Parked Cars as a Service Delivery Platform

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***Abstract*—We introduce a new view of parked cars as a massive, flexible resource that is currently wasted. Given the power supply in batteries as well as computing, communication, and sensing facilities in cars in conjunction with the precise localization they can provide, parked cars have the potential to serve as a service delivery platform with a wide range of possibilities. We describe diverse applications that can be implemented using parked cars to show the flexibility of the infrastructure. Potential user groups and service providers are discussed. As an illustrative example, a simulation study of the use case of localizing persons in need of assistance is presented. Finally, the need for new algorithms and their analysis adapted to the specifics of parked cars is also highlighted.**

I. Introduction

The search for disruptive technologies is a growing feature of the automotive industry. Driven by increased regulation, advances in technology, demographic changes, and examples of technological convergence driven paradigm shifts in the computer and telecommunications industries, automotive manufacturers are seeking new products and services to monetize cars. In this effort new partnerships are being built with e.g. cities, telcos, and energy providers. Examples of such products include new mobility offerings such as car2go, DriveNow, and Zipcar and using moving vehicles as sensing platforms to sense congestion or more generally, environmental conditions; serving principally drivers and cities.

In this paper we propose a radical departure from the traditional, one-dimensional view of a vehicle as an enabler of mobility to one where it is *a general service platform, wherein mobility is one such service*. Our objective is to develop a platform where a plethora of services can be provided to serve mobility users (drivers and passengers), cities, and citizens alike. We believe a parked car offers a number of key advantages over other infrastructure: 1) temporal and spatial stability; cars are parked for a reasonable period of time at an exact location; 2) scale; there are more than a billion geo-distributed cars in the world; and 3) collective incentives; the entire ecosystem gives rise to a business model in which all entities—car manufacturers, owners, and service providers—can benefit. The first of these also gives parked cars an edge over their moving counterparts. Finally, while parked, as it currently stands, these cars are doing no useful work.

The rich possibilities afforded by parked vehicles stem from the fact that the ubiquity of electronic devices (especially hand-held devices), Internet access, and consumerism has engendered an ecosystem where users desire to consume services almost continuously – varying from simple Internet access to automated parking. However, at present, the further penetration of this rich set of services is hampered by the need to provision dedicated support infrastructure, lack of elasticity in infrastructure due to urban dynamics, and cost-prohibitiveness at scale. In cities, parked vehicles offer a possibility to deploy such an infrastructure in a cost effective manner.

Each car is a resource container comprising processing, power, storage, and sensing (from hereon called *P2S2* resources), and when parked, generally speaking, its precise location is easily determined. Thus parked vehicles can be used as both anchors to work out the precise location of mobile devices and to extend the limited capabilities of these devices. Unfortunately, parked vehicles currently serve no useful purpose other than monopolizing and wasting their 2P2S resources that can otherwise be harnessed to provide user-facing services. The extent of this wastage is underscored by the fact that the average car remains parked up to 95% of the time [1]. In this context, using a parked car as a service delivery platform (*SDP*) opens up a new service opportunity for service application developers to take the existing synergy between mobile devices and in-car platforms one step further [2].

This proposal has the potential to change the status quo in three key ways: 1) by providing support infrastructure, 2) by monetizing a wasted resource, and 3) by enhancing mobility functions. Furthermore, the envisioned service ecosystem benefits all involved stakeholders, including car owners (incentives for allowing services to run off their vehicles), car manufacturers (increase revenue by venturing into the services market), third-party developers (designing paid apps for parked cars), and city authorities (benefit from providing services to their citizens including an alternative business model for parking space monetization).

The remainder of the paper is organized as follows. We motivate our case by presenting some surprising facts around car usage in §II. In §III we then elaborate a selection of services that can be offered off of parked cars based on the P2S2 paradigm. §IV presents implementation details and some initial research challenges. A case study of rapid pedestrian localization is discussed in §V, while §VI proposes possible incentive models for the concerned stakeholder groups. Related work is summarized in §VII and we conclude in §VIII.

