

Green Move: towards next generation sustainable smartphone-based vehicle sharing

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Abstract—This paper presents the Green Move project, which is currently ongoing at Politecnico di Milano. The goal of Green Move is to create an innovative vehicle sharing system, based on electric vehicles, which can easily be accessed by users with little required infrastructure and few intermediaries. The paper provides an overview of the project, briefly describes the architecture of the system under development, and outlines the next steps in this research.

I. INTRODUCTION

In the last few years, economic and environmental reasons have spurred a wave of activity aimed at finding innovative solutions for sustainable mobility. In 2007, the EU Council stated that, by 2050, developed countries should reduce their overall greenhouse gas emissions by 60-80% compared to 1990. Yet, the continuing growth in emissions due to transports will undermine any efforts aimed at meeting these goals if no action is taken to reduce them. This heightens the need for finding effective and concrete solutions for “green” transportation systems.

For this reason, the last decade has seen a steady growth in attention and research efforts targeting electric vehicles (EV). In fact, EVs are almost entirely *Zero Emission Vehicles* (ZEV); hence, their widespread use could greatly reduce the emissions of greenhouse gas due to urban mobility. In addition, EVs are more efficient with respect to traditional Internal Combustion Engine (ICE) vehicles. EVs, however, face some significant challenges, first and foremost the problem of energy storage. Battery packs are very expensive, and the range of an EV is directly proportional to the cost of its battery pack. The typical questions surrounding EVs are: Is the vehicle’s range sufficient for the user’s needs? Will the battery pack last long enough as to be economically convenient? The typical assumptions used to answer these questions are that: (i) the range of an EV is around 80-120 km; (ii) the life of a battery pack is around 2000 discharge/recharge cycles; (iii) the break-even point of a battery pack is around 80% of its lifetime (1600 cycles). This trade-off is depicted in Figure 1, which shows the lifetime of the vehicle plotted against its range. The figure shows that, in order to be economically sustainable, an EV must cover at least 128000 km. The only way to reach this goal in an urban scenario, where a user typically covers less than 20 km per day, is to share these vehicles among many users.

The Green Move project takes up this challenge by developing an innovative system for vehicle sharing whose key tenets are, among others: (i) heterogeneity - as any zero-emission vehicle can be integrated into the system; (ii) openness - as different ownership models are admitted; (iii) ease of use - as users may access the system with little infrastructure and few intermediaries. In this paper we present the Green Move project: its overall goals, the architecture of the system that is currently being realized in the project, and the future research steps.

The paper is structured as follows: Section II reviews vehicle sharing initiatives that have points in common with Green Move, and points out some relevant differences; Section III provides an overview of the Green Move system, and Section IV outlines its architecture and components. Section V outlines future work in the Green Move project.

II. VEHICLE SHARING SYSTEMS

In the last few years many car sharing initiatives have been promoted around the world, as car sharing (and more generally vehicle sharing) has become a viable solution for the future of urban transportation [1]. In this section we briefly report on some of these experiences, focusing on the underlying technological issues.

One of the most widespread car sharing initiatives is *Zipcar* [2], started in the early 2000’s in the US. This service, which is available in more than 90 US cities and also in London, offers different kinds of ICE or hybrid cars to registered users, who reserve vehicles via web or via phone. Users are provided with RFID cards that are used to open

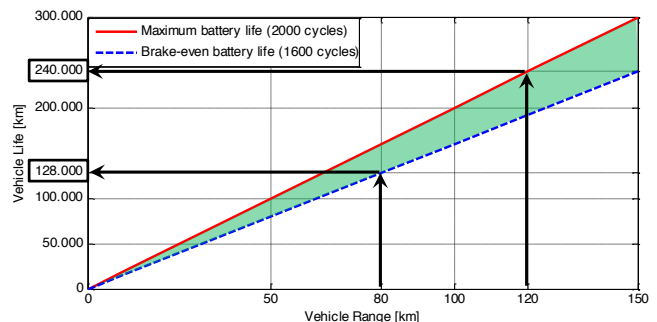


Figure 1. Trade-off between vehicle range and cost of the battery pack.

cars, and the vehicle keys are physically chained to the car, together with a fuel card; users can also locally lock/unlock the car using a smartphone app, though the interaction does not occur directly with the car, which is opened remotely by the control center when an SMS is received.

