Renewable Mobility in Smart Cities: Cloud-Based Services

Damianos Gavalas
Dept of Product & Systems Design Engineering,
University of the Aegean,
Syros, Greece
&
CTI, Patras, Greece
dgavalas@aegean.gr

Kalliopi Giannakopoulou
Dept of Computer Engineering & Informatics,
University of Patras,
Patras, Greece
&
CTI, Patras, Greece
gianakok@ceid.upatras.gr

Vlasios Kasapakis
Dept of Cultural Technology & Communication,
University of the Aegean,
Mytilene, Greece
&
CTI, Patras, Greece
v.kasapakis@aegean.gr

Dionisis Kehagias
Centre for Research and Technology Hellas/Information Technologies Institute (CERTH/ITI),
Thessaloniki, Greece
diok@iti.gr

Charalampos Konstantopoulos
Dept of Informatics,
University of Piraeus,
Piraeus, Greece
&
CTI, Patras, Greece
konstant@unipi.gr

Spyros Kontogiannis
Dept of Computer Science & Engineering,
University of Ioannina,
Ioannina, Greece
&
CTI, Patras, Greece
kontog@cs.uoi.gr

Damianos Kypriadis
Dept of Informatics,
University of Piraeus,
Piraeus, Greece
&
CTI, Patras, Greece
dkypriad@unipi.gr

Grammati Pantziou
Dept of Informatics,
Technological Educational Institution of Athens, Athens, Greece
&
CTI, Patras, Greece
pantziou@teiath.gr

Andreas Paraskevopoulos
Dept of Computer Engineering & Informatics,
University of Patras, Patras, Greece
&
CTI, Patras, Greece
paraskevop@ceid.upatras.gr

Christos Zaroliagis
Dept of Computer Engineering & Informatics,
University of Patras, Patras, Greece
&
CTI, Patras, Greece
zaro@ceid.upatras.gr

***Abstract*— Providing efficient, sustainable and personalized mobility services in urban environments that combine a spectrum of transport modes (e.g., public transport, electric vehicles, vehicle sharing, low energy and/or emission routes) constitutes a great challenge. In this work, we present MOVESMART, a holistic approach (and integrated platform) for the provision of renewable personal mobility services, leveraging crowd-sourcing data, tools for collecting real-time information by multimodal travelers, and traffic prediction mechanisms. MOVESMART guarantees real-time responses to renewable (on-demand) mobility queries for efficient multi-modal route planning that are time-dependent as well as sensitive to aperiodic incidents and traffic prediction forecasts. This paper focuses on the cloud-based (backend) services of the MOVESMART platform.**

***Keywords*—Sustainable mobility; renewable mobility; multimodal route planning; crowdsourcing; vehicle sharing; algorithm engineering.**

I. Introduction

The computation of specialized route plans for individuals is a crucial daily operation that immediately affects the quality of life and has a severe impact on the environmental footprint of an urban area. This is why technological challenges concerning the efficient computation of route plans have been extensively addressed both theoretically and in practice during the last 70 years. Nevertheless, some great challenges that still need to be addressed are (i) coping with the huge scale of the traffic data corresponding to metropolitan areas, and (ii) taking into account the temporal characteristics reported in real time for the underlying network. For example, the actual travel times of particular road segments depend strongly on both the exact time being used (e.g., rush-hour vs. night-shift, or weekly vs. weekend statistics that typically differ a lot) and the emergence of unforeseen incidents concerning the real time operation of the network (e.g., weather conditions, car accidents, etc.).

Current approaches do not adequately address the aforementioned challenges. The current approaches/systems for storing and maintaining traffic information mainly focus on returning answers for fixed departure times, and all the time-dependence updates are mainly done on the raw traffic information. Additionally, the existing approaches either provide super-polynomial space solutions, or provide heuristic approaches of non-guaranteed quality for answering route planning queries in networks with time-dependent arc costs, for fixed departure times. They do not support fast (i.e., real time) computations of time-dependent route planning profiles from an origin to any reachable destination, for certain time windows of departure. Finally, the support for efficient updating of stored traffic information, according to the periodic changes in the urban traffic statistics, is mainly based on re-building the entire pre-processed traffic structures from scratch, and this is often questionable due to the very demanding computational requirements.

