S^2-MOVE: Smart and Social Move

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***Abstract*—In this position paper we present S^2-MOVE (Smart and Social Move), a social innovation project funded by MIUR (Italian Ministry of Education, Research and University). S^2-MOVE is based on a new conception of urban community, that allows citizens to share data and decisions in a smart and innovative way. In order to implement this new vision of urban mobility, called *smart mobility*, a deep integration among citizens, private and public transportation systems and ICT is required. In this new social and challenging scenario, citizens are not just customers of a service, but they produce and share information to obtain a common goal: a smart and efficient mobility, for everyone. S^2-MOVE proposes an architecture able to collect, update, and process real-time and heterogeneous information from various electronic devices (tablets, smartphones, electronic control devices in vehicles) and from the actors of the urban scenario (public/private transportation vehicles, pedestrians, infrastructures). Mining such information allows to produce new knowledge which is then made available again to the citizens through specific services. The urban mobility issues to which S^2-MOVE can offer a contribution, are linked to two crucial aspects: continuous and shared monitoring for real-time management of urban traffic and an interactive mobile information service for drivers. In this position paper, after introducing the rationale of the project, we describe the main technological aspects involved in the design and in the implementation of the S^2-MOVE architecture. Then, we present a proof of the control approach used to create and manage fleets of vehicles and we provide some preliminary results obtained using simulation.**

I. Introduction

Urban mobility is one of the most tangible, real and quantifiable aspects that can measure the level of social innovation and quality of life in a community. Reducing traffic and ensuring the sustainability of a trip is not enough to improve urban mobility, but it is also important that all citizens have access to all the information related to each aspect of the transportation process. In order to implement this new vision of urban mobility, called *smart mobility*, a deep integration among citizens, private and public transportation systems and ICT is required [1], [10].

The S^2-MOVE project has its main purpose in the field of social innovation: creating a community of citizens that can share data and decisions in a smart and innovative way, improving the quality of life of an urban community. The S^2-MOVE is 36-months long project funded by MIUR (Italian Ministry of Education, Research and University) started on June 2012. In particular, the grant for this project funds a group of 6 young students and researchers under-30 with a social innovation target and living in the so-called "convergence regions" (i.e. Calabria, Campania, Puglia, and Sicilia) [2].

The basic idea is to give an active role to citizens and drivers, so that they can help to produce geo-referenced information and contents that can be relevant for the mobility, instead of passively take advantage of the services. In this new social scenario, the citizen is not only a customer of a service, but it can produce and share information to obtain a common goal: a smart and efficient mobility, for everyone. This target can be achieved through the implementation of a decision support system for mobility management, that takes into account also the information exchanged with the citizens.

The S^2-MOVE system is able to collect, update, and process real-time and heterogeneous information from various electronic devices (tablets, smartphones, electronic control devices in vehicles) and from the actors of the urban scenario (public/private transportation vehicles, pedestrians, infrastructures). Mining such information allows to produce new knowledge which is then made available again to the citizens through specific services. The high diffusion of intelligent communication devices supports the idea that the population is ready to "collaborate", to become a "smart citizenship" able to interact with/through advanced technologies and improve the quality of several aspects of the city life. Currently most commercial info-mobility systems are static tools that can only provide information and the mobility-on-street management is delegated entirely to the individual user (driver or pedestrian). On the other hand, planning and changing the urban routes should adapt to the current traffic conditions, that can be influenced by accidents and congestions, or can be connected with the availability of parking spaces [3]. To this end, the platform provided by S^2-MOVE allows to provide several types of functionalities thanks to the citizens collaboration and the information processing:

- *Smart Mobility Management*. Through real time and personalized information it is possible, for citizens, to plan and re-plan the urban routes, providing travel time, preventing congestions and facilitating the traffic flow.
- *Provision of quality services in/for mobility*. It is possible to receive useful information on the availability of several kinds of services (service areas, car centers, etc.) with the option to pay "on board" any fee for the services requested.
- *Creating and managing efficient fleets in the city*. Fleets

are used as additional data acquisition systems, in order to generate geo-referenced information contents on the urban traffic.
- *Innovative management of public transport*. It is possible to manage a bus network that adapts dynamically its route, basing on the traffic conditions and on the number of people that are waiting at the bus stops.
- *Dynamic LTZ (Limited Traffic Zones)*. Create adaptive LTZs that take into account the effective presence of the vehicles and the current air pollution severity. This solution can be transferred to individual traffic lanes.
- *Dynamic Car-Sharing*. If the municipality provides car-sharing services, it is possible to produce geo-referenced news (about availability and on-line payment, for example) and promote the creation of groups of user that have in common a route or a destination (offices, schools, hospitals).