A car sharing service similar to Zipcar is the Swiss *Mobility Carsharing* [3], started in 1997. In 2010 Mobility operated about 1200 stations in 450 locations in Switzerland. As for Zipcar, upon registration users receive RFID cards that are used to open the cars, that are reserved online or via phone. The keys are in the vehicle, but not chained to it, so doors can be locked/unlocked using the vehicle key itself. A simple interface available in the car allows users to modify on-the-fly the trip by extending or stopping the reservation. A fuel card is onboard to refill the car, if needed.

A more flexible car sharing service is the *car2go* project [4], which is available in cities such as Ulm, Germany, and Austin, Texas. As Daimler AG is the promoter of the initiative, cars available to Car2go users are Smart ForTwo, equipped with an RFID card reader to unlock the car. When a user registers to the service, an RFID chip is applied to her driving license. The car has an advanced user interface, and the position of every vehicle is tracked via GPS. This allows users to leave/take the car in every free parking of the city. Moreover, the reservation is optional. Employees of the car2go service refill the cars when the fuel level (which is remotely monitored) is low.

The last decade has seen the emergence of a different kind of car sharing services, the so-called “peer-to-peer” ones. With peer-to-peer car sharing any private car owner can share her own vehicle with other users. To guarantee that private cars are not damaged/stolen when lent out, the vehicles’ position must be known in real-time. Moreover, a control center keeps track of which user is using which vehicle. Therefore, shared vehicles must have features such as GPS positioning, GPRS communication with the control center, and mechanisms to identify the user.

An example of a peer-to-peer car sharing service is Google’s *Relay Rides* [5]. To join this service each would-be lender must register her vehicle on a website. Then, a technician takes care of installing on the car a “box” containing (i) a GPRS/UMTS communication module, (ii) a GPS device, (iii) an RFID card reader, and (iv) a fuel card. Users must register online, after which an RFID card is delivered to them. Reservation is also done through a website. *Relay Rides* allows lenders to configure both the schedule and the charge for the use of their vehicles. Moreover, comments on drivers’ behavior are collected in a forum; this allows a lender to avoid the most “dangerous” users.

None of the car sharing services analyzed so far focuses on electric vehicles. *yélobobile* [6] is an example of such service, which is available in La Rochelle, France. This is a traditional car sharing system, but it operates only with ZEVs, and in particular with electric cars. As in other

services users must register online, after which they are given RFID cards to unlock the cars, which are taken from recharging stations. The keys are chained to the vehicle.

More recently, the *e-Vai* car sharing service, which is also based on electric vehicles, has been set up in Milano. This initiative complements the railway service provided by the Ferrovie Nord group, thus it can be seen as an example of “last-mile” car sharing. Upon registration, a user is sent a card which is used to access both the railway and the car sharing services. Then, she accesses the electric vehicles as in a standard car sharing service.

Finally, the *autolib* service, which is available in Paris, is substituting its ICE vehicles with ZEV ones based on the Bluecar Bollorè. These vehicles have an RFID card reader, GPS localization, GPRS/UMTS connectivity and a user interface which allows users to access value-added services. Moreover, recharging stations are “smart”: they interact with the user to check her identity and to lock/unlock the cars, and also send information to the control center.

As shown in Section III, the Green Move service combines together the most interesting characteristics (use of electric vehicles, peer-to-peer sharing, etc.) that are found separately in the services listed above. However, it goes beyond them on many aspects, such as the mechanisms through which users interact with system and vehicles, which are now entirely key-less and smartphone-based.

III. OVERVIEW OF THE GREEN MOVE SYSTEM

The goal of the Green Move (GM) project is to develop a vehicle sharing solution that is innovative under many aspects: for the heterogeneity of the kinds of vehicles considered, whose only requirement is that they be electric; for the openness of the ownership model; for the interaction protocols between the users and the system, which eliminate all intermediaries. Figure 2 shows the main actors and elements in the GM system.