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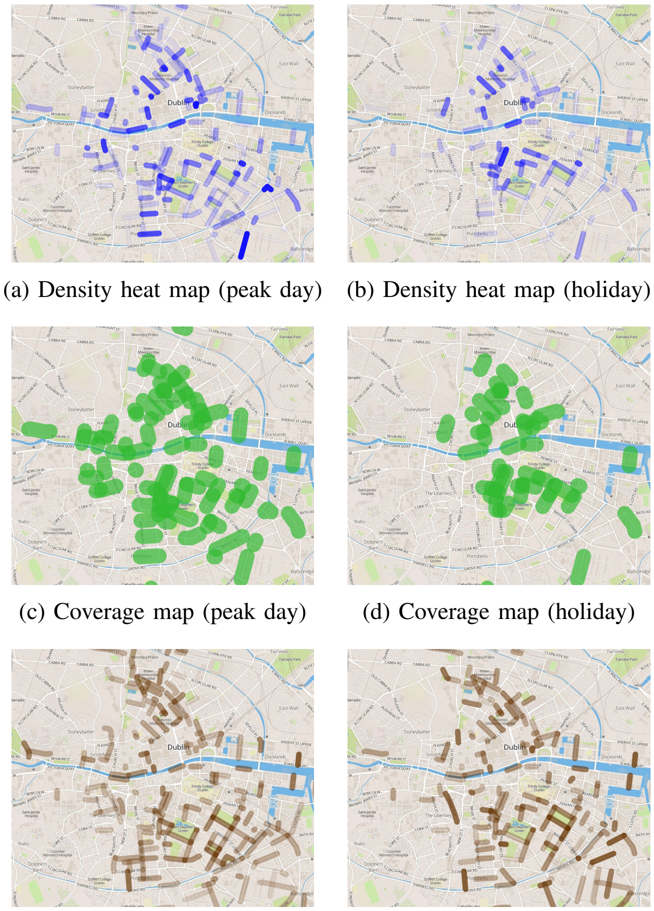
II. Some surprising facts

In just the United Kingdom, there are over 27 million registered private cars [3]. The owners of these cars make about 25 billion trips by car each year, and each trip starts from and ends with a *parking event*. Among those parking events, 57% are away from the home parking space. During weekdays the most common cause of parking is for work (28%); implying a high demand for city center parking spaces. On the other hand, home is the most popular parking space in terms of time spent for parking. On average a car is parked at home for 80% of the time, while it is in use for travel only about 4% of the time [3]. In addition, only 25% of the cars in the UK consume street parking, whereas most of the other cars are parked in garages or on driveways. Thus parked cars offer the possibility to deliver services in both residential and urban city center environments.

As a service delivery system, parked cars should satisfy several requirements. First, they should be close enough to make communication between cars possible (*density*). Second, they should be easily accessible to potential service consumers (e.g. pedestrians) (*accessibility*). Third, each car participating in the service should remain parked for a meaningful time (*stability*). In many locations, parked cars possess all of these properties in abundance. In the city of Dublin, there are 1097 coin parking meters and 365 among them are *smart* ones that can report detailed transaction records (e.g. time of transaction, parking duration, and total number of parking spaces, etc.) [4]. Figure 1 illustrates snapshots of parked cars in Dublin city center around 11am on two different dates in 2013: peak (23^{th} Dec.) and holiday (27^{th} Dec.). In the density and duration heat maps, darker color signifies higher density of parked cars, and longer parking duration, respectively. The coverage maps show accessible areas to parked cars whose density is large enough. It is evident that the city center is packed with parked cars even during the holidays. The busiest areas of Dublin city are readily accessible to the parked cars especially on the peak day as shown in the coverage maps. Our data also reveals that the average parking time in Dublin city center is about 65 minutes. Note that, unlike the density, the duration of parked cars shows little variance over periods and locations as shown in the duration heat maps.



