

Parking assisting applications: effectiveness and side-issues in managing public goods

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Abstract—With the emergence of mobile communication devices and social networking applications, new opportunities arise for various mobile networking applications. In this paper, we seek to experimentally study some fundamental properties of vehicular social applications that have been deployed to assist in the parking search process. The awareness and incentive mechanisms that are commonly incorporated in different instances of social parking applications are modeled and simulation scenarios are considered to explore particular aspects of these applications. It is shown that application users experience improved performance due to the increased efficiency they generate in the parking search process, without (substantially) degrading the performance of non-users. This is extremely important since applications managing common (public) goods should not provide benefits to their users by penalizing or almost excluding non-users. The incentive mechanisms are effective in the sense that they do provide preferential treatment to those fully cooperating but they induce rich-club phenomena and difficulties to newcomers. Interestingly, those problems, that may be a concern for all applications managing common (public) goods, seem to be alleviated by free-riding phenomena and dynamic behaviors.

I. INTRODUCTION

More than ever before, information and communication technologies (ICT) help people around the globe overcome the physical separation constraints and exchange information while working or in their leisure. On the one hand stands the integration of sensing devices of various sizes and capabilities with mobile communication devices. This enables the generation and collection of huge amounts of information, of very different spatial and temporal context, by leveraging the heterogeneity of users' interests, preferences and mobility. When sensing and radio communication technologies are mounted on vehicles, in particular, they convert them into pervasive sensing platforms. These platforms can then collect various types of information about the urban environment, ranging from natural environment status indices (humidity, temperature) to traffic conditions and parking space availability.

On the other hand, online social networking applications provide a fast and easy way to publish and share this *information* among their users. More importantly, they often process it in various ways to generate *knowledge*, which can find use in various vehicular network applications such as safety, traffic management, and infotainment applications. At the same time, these social applications instantiate virtual spaces, over which their users interact, communicate and collaborate with each other. Examples of such virtual social communities are the drivers (commuters, in general) who follow similar trajectories in their daily driving routines.

In this paper, we focus on an emerging generation of *mobile social parking* applications that seek to transform the way the search for parking space is carried out in busy urban environments, where the demand for parking space may exceed its supply. Parking assistance systems have been studied and designed by transportation engineers for some years, in an attempt to alleviate the traffic congestion problems due to the blind parking search but also the resulting environmental burden. They commonly exploit wireless communication and information sensing technologies to collect and broadcast (in centralized implementations, *e.g.*, [1]) or share (in distributed systems, *e.g.*, [2]) information about the availability of (and/or demand for) parking space within the search area. This information is then used to steer the drivers' parking choices in order to reduce the effective competition over the parking space and make the overall search process efficient. The recent social approaches [3]–[6] to the assisted parking search essentially combine elements from both implementations. They are highly distributed in that information about the location and status of parking spots is retrieved and collected by the drivers (vehicular nodes) and their smartphones, respectively; thus, they get away with the heavy infrastructure a centralized monitoring system would require. Yet, they add a centralized platform that overcomes the constraints of a distributed system regarding the information dissemination speed.

Social parking applications have been deployed over the last couple of years in different European and North American cities, including Athens [3], Paris [4], New York [5], San Francisco [6]. Several features are common across them: they run on smartphones, support multiple operating systems, and enable drivers to hand over parking spots to each other. Application users can offer their parking spot to other users seeking one; or find a parking spot for themselves by claiming a spot another user is offering. Most applications embed social comparison and gamification mechanisms in their design to incentivize users. Users are rewarded for their offers with non-monetary credits and their current credit-based ranking is monitored and published by the application. High-credit users then enjoy higher chances to be chosen by a parking spot sharer (defender) when they seek a parking spot [3]; or get informed about a vacant spot prior to other seekers [5]; or consume some of their credit when they seek available space [4] [6].

Although some of these applications are currently in use, we are aware of no systematic study of their performance and scalability properties. Questions that arise in this respect are:

- How is the advantage of the application users over non-user drivers affected by the penetration rate?

- For given penetration levels, do the application users end up largely monopolizing the parking resources so that non-user drivers are, in essence, almost excluded from using public parking spots (goods)?
- Does the virtual credit incentive mechanism induce rich-club phenomena, whereby a subset of users in a population of drivers with identical needs for parking space, seizes the parking resources by handing over spots among them and hence, continually increasing their ranking?

