these criteria, these methods can help users identify and rank the most suitable charging stations based on their specific needs and preferences. This not only improves the overall user experience but also contributes to the broader adoption of EVs by reducing range anxiety and other related concerns.

B. Routing algorithms and navigation APIs

Mapping and route-planning algorithms form the backbone of any navigation application. Traditional GPS navigation systems rely on algorithms like Dijkstra's or A* to find optimal paths between points on a road network graph [7]. The proposed system can leverage these classical shortest-path algorithms but customize them for electric vehicles [13].

For example, the routing cost calculation can integrate real-time charger availability and a vehicle's current state of charge instead of just distance. The pathfinding would then prioritize routes with adequate charging opportunities within reachable range rather than just physical distance. This helps minimize anxiety through intelligent trip planning.

Advanced algorithms like particle swarm optimization or ant colony optimization can further refine results by modeling driver preferences for amenities, connector types, and price points at charging stops. Over time, machine learning can improve the routing logic by recognizing usage patterns from aggregated anonymized trip data.

TABLE I. COMPARING DIFFERENT APIS FOR NAVIGATION AND ROUTING

Feature / API	MapBox	Google Maps	PlugShare	TomTom	OpenChargeMap
Routing Algorithm	Bidirectional A* [13]	Dijkstra's, A* [13]	Not specified	IQ Route (TomTom), EV Service [13]	Not specified
Data Source	High-value mapping and location datasets [18]	Satellite imagery, user-contributed data [20]	Crowdsourced data from EV drivers[13]	IQ Route, EV Service (TomTom), Crowdsourced data [21]	Crowdsourced data
Spatial Analysis	Buffering, point-in-polygon analysis, and spatial joins [19]	Image recognition, demarketing [20]	Not specified	IQ Route, Dynamic Feed (TomTom) [21]	Community approach, user ratings [13]
Traffic Data	Real-time traffic data [18]	Live data from users [20]	Not specified	Real-time availability (TomTom) [21]	Not specified
Customization	Third-party integration [18]	Switching layers, style markers [20]	Personalization for EV industry stakeholders [13]	Personalization for developers (TomTom) [22]	Community-driven, user uploads
Charging Station Planning	Not specified	Not specified	Trip planning based on charging stations [28]	Real-time availability (TomTom) [22]	User uploads, trip planning
Traffic and Time Constraints	Real-time traffic conditions, time-based constraints	Live data for traffic conditions[20]	Not specified	IQ Route (TomTom), Dynamic Feed [21]	Not specified
Privacy Concerns	Not specified	Image recognition privacy features [20]	Not specified	Not specified	Not specified

Community Engagement	Not specified	Not specified	User descriptions and reviews [17]	Crowdsourced data (TomTom), User uploads [21]	Community-driven
Accessibility	APIs and SDKs for integration [18]	Widely accessible	Limited to EV industry stakeholders [17]	APIs and SDKs (TomTom) [22]	Open API, no need for keys [13]
Additional Features	Mapbox Movement - Private dataset of population movement [19]	360-degree view, live data from users [20]	Personalized user experience	Dynamic Feed (TomTom)	User comments, images, ratings

C. Charging Station API Analysis

The analysis compares three prominent charging station APIs namely: Open Charge Map, PlugShare, and TomTom. All these APIs contain essential details like address, charger type, costs, charging time, and working hours[13]. Open Charge Map is an open-source model that allows users to feed in comments and images[13]. PlugShare allows user reviews, represented by a 1-10 score in the API to give a better understanding of the charging station [17]. On the other hand, TomTom lacks description and review features, but it is unique as it provides real-time charging station availability with the help of its API [21].

TomTom's real-time availability feature proves unique among the other APIs, allowing more informed route planning with the help of the accessibility of the charger[29]. The study highlights the impracticality of using Bidirectional A* for navigation and routing due to fluctuating traffic conditions[22]. Notably, TomTom consistently displays lower estimated travel times across scenarios, potentially influenced by its traffic flow considerations.[13] The analysis suggests that PlugShare, Tesla, and Google Maps share similar traffic flow estimations, with negligible variances in travel times.[13] In summary, Bidirectional A* emerges as a versatile and flexible solution for real-time graph traversal, underscoring the distinctive features and performance nuances of each charging station API [7].