(a) Density heat map (peak day) (b) Density heat map (holiday)

(c) Coverage map (peak day) (d) Coverage map (holiday)

(e) Duration heat map (peak day) (f) Duration heat map (holiday)

Fig. 1: Analysis of parked cars in Dublin city center.

III. Applications

The number of potential applications for parked cars as service delivery platforms seams nearly limitless. In this section we will thus present an overview on technology shifts along processing, power, sensing and storage that will facilitate the further development of a rich SDP ecosystem. Following this, we will describe a selection of specific public facing services IBM Research has under active consideration and investigation at its Zurich and Dublin labs to illustrate the power of parked cars as an SDP to enable radical new services as well as low-cost alternatives to existing ones.

A. Processing

Processing in modern cars is highly fragmented across close to 100 ECUs [5] and each serving a particular function. This renders them nearly impossible to recruit for other purposes. However, a substantial effort is currently being devoted to migrating to an architecture where multiple sensors feed a common environmental representation – from which various ADAS functionalities running jointly on a capable processor will draw their required data [6]. This opens up external access to processing power, dubbed *work offloading*, which could be utilized, particularly at times when vehicle services are idling (e.g., while parked). Such offloading can be achieved via an API (application programming interface) to a cloud service, or, alternatively, via direct negotiation with a parked car. We expect that methods amenable to GPU speed-up (where the bottleneck is the BUS) to be also amenable to work offloading.

B. Power

With the transition to hybrid and fully electric transportation, in terms of battery power, cars are becoming uniquely positioned among mobile devices. As energy represents a proverbial constrained resource in a mobile environment, we envision that intensive work from mobile devices can either be offloaded to a parked car or (similar to web caches) stored content can be retrieved from the latter to be serviced by the former.

C. Sensing

In tandem with faster processing, vehicles are gradually being equipped with more powerful sensors – primarily for vehicle safety and automation applications. These sensors (cameras, ultrasound, rain and gas sensors, among others) are becoming ubiquitous and highly standardized, and have the potential to remain active for considerable time spans thanks to the sizable batteries within cars. This is in stark contrast to virtually all other mobile sensor platforms. As a result, we are convinced that these sensors show strong potential for usage in additional applications besides their primary ones.

D. Storage

As storage requirements in cars grow for multimedia and infotainment reasons, this also opens up opportunities for caching and sharing of frequently requested information. As a result, cars parked cars can serve as locally relevant content caches to enable infrastructure in densely populated urban areas to scale. For instance, near tourists attractions, parked cars may propagate information, local maps, and advertisements. Tourists will be able to retrieve useful information while bypassing the WiFi backbone[4] and avoiding the high cost of 3G near museums, restaurants, parks and other tourist attractions.

E. Specific Applications

Application 1: Network Provisioning Even in suspended mode, the average phone spends almost half of its power in constantly communicating with the cellular base station to keep the connection alive [8]. In addition, 3G has the highest energy footprint for data transfer (Joules/MB) among the multi-modal communication interfaces that modern phones are equipped with [9]. In this regard, one promising service concerns the offloading of network connectivity from a mobile phone to a GSM module in a parked car. The energy savings for this delegation can be extremely rich considering that under our scheme, this function is offloaded to a user's parked car when she is in Bluetooth range. We propose that only non-trivial information is transmitted to her device over a low-power footprint medium such as Bluetooth and the connection is seamlessly switched back to the previous state (WiFi or 3G) as soon as the device leaves Bluetooth range. This enables an order of magnitude savings in energy [10]. Similarly, unlike other mobile devices, parked cars can also be leveraged to create a ubiquitous WiFi MANET, wherein the cars serve as WiFi access points and repeaters to extend the reach of existing backbone connectivity provided by 3G and LTE, as well as other WiFi access points backed by wired media. Coverage on an entire city level may be enabled by scaling the number of participating cars up or down based on the demand and the battery level of the participating cars.

