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ORIGINAL PAPER

Sustainable mobility leveraging on 5G mobile communication infrastructures in the context of smart city operations

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Abstract Economic growth has been strongly associated with urbanization, overwhelming cities with vehicles. This renders mobility inside cities problematic, since it is often associated with large waste of time in traffic congestions, environmental pollution and accidents. Cities struggle to invent and deploy continuously evolving, "smart" solutions in the domain of urban mobility, so as to improve the overall quality of life therein. In this context, the paper discusses on the fundamental challenges that cities face when trying to become smarter, focusing on the particular area of mobility-as-a-service. Moreover, the paper describes a specific framework that leverages on 5G mobile communication infrastructures, in order to increase the effectiveness of vehicular communications and the relevant mobility services and applications offered in urban environments.

Keywords Smart cities · Smart city operations · Evolving · Mobility · 5G · Mobile communications

1 Introduction

It is widely accepted that economic growth has been strongly associated with urbanization. Large cities have been gradually becoming over-condensed, whilst, at the same time, they struggle to become smarter and smarter, by providing adequately qualitative services to their citizens and visitors. This involves the provision of traditional services with unconventional methods (e.g., via Information and Communication Technologies—ICT), as well as the design and development of innovative services, mainly enabled again by ICT. This trend is reflected on the "smart cities" concept (Toppeta 2010; http://www.ibm.com/smarterplanet/us/en/smarter_cities/overview/). Further, as cities constitute evolving systems that continuously change, the aforementioned term has been gradually replaced by the term "smarter cities", to showcase exactly the evolution of cities toward systems that are continuously enhanced.

At the same time, large cities are overcrowded with vehicles and face undesirable and unpleasant everyday phenomena in the transport domain, including traffic congestions, pollution and accidents. Current mobility strategies are inefficient, leading to enormous losses of time, safety compromises, as well as degradation in the quality of life. Given the current energy source mix, this also leads to a huge waste of non-renewable fossil energy. The above highlight the necessity for developing systems for more efficient and safer mobility.

In the aforementioned context, it would be of great interest to investigate how cities try to improve their mobility practices for citizens/policymakers/businesses. This can be done only by engineering innovative strategies for aggregating large amounts of data from versatile sources (conventional and new ones), intelligently processing it and providing accurate directives associated with actual mobility status and potentials, in a multimodal and concurrently individualized fashion (Dimitrakopoulos and Demestichas 2010). However, novel ideas need to be explored, so as to perform these operations with lower infrastructure costs, catering for fast system response to external requisitions.

Lately, there has been a lot of research in various areas of Smart Cities Operations (SCOs) and also sustainable urban mobility. The paper builds on those research findings and provides the means to evolve urban mobility whilst

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minimizing infrastructure costs. As such, the contribution of this paper is manifold:

- It gathers and summarizes all challenges that arise towards the implementation of SCOs;
- It provides an insight specifically for SCOs focusing on mobility-as-a-service;
- It proposes a framework exploiting 5G mobile communication infrastructures to enhance the efficiency of V2V (and also V2I) communications, validated through indicative operational scenarios and results. The framework constitutes an evolving system, with results that are gradually enhanced (exploiting 5G vs earlier infrastructures), whereas its benefits contribute to the evolution of urban mobility;
- It creates the basis for the design and implementation of such services.

The rest of this paper is organized as follows. Section II provides some fundamental definitions in the smart cities domain, as well as an overview on the relevant research challenges in the various areas of Smart City Operations (SCOs). Section III discusses on sustainable mobility in smart cities, focusing on the main achievements and challenges. Then, section IV presents the "*Vehicell*" framework, which lies in the exploitation of 5G mobile communication infrastructures, contributing to the evolution of urban vehicular communications. The framework is presented first at a high level and then in detail, with indicative operational scenarios and results showcasing its efficiency and advantages, consisting in the minimization of infrastructure costs, the reduction of latencies and, overall, the evolution of urban vehicular communications. Concluding remarks are drawn in section V, along with an outlook on future research activities.

2 Smart cities and smart city operations (SCOs)

2.1 Basic definitions and SCO domains

There is no unique definition of the term "smart city". Instead, there have been several attempts to provide descriptive definitions of the term. As such, according to (Giffinger et al.), smart city is a city well performing in a forward-looking way in economy, people, governance, mobility, environment, and living, built on the smart combination of endowments and activities of self-decisive, independent and aware citizens. Likewise, the authors of (Harrison et al. 2010) define as smart a city connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city.