The current approaches and systems mainly focus on monitoring traffic via live traffic reports by the navigation devices themselves (upon end user's admission to do so), and partially assessing these reports in order to avoid reporting externalities (e.g., when a car parks for a while, during the trip). There is no mechanism for the end users to provide feedback a posteriori for the quality of the suggested route plans. This is nevertheless a very important parameter of the self-assessment and future improvement of a navigation system. Additionally, the potential of providing emergency reports for unforeseen events is currently only partially covered in the existing systems. A crucial need is to provide (after assessing the significance of these emergency reports) not only an appropriate alert to the involved end users, but also a contingency plan for the forthcoming disruption that was just predicted, which will cause the minimum overall disturbance to the end users.

The research project MOVESMART [8] overcomes the existing weaknesses for storing and maintain traffic information, as well as in providing efficiently time-dependent route plans in large-scale urban-traffic networks, by offering a holistic approach (and integrated platform) for the provision of renewable personal mobility services, leveraging crowd-sourcing data, tools for collecting real-time information by multimodal travelers, and traffic prediction mechanisms. The goal is to guarantee real-time responses to renewable (on-demand) mobility queries for efficient multi-modal route planning that are time-dependent as well as sensitive to aperiodic incidents (such as car accidents, sudden weather conditions, etc.) and traffic prediction forecasts.

The backend of MOVESMART is a hierarchical urban-traffic infrastructure that is hosted and maintained by a cloud-based architecture. MOVESMART creates real time urban-traffic data and metadata through its live-traffic logging system on the cloud, hosted by its urban traffic knowledge base (UTKB). One of the innovative aspects of MOVESMART is the provision of multimodal mobility services addressing the needs and limitations imposed by electric vehicles (EVs) in addition to other modes of public transport. An Energy Efficiency Assessment Module undertakes the estimation of the environmental footprint of the calculated routes thus providing a means for the holistic assessment of the provided solutions from an energy-saving point of view, including EVs.

The end-user applications of MOVESMART comprises a set of mobile applications that provide travelers a holistic approach to renewable personalized mobility in urban environments.

Overall, MOVESMART provides a bulk of services that split into two main categories: (a) backend services running on a cloud infrastructure and involving crowd-sourcing, traffic prediction, UTKB, time-dependent route planning, and energy assessment; (b) frontend services (end-user applications), in particular an integrated mobile application and offering a holistic approach to renewable mobility in urban environments that involves personalized multimodal route planning along with EV sharing and booking.

In this paper, we focus on the presentation of the cloud-based (backend) services of the MOVESMART platform.

II. AN OVERVIEW OF THE MOVESMART APPROACH

Due to the quite demanding computational requirements for the creation and maintenance of pre-processed information, a central choice in MOVESMART was to create an Urban Traffic Knowledge Base (UTKB) that resides in a cloud of urban traffic servers, and all the pre-processed data updates are handled centrally by this UTKB. The token is then passed to mobile devices (either in-car devices, or smartphones), which submit route-planning profile queries to be handled locally according to the end user's particular preferences and the available options he or she is given.

In order to deal with disconnection issues of the mobile devices, MOVESMART also provides a synchronization mechanism that periodically feeds the local devices with updates of time-dependent snapshots provided by the UTKB. To avoid the aforementioned weaknesses on traffic monitoring and digestion, MOVESMART employs a novel approach that exploits the human-computer interaction via a crowd sourcing scheme mainly collecting traffic information from ad hoc traffic sensing entities. These ad hoc traffic sensing entities may be either in-car or in-hand mobile devices (PNDs or smartphone applications) that allow either periodic, or instantaneous on-route traffic reports, on behalf of the end users. The goal is to cover the entire metropolitan network, or at least the mostly used part of it, in a way that is complementary to that of the fixed traffic sensing devices. The ad hoc traffic sensing devices may report either periodic reports (e.g., average-speed reports) on particular road segments, or some alerts for emergent incidents such as a car accident that temporarily blocks some particular road segments, or a sudden weather storm that causes an unforeseen congestion. Coping with these unforeseen incidents necessitates the consideration of dynamic networks, in which particular elements may suddenly become temporally unavailable for a certain period of time. Finally, each end user is also able to submit post-route satisfaction reports with his or her own feedback on the quality of the route plans suggested by the system, in a like/dislike fashion.