To address these questions, in Section II we model the two fundamental elements that are encountered in different instances of social parking services: the awareness (*i.e.*, information) and the incentive (*i.e.*, rankings) mechanisms. In the same section we present the details of three different driver profiles: the application users that (have access to information/services provided by the application and) share their parking spots (*i.e.*, Defenders) or simply seek parking space but do not share theirs (*i.e.*, Seekers) and the traditional drivers that do not subscribe to any such application. The model has taken into account data from recent surveys and statistics and has employed a queuing model that approximates the size of the driver population for given parking demand levels; all these are presented under Section III.

Overall, we are interested in understanding the impact of the application operation on both its users and the rest of the driver population, as well as identify key parameters, such as the penetration rate or the parking supply and demand, that can affect these social applications' efficiency. In Section IV, we set up focused scenarios that help us explore particular aspects of these applications as the parking demand scales up and competition phenomena emerge. The operation of these applications is shown to yield a significant advantage for their users at the expense of only slight (or moderate, at high-penetration-rate environments) deterioration of traditional drivers. The incentive mechanism, especially, is shown to operate efficiently, offering preferential treatment to those fully cooperating, yet it induces rich-club phenomena. Those problems are mitigated as the number of parking spot offers by application users drops. In a final scenario, drivers' behavior is allowed to alternate between the three different users' profiles. In this dynamic environment, we show that old and new application subscribers end up with similar probabilities to win the competition for parking space, indicating that dynamicity creates the conditions for a fair treatment of newcomers to such an application.

We outline related research giving emphasis on parking applications that leverage the social media layer in Section V and conclude in Section VI.

II. MODELLING THE SOCIAL PARKING APPLICATION

The primary objective of this paper is to illuminate fundamental properties that are common across the different social parking applications launched over the last couple of years. To this end, we have developed a discrete-event simulation environment that abstracts the precise details of the individual applications and rather focuses on their two critical components: the *collective awareness layer* they induce and the (*pseudo*)*credit-based mechanism* they implement for motivating their users to cooperate in the handover of spots.

Our environment is initialized with M parking spots and N driver nodes. Each driver node alternates among four possible states, $parked_{os}$, $parked_{pl}$, $search$, $idle$. Its residence time at the idle state is described by a Random Variable, t_i , and is closely related to its parking attempt rate. Upon a parking attempt, it enters the $search$ state and stays there for a maximum time of T_s^{max} . If it succeeds in seizing an on-street parking spot within this time, it jumps to the $parked_{os}$ state; otherwise, it enters the $parked_{pl}$ state (*e.g.*, equivalent to driving to a parking lot). In either case it remains parked for time t_p , which follows the parking time distribution, before returning to the idle state.

Three driver node profiles are implemented in this environment: (a) the *traditional driver*, who seeks a parking spot without assistance from any application; (b) the *parking defender* who uses the social parking application and facilitates other users of the application by informing the system when leaving a parking spot and handing over its spot to another application user who is looking for parking in the same area; and (c) the *parking seeker*, who uses the application only for getting informed about vacant spots and parking offers, but neither informs the application when she vacates a spot nor does she wait to hand it over to another application user. The traditional driver profile represents the traditional practice in searching for on-street parking space, while the other two profiles are induced by the social parking applications, instantiating the favorable cooperative norm and the annoying free-riding phenomenon, respectively. The aforementioned three profiles are described in more detail below.

Defender profile: When an application user shares a parking spot¹

- 1) locates her parking spot on the map and informs the application,
- 2) reviews the existing requests for the particular spot, accepts and replies to one based on some criterion (such as, the requesters' rating and their distance from the spot at the time of the request),
- 3) earns some rating in reward of her offer.

Seeker profile: When an application user seeks available parking spot²

- 1) submits a request of interest to every relevant offer available until the acceptance of her request or until the detection of a vacant parking spot,
- 2) if the request is accepted, parks at the particular spot, rates the Defender driver and remains parked for a time interval according to some probability distribution,
- 3) when the parking time ends, abstains from competition for a parking space for a time interval according to some probability distribution, before initiating another parking searching attempt.

¹In realized systems, user nodes that offer a parking place, may also indicate when they intend to free the spot, wait until the time they declared when they made the offer ends and watch the selected vehicle approaching before they leave the spot.