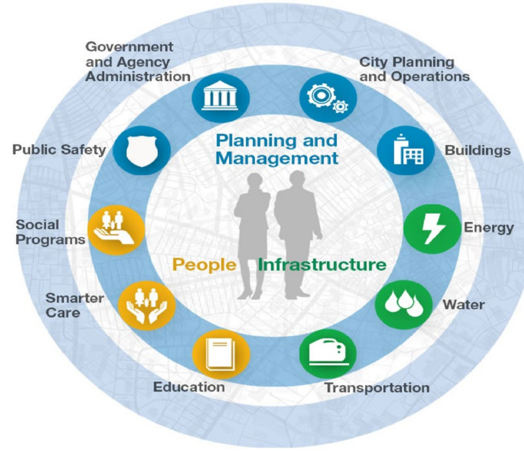

Fig. 1 Fundamental SCO domains (http://www.ibm.com/smarterplanet/us/en/smarter_cities/overview/)

In this respect, SCOs constitute an important development that is expected to have a profound impact on the socioeconomic future of Europe. ICT is a strong enabler for cities to evolve, turning "smarter" and thus offer their citizens the opportunity of a better quality of life. This can be achieved through better decision making about a variety of domains within a city. Regarding particular areas where SCOs find fertile ground for development, those include:

Healthcare which includes the provision of revolutionary services to citizens, such as the electronic patient record, innovative manners to respond to emergency incidents through the exploitation of communication technologies, advanced healthcare telematics, etc.;

Mobility which refers to the provision of innovative Vehicle-to-vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications so as to enable enhanced traffic/safety/emergency/parking management applications within the city;

Energy which refers to the provision of motives through ICT to citizens for the utilization of environmentally friendly energy sources (e.g., push messages to smart phones for discounts, etc.;

Public administration/governance which refers to e.g., ICT enabled compliance of public documents, cloud access to governance services, etc.

Some indicative domains of services (among others) provided within smart cities are outlined in the figure below (Fig. 1).

2.2 SCOs design challenges

Smart cities across the globe are evolving, becoming increasingly smarter, through capitalizing on new technologies and insights that transform their systems and operations delivery to citizen-centered useful service delivery (Dimitrakopoulos and Demestichas 2010). To be able to continue advancing in this area and consolidate a solid "smart" background", several fundamental requirements need to be addressed from an operational point of view (http://www.hitachi.com/products/smartcity/download/pdf/whitepaper.pdf). To address those requirements, SCO designers/policy makers anticipate several SCO challenges, which are also identified in the international literature. Some of them are detailed below.

2.3 Level of intelligence and association with technologies

Intelligence ("smartness") might be a difficult concept to sketch, from various viewpoints. As such, a city should appropriately consider a priori the desired levels of smartness to be achieved at short, medium and long time scale. This depends of course to a number of services that a city wants to provide to its citizens, so as to be considered "smart". Moreover, to do so, a city should consider the needs, plans and opinions of all stakeholders involved in its operations, such as: (a) citizens, (b) service providers, (c) businesses, (d) municipal authorities and (e) national standards. At the same time, all economic, environmental and people oriented viewpoints should be considered. Last, scalability of the SCOs should also be considered. This means achieving a balance not just between the interests of a particular city's stakeholders, but also taking into account relationships with neighboring cities. The above seems a complex algorithmic process with multiple variables (Difallah et al. 2013; Giffinger et al. 2007; Harrison et al. 2010).

Let it also be noted that, undoubtedly, technology constitutes the primary driver towards the transformation of a city from a conventional one to a smart one. A smart city relies, among others, on a collection of smart computing technologies applied to critical infrastructure components and services. Smart computing refers to a "new generation of integrated hardware, software, and network technologies that provide IT systems with real-time awareness of the real world and advanced analytics to help people make more intelligent decisions about alternatives and actions that will optimize business processes and business balance sheet results (Washburn et al. 2009).

2.4 Available communications technologies

SCOs can be provided through a bunch of communications technologies. In this respect, a designer should consider the available communications technologies within a city, as well as the cost of additional communications technologies to be installed for providing evolved SCOs.

As an example, SCOs are usually provided either through fiber optics, or through other infrastructure based technologies oIP, or even through cellular communications (2G/3G/4G). Lately, cloud services are also exploited, so as to minimize the complexity at network edges and facilitate ubiquitous access to services.

2.5 Scalability of smart solutions

Smartness should be scalable enough, in that a city should appropriately design the objectives to be achieved at various scales. First come the minimum objectives that will attribute "smart" characteristics to the city and will be able to provide its citizens with the minimum levels of quality needed to live a civilized life. At this high-level stage, the values of a city and its residents include many qualitative concepts and things of an emotional nature, such as lifestyle values and a sense of attachment to the neighborhood (http://www.hitachi.com/products/smartcity/download/pdf/whitepaper.pdf).