All these services are only examples related to particular and representative applications, but they are not exhaustive. In fact, the open and extensible features of the S^2-MOVE platform can enable the birth of new mobility services. The interest in social innovation produced by S^2-MOVE is demonstrated by the intention of an Italian Municipality in the south of Italy (Marano di Napoli) to act as a real testbed for the project and to experiment and benefit from the results of S^2-MOVE.

This position paper is organized as follows: after an introduction in Section I, Section II provides a description of issues related to urban mobility. In Section III is provided an overview on S^2-MOVE technologies and structural functionalities, whereas in Section IV we present some proof of the control algorithms used in the S^2-MOVE platform and in Section IV-A their results. Finally, Section V ends the paper.

II. Urban issues and their resolution through S^2-MOVE

The typical problems of urban mobility are related to the transport efficiency, strongly influenced by the presence of traffic and congestion, and to the environmental protection, related to the gas emission of cars. Recently, an increasing need of quality of transport as perceived by the individual user arises and promotes the development of new auxiliary services [6].

The urban issues which S^2-MOVE aims to solve are linked to two crucial aspects in the context of urban mobility:
- “continuous and shared” monitoring for real-time management of urban traffic;
- interactive mobile information services for drivers.

According to the identified issues, the S^2-MOVE system will be used to achieve the following technical objectives:
- *Create and managing a fleet of vehicles* to have an additional data traffic acquisition system, on the road. The fleet is used as a real network of mobile sensors, in order to increase the capillarity of the detection system and to improve usability of information. The information collected, processed, shared and disseminated through S^2-MOVE allow users to plan or re-plan their route, in real time. The fleet is managed by imposing bounds in terms of speed, intra-vehicular distance and also in terms of fuel consumption and environmental impact. Note that the creation of dynamic fleets, ensuring respect for speed limits and safety distances among cars, increases the overall safety of the urban environment. It is also possible to send customized information to fleet vehicles.
- *Implementation of new generation services for the citizens, also on-board the vehicle*, using the real-time and geo-referenced information provided by S^2-MOVE. For example, these new services allow the citizen to be notified of the available places in the closest parking areas or can enable the online payment of the parking fare solbing thus, the parking problem that is perceived as an extremely important factor for the quality of mobility, especially in areas in which there are limit on the circulation of vehicles (LTZ).

Note that the demonstrators chosen to test the effectiveness of the activities and the success of S^2-MOVE, refer to “best practices” that exist at international level. More precisely, the objectives and the activities of S^2-MOVE are inspired by “best practices” designed and deployed in Italy:
- SI.M.O.NE [4]. This project, deployed in Turin (Italy), implements a decision support system for urban mobility, with the option to map real time traffic flows (using vehicles as data acquisition systems) and provides services and information to citizens through on-board equipment installed in vehicles.

- SMARTiP [5]. This project has been deployed in the municipality of Bologna (Italy) and implements a transformation of public services through involvement and collaboration of active citizens, that can directly improve services using Internet and new technologies.

These past experiences demonstrate the feasibility and accessibility of the objectives of S^2-MOVE. In particular, we refer to part of the achievements and technological solutions provided by the cited large scale projects.

III. The S^2-MOVE Technology

The project provides a platform for decision support. As shown in Fig. 1, the system consists of the following macro functional components:
- *Central Processing System (CPS)*. The CPS is the heart of the platform and is responsible of the following features:
  - receiving, storing and processing the data;
  - managing the communication and the information exchange with the terminal devices.