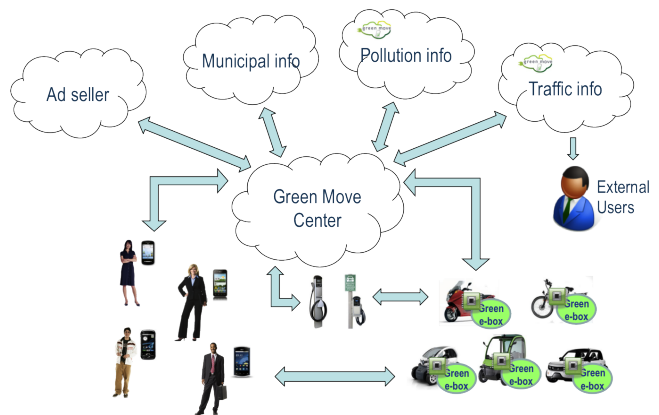


Figure 2. An overview of the Green Move system

The portfolio of vehicles targeted by the system is very wide, the only characteristic that is common to all of them

is that they are zero-emission electric vehicles. We have integrated, or are in the process of integrating, 2- and 4-wheel vehicles of different sizes and ranges, and we plan to add more types of vehicles (e.g. a 3-wheeler) in the future.

Each GM vehicle is equipped with a device, the *Green e-box* (GEB), through which the vehicle interacts with the GM system. From a technical point of view, the only requirement for a vehicle to be introduced in the GM system is to be equipped with the GEB, which enforces that the interaction between vehicle and system occurs according to the GM protocols. This opens up the possibility of adding to the GM system vehicles that are heterogeneous not only in their types, but also in their owners.

The interaction of GM users with the system occurs through the users' smartphones, on which the GM client app must be installed. The smartphone is the gateway through which a users can, among other things, retrieve the electronic key that is used to take possession of the vehicle, open/close its doors (when applicable), and enable the drive. Hence, the GM system requires no intermediaries between users and vehicles: reserving, acquiring and releasing a vehicle are all done automatically through software applications.

The Green Move Center (GMC) coordinates the activities of the GM system and offers a number of context-aware services. Some of these services are core to the system: user registration, vehicle reservation/acquisition/release/monitoring, and so on. GM also offers services that are not part of the core of the system, i.e., that are not strictly necessary to provide vehicle sharing functionalities, but which can enhance the interaction between user and system. Some of these services could be offered by external partners (both commercial and non-commercial) of the GM system, such as ad providers or the municipality; for these the GMC acts as an intermediary between them and the users. Other services (e.g., generation of traffic information) could be directly provided by the GM system both to its users and to external ones. For example, a pervasive, context-aware information distribution component, e.g. for useful traffic information or interesting ads, is currently under development. The architecture of the GM system is such that these non-core services can be dynamically added and eliminated at runtime.

IV. ARCHITECTURE OF THE GREEN MOVE SYSTEM

The core of the GM architecture, which includes the GMC, the GEBs installed on vehicles, and the users' smartphones, is shown in Figure 3. The users' smartphones and the GEBs communicate with the GMC through standard protocols. On top of them, the GM system builds higher-level mechanisms such as the secure sending of electronic keys from the GMC to users' smartphones, and richer communication mechanisms (such as T-Rex, which is briefly presented in Section IV-C) that are used, for example, for sending monitored data from vehicles to the GMC. Also,

unlike in the projects of Section II, users' smartphones communicate directly with GEBs, not only with the GMC, e.g., to open/close the doors of cars, or to enable the vehicle's drive. Users' smartphones use short-range protocols, Bluetooth in particular, to communicate with the GEB.

In the rest of this section we outline the functionalities of each of the elements depicted in Figure 3.

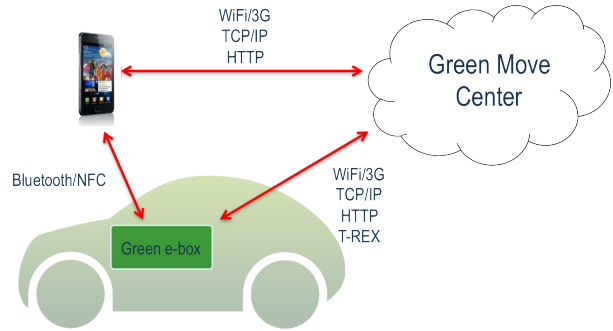


Figure 3. Overall architecture of the Green Move system.