Application 2: Mapping of Free Parking Space As the number of cars on the world's roads further increases congestion mitigation strategies become paramount. Interestingly, one study by VDA estimates that 7 to 21 percent of urban traffic is accounted for by vehicles in search of a parking space [11] – and guiding them to free spots directly would lead to a significant reduction of these numbers. However, information on free parking spaces is at present often only available locally, i.e., drivers need to explore the vicinity of their destination in a time consuming and congestion inducing manner. And while for larger parking decks, cities have started to provide information on the number of free spaces available via displays and there is an effort to make this information available online in real-time, a large number of parking spaces (e.g., along roads) remains unmonitored. We hence propose to use parked cars for detecting available parking spaces. By combining information between collaborating vehicles, and communicating this information to other road users, we will be able to provide services that facilitate automated, or semi-automated parking applications.

Application 3: Tracking and Localisation of Persons With the increase in the number of ageing citizens in Western societies, the number of patients sufferring from dementia is set to increase. It is a regular phenomenon that these patients get lost from their homes and are then very hard to locate, sometimes resulting in tragic accidents. Using parked cars as a sensing device may help to rapidly locate these patients. Several technical realisations of such a scheme can be envisaged. Using a low power Bluetooth bracelet, carried by the patient, Bluetooth devices of a fleet of parked cars could sense for a given MAC address. A prototype system is currently being implemented and extensions to detect other citizens and objects (stolen cars) are currently being planned. Special dedicated analytics are required for this application. This is detailed in the case study in §V.

IV. Baseline analytics

While many of the applications listed in the previous sections require the development of specialised analytics, all are built on a platform requiring large scale urban coverage. The basic objective in all of our applications is to provide reasonable coverage in the city to enable services, while at the same time taking into account the battery depletion of individual vehicles, and some element of fairness between vehicles. Since these services are enabled through the use of a *network* of parked cars, coordination among vehicles is required. Co-operation amongst vehicles to provide these services in an optimal and privacy preserving manner is thus of primary concern. Note that the burden carried by a single car may depend on its location relative to other cars in the system, and that this burden may change as cars enter and leave the system. Thus, plug-and-play type (self organising) load balancing solutions are required along the lines discussed in [12], [13] and other classical references. In this context several scenarios may be envisaged. The following two are currently under investigation.

A. Regulated Density Formulation

Consider the use of a network of parked vehicles to monitor a set of locations throughout a city. Specifically, consider a setting where vehicles use audio sensors to detect the presence of a nearby entity. The aim in this application is to provide a real-time, city-wide view, of the roads to detect the presence of an unknown object (for example, an Alzheimer's patient). This can be performed by monitoring a discrete (and likely very large) set of locations. Each parked vehicle is only monitoring

[4] WiFi access points undergo significant performance degradation as the number of hot-spots grows due to interference [7].

a small subset of these locations, and there may be significant overlap among the locations monitored by different vehicles. As a result of this overlap, we can balance the sensing and computational load placed on each vehicle by dividing the time that each vehicle spends in active and idle states. This load balancing also serves the dual purpose of adding robustness to the system in the face of arrivals and departures of parked vehicles. We can formally pose this as a problem of selecting the fraction of time each vehicle spends monitoring, with the objective of distributing the sensing load evenly, subject to the constraint that each location should be monitored with sufficient frequency. Mathematically, this problem may be stated as

$$\begin{aligned} \text{minimize:} \quad & \textstyle\sum_{i=1}^{n} f_i(x_i) \\ \text{subject to:} \quad & \textstyle\sum_{i \in S_j} x_i \geq l_j \quad \text{for all locations } j \\ & x_i \in [0,1] \qquad\quad \text{for all cars } i, \end{aligned}$$