²In realized systems, user nodes that seek a parking spot, define the search area for available parking spots and choose one to send a request of interest. If the request is accepted, they are provided with driving directions to the spot and if they end up parking at the particular spot, they rate the Defender driver.

Traditional driver profile: It refers to drivers that ignore the social parking application and

- 1) abstain from competing for a parking spot for a time interval that follows some probability distribution,
- 2) when the latter time interval expires, they start wandering randomly in search for a parking spot,
- 3) park at the first encountered vacant parking spot for a time interval according to some probability distribution.

Application users might exercise both profiles: they may operate as Defenders and assist others in anticipation of non-monetary credits that will increase their rating, or operate exclusively as Seekers hoping to benefit from the advantage that application users have over the traditional drivers. In environments with mixed populations, when no Seeker (or Defender) is interested in parking or when a traditional driver or Seeker vacates a spot, all interested drivers have the same chance to be served.

III. MODEL PARAMETRIZATION AND PERFORMANCE METRICS

To populate our simulator with meaningful numbers, we have drawn on real maps of on-street parking space in the city of Athens, Greece. We consider one of the busiest areas at the Athens city center featuring 140 controlled on-street parking spots. According to the report in [7], the average parking demand, L_p , in these districts, as inferred by accounting for illegally parked vehicles, can be up to 150% of the on-street parking space supply. We simulate drivers who enter this area and search for parking space once a day, on average, resulting in exponentially distributed t_i with mean equal to one day. The maximum search time before quitting search is set to $T_s^{max} = 15min$ [8] [9]. Finally, parking times t_p are assumed exponential with mean equal to one hour. The duration of simulations is ten days, which is enough time to generate a significant number of parking events for all drivers.

To compute the equivalent driver population N that yields a given over-demand ratio L_p , we devise and solve (reverse engineering) a stochastic finite-source queuing model for the parking search process. In particular, we formulate a 2D continuous-time Markov chain with states (x, y) , where x represents the number of drivers occupying an on-street parking spot or in search for one (referring to as the active population) and y represents the number of drivers that have quitted the search for an on-street spot and have ended up in a parking lot (referring to as the inactive population). If λ , μ and γ denote the rates $E[t_i]^{-1}$, $E[t_p]^{-1}$ and $E[t_s]^{-1}$, respectively, there are four different types of transitions from an initial state (i, j) to a next state (i', j') occurring at rate $q_{(i,j;i',j')}$.

1) *Transitions that increase the size i of the active population:*

$$q_{(i,j;i+1,j)} = (N - i - j)\lambda, \quad 0 \leq j \leq N - M, 0 \leq i < N - j$$

2) *Transitions that decrease the size i of the active population:*

$$q_{(i,j;i-1,j)} = \begin{cases} i\mu, & 0 \leq j \leq N - M \text{ and } 1 \leq i < M \\ M\mu, & 0 \leq j \leq N - M \text{ and } M \leq i \leq N - j \end{cases}$$

3) *Transitions that decrease the size j of the inactive population:*

$$q_{(i,j;i,j-1)} = j\mu, \quad 1 \leq j \leq N - M, 0 \leq i \leq N - j$$

4) *Transitions due to a driver quitting her search for a parking spot:*

$$q_{(i,j;i-1,j+1)} = (i - M)\gamma, \quad 0 \leq j < N - M, M < i \leq N - j$$

In our scenarios, we generally account for mixed populations of users and non-users of the application letting the application penetration rate, r_p vary in $[0, 100]\%$. Likewise, the percentage of Seekers over the application users, r_s , varies over $\{0, 30, 50, 70\}\%$. User rankings are initialized to values uniformly drawn from the intervals $[0, 2]$ (default case) or $[0, 9]$ and each parking spot handover by a parking Defender to another application user is thereafter rewarded by C credits (default value, $C = 3$) that do not age. A parking Defender offers her parking spot to the requester with the highest ranking (accumulated credit).

The impact of a social parking application on the drivers (both users and non-users) is quantified through two metrics: the parking success rate, r_{suc} , measured as the percentage of a driver's successful parking attempts; and, the time t_s spent in search for a parking spot till either capturing a parking spot or heading for a parking lot ($t_s = T_s^{max}$).