The rationale of the entire MOVESMART system is depicted in Figure 1: there is an everlasting life-cycle of traffic-information *collection* via the fixed and the ad hoc traffic-sensing entities, *prediction* of emergent (aperiodic) incidents and provision of appropriate alerts via the Traffic Prediction Mechanism (TPM), *adaptation* of the maintained data structures in the UTKB, *computation* of time-dependent route plans and incident-dependent route re-plans, and finally post-trip *assessment* of the suggested route (re-)plans directly by the end users.

Figure 1: Rationale of the MOVESMART traffic-information life cycle.

In the rest of the paper, we discuss in more detail the main backend services of the MOVESMART platform.

III. CROWD SOURCING

The *Crowd Sourcing Platform* provides an open crowd sourcing framework for collecting and managing traffic data. Collection of traffic data is divided into: a) en-route data, related with user's location and speed in real-time, b) post-route data, concerning the feedback information that users send in order to evaluate nearby reports and ensure collected data quality, and c) emergency data related with unpredictable events like car accidents, works or extreme weather phenomena that directly affect traffic conditions.

The idea of hiring and tracking users with GPS-enabled devices has been employed to obtain live traffic data and improve the accuracy and reliability of routes recommended by car navigation systems. This is especially useful to yield traffic information on road network areas not covered by fixed traffic sensing infrastructure. MOVESMART's specific contributions include:

- Enabling a mechanism for collecting real time emergency reports of disruptions, transmitted to end users (based on the significance of the reports and the reliability of the reporters). In this respect, this mechanism has a particular module capable of estimating the reliability of collected data as a means to ensure the quality and reduce the impact of malicious users. The integration of the crowd sourcing functionalities with the report evaluation algorithm has been a critical challenge, but also the main factor of success of the whole work. This is highly important for the assessment and future improvement of a crowd sourcing system.
- Using the post-route traffic information to update the traffic prediction module and thus assessing its quality. This is highly important for the assessment and future improvement of a traffic prediction system.
- Development, release and evaluation of the crowd sourcing service, initially as a standalone mobile application, called "Live Traffic Reporter"[1] and eventually as a part of the integrated "MOVESMART"[2] application. Towards this endeavor, there were several challenges that needed to be tackled in order to achieve the optimal result. Cutting-edge technologies have been used in all stages and levels of development. Our aim was to use the most optimal and effective technologies as a means to ensure that the developed application would meet all modern standards for mobile applications.

As stated above, a major contribution of the crowd sourcing mechanism that is implemented as part of the MOVESMART project is the development of a prototype reliability assessment mechanism that is used to validate the crowd sourcing information [5]. Based on the fact that the crowd sourcing mechanism collects data from various users who may send false, inaccurate or misleading information, there is a need for evaluating all collected data in such a way that their quality is ensured. To this end, we have developed a user credibility algorithm which aims to evaluate the trustworthiness of each user as well as the report evaluation algorithm that evaluates the reliability of each submitted report (emergency data). The innovative features that have been implemented include the use of the user's feedback on previous users' reports for the calculation of the credibility, as well as a new formula to calculate the overall score that is used for detecting "spam" reports.

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1 https://play.google.com/store/apps/details?id=com.iti.movesmart.crowdsourcing&hl=el

2 https://play.google.com/store/apps/details?id=gr.iti.Movesmart&hl=el

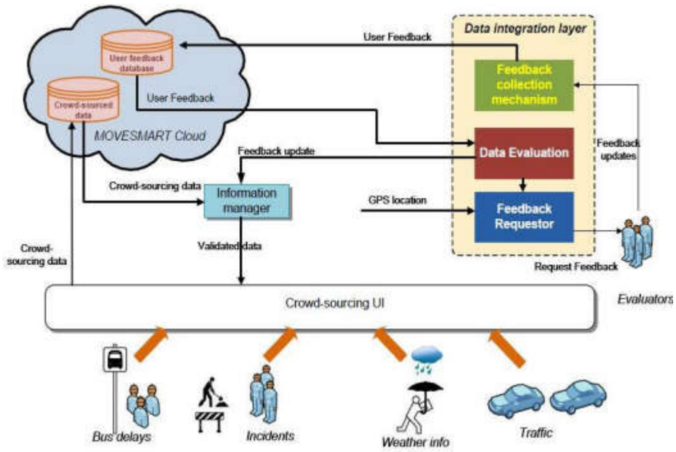

Figure 2: A high-level architectural diagram of the crowd sourcing service.