with additional constraints on the admissible depletion of the battery. Here x_i denotes the fraction of time that vehicle i spends in an active state, $f_i(x_i)$ denotes the resource consumption cost experienced by vehicle i, S_j represents the set of vehicles monitoring location j, and each constraint ensures that the expected number of vehicles monitoring location j at any time is at least l_j. While reasonably small instances of optimization problems such as this are easily solved in a centralized manner, a key challenge lies in designing distributed algorithms for the solution of large-scale instances of these problems and that facilitate plug-and-play behaviour. Moreover, the configuration of vehicles is continually changing as cars arrive in and depart from parking spaces. We anticipate much of the effort put toward the analytics enabling parked vehicle services will lie in the development of distributed optimization algorithms; in particular those that preserve privacy.

Note that, in general, the above formulation makes no attempt to enforce fairness between participating vehicles. The selection of the resource consumption costs f_i can help to enforce a form of fairness. For example, if the f_i are strictly convex and increasing, ensuring coverage by assigning small loads to many vehicles will be preferable to assigning higher loads to a smaller collection of vehicles. However, even in this setting, some vehicles may use a lot of battery power and others may use a small amount. Cars parked in relatively sparsely covered areas will be assigned a higher load than cars parked in densely covered areas. In this case, participants may be unfairly penalised by parking in a particular location. The challenge is to develop distributed algorithms resolving these issues.

B. Fairness and Optimised Consensus Formulation

An alternative load balancing formulation arises in the following context. Suppose, as before that each participating vehicle spends a fraction of time x_i in an active state. Suppose, as before we wish to detect a given moving object. Clearly, the greater x_i, the greater the probability that the i'th vehicle will detect this object if it passes within its zone of detection. Conversely, the battery of vehicle i will deplete faster as x_i increases. Suppose now that $g_i(x_i)$ is a convex function capturing this tradeoff. A reasonable *fair* optimization is the following:

$$\begin{aligned} \text{minimize:} \quad & \textstyle\sum_{i=1}^{n} g_i(x_i) \\ \text{subject to:} \quad & x_i = x_j \qquad \text{for all } i, j. \end{aligned}$$

Thus, this formulation seeks to find the best fair solution for all participating vehicles. The same comments regarding privacy and plug-and-play behaviour apply here as above.

Fig. 2: Dublin Parking Zones

V. Case study: Rapid pedestrian localization

We now provide a brief illustration of the Dementia patient tracking case study discussed in the prequel.

A. Simulation Setup

We set up a simulated environment for which we used SUMO [14], an open source, microscopic road traffic simulation package designed to deal with large road networks. It comes with a Traffic Control Interface (TraCI) [15] that allows one to adapt and manipulate the simulation on the fly[5]. We then prepared emulations of a pedestrian walking inside a region bounded by the Dublin Yellow Parking Zone[6]. Using OpenStreetMap[7] data, this resulted in a network of 24018 edges.

The main idea comprising each simulation run was to first disperse stationary vehicles (representing parked, curb-side vehicles) throughout the road network in the Yellow Zone. To this end, either between 900 and 1000 vehicles, or between 1900 and 2000 vehicles were placed at the start of random edges on the network and remained stationary for the duration of a single simulation run. Furthermore, each vehicle was bound by a circle with radius 10m, depicting Bluetooth range. A pedestrian was then let to take a walk in the Yellow Zone in a random fashion, moving at a constant speed of 1.25m/s; and each vehicle was set to looking for patients with a probability of 0.75. If the pedestrian was detected by a vehicle, then the simulation alerted us with the time step at which the detection took place, and the simulation run terminated. Fifty simulations were run with between 900 and 1000 vehicles on the road network, and a further fifty were run with between 1900 and 2000 vehicles. Simulations were left to run for a maximum of

[5]For our simulations, SUMO version 0.19.0 and Python 2.7.3 were used.

[6]Zone map available from *http://www.parkingtag.ie*

[7]*http://www.openstreetmap.org/*

TABLE I: Simulation results.