IV. SIMULATION RESULTS-EXPERIMENTATION

In this section we derive various simulation results under different mixtures of user profiles, aiming at depicting (a) the extent to which on-street public parking resources are hijacked by the social parking application users at the expense of traditional drivers and (b) the effectiveness and hidden fairness issues concerning the incentive mechanism and whether newcomers to the application are well integrated and not unfairly treated compared to existing application users.

A. *Effectiveness of the social parking application and impact on traditional drivers' performance*

A number of smart mobile applications for efficient parking spot management have recently been developed. The first version of the system in [5] was released in 2010. Two years later, the systems in [4] (with 10.800 users and 5024 parking spots), [3] and [6] started their operation. Albeit new and under-dimensioned, the systems have emerged as breakthrough applications with strong potentials for large-scale development in the near future [9]. However, it is unlike that the entire driver population will subscribe to such parking systems, independently of whether a fee will or will not be charged for the provided parking assistance service. In the first case, the applied fee might discourage possible clients, while in the second case, the requirement for acquiring and operating advanced devices or even the lack of proper promotion of the services might hinder their growth.

Two questions become relevant in this respect: (a) How the penetration rate affects the advantage of application users over traditional drivers; and (b) whether the application tends to exclude traditional drivers from utilizing public parking places. By addressing these questions, we seek to comment on the boundaries that vouch high efficiency without turning

a rivalrous (*i.e.*, occupation of a parking spot by one driver prevents simultaneous occupation by other drivers) but non-excludable (*i.e.*, drivers that have not subscribed cannot be prevented from accessing parking spots) public good into an excludable one.

Figure 1 plots the ultimate parking success rates against the drivers' rankings as shaped by the end of the simulation time, for two scenarios that differ in the intensity of the parking requests. Rankings of zero value in the plots correspond to traditional drivers, while Seekers and Defenders end up with rankings 0 – 2 and above 2, respectively. Figure 2 and 3 plot the corresponding average parking success rates for different penetration rates.

In line with intuition, the higher the penetration rate, the more frequent the handovers of parking spots between application users and thus, the lower the parking opportunities for traditional drivers. A notable advantage of exploiting the parking service emerges, especially for the Defenders, even at low penetration rates and low intensity of requests (*i.e.*, first row of results in Fig. 1). Under intense parking demand (*i.e.*, Fig. 2 and second row of results in Fig. 1), the abovementioned advantage emerges at even lower levels of penetration rate. Indeed, as the penetration rate and/or the intensity of request increase, upon a parking spot offer by a Defender, traditional drivers compete against at least one application user with high probability. Interestingly, this performance improvement of application users, both in terms of success rate and the ultimate search time, comes at the expense of only slight deterioration of the performance of traditional drivers, as depicted in Figure 2. Indeed, even in pure cooperative environments whereby the entire application user population participates in the handover/credit-building processes, users' improved performance is mostly due to the increased efficiency they generate in the parking search process, rather than excluding traditional drivers from the public parking resources (Fig. 3).

B. Effectiveness of the incentive mechanism and some concerns on its fairness

The incentive (for cooperation) mechanism is central to the operation of the social parking application and the implementation of the Defender profile. On one hand, it is expected that an effective such mechanism would result in rewarding and providing better service to the most cooperative users. On the other hand, such a mechanism should not discriminate against users with similar interests, needs and attitude towards cooperation, or against newcomers to the application. Unfortunately, incentive mechanisms that are based on the accumulation of credit occurring over time and at a rate that depends on the frequency of interactions tend to yield some discrimination, as shown below.

First, we consider environments of various penetration rates and examine the degree of correlation between ranking and satisfaction, in order to assess the effectiveness of the incentive mechanism. Indeed, the plots in Figure 1 provide useful insights regarding the effectiveness of the incentive mechanism and the resulting parking service provided to the application users. In particular, plots referring to high-penetration-rate environments (*i.e.*, $r_p > 50\%$) show a strong relation between users' rankings and induced success rate,

