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Spatial data management for green mobility

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Spatial Data Management for Green Mobility (Vision Paper)

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ABSTRACT

While many countries are developing appropriate actions towards a greener future and moving towards adopting sustainable mobility activities, the real-time management and planning of innovative transportation facilities and services in urban environments still require the development of advanced mobile data management infrastructures. Novel green mobility solutions, such as electric, hybrid, solar and hydrogen vehicles, as well as public and gig-based transportation resources are very likely to reduce the carbon footprint. However, their successful implementation still needs efficient spatio-temporal data management resources and applications to provide a clear picture and demonstrate their effectiveness. This paper discusses the major data management challenges, open issues, and application opportunities closely related to urban green mobility. Additionally, it reports on recent successful experiences and challenging research questions. Furthermore, it highlights the global benefits one can expect when developing green mobility and emphasizes how mobile data infrastructures and services will play a crucial role in achieving these goals.

CCS Concepts

• Information systems→Database management systems • Information Systems→Information Systems Applications.

Keywords

Green mobility; Mobile Data Management; Data Infrastructure

1. INTRODUCTION

Nowadays, cities are major areas where local authorities face pressure from citizens to explore and implement novel solutions for smarter and greener energy use and management. Smart cities will likely provide a substantial competitive advantage for quality of life and economic performance. However, achieving them requires the development of digital and telecommunication infrastructures to improve and deliver efficient energy and waste management, health services, transportation and traffic solutions, and many citizen services. Green mobility is a major development trend encompassing ride-hailing services, mobility-on-demand, autonomous and connected vehicles, bike sharing, pool-riding services, and economically viable automated solutions.

These initiatives aim to minimize congestion, air pollution and carbon dioxide (CO_2) emissions while promoting inclusive mobility [6]. They bring novel research challenges, such as the development of novel sensors, mobile devices, efficient networks, wireless systems, and communication protocols, along with the need to balance fog-cloud computations [26] while minimizing energy resources to support real-time integration of mobility data, services and smart and green mobility solutions [1]. Moreover, real-time spatial data architectures and infrastructures, Big Data management techniques [9], data analytics, real-time processing, and energy-conscientious AI/ML algorithms [13] should be developed to fully leverage the large volumes of incoming and available data.

While recent years have witnessed numerous innovative developments, this vision paper provides an overview of the progress in mobile data management and proposes potential solutions to further improve green mobility. Section 2 reviews current spatial data management issues, including approaches to minimize data volumes and computational processes, as well as the tradeoff between privacy and efficiency. Section 3 discusses several application opportunities, such as the implementation of vehicular networks, ride-sharing services, gig-based platforms, and the energy challenges associated with green mobility. Finally, Section 4 concludes the paper with a few visionary statements for further development and implementation of green mobilities and their contribution to smart cities.

2. DATA MANAGEMENT CHALLENGES

Smart cities are closely connected to large spatial data infrastructures that support various services, ranging from smart city management to data storage and dissemination. However, these infrastructures come with significant energy costs and varying degrees of carbon emissions, considering the operational carbon intensity of the electricity that powers them and the manufacturing process of the devices. It is also important to consider the environmental footprint of computing infrastructures [13]. In addition to reducing power consumption and CO_2 emissions, there is a clear need for efficient communication networks, and robust systems for data integration, management and sharing. These systems are crucial for effectively and efficiently coordinating and managing the vast amount of data required by smart cities. Mobile data management solutions should aim to develop appropriate and

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well-designed topologies for deploying IoT sensors in the most cost-effective and environmentally friendly manner. Exploring novel IoT architectures can ensure low latency, scalable and optimized integration of sensor-based data using innovative solutions [1].

Important progress has been made in real-time spatial data management, from Hadoop/MapReduce for integrating and managing large incoming data flows to memory-based Apache Spark engines. However, these data processing architectures still require preprocessing solutions to filter and organize the large incoming data flows at semantic, spatial and temporal levels [32]. Cloud and edge computing infrastructures must be developed to effectively handle the massive amounts of heterogeneous data collected from different devices in and around smart cities.

At the data management level, the first requirement is to develop filtering techniques that can effectively generalize, store and index incoming data (e.g., trajectories and locations), while preserving the main semantics of the data (e.g., automatically keeping the vehicle in the centre of the lane). One proposed approach uses Micro-clouds at the vehicle level within a distributed framework, where each vehicle keeps a subset of its positioning data and broadcasts data replicas to other vehicles and the cloud [16]. Context-aware data filtering and aggregation algorithms should be developed to preserve the most appropriate data [17]. A major issue is that most mobility data is collected from various distributed systems, sensors and energy devices [34]. The rapid growth of autonomous and semi-autonomous vehicles is expected to generate massive amounts of real-time sensor-based data from various devices. Integrating with high-definition maps and experience-sharing services results in costly data exchange processes that must be addressed through appropriate data filtering mechanisms.