No. of Vehicles	Detection time	σ	Prob. No detection
between 900 and 1000	10.43	9.40	0.1
between 1900 and 2000	8.62	8.35	0.02

1800s (i.e., 30min) each. If the pedestrian had not been located in this time, then the result was recorded with the pedestrian not being found.

B. *Results & Discussion*

Result of the two sets of simulations are presented in Table I. They demonstrate that people wandering randomly in the city center will be detected after around ten minutes on average, with a standard deviation of slightly less than that. More importantly, after 30 minutes, the probability of non-detection drops to ten percent (for the lower vehicle density), and two percent (for the higher vehicle density).

Despite these encouraging initial results, it should be noted that the simulations naturally neglect various important aspects, that any production-level detection system would have to account for in its design. For example, associated with each parked vehicle is a probability function that maps the probability of detecting a passing patient, the dimensions of the sidewalk, and as a function of broadcast frequency and average speed of the patient. Some indicative probability functions are given in Figure 3 (note here $\underline{y}$ represents the minimum vertical distance from a car to the sidewalk, and $\bar{y}$ corresponds to the maximum distance) as defined by typical sidewalk dimensions in Dublin. Battery consumption issues are also a concern.

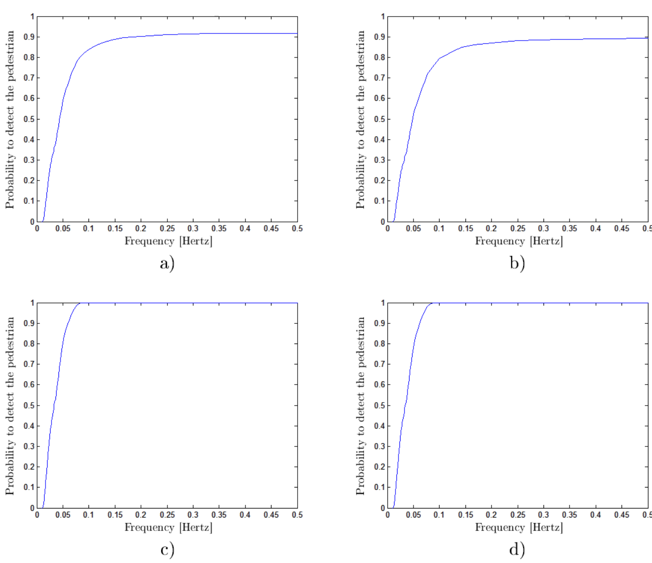


Fig. 3: Experimental results: a) general case: $\underline{y} = 1.71\,\text{m}$, $\bar{y} = 10.7\,\text{m}$, b) case $\underline{y} = 3.85\,\text{m}$, $\bar{y} = 10.7\,\text{m}$, c) case $\underline{y} = 1.71\,\text{m}$, $\bar{y} = 4.01\,\text{m}$ and d) case $\underline{y} = 2.3\,\text{m}$, $\bar{y} = 4.9$. Each point is the average of 50,000 different samples.

These include the self-discharge rate and the initial charge of the battery when the car is parked.

VI. Brief Comments on Stakeholder Groups

The basic idea put forward in this paper is to think of a car, not just as an enabler of mobility, but rather as a device to deliver services to a wide variety of stake-holder groups (mobility being just one of these services). This mimics the manner in which other companies (Apple, Google, Samsung to name but a few) view computers principally as delivery platforms, and secondly as computational tools. To emphasise this point: it is currently claimed that 20% of radio advertising is delivered via moving vehicles. Automotive manufacturers, despite providing the delivery platform, do not receive any of the associated revenue. This is a major oversight by the car manufacturers, and similar oversights can be avoided by taking a broader view of the car. We see monitized services from parked vehicles principally serving three distinct market segments: (i) municipal authorities; (ii) citizens; and (iii) drivers and their passengers. Car owners can be encouraged to enable services either through regulation, or incentives such as free parking or zonal access in exchange for battery access. To this end, we see three distinct models: (a) *static:* an owner parks her car in the usual location and turns on a service, such as WiFi connectivity with a direct charging model; (b) *opportunistic:* service providers toggle services in cars, which have already been parked at a certain location to scale with demand; and (c) *dynamic:* providers expose incentives for parking in certain locations. For instance, if a provider needs to provide a service at a particular location, it can disseminate this information to car owners and give them a higher incentive to park there.