with (expected) higher success rates being coupled with higher rankings, suggesting that the incentive mechanism is effective. Table I provides the values of the coefficient of determination for the simple regression model that is drawn as a red line in the data point sets of Figure 1. The coefficient values increase with the penetration rate. Hence, the observed outcomes/rankings are better replicated by the regression model as the penetration rate increases. This relation seems to present non-linear characteristics for very high penetration rates, which is a concern, due to the risk of having a few users, achieving high ranking, almost monopolize the resources and discourage otherwise fully cooperative users who happened to achieve lower ranking. Indeed, such concerns were founded through observations during the simulations showing that once a user wins in the initial competition round (whereby the differences in user rankings are limited and hence, the success probabilities similar for all), she immediately starts enjoying a competitive edge in the following rounds over other users with the same (Defender) profile, through the continuous credit accumulation. This rich-get-richer effect sharpens as the frequency at which drivers enter the parking search area increases, resulting in higher L_p (*i.e.*, $L_p = 165$) and, eventually, high probability for one to compete against higher-ranked drivers.

The application users' profile (*i.e.*, mixture of Defenders and Seekers) also affects the way the rankings and most importantly, drivers' satisfaction are shaped. Environments whereby the parking spot handover process is less frequent (*i.e.*, in the presence of a good portion of Seekers) provide fewer opportunities for credit-building and emergence of high rankings, thus preventing the monopolization of the parking resources by a few Defenders. Instances of these environments are depicted in Figures 4b and 5b, where the majority of the users abstain from parking spot sharing (only 3% and 24% are Defenders in these plots). Although the Defenders enjoy the benefits of the good ranking and a higher success probability, application users might instead decide to follow the Seeker profile for a number of reasons; for instance, they may not desire to wait for the implementation of the parking spot handover process.

In view of the above discussions, it becomes clear that when the applications' penetration is high and a good portion of the application users follow the Defender profile, Defenders with very low ranking are very difficult to compete against those with high ranking and improve their success rate. Such very low-ranking Defenders would be newcomers to the social parking application desiring to fully cooperate upon joining the application. This could be an issue with the application as it would not encourage (or welcome) newcomers under the above (static) conditions. As application users are strongly guided in their behavior by a strong social/behavioral layer, it is very likely that the environment in which a social parking application will operate will be a dynamic one, where users occasionally modify their profile. In real environments, traditional drivers may subscribe to the application from time to time, while users may alternate between the two application user profiles. In this context, we question whether traditional drivers have the incentive to subscribe to the application. In particular, we simulate scenarios with low initial penetration rate ($r_p = 30\%$) whereby traditional drivers stochastically (with 10% probability) become application users, while users change profiles in response to the success rate they experience.