  Storing information is supplied by a database management system based on Open Source technology. The information contained in the database is accessed by special intermediate software layer called *Connector*. For the delivery of services without special functional requirements, the well-known SOA (Service Oriented Architecture) technology is used. On the other hand, for services with special requirements (for example, real time services) there are ad-hoc software modules, called *Controllers*. Moreover, it is possible to exploit information from other pre-existing platforms, in a perspective of aggregation and integration. S^2-MOVE uses the Cloud paradigm *Infrastructure as a Service* to deploy the CPS. The choice is winning as the Cloud paradigm allows the dynamic dimensioning of the system (in terms of resources allocated and transmission band), according to the current needs of the system.

- *Distributed software Agents (DA)*. A DA is a software tools that can both provide information to end users (customer agents) and CPS (provider agent). They run on heterogeneous terminal devices (tablets, smartphones, personal computers, etc.) and they provide the following functionalities:
  - communication with the central system;
  - information exchange with the other DA. The S^2-MOVE project involves the development of specific mobile software applications for vehicle run support.
- *Hardware for intra-vehicular cooperation*. In order to support the vehicle cooperation and fleet management, the vehicle control data (regarding speed, acceleration, etc.) are collected, computed and transmitted from one vehicle to another. To enable these functions, a customized device is required on board in the vehicle. This device has to:
  - collect data from the Electronic Control Unit (ECU) in order to monitor in real-time the status of the vehicle;
  - manage the connection to the CPS. It regulates the flow of data and its conversion from CAN (Controller Area Network) messages to information understandable for the user;
  - transfer the information processed by the CPS to the ECU.

  The hardware device is an integrated embedded circuit board that interacts with the vehicle through the OBD (On Board Diagnostic) connector. It is equipped with interfaces to internal vehicle networks and allows users to monitor in real-time the status of ECUs in the vehicle. It also allows to send the control commands to ECUs, and through the wireless network to the other connected devices.

  The embedded device handles all the information exchanged inside and outside of vehicle and its aim is to collect these real-time information to support the drivers in the driving process. In addition this hardware can be used to develop *Cooperative Control*, see Fig. 1, able to realize the fleet control strategy as described in Section IV.

In these network scenarios, issues related to performance, quality and reliability of network communications among several distributed entities of heterogeneous data (video, voice, images, text, etc.) arise [34], [36]. For example, quality and reliability of network communications (especially in the wide area wireless scenarios) [7], [8] as well as mining and storage of infrastructure monitoring data [11] are of paramount importance. In S^2-MOVE we plan to use standard communication network protocols like UMTS for mobile cellular systems and IEEE 802.11 a/b/g/p for wireless systems. More precisely we plan to rely on these wireless technologies mainly for urban scenarios (communications among vehicles), according to the performance reported in literature [9], [32], [33], [35], [37], [38]. Also, we focus our attention on the standard IEEE 802.11p that has been specifically defined to support Intelligent Transportation Systems (ITS) and dramatically reduces the connection setup overhead to better suite the vehicular safety applications [12]. Such technology is currently under investigation and its performances represent an hot topic in the research community [13], [14]. We have also seen the rising of ad-hoc hardware prototypes from industry to support such research trend as recently reviewed in [17] and evaluate in [18]. Also, to improve the performance of ITS applications, these ad-hoc platforms can use network traffic prioritization schema based on lightweight network traffic classification platforms [19]. S^2-MOVE aims at taking advantage of the main findings of these pioneer works.

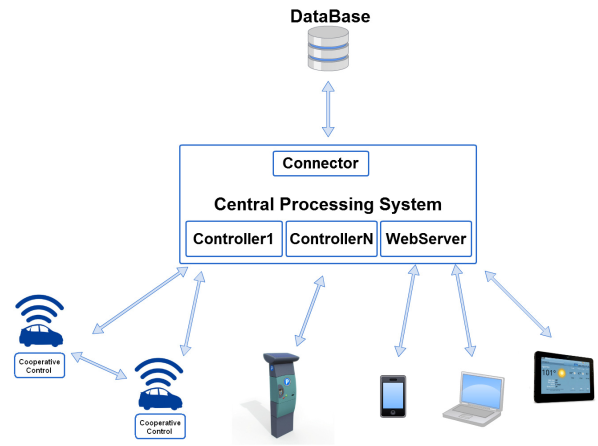

Fig. 1. The macro functional components of the S^2-MOVE platform.