Second come the fundamental objectives that will enhance the level of smartness of the city towards a desired level, such as e.g., the reduction of carbon emissions. Such objectives could be agreeable at a local/regional/national level.

Last come some longer term objectives that will further advance the smartness level already achieved, which are usually set at a local level, albeit being negotiable also at an international level in the context of organizations and fora.

2.6 Formulation of city-specific objectives

A city usually sets at a local level some standards to be achieved at various time scales. Then, some Key Performance Indicators (KPIs) are monitored, so as to evaluate the achievement of those standards. Those KPIs are nothing less than city-selected criteria/benchmarks. Moreover, KPIs should be adaptive enough to respond to new (external) requisitions (Naphade et al. 2011; Hogan et al. 2011; Difallah et al. 2013).

In order to formulate city specific objectives, factors that need to be taken into account are (a) the people and cultural diversity, as well as (b) the environment (Benouaret et al. 2013; Walravens and Ballon 2013).

2.7 Economic growth of a city

From a high level, economics viewpoint, a city can be thought of as a continuously evolving entity that enables internally operating business groups to obtain income from outside its geographical region, and then enables the obtained revenues to circulate within its region. This of course can function the other way round (extroversion).

Accordingly, the economic performance of a city can be viewed from two viewpoints: its industrial competitiveness relative to other regions, and the soundness of the finances within its region.

In this respect, it is essential that when planning and designing the provision of SCOs, one must take a holistic, long term approach. In particular, the assessment of strengths, weaknesses, opportunities and threats needs to look 10 or even 20 years ahead. Such a process will allow a city to continue attracting immense attention for businesses, whilst being comfortable and secure for its citizens (Naphade et al. 2011; Hogan et al. 2011).

2.8 Management and organization

There are only a few studies in the academic literature on smart city initiatives that adhere to address issues related to managerial and organizational factors of a city. In contrast, a wide array of previous research on IT initiatives and projects has highlighted these issues as important success factors or major challenges (Gil-García and Pardo; Scholl et al. 2009). Thus managerial and organizational concerns in smart city initiatives need to be discussed in the context of the extensive literature on e-government and IT projects success.

In this respect, the authors of (Gil-García and Pardo) suggest several challenges, namely (a), Project size, (b) Manager's attitudes and Behavior, (c) Users or organizational diversity, (d) Lack of alignment of organizational goals and project, (e) Multiple or conflicting goals, (f) resistance to change, as well as (g) Turf and conflicts.

3 Sustainable mobility in smart cities

The latest mass transit and e-mobility technologies match with city infrastructures from monorail and metro systems running through buildings at-grade, elevated or underground, to new solutions for electric vehicles. These solutions support a better way, which helps us thinking from traditional transport modes to electric public transport.

Smart mobility constitutes a key challenge at a worldwide level. The huge increase in urban population and the growing environmental topic find prosper ground to the concept of smart mobility, which proposes solutions for greener, safer and more efficient transfer of humans and freight.

Historically, mobility has been seen as a product. This includes the vehicles, physical infrastructure and fuels which used people to mobilize. But, mobility is approached as a service also. This means that mobility is a method by which we provide food, engage in economic activity, access entertainment or meet with friends and family, all through ideal movements from place to place. When we use mobile phones, web and video to manage our lives on the go, the ways in which we discharge these tasks are changing. These new capabilities rely on physical and digital infrastructure whose potential is only beginning to be carried out. By supplementing urban planning and management practices with digital technologies, there is an opportunity to improve mobility services for citizens, while managing demand on physical transport networks and generating wider economic and environmental value.

In this way, the challenges in smart mobility are (http://www.mobincity.eu/about_mobincity/project_overview):

1. To develop a system that can communicate with the vehicle and so the user is able to receive information from the surrounding environment, which can have influence in the vehicle performance (traffic information, internet-connected vehicles, parking management, car pooling, etc.);
2. To make the best effective use of the trip planning and routing of fully electric vehicles, using information from these sources including alternatives from other transport modes adapted to user's needs;
3. To set efficient and optimum charging strategies which match to user and fully electric vehicles needs and grid conditions, as well as
4. Using energy saving methods (as driving modes and In-Car Energy Management Services) within the fully electric vehicles interaction with the driver.