Figure 2 illustrates a high-level architectural diagram of the crowd sourcing service. All in all, the crowd-sourcing system consists of a user credibility management system that includes also a feedback database, and a validation component that is used in order to validate crowd-sourced information based on user credibility. The crowd-sourcing module uses the crowd-sourced information, according to the outcome of the data evaluation mechanism.

IV. Traffic Prediction

Vehicular traffic prediction at different spatiotemporal instances is considered as one of the primary means for enhancing the performance of decision support systems in modern ITS. The Traffic Prediction service is incorporated in the *Renewable Mobility on Demand* asset, a realization of Renewable Mobility on Demand based on the corresponding MOVESMART service. This service is also be included in the *Transport Data Repository* (accessible on the cloud), a set of cloud provided services in the domain of transport which will provide traffic prediction services based on historical and crowd-sourced data.

MOVESMART's specific contributions in the Traffic Prediction service include [6,7]:

- Developing novel algorithmic techniques to incorporate users' semantic feedback about traffic conditions and abnormal phenomena (e.g. due to weather alterations and accidents) into the traffic prediction scheme. The most effective existing traffic prediction methodologies have been enhanced so as to adapt upon the notification of traffic incidents. Moreover, suitable interfaces have been developed for efficiently mapping all the abnormal traffic phenomena onto measurable and exploitable information; those interfaces cater for the convenient use of the tool (and hence the maximization of the users' participation) and the effective transformation of the users' feedback.
- Enabling monitoring and assessment of the real time status of the network via live-traffic reports, and capability of both predicting short-term disruptions and suggesting in real time traffic-contingency plans to the users causing the minimum overall disturbance.
- Developing algorithmic techniques to smooth human feedback and disregard overly-biased user reports, thereby enhancing the reliability of the traffic prediction input. Third-party sources (e.g. weather forecast web services) have been also utilized to formulate a clear view on the status of the transportation network.

Graph-based Lag-STARIMA [6,7], the innovative traffic prediction parametric technique developed in MOVESMART, takes into account the topology of the network for creating regions of roads correlated to a specific road for which we wish to perform traffic prediction. Another newly-developed approach comprises a parametric technique based on clustering traffic data for creating various homogeneous road occupancy profiles. Data clustering is applied on different time periods (segments) according to the type of traffic (free flow vs. high congestion). These two approaches were evaluated by the means of a benchmarking environment, against a set of well-known techniques from the relevant literature. Available data that were used for benchmarking purposes and also for training the two techniques were derived from a network of inductive loop detectors in the city of Vitoria-Gasteiz.

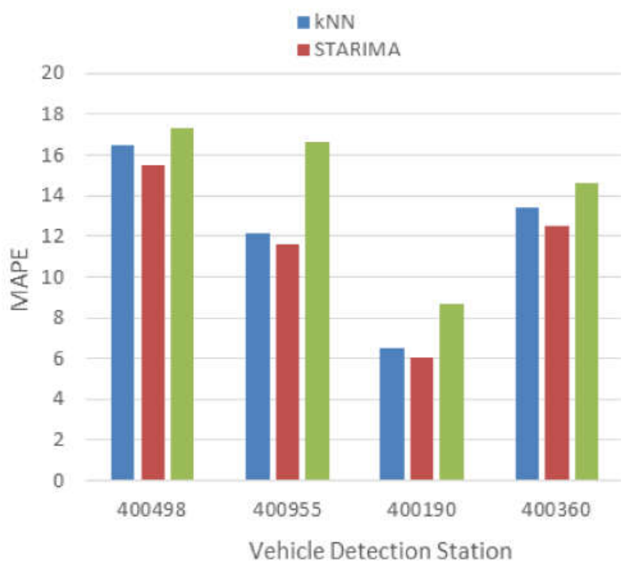

Figure 3: Prediction accuracy results by the MAPE metric.