IV. Controller design for vehicle platooning

Here we briefly describe the control approach to create and manage fleets of vehicles (see Section II). We refer to the developing of a decentralized controller on-board of each vehicle, see *Cooperative Control* in Fig. 1, such to manage each vehicle dynamics in the traffic road scenario. To pursue our goal we apply a novel strategy, i.e. [20], in order to improve smart mobility. We show some results in a preliminary simulated step (both controller and fleet are simulated with Simulink©) that will drive us to develop and validate the control action running on an hardware architecture. Among others, next steps provide validation with Hardware In the Loop simulation, where each simulated vehicle in an urban and extra-urban setting is managed by its real on-board control law, considering also the state variables of other vehicles in neighbours, i.e. same road.

The objective is twofold: to create a fleet (or platoon) of vehicles that share the same path (improving road safety, fuel consumption and environmental impact); to use the fleet for collecting data to be processed through the S^2-MOVE platform in order to receive more detailed and real-time data from urban and extra-urban settings, e.g. traffic and road surface condition. Both targets improve quality of life in a smart mobility context: first, citizens benefit of an updated real-time platform that supports public and private transportation system to avoid congestion; second, fleet cooperative control can be managed to facilitate the traffic flow. In the platoon each vehicle can share information (e.g. position, velocity, acceleration) with all the other elements of the fleet and the S^2-MOVE platform through V2V (vehicle-to-vehicle) and/or V2I (vehicle-to-infrastructure) communication [15] as in Fig. 2. The main control task is to guarantee that each vehicle in the platoon follows its corresponding preceding vehicle and a leading vehicle (e.g. the first vehicle in the platoon) at a desired distance and speed in order to guarantee compliance with the rules of the road, i.e. maximum allowable velocity and minimum intra-vehicular safety distance.

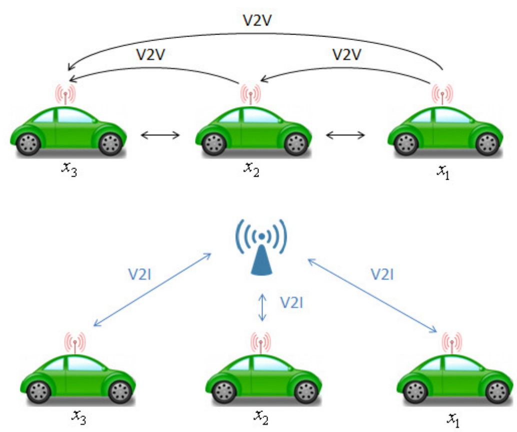

Fig. 2. S^2-MOVE fleet of vehicles.

In the platoon paradigm the first aim is to control the longitudinal dynamic of each vehicle in the presence of the driver. We suppose a fleet of n-vehicles, with $n \in \mathbb{N}^+$, and we refer to each vehicle with an index $i, \forall i \in (1, \ldots, n)$, with a consecutive numbering from first vehicle (e.g. leading vehicle) to last in the fleet. We consider the following velocity-dependent inter-vehicle *spacing policy*:

$$x_{rd,i}(t) = r_i + h_i \dot{x}_i(t), \quad (1)$$

where $x_{rd,i}$ is the desired distance between the $i-$th and the $(i-1)-$th vehicle; r_i is the desired distance at standstill (constant term); h_i is the desired headway time and $\dot{x}_i$ is the *i*-th vehicle speed. For each vehicle a local Cruise Control (ACC) strategy has to ensure that it follows its preceding vehicle according to the spacing policy (1). Onboard sensors (radar, GPS, inertial sensors) provide available measurements of vehicle position, velocity and acceleration , say x_i, $\dot{x}_i$, $\ddot{x}_i$. According with [16] and [20], the longitudinal vehicle dynamics of the $i-$th vehicle are tamed by using a classical PD control approach. The local control scheme can be described by the following closed-loop transfer function:

$$s^2 G_i(s) = \frac{1}{\tau s + 1} e^{-\tau_d s} \quad (2)$$

being τ the time constant and τ_d the delay time dues to actuator and other internal communication delays. Hence, the position of the $i-$th vehicle is $X_i(s) = G_i(s) U_i(s)$ with the control u_i being the set point for the same vehicle acceleration. Different and more complex control approaches [25], [26], [27] (recently used to control mechanical automotive systems in canonical form [23], [24], [28]) are currently under study to guarantee rapid adaptation to fast changes of the road condition and robustness with respect to disturbances and unmodeled nonlinear dynamics.