An example is a new mobility model, the Mobility-as-a-Service (MaaS). MaaS bridges the gap between public and private transport operators, envisaging the integration of all the fragmented tools (planning, booking, real time information, payment and ticketing) a traveler needs to conduct a trip. This model reduces the dependence on private vehicles and allows modern travelers in urban areas to plan and manage their transit quickly and safely using their smart phones. The key to successful uptake of such services is the effective integration among different technologies and tools.

Several EU funded initiatives are relevant to the smart mobility in smart cities in general, as well as MaaS in particular. The InSMART (http://cordis.europa.eu/project/rcn/186975_en.html) concept brings together cities, scientific and industrial organizations in order to establish and implement a comprehensive methodology for enhancing sustainable planning addressing the current and future city energy needs through an integrative and multidisciplinary planning approach. READY4SmartCities (http://cordis.europa.eu/project/rcn/110042_en.html) operates in a European context where other initiatives are currently running in order to create a common approach on Smart Cities. STEP-UP—Strategies Towards Energy Performance and Urban

Planning (http://cordis.europa.eu/project/rcn/186983_en.html) takes an integrated approach to energy planning, integrated project design, and implementation by addressing 3 vital themes together: energy and technology; economics; organisation and stakeholders. TRANSFORMation Agenda for Low Carbon Cities (http://cordis.europa.eu/project/rcn/186978_en.html) supports cities to meet the 20-20-20 targets by the integration of energy in urban management. PLEEC Planning for energy efficient cities (http://cordis.europa.eu/project/rcn/186984_en.html) gathers cities with innovative planning and ambitious energy saving goals. SMART-ACTION (http://cordis.europa.eu/project/rcn/109708_en.html) supports the development of strategic research agendas and serves as an enabler for the dissemination and further integration of results into future research and industrial developments, while coordinating international efforts.

Also, smart mobility can improve the economic gains. One way is to improve intermodal transport for better efficiencies and economic activity, for example, in Osaka, Japan, high-speed rail is blended with connections to local public transport networks to encourage public transport use and drive down the demand for roads. This reduces congestion, travel times and supports greater productivity. In another case, the efficient, integrated intelligent transport system in Medellin, Colombia, is cutting travel time into the city from many hours to 30 min, linking residents to jobs and education and driving economic gains.

In accordance with the above, the next section presents a framework that is capable of ensuring the provision of sustainable mobility services within smart cities.

4 Vehicell: a sustainable mobility framework leveraging on 5G mobile communication infrastructures

4.1 Motivation

As explained also above, current mobility strategies are inefficient, leading to enormous losses of time, safety compromises, as well as degradation in the quality of life. Given the current energy source mix, this also leads to a huge waste of non-renewable fossil energy. In response to these challenges, there has been an emergence of innovative, cost-effective cooperative mobility and automated driving solutions improving energy efficiency, individual safety and the effectiveness of public and freight transport. These initiatives together form the cornerstone of Intelligent Transport Systems (ITS).

However, despite numerous advances over the past few years, there are still plenty of efficiencies to be gained, especially in the areas of:

a. Traveler's information enhancement: Real-time, accurate and tailored information provision to the driver, especially when information originates from multiple sources and is associated with large amounts of data.
b. Deployment cost reduction: At this time, ITS are associated with high costs that are associated with the distributed infrastructure necessary for their deployment.
c. Communication availability improvement for ITS: Availability of state-of-the-art communication infrastructure/technologies nation-wide.
d. Vehicle co-operation improvement: In-vehicle intelligence, connectivity and co-ordination among heterogeneous technologies.
e. Driving safety improvement: Solutions that will assist the driver in effectively handling sudden or unforeseen situations (Advanced Driver Assistance Systems—ADAS).

Addressing these challenges necessitates research targeted at exploiting vehicular connectivity for the development of novel service concepts. These concepts should (a) minimize infrastructural costs, (b) exploit heterogeneous data and (c) operate reliably and securely.

4.2 High level framework description

Standards based vehicular networking for Vehicle-to-Vehicle (V2V) communication has been so far implemented based on IEEE 802.11p, which inherits several of the IEEE 802.x family characteristics, including simplicity and distributed medium access control mechanisms. It is at an early stage of adoption however and though it does meet the requirement for minimal infrastructure investment, it suffers from reliability, resilience to interference and stability problems, as well as faces the 'fax machine problem'—it's only any good if you can communicate with a second party that has similar equipment.