Deep learning and experience-based approaches can be explored to combine heterogeneous data sources and enable routing that minimizes data consumption for autonomous vehicles [36], in turn, reducing both communication and processing costs while ensuring effective context-aware routing. Efficient distributed data management infrastructures and data flow processing systems must be developed to support scalability, indexing, and advanced manipulation functionalities. To establish efficient pathways for data sharing, seamless integration, and consumption, a wide range of issues must be considered. These include standards, interoperability models, and legal and regulatory agreements among stakeholders and city authorities [23]. Urgent attention is needed to promote spatio-temporal data sharing and consumption models, as well as privacy guidelines that can serve as a reference for the sound and efficient implementation of mobility infrastructures and services.

A notion of an ecosystem approach has been suggested to facilitate a broad spectrum of location service applications to manipulate and discover the right data sets for a given task [21]. This will also require the development of standard interfaces and data exchange formats. Effective spatial data sharing and consumption among all stakeholders involved in transportation services can improve mobility services, enhance economic competitiveness, and reduce carbon footprints [14]. In pandemic scenarios, the development of contact-tracing applications should focus on efficient architectures, such as location-based protocols and sensors, while considering the choice between distributed and centralized architectures. Finding the right balance between efficiency and minimizing environmental and economic costs is crucial [37]. Nevertheless, privacy and data protection remain essential considerations, requiring mutual trust and a strong commitment from city managers and IT mobility companies [22].

Mobility data is often application-oriented and may not be ideally designed for shared services. There is a common reluctance to share the data unless local authorities provide incentives. To address this, eco-friendly computing applications should be developed, enabling easy reuse and recycling of data. These applications should strike a balance between green computing practices and the need to preserve business applications. Trust management and privacy protection are critical in data consumption, emphasizing the importance of finding the right trade-off balance and the cost of effective business and user applications [24].

Telecommunication companies, with their extensive radio and backbone infrastructure covering both urban and rural areas, have a significant advantage in collecting vast amounts of spatio-temporal data that capture a variety of natural phenomena on an ongoing basis, e.g., traffic, commerce and mobility patterns [8]. The ability to analyze such big data with acceptable delays and share it with key smart city enablers elevates the role of such companies. They transition from being mere network access providers to becoming information providers for future green services, contributing to the development of smart cities.

3. APPLICATION CHALLENGES

The search for smart mobility applications includes a wide range of services from public to private traffic optimization to the generation of collaborative and on-demand transportation and reducing accident rates and pollution figures. Information and Communications Technology (ICT), crowd-based and sensor-based data can play a major role in delivering advanced traffic, accessibility and mobility services [11]. The continuous development of wireless network technologies is very likely to provide many opportunities for developing efficient platforms to support green vehicular networks, safe cycling solutions and smart transportation systems. Within smart and connected communities, ubiquitous networks of connected devices equipped with smart sensors and big data analytics can improve public services and real-time traffic and reduce their environmental impact [26,29].

One of the most prevalent applications to emerge from this movement is commercial ride-sharing platforms, such as Uber, Grab, Didi Chuxing, Bolt, and Lyft [2], which continue to gain popularity for both drivers and riders. From the drivers' perspective, the gig-based job model of these platforms offers flexibility to increase their income while retaining autonomy in their decision-making and scheduling. Unlike traditional taxi ride-sharing models [27], drivers in gig-based platforms independently complete rides, taking into account their constraints and preferences, with minimal input from the service provider. Consequently, that model implicitly encourages competition among drivers, longer working hours, and hasty decisions that may not always be in their best interest [28], nor in the interest of reducing overall CO_2 emission.

Some of the significant drawbacks of this autonomous yet blind decision-making process are the increase in the number of vehicles on urban roads (i.e., congestion), as well as the phenomenon of deadheading [35]. These cause ride-sharing platforms to have a negative impact on the environment due to the rise in carbon emissions. One approach to reducing the number of vehicles on the road, while meeting customer demand, is to further promote carpooling. Existing solutions in the field of ride-sharing and taxi dispatching achieve this by either dynamically rerouting vehicles to pick up new carpooled rides as they become available [35], or by proactively planning drivers' routes with detours to maximize their chances to pick up carpooled rides along their way [5]. The problem of reducing deadheading in transportation networks has long been studied, and it has recently been applied to the ride-sharing setting with works that propose mechanisms for vehicle repositioning when idle [25] or mechanisms for ride assignment and driver dispatching with consideration for idle time [15].