The S^2-MOVE control architecture consider wireless communication with preceding and leading vehicles. The presence of the leading information allows to implement an high level controller, the so called Cooperative Adaptive Cruise Control (CACC), to create and manage the entire platoon (see [20]). When the communication with the leader is active, the CACC strategy introduces into the control-loop an additional feed-forward action based on the measure of the leading vehicle acceleration ($\ddot{x}_{lead}$), according to the control scheme depicted in Fig. 3. Note that the communication delays have been not included in Fig. 3 for simplicity.

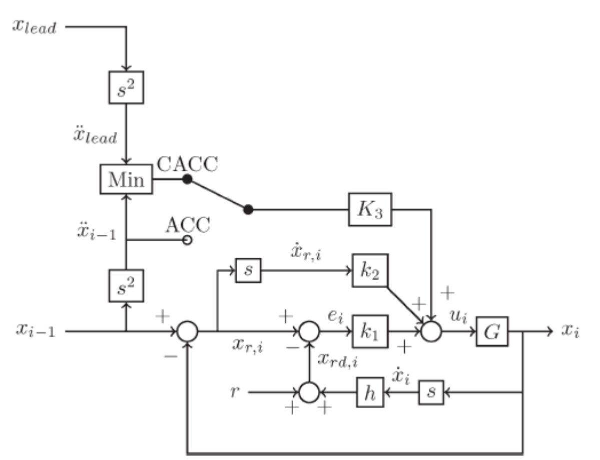

Fig. 3. S^2-MOVE onboard vehicle control architecture [20].

The feed-forward action is essentially a linear filter acting on the wireless signal described by the following transfer function:

$$K_3(s) = \frac{k_3 + k_4 s}{1 + \tau_f s} \quad (3)$$

where k_3 and k_4 are control gains to be appropriately tuned and τ_f is the time constant.

All the control gains k_j $(j = 1, \ldots, 4)$ are tuned so to ensure the so called *String Stability* (see [16] for a formal mathematical definition and further details). From an intuitive point of view, String Stability means that oscillations from the leading vehicle should not be amplified downstream in the platoon. Defining the following sensitivity function for a platoon composed by n vehicles:

$$S_k(s) = \frac{X_k}{X_{k-1}}, k = 2, ..., n, \tag{4}$$

and denoting the leading vehicle as X_1, it easily follows:

$$X_k = (\prod_{i=2}^{k} S_k) X_1. \tag{5}$$

Hence a necessary condition for achieving String Stability is:

$$\parallel S_k \parallel_\infty = \sup_\omega \mid S_k(j\omega) \mid \leq 1, \forall k \tag{6}$$

Note that, although inequality (6) is not a sufficient condition, it can be regarded as an effective performance index suitable for platoons of vehicles on a line [21].

A. Numerical Results

The strategy, based on two level control architecture described in Section IV, has been numerically validated by using a purposely designed platoon simulator. The simulator is based on the Matlab-Simulink environment [29] and it is designed to show the impact of the ACC-CACC both in an urban and highway scenario. The simulator is based on a realistic model of the longitudinal vehicles dynamics that takes into account complex nonlinear effects as air friction and tire drag [30],[31]. The controller gains k_j ($j = 1, \ldots, 4$) have been preliminary tuned to achieve string stability constraints (6).

The evidence of String Stability conditions for a 4-vehicles platoon is depicted in Fig. 4 where we notice the envelopment of both leading acceleration and velocity over the other vehicle state information: in particular the amplitude of the oscillation in the acceleration and velocity of vehicle 2 is smaller than leading vehicle (for vehicle 3 respect to vehicle 2 and for vehicle 4 respect to vehicle 3), that confirm the String Stable behavior.