On the other hand, Vehicle-to-Infrastructure (V2I) communications have been implemented based on numerous standards, such as IEEE 802.11n, DSRC and Infrared techniques. They have been widely deployed for road charging applications but the infrastructure cost makes the cost/benefit calculation challenging, demanding significant investment overhead. Further, Wide Area Networking (WAN) technologies such as 2G/GPRS/EDGE, 3G/UMTS/HSPA/HSPA+ and 4G/LTE have also been used for vehicle to back office communication, but these suffer from location accuracy which could be improved by secondary mechanism such as GPS.

Given the diverse performance requirements of a wide spectrum of vehicular networking applications, and the huge cost of deployment of specialized road infrastructure, we propose to investigate the benefits of exploiting the

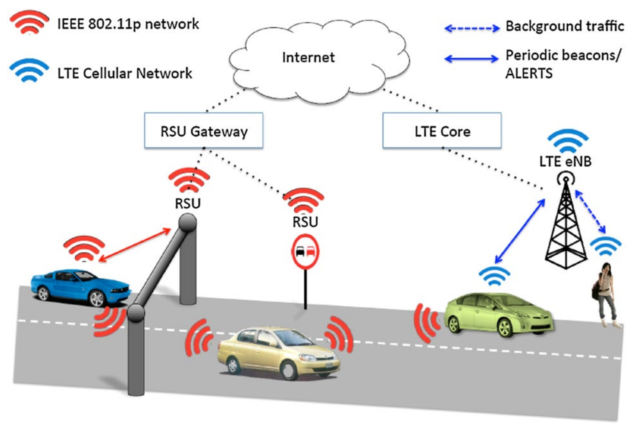

Fig. 2 High level view of the *Vehicell* framework

existing/emerging mobile communication standards (LTE-X2 interface, and most importantly 5G Device-to-Device—D2D) as suitable mechanisms for delivering automotive applications, with a focus on autonomous driving (AD). Indicative standards of this kind include:

(a) *The LTE-X2 interface* The LTE X2-UP protocol tunnels end-user packets between the LTE eNodeBs. The tunneling function supports the identification of packets with the tunnels and packet loss management.
(b) *5G-D2D* A major issue in systems beyond 4G is to make the high bit rates available in a larger portion of the cell, especially to users in an exposed position in between several base stations. In current research, this issue is addressed by cellular repeaters and macro-diversity techniques, also known as group cooperative relay, where users also could be potential cooperative nodes, thanks to the use of direct device-to-device (D2D) communication.

Overall, it is envisaged that next generation mobile technologies (4G/4G+, 5G), including D2D networking and very low latency communications, will constitute alternative technology solutions to 802.11p.

In this respect, the main idea of the "*Vehicell*" framework is to exploit emerging wireless standards to leverage Mobile Network Operators (MNOs) existing telecommunication infrastructures and (network) data, to enhance intelligence on the move for providing novel ADAS based solutions, as a stepping stone towards full AD.

As shown on Fig. 2, the *Vehicell* goal is to exploit 4G/5G MNO infrastructure/date for V2V/V2I communications as an alternative to conventional approaches based on the utilization of costly Road Side Infrastructure/Units (RSU) and IEEE 802.11p.

We advocate that the *Vehicell* solution offers multi-dimensional advantages since it promises: (a) reduced

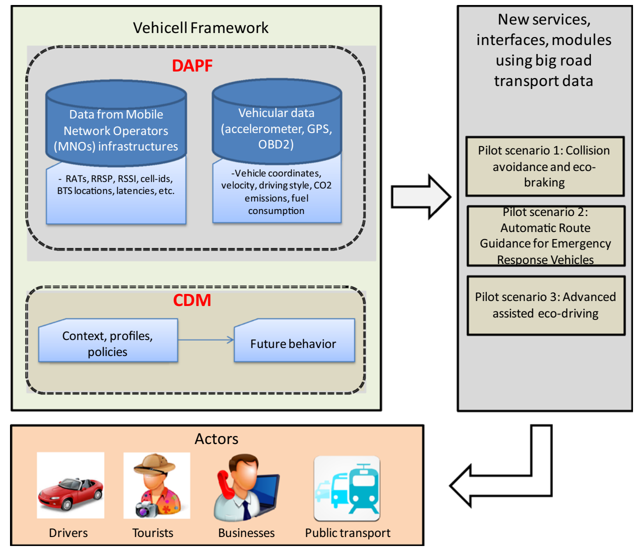

Fig. 3 Illustration of *Vehicell* architecture

latency, (b) increased reliability, (c) a more efficient and pervasive market penetration model and (d) cost-efficiency.