A. Green e-box

The GEB is the device which allows each vehicle to interact with the GM system; it is composed of an embedded board and an Android board, and its structure is depicted in Figure 4. The main tasks performed by the GEB are

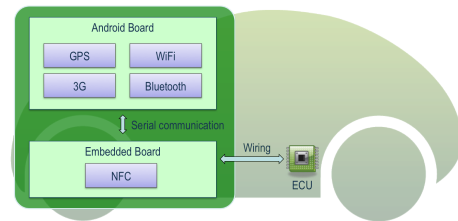


Figure 4. Architecture of the Green e-box.

the acquisition of vehicle signals and the handling of the connection both with the GMC and the user's smartphone. The signals' acquisition is carried out by the embedded board which is directly connected to the vehicle ECU. Afterwards, the acquired data are processed by the Android Board and sent to the GMC.

The main core services that the GM system offers require a constant monitoring of each electric vehicle, even when turned off and not in use. Therefore, the embedded board is directly connected to the permanent 12V line of the vehicle. The board has several analog and digital inputs, and a CAN-bus through which the GEB can adapt to the heterogeneous vehicles that are in the GM system. The main signals acquired by the board are: the level of charge of the battery and its state (charging or not); the provided current; the status of the doors (open/close, if applicable); the vehicle speed; the faults detected. Analog outputs are

provided to control the door locks and to enable the driving of the vehicle. The firmware acquires the vehicle’s data at a constant rate and converts them into appropriate units. The data are then collected in packets and sent through serial communication to the high-level Android board. When the latter receives the data it stores them in a data structure and makes them available through an interface to the modules of the Green e-Box App (GBA). The GBA has two main tasks: send/receive data from the GMC and authenticate the users by reading data from their smartphones through the bluetooth connection.

B. Users’ Smartphone App

Users interact with the GM system through an app installed on their smartphones. For reasons of openness, in the GM project we are currently targeting Android as the development platform for the Users’ Smartphone App (USA), though other platforms could be explored in the future. Currently, the USA has three main functionalities: retrieve a valid electronic key form the GMC, take possession of a reserved vehicle, and release the vehicle to the system. To access the system, the user must be authenticated in the USA with the credentials registered in the GMC. Once authenticated, the user can download on her phone the electronic keys from her account. Each user reservation that has been confirmed by the GMC has associated an electronic key, which contains all the information needed to identify the vehicle to be retrieved, the starting date and time of the reservation, and an encrypted ticket that is shared with the vehicle. When the user is near the reserved vehicle, she can send via Bluetooth the ticket to the selected vehicle. When the GEB of the vehicle receives the message from the user’s smartphone, it checks the validity of the ticket, then lets the user take possession of the vehicle if the check is successful. After the user has possession of the vehicle, she can use the USA to open and close its doors (if any) by communicating directly with the GEB, with no interaction with the GMC. This communication can occur at any time after the user is granted possession of the vehicle, even when there is no 3G or UMTS connection available with the GMC. When the user wants to release the vehicle, this is done through a specific command offered by the USA, which causes a message to be set to the GEB via the Bluetooth connection. Releasing the vehicle invalidates the ticket that is used to open/close the doors of the vehicle.

At the software level, the USA has three main components: an HTTP module that is used to interact with the GMC, and which provides the operations to establish the communication with the GMC, and to detect any connection problem; a module that provides the functionalities that are necessary to manage tickets; and a module that manages the messages exchanged via Bluetooth with the vehicle.

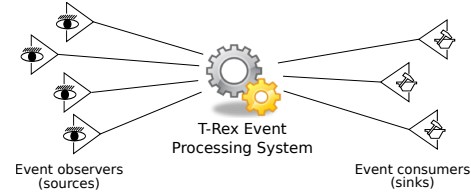


Figure 5. Overview of the T-Rex system.

C. Communication Infrastructure

A significant part of the entire communication infrastructure of the GM system relies on the observation of *events* or *situations* that occur in its environment, and on the definition of specific actions for reacting to such observations. In the simplest case, the observed events represent the position of a specific vehicle, the detection of a certain level of battery charge, or a delay in the return time for a vehicle. However, more complex observations may be required: for example, a traffic monitoring application may want to compute the shortest paths based on the positions and the speeds of other vehicles and on the average driving time on alternative paths.

Moving from these premises, we decided to base the part of the GM communication infrastructure that deals with events upon T-Rex [7], a system explicitly conceived to efficiently collect, process, and analyze events. Figure 5 gives a high-level view of T-Rex. T-Rex presents a simple API to the other components of the GM infrastructure. In particular, the *sources*, which observe simple events (e.g., the GBAs which observe the position of the vehicle at a certain point in time), can *publish* them to the system, making them available for analysis and distribution. Events are processed according to the *rules* installed into the system. These are expressed in a simple, yet expressive, language called TESLA [8]. Finally, T-Rex distributes the results of its analysis to all the *sinks*, based on their interests, as expressed through one or more *subscriptions*.