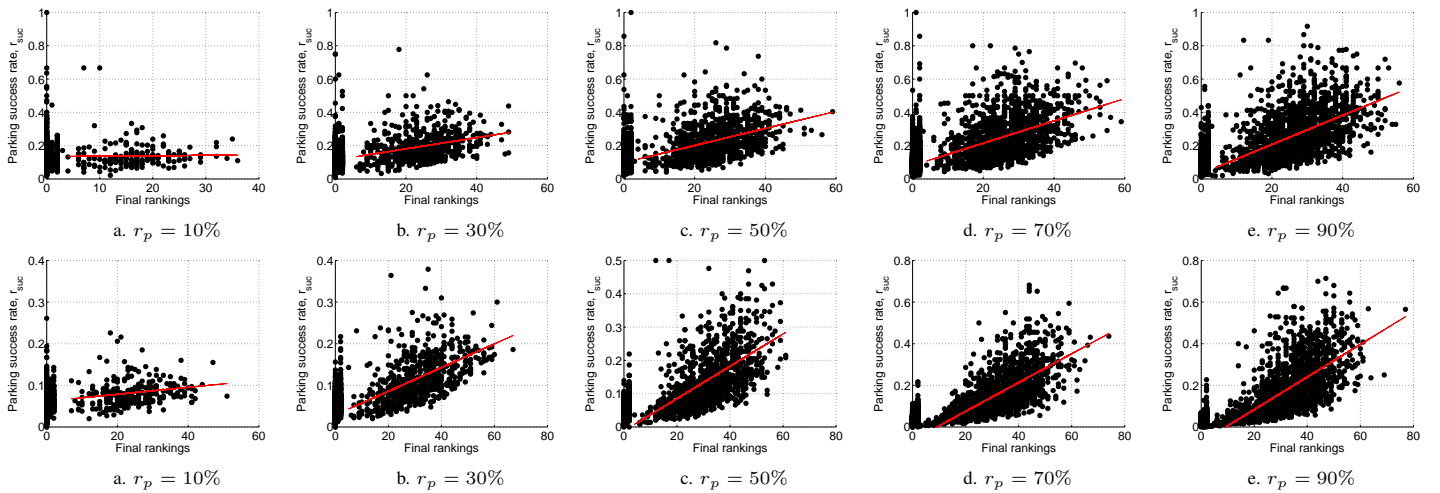


Fig. 1. Impact of penetration rates $r_p \in [10, 90]\%$ and parking request intensity $L_p \in \{150$ (first row), 165 (second row) $\}$, on the final satisfaction of traditional drivers and application users with Seekers' ratio $r_s = 50\%$. The red line corresponds to the simple linear regression model.

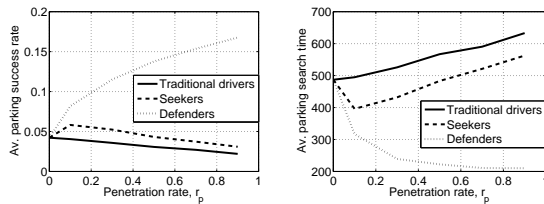


Fig. 2. Average parking success rates and search times for $L_p = 165$, $r_s = 50\%$.

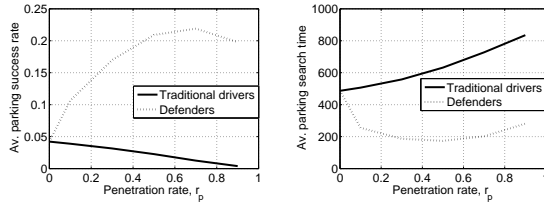


Fig. 3. Average parking success rates and search times for $L_p = 165$, $r_s = 0\%$.

That is, Seekers that win less than one fifth of the times they compete for an offered spot, start offering their place to others in anticipation of their credits (*i.e.*, assume the Defender profile). On the other hand, Defenders that see their success rate rise over 40%, might feel that there is no need for extra credits and hence, abstain from offering their place. Figure 6 illustrates the drivers' final success rates against their initial rankings without any profile transition (left plot) and with profile transitions as described above (right plot). In the first case, zero rankings yield lower success rates. On the other hand, when these profile transition rules are applied (dynamic environment), initially traditional drivers are well integrated into the application as inferred by the similar satisfaction scores they achieve (right plot).

V. RELATED WORK

Parking assistance applications lie at the intersection of vehicular traffic management and infotainment applications. The relevant work initially focused on *centralized* system implementations [1], [10], [11], [12], [13]. (For a comparative description of centralized systems and a broader summary of the work on the parking problem, see [14]). Work on opportunistic parking search assistance is rarer and more recent. In [15], parked vehicles within the same parking lot monitor

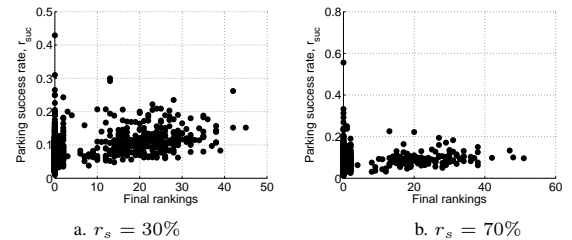


Fig. 4. Impact of the Seekers' ratio, r_s , on the final satisfaction of application users and traditional drivers, under $r_p = 10\%$ and $L_p = 157$.

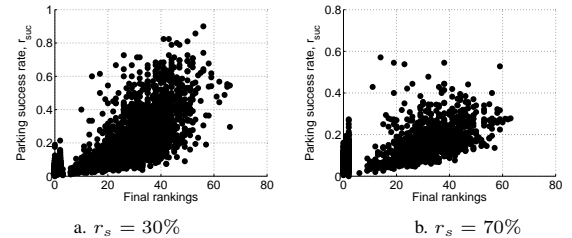


Fig. 5. Impact of the Seekers' ratio, r_s , on the final satisfaction of application users and traditional drivers, under $r_p = 80\%$ and $L_p = 157$.

its parking availability and disseminate this information to other vehicular nodes. In [2], vehicles are allowed to exchange aggregate availability information of variable accuracy about clusters of parking places, in order to limit the volume of the disseminated information. The way the opportunistic exchange of information may sharpen competition for parking space is treated in [16] and [17]. In [16], Kokolaki *et al.* show that the fully cooperative opportunistic exchange of information may sharpen competition. Motivated by similar findings, Delot *et al.* propose in [17] a distributed parking space reservation mechanism, whereby vehicles vacating a parking spot selectively distribute this information to their proximity and hence, they mitigate the competition for the scarce parking spots.