4.3 Detailed framework description

A 2nd illustration of the Vehicell framework, more detailed one, is presented in the following figure (Fig. 3). As shown, *Vehicell* utilizes various data "sources", aggregates the collected information through a Data Acquisition, Pre-processing and Fusion (DAPF) module, processes it on the basis of Cognitive Decision Making (CDM) functionality and provides as output directives to drivers to support them in accident avoidance and to mitigate the consequences of collisions.

Yet, ALL message transmissions foreseen to take place according to the *Vehicell* concept, can be realized FULLY through the existing MNO telecom infrastructures instead of needing to build costly road-side infrastructures. The latter can of course be additionally exploited when and where available, for further enhancing road safety, but it is not a necessary condition for the success of the *Vehicell* framework.

The following subsections present, in detail, the information sources *Vehicell* uses, the information itself, as well as some example operational scenarios that showcase its effectiveness.

(a) Information sources

As already mentioned, the fundamental novelty of *Vehicell* lies in the utilization of the MNOs telecom infrastructures, for any "message" transmission, instead of any other costly V2I technologies (requiring road-side infrastructures) and/or unreliable V2V technologies. To do so, the following data "sources" are utilized:

- A mobile smart phone (inside the vehicle) and/or an on-board device (if available)
- The vehicle itself (via an OBD-II device) and
- MNO-related data.

- These 3 data sources can provide significantly useful information for drivers, with minimum costs, reduced latency and high reliability, as will be shown in the sequel.

(b) Example data to be aggregated
Example data that will be collected from the above-mentioned data sources are the following:
Smartphone/Tablet and/or on-board device (ADAS)

- MNO-related info, such as: (a) Cell-id, LAC and Radio Access Technology (RAT) currently utilized, (b) Received Signal Strength Indicator (RSSI) and/or Reference Signal Received Power (RSRP) from the serving Base Stations and/or from the neighboring ones, etc.
- Information from motion sensors, environmental sensors and position sensors, such as, accelerometers, gravity sensors, gyroscopes and rotational vector sensors, barometers, photometers, and thermometers, orientation and magnetometers sensors.
- Location information (from GPS) such as latitude and longitude.

- *Vehicle/OBD-II*

- Current and average speed, acceleration, throttle/boost, coolant temperature
- Timings (0–60 km/h, 0–100 km/h, 0–1000 m, etc.)
- Current and average CO_2 emissions (trip, overall)
- Current and average consumption (trip, overall)
- Tank level, etc.

- *MNO data*

- Location of base stations (i.e., GPS coordinates)
- RAT supported per base station (GSM, UMTS, HSPA, HSPA+, 4G).

(c) Processing and outcomes
The processing of the aforementioned information is made on the basis of smart phone applications that constantly provide the RSSI/RSRP level of the phone from the x-nearest BTSs, where $x > 3$ (often $x \approx 10$). This information is extremely useful if combined with additional data provided by the MNO, such as the location of BTS/Node-Bs, the RAT (GSM, UMTS, LTE, etc.), as with the help of triangular and multi-angular calculations and GPS data (if and whenever available-considering users reluctance to utilize an always-GPS ON application due to high battery consumption), it can result in the specification of coordinates of the cell phone with very high accuracy, its velocity, etc.
Moreover, this information can pave the way for significant improvements in the provision of fast, tailor-made information which the driver is capable of processing in changing conditions, in the sense that the efficiency of this and therefore its level of "automation" depends on the RAT that is locally and currently provided by the MNO. This "progressive" procedure is further justified in the scenarios presented below.
Cell phone accelerators can act complementarily to the above information, if we consider that the acceleration/deceleration of a vehicle can exploit cognitive principles and machine learning techniques, in order to result in extracting the driver's profile and proactively identifying a forthcoming emergency, judging from the driver's reactions, which will be provided through the cell phone accelerator. The driver's profile can be used in adding further enhancements to the directives provided (explained below).
Finally, specific data extracted from the vehicle through OBD2 and sent to the cell phone or on board device can also be exploited in providing innovative nature assistance to drivers. The framework envisages that all above information are ad-hoc aggregated through a Data Acquisition, Pre-processing and Fusion (DAPF) module (see also Fig. 3), which includes semantic interoperability strategies that bring all data to a unified type of information, appropriate for further processing. This information is subsequently sent to a cloud-based Cognitive Decision Making (CDM) module (see also Fig. 3), which consists of a multi-criterion analysis tool that will provide as output individualized and proactive traffic, safety and emergency management directives, depending on a set of factors (type of RAT available in the area, driver profile, vehicle capabilities, etc.).