V. FLOW DIAGRAM

A. User Personas

User personas are fictional representations of the different types of users that will interact with the proposed EV charging station finder application. These tools are proposed with the purpose of delving into the intricacies of the users' desires, aspirations, motivations, and actions.

For the proposed application there is a user persona named User A. User A often travels for work and needs to charge his EV during these trips. The user prefers to use public charging stations but sometimes needs to charge at home. The user values the convenience and efficiency of finding charging stations.

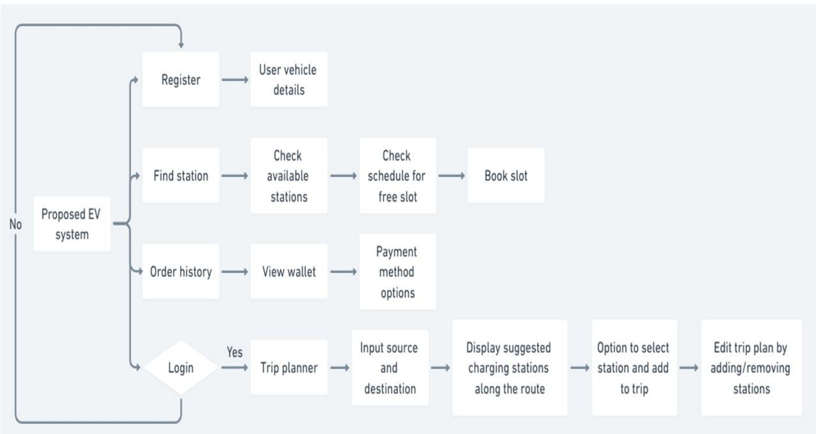

Figure 1. User flow diagram

However, User A faces a significant pain point. Although the user gets EVs from a specific company through their application, he cannot connect to any other company's EV. This limitation gives him limited options when it comes to charging their EV, which can be frustrating and inconvenient. [3]

The user also experiences difficulties in finding a suitable charging station at the right time. The high population density in Mumbai can lead to congestion at the charging stations, especially during peak hours [6]. Moreover, the absence of an integrated platform makes it difficult for users to find a suitable charging station at the right time [3].

B. User Pain Points

The existing EV charging station finder applications often lack features that can help EV users plan their charging schedule effectively, such as a slot booking feature [3]. This can lead to a lack of availability of charging slots at the desired time, which can be a significant inconvenience for EV users [6]. Furthermore, these applications often do not show charging stations from all companies, leading to a lack of transparency and convenience for the users [6].

Another issue faced by EV users is the lack of an integrated platform. Due to the lack of an integrated platform, it is difficult at times for EV users to find a suitable charging station at the right time [6]. Moreover, the high population density in Mumbai can lead to congestion at the charging stations, especially during peak hours.

The user flow diagram for the EV charging station finder application serves as a visual representation crucial for elucidating the dynamic interactions between the user and the system. This diagram plays a pivotal role in comprehending the nuanced journey of the user throughout the application, offering insights into the specific functionalities they engage with. Through a structured visualization, it aids in the systematic analysis of the user's navigation path, contributing to a comprehensive understanding of the user experience within the context of the application's features.

The homepage of the proposed system flow shall welcome users and provide quick access buttons to options like Register, Login, Find stations, and Order history. Based on the user's location or a specified location input, the "View Nearby Stations" page displays a list of charging stations that are in the vicinity. The “Trip Planner” helps users locate charging outlets along their route and plan their trip with assistance. While registering users can enter their car preferences as vehicle preferences, which aids the program in locating charging stations that suit their requirements. Users are able to examine their payment details and history on the “Order History”. Finally, users can manage their digital wallet for the application on the "Wallet Page".

The design of this feature prioritizes user-friendly interactions, offering clear instructions on managing the digital wallet. Users can easily add funds through various payment methods, ensuring a convenient process for topping up their wallet.