Figure 3 illustrates the total prediction accuracy results of the STARIMA model, compared to kNN and SVR models (using the Mean Absolute Percentage Error (MAPE) metric).

V. UTKB AND TIME-DEPENDENT ROUTE PLANNING

The computation of time-dependent route planning profiles in large-scale urban traffic networks is a particularly challenging algorithmic task. MOVESMART's specific contributions include [1,2,3,4]:

- Developing techniques for structuring and maintaining urban traffic information, so as to support the real time provision of time-dependent route-planning profiles, and establishing a trade-off between required preprocessed space and query time.
- Developing new methods for graph pre-processing approaches that enable fast responses to shortest-path queries (i.e., distance oracles) in time-dependent road networks, by exploiting the inherent hierarchical structure of the MOVESMART system, overcoming the shortcomings of existing approaches, and thus contributing to the establishment of new research paradigms.

In particular, the urban traffic knowledge base (UTKB) [1] acts as the pivotal point of all the traffic-related information (raw-traffic data) aggregated by the MOVESMART system from external sources (e.g., from loop detectors, travelers, etc.), or service-oriented traffic metadata (e.g., travel-time functions between distant points, traffic-sensitive energy-consumption factors, etc.) created and continuously updated within it. All these raw-traffic data and metadata are then at the disposal of the core routing services of MOVESMART — the core Time-Dependent Routing (TDR) service, the Multi-Modal Routing (MMR) service, and the Electric Vehicle Routing (EVR) service — which run on a dedicated virtual machine (the UTKB server) of the MOVESMART's cloud. These services are in turn exploited by the more sophisticated personalized mobility and mobility-on-demand services.

A stream of temporal traffic-related information, which is produced by the crowd sourcing application Live Traffic Reporter (LTR), is also digested by the UTKB. This stream of temporal data provides real-time information about the actual status of the network and is aggregated at the UTKB either as traveler-initiated emergency reports (e.g., blockages of road segments due to car accidents), or automatically generated traffic-prediction alerts (because of prediction of some significant deviation from the nominal behavior of a road segment). Appropriate temporal metadata are also maintained within the UTKB in real-time, and are interpolated with the previously mentioned raw-traffic data and metadata, in order to support the sophisticated time-dependent, live-traffic aware routing services of the MOVESMART system.

Finally, periodically updated snapshots of the traffic-related data are disseminated to the travelers' smartphone devices, in support of elementary routing services, as a contingency plan in case of connectivity loss with the MOVESMART system [1]. Figure 4 provides an architectural overview of the UTKB functionalities.

The Time-dependent Route Planning service is included in the *Renewable Mobility on Demand* asset, a realization of Renewable Mobility on Demand based on the corresponding MOVESMART service. This service is also included in the *Transport Data Repository* (accessible on the cloud), a set of cloud provided services in the domain of transport. Finally, Time-dependent Route Planning is included in the *Innovative Route Planner*, a generic platform for renewable mobility services based on novel time dependent and routing approaches [3,4] which take into account live traffic reporting.

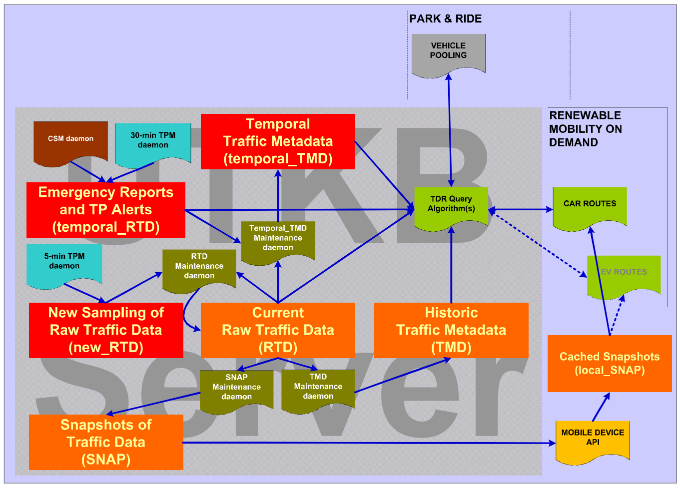

Figure 4: Overall architecture of UTKB related services.