Given the wide variety of potential applications and market segments available to service providers, we believe that several industry groups will be interested in monetizing parked cars. These include automotive manufacturers, cities, and telecommunication companies. To provide some numbers: in 2015 the mobile app and services was estimated to be worth $100 billion, and by 2017 the mobile transactions market is estimated to be worth $700 billion. Similarly, the peer-to-peer car sharing market is currently estimated to be worth $26 billion. Support services (for transporting goods as well as people such as real-time tracking) delivered from parked cars have the potential to grow the value of this space considerably. Therefore, we believe that our proposal will, (a) engender an ecosystem which combines all of these markets, and (b) increase the size of these markets both in terms of revenue as well as userbase.

VII. Related Work

Over the past decade, automotive OEMs and suppliers have been gradually introducing Advanced Driver Assistance Systems (ADAS) applications into the market ranging from traffic sign recognition, automated parking, and lane assistance, all the way to stop and go, automatic cruise control, and emergency deceleration functionality [16]. Most of these systems remain self-sufficient and do not rely on external information or communication.

More recently infotainment systems have emerged. In contrast to other ADAS applications, these non-safety critical services have more enthusiastically embraced inter-vehicular communication. An interesting aspect of some of this work is that parked cars have recently been suggested as to enable more reliable streaming of content into moving vehicles. More generally, telematics and communication have been serving as significant core enabler technologies in the areas of new mobility services, security, and infotainment. Examples in the domain of new mobility services include the automated billing of trucks on highways as well as the levying of tolls in city centres [17]. Recently, routing services have started to incorporate real-time traffic information sources from road-side units and other participating vehicles to reduce congestion and individual travel times [18]. Examples of security applications making use of messaging include emergency call (eCall) infrastructure, functionality for stolen vehicle tracking, and remote vehicle control. Similarly, vehicle relationship management applications (including on-line diagnostics and predictive maintenance, as well as pay-as-you-drive (PAYD) insurance) inherently form a relationship between vehicle owner and an external party via a (wireless) network channel. In regards to drive services, driver and passenger access to localized weather information/warnings and other alerts have been put forward [19], [20]. This also includes in-vehicle WiFi hot-spots for passengers.

Based on the reviewed services and applications, it becomes readily apparent that beyond the direct focus on mobility, public-facing services from vehicles have so far received little attention. We are not aware of any existing commercial implementations in this regard. It appears that closest related to the ideas presented in this paper are the overview articles of Gerla et al. [19] and Whaiduzzaman et al. [20] which also list several applications targeting external parties and citizens in addition to drivers and passengers by making use of (underutilized) resources within modern cars. Examples include the operation of cloud storage and computing services composed from a changing set of cars (e.g. at airports, malls or at work) [20].

VIII. Conclusion

There are more than a billion cars in the world and this number is only going to increase. In addition, these cars are parked more than 95% of the time, resulting in the underutilization of their various power, processing, storage, and sensing capabilities. Our proposed view of a car as a general service delivery platform leverages these resources to provide services to various stakeholders, outside the car, such as pedestrians. In addition, our proposed service ecosystem incentivizes this environment for all stakeholders: car owners, manufacturers, and service providers. Using a series of real-world parking statistics and simulations, we were able to argue that the proposal is not only feasible but also ready for deployment. We are currently in the process of realizing this deployment through the development of the enabling platform and a number of motivating applications, and engagement with the automotive industry.

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