In summary, the user flow diagram for the EV charging station finder application serves as a comprehensive and user-friendly representation of the user's journey. It effectively showcases the main functionalities and interactions between the user and the system, emphasizing a seamless and efficient user experience throughout the application.

VI. System Architecture

The suggested system's enhanced mapping and routing capabilities are largely derived from its distributed system architecture.

The architecture of the proposed EV charging station application is carefully designed keeping the heart of this system as the application server, which acts as the central processing unit for the application. It's like the brain of the application, handling all the data requests and responses between the mobile application and the databases. It also communicates with the authentication and payment servers, ensuring secure transactions[11].

The mobile application is the interface that users interact with. It's like the face of the application, sending requests to the application server and presenting the received data in a user-friendly way. It's designed to be intuitive and easy to navigate, allowing users to quickly find and book charging slots.

The proposed system stores information about the navigation/maps API and the external APIs for station data like availability and slot booking and it is updated in real-time to ensure the mobile application provides the most accurate and up-to-date information to the users [23].

The authentication server is like the security guard of the proposed method, verifying the identity of the users and ensuring that only authenticated users can access certain features of the application. The payment server handles the transactions between the users and the charging stations, ensuring secure and smooth transactions [11].

There is provision to store user account data, vehicle profile data, charging station data, and booking details. It ensures that all user data is stored securely and can be accessed when needed [11].

This architecture is designed to be scalable and efficient, allowing the application to handle a large number of users and transactions. It's like a well-built house that can accommodate more people and activities without

breaking down. It's also designed to be robust and reliable, providing a seamless user experience even under high load conditions.
The architecture of the proposed system is a result of extensive research and careful planning. It's been designed to address the unique needs of EV users and provide a reliable and efficient solution for finding and booking charging slots.

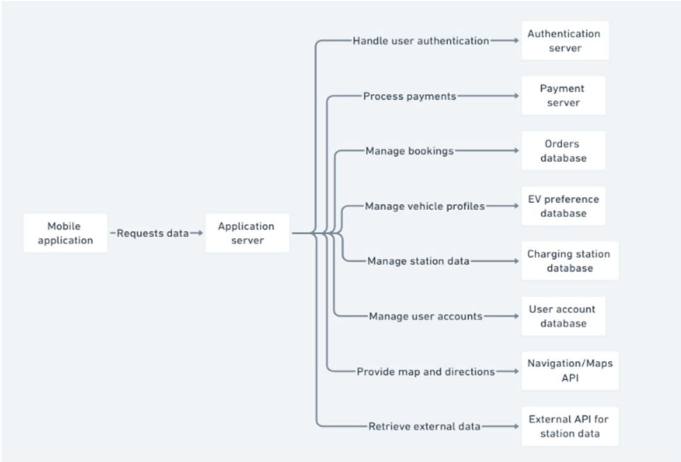

Figure 2. Architecture of proposed Mobile application for EV

VII. CONCLUSION

The research presented in this paper indicates a significant opportunity and need for a comprehensive EV charging station finder application with a booking system, specifically tailored for the city of Mumbai. The proposed application addresses the growing demand for EV infrastructure and user-friendly solutions that can integrate various charging station providers into a singular platform. The key features of strategic scheduling, real-time availability, and an intuitive user interface, supported by a robust cloud-based architecture, are poised to enhance the EV charging experience, reduce congestion, and contribute to the broader adoption of electric vehicles.
The proposed system's innovative approach to routing algorithms, navigation APIs, and ranking mechanisms, coupled with a focus on user experience and a community-driven platform, sets it apart from existing applications. By facilitating a seamless and efficient charging station finding and booking process, the application is expected to play a crucial role in supporting Mumbai's EV ecosystem.
As the EV market continues to expand, the potential for such an application extends beyond Mumbai, suggesting the scalability of the concept to other urban areas with high EV usage. The research underscores the importance of continuous improvement and adaptation to user feedback, technological advancements, and the evolving landscape of electric mobility.
The work outlined in this paper lays the groundwork for future development and research, encouraging the integration of advanced technologies and user-centric design principles in EV infrastructure. The vision for the EV charge station finder application is not just a technological innovation, but also a step towards sustainable urban transportation solutions.

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