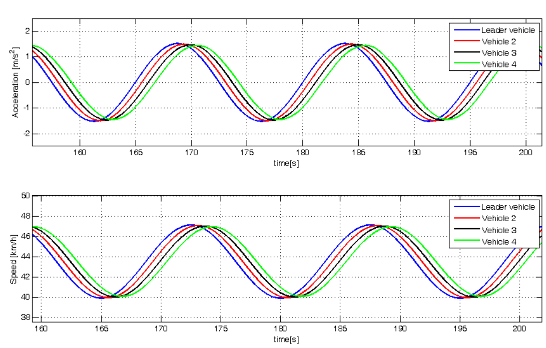

Fig. 4. S^2-MOVE String Stable behavior.

Note that the presence of bounded delays that influence both preceding and leading communication has explicitly considered in the simulation phase of the controller but not in the tuning phase. In particular V2V communication delay τ_c is bounded

$$\tau_c \in (0, \tau_{max}]$$

with τ_{max} in the order of tenths of a second.

In what follows we show, as a representative example, some maneuvers related to urban conditions according to the S^2-MOVE mission. Results, reported in Fig. 5, illustrate how the 4-vehicles platoon along an urban road reacts to the exchange of information with the S^2-MOVE platform. The platoon runs with a constant velocity along a straight road from the time instant $t = 22$ sec. At $t = 38$ sec the leading vehicle receives from the telecommunication infrastructure on a mobile device a traffic alert (e.g. traffic one-hundred and fifty meters away). According to the alarm occurrence, the leading vehicle slows down, sending its deceleration information in broadcasts to all the other vehicle in the platoon through the V2V communication channel. Results reported in Fig. 5 show how vehicles in the platoon influence each other and effectively synchronize their velocity at $t = 62$ sec reducing the effects due to the shock wave traffic. This confirms also the effectiveness of cooperative control in order to guarantee compliance with the rules of the road.

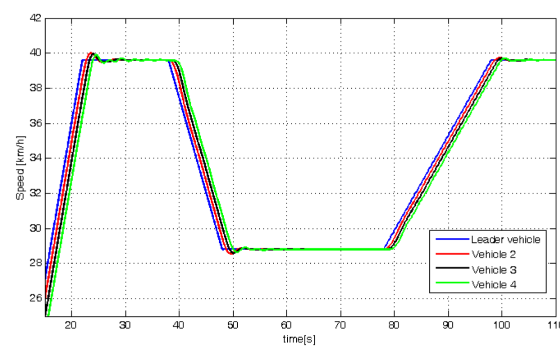

Fig. 5. S^2-MOVE CACC performances in a classic urban scenario: numerical results.

V. CONCLUSION

Today cities face the challenge of combining sustainable and competitive urban development and also in Italy, *Smart Cities* is becoming one of the most attractive topic. In this context, the project called S^2-MOVE aims at supporting the city transformation by implementing a new conception of urban community and mobility: citizens are not just passive final users of the system but actively collaborate by sharing information. S^2-MOVE aims at achieving two technical objectives: (1.) the creation and management of dynamic fleets of vehicles; (2.) the support and implementation of new generation services for the citizens. To reach these goals, the S^2-MOVE system exploits (i) standard communication network protocols, (ii) a decision support platform, and (iii) "best practices" designed and implemented in other projects deployed in Italy. Thanks also to a modular architecture, the system is able to collects, updates, and processes real-time and heterogeneous information coming from the urban environment (citizens, vehicles, sensors, etc.) and mining such information allows to produce new knowledge which is then made available for the citizens benefit. In this paper, we described the main urban issues the project aims to solve, the challenges and the technology the platform uses to manage the complexity of the urban scenario. Finally, we described a basic control approach to create and manage fleets of vehicles in an urban and/or in an highway conditions, emphasizing the development of a Cooperative Adaptive Cruise Control (CACC), applied to improve road safety and to collect data to be processed through the S^2-MOVE system.

Acknowledgment

This work and the activities described in this work are funded by MIUR in the field of "Social Innovation" of the program with the grant number PON04a3_00058. Besides, the authors would like to thank University of Napoli Federico II for providing SincroLab and ArcLab laboratories for lodging some S^2-MOVE activities.

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