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Vulnerability of opportunistic parking assistance systems to vehicular node selfishness

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A B S T R A C T

Opportunistic networking leverages the volume, heterogeneity and mobility of end user nodes to foster the dissemination of information in the absence of network infrastructure. Nevertheless, in competitive settings (where the possession of information itself is an asset) user nodes often face a strategic dilemma: cooperate, to realize the network and support the information flow, or not do so, to gain competitive advantage over the other nodes. In this paper, we investigate realistic scenarios of opportunistic parking assistance service that instantiate such dilemmas. Ideally the vehicular nodes opportunistically collect and share information on the location and availability status of the parking spots. Yet the competition for parking spots may give rise to various facets of misbehaviors, such as deferring from sharing information (free riders) and/or deliberately falsifying disseminated information (selfish liars) so as to divert others away from a particular area of own interest. Simulation results indicate that misbehaviors tend to reduce the distance between the destination and the occupied parking spot for *all* vehicles at the expense of higher parking search times. However, misbehaving nodes fail to obtain any substantial performance advantage that would indeed encourage their misbehaviors. The addition of Mobile Storage Nodes compensates for the reduction of the information flow due to free riders but has almost no effect against selfish liars. Simple analytical models drawing on mean-field arguments provide further evidence for the fundamental dynamics that emerge from the interaction of the vehicular nodes.

1. Introduction

Various mobile applications involve competition for scarce resources, which, in economic terms, fall under the umbrella of rivalrous non-excludable goods (*common goods*). Networked entities (user nodes) then have to autonomously decide whether to dispose private information about these resources. Information is essentially a kind of asset; sharing it, user nodes assist their potential competitors, in anticipation of their support in due course. Recent trends such as the smart city initiative [1] give rise to further settings, where truthful altruistic information sharing is required but not guaranteed. One of these settings, involving opportunistic city-level parking assistance systems, is the subject of this paper.

In particular, advanced parking assistance systems have been proposed (*e.g.*, [2]), and in some cases realized (*e.g.*, [3–5]) in an attempt to cope with the issue of parking space management in busy urban environments [6]. Fostered by recent advances in wireless networking, sensing and car navigation technologies, these systems aim at helping drivers find vacant parking spots easier and faster by collecting and sharing information about the location and status (occupied/vacant) of parking spots. In *centralized* systems, a central server communicating with sensors at the parking spots coordinates the parking spot assignment process: it receives the drivers' requests for parking space, reserves parking spots for them, and directs them thereto (*e.g.*, [7]). Whereas, in *opportunistic* systems, vehicles themselves serve as mobile sensing platforms that collect and store information about the location and status of parking spots and share it with each other through vehicle-to-vehicle (V2V) communication technologies (*e.g.*, [8]). Opportunistic systems do not incur the upfront infrastructure cost of centralized systems, thus presenting a lighter and more scalable solution that leverages to-be-built-in vehicle equipment. On the other hand,

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opportunistic systems lack central coordination and rely on the vehicular nodes' willingness to share collected information. This cannot be taken for granted since the sharing of information assists nodes by increasing their knowledge about parking space availability but, at the same time, *synchronizes* nodes' parking choices. This synchronization in turn increases the competition for the vacant parking spots, in particular when drivers' travel destinations overlap [9].

This study is, to the best of our knowledge, the first to question the robustness of opportunistic parking assistance systems to non-cooperative vehicular node behaviors, which deviate from the purely *altruistic* norm of *always* and *truthfully* sharing the cached information with encountered vehicles. Hence, we let nodes *misbehave* and study how this affects fundamental performance indices such as the parking search time and the distance of the acquired parking spots from the drivers' travel destinations. The dual question from the individual nodes' viewpoint is whether they *do* have incentives to misbehave in that misbehaving allows them to achieve better search times and/or parking spot-destination distances. Two intuitive misbehavior instances are considered. In the first one, nodes defer from sharing parking information with other vehicles essentially acting as *free riders*. In the second one, they deliberately falsify information about the parking spots' status (*selfish liars*), *i.e.*, spots close to the misbehaving vehicle's destination are advertised as occupied whereas all others as vacant. The two misbehaviors essentially impair in different manner the *amount* and *accuracy* of information that is disseminated across the network.