(d) Benefits of framework
The *Vehicell* framework can bring about significant advantages, with respect to safe and connected automation in road transport, compared to existing solutions, for all stakeholder involved (drivers, citizens, public authorities and businesses). These advantages can be summarized as follows:

- *Reduced latency* As explained also through the operational scenarios, *Vehicell* operates with significantly lower latencies (from 10 to 20 ms), compared to existing vehicle connectivity solutions (e.g., IEEE 802.11p - > 60 ms) and thus can guarantee for faster decision making and, in return, increased active safety for drivers (Hameed Mir and Filali 2014).
- *Increased reliability and robustness* The *Vehicell* framework will bring a revolution to current road transport automation solutions, since it will be able to provide a support for accurate, stable, reliable and proactive tailor-made directives (assistance) to drivers. Reliability is higher than that of existing approaches (e.g., IEEE 802.11p (Hafeez et al. 2010; Bai and Krishnan 2006)).
- *Increased cost-efficiency. Vehicell* is inherently cost-efficient, since its main idea from its conception was to use existing infrastructures (namely telecommunication infrastructure), whilst exploiting their benefits (reduced latency, increased reliability), in order to provide innovative ADAS to drivers without the costs for road infrastructure.
- *Resulting reduced energy footprint* The CDM along with its decision making support process can constitute a seminal move towards enhancing Green Driving Support Systems, through providing "greener" directives that will result in lower CO_2 emissions compared to current conditions, which will positively impact the European society as a whole.
- *Increased security, privacy and confidentiality* The *Vehicell* solution is protected against jamming and tapping through the utilization of the mobile communication infrastructure mechanisms, compared to current vehicular networking approaches [e.g. IEEE 802.11p (Araniti et al. 2013; Kim et al. 2012; Vinel 2012)].
- *Easy integration (availability)* With *Vehicell*, drivers, businesses and public service providers will have the possibility to communicate with each other and share useful information. One of the major challenges of public service providers and local authorities is the need to manage the multiple interfaces to the different legacy and newly introduced systems. *Vehicell* will overcome this by introducing a unified frontend to the system having a built in capability to support and integrate legacy deployed solutions and thus introduce the real added value for the operators and decision makers in adoption of *Vehicell* solution from the business perspective. This is particularly easy due to the utilization of existing user equipment (smartphones).

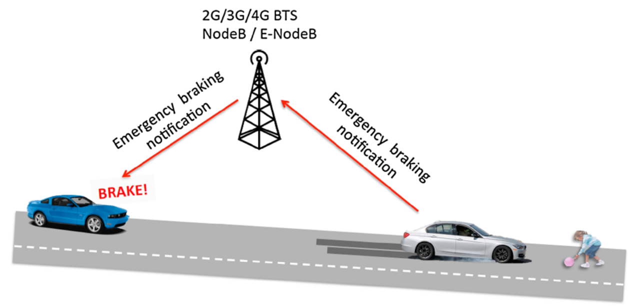

Fig. 4 Scenario 1 - collision avoidance and eco-braking

4.4 Operational scenarios and indicative results

This subsection describes some indicative scenarios that showcase the necessity and efficiency of the *Vehicell* framework.

4.4.1 Scenario 1: collision avoidance

Scenario 1 envisages a faster, more reliable and more secure collision avoidance use case compared to today's solutions, as illustrated in Fig. 4.

A cell phone inside a vehicle (blue vehicle) is currently located within an LTE service area and a potential emergency incident (e.g., sudden brake) takes place close to it. The vehicle involved in the incident (white vehicle) can notify the nearest eNB and the eNB can inform the blue vehicle accordingly, with the communication taking place through the X2-AP protocol, over the X2 interface designed for LTE. The overall required latency is <20 ms, this being appropriate for most of today's available, as well as future vehicular applications.

The resulting advantages of such low latency are obvious, since even emergency braking can be activated. The emergency messages will have a structure compliant with the ETSI standards Decentralized Environmental Notification Message (DENM) (ETSI TS 102 637-3) and Cooperative Awareness Message (CAM) (ETSI TS 102 637-2). Therefore the applications layers for the emergency braking functions will be identical, whether the messages are transmitted only through mobile communication systems (i.e., LTE). Moreover, the absence of road side infrastructure costs renders this solution attractive.

The aforementioned scenario is even more challenging in the case of a 5G service area, where the potential D2D communication (without even the communication through any base station) will support even lower latencies (<10 ms), paving the way for progressively autonomous driving applications. On the other hand, in the case that the cell phones in vehicle A and vehicle B are located in a UMTS (3G) service area, latency drops down to >60 ms. This can be acceptable for some fundamental vehicular applications. Moreover, considering the existence of a GSM service area, the required latency would be >600 ms on average. This latency is calculated stressing the necessity of data (re)transmission within the same cell, which is needed for minimizing the required Round Trip Time (RTT). However, such high latencies are inappropriate for most of the vehicular applications, since they prohibit any substantial real-time emergency management. *Vehicell* will also explore all the potential combinations among the current RATs (e.g. GSM–UMTS, LTE-UMTS, etc.), since neighbouring vehicles may be served through versatile RATs.