Yet, to the best of our knowledge, none of the existing works has investigated either problem with the realistic constraints that drivers face when driving for commercial ride-sharing platforms. On these platforms, drivers make all ride choices and idling decisions autonomously, without explicit interference from the service provider. Therefore, we argue that these negative environmental impacts can be reduced, and thus greener mobility can be promoted, if drivers are equipped with more information about surrounding rides and drivers, which can only be achieved through driver cooperation and information sharing while maintaining their roles within these well-known commercial platforms. Driver Guidance System developed based on real-time data analytics and large-scale optimization (e.g., Waze) to help taxi drivers has demonstrated the power of real-time information and its positive impact on the decision-making behavior of drivers [18]. Consequently, there is a need for the design and development of application programming interfaces (APIs) and innovative visualization interfaces that support the delivery of real-time streaming spatial data and applications, while providing strong connections between final users and the stakeholders.

The design and distribution of charging station infrastructures to optimize users' demands for electric vehicles are likely to facilitate the adoption of these technologies and improve the environmental impact [20]. IoT components play a major role in smart city infrastructure by connecting sensors, people and services [19]. However, their widespread use in data delivery leads to a high amount of energy consumption. Green IoT appears as a major trend to contribute to cost-effective solutions [3]. Cutting-edge computer paradigms with embedded cognitive capabilities should be progressively introduced into the realms of vehicles and data infrastructure to support the development of novel intelligent mobility services [33]. The planning and development processes of electric transportation modes should be regularly evaluated with the right balance between demand figures and the aggregate cost of the whole system [12].

In the context of Green Mobility, the Vehicle-to-Grid charger allows Electric Vehicle (EV) owners to store excess amounts of renewable energy in the batteries of idle vehicles and reuse it when needed. In this context, energy planning systems, such as the Energy Planner and Green Planner AI algorithms become critical in shifting loads and aligning renewable energy production with its consumption [7]. This also highlights the importance of advanced spatial data management algorithms that exploit temporal and spatial dimensions to optimize self-consumption patterns [39]. In particular, the Internet of Vehicles (IoV) paradigm [38] can be extended to enable collaborative management of energy-aware routing and scheduling the charging of electric cars.

Mobile data management tools enable the instrumentation of the system through a dashboard that provides operational, analytical, and forecasting data feeds to the stakeholders. Eco-routing refers to smart solutions aiming to reduce automobile fuel consumption and thus greenhouse gas (GHG) emissions. In this context, the EcoTour application annotates an OpenStreetMap map with optimal routes based on green criteria [4]. Similar approaches are nowadays also brought forward by Google Maps (with EV routes), systems such as abetterrouteplanner.com or on-board navigation systems of EV vehicles (e.g., e-Route Planner in the VW.OS operating system 3.0). Car-sharing programs, such as the We Move mobile app, also expose the importance of mobility smartphone apps play in this new era of matching mobility needs to assets, such as car renting [31].

4. CONCLUSION

There is clearly a major challenge for the research community to provide effective management and operating solutions for urban green mobility, both in terms of services to be delivered to citizens and advanced systems for understanding, managing, and planning urban mobility. The issues are multiple, ranging from developing eco-sensors and optimized topologies for integrating spatio-temporal mobility data in real-time, to implementing optimal integration processes for these large real-time data flows and data-sharing concepts. This requires clear and identifiable governance practices and compliance with ethics and data protection regulations.

Furthermore, the upcoming development of 6G communication technologies, with terabytes per second of data flows and low latency, opens up novel opportunities to generate massive interlinked mobile data networks and connected smart cities in a massive lake of data exchange and global services [30]. However, the environmental impact of these advancements still needs to be evaluated. This leads to an open decentralized ecosystem allowing all mobility data generators and providers to share data platforms and services, as demonstrated by the ongoing development of the Mobility Data Space project in Germany [10] related to the EU's initiative on Data Spaces. Thus, it becomes crucial to encourage the adoption of green mobility behaviors and ensure their successful implementations that benefit citizens and decision-makers, by bridging the existing gaps between mobile data management solutions and policies/strategies to implement them.

Through this anticipated progress, a critical look at the actual environmental cost of mobile spatio-temporal data management infrastructures and solutions must be taken, with the understanding that they are not easy to identify and that future needs must be anticipated. Especially with the constant evolution of technologies, in terms of physical sensors and hardware and software data engines, this progress as well as its impact on the environment, in terms of emissions and maintenance costs, create major challenges for the spatial data research community. Finally, such solutions must be imagined not only for our developed societies' modern and industrial cities, but also for those that do not benefit from all of our wealthiest cities' advanced capabilities.

Spatial data management for green mobility should not be limited to urban systems alone but should be also extended to aerial and maritime transportation, which are significant contributors to greenhouse gas emissions. Robust and scalable air traffic management systems should be improved to reduce fuel consumption and emissions. Similarly, large data infrastructures should provide valuable support for data analytics to optimise maritime routes at the regional and global levels. Finally, close interaction between industry stakeholders, technology providers, and regulatory bodies is essential to support the goals of green mobility, safety, efficiency, and sustainability.

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