The problem under consideration features strong spatiotemporal dynamics that are not conducive to analytical investigation. Early simulation results are reported in [10]. In this paper we expand the simulation study and furnish analytical arguments that support the credibility of the simulation findings and give further insights to the problem dynamics. Notably, the results do not lie always in line with intuition. In almost all cases misbehaving nodes fail to obtain distinctly better performance than cooperative nodes. Both types of misbehavior, through different mechanisms, tend to reduce the destination-spot distances and increase the parking search times for *all* vehicles, the latter increase becoming quickly prohibitive when drivers' destinations overlap. This *fate-sharing* effect essentially weakens vehicles' incentives to misbehave and increases the system resilience to selfishly-thinking drivers. On the other hand, neither of the two misbehaviors attenuates the *synchronization phenomena* emerging at the cache contents, and subsequently, the mobility patterns of vehicles when their destinations overlap. The introduction of Mobile Storage Nodes in this case, which collect and share parking information with parking-seeking vehicles, has a sharply different impact on the two misbehavior instances. Whereas, in the presence of free riders, a few of them suffice to restore the information flow at the levels of a cooperative system, they have negligible impact in the presence of selfish-liars: even a few misbehaving vehicles suffice to overwrite the fresh information Mobile Storage Nodes carry and convert them into relays of forged information. To strengthen our confidence in the simulation results, we formulate simple analytical arguments that capture surprising well the fundamental behavior of the system without accounting for the finer practical details of the context (*i.e.*, vehicles, parking spots), let alone for the finer details of the application (*i.e.*, road grid and vehicle movement patterns).

The basic operation of the opportunistic parking assistance system and the two obvious ways selfish nodes may try to manipulate it are reviewed in Section 2. The simulation environment and our methodology are described in Section 3. We present and discuss the simulation results along with the analytical insights to them in Section 4, outline the related research in Section 5 and conclude our work in Section 6.

2. Opportunistically-assisted parking search and imperfect cooperation

According to the current common practice in search for parking space, drivers wander around their travel destination and sequentially check the availability of encountered parking spots. Typically, the search is initially carried out within an area around the drivers' travel destination (*initial parking search area*), whose size depends on the drivers' attitude and sense of traffic load and parking demand thereby. The radius of the search area then grows progressively as parking search time increases until drivers find a vacant parking spot and occupy it. This, essentially *blind*, search practice gives often rise to congestion problems and results in fuel/time wastage, especially around popular travel destinations such as shopping areas and business districts in big cities.

Recent advances in wireless communication, sensing and navigation technologies promise to make the parking search process smarter and more efficient. One way to do this is by equipping parking spots with sensors providing information about their occupancy status (*e.g.*, [8]) and vehicles with devices (*e.g.*, PDAs supporting ad-hoc communication mode) able to collect and share information about parking spots' location and status as they circulate around. Alternatively, sensors can be mounted onboard the vehicles and actively monitor road-side parking availability (*e.g.*, via ultrasonic rangefinders, [2]). However it is collected, this information can be further filtered across time (*ageing*) and space through use of timestamps and knowledge of the parking spot coordinates (*e.g.*, via GPS) and help vehicles make more informed decisions. Rather than wandering randomly in the parking search area, a vehicle can now direct its search towards selected parking spots that are listed in its cache as the closest vacant ones to its travel destination. If the spot is actually vacant when it arrives at it, it occupies it; otherwise, it repeats the spot selection process, being also prompt to occupy any vacant spot it may find on its way to the candidate spot.

Critical for the efficiency of this *opportunistically-assisted* parking search are the *amount* and *accuracy/timeliness* of the information that is stored at the vehicles' caches and shared among them. Both are subject to strong spatiotemporal effects: vehicles generally possess partial rather than global information about parking space availability and as the status of parking spots changes over time stored data are potentially outdated after some time interval. Moreover, vehicular nodes have good reasons to hide information from other, potentially competitor, vehicles. Overall, the processes of information dissemination (benefiting discovery of parking spots and their availability) and competition growth (reducing the chances to acquire a spot) are coupled and counter-acting. Indeed, the faster information circulates across the wireless opportunistic networking environment, the more similar (accurate or not) data are stored in the caches of vehicles. Thus, depending on the travel destinations of users, the movement patterns of individual vehicles get synchronized and sharpen the effective competition for given parking spots. This additional level of competition, this time for information at the "service discovery" level, motivates various deviations from the perfectly cooperative (altruistic) behavior.

In this paper, we consider in detail two such deviations, hereafter called misbehaviors for the sake of brevity. In the first one, misbehaving nodes defer from sharing their own information with other vehicles, while readily accepting such information from other vehicles that make it available. These free riders reduce the amount of disseminated information but also its accuracy since vehicles' caches are less frequently updated with fresh information about the spots' occupancy status. On the contrary, the second misbehavior instance involves the dissemination of falsified information about the status of parking spots. Nodes do so in order to