The aforementioned Time-dependent Route Planning services have already been incorporated in the Integrated MOVESMART application (available at Google Play).

VI. ENERGY EFFICIENCY ASSESMENT MODULE

Energy efficiency assessment methodologies aim to provide novel algorithmic approaches and services to support the energy-efficient intermodal mobility of individuals (with emphasis on environmentally friendly means of transportation, such as bicycles and electric transportation media), in order to assist the traveler to combine various means of transportation in an energy-efficient way. However, the design of such a service for travelers is a major algorithmic and technical challenge, since various aspects, models, and parameters of energy efficiency need to be considered within the renewable mobility scenario in order to achieve the requested energy-efficient multimodal route planning for individuals. There are certain different ways/methodologies and corresponding simulation tools (i.e., COPERT, ADVISOR, GREET, etc.) to calculate the emissions and the energy efficiency of conventional vehicles as well as of EVs (along with that of the electromobility in general) while in action or when parked. MOVESMART's specific contributions include:

- Developing novel algorithmic approaches to compute emissions and energy consumption of journeys that combine different modes of transport, including conventional and electric vehicles, buses and trams.

- Providing the required expertise for the selection/development/combination of the proper methodologies in order to consider the characteristics of the applied EVs in the MOVESMART project for the energy efficiency as well as the calculation of the emissions.

In the field of energy efficiency assessment, MOVESMART proposed methods to assess and compare the environmental impact of multimodal journeys, in terms of both energy consumption and emissions. On the one hand, the methods take energy operational processes into account, i.e., producing, transporting, manufacturing and distributing fuels and electricity. On the other hand, the methods consider vehicle operational processes, evaluating the efficiency of the vehicles themselves.

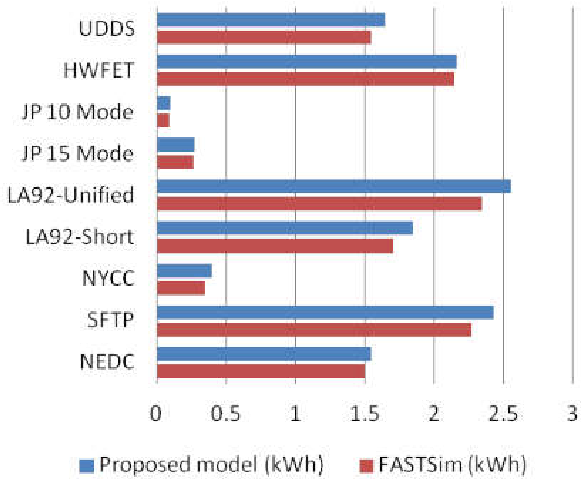

Figure 5: Validation results of energy consumption model for electric cars.

Figure 5 shows the comparative results of energy consumption for each one of the driving cycles, after simulating the performance of the test vehicle with the proposed model and FASTSim [9]. A careful examination of the results reveals that the maximum difference (in absolute values) between the two approaches is observed in the LA92-Unified cycle, which is the longest one in terms of time and represents aggressive city-driving conditions, while particularly small differences are observed in the case of smoother driving cycles, such as JP 10 Mode, JP 15 Mode and HWFET. In general, the results obtained indicate that the output of the developed model follows with sufficient accuracy the FASTSim output under different (simulated) driving conditions.

The MOVESMART Energy Efficiency Assessment service is already included in the Integrated MOVESMART application and is also included in the *Transport Data Repository* (accessible on the cloud), a set of cloud provided services in the domain of transport.

VII. Conclusions

We provided on overview of the cloud-based services of the MOVESMART holistic platform for renewable mobility services in smart cities. The MOVESMART approach provides personal mobility services, leverages crowd-sourcing techniques for collecting real-time traffic information and encompasses effective traffic prediction mechanisms. MOVESMART guarantees real-time responses to renewable (on-demand) mobility queries for efficient multi-modal route planning that are time-dependent as well as sensitive to aperiodic incidents and traffic prediction forecasts.

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