4.4.2 Scenario 2: automated route guidance for emergency response vehicles

From data regarding traffic speed of individual vehicles and traffic concentration, it will be possible to generate a real time traffic map, with a high degree of accuracy. Compared to current mobile apps (e.g., www.waze.com), the *Vehicell* framework offers higher reliability, since it will guarantee service provision without necessitating a community participation). Using intelligent algorithms, it will be possible to determine the fastest route to a destination, utilizing actual times, rather than estimates that ignore delays caused by irregular traffic (a frequent occurrence), or unforeseeable events (accidents). By plotting the processed data onto a map, it is possible to display:

- Real-time average speed of traffic on a road, including: (a) on an individual segment of road, (b) at an intersection and (c) on individual road lanes.
- Predict changes in those traffic speeds, based on traffic in the broader area
- The fastest route to a destination based on current traffic speeds and precise estimations of future traffic speeds. The time to destination will be calculated based on the driver's "driving profile".

Furthermore, the software is able to identify which vehicle in a fleet, can reach a destination in the shortest time, taking into consideration actual situational awareness, rather than broad, inaccurate estimations. Such route guidance can one day lead to fully automated response services and can be utilised by unmanned taxiing companies for efficient passenger transport, with a profound impact on eco-driving, by providing significant improvements in fuel economy.

4.4.3 Scenario 3: advanced assisted eco-driving

The 3rd scenario envisages the utilization of the accelerometer and of the in-vehicle *OBD-II*, so as to devise eco-driving directives. In particular, the accelerometer and the *OBD-II* can provide several data on the current fuel consumption, the CO_2 emissions, the road vehicle condition and the driver profile (driving style). This information that will be aggregated by the DAPF, can be processed by the CDM, which will consider various criteria and will provide a twofold outcome:

- Extract the most appropriate (re)route for the vehicle dynamically, depending on the traffic (real-time estimation through RSSI/RSRP/GPS) and the expected CO_2 emissions and fuel consumption.
- Gather long-term statistical data leading to knowledge and experience, in order to extract an overall eco-driving profile of the driver and provide information to insurance companies.

5 Conclusions and future work

This paper discussed on smart mobility services offered in the context of SCOs. As such, it first provided some fundamental definitions in the smart cities domain, as well as some basic challenges that cities face when designing SCOs. Then it focused on smart mobility that falls in the realm of SCOs, presenting its main research achievements and challenges. Moreover, it presented a framework that is based on the exploitation of 4G and beyond, most importantly 5G mobile communication infrastructures, so as to improve the efficiency of vehicular communications. The framework is considered an evolving one, as it provides enhanced results through exploiting improved/new generation communication infrastructures. Finally, indicative operational scenarios were described for showcasing the effectiveness of the proposed framework.

Indeed, cities constitute evolving systems, becoming continuously smarter and continuously enhancing, growing and optimizing the set of services offered to their citizens and visitors. This naturally requires capital expenditure and calls for novel solutions in various areas. Transportation is an area where SCOs find prosper ground since it can increase the quality of living and moving within large cities.

The *Vehicell* framework promises a novel, cost-efficient and reliable technology to enable connectivity in road transport, which will be quantifiably better than current approaches. Moreover, it promises to transform traffic data to make it more useful, and on the infrastructure necessary for performing spatiotemporal visual analytics for the mobility use cases supported. Last, the framework is capable of providing completely tailor-made mobility solutions to citizens, within an environment of interconnected people, vehicles and the surrounding infrastructure. Overall, the framework's advantages mainly consist in the minimization of infrastructure costs, the reduction of latencies and, overall, the improvement of quality of urban vehicular communications.

Several exciting areas are yet to be explored in the area of mobility offered in the context of SCOs. In particular, the further exploitation of intelligent transport systems principles in SCOs can lead to a 100 % real-time assessment of traffic congestions, a priori identification of forthcoming dangers, as well as to the provision of open APIs and interfaces for intermodal sustainable mobility-as-a-service solutions inside cities/regions. Moreover, city-wide services can inform drivers on city-specific events (cultural, etc.), as well as on city-specific incidents (e.g., protests, works, etc.) and offer also targeted/focused ads and infotainment.

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