The more recent approaches to the assisted parking search, which are the focus of this paper, add a social media layer over the vehicular network. Some of them have been already deployed and attracted media attention in different cities. The Parkomotivo system in Lugano (Switzerland) [18] relies on a dedicated wireless sensor network and a data mining engine to monitor and analyze on-street parking patterns in the city. Drivers can receive real-time parking availability information

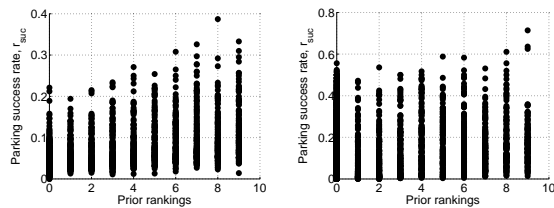


Fig. 6. Final parking success rates in driver populations with static (left) and dynamic (right) drivers' profiles, under (initial rates) $r_p = 30\%$, $r_s = 50\%$, $L_p = 165$.

through the Parkomotivo's tweet stream. More interesting and even newer are social parking applications. These have a strong distributed flavor in that the mobile applications run on drivers' smartphones (or could run on-board vehicles) and information is collected opportunistically as these move around in the city. Yet, they are coupled by a social networking front end that lets the information spread (and reservations happen) almost instantaneously, in ways that resemble a centralized system. In addition, they devise an incentive mechanism that rewards altruistic behavior with non-monetary credits and either prioritizes highly-ranked users or controls users' access to the service. ParkingDefenders in [3] and ParkShark in [5] are two instances of the first type of this application paradigm in the cities of Athens (Greece) and New York, respectively: users can offer their parking spot to the rest of the users or find a parking spot for themselves by claiming a spot another user is offering. The application users are getting credit points each time they handover a parking spot to another application user. While in search for a parking spot, highly-ranked users have higher chances to be chosen by a parking spot sharer in [3] or get informed prior to others about a vacant spot in [5]. Similarly, paradigms of the second type are the systems in [4] (Paris) and [6] (San Francisco). The subscribers announce when they leave a spot and hand their spot to another driver who announced that she is looking for one. The offer is rewarded by and the benefiter incur an amount of non-monetary credits.

Our work draws on social networking to realize decentralized reservations and thus, address the uncoordinated parking search problem. Like [3] and [5], a ranking mechanism provides incentives for offering parking places. On the other hand, contrary to [4] and [6], submitting requests for available parking spaces does not cost any credit points.

VI. CONCLUSIONS

The paper has looked into some key properties of a particular instance of vehicular social applications with respect to the parking search process. In our study, we model two fundamental elements that are commonly encountered in various realized parking systems: the awareness-information and the incentive-ranking mechanisms. The simulation results reveal a high advantage for the application users over the traditional drivers. However, as the penetration rate and/or the competition (parking demand) are intensified, the traditional drivers suffer only slight to moderate service deterioration with respect to what they experience in the absence of the application. In addition, it is shown that the incentive mechanisms are effective in the sense that they do provide preferential treatment to those fully cooperating, yet they induce rich-club phenomena whereby a subset of users with high ranking seizes the parking resources. Different conditions (*i.e.*, awareness/incentive mech-

TABLE I. COEFFICIENT OF DETERMINATION, R^2 FOR THE SIMPLE REGRESSION MODELS ON THE DATA POINT SETS IN FIGURE 1.

| | | r_p | | | | |
|-------|-----|---------------------|------|------|------|------|
| | | 10% | 30% | 50% | 70% | 90% |
| L_p | 150 | $4.2 \cdot 10^{-4}$ | 0.09 | 0.15 | 0.19 | 0.28 |
| | 165 | 0.043 | 0.29 | 0.35 | 0.45 | 0.44 |

anism, selection criterion for parking spot handovers) might change these side effects. This may be a concern and an issue worth looking into more carefully in the future.

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