The adoption of T-Rex provides several benefits: *efficiency*, as T-Rex is designed to perform the processing of events and to generate results with a low delay (typically, in the sub-millisecond range); *scalability*, since T-Rex is capable of providing low processing delay and hardware resource consumption even in presence of a large number of sources, rules, and sinks; *modularity*, as T-Rex incorporates the management of events into a single software component, whose behavior is defined in a simple way through the set of deployed TESLA rules.

D. Green Move Center

The GMC sits in the middle of most of the interactions occurring in the GM system, so it was designed with the goal of achieving flexibility and scalability. The GMC is a Ruby on Rails application, which acts both as the web front-end for users of the vehicle sharing system and the API back-end

with which the GBAs and the USAs interact. The GMC APIs are exposed via HTTP as a simple set of restful resources. The same codebase is used for asynchronous tasks like executing background jobs and communicating with the T-Rex engine. Leveraging the latter, the GMC enables interested parties to receive and analyze relevant data produced in the GM system. For example, the positions of the vehicles as detected by the GPS sensors installed on them are currently collected by the vehicles, then sent as T-Rex events to the GMC, where they are logged in a database that is registered as a T-Rex sink. If other components of the GMC need to access the information about the position of the vehicles, they can either query the GMC DB (for example if they need historical data on vehicles' positions), or they can subscribe as T-Rex sinks to the "vehicle position" event, for example if they need position data in real time. In fact, the GMC currently includes both a NoSQL DB that stores sensor data, to be periodically mined in order to extract useful knowledge about vehicles' conditions or traffic trends, and a traditional relational DB that stores administrative and personal data. The reservation logic uses the data retrieved from vehicles to help the user find the nearest vehicle (the user position can be determined by both the GMC website and the smartphone app). Currently the GMC supports user registration and authentication, basic reservation management and encrypted communications with both the USAs and the GBAs for the exchange of the ticket data.

V. GOING FORWARD

In this paper we outlined the goals and architecture of the GM system, which has been under development at Politecnico di Milano for the past year. A short demo video of some of the parts currently implemented is available at <http://www.youtube.com/watch?v=SRbP1IRp1k>.

The future development of the GM system will proceed along many directions. Here we outline only some of them.

The communication between the users' smartphones and the GEB, which is currently based on Bluetooth technology, will be expanded to also include the possibility of using Near Field Communication (NFC) devices. NFC is an appealing technology, as it allows for the creation of communication channels in a more lightweight manner than Bluetooth. However, it is not yet widespread in smartphones (though one can assume that this will change in the near future), so NFC-based interaction mechanisms will not entirely replace Bluetooth-based ones, but rather complement them.

We will also explore the possibility of using data streaming mechanisms for sending monitored data from vehicles to the GMC in alternative, or in collaboration with T-Rex, such as for example PerLa [9].

The reservation mechanisms will be enriched with the addition of capabilities for performing time series analysis. This will allow us to produce better, context- and user-aware forecasts of the availability of the vehicles managed

by the system. A prototype based on logic programming is currently being studied.

We intend to exploit the special combination of features of the GM system (i.e., existence of a rich dynamic data stream coming from moving vehicles, knowledge of the electrical and mechanical features of each vehicle, possibility of accurately profiling the frequent users of the GM service) to provide useful, personalized services to the driver, such as advice on the driving style [10] to optimize parameters such as performance, sustainability, or driving range.

Finally, we will extend the GMC to allow GM partners to dynamically add services to the system, including the possibility of uploading dynamically, to the GBA, new software modules that provide additional functionalities; these new modules will have the form of Android libraries, which will be distributed to GEBs using the event system provided by the T-Rex engine. A component named GMCodeAgent is currently being developed to introduce suitable code loading capabilities in the GBA. This component is basically an Android service which subscribes to suitable events via T-Rex, then downloads the code from a URL provided in the event data and uses the Android Dex class loader to add functionalities to the GBA. The code loaded via GMCodeAgent has itself access to the T-Rex engine and to the data provided by sensors available on the vehicle, so complex functionalities can be added on demand and removed later to free resources.

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